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17 February 1961

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Weapon System 117L
Communications and Control Subsystem

ENGINEERING ANALYSIS REPORT

1693

DISCOVERER PROGRAM

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Prepared for
Air Force Ballistic Missile Division,
Air Research and Development Command
United States Air Force
Inglewood, California

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Technical Operating Report

1693

WEAPON SYSTEM 117L
COMMUNICATIONS AND CONTROL SUBSYSTEM
ENGINEERING ANALYSIS REPORT, DISCOVERER PROGRAM

Prepared by

PHILCO CORPORATION
Western Development Laboratories
Palo Alto, California

SUBSYSTEM ENGINEERING ANALYSIS

Contract Number AF04(647)-532
Exhibit B
AFBM Exhibit 58-1, Paragraph 3.15
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and 1.2.3

Prepared for

AIR FORCE BALLISTIC MISSILE DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
Inglewood, California

WDL-TR-1394

FOREWORD

This Technical Operating Report on the definitized Contract AF04 (647)-532 is submitted in accordance with Exhibit "B" of that contract and Section III, Paragraph 3.15 of AFBM Exhibit 58-1.

This report was prepared by the Philco WDL C&C Systems Department in fulfilling the requirements of Paragraph 1.2.1.1 of AFBM Exhibit 60-63, dated 10 November 1960, Paragraph 1.2.3 of which covers preparation, publication, and distribution of reports.

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SECTION 1
GENERAL DESCRIPTION

1.1 Objectives

As its name implies, the Discoverer Program is the "test-bed" for the development of concepts and techniques and the collection of information believed useful for future programs. Thus, the long-range objectives are the refinement of equipment and procedures to be used in the Midas and Samos Programs and in future deep space probes.

One of the prime objectives of the Discoverer Program is to eject and recover a capsule from an orbiting vehicle. While in orbit, the satellite serves as a carrier for scientific materials and for the telemetry of functional, environmental, and geophysical data. The mission of the program also includes aero-medical research and other specialized tests according to the specific requirements of a particular flight.

The overall plan for Weapons System 117L calls for a series of programs including the Discoverer, Midas, and Samos satellites and is divided into a number of subsystem designated A through L. The Communications and Control Subsystem (Subsystem H) of the WS-117L Discoverer Program is the subject of this report.

Although this report is concerned primarily with Subsystem H (SS/H), topics relating to other subsystems, such as the vehicle descriptions, are included for purposes of continuity. Some items were in a state of change at this time and will be presented in future revisions to this report.

1.2 Subsystem Design Criteria

The criterion used throughout the design of the Ground-Space Communications and Control Subsystem was to utilize essentially existing equipment with only necessary modifications as required for the Discoverer Program. To establish the number of stations necessary for the Discoverer Program in time to meet the vehicle readiness schedule, equipment concepts requiring extensive development of new components or techniques were avoided. After preliminary analysis, the major equipment of the subsystem was designed and specified.

Some development and redesign of existing equipment was necessary, however, to insure harmonious operation with a reasonable amount of redundancy and reliability. In some cases, extensive redesign of circuitry was required to increase system performance and reliability; an example of this would be the incorporation of a low-noise front end utilizing a traveling-wave-tube amplifier in the very long range radar (Verlort). In other instances, equipment was redesigned to provide added capability, such as increased power output in the S-band beacon. A ground timing system, a fully automatic vehicle command and guidance control, and an automatic data transmission system were designed and fabricated. These and other units were developed specifically for the Discoverer Program.

Because of the rapid implementation and adaptation of existing equipment required to produce a workable system for Discoverer, it is natural to expect that numerous modifications would evolve as a result of operational experience during actual vehicle flights and the demands for support of other programs. These modifications are listed and briefly described in Appendix B.

1.3 Operational Requirements and Characteristics

Subsystem H equipment can be divided into two major categories: ground equipment and vehicle equipment. Ground equipment is designed to perform the functions necessary for vehicle acquisition and tracking, for orbital computation and programming, for vehicle command and control, and for the reception and recording of telemetry data. Vehicle equipment provides for the reception and decoding of commands and the transmission of telemetry data to the ground receivers. A simplified block diagram of Subsystem H is presented in Fig. 1-1.

1.3.1 Acquisition and Tracking Function

The Verlort radar system is the principal ground equipment for Discoverer vehicle acquisition and tracking. The radar system also provides the only means by which commands may be transmitted from the ground to the vehicle.

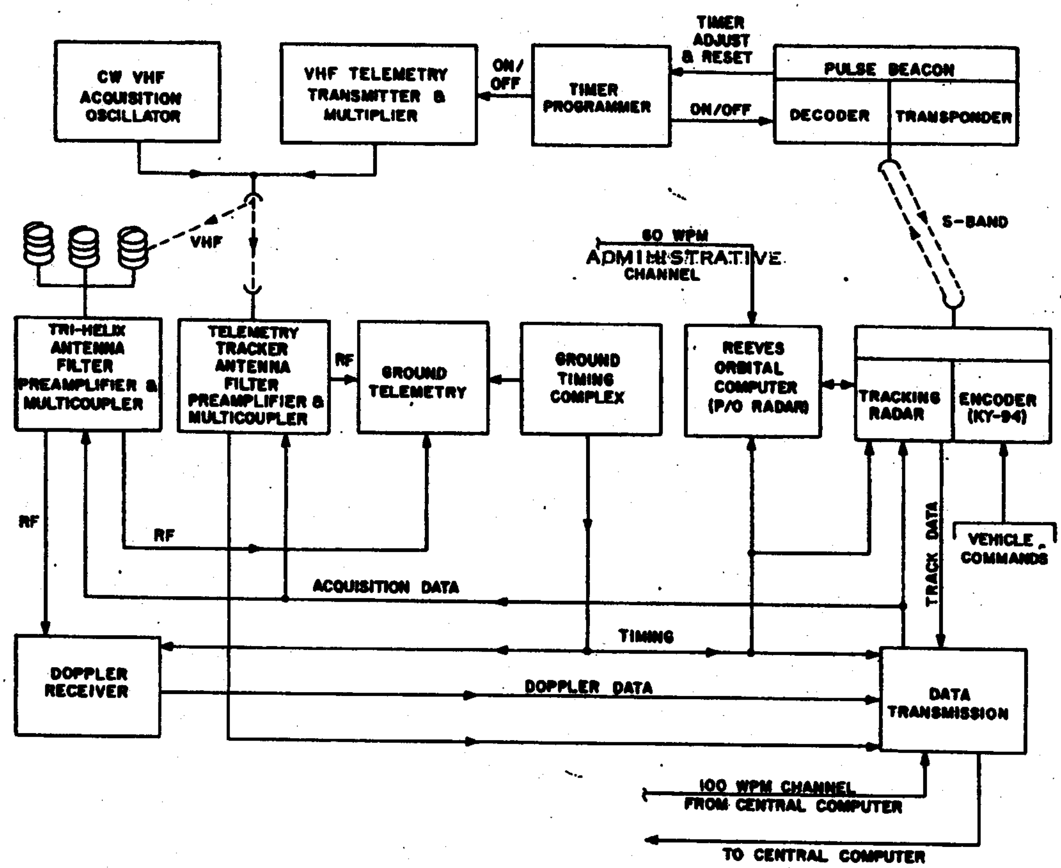


Fig. 1-1 Simplified Block Diagram of Subsystem H

<u>Radar Tracking System</u>. One Verlort radar system is installed at each SS/H Discoverer tracking station. The Verlort radar is designed to lock-on and automatically track the vehicle on receipt of pulse signals transmitted from the beacon transponder in the vehicle. The beacon is pre-set to respond only to time-coded radar pulses; it responds by transmitting 2-kw pulses which are then tracked by the radar in azimuth, elevation, and range. These coordinates are converted to digital form and processed by the data handling and control equipment into teletype format for transmission to the central computer at the Satellite Test Annex (STA). Additional outputs operate automatic plotboards and provide slaving data to control other tracking antennas of the station.

<u>Acquisition</u>. Prior to acquisition, the central computer transmits an acquisition program to the tracking stations. The acquisition program from the central computer contains azimuth, elevation, range, and time information to be applied to the radar at the correct time to position the antenna and range gate to a predicted moving point in space. This point describes the predicted vehicle orbit. In the event the acquisition program contains "rough spots" because of computer errors, missing data, or teletype transmission difficulties, a "coast" command may be given manually to disconnect the output of the acquisition programmer until the errors or discrepancies have passed.

<u>Tracking</u>. Once acquisition has been made, the vehicle is tracked by the radar to provide position data to the central computer and slaving data to the tri-helix antenna and the telemetry tracker, (a modified TLM-18, Philco R-1162). If lock-on is lost, the satellite may be reacquired by slaving the radar to the acquisition programmer or orbital computer. The orbital computer positions the radar antenna and range gate according to the continually updated orbital prediction. The original orbital computer computations are based on the six-parameter inputs contained in the acquisition summary message from the central computer.

As the radar tracks the vehicle, real-time tracking data is compared to the predicted data. Errors in the predicted data are displayed as meter readings to the operator who nulls these errors and updates the predicted orbit by adjusting appropriate controls.

Doppler Tracking System. The Doppler receiving system has two major purposes: (1) to acquire the satellite at the earliest possible moment during a pass, and (2) to provide tracking data to the central computer for calculating limited vehicle orbit parameters in case of failure of other tracking systems.

Should the Doppler system acquire the vehicle before the other tracking equipment when only predicted parameters are known, synchro outputs of the tri-helix antenna may be used to slave the radar antenna or the telemetry tracker until such time as they can acquire. For early acquisition, a wide beam VHF tri-helix antenna, coupled with the highly sensitive phase-coherent Doppler receiver, is used to receive the signal from a low-powered VHF CW acquisition transmitter in the vehicle. This also provides a signal for Doppler frequency measurement.

Telemetry Tracking System. The Philco R-1162 telemetry tracker is a high-gain antenna that automatically tracks the satellite on the FM/FM signal from the vehicle telemetry transmitter. The antenna receives telemetry data and provides azimuth and elevation tracking coordinates in digital form to be sent to the central computer as a supplement to the Verlort radar information. Additional outputs operate automatic plotboards and provide slaving data to control other equipment.

There are three main modes of operation for the telemetry tracker antenna system: (1) standby, (2) manual, and (3) automatic. The system is placed in the standby mode when it is not tracking, or after the antennas have been positioned manually to the sector where a signal is expected to appear. In the manual mode of operation, the antenna can be slewed in azimuth and elevation, as desired. If an r-f signal is received during the manual mode, the system will go into the automatic mode. Automatic tracking continues until the r-f signal level falls below 1.5 microvolts or until the antenna is pulled away from the signal by manual slewing.

The telemetry tracker antenna system is capable of being directed in azimuth and elevation by an external slaving source. Possible sources of this information are the Verlort radar, tri-helix antenna, and the acquisition programmer.

1.3.2 Central Computer Function

The central computer for the Discoverer program is the Remington Rand 1103AF computer, which is located at LMSD, Sunnyvale. Tracking data arrives at the central computer from the tracking stations in digital form, punched on 5-level teletype tape. The computer smooths the data and integrates it, using the equations of motion. From these calculations, the computer generates acquisition data to be routed back to the tracking stations, where it is used to assist in acquiring the vehicle on future passes. The central computer also generates predicted orbital parameters, which are used by the radar computing equipment, and certain timing and command signals, which are routed to the vehicle via tracking station radar-beacon links.

1.3.3 Ground Station Command and Control

Administrative and operational control of the SS/H ground station complex is centered at the Satellite Test Annex at Sunnyvale. Various interstation telephone and teletype facilities provide the necessary channels to integrate the system.

At the tracking station, command and control functions are at three control positions: (1) the shift supervisor's console, (2) the acquisition and tracking console, and (3) the vehicle command console. The positions are located in the administration and control van or building.

The shift supervisor's console (see Fig. 4-35) provides displays and controls that enable the operator to ascertain the operational status of the entire station prior to and during a pass. Station readiness before a launch is verified by the shift supervisor to the STA over the interstation communication channels. All maintenance and operational activities are coordinated by the shift supervisor.

As systems supervisor for the tracking equipment, the operator at the acquisition and tracking operating position of the master control console (see Fig. 4-37) monitors the progress of all tracking equipment, controls the flow of tracking and slave data, and is responsible for the overall system integration of the tracked equipment into an operational unit. During warmup, checkout, acquisition, and tracking operations, he determines the operational readiness of all equipment under his supervision and reports this information to the shift supervisor.

Vehicle commands are initiated at the vehicle command position of the master control console and sent to the satellite by coded-pulse, time-modulated signals from the S-band tracking radar as the satellite passes within range of the tracking station. The commands are received by the beacon transponder in the vehicle and decoded by the command decoder, which actuates relays that cause the command to be acted upon. If the command has been received correctly, a command verification signal is returned to the ground station.

1.3.4 Telemetry Data

Environmental and other information from the vehicle is transmitted as subcarrier modulation by the VHF telemetry transmitter and received by the telemetry tracking antenna or tri-helix antenna at the tracking station. The telemetry data is routed directly to the receivers and FM demultiplex equipment in the telemetry area. The telemetry data from the vehicle is recorded on magnetic tape and the required real-time readouts are transmitted to the STA via voice line.

1.3.5 Timing Function

A ground timing system supplies the time reference, or base, by which all station activities are synchronized. Although each station has its own timing system, all stations are synchronized to a single time reference known as system time (ST). System time, along with certain other pertinent time indications, is displayed prominently throughout the station at designated operating and control locations. All tracking, acquisition, and telemetry data are labeled with respect to time. Vehicle functions are precisely programmed with respect to system time.

Ground Timing. The heart of the ground timing system is the dual-unit central timing generator, which generates the basic timing signals to be used throughout each station. Remote timing terminal units distribute the timing signals from the timing generator on a 1-kc amplitude modulated carrier, and remote time indicators display the timing signals.

Both sections of the dual timing generator operate continuously . One unit is connected to the system; the other unit is used as a backup. Each unit is synchronized by a 1-second standard time signal broadcast from radio stations WWV and WWVH. The radio signal is received on a fixed-tuned receiver provided as part of the installation. Provision is made at each of the central timing units to compensate for differences in propagation time from WWV or WWVH to each of the tracking sites, thereby permitting station times to be within 8 milliseconds of each other.

1.3.6 Data Transmission and Display Function

Data transmission for SS/H is primarily concerned with the flow of antenna slaving data, predicted orbital data, and tracking data (1) between tracking stations and the central computer, and (2) between equipment, operating positions, and display units within a station.

Interstation data transmission is in digital form, while intrastation transmission channels use digital, synchro, and analog techniques. Digital data transmission is used to transmit high-accuracy data over relatively long distances. Synchro data transmission is used as a backup for the intrastation digital data transmission system. Plotboard data are transmitted by d-c digital, synchro, and analog means. Angular data to operate antenna position indicators are transmitted by synchro means only.

Slave Tracking Data. Station tracking antennas can be slaved to each other or to an acquisition program generated at the central computer. The acquisition and tracking controller determines which synchro tracking data is to be applied to the slave bus; this data is used as a slaving source to position other local antennas. The data appears as angular position information; i.e., azimuth and elevation, on the outer ring of the tracking equipment control position indicators.

1.3.7 Communications Function

The types of ground station communication circuits include teletype, telephone, and radio, interconnecting the launch, tracking, telemetry, and control facilities for the transmission of SS/H data, operating instructions, and administrative orders.

The communication function is divided into two separate systems: (1) the interstation communication system, which consists of the circuits and channels necessary to connect all of the ground tracking stations together into an integrated network; and (2) the intrastation communication system, which consists of the circuits and equipment necessary to support on-station activities and to terminate the interstation system.

1.4 Vehicle Functions

The Discoverer flights are designated for reference purposes by Roman numerals, and the vehicle is identified by a four digit number. A summary table of flights to the present time is given in Appendix D. Flights through Flight XV used the Agena-A Discoverer satellite, while subsequent flights have or will probably use the Agena-B. The active orbit lifetime for flights through Flight XV was 27 hours, but the flights to follow will have an active orbit up to 100 hours.

The Discoverer Satellite airframe as indicated in Fig. 1-2 consists of the following: forward midbody assembly, including the forward equipment rack; the aft midbody assembly; aft equipment rack; adapter assembly including provisions for retro-rockets; propellant tanks; pressure spheres; and fairings. The recovery capsule is carried in the forward end of the airframe.

The vehicle communications and control subsystem is shown in Fig. 1-3.

The Discoverer satellite S-Band transponder, located in the forward equipment rack, supplies response pulses to the Verlort radar coded interrogations. These responses are used at the Verlort radar as a means of determining vehicle position. The transponder also receives, decodes, and delivers ground-to-space real-time commands for operation of vehicle functions. The S-Band transponder equipment includes a decoder and an antenna.

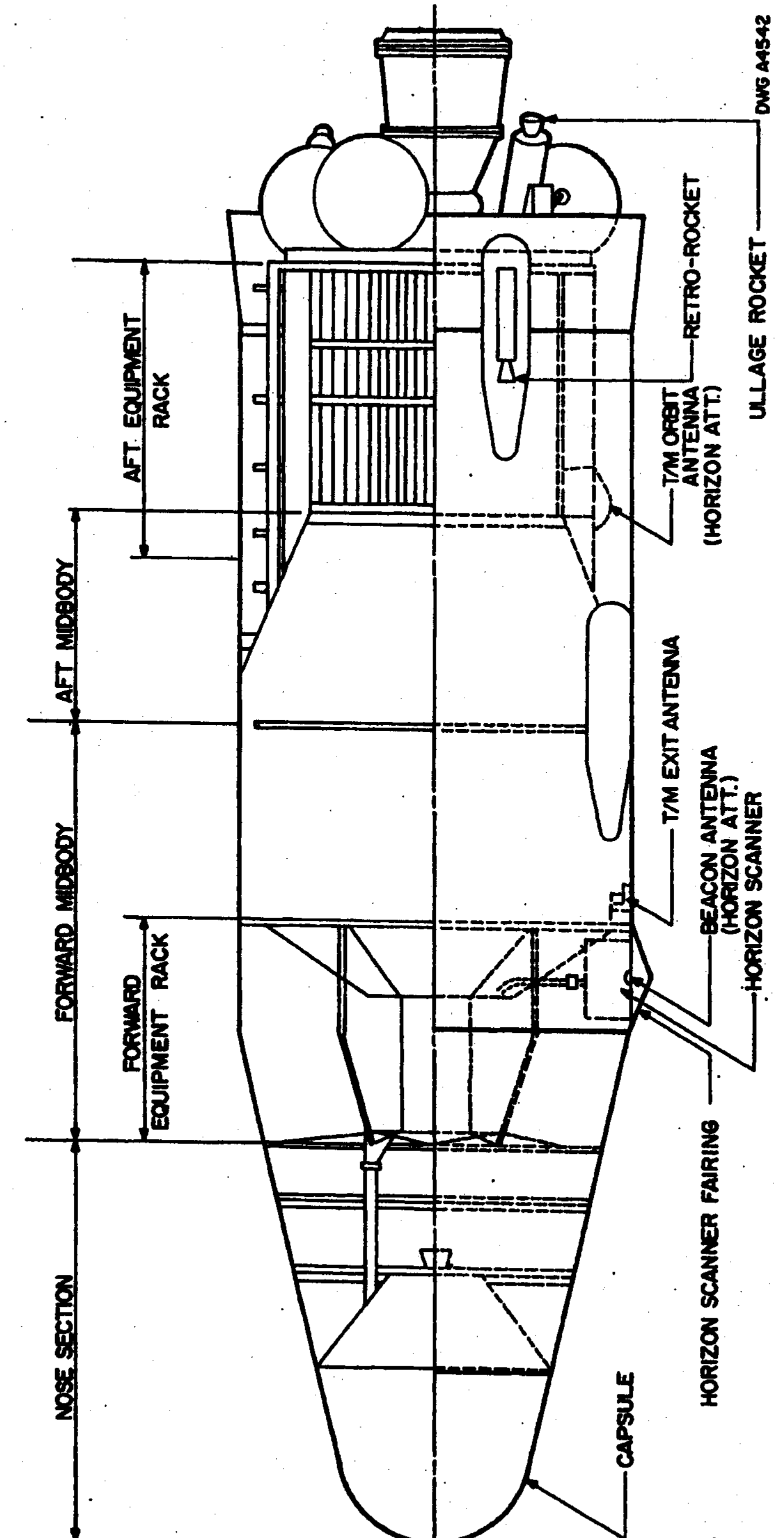


Fig. 1-2 Discoverer Satellite Airframe

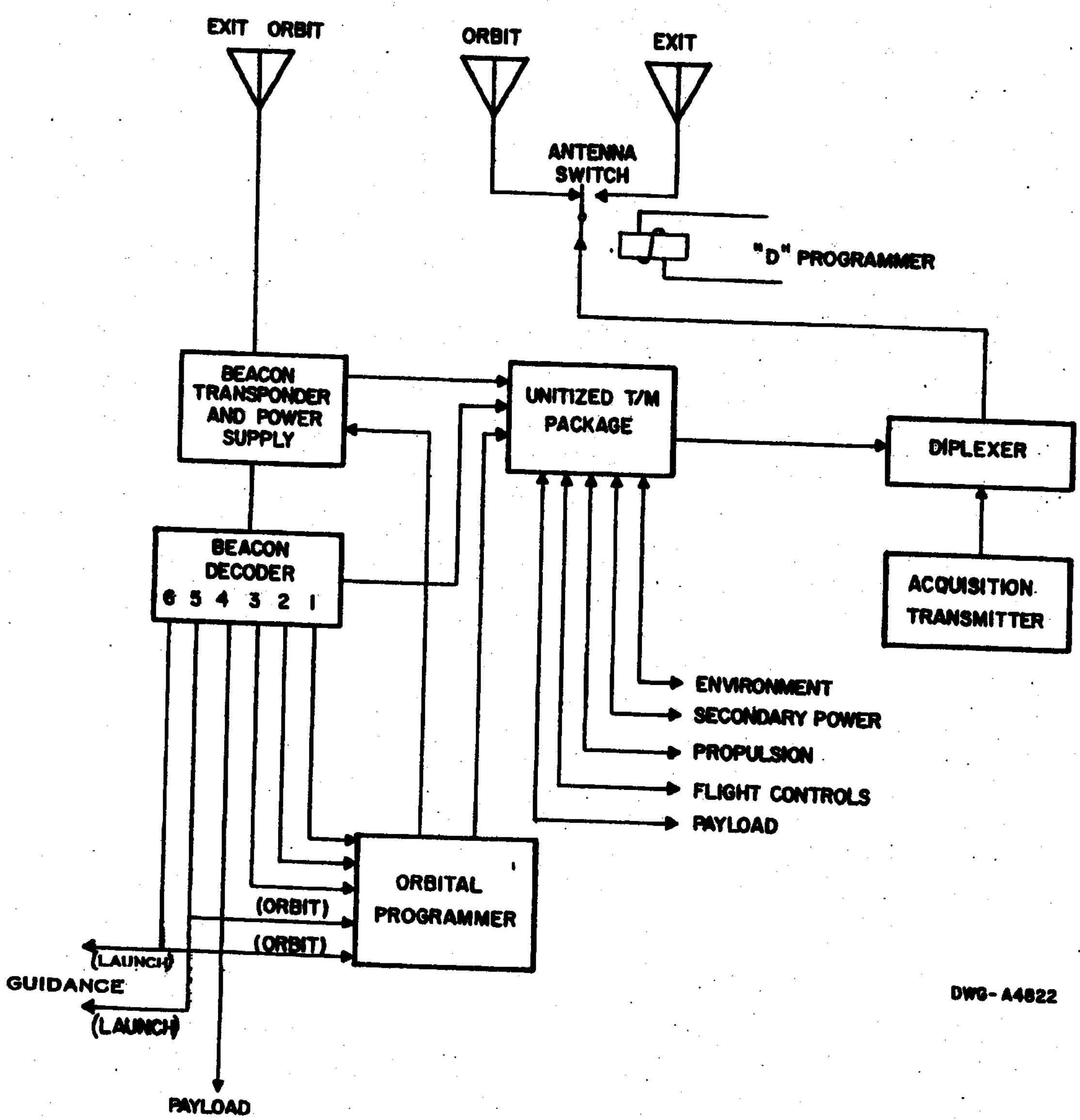


Fig. 1-3 Vehicle Communications and Control, Simplified Block Diagram

The acquisition beacon is located in the forward equipment rack. This unit operates continuously, providing backup in the event that other acquisition methods are unsuccessful. The transmitter is a low-power, crystal-controlled, UHF CW transmitter whose output is diplexed into a common antenna with the VHF telemetry transmitter. The acquisition beacon is isolated from the telemetry transmitter by a two channel diplexer.

The orbital programmer, located in the forward equipment rack, turns on vehicle equipment cyclically, and is capable of initiating the recovery sequence of events for ejection of the recovery capsule. An alternate cycle of different composition from the normal cycle can be accommodated. Ground commands can reset and change periods.

An S-Band transponder antenna, located in the forward midbody, and VHF antennas, one is the forward midbody for ascent and one in the aft equipment rack for orbit, are carried for the ascent and orbit phases.

The VHF ascent and orbit antennas are multiplexed to serve both the telemeter transmitter and the acquisition beacon transmitter.

An FM/FM telemeter, in the forward equipment rack, is carried to obtain and transmit orbital-stage functional, environmental, and other scientific data.

1.5 Station Installations

There are five principal tracking stations (Fig. 1-4) for the Discoverer Program, and they are located as follows:

a. Vandenberg Air Force Base, California
b. Point Mugu, California
c. Kaena Point, Hawaii
d. Kodiak Island, Alaska
e. New Boston, New Hampshire

Point Mugu is used primarily for ascent tracking, telemetry, and guidance commanding. The requirement for transmission of guidance commands from Point Mugu is scheduled to be eliminated in the near future. The Bell Telephone Laboratory (BTL) guidance system at VAFB is presently being evaluated for compatibility with the Discoverer Vehicle configuration. It is anticipated that the Point Mugu tracking station will be phased out upon satisfactory completion of BTL system tests.

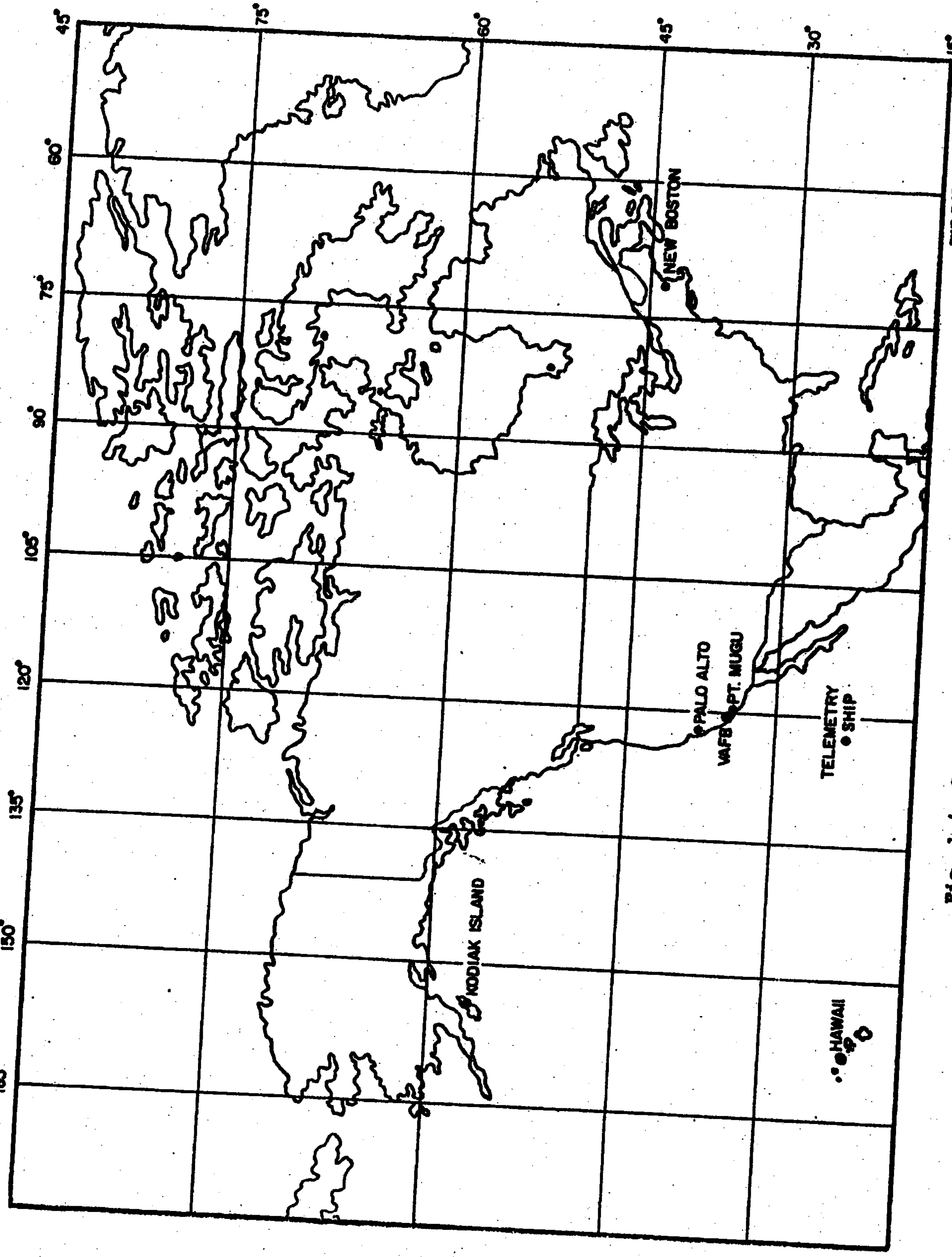


Fig. 1-4 Ground Station Complex, Discoverer Program

Ascent tracking and telemetry functions would then be performed solely by the Vandenberg tracking station.

The original station configuration included a station at Annette, Alaska. Operational experience revealed that this station provided unnecessary redundancy and Annette was phased out in December 1959.

The equipment complement for each station is given in Table 1-1.

Two general types of installation are utilized for the Discoverer Program; (1) stations made up entirely of mobile van-mounted equipment, such as Point Mugu and New Boston; and (2) those stations made up of both van-mounted and permanent building installations, such as Hawaii, Vandenberg, and Kodiak. Detailed information on the individual sites is available in existing documents. A brief description of tracking station configuration and equipment layout is included in the following paragraphs.

1.5.1 Vandenberg Tracking Station

The Vandenberg tracking station occupies a section of Vandenberg Air Force Base (formerly Cooke AFB). The tracking station installation is located in two areas separated by a distance of approximately 13,000 feet. The station configuration is shown in Figs. 1-5 and 1-6.

Transmitting Area. The transmitting area is made up of the following major facilities:

a. Radar van
b. Radar pedestal and antenna
c. Optical tracker
d. Data transmission van
e. Boresight towers (2)
f. Diesel generators

Receiving Area. The receiving area contains the following facilities:

a. VHF telemetry building
b. Telemetry tracker antenna
c. Tri-helix antenna
d. WWV antenna
e. Boresight tower

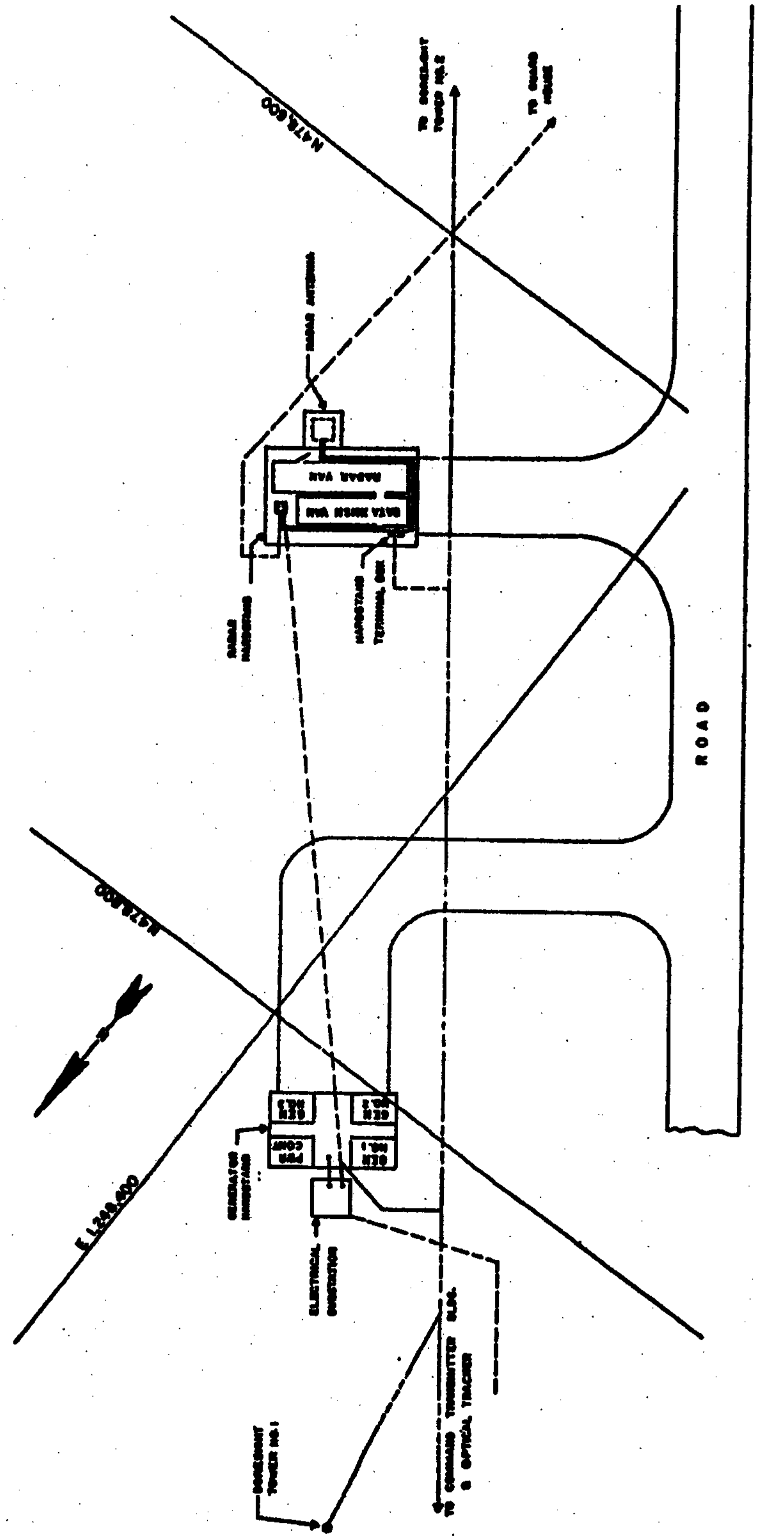


Fig. 1-5 Vandenberg Tracking Station Transmitting Area

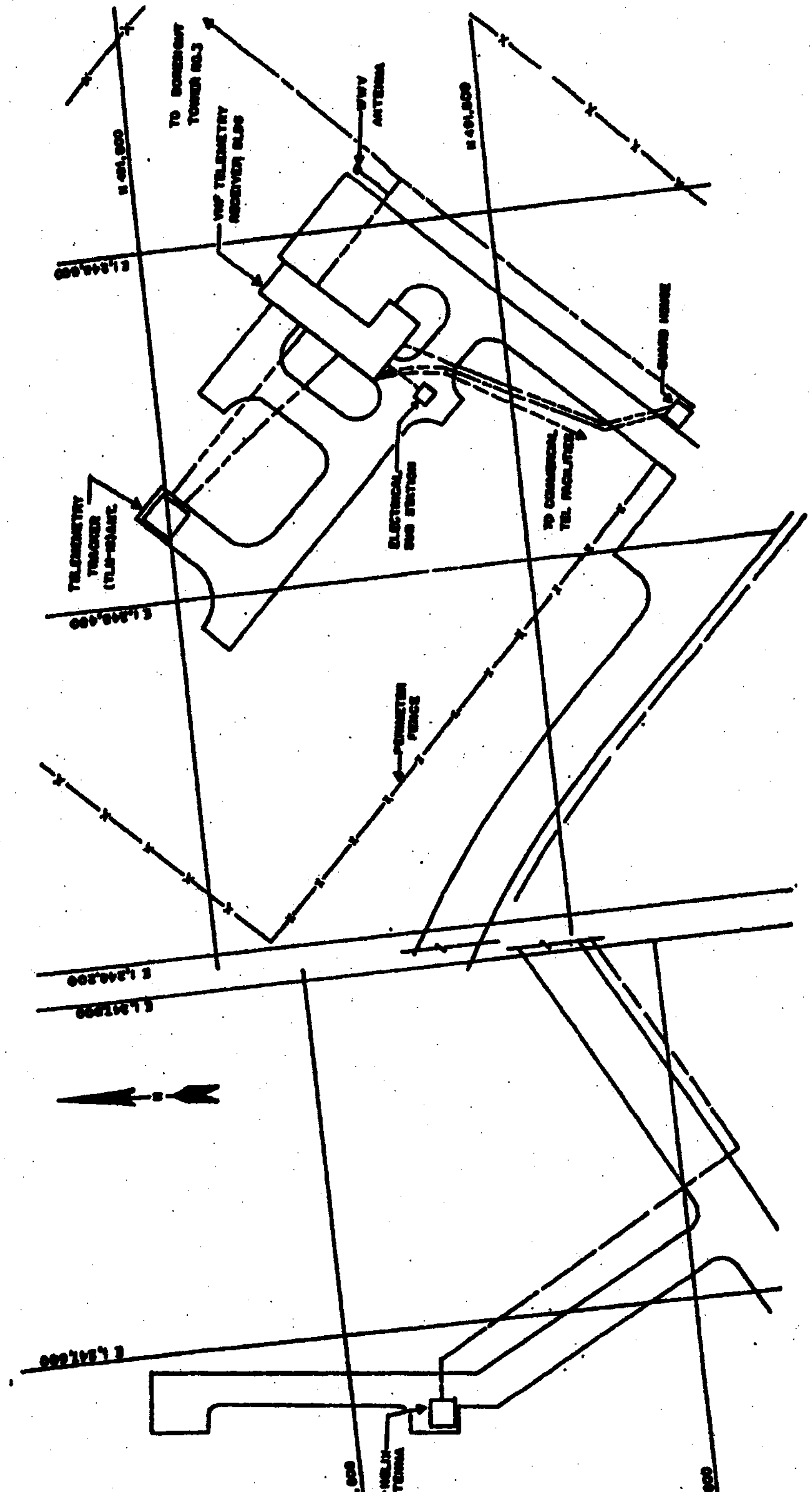


Fig. 1-6 Vandenberg Tracking Station Receiving Area

TABLE 1-1

TRACKING STATIONS - MAJOR EQUIPMENT

EQUIPMENT	VAFB	MUGU	HAWAII	CHINIAK	NEW BOSTON
Verlort Radar	X	X	X	X	X
Telemetry Tracker	X		X		
Tri-Helix Antenna	X	X	X	X	X
Doppler Receiver and Recorder	X	X	X	X	X
Communications	X	X	X	X	X
Data Transmission	X	X	X	X	X
Control Consoles and Display	X	X	X	X	X
Optical Tracker	X				
Reeves Guidance Computer		X			
Telemetry Receiving and Recording	X	X	X	X	X
Timing	X	X	X	X	X

The following major items of equipment are housed in the VHF telemetry building:

a. Data transmission equipment
b. Doppler equipment
c. Telemetry equipment
d. Master timing generator
e. Communications equipment
f. Teletype equipment
g. Tri-helix control equipment
h. SS/H shift supervisor's console
i. Master control console
j. Plot boards (3)

1.5.2 Point Mugu Tracking Station

The Point Mugu tracking station is located at the Naval Air Missile Test Center (NAMTC), Point Mugu, California. The installation is in two general areas which are approximately 2,000 feet apart. The station configuration is shown in Fig. 1-7 and 1-8.

Transmitting Area. The following facilities are located within this area:

a. Radar van
b. Radar antenna and pedestal
c. Data transmission van
d. Administration and control van
e. Boresight towers (2)
f. Mobile diesel generators (3) and mobile switching facilities
g. Communications and maintenance van

Receiving Area. The following facilities are located within this area:

a. Instrumentation van
b. Telemetry van
c. Electronic maintenance and storage van
d. Tri-helix antenna
e. WWV antenna

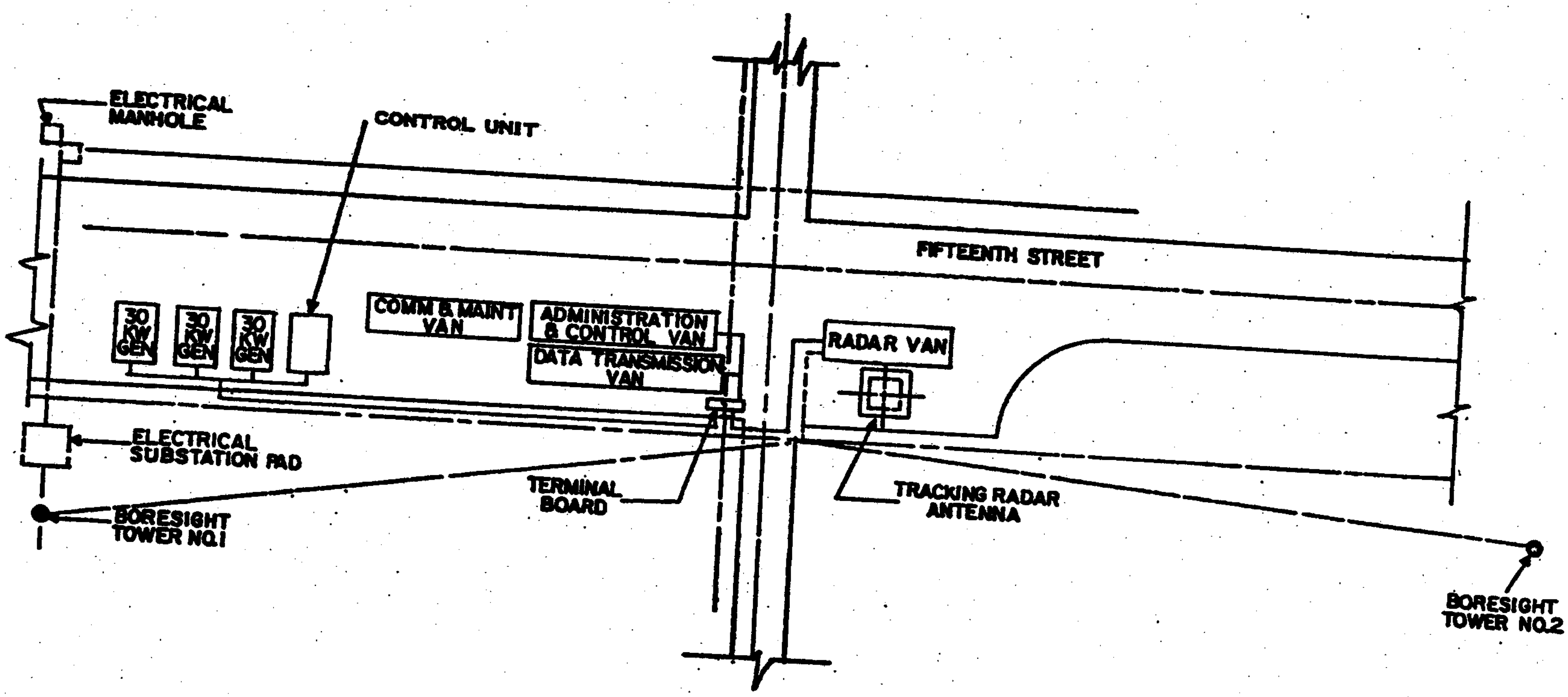


Fig. 1-7 Point Mugu Tracking Station-Transmitting Area

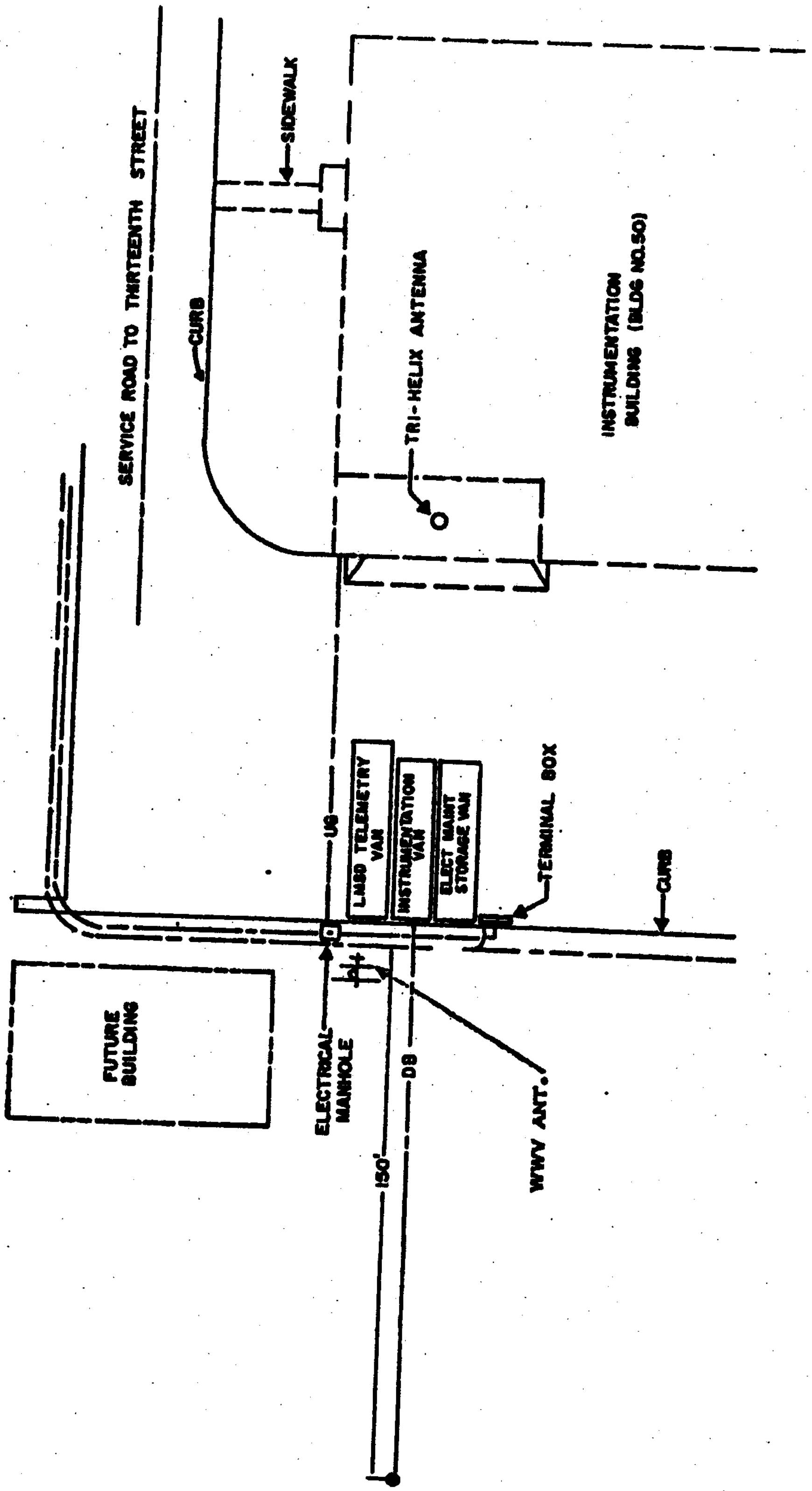


Fig. 1-8 Point Mugu Tracking Station Receiver Area

1.5.3 Hawaii Tracking Station

The Hawaii tracking station is located on the westernmost point of the Island of Oahu, Hawaii. The receiving area is situated 2.3 miles southwest of Dillingham airstrip. The transmitting area is located approximately 8,000 feet northeast of the receiving area. The station configuration is shown in Figs. 1-9 and 1-10.

Transmitting Area. The following major facilities make up the transmitting area:

a. Radar van
b. Radar antenna and pedestal
c. Boresight towers (2)
d. Data transmission van
e. Diesel generators (3) and switching unit

Receiving Area. The receiving area is made up of the following facilities:

a. Administration and VHF telemetry receiver building
b. Telemetry tracker antenna
c. Tri-helix antenna
d. WWVH antenna
e. Boresight tower
f. Maintenance and storage van

The following equipment and components are housed in the administration and VHF telemetry receiver building:

a. Data transmission equipment
b. Doppler equipment
c. Telemetry equipment
d. Master timing generator
e. Communications equipment
f. Teletype equipment
g. Tri-helix antenna control equipment
h. Telemetry tracker control equipment
i. SS/H shift supervisor's console
j. Master control console
k. Plot boards (2)
l. WWVH antenna (on top of building)

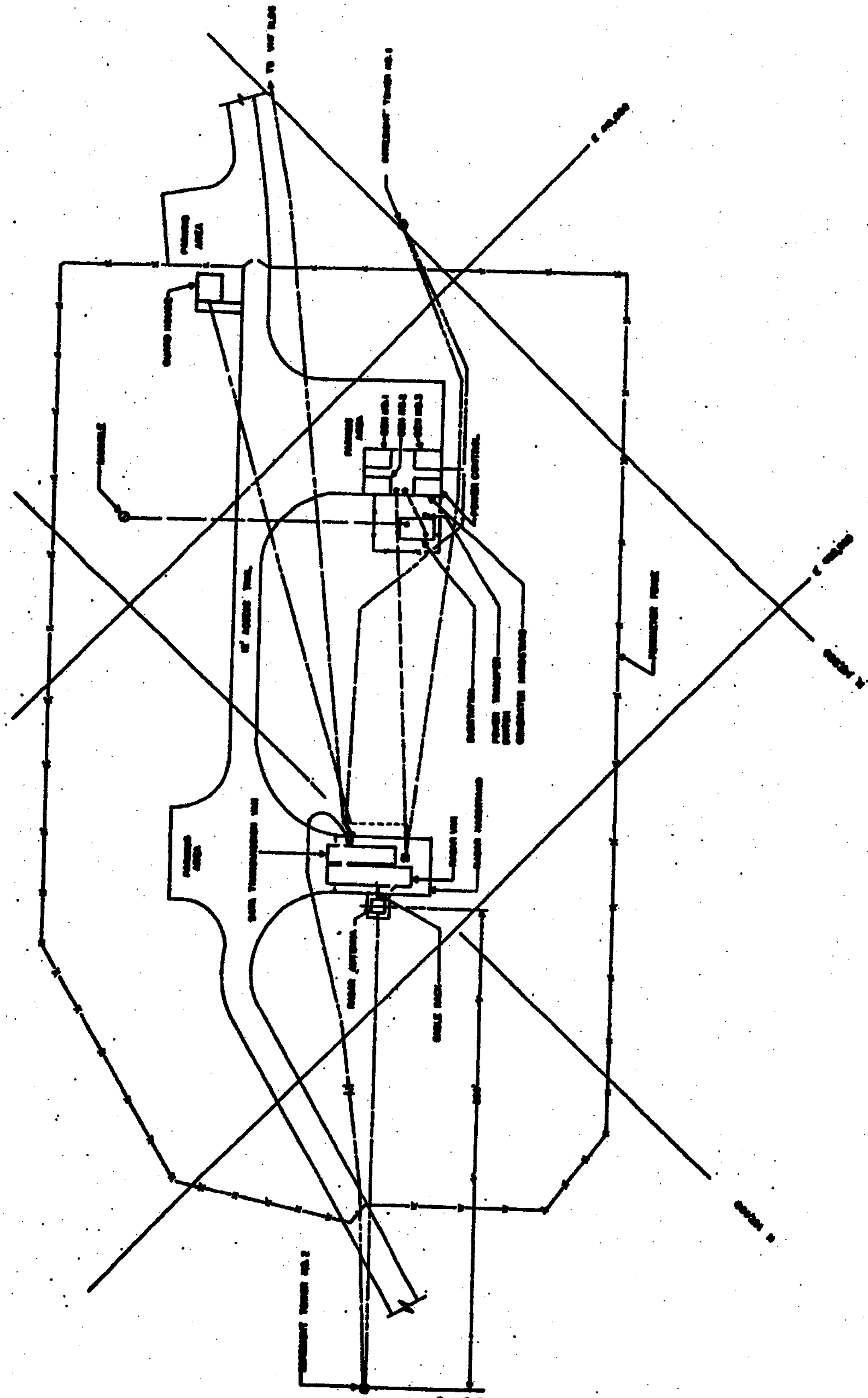


Fig. 1-9 Hawaii Tracking Station Transmitting Area

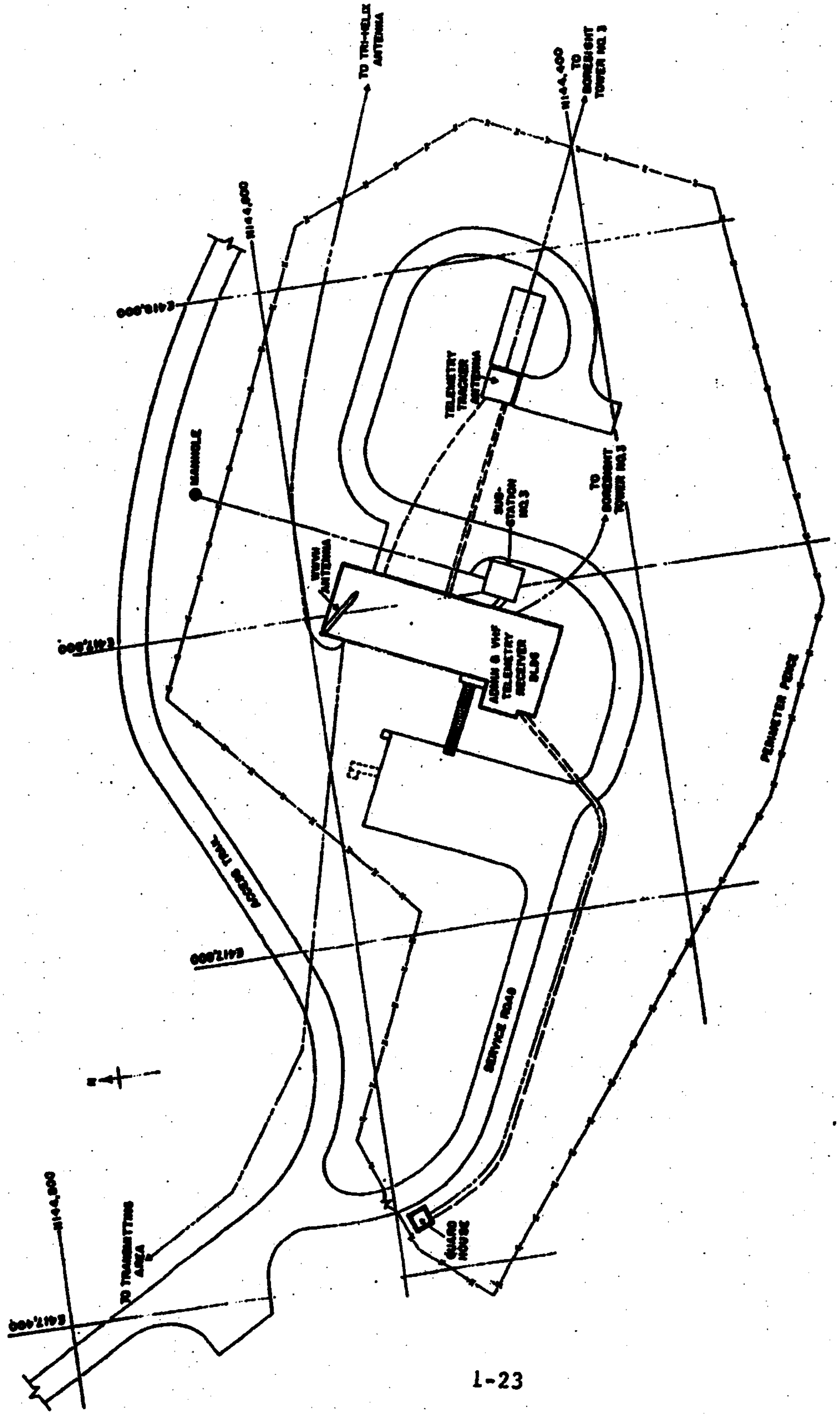


Fig. 1-10 Hawaii Tracking Station Receiving Area

1.5.4 Kodiak Tracking Station

The Kodiak tracking station is located within Chiniak Air Force Station, Cape Chiniak, Kodiak, Alaska. The tracking station consists of two separate areas which are approximately 1,800 feet apart. The station layout is shown in Figs. 1-11 and 1-12.

Transmitting Area. The transmitting area contains the following major facilities:

a. Composite building
b. Radar van
c. Radar antenna and pedestal (with inflatable radome)
d. Data transmission van
e. Boresight towers (2)

The composite building houses the following equipment:

a. Shift supervisor's console
b. Master control console
c. Plot board
d. Teletype equipment
e. Communications equipment
f. Timing terminal unit
g. 100 KW diesel generators (4)

Receiving Area. The receiving area contains the following major facilities:

a. Instrumentation van
b. Maintenance and storage van
c. Telemetry van
d. Tri-helix antenna (with rigid radome)
e. WWV antenna

In addition, direction finding equipment associated with the tri-helix antenna was located in the receiving area but was subsequently removed for installation on a telemetry ship to assist in recovery operations. This proved to be unsatisfactory because of insufficient ship stability. At the present writing its reinstallation at the Kodiak Station is being negotiated.

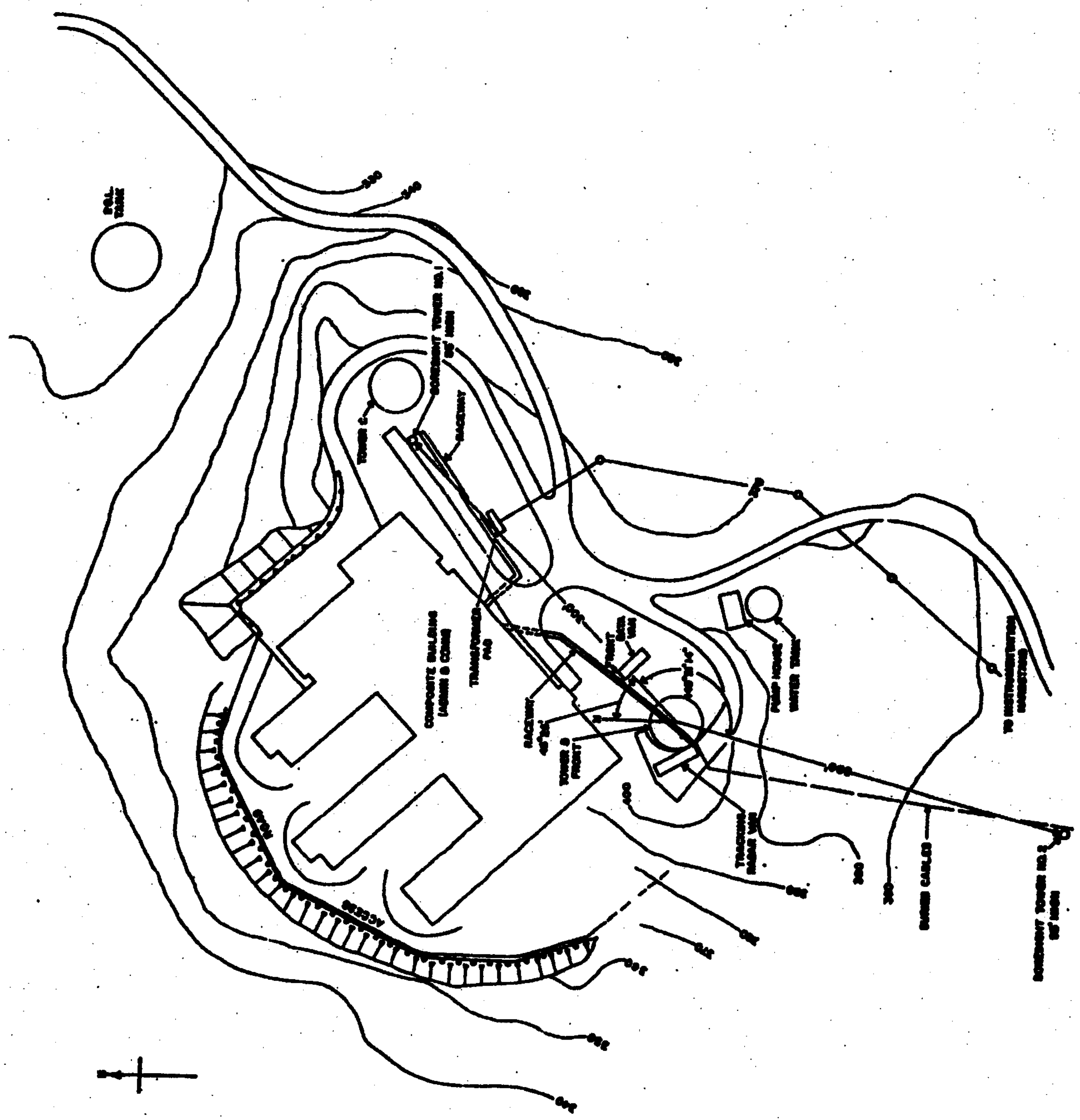


Fig. 1-11 Kodiak Tracking Station Transmitting Area

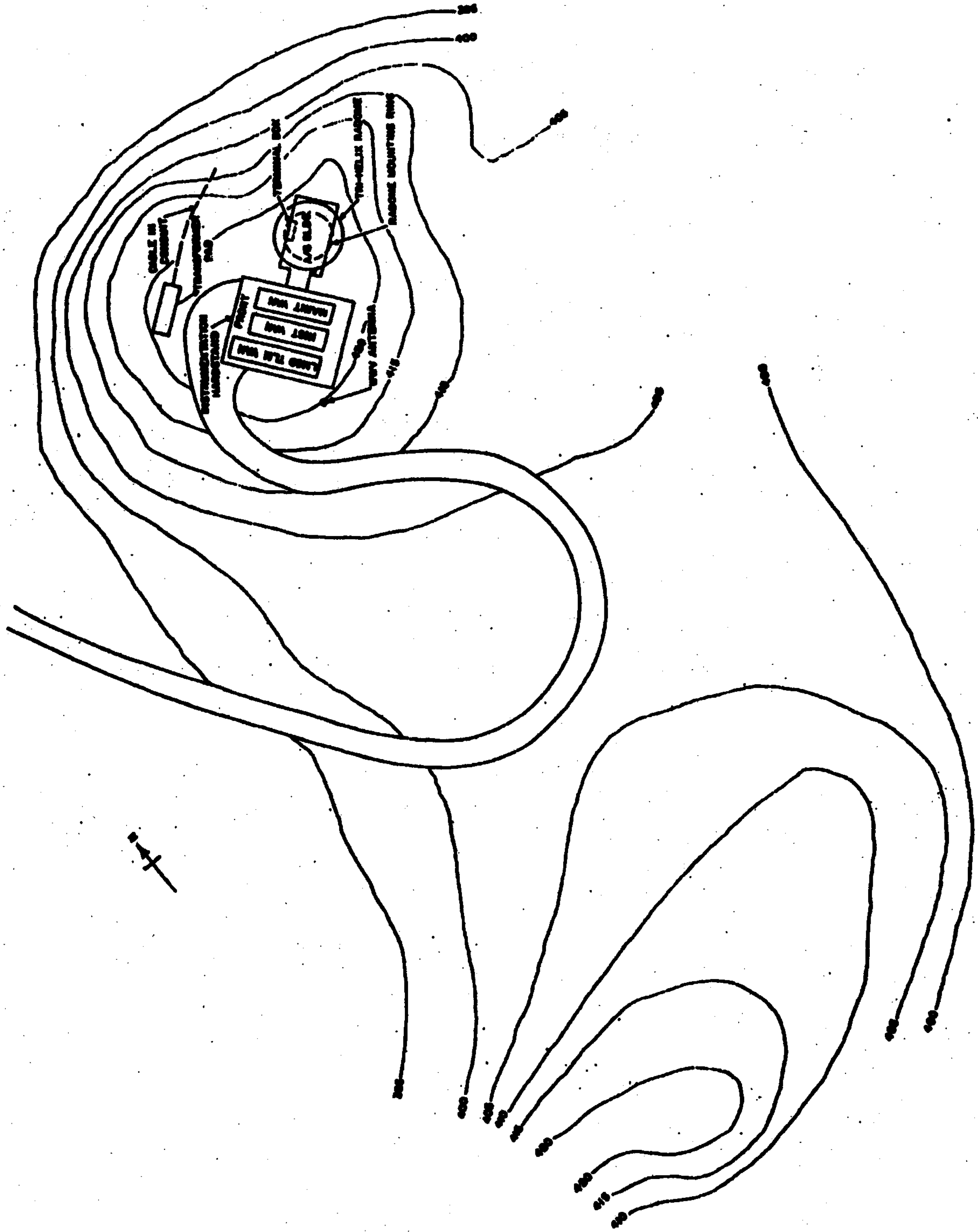


Fig. 1-12 Kodiak Tracking Station Receiving Area

1.5.5 New Boston Tracking Station

The New Boston tracking station is located just west of Manchester, New Hampshire. The installation is made in two general areas which are separated by a distance of 11,000 feet. The station configuration is shown in Fig. 1-13.

Transmitting Area. The transmitting area is made up of the following facilities:

a. Radar van
b. Radar antenna and pedestal (with radome)
c. Data transmission van
d. Administration and control van
e. Boresight tower

Receiving Area. The following major facilities are included in the receiving area:

a. Telemetry van
b. Instrumentation van
c. Tri-helix antenna (with radome)
d. WWV antenna

1.5.6 Pacific Missile Range

In addition, the Pacific Missile Range provides downrange coverage for Discoverer launches with a telemetry ship (Victory class) and with one or more partially equipped ships for use during a capsule recovery operation. In a similar manner a number of locations in the Hawaiian area (Johnston Island, Tern Island, Christmas Island, Barking Sands, etc.) may be called upon to support during recovery.

The telemetry ship has the following capabilities:

a. Receive, discriminate and record telemetry data
b. Receive and read out Doppler data
c. Index recorded data with system time and display system time.
d. Communicate with other ships or shore - based stations on phone, CW or teletype via single side band radio (SSB).
e. Angle track with punched tape readout.

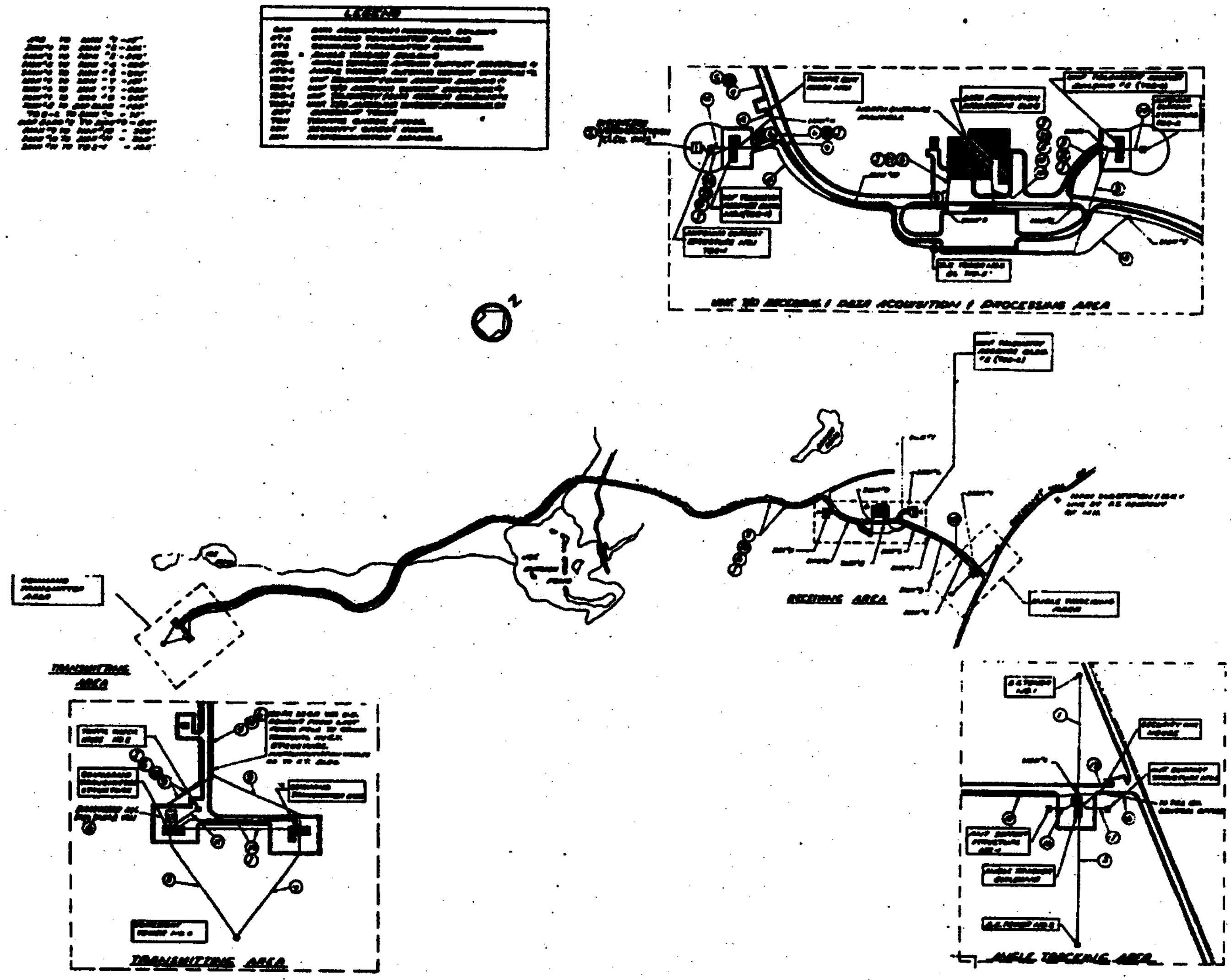


Fig. 1-13 Layout of New Boston Tracking Station

1.6 Inter-Relation with Other Programs

Increasing use is being made of the Discoverer communication and control facilities for the support of other programs, since these facilities are available and have been proven out during a number of successful vehicle flights. Currently, this support, of both a primary and backup nature, is being given to the Samos, Midas, and Advent Programs.

Thus Verlort tracking and commanding and VHF telemetry and Doppler reception are used in the Midas and Samos programs and to some degree in the Advent program. The support entails modifications to the Discoverer equipment; details of these modifications appear in Appendix C of this report.

SECTION 2

VEHICLE TRACKING AND COMMANDING SYSTEM

2.1 General

The vehicle tracking capability furnishes the data for determining orbit parameters and maintains proper orientation of the data receiving links. The command capability allows control or adjustment of certain vehicle functions.

The Discoverer tracking capability is furnished by two automatic tracking systems and one manual system. The automatic tracking system is the Verlort radar at all Discoverer tracking stations and the telemetry tracker at VAFB and Hawaii. The manual system is the tri-helix antenna at all stations.

The Verlort radar is the principal ground-based unit for acquisition, tracking, and commanding functions. The radar is designed to interrogate a beacon transponder in the vehicle and track automatically on the return signal. The beacon is preset to respond only to one of six possible time-coded pulse combinations. When the beacon is triggered by appropriately coded pulses from the Verlort, it responds by transmitting pulses back to the radar. The radar tracks these pulses in azimuth and elevation and measures the slant range to the vehicle. The azimuth, elevation, and range data generated by the radar are available in the form of digital pulses, polar analog synchro signals, and analog d-c signals. Sixteen-bit digital azimuth and elevation data, 18-bit range data, and two quality bits are routed to digital-to-teletype (D/TT) converters. This tracking data is converted to teletype format and transmitted with time indentification and message headings to the central computer. The Verlort synchro tracking data is made available for slaving other antennas, such as the telemetry tracker and tri-helix antennas. The analog d-c signals are supplied to polar-to-cartesian converters (P/C) and converted to cartesian x, y, and z coordinates for plot board use and remote slaving applications.

The Verlort radar provides the only means by which commands may be transmitted from the ground to the vehicle. Commands are transmitted from the radar to the vehicle by a three-pulse code. The two outer pulses provide a fixed frame which is detected and responded to by the beacon, and which serves as a time reference for a time-modulated middle pulse. The outer pulse spacing is determined by the beacon coding used. The middle pulse of the three pulse code is time-modulated by two tones selected from four available tones provided by tuning fork oscillators located in the radar pulse coder.

The Telemetry Tracker is primarily a data receiving antenna that is capable of automatic track on a VHF signal. Angle tracking data is produced which can be used as backup to the Verlort tracking data. See Paragraph 3.1 for a detailed description.

The tri-helix is a Doppler and data receiving antenna which is manually positioned using signal strength indicators. See Paragraph 3.2.2 for a detailed description.

2.2 Very Long Range Tracking Radar (VERLORT) (Figs. 2-1 and 2-2)

The Verlort is basically a MOD II (SCR-584) radar modified to meet Discoverer requirements. Major modifications were performed as follows:

a. Extension of maximum range capability from 400 to 2300 miles

b. Addition of an analog orbital computer to serve as a memory device to provide a carry-over during a temporary loss of track

c. Incorporation of a low-noise front end utilizing a traveling-wave-tube amplifier to increase system performance and reliability

d. Redesign of the antenna feed assembly and pedestal and the incorporation of precision analog and digital encoders to provide increased accuracy in both the tracking and the tracking data

e. Addition of a guidance computer at Pt. Mugu to generate second stage guidance correction commands.

A typical floor plan layout of the Verlort van is presented in Fig. 2-3.

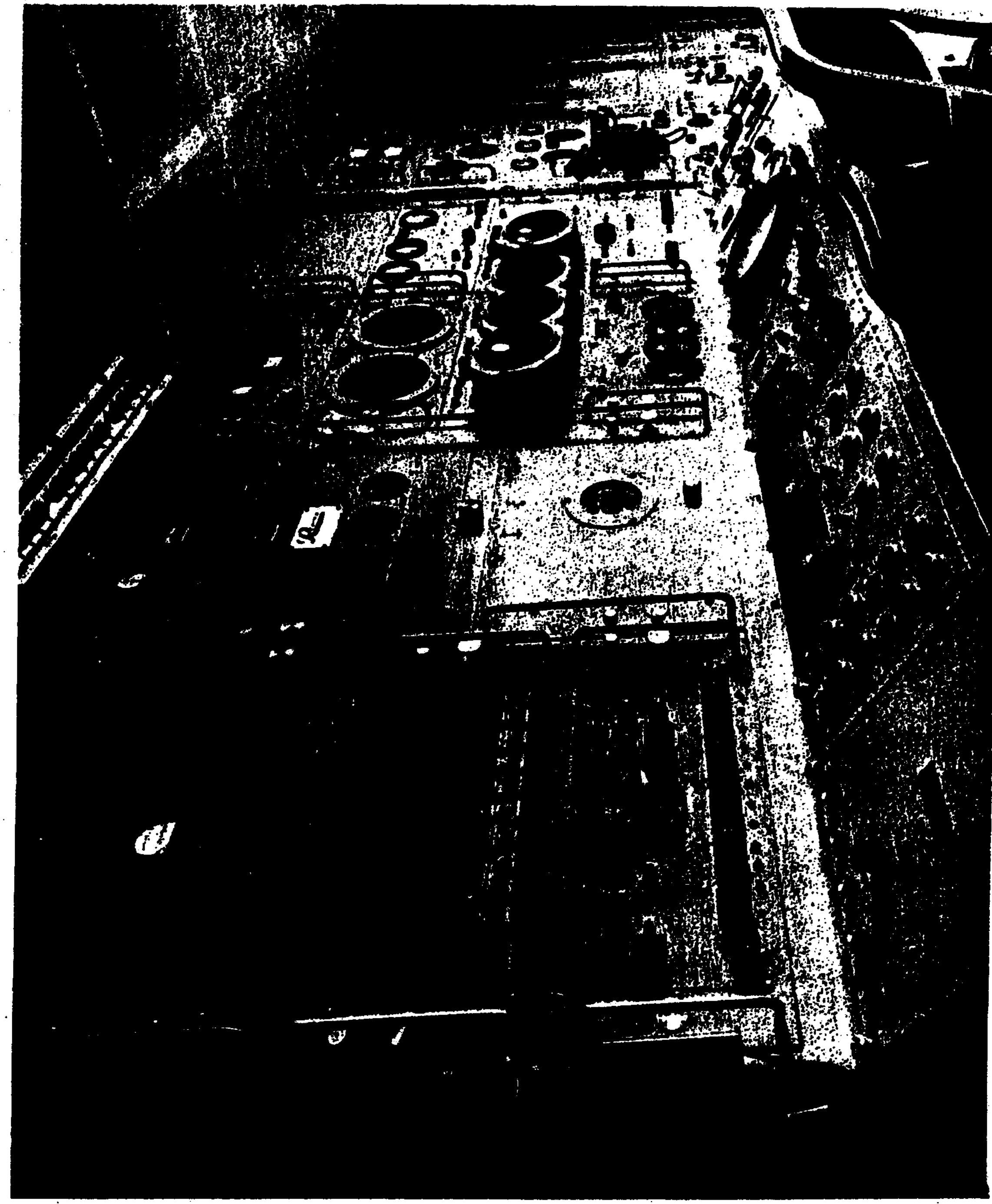


Fig. 2-1 Verlort Van Interior

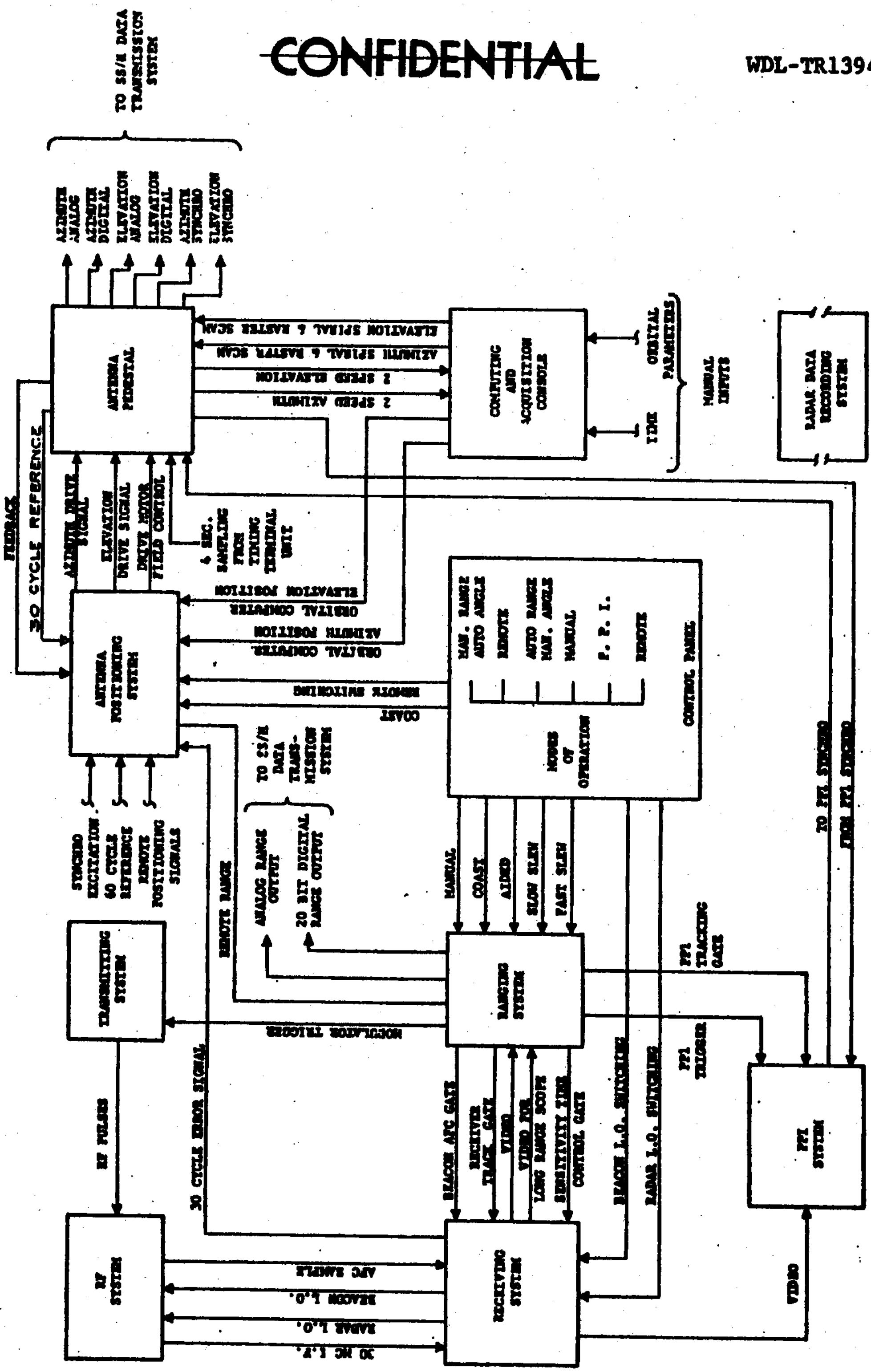


Fig. 2-2 Verlort Radar System Simplified Block Diagram

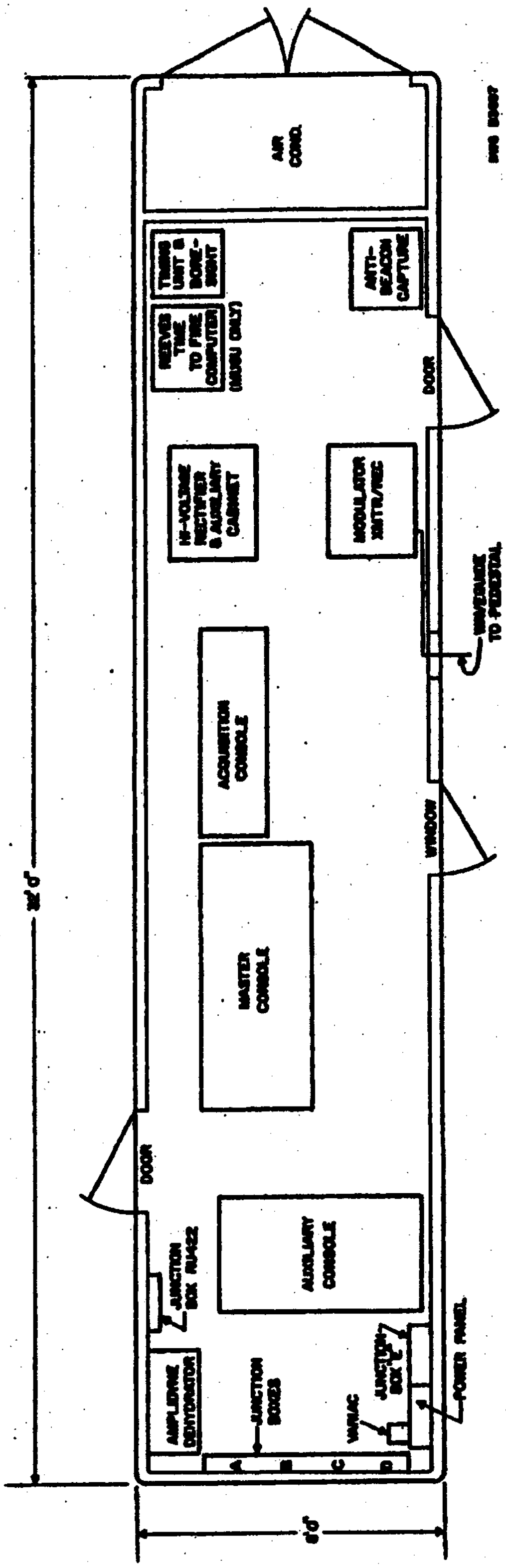


Fig. 2-3 Typical Radar Van

2.2.1 Transmitting System

The radar transmitting system generates 0.8 microsecond wide time-coded r-f pulses at a frequency of 2850 mc. The peak power output is 250 kw minimum. During radar operation, coded trigger and command pulses that are developed by the beacon coder in the range system are applied to the driver unit in the transmitting system. The pulses are processed and ultimately applied to a keyer tube in the modulator. The keyer tube acts as an electronic switch and allows the modulator capacitor to discharge through the magnetron for the duration of the 0.8 microsecond pulse. Parasitic oscillations that occur at the end of the keying pulse are suppressed by damping diodes in the modulator. The radar pulse group configuration is illustrated in Fig. 2-4.

2.2.2 R-F System

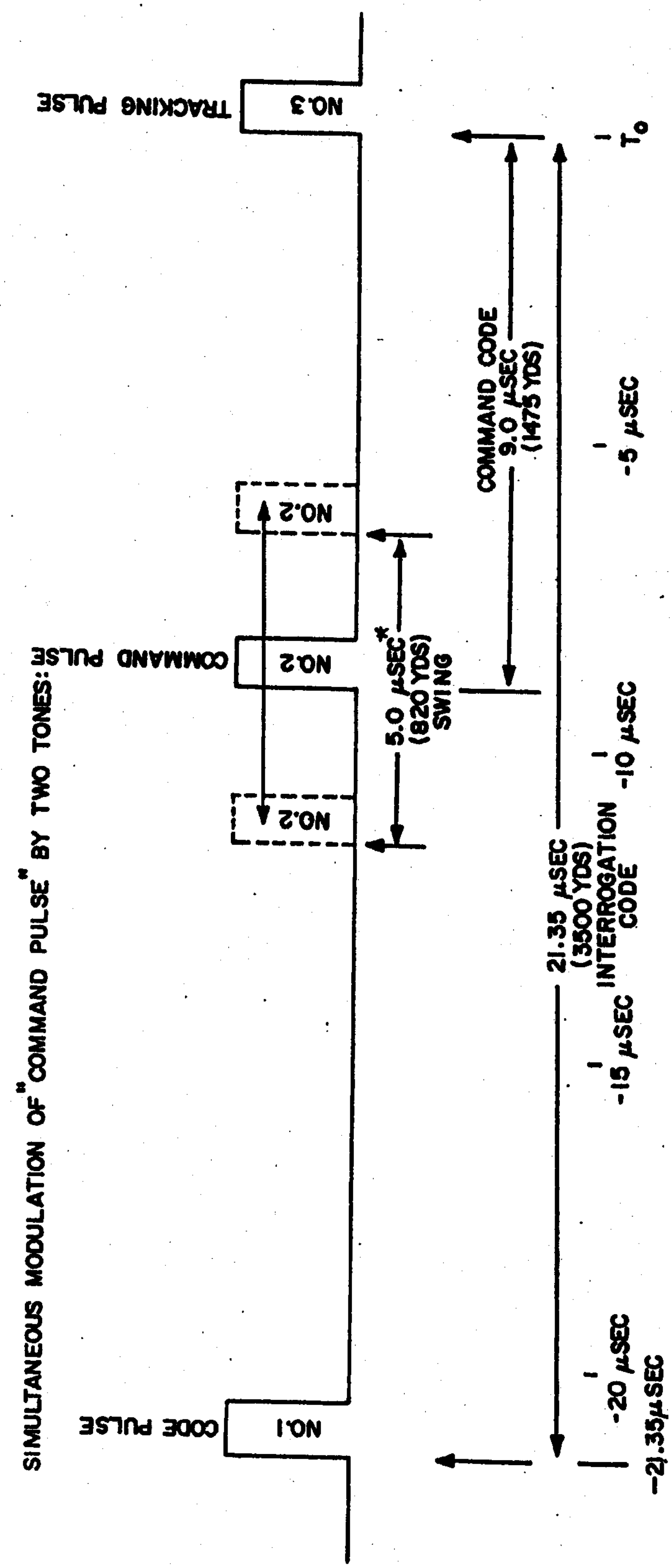
The r-f system conducts the r-f pulses from the magnetron in the transmitting system through a ferrite isolator in the r-f system to the nutating antenna for radiation into space. In addition, the r-f system receives the r-f signals transmitted by the vehicle beacon transponder and conducts these signals to the receiving system. Utilization of the same r-f system for both transmitting and receiving requires a duplexer to protect the receiver from the strong transmitted pulse.

The antenna system uses a nutating feed to provide a conical scan at either 50 per cent or 80 per cent cross-over. The 10-foot parabolic reflector has a beamwidth of 2.5 degrees at half power points.

From experience and tests, a waveguide variable attenuator was found to be necessary, so one was installed at VAFB tracking station to reduce the received signal during pre-launch vehicle checks. This protects the receiver from excessive signal and eliminates ground reflections. Also, some side lobe tracking had been experienced and the attenuator serves to avoid this condition, possible during the early launch phase.

2.2.3 Receiving System

The receiving system has a minimum discernible signal of -103 dbm and a noise figure better than 7 db. This is accomplished by use of traveling-wave-tube amplifier having a minimum gain of 25 db at S-Band frequencies.



*NOTE: 5.0 μsec spacing is 5.5 ± 0.5u seq in the transistorized beacon RT-5.

Fig. 2-4 Radar Beacon Pulse Group Configuration

The receiving system amplifies and detects the signals received by the r-f system and converts them into video signals for presentation of the PPI and range scopes and for activating the automatic tracking circuits in the range system. The receiving system also develops the 30-cps error signal which is used in the antenna positioning system to develop azimuth and elevation error signals that automatically position the antenna.

The 30-mc i-f signal from the crystal detector in the r-f system is amplified, detected, amplified again, and applied to an agc and remote video unit. The agc and remote video unit provides the 30-cps error signal to the antenna positioning system, and the manual and automatic gain control voltages for the receiver i-f strip. The agc voltage maintains the video output of the receiver i-f strip at a constant average voltage. An error-tracking gate from the automatic range tracking unit gates the agc and remote video unit to allow only the responses of the beacon transponder to be passed during automatic range tracking. A sensitivity time control gate limits the receiver gain just prior to, and after, the main bang to limit the amount of ground clutter appearing on the various radar video displays. The output video is applied to the range system for display on the radar range indicators and for use in automatic range tracking, and the PPI system for display on the PPI scope.

2.2.4 Ranging System

The ranging system generates the timing triggers and gates which synchronize the radar equipment and make the accurate determination of range possible. In addition, the range system presents continuous range information on four types of "A" display, furnishes a dial indication of the range to a selected target, makes slant range data available in synchro, d-c analog, and digital form, and contains the components necessary for automatic, aided, programmed, and manual range tracking.

The basic timing signal of the radar is generated by an 82-kc crystal-controlled oscillator. The output of the 82-kc oscillator is amplified, counted down, and otherwise processed to provide the basic 410-pps, 512-pps, and 584-pps pulse repetition frequencies to the modulator in the transmitting system. In addition, triggers which synchronize the range sweeps and the display sweeps within the ranging system and the PPI sweep within the PPI system are generated. The total range cycle is determined by a 28-cps generator.

The 2300-mile tracking range of the Verlort radar is accomplished with the use of PRF's between 400 and 600 pps by triggering the beacon with every transmitted pulse and by receiving the beacon responses during PRF intervals. This technique results in a target appearing during every PRF period from the transmitted pulse at t_o out to the total length of 2300-mile range sweep. The Verlort radar switches PRF automatically with range changes to prevent interference between the transmitted and received pulse. Target identification is made and range ambiguity is resolved by eliminating one transmitted pulse during the total 28-cps range cycle. Elimination of one transmitted pulse eliminates one of the beacon responses which would normally occur during one of the PRF periods. The absence of a beacon response pulse from one of the PRF periods identifies that period as the one which contains the beacon range within its limits. The long-range indicator contains those 32,000-yard segments of the 400,000-yard sweeps which are brightened on the 400,000-yard indicator. The 400,000-yard indicator is brightened by a 32,000-yard gate which corresponds to the 32,000-yard sweep. The 32,000-yard sweep is brightened by a 2000-yard gate which corresponds to the 2000-yard sweep, and the range strobe occurs in time with the range tracking gates. When the range control is slewed so that the 32,000-yard illuminated gate is placed at the range of the target on the 400,000-yard scope, targets appear on each of the 32,000-yard sweeps on the long-range indicator except that sweep which identifies the 400,000 yard PRF period which contains the beacon response. This is identified also by the fact that it is brightened. The brightened sweep on the long-range indicator jumps from one 400,000-yard segment to another as the range control is slewed in and out. Ambiguity is resolved and range identified by positioning the 32,000-yard gate, the 2000-yard gate, and the range strobe so that they are positioned over the targets on each of the indicators. When this is done, the sweep containing no target on the long range indicator is brightened and the radar range tracking gates are positioned with enough precision to accomplish range lock-on.

2.2.5 Pulse Coder (KY-94, Command Encoder)

The pulse coder enables the transmission of commands through the Verlort-beacon link by coded pulse-time-modulated Verlort transmissions. It further provides one of six beacon interrogation codes. The pulse coder generates two pulses, Pulse 1 and Pulse 2, which are known as the code pulse and control interval pulse respectively. These pulses have a specific time relationship to the transmitter trigger, or tracking pulse (See Fig. 2-4). The range system provides the reference input to the pulse coder that is needed to establish this time relationship. The pulses are fed to the ranging system and then applied to the transmitter exciter.

Pulse Code Intervals. The position of pulse 1 in relation to Pulse 3 is known as the pulse code interval. Any one of six intervals may be manually selected by the radar operator. The spacing may be varied from 21.35 microseconds to 36.60 microseconds in intervals of 3.05 microseconds.

Commands. The rest position of Pulse 2 is 9 microseconds before Pulse 3. For commanding, the position of this pulse is varied, or pulse time-modulated, by means of an audio frequency. The amount of shift at any moment is governed by the instantaneous amplitude of the modulating signal, which is the sum of two tone voltages. Approximately 3 volts is required for a shift of one microsecond. The present command structure requires four tones, identified as tones A, B, C and D. These are generated by tuning fork tone oscillators and selected in combinations of two as directed by logic circuitry in the Vehicle Command Controller (VCC) console. Two additional tones are available but are not used. The frequencies of the tones utilized are listed below.

TONE	FREQUENCY
A	73.2 cps
B	91.5 cps
C	122.0 cps
D	154.0 cps

A temporary modification was installed on the pulse coder to permit manual disabling of the command pulse to eliminate the problem of command dumping as described in Paragraph 2.4.2. This modification consisted of a toggle switch to interrupt the Pulse 2 channel of the pulse coder. The permanent modification (RP-21) to be performed will provide for normal two pulse operation with automatic switching to three pulse for commanding.

2.2.6 Antenna Position System

The antenna positioning system positions the radar antenna in azimuth and elevation either manually, remotely or automatically. In addition, the antenna positioning system provides analog, synchro, and digital antenna azimuth and elevation data to the SS/H data transmission system, and two-speed azimuth and elevation synchro data to the orbital computer.

The antenna positioning control, in the manual and PPI operation, supplies the signal voltages which drive the antenna positioning system. The stators of azimuth and elevation synchros in the control unit are rotated by handwheels for manual operation, and by a motor for PPI operation. A cam arrangement provides elevation scanning in the PPI mode.

In remote operation, remote data from three sources is applied to the antenna positioning system. Switches on the control panel select the desired remote source; i.e., acquisition program, orbital computer, or slave data bus. Remote antenna angle data is routed to the dual antenna position indicators for angular display of the data.

Spiral and raster scans which may be used to program the position of the antenna are supplied to the antenna servo by the antenna positioning system. The raster scan is available only in the manual mode of operation. It is generated in the acquisition console by a series of stepping relays. The spiral scan is available only in the remote mode of operation. It is generated by a resolver which provides azimuth and elevation error signals to the antenna control circuits. The spiral scan centers about the point in space defined by the remote data being utilized. The operator can stop the scan at any point and manually back up along the path of the spiral.

Azimuth and elevation potentiometers, one-speed and 36-speed synchros, and digital code wheels located in the antenna pedestal are positioned by the antenna. The outputs of these data transmission devices are made available to the SS/H data transmission system and to the orbital computer.

2.2.7 Radar Data Recording System

The radar data recording system consists of a 6-channel and a 100-channel electric pen recorder. Any one of several chart speeds can be selected as desired while the drive is either running or stopped. The 6-channel recorder instantaneously charts, in permanent form, a selected number of variable functions at a writing frequency response of from 0 to 100 cps. The 100-channel recorder furnishes an on-off indication and does not provide an indication of amplitude fluctuations of the monitored signal. Table 2-1 contains the standard listing of functions to be recorded on the 6- and 100- channel recorder. This standardization is being accomplished by Modification RP-70.

2.2.8 Verlort Orbital Computing System

The orbital computer, Figs. 2-5 and 2-6, may be used to automatically control the radar search pattern to locate an orbiting vehicle. The search pattern is started at a predicted time when the orbiting vehicle will be within range of the radar. The orbital computer uses data concerning the orbiting vehicle's motion and the predicted horizon position at a defined time to extrapolate the continuous coordinates (azimuth, elevation, and slant range) of the orbiting vehicle's pass. These coordinates are available for automatically directing the radar search until the orbiting vehicle is acquired for a radar lock-on and automatic tracking. The computer produces two modes of sçanning, raster and spiral, to improve the chances of initial acquisition and reacquisition if necessary. It also has error detection circuits to determine the input data errors after radar acquisition and lock-on. These errors are then corrected to provide a more accurate extrapolation by changing the manual input controls. This extrapolation could be used to search if the radar loses automatic track. Since the computer instrumentation is based upon a circular orbit, these corrections also compensate for deviations

TABLE 2-1

VERLORT RECORDER STANDARDIZATION

6-PEN

Channel	Function
Margin	Time Marks
1	AGC (Automatic Gain Control)
2	Azimuth Error
3	Elevation Error
4	Range Error and Command Mode
5	Range Rate
6	Time Code Word and PRF
Margin	On Target Indication

100-PEN

Channel	Function
0 - 10	
1	Time Code Word
2	Transmitter ON
3	Automatic Passive Tracking
4	PRF 410
5	PRF 512
6	PRF 584
7	Remote 1 (Optical Tracker)
8	Remote 2 (Slave Data Base)
9	Remote 3 (Reeves Orbital Computer)
10	Remote 4 (ACQ Computer)
10 - 20	
1	Raster Scan
2	Spiral Scan
3	PPI Scan
4	Azimuth Manual
5	Azimuth Automatic

TABLE 2-1

(Continued)

100-PEN

Channel	Function
6	Elevation Manual
7	Elevation Automatic
8	Range Manual
9	Range Automatic
10	Coast
20 - 30	
1	Azimuth Smoothing A
2	Azimuth Smoothing B
3	Azimuth Smoothing C
4	Azimuth Smoothing D
5	Elevation Smoothing A
6	Elevation Smoothing B
7	Elevation Smoothing C
8	Elevation Smoothing D
9	Boresight Camera ON
10	Line Voltage Dropout
30 - 40	
1	Radar Quality Bit (On target)
2	Radar L.O. Man
3	Radar L.O. AFC
4	Beacon L.O. Man
5	Beacon L.O. AFC
6	Command Coder Mode 1
7	Command Coder Local (Radar Van)
8	Command Coder Remote (V.C.C.)
9	Two Pulse Mode
10	Three Pulse Mode (Center pulse on)

TABLE 2-1
(Continued)

100-PEN

Channel	Function
40 - 50	
1	Command 1 *
2	Command 2 *
3	Command 3 *
4	Command 4 *
5	Command 5 *
6	Command 6 *
7	Tone A *
8	Tone B *
9	Tone C *
10	Tone D *

* From Monitor Beacon - indication that commands were radiated.

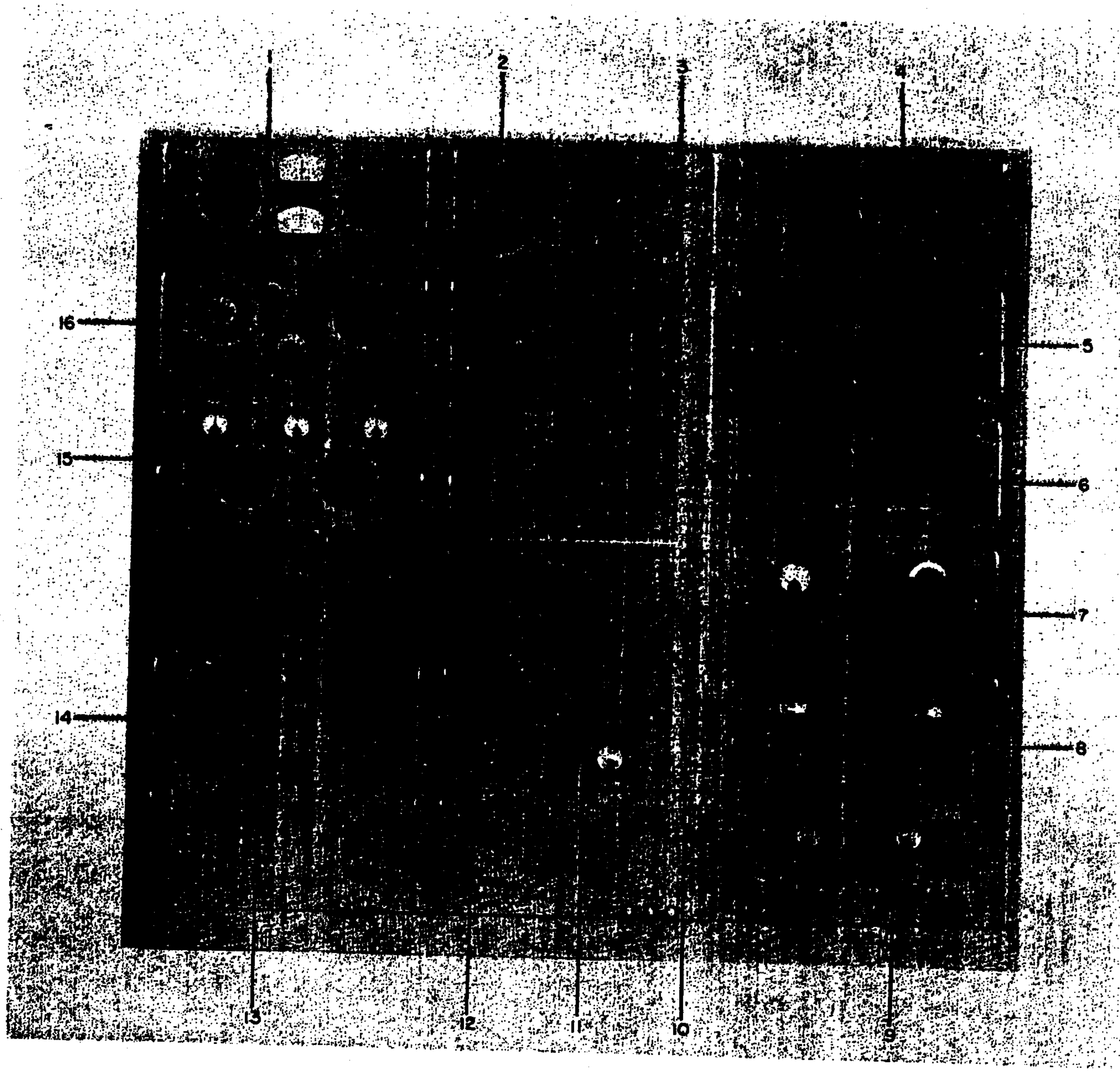


Fig. 2-5 Orbital Computer

Legend

1. Azimuth and Elevation Unit
2. Spiral Scan Unit
3. Electronic Unit No. 1
4. Slave Range Unit No. 1
5. Slave Range Unit No. 2
6. Slew Servo Amplifier
7. Beacon Sharing Sync
8. Traveling Wave Tube Power Supply
9. Master Power Supply
10. Electronic Unit No. 2
11. Power Supply No. 3
12. Power Supply No. 1
13. Power Supply No. 2
14. Relay Unit No. 1
15. Timer and Longitude Unit
16. Slant Range Unit

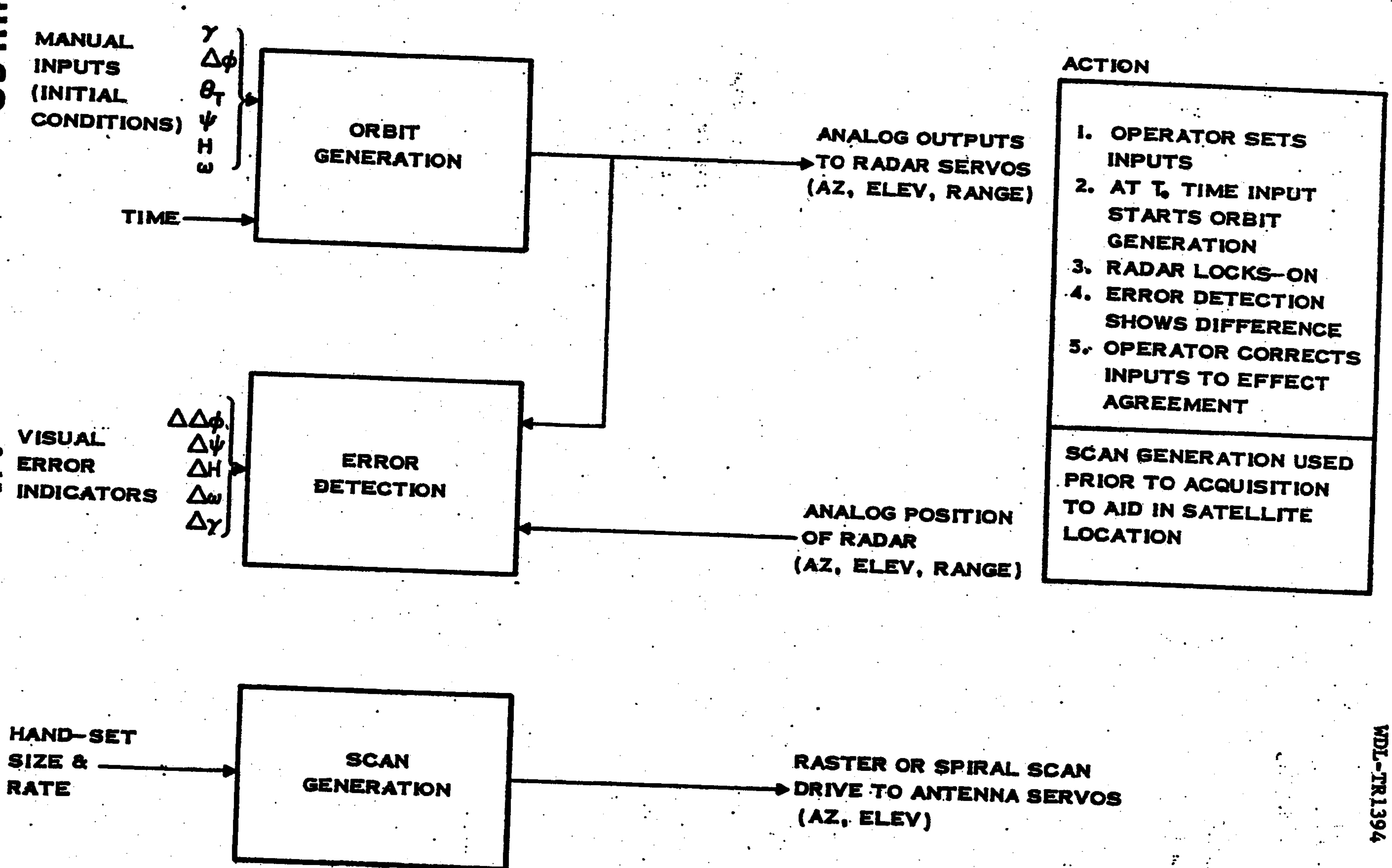


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Fig. 2-6 Verlort Orbital Computer Block Diagram produced by elliptical orbits and thus provide a more precise search control during an orbiting vehicle pass.

Orbit Generation. The orbital computer generates a continuous circular orbit as a function of time, based upon six manually inserted parameters. This involves the solution of spherical triangles in relation to the surface of the earth (Fig. 2-7). These solutions yield azimuth angle (A) and earth central angle (K) as functions of the following parameters:

a. Inclination of Orbit (γ)
b. Latitude of Tracking Station (θ_T)
c. Relation Longitude ($\Delta\theta$)(between tracking station and ascending node)
d. Orbital Angle (ψ)
e. Orbital Rate (ω)

Solution for elevation angle (E) and slant range (R) is generated as a function of earth's central angel (K) and the last manually inserted parameter; the height of the satellite (H).

Once the input quantities have been properly set, the computer then generates, within certain limitations, the position of the satellite as a continuous function of time. If for any reason the radar ceases to track the satellite, the computer solution may be used to position the radar to re-acquiring the satellite.

Error Detection. The vehicle's orbit is not exactly spherical, so some errors in the input data for the acquisition computer may be expected. Consequently, when the radar is locked on the target in the automatic mode, the orbiting vehicle's position, as defined by radar tracking, may be expected to vary from the orbital computer's continuing solutions. It is desirable to have the orbital computer's input data corrected periodically according to radar tracking data in the event the computer is needed for reacquisition.

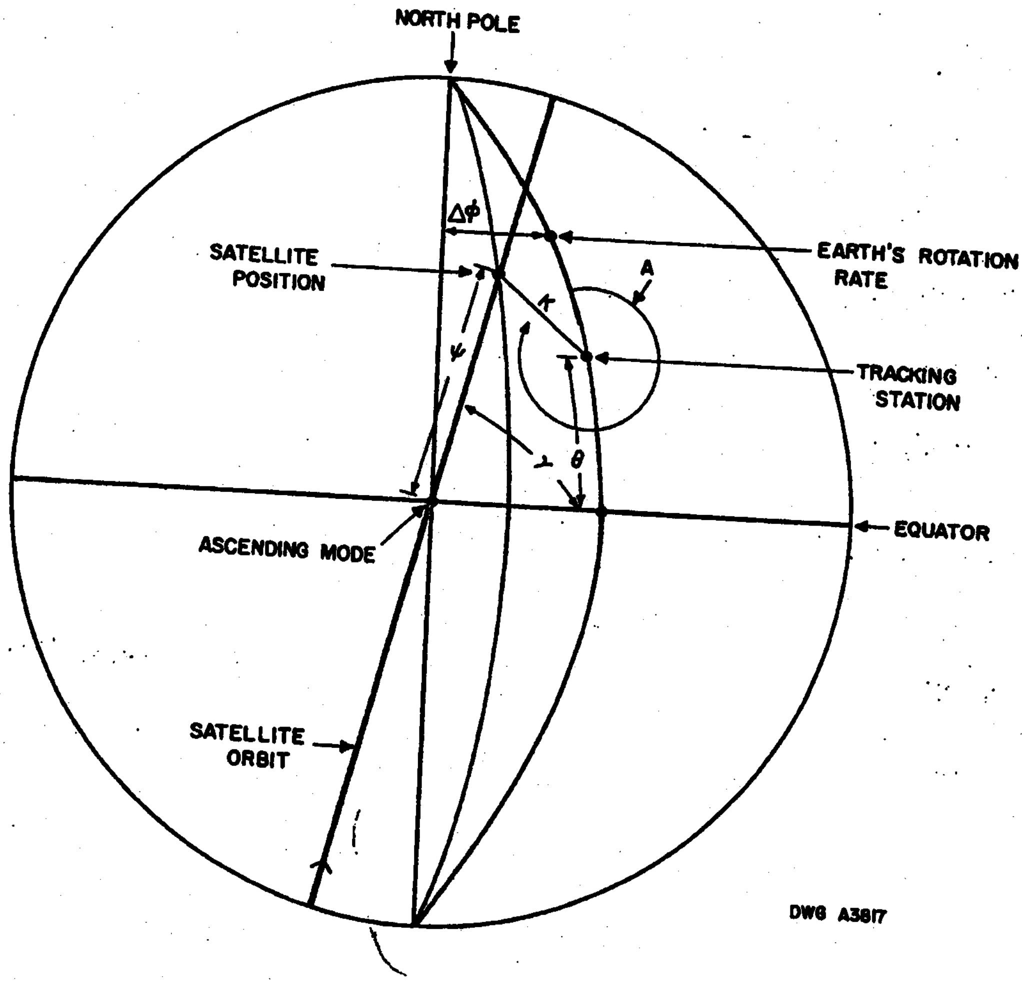


Fig. 2-7 Orbital Computer Solution of Spherical Triangles

$$\tan A = \frac{N_A}{D_A}$$

$$= \frac{-\sin(\Delta\phi)\cos\psi + \cos(\Delta\phi)\cos\gamma\sin\psi}{\sin\gamma\sin\psi\cos\theta_T - \sin\theta_T\left[\cos(\Delta\phi)\cos\psi + \sin(\Delta\phi)\cos\gamma\sin\psi\right]}$$

$$\sin K = \sqrt{N_A^{\,2} + D_A^{\,2}}$$

$$\cos K = \sin\gamma\sin\psi\sin\theta_T\left[\cos(\Delta\phi)\cos\psi + \sin(\Delta\phi)\cos\gamma\sin\psi\right]$$

(continued on reverse)

$$\tan E = \frac{(R_e + H)\cos K - R_e}{(R_e + H)\sin K} = \frac{N_e}{D_e}$$

$$R = \sqrt{N_E{}^2 + D_E{}^2}$$

$$\psi = (\psi_o) + \omega(T - T_o)$$

$$\Delta\phi = (\Delta\phi)_o + \Omega\,(T - T_o)$$

θ_T (Theta)	=	Latitude of Tracking Station(Always Positive in Northern Hemisphere)
γ (Gamma)	=	Inclination of Orbit, CCW From Equator at Ascending Mode (approaching North)
$\Delta\phi$ (Delta-Phi)	=	Relative Longitude Between Tracking Station and Ascending Mode (positive when east)
K (Kappa)	=	Angle Subtended at Center of Earth Between Tracking Station and Present Position of Satellite (always positive)
Ω (Cap. Omega)	=	Angular Velocity of the Earth
ω (Small Omega)	=	Orbital Rate of Satellite
R_e (Rea)	=	Radius of earth to Tracking Station
H (E')	=	Height of Satellite Above Sphere <u>through</u> Tracking Station
A (Alpha)	=	Azimuth Angle of Line of Sight to Satellite (CW from north)
E (Epsilon)	=	Elevation Angle of Line of Sight to Satellite Measured from Horiz. Plane at Station
R (Rae)	=	Slant Range to Satellite From Station
T (Tee)	=	Time Measured from Arbitrary Point
T_o ($T_{subzero}$)	=	Time Satellite Appears on Horizon
ψ_o (PSI_{zero})	=	Value of ψ when $T = T_o$
$\Delta\phi_o$ (Delta-Phi_{zero}	=	Value of $\Delta\phi$ when $T = T_o$
ψ (PSI)	=	Orbital Angle of the Satellite

The error detection circuits essentially compare the computer's definitions of azimuth, elevation and slant range with those transmitted by the radar synchro systems in the automatic mode. Differences are processed by computing loops to extract the $H, \gamma, \omega, \Delta\phi$ and ψ input factor errors. These are indicated on meters to show the changes in the input control settings which are necessary. Instantaneous errors are used to correct the input quantities $\Delta\phi$, ψ, and H. Variations of errors over a fixed-time interval are used to correct the input quantities γ and ω.

Scanning Generation. The acquisition computer contains a scan control system to enable an automatic radar search in either a raster or a spiral pattern. Raster scanning cannot be initiated in a remote mode and is used with a manually controlled search to acquire an orbiting vehicle. The raster search follows a specific pattern of sweeps in azimuth, steps in elevation and in interlaced return pattern. The width, speed, and the height of the raster are controlled by the operator.

Spiral scan is available only while the radar antenna is being driven in the remote mode by the acquisition computer. The radar search pattern produced is an expanding and contracting spiral around the computed position of the orbiting vehicle and can be initiated to acquire or reacquire the orbiting vehicle during a pass. The size and speed of the spiral can be selected by the operator.

Orbital Computer Utilization. With availability of the acquisition programmer, the orbital computer is primarily a back up for that equipment, except for the raster scan capability utilized for initial acquisition.

When a good track is initiated, allowing updating of the computer, an interruption of track requiring selection of a remote mode of operation (orbital computer or acquisition programmer) is seldom experienced. In cases of poor track, such as a marginal beacon or a tumbling vehicle, where selection of a remote mode is required for re-acquisition, the acquisition programmer usually provides a more accurate data source. This is partly due to the difficulty experienced updating the orbital computer with a poor track.

The orbital computer is useful in simulating orbit tracking operations for station operator training and equipment checkout, although there is no advantage over the acquisition programmer for the same purpose.

2.2.9 Launch Guidance

The successful injection of a Discoverer vehicle into orbit requires proper timing of the satellite engine ignition and length of burning. These functions are controlled by the vehicle SS/D Timer and guidance integrator. Provision has been made for adjusting these timing functions by ground command through the Verlort-beacon link. Command 5 (time-to-fire correction) will delay initiation of the engine firing sequence by disengaging the timer clutch for the duration of the signal. Command 6 (velocity-to-be-gained correction) will reduce the velocity-to-be-gained setting in the guidance integrator by approximately 50 ft/sec for each second of command duration. As a backup in the event no ground commands are received by the vehicle, a nominal ignition delay set into the orbital programmer is utilized. Command 6 must be transmitted immediately following termination of Command 5 in order to override the orbital programmer hold on the SS/D timer. This necessitates transmission of at least 1 second of Command 6.

The required guidance commands (5 and 6) are generated by the Point Mugu Verlort (Fig. 2-8). (See paragraph 1.5 for possible elimination of this requirement.) The Point Mugu Verlort includes a guidance (time-to-fire) computer (Fig. 2-9) to provide the necessary command corrections for deviation of the booster from the nominal flight path. These corrections can be performed within deviation limits of $\pm 10^{\circ}$ in azimuth and elevation and 33.3 k-yards in range from pre-set nominal trajectory parameters. As a back-up to the guidance computer, nominal values of the guidance commands are pre-set into the guidance command panel for transmission to the vehicle in the event of computer malfunction. The computer operator can switch the Verlort KY-94 command encoder input from the computer to the guidance command panel of the station master control console in the event vehicle trajectory deviations exceed computer limits. The timing start switch on the guidance command

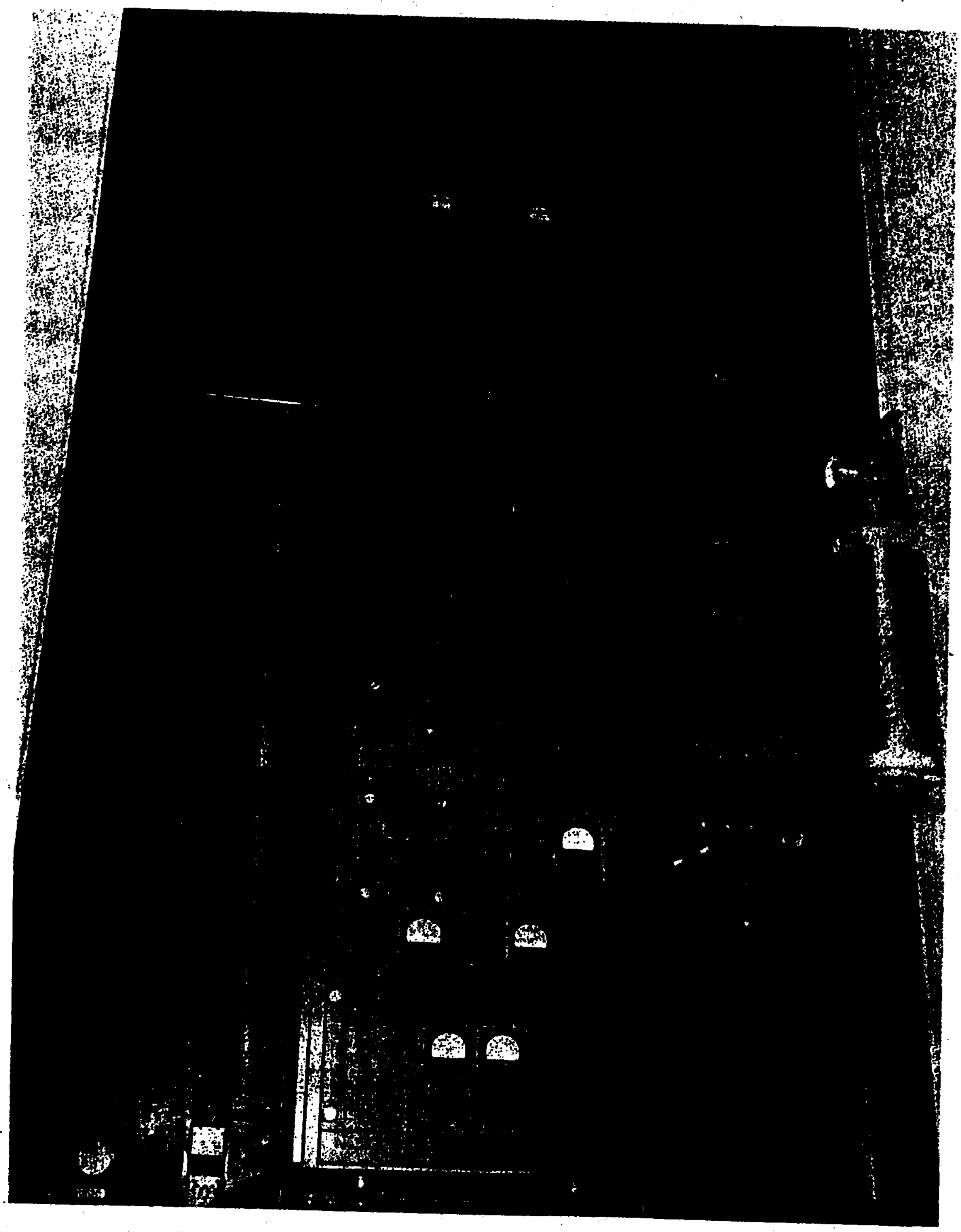


Fig. 2-9 Guidance Computer

panel is also the source of the T_L, or lift-off, signal which activates the computer time base. The nominal command values from the ground are preferable to the nominal airborne delay since the ground command can be executed with greater precision.

Guidance Computer. The guidance computer (Fig. 2-9) normally controls the Verlort KY-94 command encoder for the issuance of Commands 5 and 6 to provide the necessary second stage guidance. Nominal flight trajectory parameters are pre-set into the computer, where, at two pre-set timing intervals, they are compared with the actual trajectory of the vehicle in flight as determined by the tracking radar's azimuth, elevation, and range data. If the vehicle follows the nominal flight path, then the duration of Command 5 and 6 is fixed at the preset value inserted into the computer. If the vehicle deviates from this flight path, either by change of direction or by traversing the flight path too quickly or slowly, then it is necessary to vary the duration of each command. The correction to the duration of each command serves to place the vehicle into a more desirable flight path depending upon the extent of booster deviation. The actual duration of each command can be represented as the sum of a predetermined duration and a corrective duration. The corrective duration is solely dependent upon and proportional to the instantaneous difference between the vehicle's space coordinates furnished by the radar and the predetermined space coordinates at two pre-determined sampling times after liftoff but prior to the start of either command.

The sequence of events that must be followed is illustrated below in Fig. 2-10.

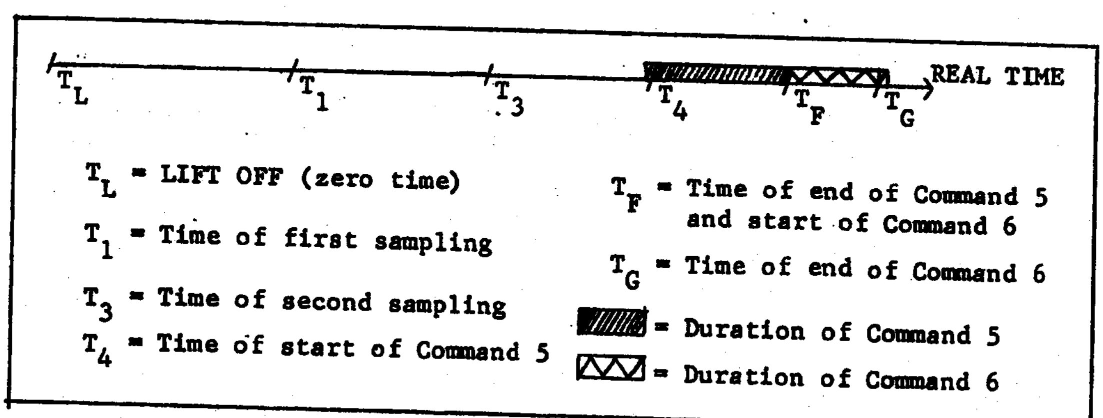


Fig. 2-10 Guidance Computer Sequence of Events

The time T_L represents time of liftoff of the vehicle and zero time for the computer. At T_1, three instantaneous differences are formed, scaled into time corrections, and retained for future use. The differences are a range difference, an azimuth difference and an elevation difference. They result from subtracting observed missile range, azimuth, and elevation, respectively, from theoretical range, azimuth, and elevation at time T_1. For each difference, there are two independent scale factors, one for each command. After applying the scale factors and summing appropriately, the results are two time corrections, one for each command. These corrections are stored for future use.

At time T_3, two more corrections are formed, identically as they were at time T_1, except that the theoretical space coordinates are different, and the scale factors for the second sampling are independent of the first set.

At time T_4 the first command, Command 5, is turned on and remains on until time T_F. The interval between T_4 and T_F equals the algebraic sum of a predetermined interval and the corrections developed for Command 5 at sampling times T_1 and T_3. Depending upon the vehicle's flight path, each correction may independently add to or subtract from the predetermined interval to form the actual duration of Command 5.

At time T_F, Command 5 is discontinued and the second command, Command 6, is turned on and remains on until time T_G. The interval between time T_F and time T_G equals the algebraic sum of another predetermined interval plus the two corrections developed for Command 6 at sampling times T_1 and T_3. These two corrections may also independently add to or subtract from the predetermined interval to form the actual duration of Command 6.

In order for the guidance computer to satisfy the above requirements, it requires as inputs the actual vehicle coordinates and a signal designating time of liftoff. All the other quantities, which are the theoretical coordinates at both sampling times, the predetermined times after liftoff of both samplings, the starting time and nominal duration of both commands, and the scale factors for both intervals, are preset within the computer prior to liftoff. Also built into the computer is a time base generator, which is activated by the liftoff signal from the guidance command panel. The output of the time base generator is proportional to elapsed time after liftoff. When the time base generator output equals each of the preset and corrected times, relays are activated, which, in combination with the appropriate circuits, carry out the sampling, the development and storage of the corrections, the insertion of the corrections, and the start and stop of both commands.

Guidance Command System Analysis. Operational experience has resulted in sole dependence upon the Pt. Mugu guidance computer for computation of ground guidance command corrections. The manual back-up method involving operator computation of corrections utilizing the plot-board has been discontinued since there is insufficient time available for the necessary computation and because of the reliability experienced with the guidance computer. The manual back-up method of computation required measuring the deviation of the plotted launch trajectory from the pre-plotted nominal trajectory, in terms of required time corrections, at two points during second-stage coast after boost. These time corrections were then inserted into the guidance command panel for transmission, if necessary, as decided by the guidance computer operator.

Deviations from nominal in the launch trajectory beyond the 10° azimuth and elevation angle limits and the 33.3-kiloyard range limits of the guidance computer will result in overloading of the associated d-c amplifiers. This could produce improper time durations of command 5 and 6 without any external indication to the computer operator. To overcome this condition, information regarding the conformity of the plotted trajectory with the nominal pre-plot was relayed to the computer operator by the plotboard operator. This is satisfactory except for marginal conditions difficult to interpret. A modification to provide a more positive indication to the computer operator was installed by LMSD, the operating agency, at Pt. Mugu. An indication of azimuth, elevation and range deviation at the two look-points was provided by installing three error-indicating meters in the associated d-c amplifier circuits.

2.2.10 Calibration System

The Verlort installation includes the following auxiliary equipment for calibration purposes.

a. Boresight telescope
b. Boresight camera (Fig. 2-11)
c. Boresight target boards
d. UHF signal generator (HP616AR)
e. Counter (Beckman 7360R)

The boresight telescope, boresight camera, target boards, and signal generator are used to calibrate the angular tracking accuracy. The counter is used to determine the range master oscillator frequency to establish an accurate base for range tracking. The counter is also used in determining the command tone frequencies of the pulse coder.

A beacon target is simulated by feeding the output of the UHF signal generator via coaxial cable to an r-f feedhorn mounted on an optically patterned target board (Fig. 2-12). The boresight target board is mounted approximately 300 feet from the radar antenna providing an elevation angle of 2 to 3 degrees. The center of the feed horn is a surveyed point and the Verlort angular readouts may be calibrated by locking on the feedhorn. Parallax compensating reference points on the boresight boards allow collimation of the electrical axis of the antenna and the optical axis of the boresight telescope and the boresight camera. For calibration purposes, experience has shown that the boresight camera optics because of their firmer mounting, are less susceptible than the telescope to axis deviations.

The boresight board is mounted on poles and cannot be regarded as a precise calibration reference point for long periods of time. Random errors caused by wind loading of the boresight board can be minimized by the selection of a suitable day for alignment. However, over a period of time, a systematic error can be introduced because of boresight board shift, such as caused by weather and settling or because of shifts in the radio-frequency path, caused by changes in the terrain that create reflections of the boresight signal.

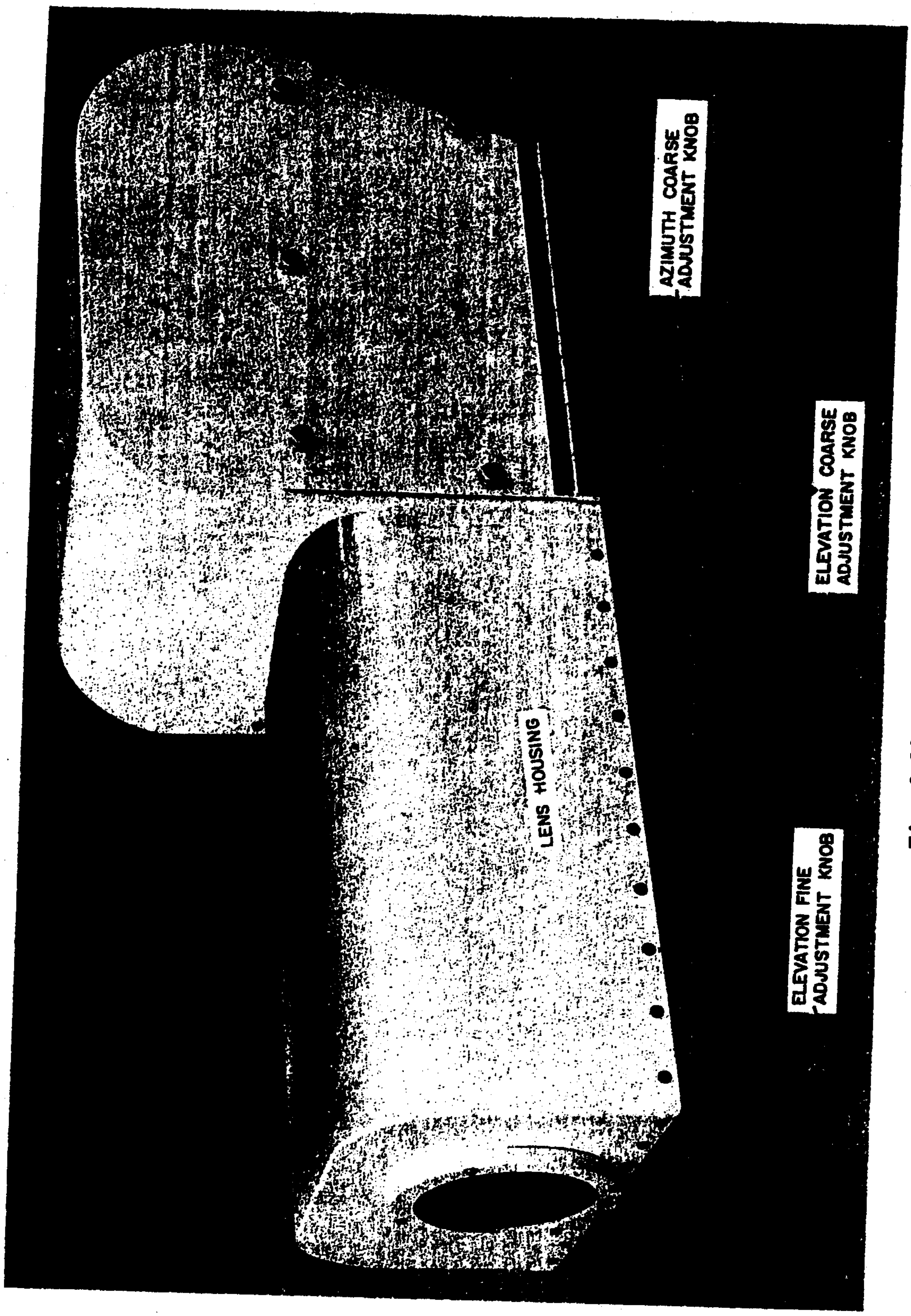


Fig. 2-11 Boresight Camera

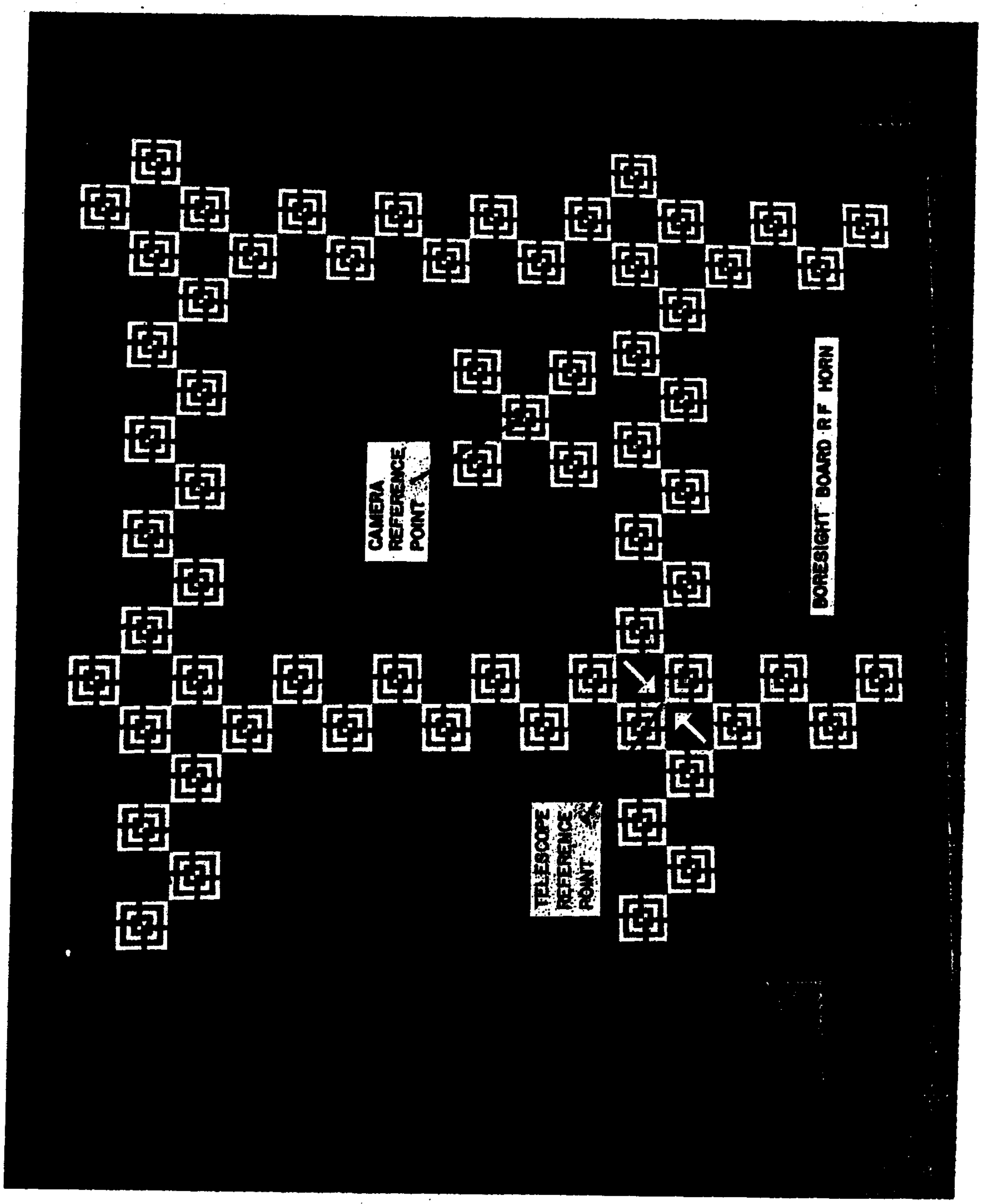


Fig. 2-12 Calibrated Boresight Board

The preferred method for calibration of Verlort angular tracking data involves radar tracking of a beacon-equipped air craft and collimating the electrical and optical axis using the boresight camera. After collimation a sighting on Polaris through the optics of the camera is used to calibrate the angular digital data readout.

Boresight Camera. The boresight camera is a Model 624 Tracking Camera Assembly consisting of a 35 mm reflex type motion picture camera, a 40-inch lens assembly, a data recorder, and a secondary mounting assembly. The camera is driven by a synchronous motor at a frame rate of 24 pictures per second and is equipped with a film magazine having a capacity of 400 ft. of film. An adjustable shutter opening that allows for variations of exposure time is included. A data recorder unit provides for recording coded words, timing signal, and event marker pulses on three channels simultaneously. The camera is remotely controlled from a unit located at the radar console.

2.2.11 Optical Tracker

The VAFB tracking system includes an optical tracker to provide slave tracking data to the Verlort during the initial launch phase. The optical tracker (Fig. 2-13) consists of a gun director MK51 MOD 3 (modified), a gun sight MK 15 MOD 15 (modified) and a gun camera AN-N-6.

The optical tracker is mounted on a concrete hardstand close to the Verlort. The director has been modified by disabling the gyros and setting the range functions to zero, so that it will give present azimuth and elevation position information to the Verlort.

2.2.12 Ground Beacon Verification (RP-71)

The recent installation of the ground beacon verification system in the Verlort van permits visual monitoring of the tone-modulated pulses transmitted by the Verlort in the command mode. Verifications of proper tone modulation utilized for command purposes is indicated by illumination of appropriate tone and command indicator lamps on the monitor unit. A van-mounted S-Band beacon of the type used in the vehicle is triggered by suitable transmitted commands, which may be obtained at either the directional coupler or the boresight board feedhorn cable connectors availabe at the boresight racks. The transmitted pulses

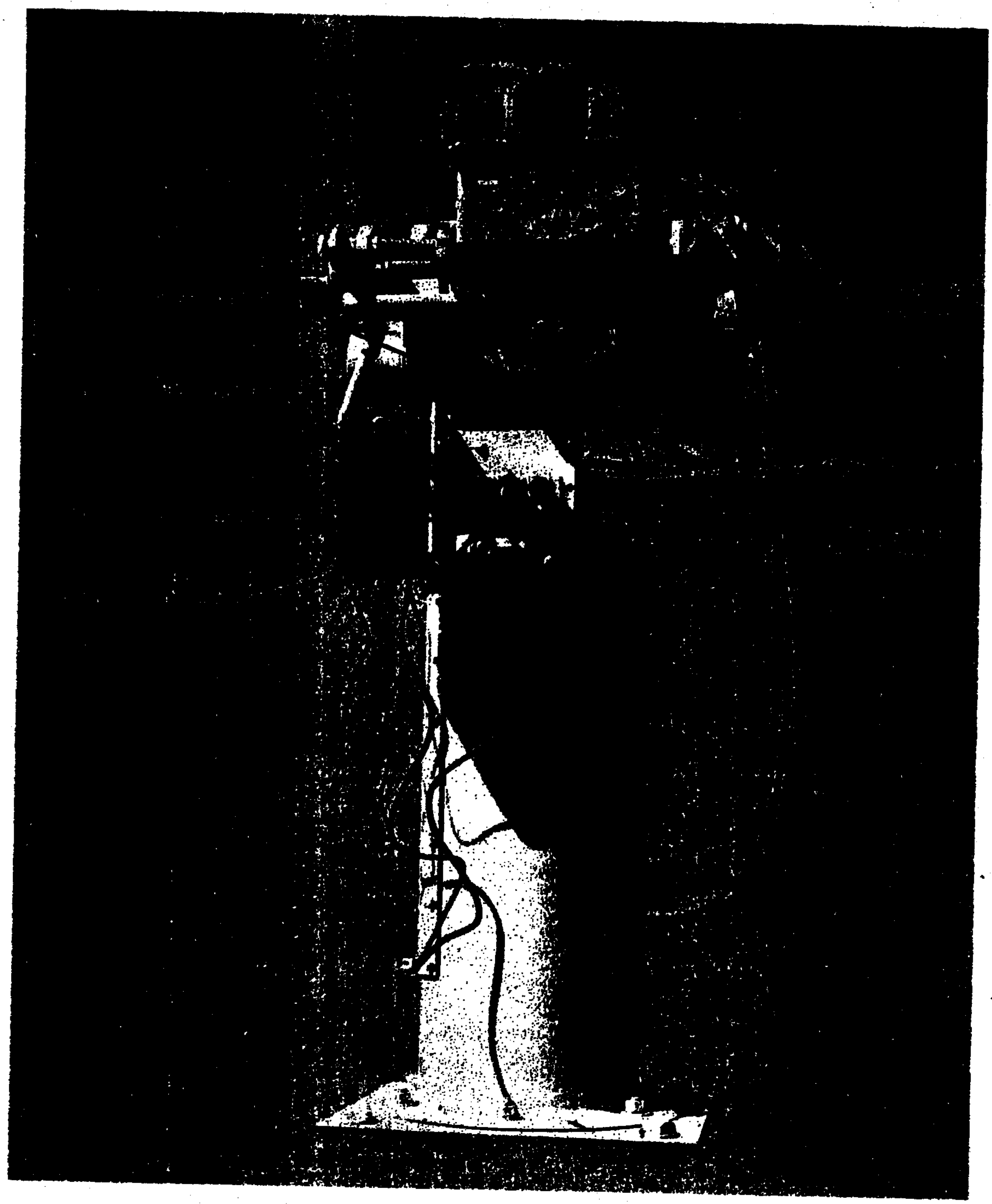


Fig. 2-13 Optical Tracker

are attenuated by the directional coupler and by an adjustable attenuator in the ground beacon verification unit to approximately -40 dbm to prevent blocking in the beacon receiver . A microammeter is provided which under these conditions reads approximately 10 microamperes (dependent on the selected PRF). The tone-modulated pulses are demodulated and decoded to activate beacon tone and command relays to provide the visual indications. Additional relay closures are available for recording and remote indicating functions as required.

2.2.13 Anti-Beacon Capture Circuit

Paragraph 2.4.2 contains a description of beacon capture problems which can be encountered with two radar actively interrogating the beacon. The anti beacon-capture circuit modification (RP-68) provides automatic rephasing of the Verlort master range PRF when beacon capture occurs. This is done by resetting the final phantastron in the Verlort master range unit, with the loss of gated video. This reset action causes the Verlort magnetron to be triggered 1200 microseconds earlier than normal, shifting the relative PRF phasing with respect to the capturing pulse. This shift corresponds to approximately 50 per cent of the 410 PRF spacing.

2.2.14 Passive Track Modification (RP-67)

Due to the beacon tracking and commanding difficulties experienced with multiple active radars, as described in Section 2.3.2, and the desirability of getting as much tracking data as possible during the visible portions of an orbit, a passive track modification (RP67, -A and -B) was installed to permit a radar to track passively utilizing the return of another radar and thereby provide valid angle data. This modification provides for the selection of either the ART (Automatic Range Tracking) gate or the beacon video return to trigger the early and late track gates. This in turn makes the angle track gate. The video in the remote video and agc chassis will be delayed 1.0 microseconds in order that it be coincident with the angle track gate when the beacon video return is used to trigger the early and late gate. Only the video in the range gate is used.

The modification also provides an additional punched "Quality Bit" on the teletype tape output of the D/TT converter when the Verlort is in the "Passive Track" mode of operation. This bit appears on the tape in place of the 10 yard range bit (R18).

2.2.15 Equipment Capability

Receiving System.

a. Traveling wave-tube amplifier: Minimum gain is 25 db over 2700- to 2950- mc.

b. R-F filter: Approximately 0.5 db insertion loss; bandpass is 30 mc.

c. Wavemeter: ±1 mc accuracy over tuning range of 2700- to 2950- mc.

d. I-F center frequency: 30 ± 0.5 mc.

e. I-F bandwidth: 2.75 ±0.25 mc at 3 db points.

f. AGC dynamic range: Minimum of 65 db.

g. Beacon delay: Continuously variable 0- to 600- yard delay of tracking gate.

h. Minimum discernible signal: Below -103 dbm.

i. Noise figure: 9 db maximum

j. General: Dual i-f strips and local oscillators permit simultaneous radar and beacon tracking; radar AFC circuit referenced to transmitted frequency; beacon AFC circuit referenced to received signal.

Transmitting System.

a. Frequency: 2700 to 2900 mc (set at 2850 mc).

b. Magnetron: Tunable, type 5586.

c. Peak power output: 250 kw minimum (300 watts average).

d. Pulse repetition frequencies: 410, 512, and 584 pulses per second. (Changed with tracking range).

e. Pulse coder: Permits transmission of three-pulse code - first and third for coding and second coding pulse for transmission of 6 on-off commands by means of tone modulated pulse position.

f. Pulse width: 0.8 microsecond.

Antenna System.

a. Size: 10-foot parabolic dish.

b. Gain: 37 db.

c. Polarization: circular

d. Beamwidth: 2.5 degrees at 3-db points.

e. Conical nutation crossover: 80 per cent.

f. Azimuth coverage: 6400 mils.

g. Elevation coverage: -30 mils to +1580 mils.

Range System.

a. Master Timing: 81.946-kc crystal-controlled oscillator (one in use, one standby). Temperature stability of crystals is better than 0.1 part per million per degree Centigrade. Crystals are mounted in ovens having temperature stability of ± 1 degree.

b. Beacon Phasing: Frequency of one crystal is continuously variable within range of 81.946 ± 0.0025 kc.

c. PRF Switching: Switches automatically with range to prevent interference between transmitted pulse and target return.

PRF	Yards x 10^6	PRF	Yards x 10^6
410	0 to 0.345	512	2.345 to 2.410
512	0.345 to 0.410	410	2.410 to 2.745
410	0.410 to 0.745	512	2.745 to 2.810
512	0.745 to 0.810	410	2.810 to 3.145
410	0.810 to 1.145	584	3.145 to 3.210
512	1.145 to 1.210	410	3.210 to 3.545
410	1.210 to 1.545	512	3.545 to 3.610
584	1.545 to 1.610	410	3.610 to 3.945
410	1.610 to 1.945	512	3.945 to 4.010
512	1.945 to 2.010	410	4.010 to 4.345
410	2.010 to 2.345	512	4.345 to 4.410
		410	4.410 to Limit Stop

d. Automatic Range Tracking:

(1) Range: 10,000 yds/sec minimum.

(2) Error: ±100 yds maximum at 10,000 yds/sec tracking rate

(3) Signal requirements: -98 dbm minimum

(4) Range memory switch: Causes range tracking rate at moment of switch actuation to be maintained for a minimum of 4 seconds.

e. Mutual Range Tracking:

(1) Fast slew rate: 500,000 yds/sec minimum.

(2) Slow slew rate: 40,000 yds/sec ±10%

(3) Aided rate: Continuously adjustable from zero to a minimum of 10,000 yds/sec.

f. Displacement control: Rate and direction of tracking gate movement determined by speed and direction of control operation.

g. Range limit stops:

(1) Lower Limit: Less than 25,000 yards.

(2) Upper Limit: Greater than 4,600,000 yards.

h. Range displays:

(1) Dials: Four direct-reading dials - 10,000 yds/rev, 100,000 yds/rev, 1 million yds/rev, and 10 million yds/rev.

i. Scopes:

(1) 2000-yd scope: Sweep initiated approximately 1000 yds prior to tracking gate, whose position is indicated by a one-microsecond sweep brightener.

(2) 32,000-yd scope: Sweep initiates approximately 16,000 yards prior to tracking gate. Displays 2000-yd sweep brightener corresponding to sweep on 2000-yd scope.

(3) 400,000-yd scope: Displays 32,000-yd sweep brightener corresponding to sweep on 32,000-yd scope.

(4) Long range scope: Displays two vertical columns of short--trace sweeps corresponding to the selected 32,000 yard portions of successive inter-pulse periods. The true range of the target being tracked is indicated by the absence of the target on one of the sweeps when the transmitter pulse is inhibited at a 28-cps rate. The sweep corresponding to the 32,000-yard portion containing the tracking gate is intensified.

Antenna Positioning System.

a. Elevation: -1.5 degrees to +90 degrees.

b. Azimuth: 360 degrees.

c. Limit switches:

(1) Mechanical: -2 degrees and +90 degrees.

(2) Electrical: Upper limit at 78 degrees: capable of manual override. Lower limit switches at +7 degrees and -1.5 degrees.

d. Modes:

(1) Automatic: Controlled by 30-cps error voltages.

(2) Manual: Manually positioned synchros and follow-ups.

(3) PPI: Variable speed motor (0 to 20 rpm) positioning synchros.

(4) Remote: Controlled by one-speed synchro information from remote source.

e. Smoothing: Magnitude of azimuth and elevation smoothing selectable in five steps each.

f. Drive Motors: (d-c type, shunt-mound)

(1) Azimuth: 1-1/4 hp at 3450 rpm.

(2) Elevation: 3/4 hp at 3450 rpm.

Data Transmission System.

a. Shaft-to-digital encoders:

(1) Azimuth and elevation: 16-bit parallel cyclic binary code representing 0 to 360 degrees. Each bit represents approximately 19.77 seconds of arc.

(2) Range: 19-bit parallel cyclic binary code representing 0 to 5,120,000 yards. Each bit represents 9.765625 yards. (Only 18 bits utilized; least significant position used as passive track quality bit).

b. Analog data: d-c voltages proportional to slant range, ground range, height, east-west ground range, and north-south ground range.

(1) Azimuth potentiometer: At 10 degrees azimuth angle, sine and cosine voltages are accurate to 0.1 per cent and 0.3 per cent, respectively. Resolution is 0.06 per cent at sine 0 degree or cosine 90 degrees and 0.005 per cent at sine 90 degrees and cosine 0 degree. Range of potentiometer is continuous through 360 degrees.

(2) Elevation potentiometer: At 10 degrees elevation angle, sine and cosine voltages are accurate to 0.04 per cent and 0.02 per cent respectively. Resolution is 0.02 per cent at sine 0 degrees or cosine 90 degrees and 0.002 per cent at sine 90 degrees or cosine 0 degrees. Range is -11.25 degrees to +90 degrees.

(3) Range potentiometer: Linearity is 0.007 per cent.

c. Synchro data: One-speed azimuth and elevation synchro data accurate to ±1 degree is available for slaving external equipment.

Acquisition System. This system consists of a Reeves orbit computer and associated equipment capable of automatically controlling radar search to assist radar in acquiring an earth satellite whose motion and predicted horizon time are known.

a. Indicator accuracy:

(1) Azimuth and elevation: Accurate to within ±1 degree of position defined by input data.

(2) Range: Accurate to within 10,000 yards of range defined by input data.

b. Radar slaving: One-speed synchro data slaves radar to within ±1 degree in angle and ±1000 yards in range.

c. Raster scan: Aid in initial acquisition of satellite at horizon.

(1) Speed: Greater than 10 degrees per second

(2) Width: Controllable from 10 degrees to 120 degrees in 10-degree steps.

(3) Vertical movement: 2.5 degree steps.

(4) Height: Controllable from 0 degree to 20 degrees in 5-degree steps.

d. Spiral scan: Reacquisition aid if satellite track is lost during a pass.

(1) Spiral diameter: Controllable from 10 degrees to 20 degrees in 5-degree steps.

e. Error detection: Permits comparing computers' definitions of azimuth, elevation, and slant range with those provided by the radar when tracking satellite in order to upgrade orbit data.

2.3 Command System

2.3.1 General

The functions of the equipment within the vehicle are controlled in two ways. Those functions which are repetitive in a predictable cycle are controlled by an orbital programmer, which is adjustable by ground command to compensate for variations in orbit period. Functions of a nonrepetitive or random nature are controlled by direct command from the ground.

The basic command loop originates at the Vehicle Command Controller (VCC) console with six command buttons and terminates in six respective real-time verification lights. Depressing a command button applys two DC voltages to the KY-94 command encoder, which issues two corresponding audio tones for pulse position modulation of the Verlort command pulse. A total of four audio tones are used, from which six commands can be generated. The radar transmits its pulse code to the S-band beacon, which decodes the signal and energizes two relays, corresponding to the tones, which control vehicle actions. This response includes providing two d-c signals to the telemetry commutator for relay via the telemetry link to the console logic. The console logic then energizes a lamp associated with the transmitted command, indicating verification of command receipt by the beacon. Because of the decoding logic used, only one command can be issued at a time.

The following is the list of vehicle functions controlled by the six ground commands from the VCC. This is the recent configuration and is subject to change depending upon the requirements of a particular flight.

Command 1 - Increase/Decrease. Changes the direction of the orbital programmer 11-second-increment period adjustment controlled by Command 2.

Command 2 - Step. Provides an 11-second change in orbital programmer period in the direction dictated by the increase/decrease switch (Command 1).

Command 3 - Reset. Activates orbital program tape reset mechanism during the "reset enable" period of the program tape for correlation with selected latitude positions.

Command 4 - Payload Function Selector. Selects one of eleven payload functions in the vehicle.

Command 5 - Alternate Re-entry Selector (After Launch Phase). Enables or disable alternate re-entry and recovery. To effect re-entry on a non-nominal day, it is necessary to transmit Command 5 with the increase/decrease switch (Command 1) in the increase position. The alternate re-entry can be disabled by transmitting Command 5 with the increase/decrease switch in the decrease position.

Command 6 - Skip/Repeat (After Launch Phase). Causes the orbital programmer to skip or repeat a programmer orbit pass. To skip an orbit pass, the increase/decrease switch (Command 1) must be in the increase position when Command 6 is transmitted. To repeat an orbit pass, the increase/decrease switch must be in the decrease position when Command 6 is transmitted.

During the launch phase, Commands 5 and 6 are utilized for the launch guidance function. This function is performed at Pt. Mugu utilizing the guidance computer backed up by the command guidance panel. Commands 5 and 6 perform the following functions during the launch phase:

Command 5 - Time-to-Fire Correction (Launch Phase). Adjusts the time of second-stage ignition.

Command 6 - Velocity-to-be-Gained Correction (Launch Phase). Adjusts the length of second-stage ignition.

2.3.2 Vehicle Command Controller (VCC) Console

The VCC console (Fig. 2-14) provides a means of initiating the real time commands for vehicle control and providing a visual presentation of time intervals pertaining to vehicle position. These functions are furnished respectively by the command control unit and the time indicator control unit, with associated equipment. The VCC is located in the station master control console.

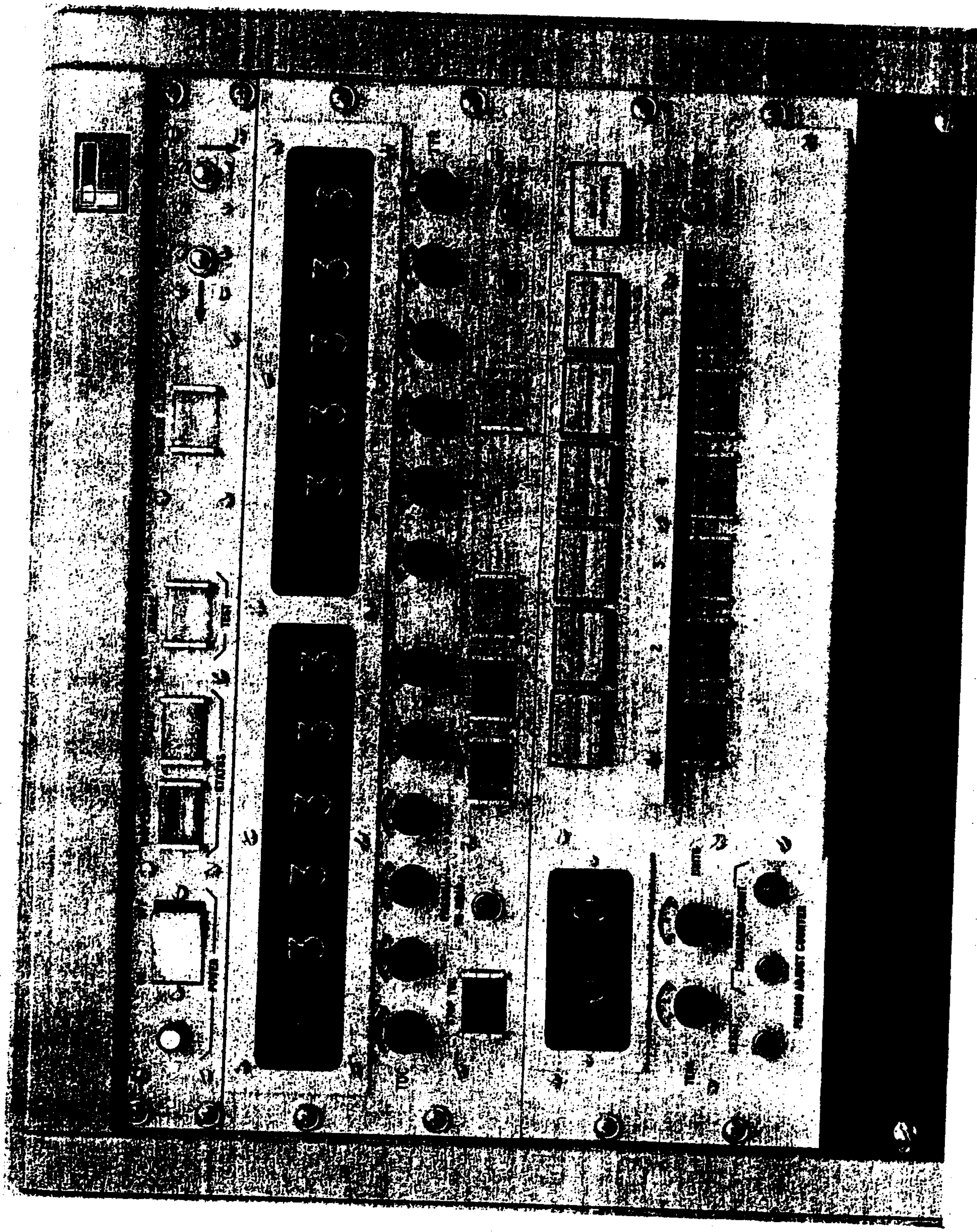


Fig. 2-14 Vehicle Command Control Panel

Command Control Unit. The command control unit consists of a control logic section, a verification matrix, a period adjust counter, and a means of initiating commands and displaying a record of those commands initiated and verified.

The command control panel contains the six command button switches for control of vehicle functions. Activation of the command switch selects two associated tones in the command encoder which time modulates a radar pulse. The tone combinations selected for each of the six commands are given below.

Command	Tone Combination
1	A and B
2	B and C
3	A and D
4	A and C
5	B and D
6	C and D

The original configuration has the tones for Command #2 and 4 reversed. Experience revealed tone A to be less reliable than the others, due to harmonic susceptability. Due to the high use factor of Command 2 compared to Command 4, the tone combinations were reversed (EC-99) to provide more reliable Command 2 operation.

The command logic is capable of the following:

a. Identifying the commands manually initiated.

b. Initiating the command signal for a given interval as follows:

(1) Commands 1, 3 and 4 for one-second, repeated at 1-second intervals for actuation period.

(2) Command 2 at intervals of one second on and one second off for the number set into the period adjust counter.

(3) Command 5 and 6, continuous transmission for length of actuation.

c. Indicating that verification has been received for the command initiated.

d. Providing interlocks to establish the following priority of command sequence:

   (1) Command 4 is to lock out all other commands.

   (2) Command 3 is to interrupt commands 1, 2, 5 and 6.

   (3) Command 2 is capable of being interrupted by any command without affecting the cycling nature of the command.

Associated with the six command switches are six verification lights which indicate that the command loop has been completed. The verification matrix receives, recognizes, and identifies the verification signal for a particular command transmitted, and provides an indication that verification has been received. The verification loop utilizes a commutated telemetry channel which early operations revealed was subject to synchronization problems producing spurious indications of verification. A sync alarm was added to provide an indication of a non-synchronous decommutator condition to invalidate verification indications during this period.

The period adjust counter counts the number of commands transmitted for Command 2. The number of step commands required are set in, using the dials below the indicator. The step command sequence is activated using Button 2. The command is then repeatedly transmitted until the indicator displays the same number as that set on the dials. The counter recognizes when a coincidence exists and disables the command.

Activation of the reset switch sets the indicator to zero and allows Commands 1, 2, 3, and 4 to be re-issued without clearing the panel.

A reset monitor light indicates the enabled period of the vehicle program tape reset functions as furnished by the beacon telemetry link.

<u>Time Indicator Control Unit</u>. The time indicator control unit consists of a TOC (Time of Crossing) accumulator, TTR (Time to Reset) accumulator and a logic section. The TOC and TTR with associated controls are presented on the time indicator control panel.

The TOC (time of crossing) display is a six-digit time display which can be preset to any number (normally system time). It counts up in seconds from that number. The latitude crossing unit on the plot boards can provide a signal to stop the TOC display when the plot crosses a pre-set latitude. Thus, the TOC can be used to provide the system time that the vehicle crossed a selected latitude.

The TTR (time to reset) display shows the same six-digit time word as the active TOC display. When the time to reset the vehicle programmer has been calculated and set in below the TTR display, activation of the coincidence switch will enable automatic transmission of the programmer reset command (Command 3) when the TTR display coincides with the pre-set TTR time.

The time indicator control logic is capable of:

a. Clearing both the TOC and TTR accumulators to zero.

b. Simultaneously setting any time word into both the TOC and TTR accumulators.

c. Receiving and counting one second timing pulses.

d. Recognizing TTR coincidence.

e. Stopping the TOC accumulator either from a remote switch closure or a manually operated switch on the indicator control panel.

Associated with the VCC and located on the tracking indicator panel, which is adjacent to the VCC, are meter indications of the following vehicle data: (See Fig. 4-39)

a. Temperature. Four meters are used to provide a real-time telemetered indication of the following vehicle equipment temperatures: radar beacon, power supply, command decoder, and telemetry transmitter. Associated with each of the temperature indicators is an alarm light which indicates that a limiting condition exists and the vehicle equipment must be turned off. These indicators have not been utilized since telemetered data on these functions has not been provided.

b. Beacon Power. The beacon power indicator provides a real-time telemetry indication of the beacon output in response to radar interrogation.

c. Beacon Signal Level. The beacon signal level indicator provides a real-time telemetry indication of the radar signal received by the beacon.

2.3.3 SS/L and Timer Readout Panel (Fig. 2-15)

With the replacement of the SS/H vehicle timer by the Fairchild Orbital Programmer, an additional panel was installed adjacent to the VCC at all Discoverer stations except Pt. Mugu, to provide a status indication of certain vehicle functions. This is the SS/L and Timer Readout Panel (RP-39) which provides the following:

a. A display of timer period in numerical step position by indicating the telemetered position of the 11-second and 110-second stepper switch in the vehicle programmer (EC-117). The indicated step position may vary from 00 to 99, representing orbital periods from 90 to 108.15 minutes. This represents a change from the original configuration, where the orbital period readout was made in seconds with telemetered positions from the stepper switches representing 10 and 100 seconds respectively. However, a slowdown of the basic timer frequency to accommodate larger orbit periods (originally 84 to 100.5 minutes) resulted in each step interval being slightly longer, making the readout in seconds invalid.

   The input for each indicator is a 10 level 0-to-5 volt d-c signal with each one-half volt level corresponding to each of the ten positions of the interval stepper.

b. An increase/decrease display to indicate whether the timer is set to increase or decrease its period when timer step commands are received. The input signal is zero volts for INCREASE and 5-volts d-c for DECREASE.

c. A number display corresponding to the telemetered position of the SS/L stepper switch. This position is telemetered as a four-bit binary gray code representing decimal numbers 1 through 11. The SS/L readout contains the logic to convert from the gray code to the decimal output.

The following readout were added (RP-74) to the SS/L and Timer Readout Panel after the initial installation.

d. A tone tell-tale display providing a more reliable means of verification for commands #1 through #4. The tone tell-tale verification loop uses four frequencies on a continuous telemetry channel; one for each command. This avoids the decommutation sync difficulties of the normal verification loop.

e. A re-entry selector indicator which provides a NORMAL indication until a telemetered signal activates the ALTERNATE indicator as the result of an alternate re-entry command (Command 5) transmission.

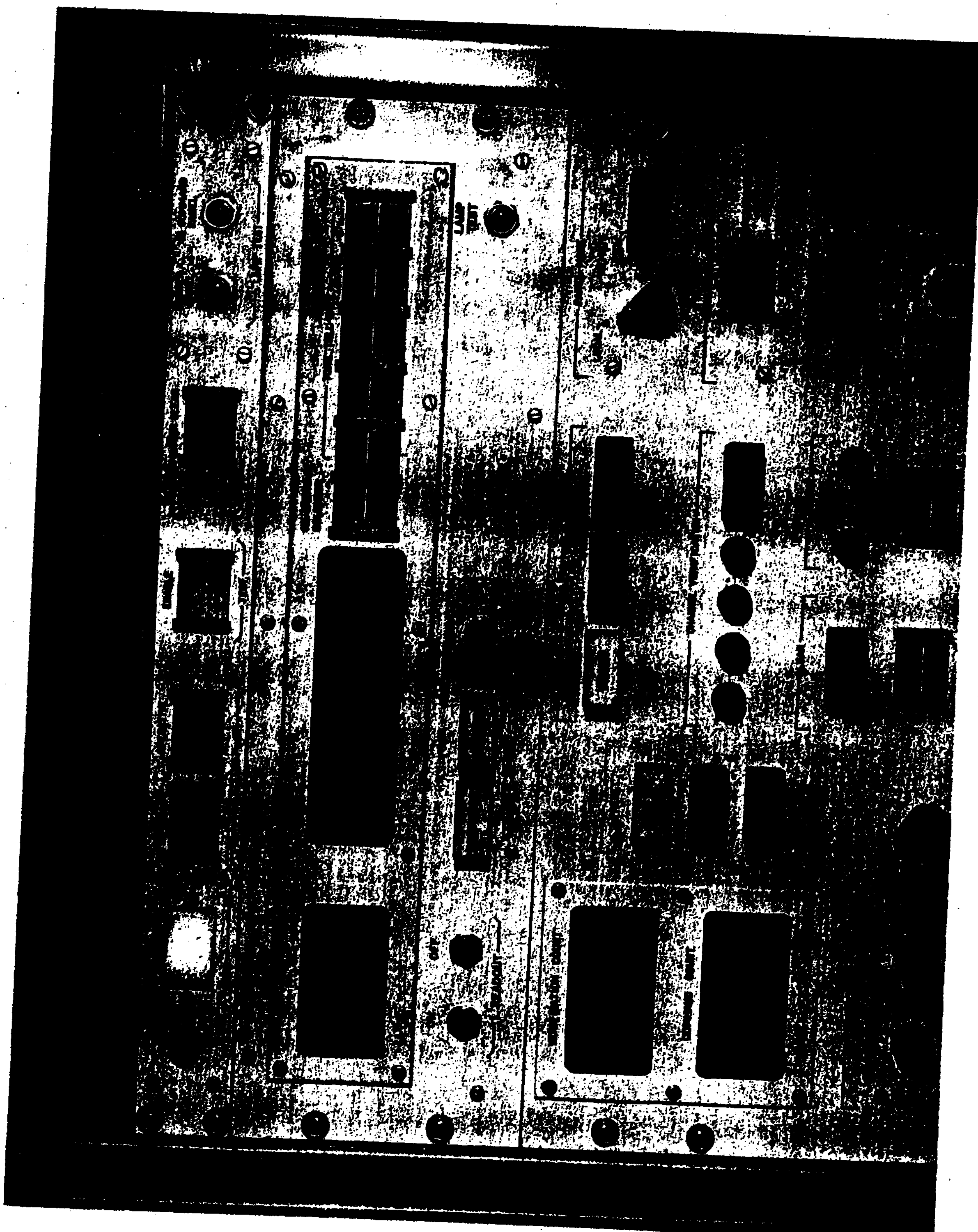


Fig. 2-15 SS/L and Timer Readout Panel

The installation of the SS/L and Timer Readout Panel included the following changes to the VCC:

a. Command 1, 3 and 4 -- Latching of the verification lamp was eliminated to permit repeat commands as required.

b. Command 2 -- The available number of step commands was increased from 39 to 99. The counter was rewired to provide counting of issued commands only. The reset switch was rewired to permit unlatching of the switch and verification lamp.

2.3.4 Guidance Command Panel

During the vehicle launch and ascent phase, the command control panel in the vehicle command control console at Pt. Mugu is replaced by the guidance command panel (Fig. 2-16). This panel provides the vehicle command controller with a backup command capability for adjusting the time and duration of second-stage ignition if the guidance computer fails.

Time Display. The time display is a three-digit number counting seconds after lift off. This display is manually started when the lift-off tone is received from the block-house over the intrastation communications system.

First and Second Marks. The first and second mark circuitry provides two sequential signals of one-second duration when the elapsed time after lift-off coincides with preset first and second look marks. These signals were used to interrupt the plot board trace within the first and second look nomograms as part of the manual guidance computation, which is no longer used. (See Paragraph 2.2.9.)

Commands 5 and 6. Nominal values for Commands 5 and 6 are preset in the panel in terms of elapsed time (in seconds after lift off) of initiation and termination. The three times involved are Time to Fire Five, Time to Stop Five and Start Six, and Time to Stop Six. When the elapsed time after lift-off coincides with the preset times, commands of the proper duration are available for use as the command encoder input at the discretion of the guidance computer operator. (See Paragraph 2.2.9.) Visual indication of the active command interval and verification is provided.

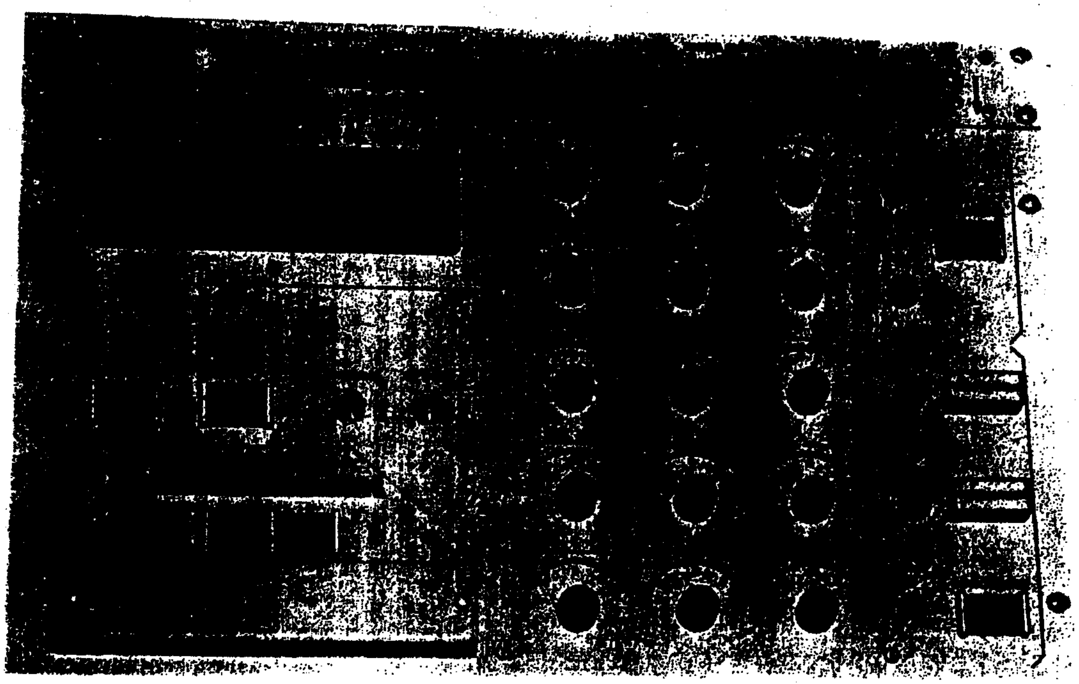


Fig. 2-16 Guidance Command Panel

Manual switches are provided for Commands 5 and 6 to override the automatic function if necessary. Direct access to these switches has been blocked to eliminate the possibility of manual activation during an operation.

2.4 S-Band Beacon System

In order to achieve the long-range tracking necessary in the Discoverer Program, a radar beacon transponder for operation with the Verlort Radar is carred in the vehicle. The link also provides a vehicle command capability by using a command decoder with the transponder. (Figures 2-17 and 2-18.)

Radar beacon Types 3bb-2 and 3bb-2A (Avion Type 449 and 449A) have been utilized since the start of the Discoverer Program, but delivery of this item has been discontinued. A transistorized version of the beacon, Type RT-5, has been developed and is being delivered to meet Discoverer requirements. However, it is anticipated that future Discoverer requirements will be met by either of these two beacons since a number of the original Type 3bb-2A are still available. The following are the major advantages of the transistorized beacon Type RT-5 in comparison with Type 3bb-2A:

a. Lighter weight
b. Better X- and C-band rejection
c. Better image rejection
d. Lower input power requirement
e. Wide operating range in input voltage
f. Greater expected reliability.

For tracking, the S-band beacon responds to two interrogation pulses by transmitting an output pulse. The closest interrogation pulse spacing is 21.35 microseconds with five additional 3.05 microsecond steps available.

When issuing a command, the Verlort radar transmits a three pulse code (See Fig. 2-4). The first and third are the preset tracking pulses and the center pulse is the command pulse, which is position-modulated about a rest location 9 microseconds before the third pulse. Modulation is accomplished in the Verlort radar with two linearly mixed audio tones.

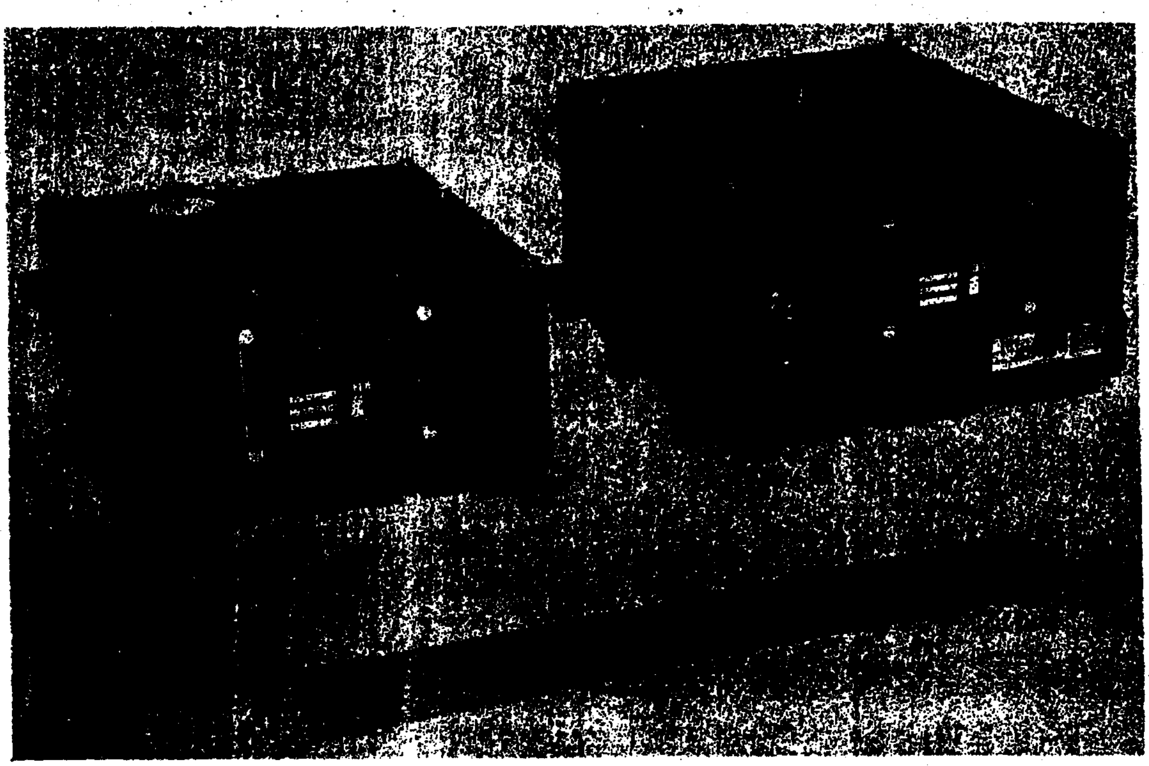
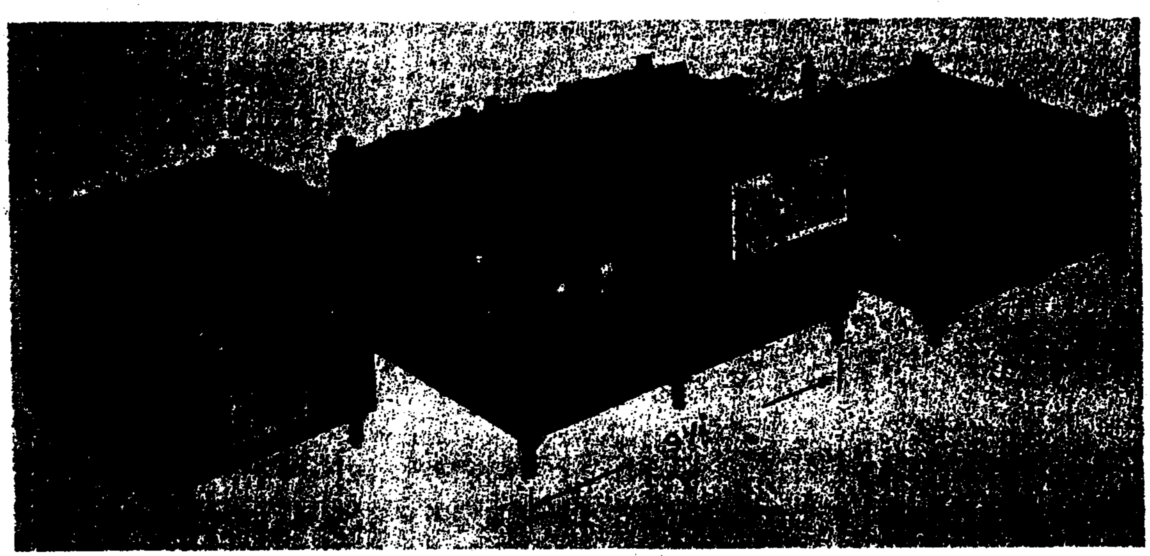
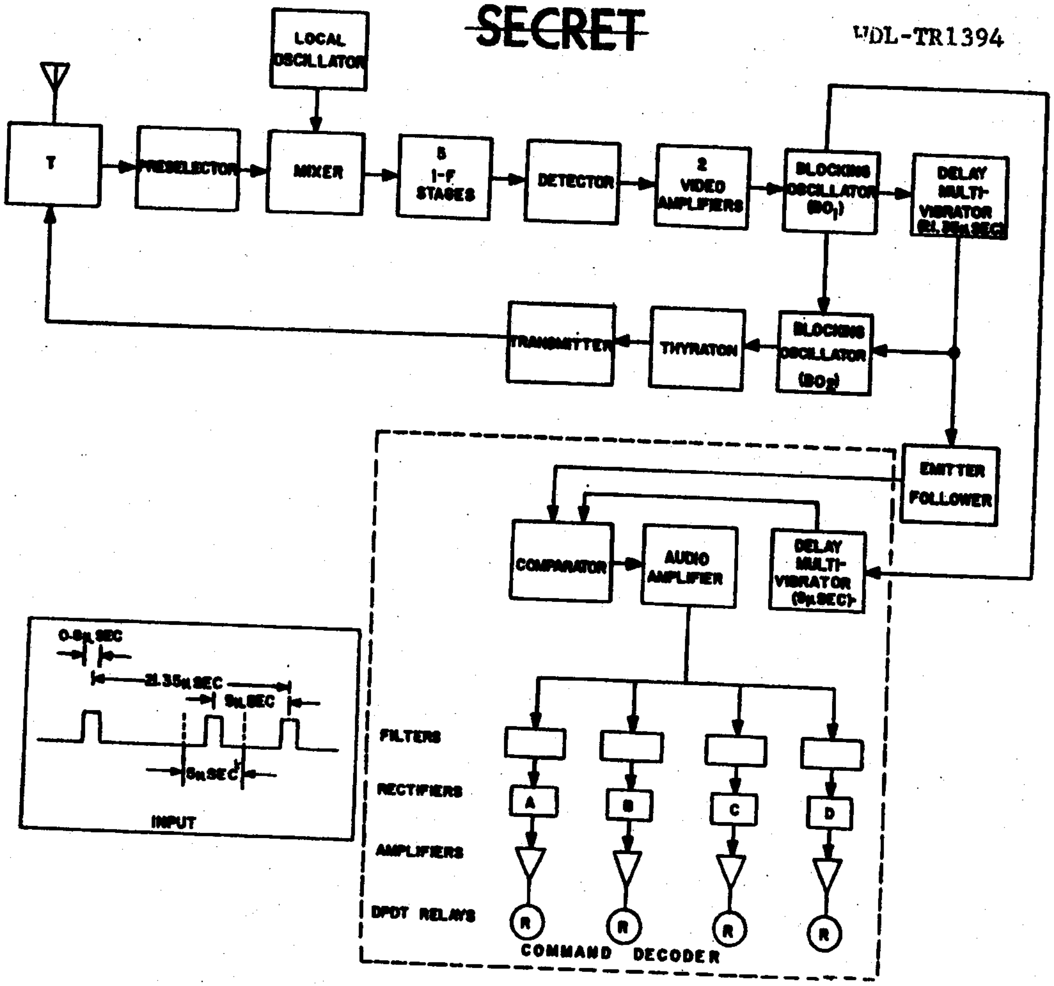


Fig. 2-17 Type RT-5 Transistorized Beacon



Type 3bb2 Beacon



*Note: 5.0μ sec spacing is 5.5 ± 0.5μ sec in the transistorized beacon, RT-5

Fig. 2-18 Radar Beacon and Command Decoder Block Diagram

The comparator in the command decoder reproduces the two audio tones, which are filtered, rectified, and amplified to operate two corresponding relays. One set of contacts on each relay is available to control the desired vehicle action and the other set is for telemetry verifying the command receipt.

2.4.1 System Characteristics

The Type 3bb-2A and the transistorized Type RT-5 S-band beacon transponders have the following characteristics: (Characteristics of the transistorized beacon (Type RT-5) which are different are in parenthesis.)

General. The beacons are composed of the following components:

a. S-band superhetrodyne receiver
b. Two-pulse interrogation decoder
c. S-band transmitter
d. Power supply
e. Command decoder

Component Details

a.	Stability	±2 mcs
b.	Life	250 hours (.99 reliability)
c.	Physical	600 cubic inches 30 lbs (500 cu. in/20 lbs)
d.	Receiver:	
(1)	Type:	Superheterodyne
(2)	Frequency:	2800 to 3000 mc; set at 2850 mc
(3)	Sensitivity:	-70 dbm minimum for 100% triggering (-65 min., -70 max)
(4)	I-F frequency:	60 mc (50 mc)
(5)	Bandwidth:	8 ± 2 mc
(6)	Image rejection:	30 db maximum
(7)	Interference Rejection:	(C- and X-band of -35 dbm)

e. Interrogation decoder:

(1) Type:	Multivibrator delay and coincidence diode
(2) Accepted signal:	Radar pulses Nos. 1 and 3, 0.8 microsecond wide, spaced from 21.35 to 36.6 microseconds at 3.05 microsecond intervals. Positive rejection at ±1.5 microseconds from specified interval.
(3) Recovery time:	45 microseconds (less)

f. Transmitter:

(1) Type:	Triode and cavity, plate modulated
(2) Frequency:	2800 to 3000 mc; set at 2920 mc
(3) Peak Power:	1.8 kw minimum, single pulse (1 kw min - 2.6 kw max)
(4) Pulse width:	0.8 ± 0.1 microseconds at half power points (0.8 ± 0.2 microseconds)
(5) PRF:	Full power; 200 to 1250 pps, reduced power up to 2000 pps (Full power: 1600 pps)
(6) Response delay:	1 ± 0.5 microsecond
(7) Recovery time:	200 microseconds maximum

g. Command Decoder

(1) Function:	Demodulation of the command pulses to provide the vehicle with on-off commands
(2) Pulse position:	9 microseconds before radar pulse No. 3
(3) Position modulation:	Swing: 2.5 (2.75) microseconds for each of two audio tones. Total swing: 5(5.5 ± 0.5) microseconds peak-to-peak under simultaneous modulation of two tones.

(4) Tones demodulated: Four: A at 73.2 cps, B at 91.5 cps, C at 122.0 cps, and D at 154.2 cps.

(5) Number of commands: Six on-off commands obtained by the combined closure of two tone-activated relays. Command numbers and the tones required to produce them are as follows:

Command	Tone
1	A + B
2	B + C
3	A + D
4	A + C
5	B + D
6	C + D

(6) Command Response Time: 200 milliseconds

Receiver Bandpass Response Type 3bb-2A. Figure 2-19 shows the beacon receiver bandpass curve (dbw and dbm versus frequency) plotted in absolute power. This allows a direct determination of the power required at a given frequency to cause interference to the beacon. The curve is sufficiently narrow (60 db down at 40 mc) to eliminate much of the possible S-band interference. Also, the image frequency response is sufficiently below the normal threshold (greater than 30 db down) that other radars operating at that frequency should not pose a serious interference problem at orbital distances.

X- and C-Band Response, Type 3bb-2A. Because of the nature of the cavities used in the preselector, it is possible for them to operate in a different mode at certain frequencies higher than those for which they were designed. This factor, plus the presence of local oscillator harmonics, can cause the beacon to respond at frequencies widely removed from the desired ones.

Figure 2-20 is a plot of maximum sensitivity versus frequency of the beacon, covering the spectrum from 2 to 12 kmc. At two points, 8.26 and 8.4 kmc, response occurs at only -41 db and -35 db, respectively,

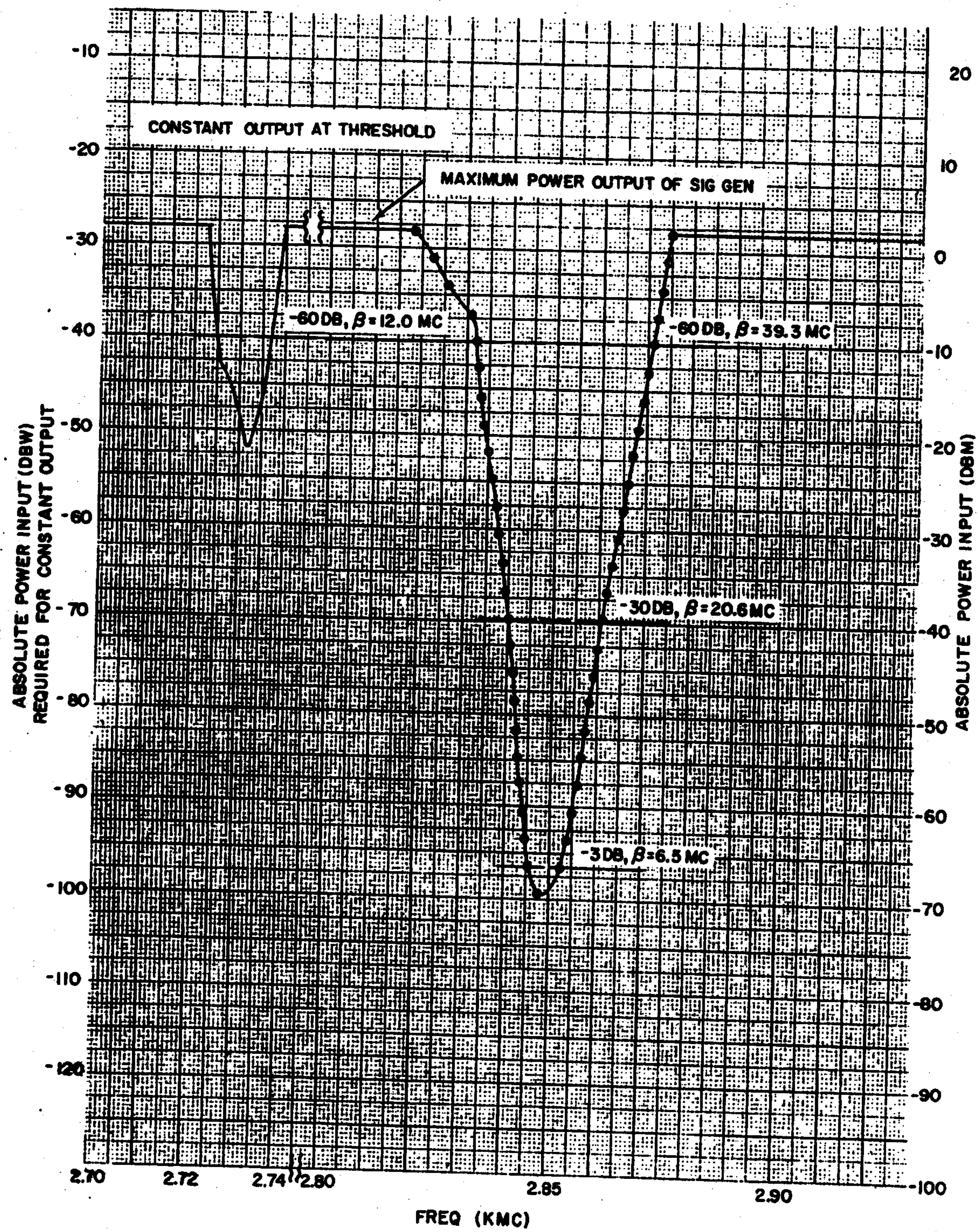


Fig. 2-19 Measured Bandpass Characteristics of 3bb2A Beacon Receiver

from normal threshold. This was felt to be sufficiently high to warrant installation of the low-pass filter within the beacon package.

2.4.2 Interference Considerations

General. The following interference analysis pertains to the Type 3bb-2A beacon. Although similar experience is not yet available on the transistorized beacon, it is anticipated the transistorized beacon is subject to much the same interference considerations, although to a lesser degree.

As a result of tests and actual operating experience it has been found that under certain conditions, blocking of the interrogation and command pulses could occur. Under the most serious conditions, this could cause the Verlort radar to lose track, or in some instances, it could cause the breaking up of a desired command or the generation of a false one.

The susceptibility of the system to blocking under certain types of interference appears to be due mainly to the type of circuitry used in the beacon, and, at higher interrogation rates, to the fundamental limitations of the interrogator-transponder duty cycle and minimum recovery time considerations.

The susceptibility of the command function to interference is due mainly to the fundamental limitations of the tone-modulated pulse position system used and of the circuitry of the decoder unit.

False commands must be eliminated entirely since, in some cases, such an occurrence could mean loss of a vehicle, and therefore, the failure of a flight. Blocking is not quite as serious, since it only means a lost command or, at worst, a temporary tracking difficulty. The degree of seriousness is a function of the specific command being sent and the duration of the blocking.

Tracking Interference. Two types of tracking interference occur. These are designated as "beacon blocking" and "beacon capture". For either condition to exist, sufficient energy must be available at the beacon to trigger the transponder.

Beacon blocking is expressed as the percentage of time the beacon fails to reply to a proper interrogation pulse group because of interference. This can vary from zero to nearly 100 per cent, depending on the severity of the interference. Beacon blocking is distributed evenly when under the influence of random interference, and achieves a very high percentage of blocking at a cyclic rate when due to interference from a radar or radars whose PRF's are very close to or at multiples or sub-multiples of the prime radar's PRF.

The beacon requires two pulses of the three-pulse group transmitted by the radar to generate the single-pulse response used for tracking. This interrogation code is composed of the No. 1 code pulse and the No. 3 radar pulse (see Fig. 2-4). The No. 2 pulse or command pulse is not part of the interrogation function.

The separation of the No. 1 pulse and No. 3 pulse can be varied from 21.35 microseconds to 36.6 microseconds, in steps of 3.05 microseconds, to provide six interrogation codes. In Discoverer flights, Code No. 1 is used at a pulse separation of 21.35 microseconds.

After suitable amplification and detection in the circuits of the superheterodyne receiver, the pulses are applied to the interrogation decoder. Pulse No. 1 triggers blocking oscillator BO-1. Two outputs are taken from BO-1; one is fed to a diode clamp, and the other triggers a one-shot delay multivibrator, the period of which is adjusted to the interval of the interrogation code in use. Its output, occuring at the end of its cycle, consists of a broad pulse approximately 1.8 microseconds wide, which can be called the interrogation gate. This gate unclamps the coincidence diode. If the code spacing is correct, pulse No. 3 arrives at the diode at the time it is unclamped and goes on to trigger blocking oscillator BO-2. The BO-2 pulse fires the hydrogen thyratron modulator tube which in turn fires the transmitter tube, sending out the reply pulse. If pulse No. 3 is not present at the same time the interrogation gate is on, the beacon will not respond.

During their action time, the BO-1, delay multivibrator, and BO-2 circuits are insensitive to pulses which may be applied to them. After operation, this insensitivity extends into a longer period called the recovery time. It is during this period that the circuit conditions reset themselves to the state necessary to repeat an active cycle when triggered by subsequent pulses. The recovery time of the BO-1 and BO-2 circuits are not very great, but the recovery time of the delay multivibrator is approximately 45 microseconds.

From the above it can be seen that a single extraneous pulse, of the right frequency and power level, can pass through the receiver and trigger BO-1 and the delay multivibrator. This will not cause the beacon to respond, but it will render it insensitive and unable to respond to a proper interrogation code for a period equal to the recovery time of the multivibrator. Thus, an interfering pulse arriving at the decoding circuits 45 microseconds or less before a proper code group can block the beacon from responding. A quantum of tracking information will be lost each time blocking occurs; however, this should not present a serious problem unless it happens an appreciable percentage of the time.

The most common case of this type of interference will occur when another radar, at the same frequency but with a slightly different PRF, passes through the tracking radar PRF. This pass-through will require a time (when the offending pulse or pulses are within a 100-microsecond period preceding the normal trigger time) that is inversely proportional to the difference in PRF of the two radars. The condition is, of course, aggravated if the interfering radar is transmitting two or three pulses in its pulse group, or if there are more than one interfering radars. When the PRF difference between the interfering radars and the tracking radar is less than 100 cycles per second, the block achieves high percentages at cyclic rates. At very low PRF differences (less than one cycle per second), the periods of total blocking may be long enough to cause the tracking radar to go out of automatic track.

At PRF differences greater than 10 cycles per second, the interference can be considered random. For the random case the percentage of blocking will approximate:

$$\% \, B = (1 - 2^{-nt}) \, (100)$$

where

n = random pulses per second at beacon

t = beacon recovery time

Figure 2-21 shows per cent of blocking as a function of random pulse density. Assuming the radar can function with 70 per cent of the total available information, random blocking does not appear to be a serious problem for vehicle tracking.

The one exception to the above statement is that the transmitter requires a minimum of 500 microseconds between pulse transmissions. Thus, a radar or combination of radars capable of triggering the transmitter in excess of 2000 pulses per second will cause a high blocking percentage.

Beacon capture is a special case of beacon blocking by an interfering radar capable of triggering the beacon at a PRF a fraction of a cycle higher in frequency than the tracking radar. The offending PRF, in drifting slowly through the prime radar's pulses, has the effect of blocking the prime radar's beacon reply and substituting its own reply in its place. Since the offending PRF is slightly higher in frequency than the prime radar, the beacon reply occurs at a fictitiously shorter and shorter range as seen by the prime radar until it is dragged through the radar's magentron pulses and becomes lost. The conditions necessary for this to occur are as follows:

a. Correct transmitting frequency
b. Interrogation pulse spacing set to correct code
c. PRF higher by a fraction of a cycle
d. Radar illuminating the beacon for several seconds.

It may appear that these conditions are rather stringent; however, they occur readily in an area such as the launch site where several radars having the required characterisitics are located, particularly when it is desired to "share" the vehicle beacon during launch operations.

Beacon capture may also be experienced with properly calibrated PRF's during PRF changes which result in near coincident interrogation. Changes in range rates resulting from vehicle motion will also provide a "pass-through" effect.

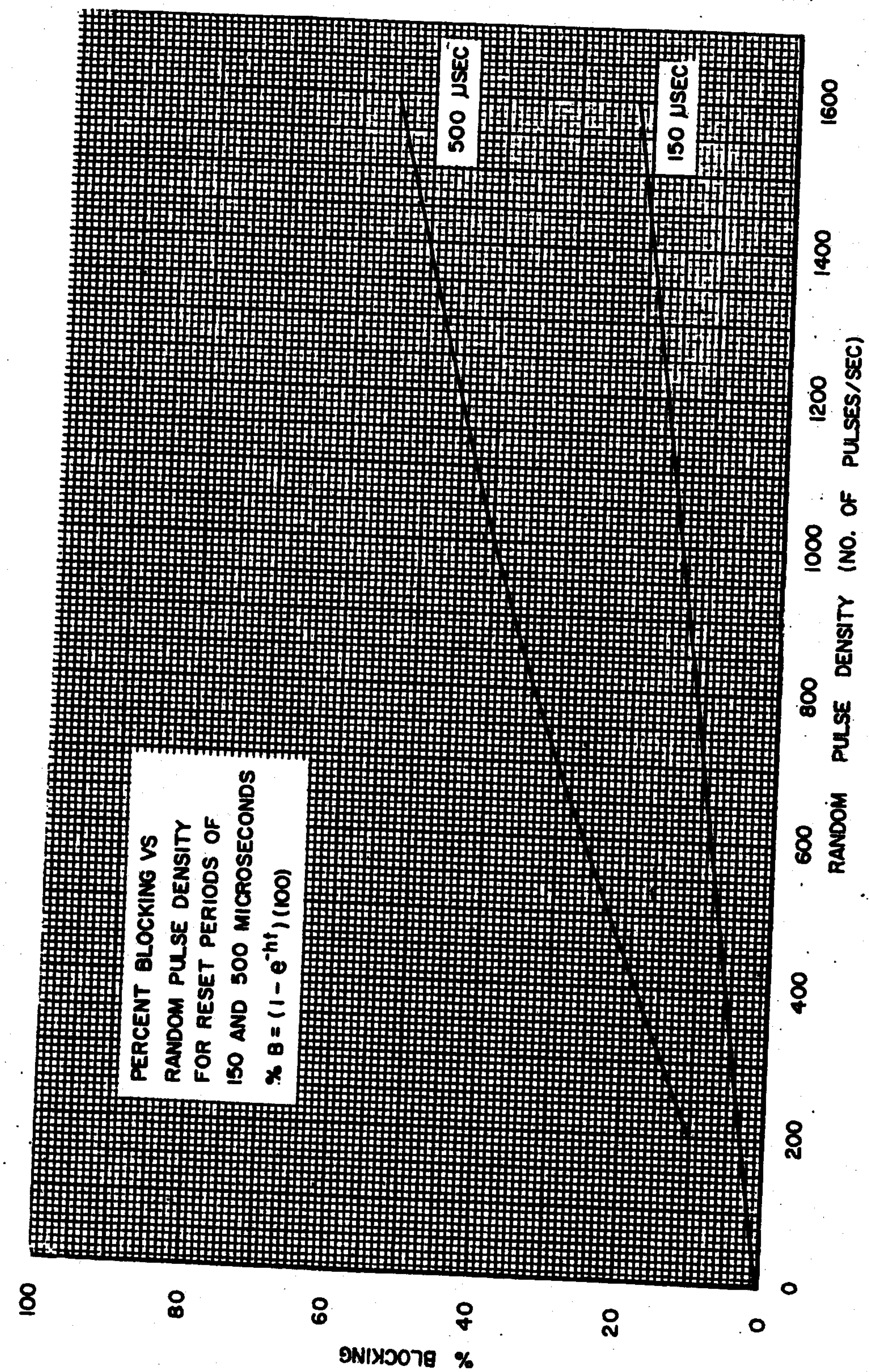


Fig. 2-21 3bb2A Beacon Blocking Percentage

Command Interference. The same types of interference that will affect the tracking link will also affect the commanding link, i.e., block and capture. These can cause a command to be partially blocked or complete blocked, depending on the nature of the interference, the duration of the interference, and the particular command being transmitted. Other effects noted, which are peculiar to the command link, are command dumping and false commands.

Partial or complete blocking of a command can occur when a sufficient percentage of the command radar's pulses have been blocked by interference. Too few position-modulated pulses are demodulated in the beacon command decoder to activate the tone-operated relay circuits or keep them activated solidly.

Susceptibility to command blocking is not only due to the recovery time of the interrogation decoder circuits and command decoder circuits, but also to recovery time limitations inherent in the gas-tube resonant charging circuit of the modulator.

Blocking periods of short duration (less than150 milliseconds) tend to be overlooked by the command relay circuits due to their hold-in time constant.

The intermittent nature of most interference has a tendency to release the tone relays for only short period ranging from 150 to 800 milliseconds. For this reason there is an advantage in transmitting commands for at least a one-second duration. If interference is present, this procedure provides a greater chance that the relay will be closed during at least part of this command period.

When a command is interrupted, the effect it has on the vehicle is dependent upon the nature of the specific command being sent. Because of this, each command, and the effect momentary blocking has on the command, must be considered individually. Also, it should be noted that an interrupted command may look like several issuances of the same command, or that the duration of a time-keyed command has apparently been shortened.

Command dumping is a condition evidenced by an apparent lowering of the position-modulation amplitude (swing) of the command transmission. This condition occurs when three-pulse radars are tracking the beacon while the prime radar is sending commands. This condition occurs even when the secondary radars have properly phased their PRF's and are not causing tracking interference.

The exact mechanism by which modulation amplitude is apparently attenuated is complex and involves an averaging process that takes place in the boxcar circuit of the command demodulation chain. It appears that the wanted full-amplitude tone signals being demodulated are averaged out with the zero tones (total lack of tones) transmitted by the secondary tracking radar. Each time a secondary radar three-pulse group arrives at the position-demodulation circuits, it dumps part of the charge built up on the boxcar storage condenser by the pulses from the commanding radar. The overall effect is the same as if the commanding radar has been improperly adjusted to produce insufficient command-pulse position modulation. This results in either total or intermittent blocking of the wanted command.

Command relay closures in the airborne command decoder unit that are not the result of tones keyed in the pulse coder assembly (KY-94) of the prime Verlort radar give rise to false commands. Normal command transmission requires that two of the four tones available be paired to achieve the two relay closures necessary for a single command. Certain conditions can cause a spurious tone to be produced either outside the beacon or within the decoder circuits, but the probability is very remote that two tones will be produced and that each of these will be a correct frequency. In other words, the changes that a command (two tone relays closing) will be produced in the beacon when none is being sent from the ground are very unlikely.

An entirely different condition exists when a command is being sent. During this period, two tones are being actively demodulated (to produce one command). If a spurious tone, at one of the other two acceptable frequencies, appears during this time, it will combine with each of the two tones already present and create two additional, and false, commands.

The spurious tone can either be at a correct tone frequency or be of a frequency which will add, subtract, or otherwise combine with the tones present, their harmonics or subharmonics, and form a new tone which falls in the passband of one of the tone filters.

The density of interference required to cause the position demodulation circuits to produce a spurious tone is, fortunately, quite high. Also, more than one of the interferring radars must have PRF's which differ in frequency from the prime radar PRF by specific amounts so that the combining mixing, or beating phenomena necessary for spurious tone generation at a correct frequency can take place.

High-level electrical noise produced within the vehicle by arcing electrical equipment such as switches, relay contacts, vibrators, motor commutators, etc., can get into the sensitive receiver circuits and have the same effect as random radar interference.

It is interesting to note that the interfering tone can come about by either amplitude modulation (blocking) of the "carrier" (PRF), or the interfering pulses can ride through the prime radar pulse group and be detected, pulse position-wise, as if they belonged to that group. During periods of very high density interference, both conditions are present.

The fact that these circuits are sensitive to amplitude modulation of the PRF makes them vulnerable to conditions which affect the signal level of the radar pulses as seen by the beacon. The depth of modulation must be sufficient to cause the signal level to drop below triggering threshold during all or part of the negative half of the modulation cycle. This can be caused by the following conditions:

a. Nutation of the radar beam when slightly off target at long ranges (threshold signal conditions).

b. Nutation of the radar main lobe or side lobes when far off target at short ranges.

c. Rapid tumbling or rolling of vehicle.

d. Vehicle traveling at high speed through Fresnel zones of radar beam at great distance and low elevation.

The most common occurrence of signal strength variation at a high rate (amplitude modulation) occurs as in (a) and (b) above, due to the conical scanning of the radar beam. When the radar is locked-on in automatic track, the vehicle is evenly illuminated by the radar; however, when the radar is not looking directly at the vehicle, the signal strength, as seen by the beacon, follows a cyclic amplitude modulation at the scan rate of 30 cycles.

Then modulation will be of sufficient amplitude to trigger the beacon during part of its cycle and fall below threshold at another part, depending on the angular offset and range of the vehicle from the radar.

The 30-cycle scan frequency is one which can beat with three of the tone frequencies used, and produce spurious tones which can fall within the passband of three of the filters. The tone frequencies with which 30 cycles will react, the spurious tones produced, the false command produced, and the susceptibility each command has of being produced falsely is presented in Table 2-2. The last column of this table indicates the number of times that the particular command could possibly be registered falsely during any period in which all six commands were sent, i.e., Commands 1 and 3 are the least susceptible and 2 and 6 are most susceptible to being falsely produced.

The data in Table 2-2 represents what is theoretically possible. In practice the interaction is not as severe as it appears at first glance in the tabulation. The effects have been noticed, however, during both laboratory and flight tests. The increased tendency of Commands 2, 5 and 6 to appear as false commands was quite discernable.

As observed in the preceding paragraphs, the beacon is most vulnerable to production of false commands when it is in the process of receiving a wanted command. The generation of false commands during noncommand periods is almost impossible, short of beacon or radar modification or serious misalignment of either or both units.

Rigid radar operating procedures to ensure that solid automatic tracking conditions prevail prior to and during transmission of commandsare necessary to ensure freedom from scan frequency interaction.

TABLE 2-2

SCAN FREQUENCY INTERACTION WITH COMMAND TONES

Command Number	Tones Used	Tones $\pm$F Scan	Spurious Tone Produced	False Command Produced	False Command Susceptibility
1	A&B	B+30	C	2&4	1/6
2	B&C	C+30	D	5&6	4/6
3	A&D	D-30	C	2&6	1/6
4	A&C	C-30 C+30	B D	1,3,4,5&6	2/6
5	B&D	B+30 D-30	C	4&6	3/6
6	C&D	C-30	B	4&5	4/6

Minimizing Interference. The type 3bb-2A S-band beacon transponder in conjunction with the Verlort radar is able to provide a satisfactory ground-space tracking and command link under most of the conditions to be encountered during the launch and subsequent orbital phase of satellite operation. However, to assure reliable and interference-free performance, certain precautions must be observed in the initial tune-up and alignment of both the airborne and ground-based components of this link.

The reliability margin of this link is affected by the presence of interference. This susceptibility to interference in both the tracking and commanding modes has been substantially reduced by suitable modifications to the airborne beacon. One of these modifications renders the command-tone demodulator circuits insensitive to two-pulse code groups. It requires that a command pulse be present to alter the charge on the boxcar condenser of the detector circuit. This eliminates the command dumping problem since modification of the radar for two pulse operation (see Paragraph 2.2.5).

Proper calibration and sharing (phasing) procedures minimize tracking interference and make it possible for several Verlort radars to operate in the same vicinity. The anti-beacon capture modification (see Paragraph 2.2.13) provides automatic PRF phasing when beacon capture occurs. The reaction time of the anti-beacon capture circuit is sufficiently rapid to allow an effective portion of a 1-second duration command to be received and acted upon. However, in cases of duration-critical "one shot" commands such as Commands 5 and 6, used for guidance during the launch phase, a sequenced operation of the radars is advisable.

The importance of proper alignment of the beacon and radar circuits cannot be overemphasized. What was thought to be equipment trouble as first encountered in performing both laboratory and flight tests was actually equipment maladjustment. It is not impossible that this also could be a cause of trouble during an actual firing operation. For this reason, the following should be kept in mind. Correct operation is very dependent on tight tolerance in r-f frequency adjustments, threshold adjustments, pulse positions, pulse time deviations, etc. This makes it mandatory that the radar and beacon circuits be adjusted with the utmost care, using accurately calibrated test equipment. The "quick fix" rule-of-thumb type of repair, without proper equipment and by inexperienced personnel, cannot be made. The approved servicing and alignment procedures prescribed for both the radar and beacon must be carefully followed.

Modifications made to the Avion Type 3bb-2 beacon to alleviate interference are listed here in detail. The modified beacon is identified as Type 3bb-2A.

a. Installation of low-pass filter in r-f input line.

b. Shortening of time constant (recovery time) in the interrogation-decoding delay multivibrator.

c. Shortening of time constants (recovery time) in the command pulse delay multivibrator.

d. Taking the command enabling gate from the output of the interrogation decoder's coincidence diode instead of from the output of the thyratron modulator tube.

e. Addition of a transistor clamp circuit in the command demodulator circuits to render them insensitive to other than three-pulse groups.

f. Rewiring of tone relays to provide an interlock feature which will interrupt the continuity of a command circuit if a third relay should falsely close due to a spurious tone.

2.5 Analysis of Vehicle Tracking Data

This is a preliminary analysis and summary of the tracking capability of the ground support equipment for Discoverer flights VI, VII, XI, and XIII. The tracking data used were the numeric listings generated by the 1103 computer (see Section 6) based upon the Verlort radar and the R-1162 digital tracking data as received from the various tracking stations via 100 wpm teletype system. Only the data considered of good quality was analyzed. The definition of good quality required the data to be without erratic points. The comparison of simultaneous radar tracking data was achieved by transforming the data of the active station into the coordinates of the other tracking station. Assuming that the surveys of the stations are correct, there should be no error between the transformed data and the other tracking station data due to the transformation routine.

The Comparative tracking data obtained is not to be construed as representing the tracking accuracy of the equipment, since the preliminary analysis was not extensive enough to reveal the error sources. The data is presented merely to indicate the need for further investigative work. Additional analysis is in progress in which ephemeris data will be compared to Verlort tracking data. Verlort data will in turn be compared with best-fit curves, and, in general, more detailed comparisons will be made from which valid operational performance results, may be expected.

In the following discussion, the active-active mode is defined as the case when two Verlort radars are simultaneously active-tracking. The active-passive mode is defined as the case when one Verlort radar interrogates and receives the signals from the satellite, while one or more passive radars track the signal from the satellite being interrogated by the active station. During active-passive tracking, the range data from the passive radar is not valid.

2.5.1 Discoverer VI

The comparison of Verlort angle tracking data to the R-1162 data was made for Hawaii Pass 9 and 10. The difference between the two groups of angle data, excluding bad points, varied from 2 milliradians to 9 milliradians. If it were not for cyclic tracking error in the Hawaii Verlort radar, especially during the ninth pass, the difference between the two groups would be less than 5 milliradians with the average difference approaching zero. The difference between the two groups of VAFB data indicated an increase in the jitter of raw data while the slope of the best fit curve through the differences indicated a possible existence of a calibration error.

2.5.2 Discoverer VIII

Prior to Discoverer VIII, Modification RP-67, (automatic passive tracking) was installed on all Verlort radars. This modification of the Verlort radar permits the passive station to obtain accurate angle data as the satellite is interrogated by an active station. The ascent and Passes 8, 9 and 15 were analyzed.

Only during the launch phase of Discoverer VIII was there simultaneous active tracking between VAFB and Mugu Verlort radar which could be analyzed. The result of the simultaneous active tracking transformation showed the following average deviations:

Elevation -- 10 milliradians rms from the mean.

Azimuth -- 5 milliradians rms from the mean.

The comparison of the Verlort angular data to that of the R-1162 telemetry antenna for ascent and Pass 8 at VAFB and Pass 1 and Pass 9 at Hawaii indicated that the rms deviation from the mean was less than 10 milliradians on all angles except the azimuth angle of Pass 9 at Hawaii, where a maximum difference of 9 degrees occurred at the point of closest approach. The maximum azimuth angular velocity for Pass 9 Hawaii was 2 degrees per second, averaged over a four-second period.

The comparison of the ephemeris data with the Verlort tracking data was performed on Pass 8 Annette, Pass 9 Hawaii, and Pass 15 Kodiak. In all cases the Verlort data led the ephemeris data; on the azimuth of Pass 9 Hawaii, at the point of closest approach, the error was as much as 7 degrees. There were also range differences with the Verlort data leading the ephemeris data until the point of closest approach after which the Verlort data lagged the ephemeris data. The bias was as great as 10 nm on Pass 9 Hawaii.

Discoverer VIII had a very elliptical orbit, which probably caused discrepancies in the comparative difference between the Verlort and the ephemeris data.

2.5.3 Discoverer XI

The three stations, VAFB, Mugu, and Hawaii, were tracking the passes of Discoverer XI. Very few passes were analyzed since the quality of the data was very poor.

The comparison of the Verlort angular data to that of the R-1162 telemetry antenna for ascent, VAFB, gave 14.0 milliradians rms deviation from the mean for azimuth and 14.3 milliradians rms deviation from the mean for elevation.

For Pass 9, VAFB, the azimuth angle comparison gave 9.5 milliradians rms deviation from the mean, and the elevation angle comparison gave 7.7 milliradians rms deviation from the mean. For Pass 10, Hawaii, the azimuth angle comparison gave an rms deviation from the mean of 9.6 milliradians and the elevation angle comparison gave an rms deviation from the mean of 8.6 milliradians.

2.5.4 Discoverer XIII

Four stations, VAFB, Mugu, Hawaii and Kodiak, were tracking during the various passes of Discoverer XIII, and the comparative differences were obtained between the transformed data and the station data.

There was an active-active tracking interval during ascent when both stations, Mugu and VAFB, were tracking for a period of 176 seconds. The azimuth angle comparison gave 4.4 milliradians rms deviation from the mean and the elevation angle gave an rms deviation from the mean of 3.3 milliradians and the range comparative difference was 0.62 nautical miles rms deviation from the mean.

There was an active-passive tracking interval during ascent and Passes 9 and 10. During ascent, when both VAFB and Mugu were tracking, the azimuth angle comparison gave 2.6 milliradians rms deviation from the mean and the elevation angle comparison gave 2.4 milliradians rms deviation from the mean. During Pass 9, where the Mugu and Hawaii Verlort radars were tracking simultaneously, the azimuth angle comparison gave 5.4 milliradians rms deviation from the mean. During the tenth pass, Hawaii and Kodiak radars were tracking for about 212 seconds. The rms deviation from the mean for the azimuth angle comparison was 10.946 milliradians and the rms deviation from the mean for elevation angle comparison was 28.4 milliradians.

The comparison of the Verlort angular data to that of the R-1162 telemetry antenna for Pass 2, Hawaii, gave for the azimuth angle comparison an rms deviation from the mean of 9.386 milliradians and the elevation angle comparison gave an rms deviation from the mean of 9.0625 milliradians. For Pass 8, VAFB, the azimuth angle comparison gave an rms deviation of 1.8588 milliradians from the mean, and the elevation angle comparison gave an rms deviation of 1.60402 milliradians from the mean. For Pass 10, Hawaii, the azimuth angle comparison gave 38.2893 milliradians rms deviation from the mean and the elevation angle comparison gave an rms deviation from the mean of 19.9511 milliradians.

2.5.5 Conclusion

In the present analysis, the wide range of apparent errors indicated that there were several non-random factors present in the data. Some of the data indicated errors which exceeded any rational correlation with the physical phenomenon involved in the tracking system.

SECTION 3

VHF, DOPPLER TRACKING, AND TELEMETRY

3.1 Introduction

The VHF, Doppler tracking, and telemetry system receives and records the vehicle FM/FM telemetry and Doppler frequency data. The major items of equipment are the R-1162 telemetry tracker, the tri-helix antenna, the Doppler receiving system and the telemetry receiving and recording system. The telemetry tracker is the primary telemetry-receiving antenna at the Vandenberg and Hawaii tracking stations. The tri-helix antenna supplies the signal for the Doppler receiving system at all stations. The tri-helix also serves as the primary telemetry-receiving antenna at Kodiak, New Boston and Point Mugu tracking stations and as a backup at VTS and Hawaii.

3.2 Telemetry Tracker (Fig. 3-1, 3-2, 3-3 and 3-4.)

The R-1162 telemetry tracker is a high-gain antenna system capable of tracking automatically on a CW or FM telemetry signal in the VHF frequency range of 216 to 245 mc. The primary function of the system is to receive the vehicle's telemetry data and convey it to the ground station telemetry equipment for processing. The antenna also provides azimuth and elevation tracking data in digital form, which can be transmitted to the central computer as a supplement to the information provided by the radar. Synchro outputs from the azimuth and elevation shafts of the antenna are used to actuate plotboard indicators and to provide slaving information to position other local tracking antennas.

The telemetry tracker antenna system is capable of manual, automatic, or slaved operation. Normally, the system will operate in the self-tracking or automatic mode, using the FM telemetry signal from the vehicle as the signal source. Tracking accuracy of the present equipment is within ± 0.75 degree at a slew rate of six degrees per second. The maximum slew rate is 10 degrees per second in both elevation and azimuth, and the acceleration rate is five degrees per second per second. Azimuth coverage of the antenna is 360 degrees. In elevation, the antenna tracks automatically between zero degrees and 86 degrees, and

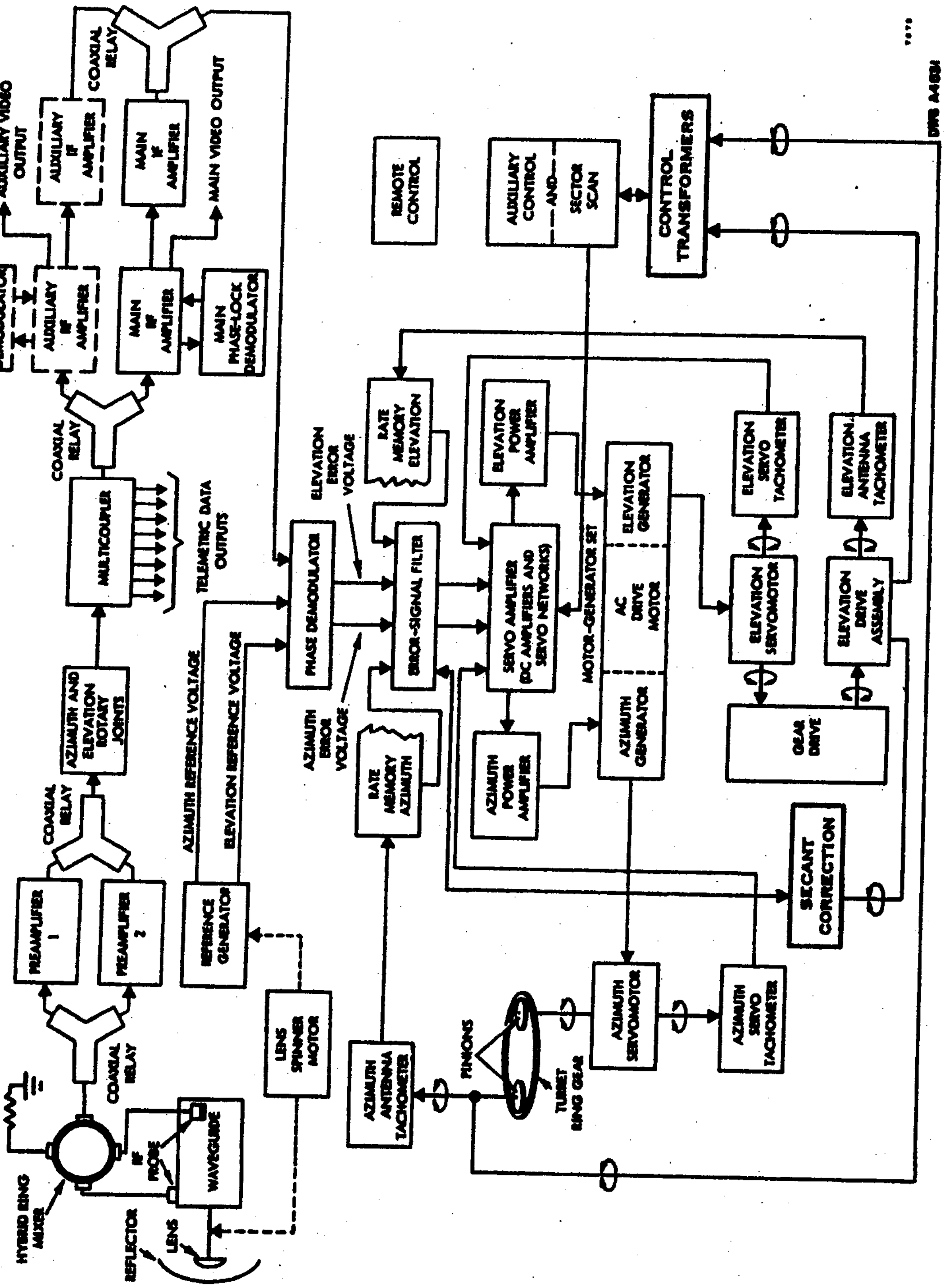


Fig. 3-1-Telemetry Tracker System Block Diagram

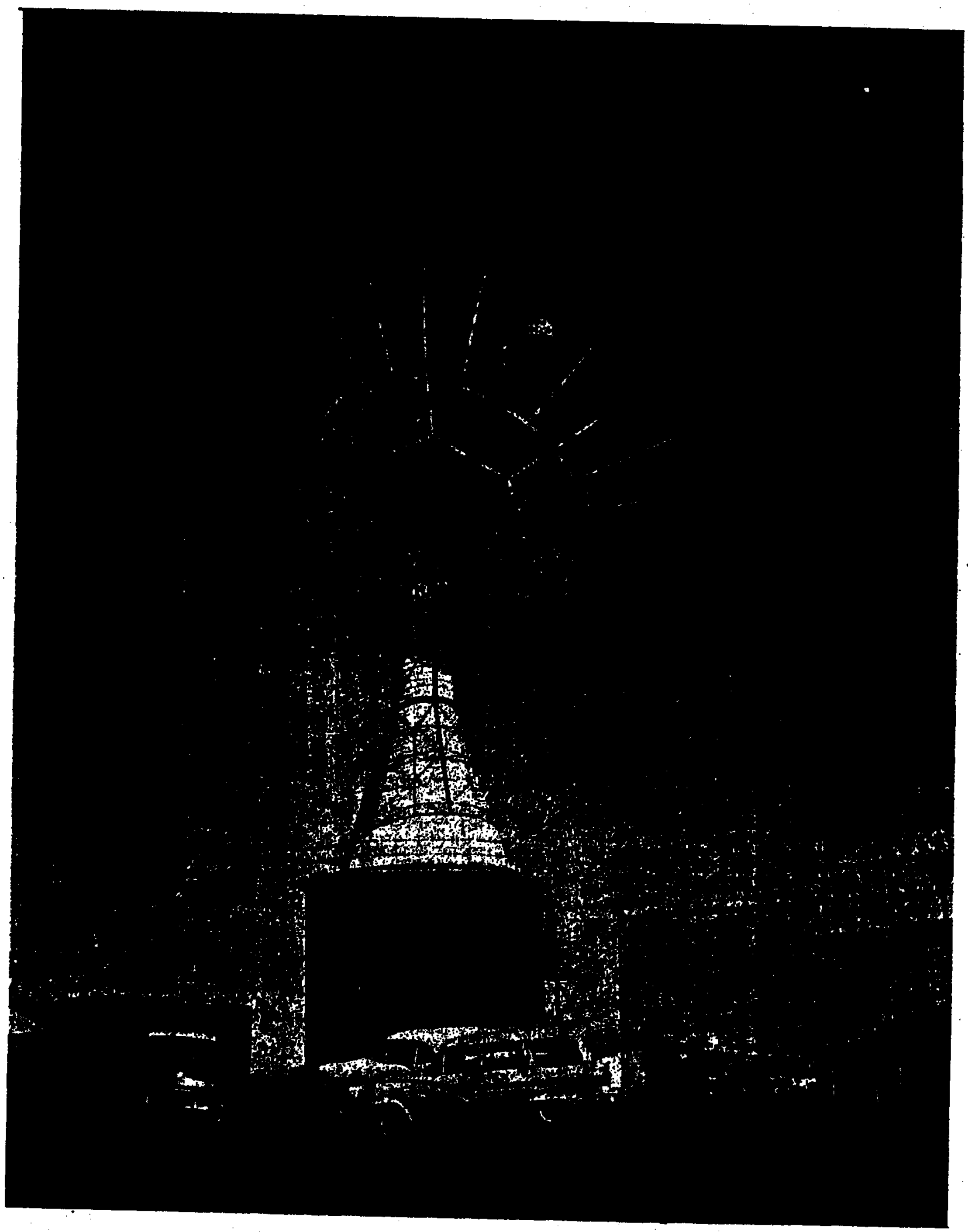


Fig. 3-2 Telemetry Tracker Antenna

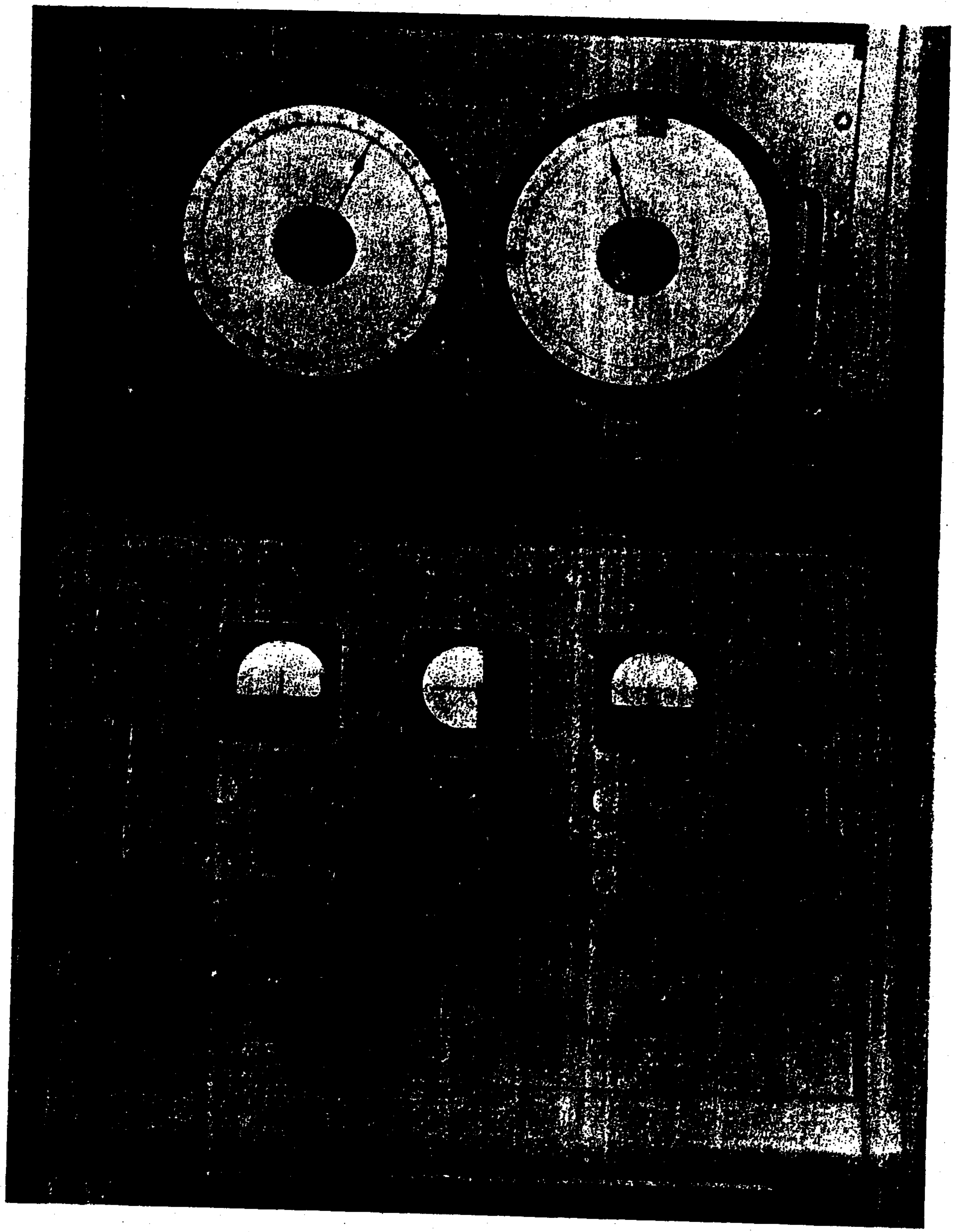


Fig. 3-3 Telemetry Tracker Control Panel

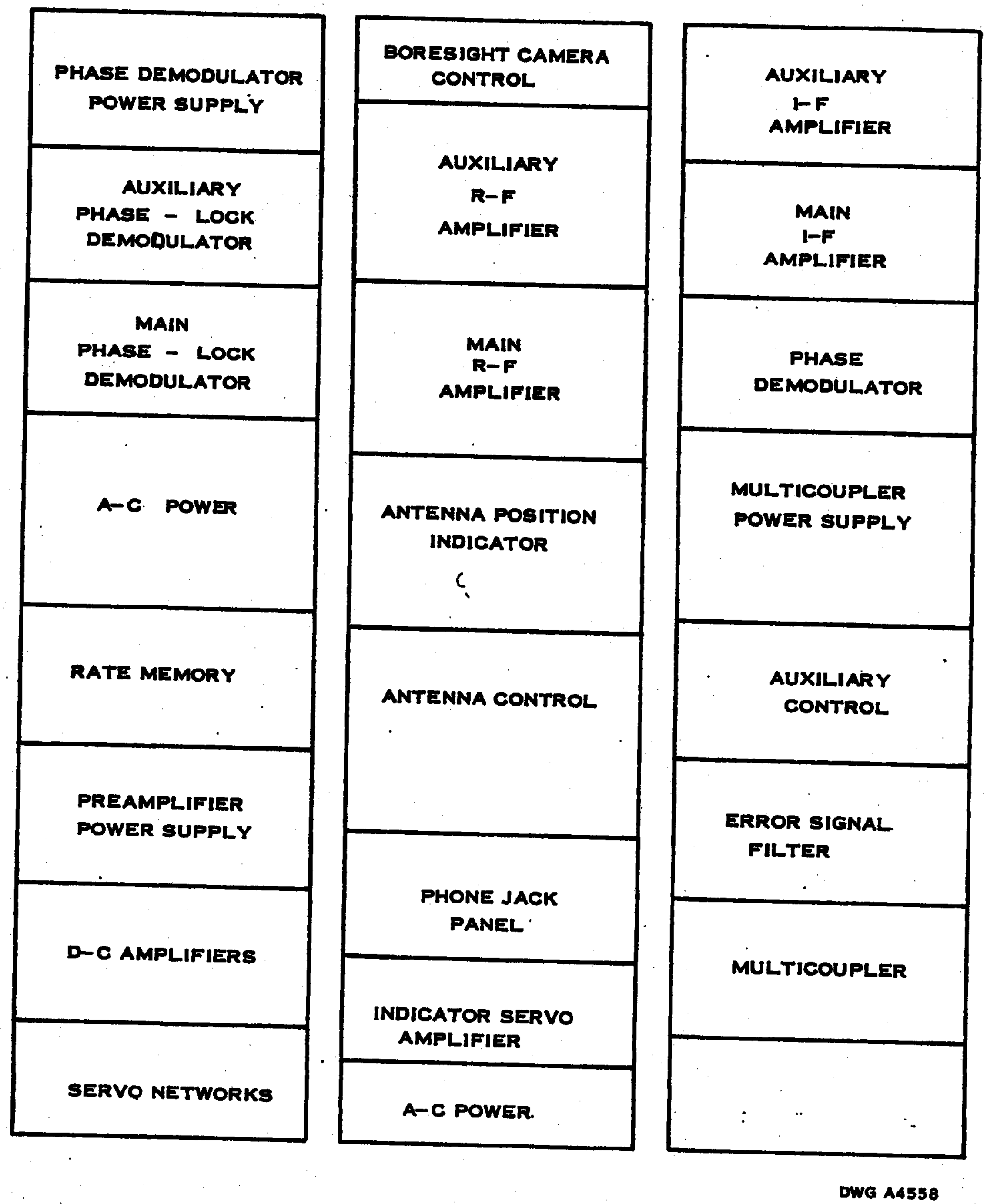


Fig. 3-4 Telemetry Tracker Rack Configuration

it tracks manually from zero degrees to 92 degrees. Mechanical stops are placed at the minus 3-degree and plus 96-degree points to prevent damage from overtravel. The antenna system includes automatic azimuth sector scan which can be varied from plus or minus 10 degrees to plus or minus 60 degrees.

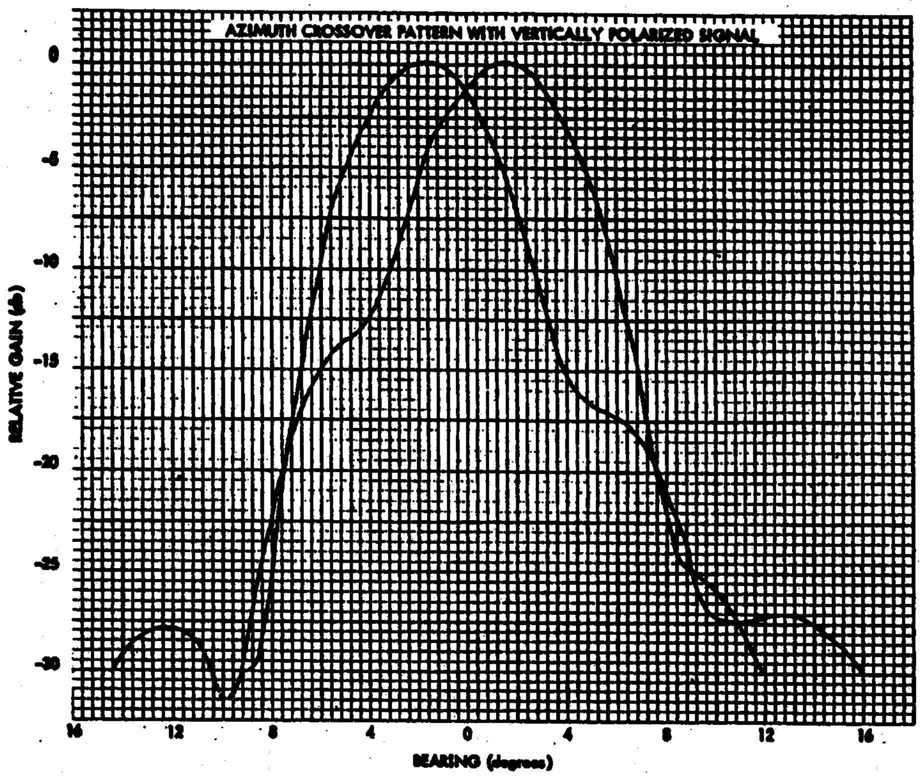
At both Vandenberg and Hawaii the antenna is installed on top of a concrete structure (see Fig. 1-5 and 1-7) and the console control equipment is located in the VHF building (see Fig. 4-5 and 4-6).

3.2.1 Antenna

The telemetry tracker receives r-f signals at the 60-foot reflector, which focuses them toward the lens in the feed assembly. The antenna feed assembly consists of the dielectric scanning lens, pickup probes, a circular wave guide, a hybrid ring mixer, and a preamplifier. Conical scan is provided by rotating the lens at 600 rpm. The acquisition beam width (Fig. 3-5) resulting from the conical scan is approximately eight degrees. The conical scan results in amplitude modulation of the incoming r-f signal at 10 cps. This amplitude-modulated signal is used to develop error voltages proportional to the displacement of the target from the center of the scan pattern, and these voltages control the antenna positioning system. The r-f signal is fed from the lens through a waveguide containing horizontally and vertically polarized r-f probes to a hybrid ring mixer that combines the signals from the two probes to obtain circular polarization. In order to obtain a low noise-figure, the r-f signal is coupled to a preamplifier which amplifies the signal for transmission through the elevation and azimuth rotary joints to the rack-mounted multicoupler. Two preamplifiers are available for redundancy. A coaxial switch remotely controlled from the operator's position transfers the r-f signal from one preamplifier to the other.

3.2.2 Multicoupler

The r-f telemetry signal from the output of the preamplifier is connected to the input of the multicoupler in the control rack. The multicoupler provides nine individual isolated outputs for further distribution of the signal. The multicoupler is designed for operation in the 215- to 245-mc region and produces a 1- to 2-db gain with a



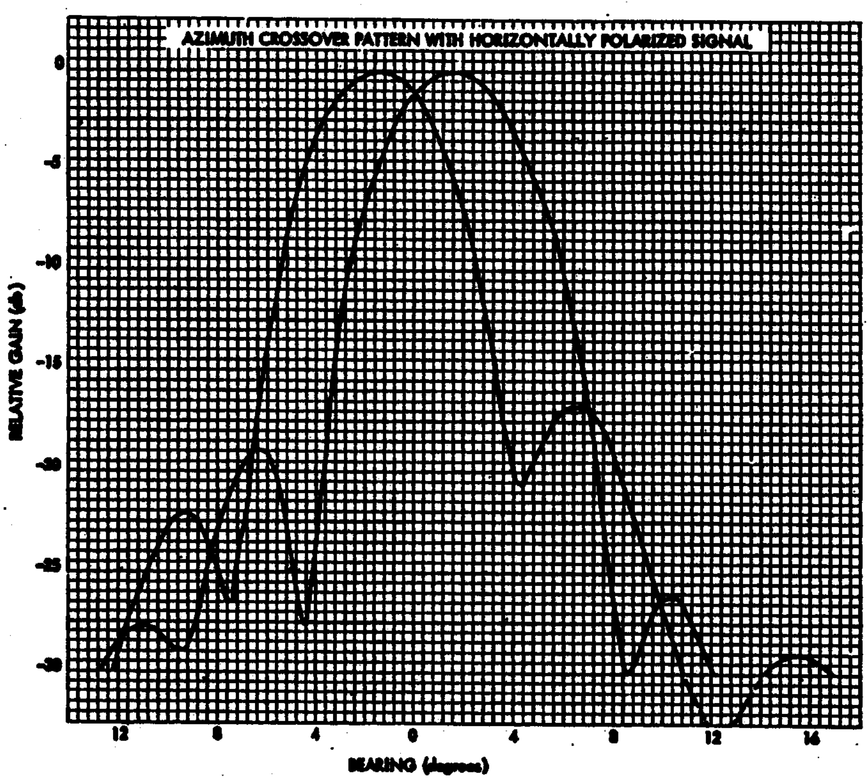


Fig. 3-5 Telemetry Tracker Field Strength

bandwidth of approximately 30 mc. One output of the multicoupler is utilized to convey the complex FM signal to the telemetry receivers and the auxiliary equipment, and another output is applied to the FM receiver by a switch on the console.

3.2.3 Phase Demodulator

The phase demodulator separates the 10-cps antenna error signal into its azimuth and elevation components. The phase and amplitude of the 10-cps error signal received from the FM/AM receiving system is compared with the azimuth and elevation 10-cps reference signals received from the reference generator rotated by the lens-spinner motor on the antenna feed system. The azimuth and elevation error signals from the output of the phase demodulator are d-c voltages which are proportional to the azimuth and elevation angular displacement of the antenna with respect to the actual position of the vehicle. The output of the phase demodulator is applied to the antenna drive motors after being filtered and amplified.

3.2.4 Rate Memory

A rate memory circuit is provided which permits the antenna to continue tracking at its original rate for a maximum of 25 seconds after loss of a signal. The antenna tracks automatically on a signal input of 1.5 microvolts or higher. If the signal falls below 1.5 microvolts, the rate memory circuit cuts in automatically and continues to position the antenna in its original plane and rate with an error of less than 10 per cent. A relay circuit in the limiter stage of the FM receiver actuates another relay in the error signal filter unit which connects the memory circuit into the system. The rate memory circuit is controlled by the voltage applied to it by the azimuth and elevation rate generator.

3.2.5 Equipment Characteristics

Antenna

a. Reflector diameter: 60 feet
b. Frequency band: 216 to 245 mc
c. Gain above isotropic radiator: 31 db
d. Polarization: circular; axial ratio 1.26 or better
e. Scan frequency: 10 cps
f. Beamwidth to half power points (static) 4.6 degrees

R-F Preamplifier and Multicoupler

a. Frequency band: 216 to 245 mc
b. Gain: 30 db nominal
c. Noise figure: 4.5 db
d. Telemetry outputs for data: 8
e. Output impedance: 50 ohms
f. Isolation (between outputs): 30 db minimum
g. Response: within 3 db of maximum over specified band

Tracking Receiver (Nems-Clarke NC1400)

a. Frequency band: 216 to 245 mc
b. Frequency stability: crystal controlled
c. Gain: 130 db
d. Noise figure: 7 db
e. I-F bandwidth: 100 kc or 500 kc

Servo System (Manual or Automatic Tracking)

a. Overall tracking accuracy at 6^{o}/second: 0.75 degrees
b. Tracking and slew rates: (elevation and azimuth): 10^{o} per second maximum
c. Acceleration rates (elevation and azimuth): 5 degrees per second per second maximum
d. Elevation tracking limits:
   0 to +86 degrees, automatic
   0 to +92 degrees, manual
e. Elevation rate limit switch: adjustable from -1 to +15 degrees
f. Limited elevation tracking rate: 3 degrees per second from ERI switch setting to -1 degree
g. Azimuth tracking limits: none (continuous)
h. Acquisition signal: 1.5 microvolts at antenna terminals
i. Signal below 1.5 μv: Antenna will continue to track with less than 10 per cent falloff

Primary Controls and Indicators

a. Master pushbutton on-off controls
b. Mode selector for manual, automatic, or standby operation
c. Azimuth and elevation antenna position indicators
d. Controls for elevation and azimuth manual tracking ranges
e. Elevation and azimuth relative error signal indicators
f. R-F signal strength indicators
g. Servo limit over-ride
h. Electrical limit over-ride
i. Jacks for telephone attachment
j. Brake indicator
k. Receiver select switch (optional)

Power Requirements

a. Motor-generator installation: Three-phase, 60 cps, 208/120 volts, 60 kw
b. Control installation: Single-phase, 60 cps, 115 volts, 5 kw

3.3 VHF Acquisition and Doppler Tracking

The primary objective of the Subsystem H Doppler system (Fig. 3-6) is to permit acquisition of the vehicle at the earliest possible moment during a pass within range of the tracking station. This objective is accomplished by use of the broad-beam characteristics of the tri-helix antenna coupled with a sensitive phase-coherent Doppler receiver to receive the output of the vehicle-borne acquisition transmitter. The second objective is to record Doppler frequency data for transmission to the central computer for processing to obtain such data as Doppler S-curves and minimum slant range. For this purpose, the tri-helix antenna and the phase-coherent receiver are used in conjunction with suitable measuring and recording equipment to permit recording of Doppler frequency data for transmission via 100-wpm teletype. The information thus provided from several stations can be used to calculate limited vehicle orbit parameters.

3.3.1 Vehicle CW Transmitter

The signal from a low powered, continuously radiating VHF CW acquisition transmitter in the vehicle is utilized as the signal source for acquisition and making Doppler measurements. This transistorized crystal-controlled transmitter has a power output of 10 milliwatts minimum at a frequency of 232.4 mc (designed to vary slightly according to the vehicle) with a stability of 1 part in 10^5. The acquisition margin at 1500 n.m. is 9 db (Appendix A-2) assuming proper vehicle stabilization.

3.3.2 Tri-Helix Antenna

The tri-helix antenna is utilized to receive two separate signals from the vehicle simultaneously. One of these is the CW acquisition transmitter signal and the other is the FM telemetry transmitter signal at 237.8 mc. The CW and telemetry signals from the tri-helix

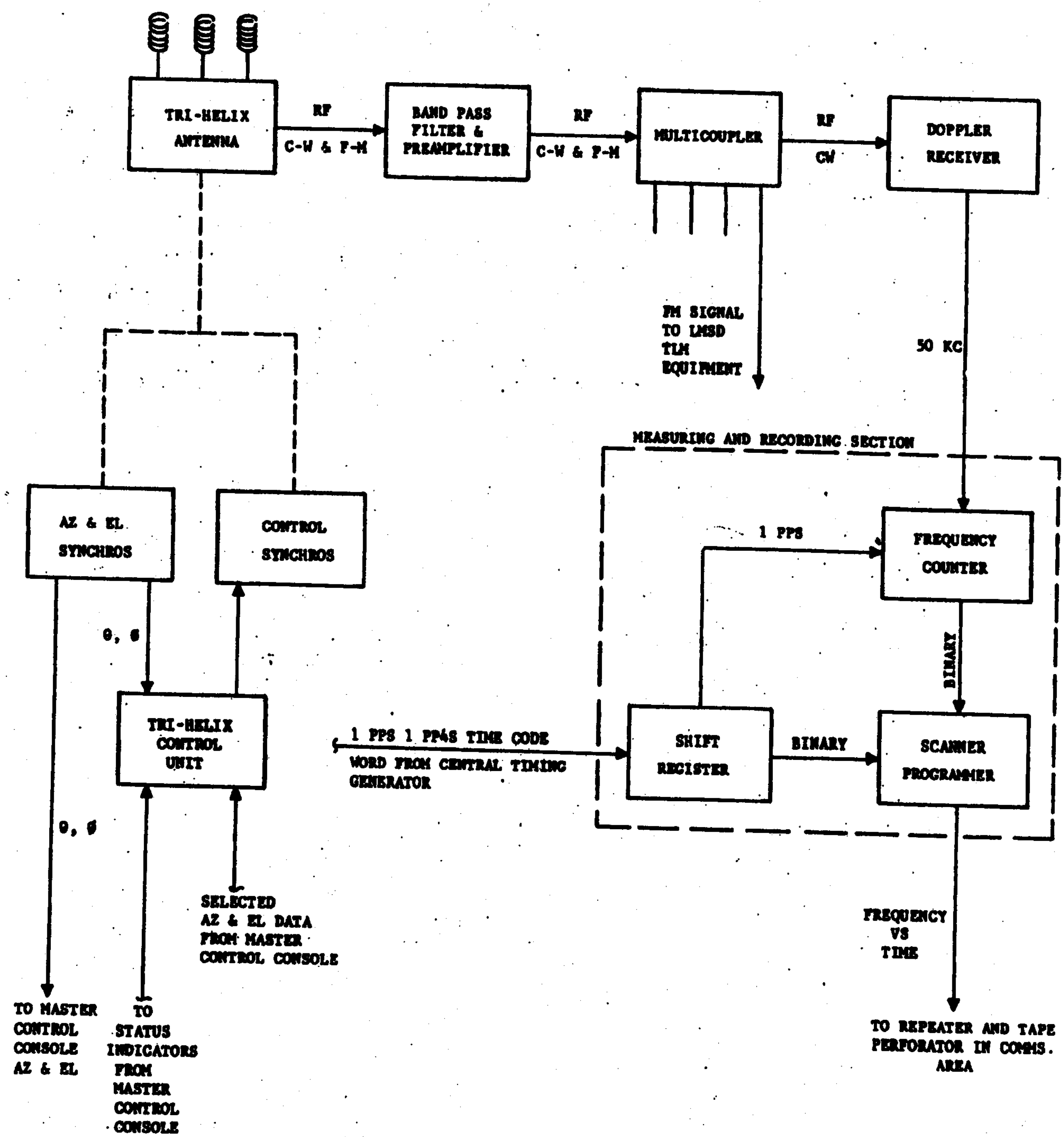


Fig. 3-6 Doppler System Block Diagram

antenna are routed to a band-pass filter and preamplifier installed at the antenna. The bandpass filter helps reduce interference by rejecting all signals outside its 7-mc bandpass. The preamplifier provides an r-f gain of approximately 20 db with a corresponding gain in signal-to-noise ratio. The design bandwidth of the preamplifier is 30 mc. The output of the preamplifier is routed by means of coaxial cable to a multicoupler located at the tri-helix control position. The multicoupler connects up to six receivers to the single tri-helix antenna without degradation of Doppler system operation. The multicoupler has a unity gain figure and provides a minimum of 37 db isolation between outputs. Four multicoupler outputs are used to convey the r-f telemetry signal to the telemetry FM receivers, and one output conveys the CW acquisition transmitter r-f signal to the Doppler receiver. The FM telemetry signal does not interfere with the operation of the Doppler equipment since its frequency is outside the pass band of the r-f and i-f stages of the Doppler receiver.

The tri-helix antenna (Fig. 3-7) consists of a three-element helical array on a hexagonal groundplane, which is mounted on the yoke of a rotator. The array can be rotated in azimuth 360 degrees each side of a center position, or a total of 720 degrees, and elevation rotation can be made over a full 180 degrees. The antenna operates in the frequency range of 215-265 mc. The three helices are fed in phase, and each element has a circularly polarized beam with maximum gain in the direction of the longitudinal axis. Feeding three helices in phase provides a reduced beamwidth and greater gain than is possible with a single helix. The resultant beam (Fig. 3-8) of the array is circularly polarized with a nominal width of 20 degrees in both vertical and horizontal planes and a nominal gain of 15 db. The beamwidth is purposely broad because of the possibility of nulls in the vehicle transmitting antenna and because of the uncertainty in the initial acquisition of the vehicle. The antenna is circularly polarized to allow for variations in the polarization of the received signal resulting from ionospheric Faraday effects.

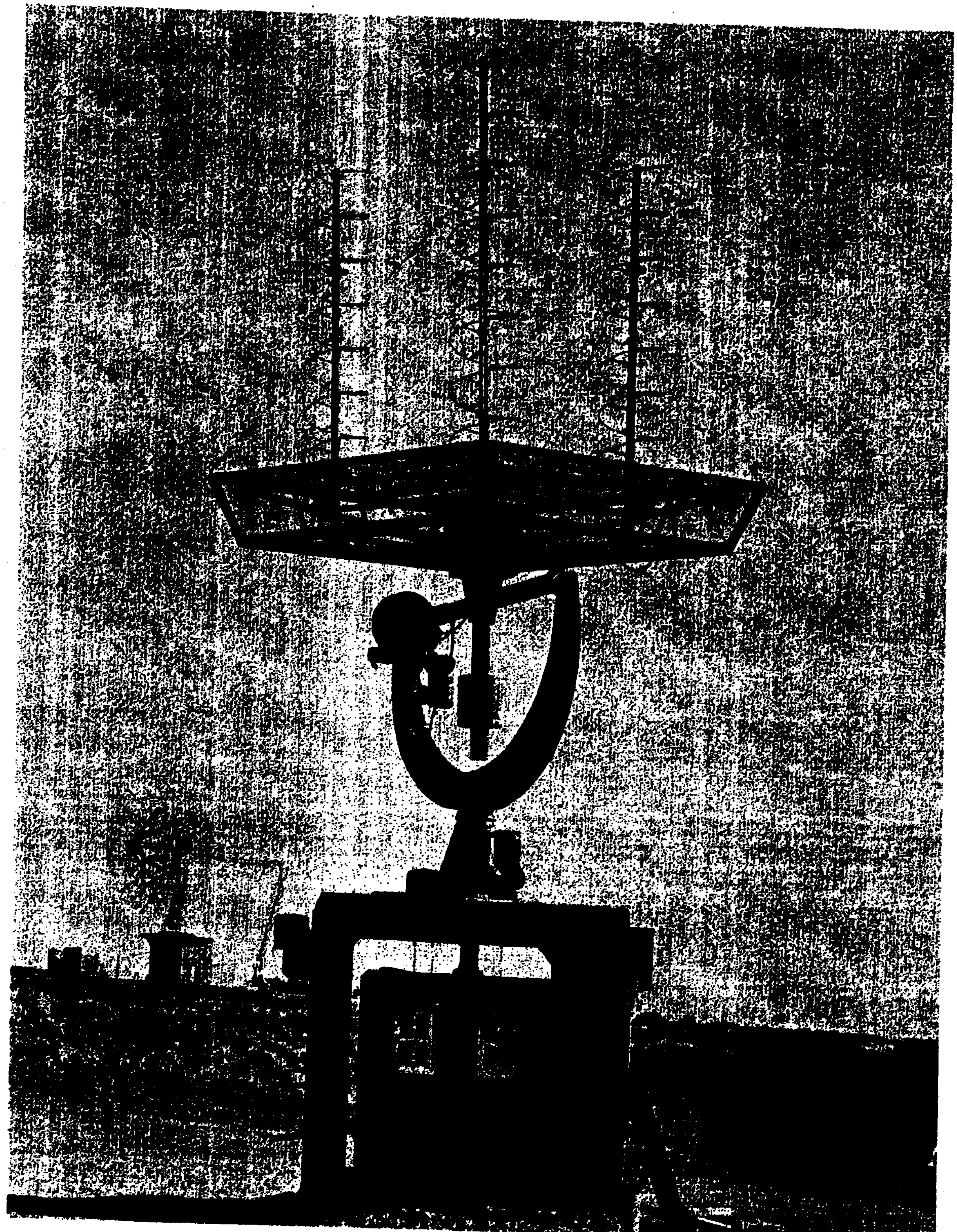


Fig. 3-7 Trihelix Antenna

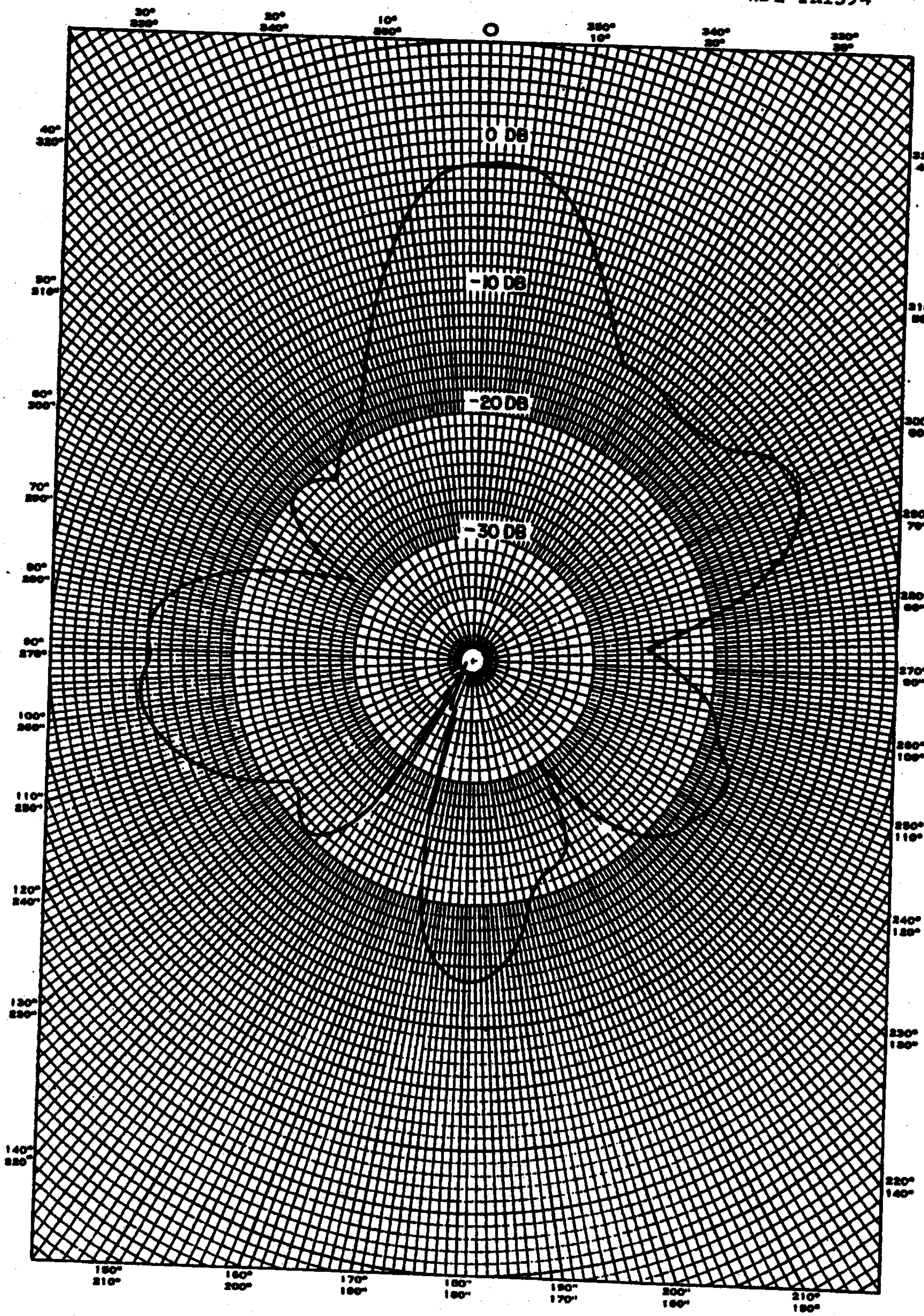


Fig. 3-8 Tri-Helix Antenna Horizontal Directivity Pattern

The tri-helix antenna control and indicator system positions the antenna in the desired direction, either manually or automatically. The antenna control and indicator panels (Fig. 3-9) are located in the VHF buildings at Vandenberg (see Fig. 4-5) and Hawaii (see Fig. 4-6), and in the instrumentation vans (Fig. 3-10) at Kodiak, New Boston, and Point Mugu. The control panel contains a "joy stick" for manually controlling the direction and speed of the antenna. In tracking, the antenna is positioned for maximum signal strength as indicated by a signal strength meter. This meter is located on the indicator panel with azimuth and elevation position indicator dials and status lights. In automatic operation, the antenna uses slave bus data for positioning.

The tri-helix antenna is driven in azimuth and elevation by d-c compound-wound motors operating through suitable gear trains. The antenna can be moved at speeds up to 30 degrees per second in manual mode. A fixed speed of 6 degrees per second is employed in the slaved automatic mode. Limit switches located within the drive assemblies limit the motion of the antenna. The minimum limit on azimuth is 705 degrees, and the minimum limit on elevation is 166 degrees. These rotation limits are manually adjusted electrical stops set to prevent the antenna from swinging into the mechanical stops.

3.3.3 Phase Coherent Receiver

The phase coherent receiver receives the CW acquisition signal from the multicoupler and produces an output signal whose frequency is normally 50 kc, plus or minus one-sixth of the input deviation frequency. This signal is recorded by the measuring and recording system. The output is obtained by mixing the output frequency of the voltage controlled oscillator with the frequency of a very stable local oscillator (4.95 mc). Therefore, the frequency of the voltage controlled oscillator is normally 5 mc plus or minus one-sixth of the input deviation. This fraction of the input deviation results from the use of the second feedback loop which increases the loop gain of the receiver by a factor of six, thereby increasing the tracking range, but decreasing the output deviation by the same factor.

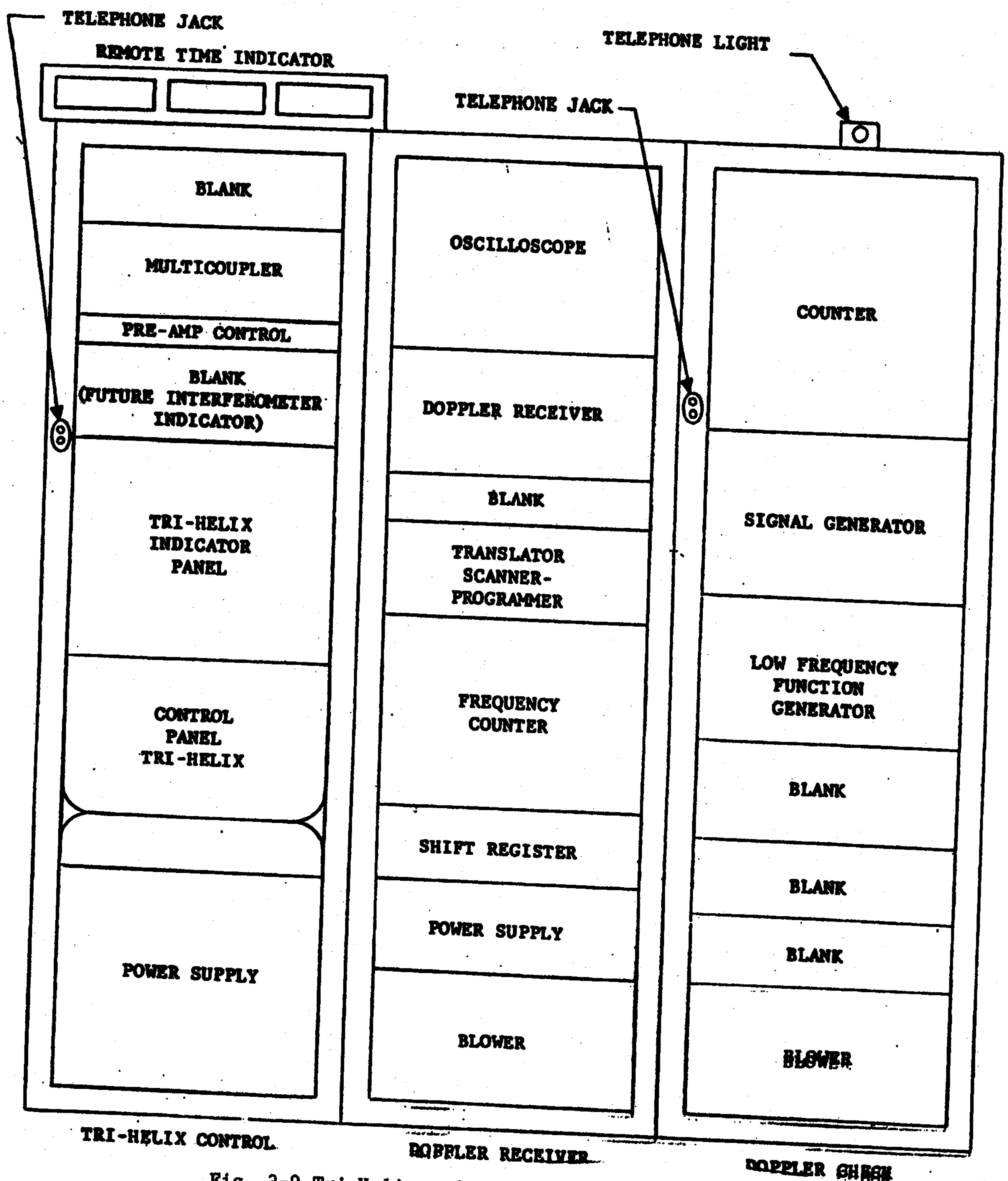


Fig. 3-9 Tri-Helix and Doppler Control Rack Layout

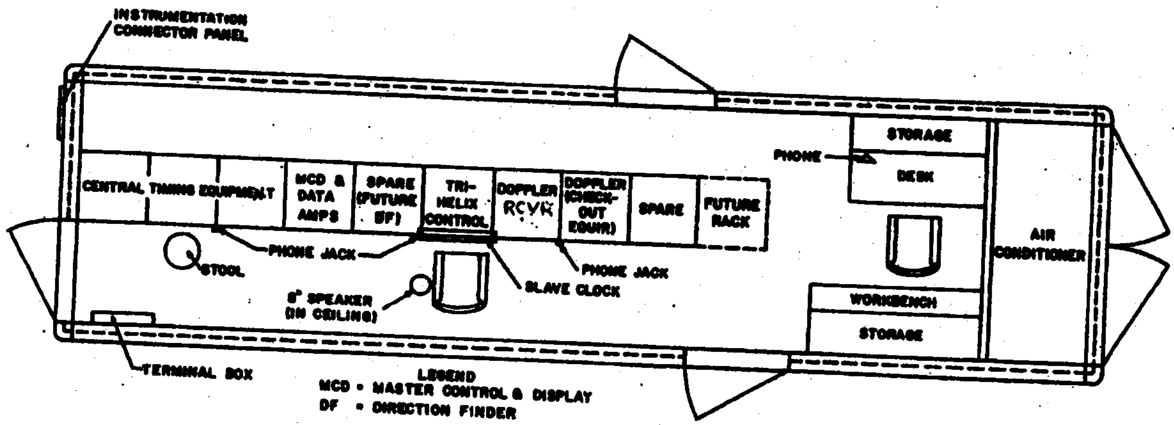


Fig. 3-10 Typical Instrumentation Van Floor Plan

The receiver uses a phase lock loop principle. The phase detector multiplies the input signal and the output of the voltage controlled oscillator. Average phase-detector output is preportional to the cosine of the phase angle between the two inputs so than at 90° there is an output null. If the phase varies from 90°, phase-detector output will be either plus or minus, depending upon the sign of the variation. The dc amplifier amplifies the error signal and controls the voltage controlled oscillator to drive the phase error back to zero. Thus, we have an electronic servo in which an extremely narrow-band filter is capable of tracking an input signal even though that signal may deviate far from its nominal frequency. The narrow-band characteristics of the receiver permit operation with very weak input signal strengths. The phase-coherent receiver makes use of correlation detection which depends on predicting circuits that use the immediate past history of the input signal to predict its future characteristics. The accuracy of the prediction will then be best for the immediate future and will decrease for more remote times. Since the type of signal of concern here is a slowly varying CW signal, a narrow-band predictor is used with the phase-coherent receiver. The receiver uses both frequency multiplication and limiting action to modify the response of the tracking loop.

3.3.4 Doppler Frequency Measuring and Recording System

The frequency measuring system (Fig. 3-9) receives the nominal 50-kc output signal from the phase coherent receiver, precisely measures the frequency once every two seconds, and punches this information on a punched paper tape. Binary-coded time information from the master ground timing system is received once every four seconds in synchronism with the frequency information and recorded with each frequency measurement. A quality bit indicating that the phase coherent receiver is in a phase-lock condition is also recorded once every two seconds. Header information denoting the month, day, station number, format identity, and quality factor can be entered manually and recorded on the punched tape.

The five components described below comprise the Doppler frequency measuring and recording system. Two of the components are commercial instruments, adapted for use with the system. The remaining three have been designed specifically for use in this system.

Frequency Counter. The input frequency is measured by a Hewlett-Packard electronic counter with an external precision time-base gating signal. The counter has been modified so that the plug-in counting units read and store the frequency count as binary information.

Shift Register. The shift register stores the binary-coded time information and provides an externally synchronized gating pulse to the counter. The binary-coded input signals to the shift register are received in a series pulse train and stored in parallel cascaded binaries.

Scanner/Programmer. The provision for manual data-entry located on the scanner/programmer includes a series of switches with which the operator "writes in" binary-coded information about the date and station number. When the counter has completed a frequency measurement, it commands the scanner/programmer to "look at" the stored data in the shift register and the already preselected date and station number. As the scanner/programmer "reads" the information, in series-parallel form (four bits at a time), it sends it as binary electrical pulses to the tape punch equipment.

Repeater. A repeater is installed near the tape punch machine to provide power amplification for driving the punch solenoids and clutch magnet. The repeater contains relays for restoring the scanner information to a power level adequate to punch signals.

Tape Punch. The tape punch is a Friden Commercial Controls Motorized Tape Punch, Model 2. The tape punch perforates standard five-level paper tape upon receipt of a punch command.

3.3.5 VHF Doppler System Characteristics

Doppler Frequency Measuring System

a. Records frequency in binary code.

b. Adds time, date, station, and quality information to the frequency information.

c. Initiates and stops frequency measurement by precision time information.

Antenna

a. Type: tri-helix mounted on a rotator

b. Half-power beamwidth: 20 ± 5 degrees

c. Polarization: right circular by IRE definition

d. Gain: 15.0 db nominal

e. Design frequency: 235 to 245 mc

f. Impedance: 50 ohms

g. VSWR: less than 1.5 over the design frequency range.

Antenna Rotator and Control System

a. Azimuth rotation: 705° (minimum limit stop setting)

b. Elevation rotation: 166° (minimum limit stop setting)

c. Rotation rates: 1 rpm autoslaving, 0 to 5 rpm (variable) manual

d. Automatic slaving accuracy: ± 2°

R-f Bandpass Filter

a. Bandpass: 6 mc at 0.25 db points

b. Center frequency (fixed): 235.4 mc

c. Insertion loss: 1.25 db

d. Input impedance: 50 ohms

e. Output impedance: 50 ohms

f. Attenuation: 28 db at 30 to 180 mc
50 db at 395 to 1200 mc
80 db at 1200 to 2900 mc

R-f Preamplifier

a. Gain: 20 ± 3 db

b. Bandwidth: 30 ± 3 mc

c. Center frequency: 230 mc

d. Noise figure without filter: 4.5 db

e. Input impedance: 50 ohms

f. Output impedance: 50 ohms

Multicoupler

a. Bandpass: 30 ± 5 mc

b. Center frequency: 230 mc

c. Gain: unity (approximate)

d. Input impedance: 50 ohms

e. Number of outputs: 6

f. Output impedance: 50 ohms

g. Isolation between outputs: 37 db (minimum)

Receiver

a. Type: phase coherent

b. Input frequency: 225 to 245 mc

c. Input signal power: -30 dbm to -150 dbm plus measured noise figure of receiver

d. Tracking range: ± 25 kc from nominal input frequency

e. Tracking rate: 145 cps/sec

f. Sensitivity: -150 dbm plus measured noise figure of receiver

g. Acquisition (manual): ± 25 kc from nominal input frequency and signal strength of -30 dbm to -145 dbm plus measured noise figure of receiver

h. Acquisition (automatic): ± 9 kc from nominal input frequency and signal strength of -30 dbm to -140 dbm plus measured noise figure of receiver

i. Output frequency: 50 kc ± 1/6 Doppler frequency

j. Stability of output: 150 cps (rms)/hr

k. Output voltage: 0.7 volt rms ± 10 per cent to 5.0 volts rms ± 10 per cent

Frequency Counter

a. Signal input frequency: 50 ± 40 kc

b. Signal input level: 0.2 volt rms/min

c. Counting rate: one count every 2 seconds

d. Count duration: 1 second

e. Synchronization: external source 1 pps

f. Sync input signal: 1.0 volt peak-to-peak ± 10 per cent and duration of 10 milliseconds

g. Output signal: 18-bit straight binary code

h. Accuracy: ± 1 cps plus accuracy of synchronization pulse.

3.3.6 VHF Direction Finder

The VHF direction finder (see Paragraph 1.5.4) is a two-axis direction finding system designed for use with the tri-helix antenna of the VHF Doppler receiving system. The direction finder, operating with the tri-helix antenna and control system and the Motorola phase coherent receiver, provides the operator with visual indications of azimuth and elevation pointing error of the antenna. A simplified block diagram of the system is shown in Fig. 3-11.

The VHF direction finder increases the pointing accuracy of the tri-helix antenna from ± 5 degrees to ± 1 degree. This has the following advantages:

a. The accuracy of tri-helix slave data available to the Verlort is increased. This is of particular advantage at Kodiak during the first pass when acquisition data may not be accurate. Under this condition, the tri-helix with its wide beamwidth could acquire more easily than the Verlort with its narrower beamwidth. The tri-helix position data could then be used to slave the Verlort to assist acquisition. It is important that the Kodiak Verlort acquire on the first pass to verify orbit achievement and provide track data to update the vehicle ephemeris.

b. The possibility of interrupting continuity of Doppler track data due to antenna misorientation is reduced.

c. More accurate capsule position data would be available from the tri-helix for vectoring of the recovery force. This would be particularly useful at Kodiak in those instances in which the station is required to support recovery operation.

Description. The VHF direction finder system consists of a special hybrid assembly located on the tri-helix antenna, a modulator unit located at the base of the antenna pedestal, and five rack-mounted indicator and power supply units at the receiving area. The multicoupler and the phase coherent receiver of the VHF Doppler receiving system are used as components of the direction finder system.

The antenna hybrid assembly consists of four hybrid rings in a weatherproof box mounted on the back of the tri-helix antenna ground screen. The modulator unit is composed of the azimuth, elevation, and

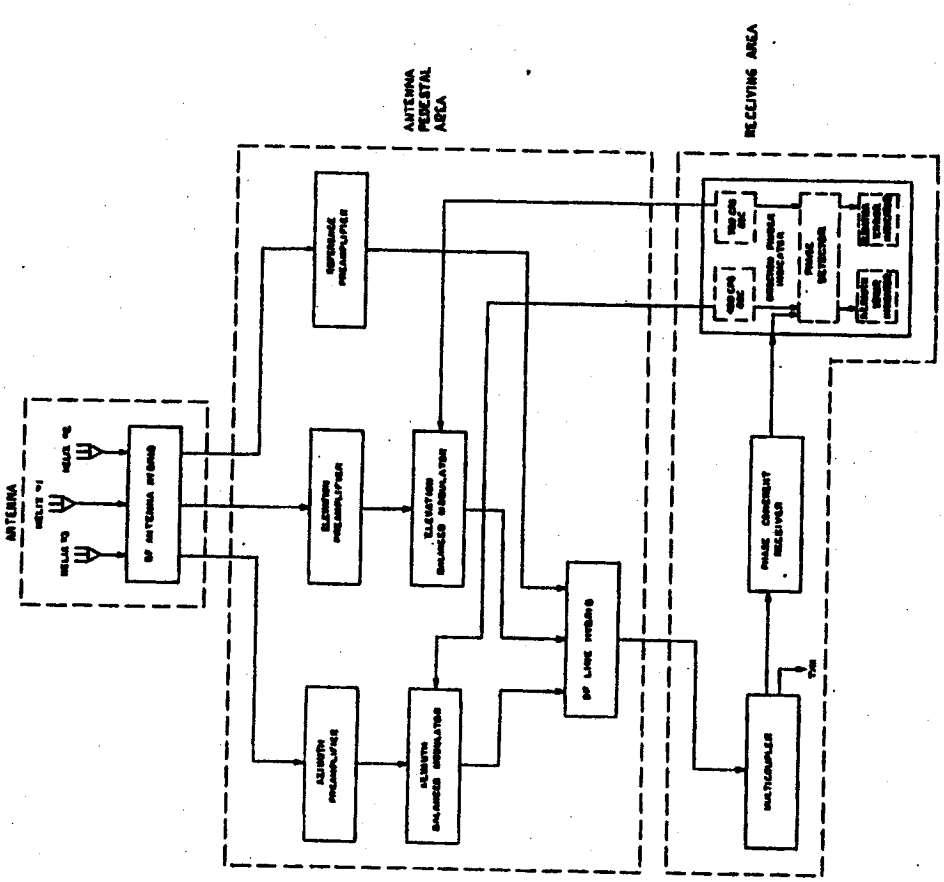


Fig. 3-11 Block Diagram VHF Direction Finder

reference preamplifiers, the azimuth and elevation balanced modulators, the modulator power supply, and the line hybrid assembly. The indicator unit is a two-channel unit which supplies the audio frequency reference voltages used in the system, detects and displays the azimuth and elevation pointing error of the tri-helix antenna, and incorporates a circuit to indicate receiver limiting. The remote indicator panel is an auxiliary set of indicators for remote display of the pointing error and has an indicator light to indicate receiver limiting. The Nems-Clark preamplifiers (azimuth, elevation, and reference) are broadband, two-stage, grounded grid, r-f amplifiers used to increase the sensitivity of the system. They are installed in the modulator unit. Power for the preamplifiers is supplied by the remote power panel located in the receiving area.

The VHF direction finder can be described as an r-f phase-comparing null indicator with a moveable baseline. To present a brief theory of operation, a single axis system, one with only two antenna elements, will be discussed. Figure 3-12 shows the antenna elements (A_1 and A_2), wavefront (L_1 and L_2) from the transmitter, and voltage (E_1 and E_2) induced in the antennas.

A wave front arriving from a distant target is represented by parallel lines L_1 and L_2. If the antenna is not pointing "on target," the wave-front arrives at A_1 and A_2 at different times. The voltage induced in A_1 lags behind the voltage in A_2 by a phase angle proportional to the difference in path length (d sin θ).

Directional information can be obtained by phase comparing the voltages, E_1 and E_2, induced in the two antenna elements. A hybrid ring, as shown in Fig. 3-11, is a simple and convenient phase-comparing device. The hybrid ring is made up of coaxial cable in 1/4 λ and 3/4 λ lengths as shown.

The voltages E_1 and E_2 from the antenna are placed on the hybrid ring at points A and C. The sum (Σ) and the difference (Δ) appear at corners B and D. The sum is used as a reference and difference is used to indicate pointing error. The magnitude of the difference signal

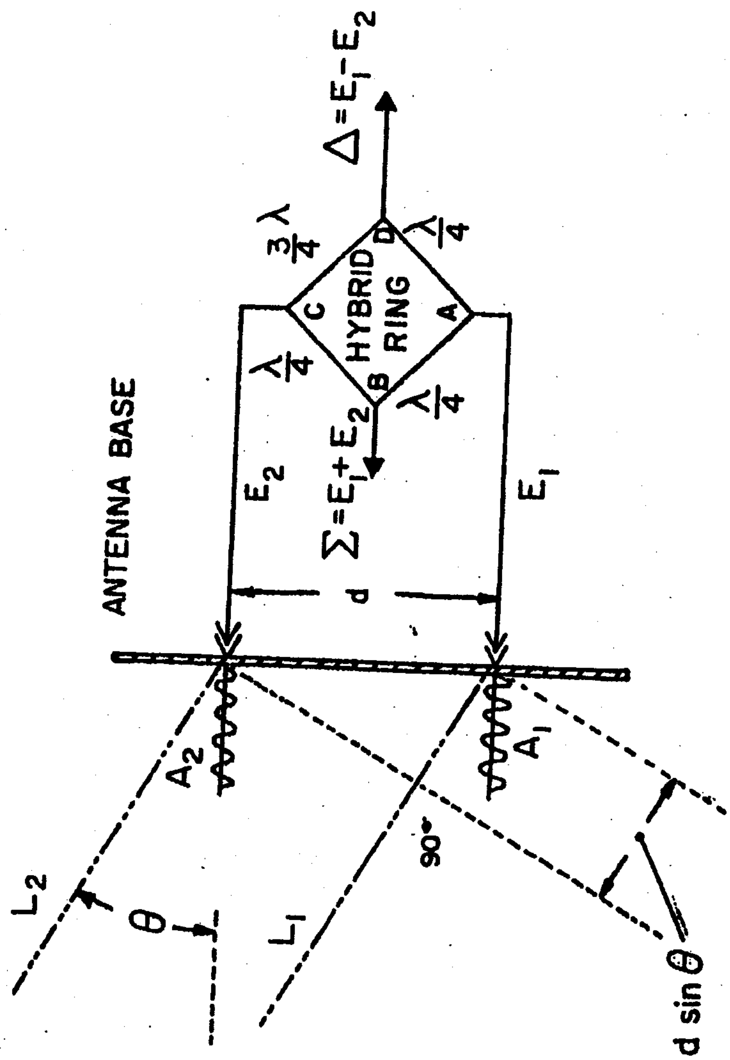


Fig. 3-12 Antenna and D/F Hybrid Ring

is proportional to the amount of angular pointing error, while the phase of the difference signal, with respect to the reference signal, gives the direction of pointing error. The difference signal goes through a sharp null and reverses phase as the antenna moves through the "on target" position.

The difference signal from the hybrid ring is amplified and sent through a balanced modulator, where it is amplitude modulated with an audio modulating voltage. The output of the balanced modulator is double-sideband suppressed-carrier. These sidebands are combined with the reference signal in another hybrid ring so they can be detected in receiver. The output of the receiver is an audio signal with an amplitude proportional to the angular pointing error and a phase indicative of the pointing direction.

The audio output from the receiver is sent to the indicator unit where it is synchronously detected in a balanced phase detector circuit that is referenced to the same audio voltage as used in the balanced modulator. When the antenna is pointed "on target" no error voltage is present, so there is no output from the detector circuit. When the antenna is moved off target in either direction, a d-c voltage appears at the output of the detector circuit with a polarity indicative of the direction the antenna was moved off target and an amplitude proportional to the angular distance the antenna was moved.

This d-c voltage is applied to a vacuum tube bridge circuit with an appropriate indicating meter. The center zero indicating meter displays the direction and proportional amount of pointing error of the antennas.

Operation. The VHF direction finder operates in conjunction with the VHF doppler receiving system. Acquisition and initial tracking of the target for very weak transmitted signals is accomplished using the Motorola phase-coherent receiver. Dependable pointing error information from the direction finder indicator meters is limited by the noise fluctuation of the meters at low signal level (when the signal strength meter reads less than approximately 10 to 15 microamperes). Once the signal strength has increased above this level, the noise fluctuations have decreased to where the pointing error of the antenna can be determined using the meters. The antenna can be pointed on target with an error of less than two degrees and, as the signal strength increases, the error will decrease to less than one degree.

VHF D/F System Characteristics

VHF Direction Finder System

Input signal frequency	cw acquisition frequency
Sensitivity (at antenna output terminals	-130 dbm
Accuracy:	
signals weaker than -110 dbm:	± 2 degrees
signals stronger than -110 dbm:	± 1 degree
Tracking rate	30 degrees/sec. max.

Antenna Hybrid

Input impedance	30 ohms, nominal
Output impedance	50 ohms, nominal
Gain (reference channel)	Unity (approximately)
Bandwidth:	
azimuth and elevation Channel	1 per cent maximum
reference channel	5 per cent minimum
VSWR, reference channel	1.5:1 maximum

Preamplifiers

Gain in pass band	20 ± 3 db
Pass Band	215 to 245 megacycles
Noise figure	6 db, maximum
Impedance (input and output)	50 ohms, nominal

Balanced Modulator

Frequency range	60-2300 megacycles
Modulation frequency range	0-20 megacycles
Impedance (input and output)	50 ohms, nominal

Line Hybrid

Impedance (input and output)	50 ohms, nominal
Bandwidth	5 per cent, minimum
Insertion loss;	
modulation signal channel	6 db, maximum
reference signal channel	3 db
Frequency range	230 to 240 megacycles

3.4 Telemetry

The VHF FM/FM telemetry receiving and recording equipment is designed to amplify, demodulate, decommutate, record, and display the instrumentation data signals received from the vehicle by the telemetry tracker and tri-helix antennas. This equipment is installed in twelve adjacent cabinet-type racks (see Fig. 3-13 and 3-14) located in the VHF buildings at Vandenberg and Hawaii and in LMSD telemetry vans at Kodiak, New Boston, and Point Mugu (see Fig. 3-15). A block diagram of the telemetry receiving and recording system is shown in Fig. 3-16. Major items of equipment are as follows:

a. FM receivers
b. Tape recorders
c. Subcarrier discriminators
d. Decommutator stations
e. Recording oscillograph
f. Monitor and control panels
g. Time reference unit
h. Test equipment

3.4.1 Receivers

Five Nems-Clarke Model 1302A receivers are provided. At Vandenberg and Hawaii, three of these receivers are normally operated from the output of the telemetry tracker multicoupler, one from the output of the tri-helix multicoupler, and one is maintained in standby condition as on operational spare. At Kodiak, New Boston, and Point Mugu, four of the receivers are operated from the output of the tri-helix multicoupler with one as standby. All receivers are adjusted

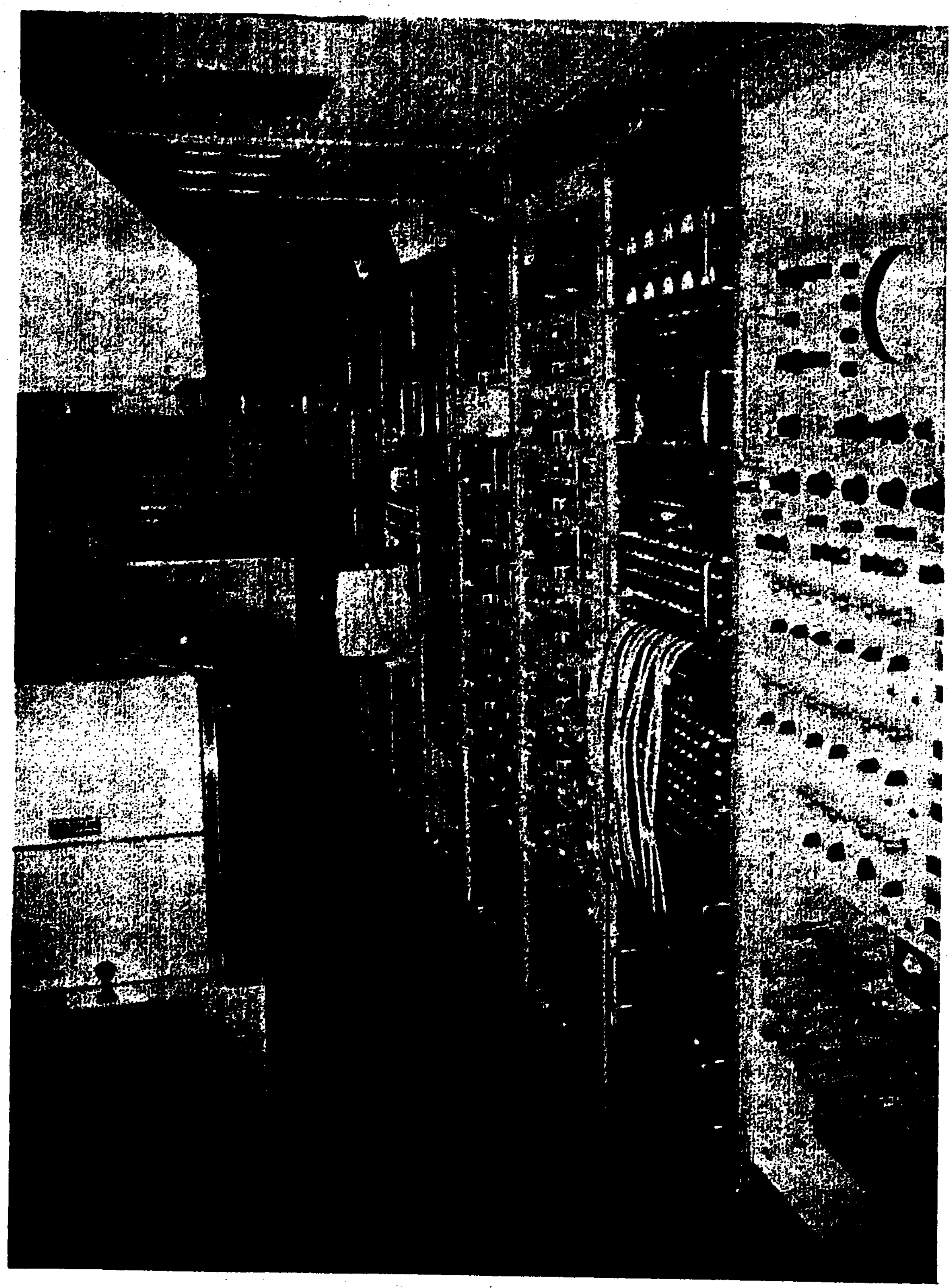


Fig. 3-13 LMSD Telemetry and Decommutation Equipment

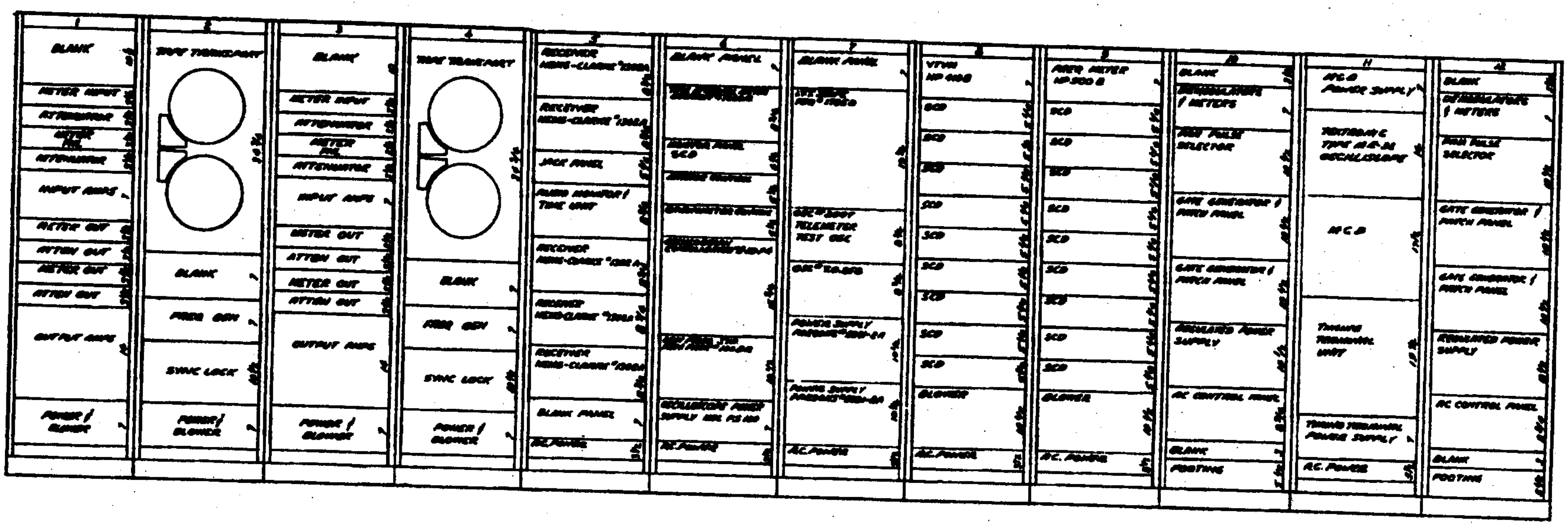


Fig. 3-14 Telemetry Equipment Rack Configuration

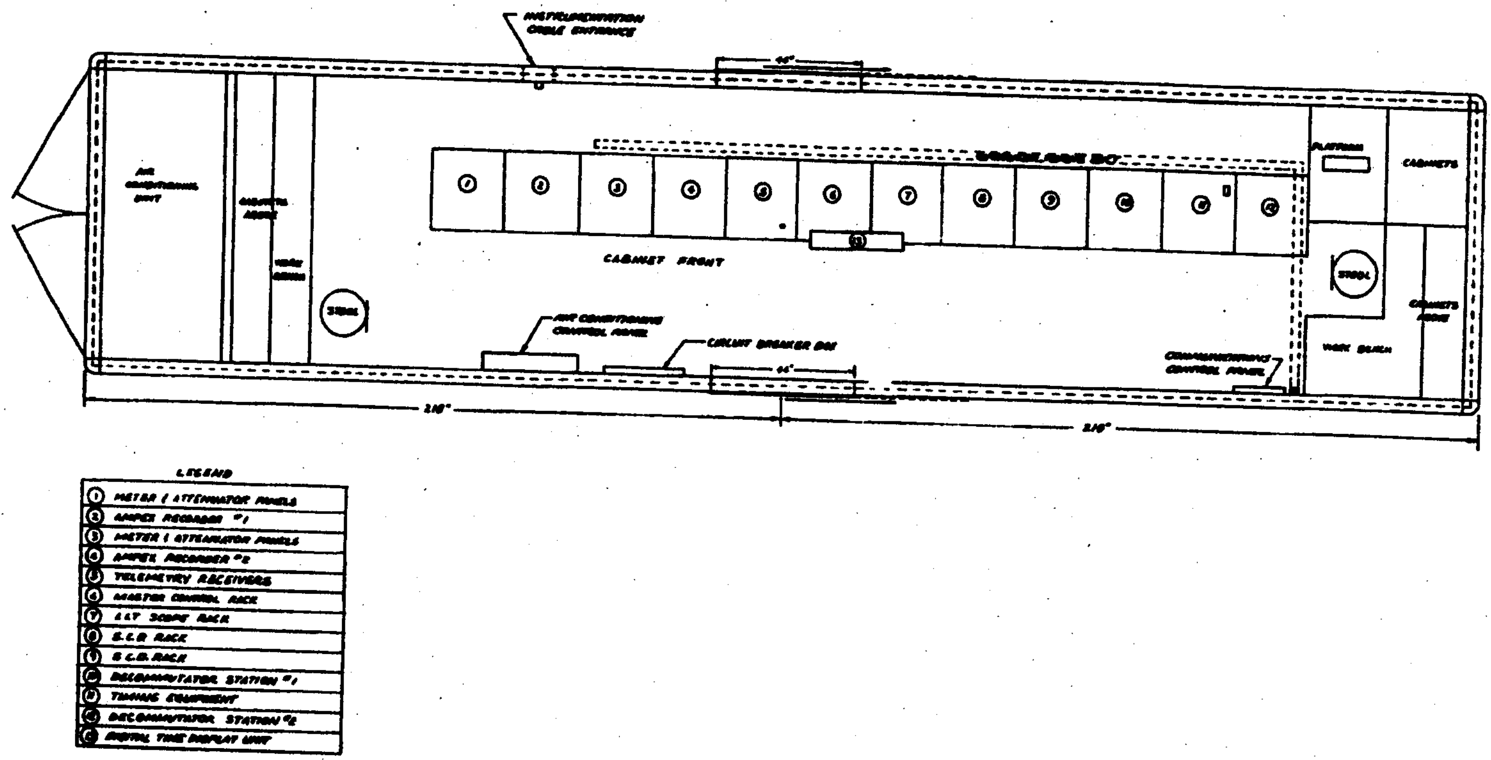


Fig. 3-15 Telemetry Van, Typical Floor Plan

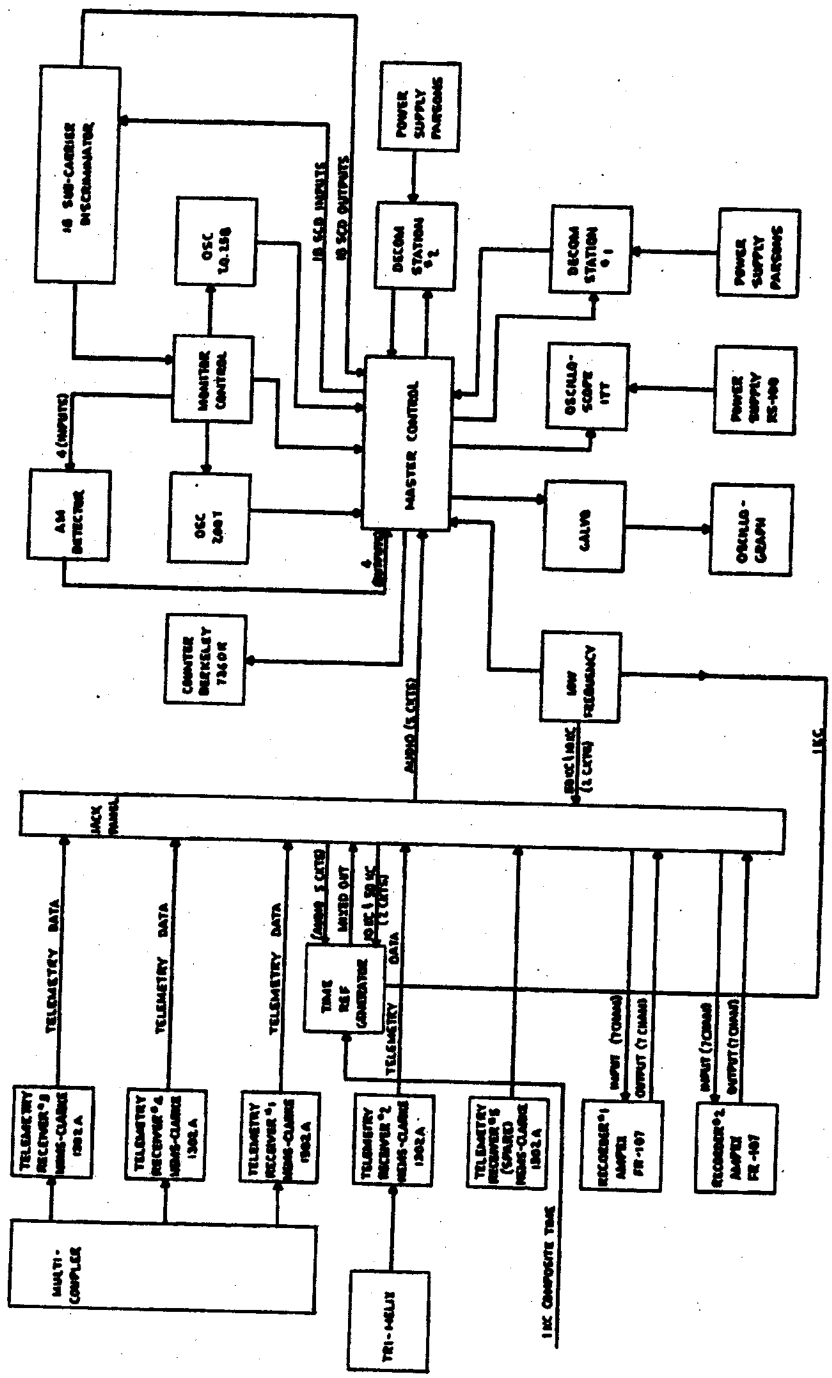


Fig. 3-16 Telemetry Receiving and Recording System Block Diagram

to operate in the FM mode with 300 kc i-f bandwidth. Video output of the receivers is fed to the monitor and control panels, and then routed to the tape recorders and subcarrier discriminators.

3.4.2 Tape Recorders

The composite signal outputs of the various receivers are recorded on two Ampex Model FR-107A Magnetic Tape Recorders. Each recorder has seven independent tracks that are selectable by patching on the jack panel of the monitor and control facility. Six tape speeds from 1-7/8 through 60 inches per second are available. Frequency response is from 100 to 130,000 cps at maximum tape speed.

3.4.3 Subcarrier Discriminators

Real time telemetry signals from the receivers, or recorded telemetry signals from the magnetic tape recorders, are routed through the monitor and control panels to the subcarrier discriminators for conversion of the various subcarrier frequencies of the composite telemetry signal to the varying d-c outputs required for recording and display. Eighteen Data Control Systems Model GFD-2 subcarrier discriminators are provided. Standard IRIG channel frequencies from 400 to 70,000 cps and frequency deviations of ±7.5 or ±15.0 per cent (5 highest bands only) are provided by plug-in tuning units. Outputs of the subcarrier discriminators are routed back to the monitor and control panels for distribution to the recording oscillograph or decommutator stations as appropriate.

3.4.4 Decommutator Stations

Commutated channel outputs are routed to one of the two Parsons Model 5201 decommutator stations for data demodulation. Each station is capable of demodulating a single composite data signal into a maximum of thirty data channels. Output of the decommutator stations is returned to the monitor and control panel for routing to the recording oscillograph, monitor oscilloscope, and to the master control console for real time telemetry readout and command verification.

3.4.5 Recording Oscillograph

A thirty-six channel Consolidated Electrodynamics Company (CEC) Model 5-119-P4 Recording Oscillograph is used for analog recording of the telemetered instrumentation signals. A frequency response up to 5,000 cps on individual channels can be made available by selection of suitable galvanometers. A Datarite magazine and oscillograph processor are available to provide concurrent observation and permanent photographic recording of the analog telemetry signals. Standard record width is twelve inches. Record lengths of either 250 or 500 feet (thin base paper) can be recorded at speeds from 0.1 to 100 inches per second, as required.

3.4.6 Monitor and Control Panels

Monitor and control panels are provided for monitor switching and the patching of data signals during normal record or playback operation. Straight-through patching is provided whenever practical along with ample patch cords for completely flexible routing of signal flow between components of the receiving and recording equipment. Monitor and control panels include the following facilities:

a. Jack Panel: Patch panel for receiver outputs
b. Master Control: Plugboard for programming signals throughout the station
c. Galvanometer Control: To drive galvanometers off-scale when not in use
d. Monitor Panel: To control and provide for monitoring of all signals during normal operation

3.4.7 Time Reference Unit

The time reference unit (counter) provides audio monitoring of signals and conditioning of coded timing and standard frequency signals during recording and playback of data.

3.4.8 Test Equipment

The following major items of test equipment are rack-mounted within the telemetry receiving and recording system to facilitate system checkout, operation and maintenance.

a. Oscilloscope, Federal Telephone (ITT) Model 1735D
b. Oscilloscope, Tektronix Model RM-32

c. Time Interval Meter, Berkeley Model 7360R

d. Low Frequency Standard, Hewlett-Packard Model 100DR

e. Vacuum Tube Voltmeter, Hewlett-Packard Model 410B

f. Telemetry Oscillator, Hewlett-Packard Model 200T

g. Electronic Frequency Meter, Hewlett-Packard Model 500B

h. 7-Point Calibrator

3.4.9 <u>1302A Telemetry Receiver Characteristics</u>

a.	Tuning range	55-260 mc
b.	I-F rejection	70 db, minimum
c.	Image rejection	60 db, minimum
d.	Noise figure	6 db, maximum
e.	Absolute sensitivity measured without band-restricting filters	4 μv produces at least 23 db signal-to-noise with 100-kc deviation, 1-kc modulation frequency
f.	I-F frequencies	21.4 and 1 mc
g.	I-F bandwidth	300 kc and 10 kc
h.	Outputs provided	1. Signal--wide band for supplying high-impedance load. 2. Monitor--panel-mounted speaker, headphones, or 600 ohms balanced output for external use.
i.	FM output	0.10 volt per kc, approx.
j.	AM outputs 300-kc and 10-kc strips	Approx. 10v rms for 500-μv input modulated 50 per cent at 1 kc.
k.	FM output stability	Varies less than 2 db for inputs above 1 μv.
l.	AM output stability both i-f strips	7 db maximum variation for 40-db variation in input.
m.	Input impedance	Approx. 50 ohms.
n.	Video response	10 cps to 300 kc
o.	Video bandwidth control	5 positions--1, 3, 10, 30, and 300 kc

p. Power input — 115/230 volts, 50 to 60 cps and 400 cps

q. Power consumption — 127 watts

r. Weight — 40 pounds

3.5 Analysis of Doppler Tracking

Since Doppler techniques are planned for other WS-117L programs, it is reasonable that the Discoverer Program be used as a "proving ground" for the techniques, whether they be Doppler only, or Doppler-plus-angles. The use of improved Doppler techniques with the Discoverer series would provide a general comparison between Doppler methods and the range-plus-angle tracking system, provided by the Verlort. This would be a critical comparison, since the atmospheric refraction effects and drag effects are most pronounced at the Discoverer altitudes.

Also, separate Doppler tracking stations might be used to provide additional orbit tracking data for certain vehicles of the Discoverer series. For special low-altitude orbits, where it is desirable to accurately position the vehicle in space as a function of time, it is desirable to provide supplemental tracking data above and beyond that obtainable through the existing Discoverer five-station tracking network. This requirement arises from the fact that drag is a significant factor in orbits below 200 nautical miles altitude. Studies have shown that at least one and preferably two tracking looks must be recorded during each orbit to be able to accurately determine the space-position of the vehicle to within 0.1 n. mile at a given time. The existing five-station Discoverer network only provides data on approximately 20 per cent of the orbits.

3.5.1 Basic Features of Doppler Tracking

The use of the properties of the Doppler frequency shift in the determination of satellite ephemerides has recently given rise to considerable development efforts. Instrumentation around Doppler Tracking procedures yields greater simplicity in satellite equipment and in some instances in ground equipment. In addition, Doppler techniques allow the conservation of bandwidth in the transmission links and thereby reduce the required satellite transmitter power. While the Doppler techniques allow reduction in tracking equipment, they generally increase the data processing function. There are two basic tracking systems under consideration; those which employ Doppler information only, and those which employ Doppler plus angular (azimuth, elevation) information in the determination of satellite ephemerides.

The basic Doppler principle of wave mechanics, relating the compression (or expansion) in wave length with the velocity of an approaching (or receding) emitter is:

$$\frac{\Delta \lambda}{\lambda} = \frac{\dot{S}}{C} \tag{1}$$

where

λ = wave length at the source

$\dot{S}$ = relative velocity of source with respect to observer

C = velocity of light.

Since the frequency $f = C/\lambda$, then

$$\frac{\Delta \lambda}{\lambda} = -\frac{\Delta f}{f} \tag{2}$$

therefore,

$$\frac{\dot{S}}{C} = \frac{\Delta f}{f} \tag{3}$$

or

$$\dot{S} = -\lambda \Delta f = -\lambda f_d \tag{4}$$

Equation (4) then, relates the rate of change of the slant range from a tracking station to a satellite, to the Doppler frequency shift f_d. As a satellite passes from horizon to horizon, a Doppler receiver generates the familiar "S" curve of Doppler frequency versus time. The slope of the Doppler curve increases as the source of signal emission comes closer, with the maximum slope occurring at the time of minimum slant range, when the Doppler frequency is zero. In general, the more distant the source is, the less is the slope of the curve and the more linear is its appearance.

It may readily be shown that the Doppler curve is a function of all the orbital parameters. Using a rectangular coordinate system with origin at the tracking station, and axes x,y,z, the slant range S is given by

$$S^2 = x^2 + y^2 + z^2$$

and therefore,

$$\dot{S} = \frac{x\dot{x} - y\dot{y} - z\dot{z}}{S} = -\lambda f_d \quad (5)$$

The set of variables x,y,z and $\dot{x},\dot{y},\dot{z}$, which define the position and velocity of the satellite as a function of time, are easily transformed into geocentric coordinate system. This gives the set of variables x_o, y_o, z_o, and $\dot{x}_o, \dot{y}_o, \dot{z}_o$ with respect to the center of the earth. These variables are in turn immediately transferrable into a polar coordinate system yielding six more variables which are usually referred to as the orbital parameters. The six orbital parameters pertain to the standard mathematical model, a derivative of Kepler's laws, usually used to specify a near-earth satellite's orbit in inertial space. This model assumes that the satellite traces out an elliptical trajectory in the orbital plane, with the earth center at one focus of the ellipse. Strictly speaking, this model is not correct, because near-earth satellites do not have reentrant orbits, due to perturbations caused by the earth's oblateness and atmosphere. Of course, these equations can be and are modified to include the effects of drag, earth's rotation, earth's oblateness, etc., in the actual computational schemes.

In theory, all six orbital parameters can be determined from the measurement of the received Doppler frequency at six separate points in time; however, the effects of noise and other error sources (refraction, transmitter instabilities, etc.) make this impossible. In practice, the Doppler frequency is sampled several hundred times during a satellite pass, giving enough redundancy in the data so that the effects of the uncertainties are minimized.

Problems arise, however, when one considers the sensitivity of the Doppler curve to variations of the orbital parameters. It can be shown (Philco WDL-TR-1310, "Midas Doppler Tracking Study") that singularities of a function defined in a six-dimensional space will occur in the proximity of one another, if there is a large correlation among the behavior of the variables. The large correlation in the alteration of the Doppler curve created by the variation of the individual orbital parameters has been shown by Guier and Weiffenback.[1] Figure 3-17 shows the sensitivity of the Doppler curve to parameter variations for a pass of a satellite at a slant range of 400 nautical miles, in a polar orbit with eccentricity ϵ of 0.02. The variables used in the figure are:

i = inclination angle of orbital plane
Ω = right ascension of ascending node
T_s = period of orbit
ω = argument of perigee

The ordinate of Fig. 3-17 refers to the error in Doppler velocity, in units of slant range ve..ocity $\dot{S} = Cf_d/f$. Additional complications are brought about by the effects of earth's rotation on the Doppler curve. Earth's rotation introduces components into the Doppler curve that are similar to those introduced by variation of the parameters of the ellipse.

Any properly instrumented Doppler curve is unique, however. If the earth did not rotate, a set of two satellite orbits with the same elliptical parameters and equal minimum slant ranges (such as the two circular orbits of Fig. 3-18) would exist that would produce the same Doppler curve at the tracking station. Since the earth does rotate, each orbit has its Doppler curve affected differently by the motion of the earth. Hence, earth's rotation enables all Doppler curves to be unique. That is, in theory, any particular Doppler curve defines one specific satellite orbit.

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1. Guier, W. H. and Weiffenback, G. C., "The Doppler Determination of Orbits," paper delivered at NASA Conference on Orbit and Space Determination, 12 March 1959.

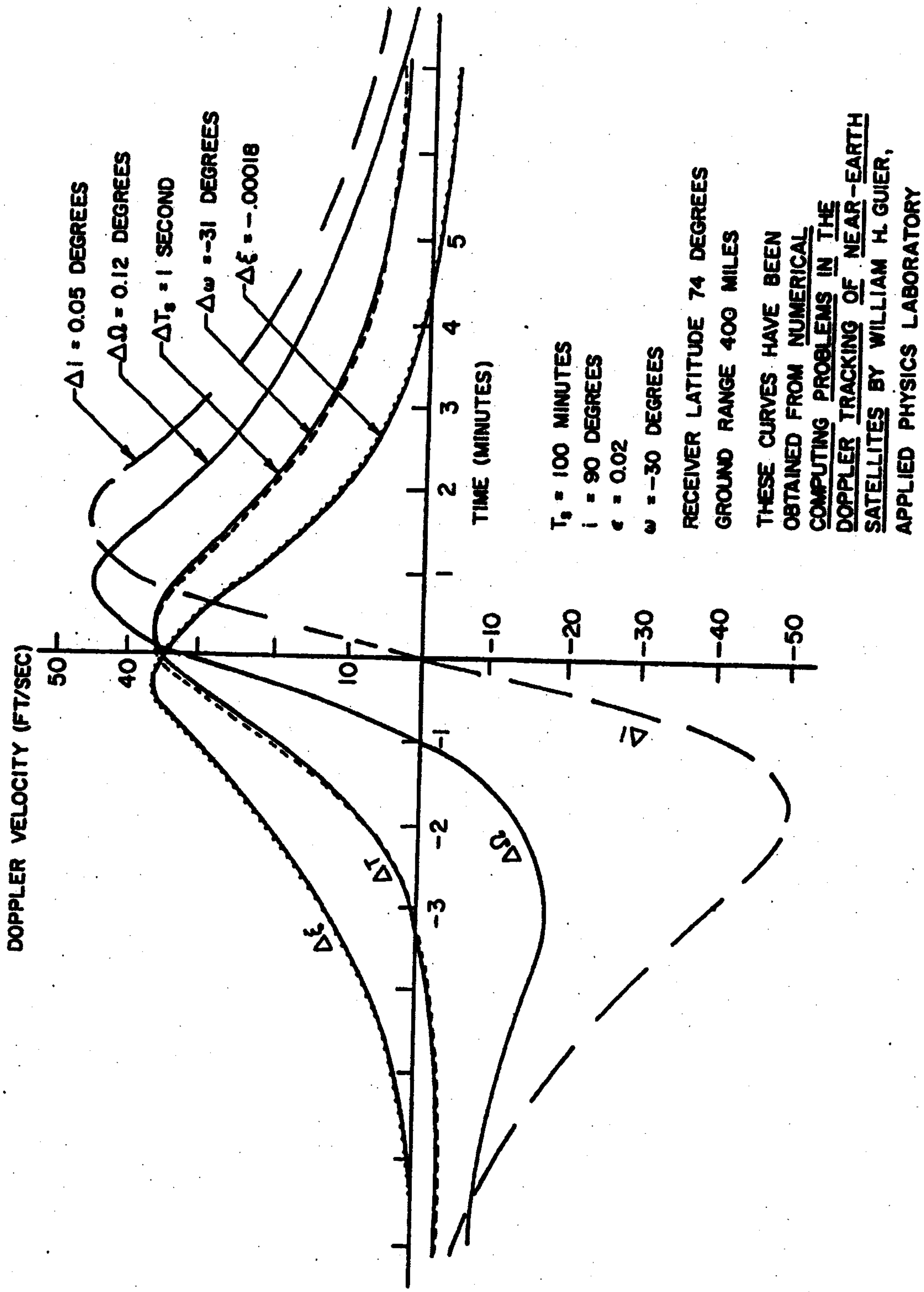


Fig. 3-17 Sensitivity of Doppler Curves to Variations in Orbital Parameters

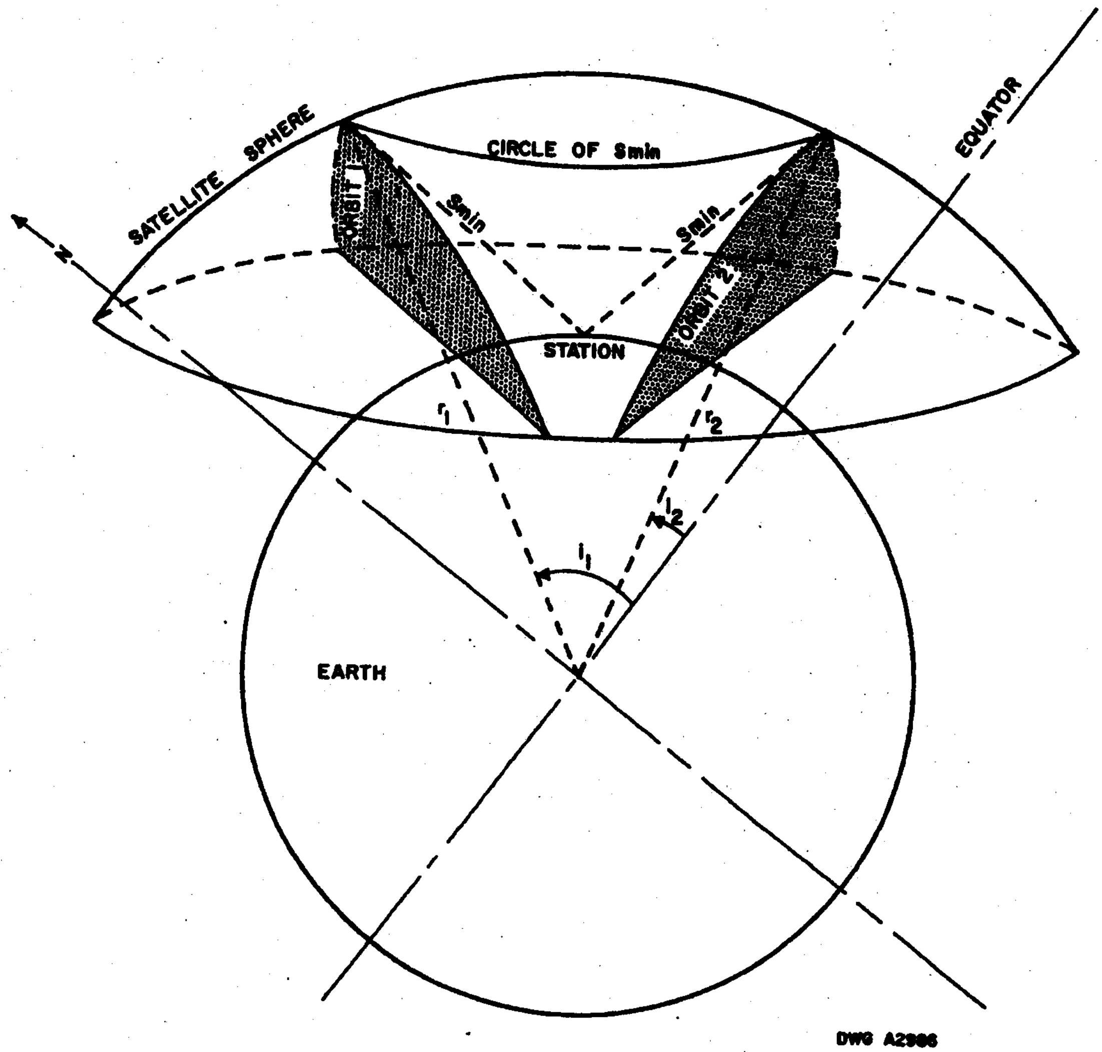


Fig. 3-18 The Importance of the Earth's Rotation in Making Doppler Curves Unique

3.5.2 Methods of Computation

A number of statistical methods have been developed specifically for the orbit determination problem. Generally, they are known as "least squares" estimation methods since they involve the determination of parameter estimates from a minimization of a weighted sum of squares of errors in functions of the measurements.

The first step is the adoption of a mathematical model representing the satellite's physical environment, (coordinate system, equations of motion, etc.). The more realistic the model is, the more accurate is the determination or prediction derived from it, and the longer is the period of time during which such predictions are reliable. On the other hand, a price is paid for the increased accuracy in that the system parameters are more difficult to determine and the predictions are more difficult to obtain.

Hence, a compromise between precision and simplicity must be made. In practice, so much precision is required of the mathematical model that the corresponding determination of orbital parameters requires the use of some iterative procedure.

Iteration requires that an initial approximation of the parameter values be made. The iteration procedure itself, about these "initial conditions," is then accomplished by a digital computer; however, success cannot be altogether assurred a priori. The iteration may fail to converge; it may converge upon an inappropriate parameter value; or it may converge correctly, but require a prohibitively long computer time to do so.

To a large extent, the desirable (or undesirable) features of the computer iteration scheme depend on the accuracy of the initial conditions--the initial approximation to the parameters. The less realistic the initial conditions are, the longer and more extensive are the iteration schemes. Fortunately, the accuracy requirements of the initial approximation are sufficiently relaxed that they can be met with relatively simple procedures. A comprehensive discussion of the various least squares techniques may be found in Philco WDL-TR-1310, Appendix A.

The above discussion of the least squares techniques refers to any tracking system, whether it be Doppler-only or Doppler-plus-angles or range-plus-angles. In the case of Doppler-only, the gains achieved in equipment reduction are partially paid for with a more extensive and time-consuming computational procedure. Specifically, the computation process for reducing the Doppler-only data requires some two to five hours per station per pass on a high speed data processing machine. This makes the Doppler-only technique generally prohibitive for the quick prediction of an ephemeris required for acquisition data for other stations. It is possible, however, to adequately define the ephemeris sometime after the data has been acquired.

3.5.3 Altitudes, Slant Ranges and Doppler Rates Involved

Discoverer series altitudes range from approximately 90 nautical miles to 650 nautical miles. With a minimum elevation angle of 15^{o}, slant ranges up to 1500 n. miles may be incurred. At zero elevation the maximum slant range is 2200 n. miles. In general, the maximum slant range to be incurred may be found from the basic triangle depicting station - satellite geometry; with one side being the radius of earth R_o, one side the slant range S, and the remaining side the earth-center to satellite distance $(R_o + h)$. This triangle easily gives

$$\frac{S_{max}}{R_o} = - \text{Sin } E_{min} + \sqrt{\frac{(R_o + h)^2}{(\ R_o\ )} - \text{Cos}^2\ E_{min}} \qquad (6)$$

Where E is the antenna elevation angle, and h is the altitude of the satellite. This triangle also yeilds the maximum Doppler shift obtainable;

$$\frac{f_{d(max)}}{f_t} = \frac{V}{C} \cos(\theta + E_{min}) \qquad (7)$$

Where θ is the earth-central angle between the station and the satellite. This angle is given by

$$\theta = \sin^{-1} \left[\frac{S_{max}}{R_o + h} \cos E_{min} \right] \qquad (8)$$

The term V in Equation (7) is the velocity of the satellite normal to the line (R_o + h). This velocity may be closely approximated with

$$V^2 = \frac{GM}{R_o + h} \qquad (9)$$

Where GM is the earth gravitational constant $6.275 \times 10^4 \ \frac{n.\ mi^3}{sec^2}$.

So, from Equation (7) and using H = 90 n. miles, the maximum Doppler shift (normalized) is seen to be approximately 25,000 fps at an elevation angle of 15°. Therefore, the maximum Doppler shift is about ± 5.5 kc at a transmitted frequency of 216 mc, and about ± 10 kc at a transmitted frequency of 400 mc.

3.5.4 Effects of Atmospheric Refraction on Doppler Measurements

Tropospheric and ionospheric refraction deteriorate the accuracy of Doppler as well as range and angular measurements. To some extent the refractive effects can be predicted and the measurement can be corrected. Various methods for compensating refractive errors have been devised, and some practical types of angular correction, utilizing standard atmospheric conditions, are effective. Corrections for Doppler measurements are fewer and not as simple nor generally as accurate.

The effects of refraction on Doppler measurements are essentially bending of the wave path and changing the propagation velocity of the wave. While the magnitude of the effects of refraction on Doppler and range measurements may be comparable, the analysis for each is different since Doppler measurements are dependent upon the phase velocity of the wave, and most range measurements depend on the group velocity of the wave. An analytical expression for the received Doppler frequency from a satellite to a tracking station is derived in Philco WDL-TR1411, "Samos Doppler Tracking Study," (Secret) Appendix A, Equation A-10. Using it, the Doppler refractive error Δf_d may be expressed as

$$\Delta f_d = -f_d(\gamma - \delta) \tan \psi - m_v f_d$$

$$-f/c \int_s \frac{\partial m}{\partial a} \frac{da}{dt} ds \quad -f/c \int_s \frac{\partial m}{\partial h} \frac{dh}{dt} ds$$

where

f_d = frequency at the transmitter

γ = total amount of "ray" bending

δ = error in elevation angle due to refraction

ψ = angle between the satellite velocity vector and the slant range vector

m = modulus of refraction

m_v = modulus of refraction at the vehicle

a = atmospheric conditions at a point on S

h = altitude of a point on S

S = radio path from transmitter to receiver

c = velocity of light

t = time

In Equation (10), the terms describe errors arising from:

a. Refractive bending causing the wave to arrive or leave in a direction different from the straight line path from the vehicle to the ground station --- $f_d(\gamma - \delta) \tan \psi$.

b. Ionization at the vehicle --- $m_v \, f_d$

c. Changing atmospheric conditions ---

$$\frac{f}{c} \int_s \frac{\partial m}{\partial a} \frac{da}{dt} ds$$

d. Changing index of refraction along the path between the vehicle and ground station as the vehicle moves ---

$$\frac{f}{c} \int_s \frac{\partial m}{\partial h} \frac{dh}{dt} ds$$

This shows that Doppler tracking is susceptible to several types of errors, only one of which is refractive bending. Unfortunately, the magnitudes of the other types of errors are less predictable than the amount of bending. This prevents compensation of Doppler tracking errors by means of standard corrections from being effective for most frequencies.

Consider the case of a satellite in a circular 155 nautical mile orbit and qualitatively analyze the Doppler error terms. The first error term due to refractive bending will be near its maximum possible value because the satellite is at the altitude of maximum ionization. For altitudes greater than this height, the factor $(\gamma - \delta)$ decreases and for lower altitudes tan ψ decreases. The value of the second term is at its maximum since the modulus of refraction, m_v, is directly proportional to the ion density. The third term has a magnitude comparable to its maximum value since all of the troposphere and an appreciable part of the ionosphere are below the vehicle. The final term, as with the first two, is at its maximum value. It is then apparent that a 155 nautical mile orbit is the worst case for Doppler errors due to refraction. Similarly, 155 n. miles is also the worst case for errors in angular measurements due to refraction. Above this altitude, the index of refraction starts increasing, an effect which bends the wave up rather than down, decreasing the elevation angle error.

The magnitudes of the Doppler error terms for a satellite in a 155 n. mile orbit are shown in Table 3-1. This table was computed for the case of the satellite located at an elevation angle of 5^{o} above the horizon, in an overhead pass and transmitting a frequency f_t. Examining the magnitude of each term, it is seen that all except the atmospheric change term are very dependent upon frequency. This points out the fact that at 200 mc, the terms are dominated by ionospheric effects; at 2,000 mc, the ionospheric effects have become small compared to the tropospheric effects, which are effectively independent of frequency. Increasing the frequency above 2,000 mc would result in very little decrease in the refractive Doppler error.

Consider compensating these errors. The ionospheric density at this altitude has been found to vary by as much as 100 per cent daily.[2] Throughout a sunspon cycle, the ion density varies 1600 per cent. The values given in Table 3-1 are for a dense ionosphere. Table

2 Hames, T.G., and Stuart, W.D., "The Electron Content and Distribution in the Ionosphere," Proc. IRE, Vol. 48, p. 1786, October 1960.

3-2 shows the error remaining after a correction based on a standard troposphere and an average ionosphere has been made to the values shown in Table 3-1.

TABLE 3-1

DOPPLER ERRORS DUE TO REFRACTION

	f_t = 200 mc	f_t = 400 mc	f_t = 2,000 mc
Actual Doppler velocity	± 24,200 fps	± 24,200 fps	± 24,200 fps
Change in path structure	± 35.0 fps	± 8.4 fps	± 1.6 fps
Atmospheric changes	± 0.067 fps	± 0.062 fps	± 0.06 fps
Refractive bending	± 33.4 fps	± 9.6 fps	± 2.2 fps
Ionization at the vehicle	∓ 33.6 fps	∓ 9.06 fps	∓ 0.3 fps
Total Doppler error	34.87 fps	9.0 fps	3.56 fps
% Error	0.14 %	0.037 %	0.015 %

TABLE 3-2

DOPPLER VELOCITY ERROR REMAINING AFTER A STANDARD CORRECTION

	f_t = 200 mc	f_t = 400 mc	f_t = 2,000 mc
Actual Doppler velocity	± 24,200 fps	± 24,200 fps	± 24,200 fps
Change in path structure	± 25.2 fps	± 5.3 fps	± 0.355 fps
Atmospheric changes	± 0.067 fps	± 0.062 fps	± 0.060 fps
Refractive bending	± 23.8 fps	± 7.15 fps	± 0.22 fps
Ionization at the vehicle	∓ 25.2 fps	∓ 6.8 fps	∓ 0.22 fps
Total remaining Doppler Error	23.87 fps	5.71 fps	0.42 fps
% Remaining Doppler error	0.0986 %	0.0236 %	0.00174 %

As might be expected, a correction of this type results in an effective compensation of the tropospheric errors and an ineffective compensation for ionospheric effects. Thus Doppler refraction errors can be effectively compensated for high frequencies, above 400 mc, but they cannot as yet be effectively compensated for frequencies below 400 mc.

It should be restated that the values presented in Tables 3-1 and 3-2 are generally the maximum obtainable at the specific frequencies, due to the 155 nautical mile altitude, and the elevation angle of 5^{o}. Further study shows that the errors decrease rather rapidly with increasing altitude. It may be concluded that atmospheric refraction effects on Doppler measurements are such that measuring the rate of change of slant range to better than 1.0 fps is permissible, utilizing a correction for a standard atmosphere, at:

a. 2000 mc and any altitude

b. 400 mc and altitudes above 1000 n.m

c. 200 mc and altitudes above 2000 n.m

Thus, measuring the slant range rate at altitudes under the above will give a reduced amount of "accurate" (1.0 ft/sec) data, since the minimum (usable) elevation angle is larger, say 15^{o}.

3.5.5 Reference Frequency

When using Doppler techniques, it is desireable that $\dot{S}$, the rate of change of slant range, be measured to an accuracy on the order of 1.0 fps. From Equation (3), it is seen that this requires frequencies to be measured to one part in 10^{9}. That is, at a fundamental of 200 mc, the measurement of Doppler frequency should be made to an accuracy of 0.2 cps. Measurements to this order of accuracy will permit the determination of the position of the vehicle to within $\pm$ 0.1 n.m. In order that measurements of Doppler frequency to such an accuracy be realistic, the received frequency should be free of bias errors due to drift, refraction, etc. that exceed the permissible deviation. The stability of the frequency source, then, must be on the order of one part in 10^{9} during the time of measurement, which is about 15 minutes for one pass over a station.

The problem also lies in defining the primary frequency of the reference oscillator used for the Doppler measurements. If the primary frequency is not adequately controlled, frequency must be treated as an independent variable, and for each additional set of data an additional parameter (frequency) is introduced. It is not always possible to find satisfactory solutions to such a multivariable problem. Two approaches are available to eliminate the need for the consideration of additional variables. One is the use of a highly stable airborne oscillator as the primary frequency source. This generally requires very sophisticated temperature control or compensation in the vehicle. The second is the use of an airborne transponder which displaces a ground-transmitted frequency by a defined amount and retransmits it to the ground. Here the stability problem is contained in the ground instrumentation system, where it is much simpler to handle.

3.5.6 Brief Description of the APL System

The essential features of the APL Doppler tracking system are, briefly:

a. Doppler-only tracking

b. One-way Doppler - use of ultra-stable vehicle transmitter

c. Two frequency transmission - partial compensation for refraction.

The Doppler-only technique was perfected by the Applied Physics Laboratory at John Hopkins University for use in the Transit satellite program. The satellite is equipped with a very stable frequency source and satellite transmissions are monitored by ground stations. The ground stations lie in a Doppler net so that several stations observe the satellite in a single orbital pass. This provides the multiple sets of data for the required redundancy.

The APL technique utilizes a least squares method for orbital parameter estimation and obtaining initial conditions, as discussed in

Section 3.5.2. A least squares fit is made between the observed Doppler curve and a theoretical Doppler curve. Let

$f_{d\tau}(t)$ = theoretical Doppler frequency at time t .

$f_{do}(t)$ = observed Doppler frequency at time t .

The function $f_{d\tau}(t)$ is dependent on the initial conditions. Hence by changing the initial conditions, it is possible to change the numerical value of $f_{d\tau}(t)$ at any given time, t_o . Therefore, by changing the values of the initial conditions, it is possible to minimize

$$\delta i = \sum_{i=1}^{N} \left[f_{do}(t_i) - f_{d\tau}(t_i) \right]^2$$

Hency, the problem is one of finding the absolute minimum of a surface in a six-dimensional space.

The Doppler-only technique, while offering its obvious advantages, poses certain difficulties, as discussed in the previous paragraphs. These are the lengthy iteration times required for adequate parameter determination, the high stability required for the reference oscillator, and the effects of refractive errors at the lower altitudes and lower frequencies. The APL system in its developmental stages required up to 27 hours of computational procedure to yield reliable results. As previously stated, the iteration times have been reduced to two to five hours. It is concievable that research on improved estimation procedures for Doppler-only systems may well lead to superior techniques, allowing the quick-prediction of orbital parameters provided by Doppler-plus-angle and range-plus-angle systems.

An ultra stable oscillator is utilized by APL in the satellite beacon transmitter, providing direct transmission to the ground. This oscillator is reported to have a short term stability of one part in 10^9 ("short term" implies at least the time span of one satellite pass, about 15 minutes) and was developed for APL by Hermes Electronics Co.[3] The reference frequency at the ground station has a stability of

3 "Precision Doppler Satellite Vehicle Equipments and Downrange Facilities and Equipment", Lockheed Missile Systems Division, Sunnyvale, Calif., LMSD-446132.

one part in 10^9 for 15 minutes, or better.[4] The state of the art in stable oscillator design is improving, however, and recent data sheets from Hermes Electronics Co. (Model 105-Ruggedized Transistorized Ultra-Stable Oscillators) state a stability of better than five parts in 10^{10} per day. This order of stability is also quoted in a recent Lockheed Missile Systems Division Report[3] for airborne-type oscillators as "off-the-shelf" items.

Generally, the accuracies attained in the time and frequency units and the satellite transmitter stability determine the accuracy of the basic Doppler data--in the absence of refractive effects. This brings up one of the more salient features of the APL system. This is the use of two-frequency transmission from the satellite and the resulting partial compensation for ionospheric refraction. As discussed in Section 3.5.4, the errors due to refraction can be prohibitively large at the low altitudes and low frequencies (200 mc).

As a means of eliminating this problem, APL has developed an analog refraction correction unit, which makes use of the known dispersion properties of ionospheric refraction. The analog instrumentation scheme is pictorially represented in Fig. 3-19 (abstracted from Weiffenback[4]). This provides the means of extracting $\Delta f_o^{(1)}(t)$, the "unrefracted" Doppler shift for the satellite transmitter frequency f_1. The observed Doppler shift may be approximated by a power series which includes only the first two terms, the unrefracted or "vacuum" Doppler shift term as it would be in the absence of ionosphere, and the first-order "error term" resulting from ionospheric effects. Measurement of the Doppler shifts of the two coherent transmitted frequencies f_1 and f_2 allows the construction of two simultaneous equations that can be solved for the "unrefracted" Doppler shift term, or the first-order "error term" coefficient, by elimination. f_1 is in the neighborhood of 200 mc. (Note: f_c' shown in Fig. 3-19 is known constant. The final multiplication is done in the central computer.)

4 G.C. Weiffenback, "Measurement of the Doppler Shift of Radio Transmissions from Satellites", Proc. I.R.E., Vol. 48, p. 752, April 1960.

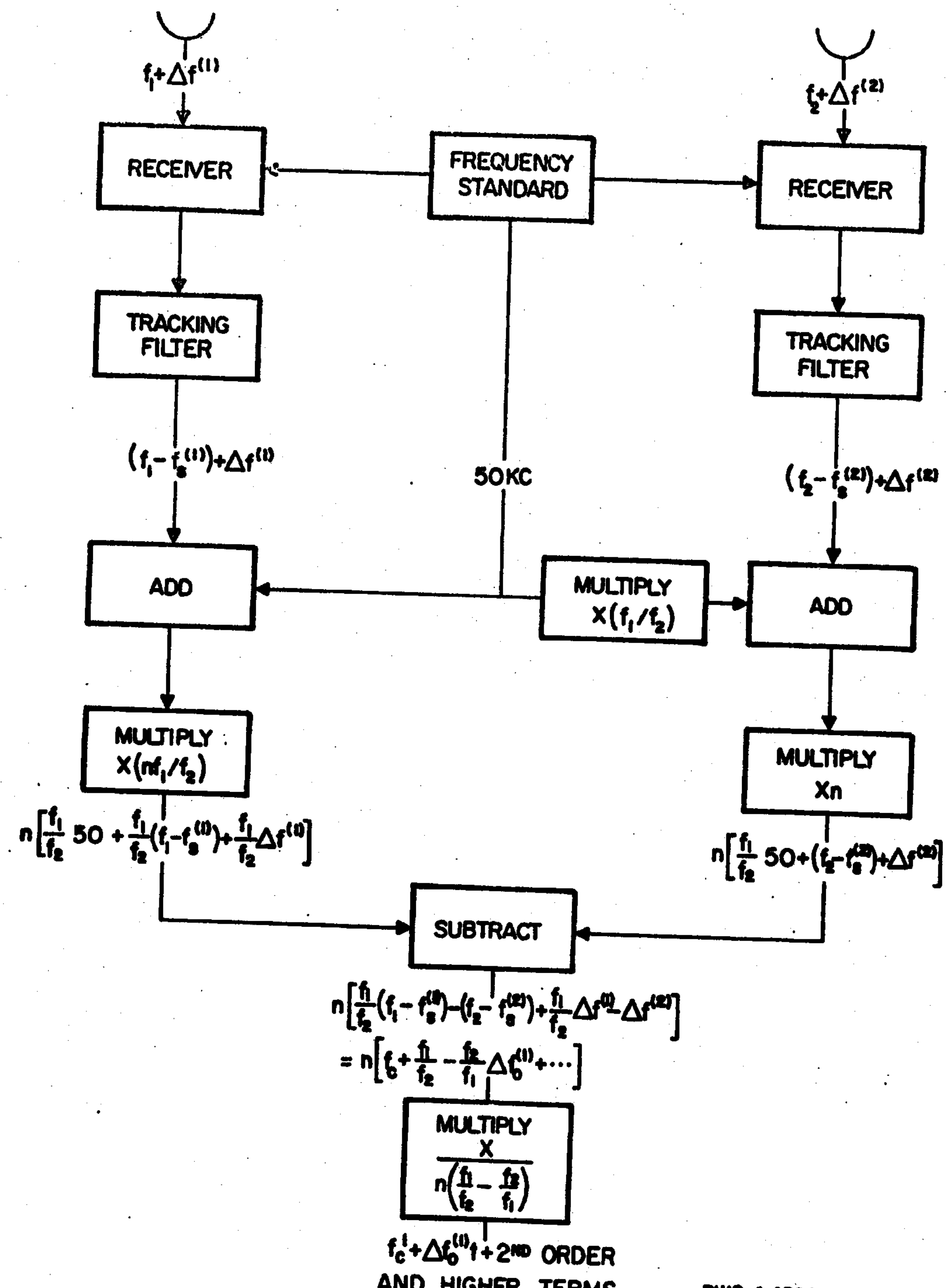


Fig. 3-19 Analog Refraction Correction Unit

Thus all that remains are the second and higher order "error" terms due to ionospheric refractive effects and the tropospheric refractive effects. The two-frequency method does not correct for tropospheric effects, obviously, since these effects are independent of frequency. It can be shown that the first-order ionospheric error-term constitutes more than 95 per cent of the total ionospheric refraction effects at 200 mc, and that the refractive effects of the troposphere can be corrected to about one-tenth of their value.[5] Hence, considering the magnitudes of the terms presented in Tables 3-1 and 3-2, it can be stated that the APL two-frequency method, together with a standard tropospheric correction, will sufficiently compensate for refraction to permit the measurement of $\dot{S}$, the rate of change of slant range to 1.0 fps, other factors allowing.

Thus, the APL system for satellite tracking provides a credible method of orbit determination, allowing for the obvious reliability problem with an ultra-stable airborne oscillator, but it does not yield quick enough solutions for reliable orbit prediction.

3.5.7 Brief Description of the STL System

The essential features of the Space Technology Laboratories Doppler tracking system are:

a. Doppler-plus-angle tracking

b. Two-way Doppler - use of vehicle transponder

Space Technology Laboratories has been a major proponent of Doppler-plus-angle tracking systems. Their system, with the Doppler transponder, has been used in the Explorer VI and Pioneer V vehicles. The Doppler transponder provides coherent retransmission of the ground-transmitted carrier in order to allow determination of the vehicle velocity with Doppler measurements. Direction of the vehicle is given by angle-tracking of the ground-received signal. The STL system is based on the premise that the use of Doppler-plus-angle data removes the problem of

5 "Precision of Compensated Tracking Systems", Hermes Electronics Co., Report No. M-810, November 5, 1959.

subsidiary singularities that is experienced in the APL estimation procedure. Thus, the Doppler-plus-angle technique provides for the quick prediction of orbital parameters that is not allowed with the Doppler-only techniques. Employing a weighted least-squares error criterion, STL minimizes the function

$$\delta i = \sum_{i=1}^{N} \left(u \left[f_{do}(t_i) - f_{d\tau}(t_i) \right]^2 + v \left[E_o(t_i) - E_\tau(t_i) \right]^2 + w \left[A_o(t_i) - A_\tau(t_i) \right]^2 \right) \quad (12)$$

where u, v, and w are weighting coefficients selected to make each term dimensionless, and

f_{do} = observed Doppler frequency
$f_{d\tau}$ = theoretical Doppler frequency
E_o = observed elevation angle
E_τ = theoretical elevation angle
A_o = observed azimuth angle
A_τ = theoretical elevation angle

STL employs differential correction procedures to obtain initial conditions. The use of the transponder system alleviates one of the problems in estimating initial conditions, since the fundamental frequency and hence the time at which zero Doppler shift occurs (the time of minimum slant range) is accurately known. Refraction has very little effect on this, as seen in Equation (10). When f_d is zero, $\frac{dh}{dt}$ is very nearly zero (exactly zero for a circular orbit) and the only term remaining is the third term, due to changing atmospheric conditions. Since zero Doppler shift occurs at very nearly (exactly for a circular orbit) the maximum elevation angle, this remaining term is very small. (The values given in Tables 3-1 and 3-2 are for an elevation angle of 5^o.)

The STL Doppler system, however, is still subject to refractive effects. Table 3-2 shows that for a frequency of 400 mc at an altitude of 155 nautical miles and an elevation angle of 5^o, the error remaining after a standard correction can be as high as 5.7 fps. This is a maximum, however, so the system does approach the desired accuracy of 1.0 fps since the error decreases rapidly with elevation angle and altitude.

The use of the transponder system also allows high-order frequency stability to be achieved, with increased reliability, since the reference oscillator is contained in the ground instrumentation. Figure 3-20 shows a simplified STL-type Doppler transponder system. A typical sequence of operation is the following: The ground transmitter emits a signal at a frequency of approximately 400 mc. This signal is picked up by the receiver in the satellite at a frequency of 400 mc plus the Doppler frequency f_{d_1}; the transceiver in the satellite multiplies the frequency of the received signal by a factor of 16/17 and retransmits it. The retransmitted signal has a frequency of 16/17 $(f_t + f_{d_1})$ and this signal is again modified by a Doppler shift f_{d_2}. It is then picked up by the same ground antenna that emitted the original signal. A diplexer in the antenna selects the received signal and sends it to the ground receiver. The receiver output containing the Doppler information is further processed in the Doppler extraction circuits. For more detail, see "Combined SAMOS/Comsat Tracking, Command and Telemetry System Study", Space Technology Laboratories, STL-GM 59-0000-054-99. 20 Jan. 1960 (Secret).

3.5.8 Conclusions

The foregoing leads to some basic conclusions. If orbit prediction is to be made quickly from one pass, an angle tracking system is required with the Doppler measurement system. If retrospect orbit determination is required, Doppler-only techniques are sufficient. In the latter case, the accuracies obtainable in orbital parameters depend on the accuracy attained in the timing and frequency units, and the handling of refractive effects. Doppler-only techniques, due to their relative simplicity, are also desirable for supplemental tracking stations when range (or Doppler)-plus-angle data is available from previous-pass stations for control purposes.

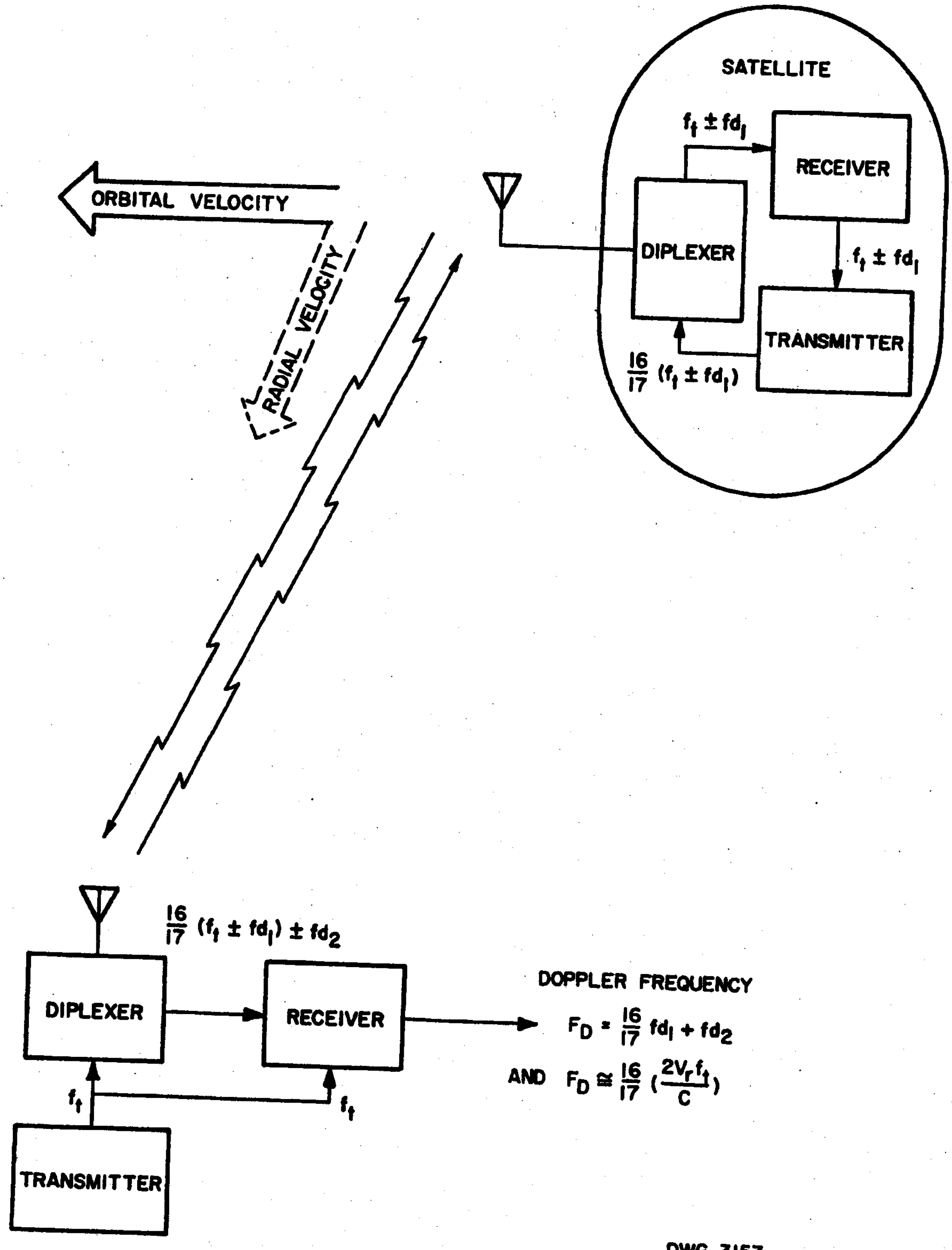


Fig. 3-20 Typical Doppler Transponder System

Study of Doppler-plus-angle techniques has revealed that their basic accuracy is equivalent to that of range-plus-angle systems. The same study has shown that after first order corrections for the effects of refraction, the same order of magnitude of residual errors remain in range data as in Doppler data. Also, the time required to accurately estimate initial conditions, and consequently orbital parameters, from Doppler-plus-angle data (one to two minutes). It was on this basis that Doppler-plus-angle instrumentation was proposed for the Midas Program, since a range-tone system wastes power and requires intricate handling of the ranging tones both on the ground and in the satellite. Similarily, "Midas Doppler Tracking Study" - Philco WDL-TR1310 (Secret) 15 July 1960, a forthcoming Philco report[7] presents a comprehensive analysis of Doppler tracking techniques for low altitude orbits and also presents the results of a computer simulation study which compares the orbital prediction capabilities of Doppler-plus-angle data and range-plus-angle data. The study also includes the effects of refraction, earth oblateness, and low altitude drag in the computer scheme. The results show that Doppler data accurate to 1.0 fps is roughly equivalent (better, actually) to range data accurate to 0.1 nautical mile, when used with equivalent angle tracking. This order of comparison is further substantiated in a recent study[8] by JPL which concludes that "excellent predictions can be computed with angular data from one pass as bad as 0.2 degrees rms (error) when combined with (Doppler) velocity data better than 1.0 meter/sec or range data better than 1.0 kilometer."

3.5.9 Discoverer Doppler

The present Discoverer Doppler system contains a Motorola phase coherent receiver (Model 201-21157), with a frequency stability of one part in 10^6 per hour. It receives a 225-260 mc signal continuously transmitted by the vehicle acquisition transmitter. This receiver

7 "Samos Doppler Tracking Study" Philco WDL-TR1411 (Secret) Dec. 1960.

8 "Satellite Orbit Determination and Prediction Utilizing the JPL Goldstone 85-ft Antenna and the JPL Tracking Program"-Jet Propulsion Laboratory, Pasadena, Calif., TR #34-27, Feb. 23, 1960.

produces a Doppler frequency output which is recorded as frequency versus time in binary form on teletype tape along with a digital time reference. The Doppler data can be analyzed and used to calculate limited orbital parameters in case of failure of the Verlort tracking system. The system also provides a backup acquisition function. Used in conjunction with a wide-beam tri-helix antenna, the highly sensitive Doppler receiver is capable of detecting the acquisition transmitter at the maximum slant range. Details of the present Doppler and tri-helix equipment may be found in Section 3.3 of this report.

An upgrading of the Discoverer Doppler system would involve a similar modification to that being planned for the South Africa Midas Tracking Station. The Motorola receiver is being modified so that the frequency stability of the final ground system is increased from one part in 10^6 per hour to one part in 10^9 per day, by providing an ultra stable oscillator, which operates into a series of multipliers and mixers in the Doppler expander chassis. In addition, the r-f mixer, and oscillator stages are being modified to receive a fixed frequency of 216 mc $\pm$ 11.520 kc.

It has also been suggested that the vehicle transmitter effective stability may be upgraded most easily with temperature compensation. The effect of temperature on the transmitted frequency must be accurately known a priori, by extensive calibration, and then the temperature of the vehicle transmitter can be monitored during the tracking pass via telemetry.

The use of the Doppler system modification above is a relatively simple and expedient step. The accuracy of the acquired Doppler data, however, may be somewhat limited. As has been pointed out, the effects of refraction on Doppler data in the 200 mc range can be quite large. As shown in Table 3-2, the residual error found after a correction for a standard troposphere and an average ionosphere is about 24 cps at an elevation of 5° for a vehicle altitude of 155 nautical miles. Similar calculations for the same altitude show that the residual error at 45°

elevation angle is about five cps. These errors, however, are the maximum that would occur, at this "worst" altitude, taking the maximum variation of the properties of the ionosphere. The probable error is considerably less and decreases with altitude.

Other possible sources of deviation in the measured Doppler curve are found in the magnitude of the sampling rate, size of the sample, and method of counting. These errors, however, are generally small compared to the refractive errors above. In the Discoverer system, the Doppler curve is sampled every two seconds, and the number of cycles in a specific period (one second) are counted. (In the APL system, the time, or period, of a specific number of cycles is measured every two seconds.) Using Equation (7), with associated geometry, and assuming a circular orbit about a stationary earth, it can be shown that the maximum rate of change of the slope of the Doppler curve, for an altitude of 155 n. miles, is about 3.75 cps/sec. Thus, in a one second sample, the maximum error in choosing the Doppler frequency as the average value of the sample would be less than two cps. This maximum, however, occurs only at one point, (the point of maximum curvature) and the deviations are normally much less, since the Doppler curve is basically a smooth, monotonic curve.

Thus it is seen that with the increased stability of the system, the largest errors incurred in the process are those due to refractive effects. This, of course, is the reason for the APL two-frequency technique. It is also one of the primary reasons for increasing the fundamental frequency of future Doppler tracking systems. Therefore, it is estimated that the Discoverer Doppler system, as modified, will yield Doppler data with a maximum error of about $\pm$ 12 cps for elevation angles above 15°, after a standard correctiin. For Discoverer flights in the higher altitudes, such as 500 nautical miles, the maximum error will be considerably less.

Thus, while the accuracy of this system will obviously be "borderline", its use will undoubtedly prove enlightening, providing a comparison with the Verlort system, general experimentation of methods, and system design criteria for future WS-117L Doppler systems.

SECTION 4

DATA TRANSMISSION AND DISPLAY SYSTEM

4.1 Introduction

The data transmission and display system is a grouping of electronic and electro-mechanical units constituting an integrated ground electronic system which: (1) gathers, (2) processes, (3) converts, (4) records, (5) transmits, and (6) displays data, all in the various forms necessary to aid the vehicle acquisition and tracking functions of the ground station.

The data transmission and display function transmits equipment status data, antenna slaving data, vehicle position data, and predicted orbit data within and between the SS/H tracking stations. Each of the Subsystem H tracking stations collects time-labeled vehicle position information and transmits this information via 100-wpm teletype to a central computer. The central computer generates a predicted vehicle orbit for the next pass and transmits the predicted orbit via 100-wpm teletype to the tracking stations, where it is received on teletype tape. It is used to plot the predicted orbit on the station plotboards and to position the tracking antennas and radar range gate to the predicted vehicle positions at the correct time to aid acquisition and lock-on.

Antenna position data is applied to plotboards (Verlort and R1162), to antenna position indicators, and from a selected tracking device to the antenna slaving bus. The tracking antenna position is transmitted to the local slaved antennas by synchro data and, in the case of VAFB and Mugu, to the remote radar and plotboard over a digital data transmission link. A digital data link, with synchro backup, is used at VAFB and Hawaii to transmit radar antenna position data to the slave bus, due to the long distance involved. The other stations use synchro-data alone. The radar plotboards plot cartesian x, y, and z data from d-c analog outputs. The telemetry tracker plotboard plots polar θ (azimuth) and ϕ (elevation) data from synchro outputs. Angular data to operate the antenna position indicators is transmitted by synchro means only.

The VAFB and Point Mugu inter- and intrastation data transmission network is presented in simplified block diagram form in Fig. 4-1. A more detailed block diagram of the VAFB intrastation data transmission system is presented in Fig. 4-2. As indicated in Fig. 4-1, Point Mugu differs from VAFB in that Point Mugu does not have an optical tracker, telemetry tracker, or an intrastation digital data transmission system. The Hawaii network is identical to VAFB except for the optical tracker and the VAFB-Point Mugu interstation real-time slaving link. The Kodiak and NBTS networks are identical to Point Mugu except for the VAFB-Point Mugu real-time slaving link. In view of the duplication, only the VAFB and Point Mugu stations will be discussed.

4.2 Interstation Data Transmission Network

The interstation data transmission network (see Fig. 4-3) collects tracking data from the radar, the telemetry tracker (Mugu excepted), the Doppler receiver, and the terminal timing unit. It transmits the data to the central computer via 100-wpm teletype. In the event of a 100-wpm teletype failure, the tracking data may be transmitted via the 60-wpm administration and control teletype. In addition, the interstation data transmission network receives the predicted orbit data from the central computer and transmits it to the plotboards as a preplot program, or to the tracking devices as a real-time acquisition program.

The data transmission links from the radar and telemetry tracker to the central computer are identical except that the telemetry tracker produces no range data and only 13-bit azimuth and elevation data. Only the radar-to-central computer link is discussed here. The radar collects polar antenna azimuth (θ), elevation (ϕ), and slant range (r) data. The θ and ϕ data are coded in cyclic binary form by 16-bit Baldwin encoders which are coupled to the antenna azimuth and elevation drives. The range data is encoded by two 10-bit Giannini code wheels. A coarse code wheel encodes 10,240,000 yards in one revolution and the

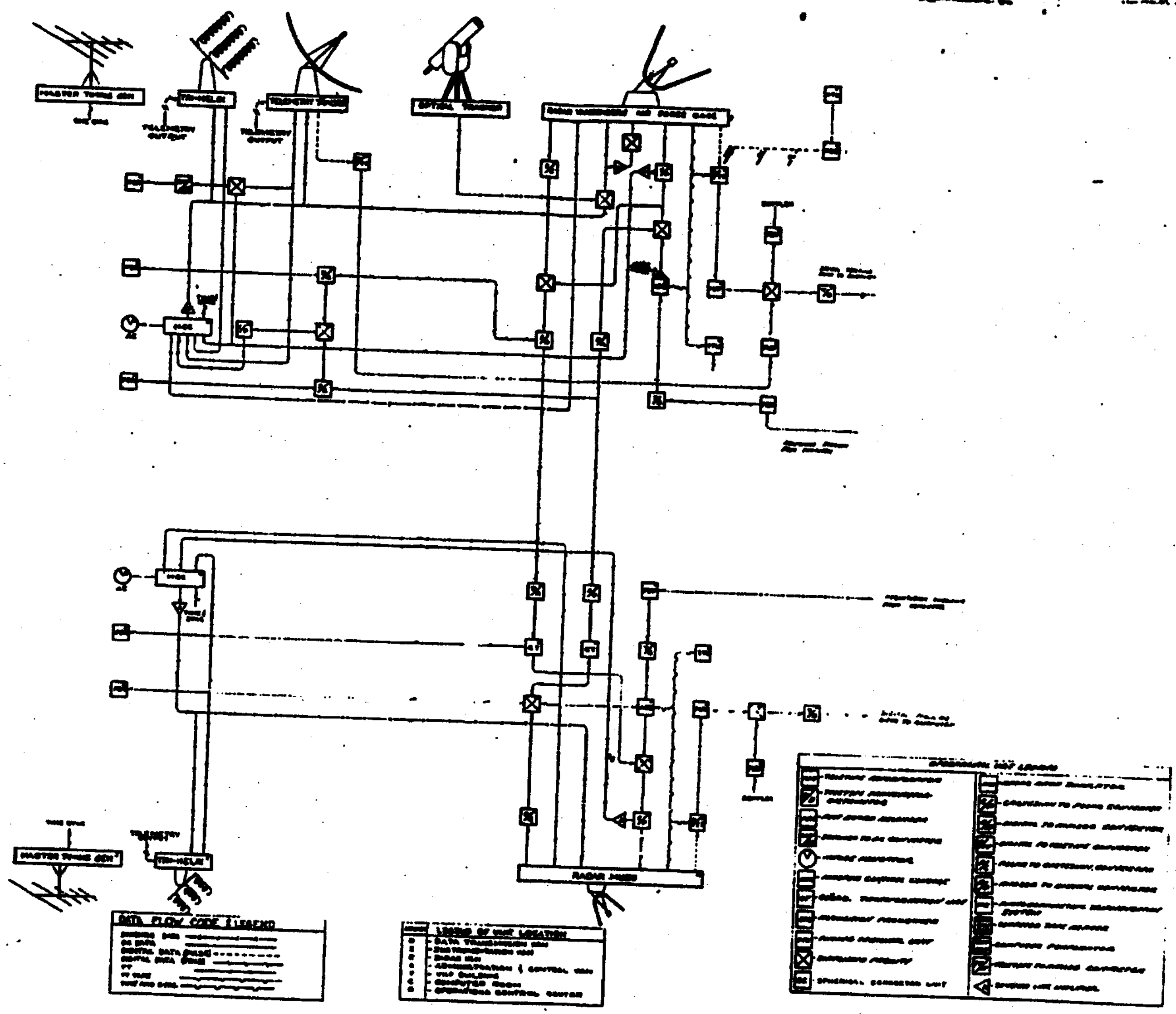


Fig. 4-1 VAFB-Pt. Mugu Inter-and-Intrastation Data Transmission Network

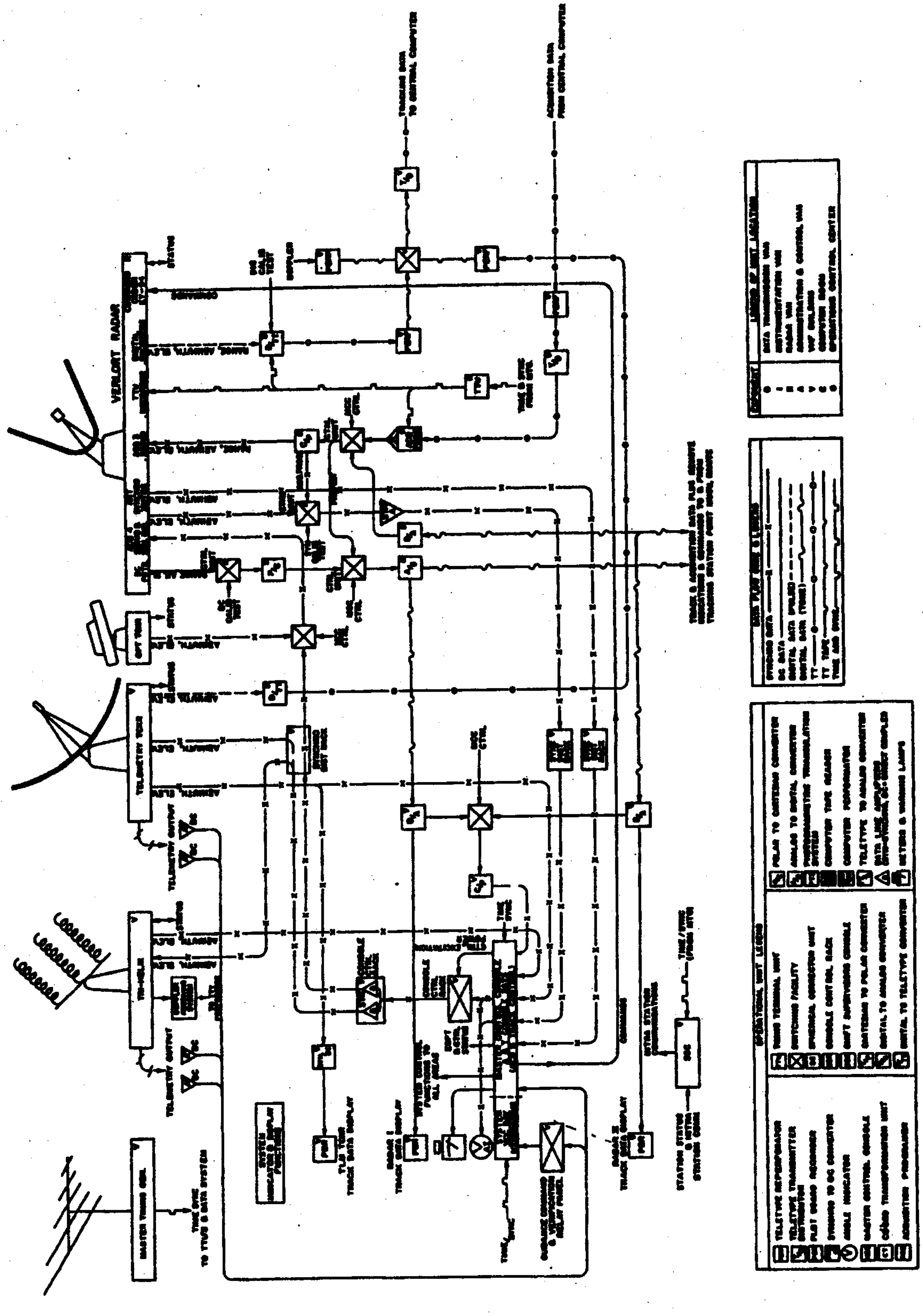


Fig. 4-2 VAFB. Data Flow, Block Diagram

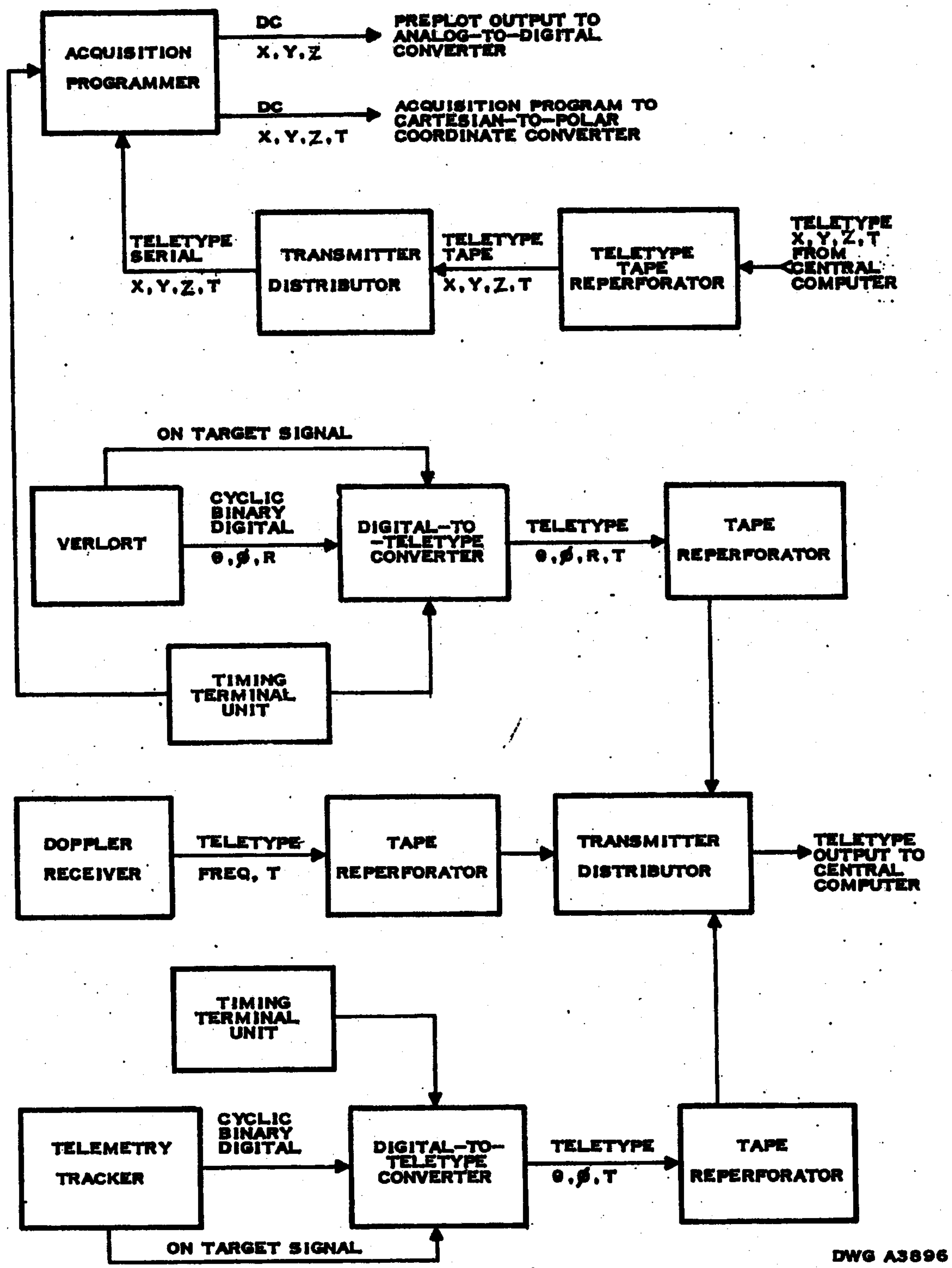


Fig. 4-3 Interstation TTY Data Transmission Network Block Diagram

fine code wheel encodes 10,000 yards in one revolution. The range information is encoded as a 20-bit digital code. One of the range bits is used for ambiguity resolution and one (the least significant) is used as a passive track quality bit leaving 18 bits available for range presentation. The 16-bit θ and ϕ data and the 18-bit r data are applied in parallel to magnetic core shift registers in the digital-to-teletype (D/TT) converter and read out of the shift registers. Time information in the form of a digital time word from the timing terminal unit is also read into magnetic core shift registers and read out serially. As the azimuth, elevation, and range data are read out of the shift registers, they are converted from cyclic binary to binary form, then converted to teletype form and transmitted via 100-wpm teletype to the central computer.

The polar θ, ϕ, and r data and the time data in teletype form may be recorded on D/TT magnetic tape for later transmission to the central computer. Frequency and time data from the Doppler receiver are in teletype form as they leave the unit. The frequency and time data are punched on teletype tape and transmitted later via 100-wpm teletype to the central computer. The frequency and time data provide the central computer with the minimum range of the vehicle and the time this minimum range occurred.

The central computer-to-station link of the interstation data transmission system starts at the central computer. The predicted x, y, z, and t data for a particular station are transmitted via 100-wpm teletype. The teletype information is applied to a tape perforator and the x, y, z, and t data are stored on the perforated tape for future use as a preplot program or as an acquisition program capable of directing all of the tracking instruments in real-time for vehicle acquisition. In the event acquisition by the tracking instruments is delayed, the acquisition program may be continued and the tracking instruments slaved to it as the best estimate of the vehicle orbit. If acquisition is not achieved during the pass, tracking data are not sent to the central computer.

The preplot program is transmitted to the station plotboards prior to real-time acquisition and tracking. This allows a plot of the predicted orbit to be made prior to the time the vehicle pass is made. During the pass, a real-time plot is made. The two plots permit comparison of the acquisition programmer preplot and the actual orbit as tracked by the radar or the telemetry tracker.

4.3 Intrastation Data Transmission Network

The intrastation data transmission network (Fig. 4-2) transmits antenna position and equipment status data within a station and terminates the real time slaving link between VAFB and Point Mugu. Position data is transmitted to and from the slave data bus, position indicators, the local plotboards, and the remote radar and plotboard.

With the input from the central computer, the acquisition programmer generates preplot or real-time slave data in cartesian x, y, and z form. For a preplot, the cartesian data is transmitted to the plotting board. For real time slaving, the data is applied to a cartesian-to-polar (C/P) converter. The x, y and z data are converted to θ, ϕ, and r synchro data and applied to the radar antenna and range servos. The acquisition program θ and ϕ data can be made available to the slave bus for slaving the Telemetry Tracker and Tri-helix antennas.

The tracking data from the Verlort is in polar form and expresses the vehicle position in terms of the radar antenna azimuth (θ), elevation angle (ϕ) and slant range (r). For intrastation use, this data is in d-c and synchro form.

The d-c polar position data from the radar are converted to cartesian coordinates in a polar-to-cartesian (P/C) converter. The output of the P/C consists of three d-c voltages representing the radar plane cartesian x, y and z. At Point Mugu, this output is applied directly to the local radar plotting board and the Mugu/VAFB real time slaving link through coordinate transformation and analog-to-digital (A/D) converter units. At VAFB, this d-c output of the P/C converter is applied to an A/D converter for data transmission to the receiver site and the remote real time slaving link.

The A/D transceiver converts the d-c x, y, and z analog input from the P/C converter to 15-bit digital x, y, and z data. The digital data are transmitted over voice-quality lines without loss of information. The analog input to the A/D transceiver is sampled 10 times a second and transmitted at the same rate. The total 15 bits x, 15 bits y, and 15 bits z, 6 bits auxiliary, and one synchronizing bit are transmitted. The synchronizing bit marks the beginning of a new digital word and is usually referred to as the end of word (EOW) burst. The EOW burst is twice as long as a data burst for easy discrimination at the digital-to-analog(D/A) converter at the other end of the line.

The digital x, y, and z tracking data from the VAFB A/D transceiver are transmitted across the station to the D/A transceiver which converts the digital data back to d-c. The plotboard plots the real-time tracking data from the radar. This same digital link is used for the preplot input from the acquisition programmer. Both plots are in radar plane x, y, and z coordinates.

At VAFB, the output of the Radar I D/A transceiver is applied as a local input to the slave bus C/P converter. The C/P converter converts the Radar I data into the two-parameter (θ, ϕ) polar from for ultimate application to the VAFB slave-data bus via the acquisition and tracking console. Radar data from the Point Mugu radar (Radar II) also may be applied to the C/P converter which drives the VAFB slave-data bus. The availability of local Radar I and remote Radar II tracking data on the slave-data bus permits the slaving of the VAFB radar, telemetry tracker, and tri-helix to the remote radar. Locally, the telemetry tracker and the tri-helix may be slaved to the VAFB radar. The digital-data transmission network at the VAFB-Point Mugu complex supplies the slave-data bus at either the VAFB or Point Mugu location with radar tracking data from either the VAFB or Point Mugu radars. At either station, the local radar is referred to as Radar I and the remote radar is referred to as Radar II.

The digital x, y, and z data output of the VAFB A/D transceiver also is transmitted to the downrange station at Point Mugu to slave the remote radar to the local VAFB radar. At Point Mugu, the digital x, y, and z data are converted to analog x, y, and z data by a D/A converter. The d-c x, y, and z data are in VAFB radar plane coordinates. A coordinate transformation is performed on the VAFB x, y, and z data in order to drive the remote radar and plotboards in Point Mugu radar plane coordinates. Coordinate transformation is performed in a coordinate transformer by converting the x, y, and z coordinates to geocentric polar coordinates referenced to the center of the earth, then rotating the geocentric polar coordinates to those of the remote station and converting the new geocentric polar coordinates to cartesian x, y, and z coordinates. After coordinate transformation, the d-c x, y, and z tracking data are reconverted to polar coordinates by the Point Mugu C/P converter and applied to the Point Mugu radar as synchro θ, ϕ, and r. This permits slaving the Point Mugu radar to the VAFB radar. Two-parameter synchro data (θ and ϕ) are applied to the Point Mugu C/P converter and made available for application to the Point Mugu slave-data bus. The d-c x, y, and z output of the Point Mugu receive coordinate transformer also is made available to the Mugu Radar II plotboard for plotting of VAFB data.

The d-c x, y, and z output of the Point Mugu C/P converter is applied to a transmit coordinate transformer which converts the Point Mugu tracking data to VAFB coordinates. These coordinates are then converted to digital form for transmission to VAFB by an A/D converter. At VAFB the tracking data from Point Mugu ultimately are made available to the VAFB radar, plotboard and slave-data bus. The digital x, y, and z data from Point Mugu which are made available to the VAFB radar are first converted to d-c x, y, and z data by a D/A converter. The d-c x, y, and z coordinates are converted to polar data by a C/P converter and the resulting θ, ϕ and two-speed r are available to slave the VAFB radar to the Point Mugu radar. The digital x, y, and z data from Point Mugu which are made available to the plotboard are first converted to d-c x, y, and z data by a D/A converter at the receiver area. The d-c x, y, and z data drive the VAFB Radar II plotboard. The remote Radar II d-c x, y, and z data are also made available to a C/P converter for conversion to synchro θ and ϕ and for application to the acquisition and tracking control console. The remote radar tracking data may then be applied to the slave-data bus.

Of the six auxiliary bits available to the D/A transceiver system, three are utilized to transmit Radar II status information over the VAFB-Point Mugu real time slaving link. The other three bits are not utilized.

4.3.1 VAFB Synchro-Data Transmission Network

A simplified block diagram of the VAFB synchro-data transmission network is shown in Fig. 4-2. The synchro-data transmission network transmits synchro data from each of the tracking instruments and the acquisition programmer to a slave tracking command panel for distribtuion on a slave-data bus and to the master control console indicators. The number of synchro inputs to the slave tracking command panel varies according to the complexity of the tracking station. At Vandenberg there are six major synchro inputs to the slave tracking command panel (local radar digital and synchro, acquisition programmer, remote radar, telemetry tracker, and tri-helix). These synchro inputs are selected by the acquisition and tracking controller and are applied to the slave-data bus. An indicator at each of the tracking equipment consoles informs the operator of the kind of data on the slave-data bus. Dual angular-position indicators at the telemetry tracker and tri-helix equipment consoles indicate the angular position of the tracking antenna, and the angular position dictated by the data on the slave-data bus. At the radar, the dual angle indicators are positioned by the tracking antenna and by the data selected by the remote selection switch. In the ACQ 3 (Remote 3) position, either the acquisition programmer or the remote radar positions the dual indicators. In the ACQ 4 (Remote 4) position, the data on the slave-data bus positions the dual indicators. If the radar is operated in remote, the radar antenna is slaved to the same source as the dual indicators, the acquisition programmer, the remote radar, or the slave-data bus, and the dual bus indicators are disabled to reduce the load on the synchro-data transmission system. The telemetry tracker and tri-helix must be operated in SLAVE TRK before their antennas are slaved to the data on the slave-data bus.

The acquisition and tracking controller selects either the acqusition program x, y, and z data or the remote radar x, y, and z data as an input to the Verlor C/P converter. This C/P provides the three parameter (θ, ϕ, r) synchro data to slave the radar in the ACQ 3 mode. The range data are 1:1 and 1:25 two-speed synchro data for the accurate positioning of the radar range gate during acquisition. When the acquisition programmer is selected, the angle (θ, ϕ) output of the Verlort C/P is also applied to the Verlort synchro link dual three-channel synchro line amplifier for routing to the slave track command panel. This link is normally used to route Radar I auxiliary synchro data to the slave track panel as a backup to the Verlort digital link.

The inputs to the slave tracking command panel are all two-parameter (θ, ϕ) synchro data. The acquisition and tracking controller selects either the local or the remote radar d-c x, y, and z data from the D/A transceivers associated with the VAFB plotboards for routing to the slave track C/P converter. The θ and ϕ synchro output of the converter are applied to the slave track command panel, providing either local or remote radar slave data.

Of the six synchro inputs to the slave tracking command panel, only one at a time can be placed on the slave data bus. This data is applied to dual three-channel synchro line amplifiers for routing to tracking equipment.

Two-parameter (θ and ϕ) synchro data from the local radar, the telemetry tracker, and the tri-helix are routed to the slave tracking command panel and made available to the slave-data bus. Range data from Radar I is transmitted to a range indicator on the master control console. Synchro data from Radar I and the telemetry tracker are applied to the dual indicators on the master control console. Tri-helix synchro data are applied to a single angle indicator on the master control console. Synchro data from the telemetry tracker are routed to a synchro-to-d-c converter, converted to d-c, and applied to the telemetry tracker plotboard. The telemetry tracker polar data are plotted directly.

4.3.2 Point Mugu Synchro Data Transmission Network

The synchro data transmission network at Point Mugu differs from the VAFB network in that fewer units route synchro data to the slave-data bus. At Point Mugu, the Radar I auxiliary and telemetry tracker synchro data are not made available to the slave tracking command panel and the slave-data bus (see Fig.4-1).

4.4 Equipment Description

The data transmission equipment is installed either in air conditioned vans or buildings. All stations include a Data Transmission van which contains the major data transmission equipment (Fig. 4-4). The display and control functions are installed in buildings at VAFB, Hawaii and Kodiak (Figs. 4-5, 4-6, and 4-7), and in Administration and Control vans at Point Mugu and NBTS (Fig. 4-9).

4.4.1 Digital-to-Analog Transceiver (Fig. 4-10 and 4-11)

The digital-to-analog (D/A) transceiver converts the digital pulse train from the A/D transceiver to voltages equal to the original analog x, y, and z coordinate input to the A/D transceiver. The pulse train containing multiplexed x, y, and z rectangular coordinate data represents the position of 15 relays in each channel of the A/D transceiver. The relay positions in the A/D transceiver channels determine the value of comparison voltages generated to equal the original analog input. The pulse train input to the D/A transceiver positions relays in patterns identical to those in the A/D transceiver. Under these conditions, the original analog inputs are reproduced with an accuracy of $\pm$ 0.004 volt.

Multiplexed x, y, and z channel digital-data tone bursts enter the D/A data processing and control function where they are detected and shaped. The shaped pulses excite a ringing filter which generates master timing signals. The multiplexed data words are serially read into a magnetic core shift register and stored. At the end of each word, the magnetic core shift register has stored the pattern of input pulses of the rectangular x, y, and z coordinates. At the correct time, a read-in pulse is applied to the magnetic core shift register. When a read-in pulse and core-drive pulse are applied

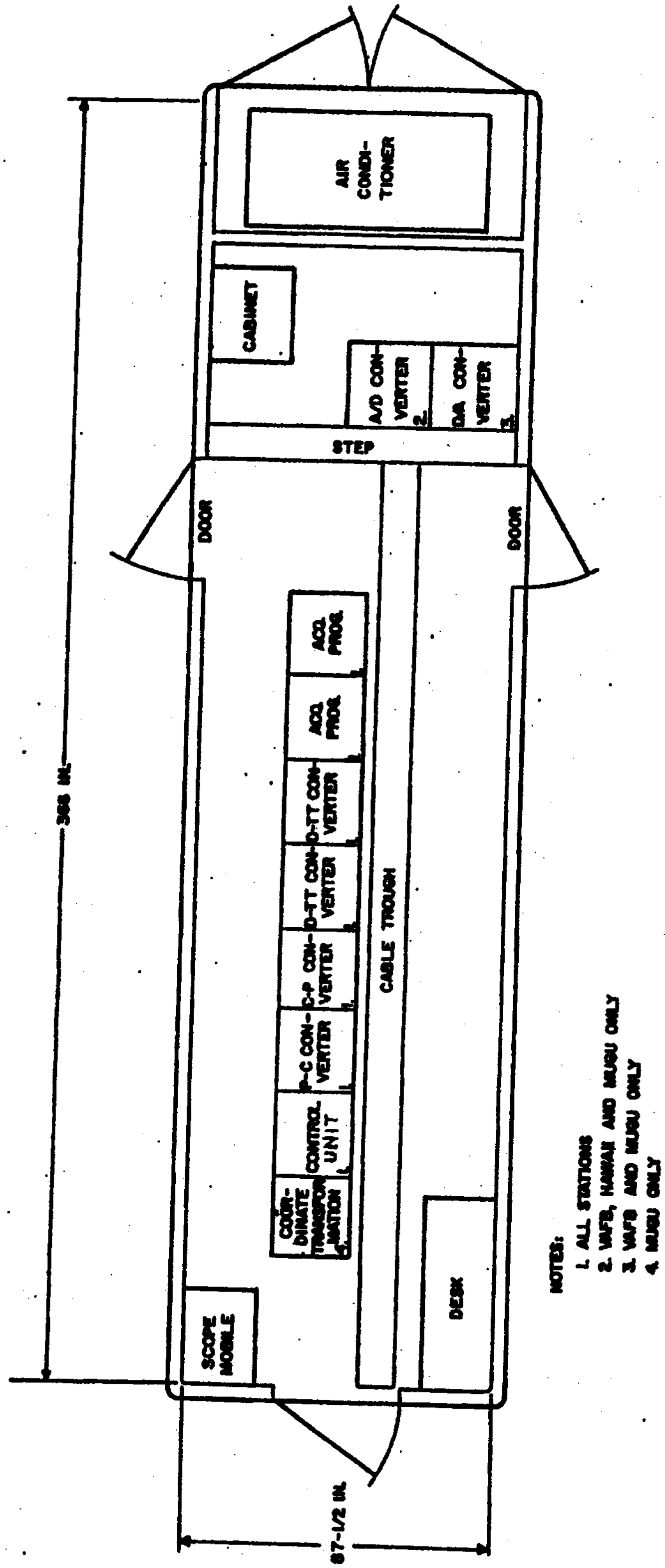
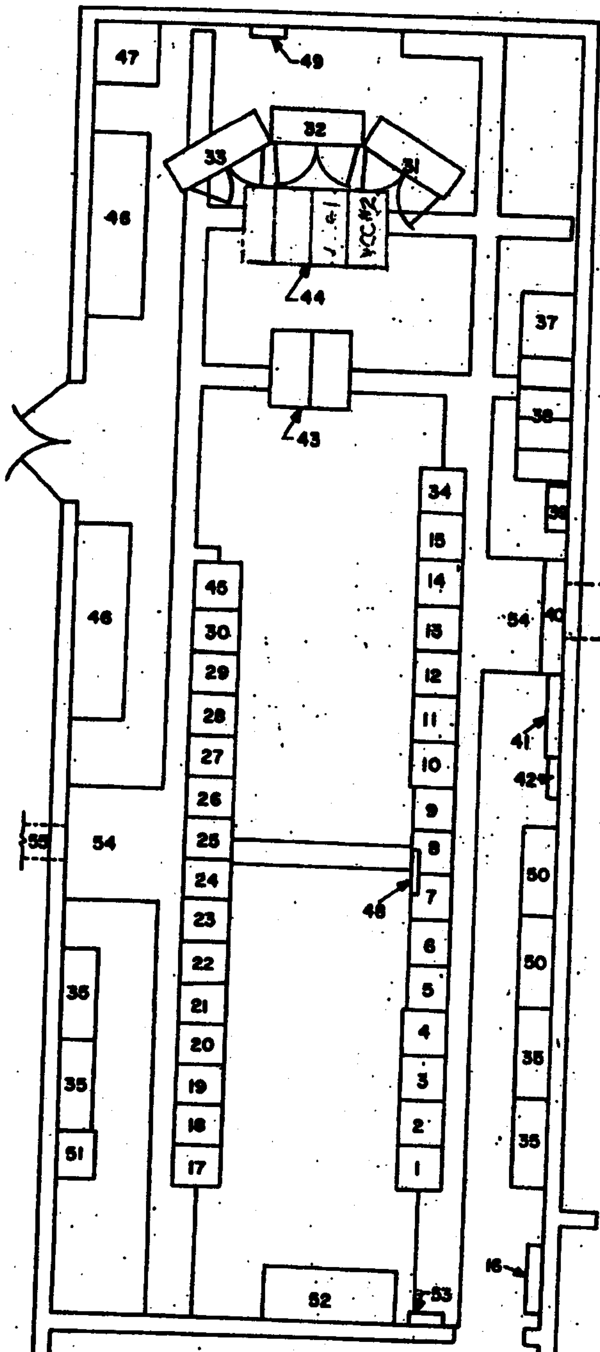


Fig. 4-4 Data Transmission Van (Typical)



NO	DESCRIPTION
1	SYNCHRO DISTRIBUTION RACK
2,3	D/A (DIGITAL TO ANALOG) CONV. RACKS
4	C/P CARTESIAN TO POLAR COORD. CONV. RACK
5 THRU 9	TELEMETRY TRACKER R-1162 RACKS
10,11	DOPPLER RECEIVER RACKS
12	TRI-HELIX CONTROL & MULTI-COUPLER RACK
13,14,15	TIMING RACKS
16	BOOK CASE
17 THRU 20	LMSD FM/FM TELEMETRY RACKS
21 THRU 29	LMSD FM/FM TELEMETRY & DECOM RACKS
30	DIGITAL TO TELETYPE (D/TT) CONVERTER RACK-1
31	RADAR I PLOT
32	DOWN RANGE RADAR II PLOT BOARD
33	TELEMETRY TRACKER R-1162 PLOT BOARD
34	CONSOLE CONTROL RACK
35	MAINTENANCE PARTS
37	TELETYPE AUTO SEND & RECEIVE (ADMIN.)
38	2 TELETYPE TD & 4 TTY REPERF
39	AUDIO AMPLIFIERS (2) 1-KELLOGG (SELECTOPHONE PAGING) 1-KELLOGG (LMSD PAGE)
40	CABLE PROTECTOR & MAIN DISTRIBUTION FRAME
41	SELECTO-PHONE DIAL SW & AC OPERATED BAT. ELIMINATOR
42	LONG LINE TELEPHONE EQUIP & 20 CYCLE RING'S SUPPLY
43	SS/H SHIFT SUPERVISOR CONSOLE
44	MASTER CONTROL CONSOLE
45	DIGITAL TO TELETYPE (D/TT) CONVERTER RACK-2
46	WORKBENCH
47	PLOTTING CHART STORAGE
48,49	REMOTE TIME INDICATORS (SLAVE CLOCKS)
50	TUBE STORAGE
51	FILE CABINETS
52	DESK
53	"PP"
54	INSTRUMENTATION MANHOLE
55	INSTRUMENTATION DUCT TO R-1162 ANTENNA

Fig. 4-5 VAFB VHF Telemetry Building Floor Plan

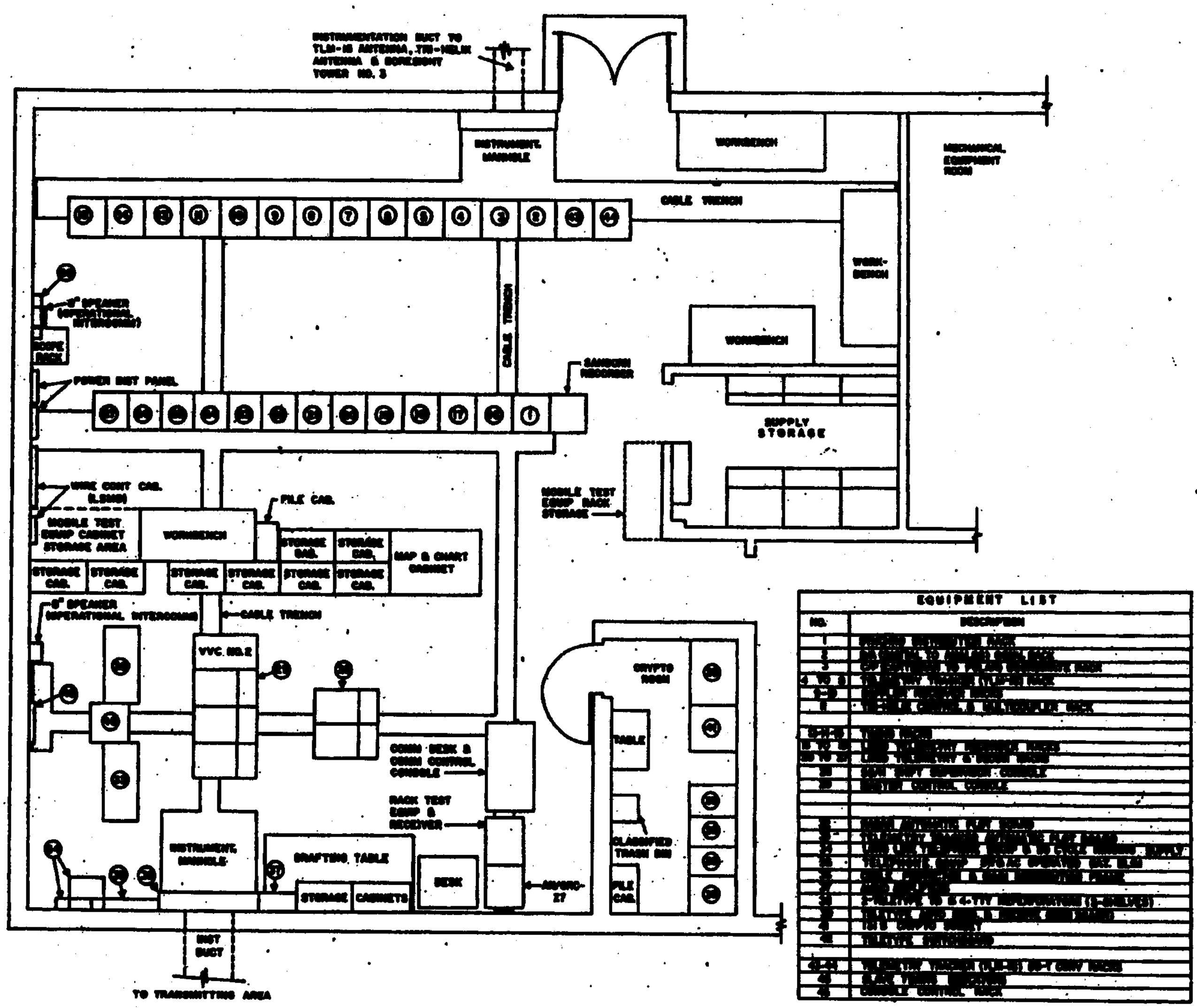


Fig. 4-6 Hawaii VHF Building Floor Plan

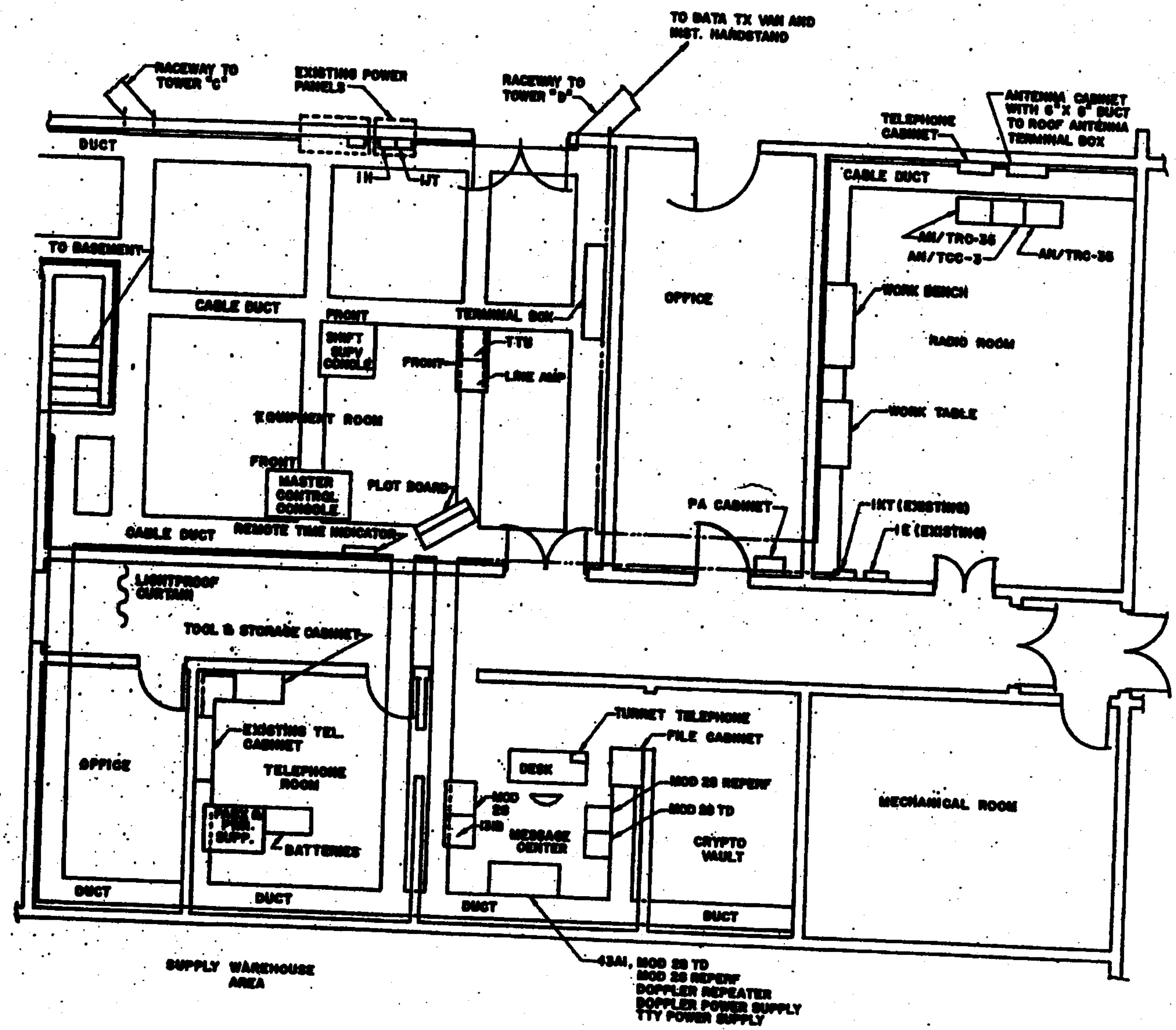


Fig. 4-7 Kodiak Composite Building Floor Plan

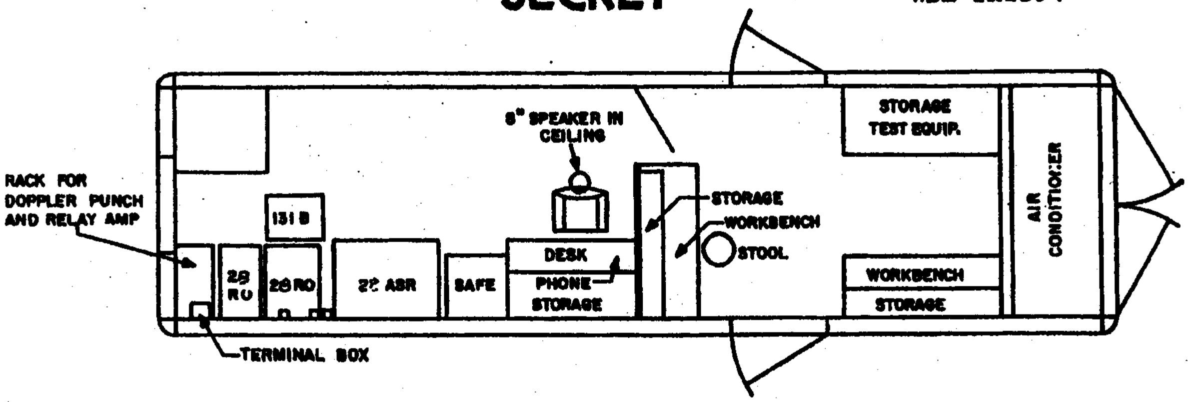
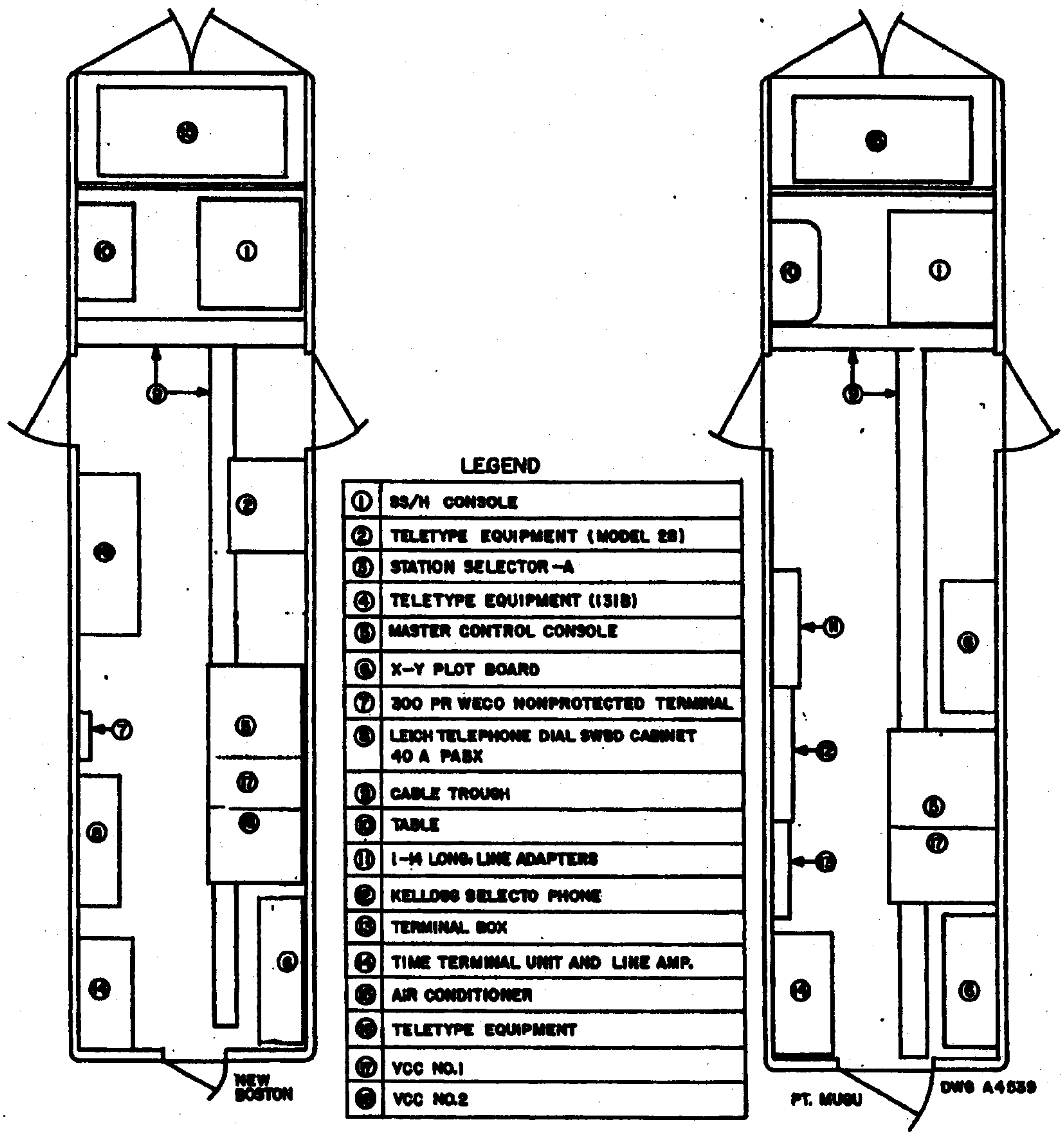


Fig. 4-8 Communications and Maintenance Van, Point Mugu



LEGEND

①	SS/H CONSOLE
②	TELETYPE EQUIPMENT (MODEL 28)
③	STATION SELECTOR—A
④	TELETYPE EQUIPMENT (131B)
⑤	MASTER CONTROL CONSOLE
⑥	X-Y PLOT BOARD
⑦	300 PR WECO NONPROTECTED TERMINAL
⑧	LEICH TELEPHONE DIAL SWBD CABINET 40 A PABX
⑨	CABLE TROUGH
⑩	TABLE
⑪	1-14 LONG LINE ADAPTERS
⑫	KELLOGG SELECTO PHONE
⑬	TERMINAL BOX
⑭	TIME TERMINAL UNIT AND LINE AMP.
⑮	AIR CONDITIONER
⑯	TELETYPE EQUIPMENT
⑰	VCC NO.1
⑱	VCC NO.2

Fig. 4-9 Administration and Control Van, Floor Plan

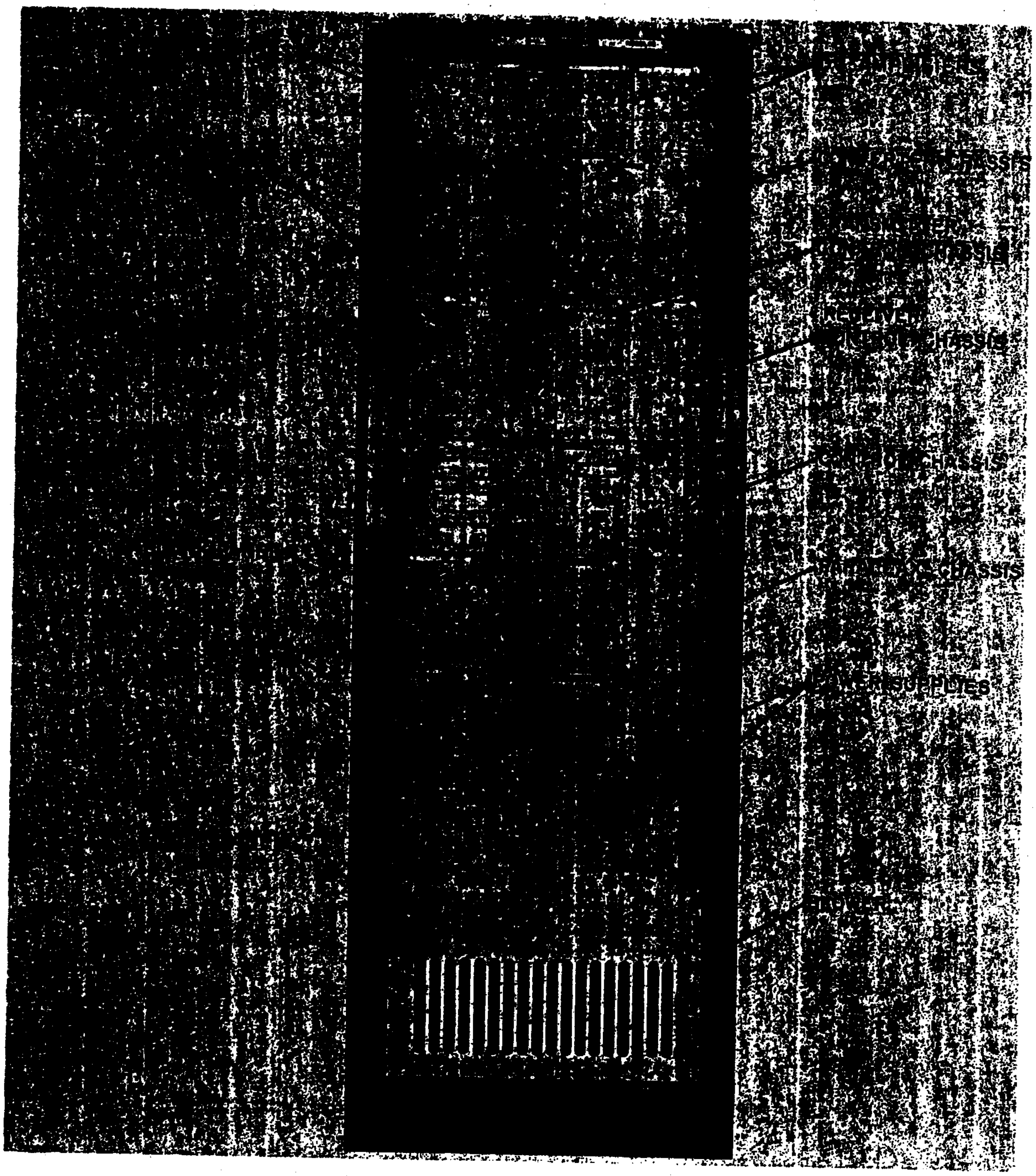


Fig. 4-10 Digital-to-Analog Transceiver

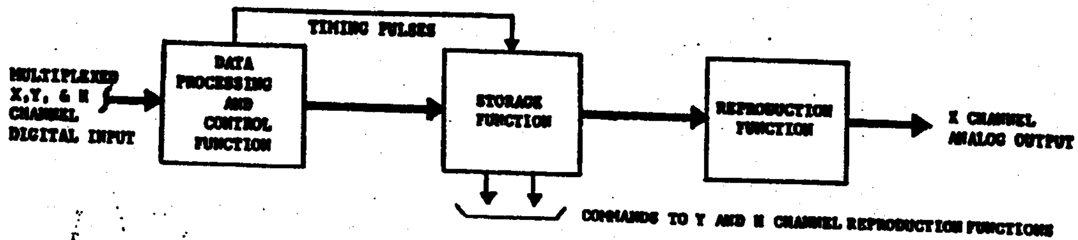


Fig. 4-11 Digital-to-Analog Transceiver, Simplified Block Diagram

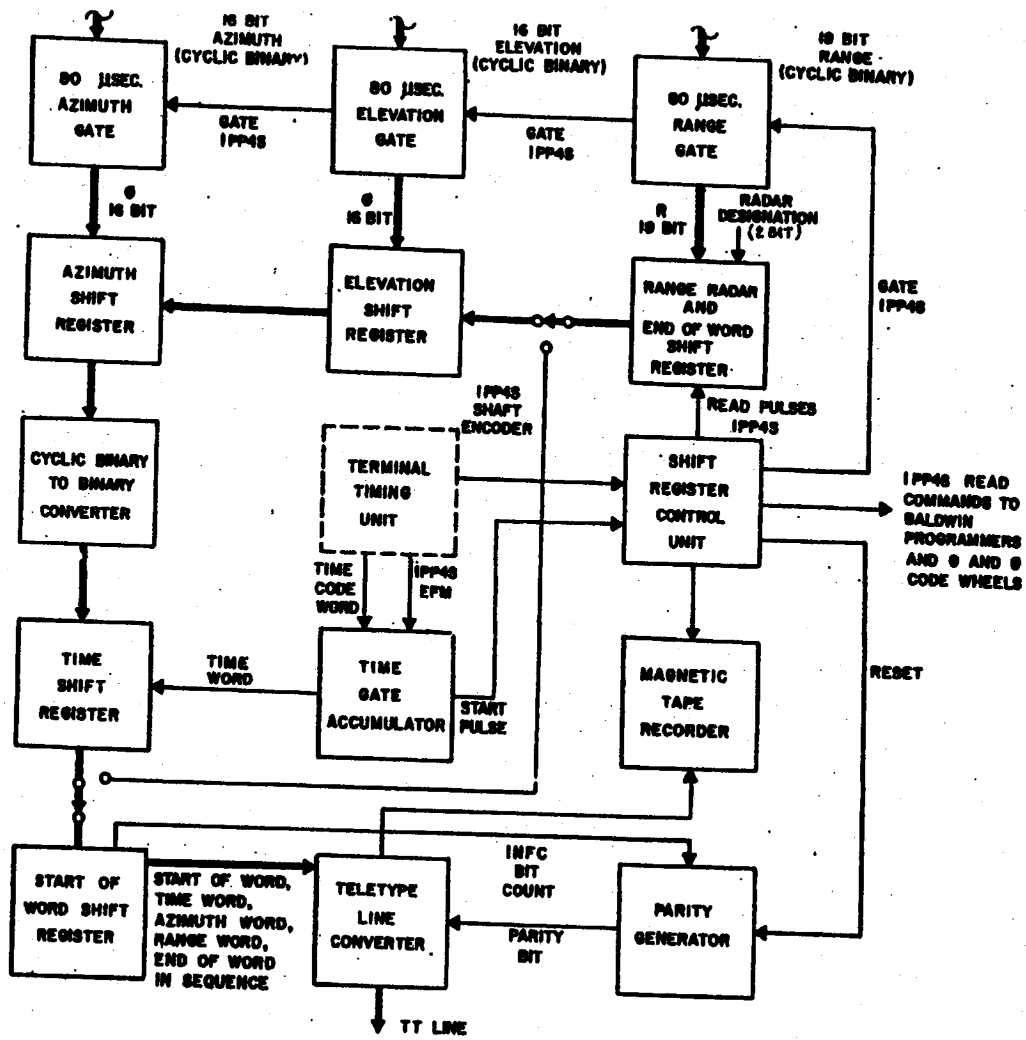


Fig. 4-12 Digital/Teletype Converter Block Diagram

simultaneously to a core which is in a "1" state, the core pulses an associated flip-flop. The flip-flop then commands its associated feedback relay to open. This action occurs to all "1" state cores simultaneously, so that work stored in the core is expelled as a unit.

The expelled words position relays in the reproduction function. The reproduction function contains a variable gain device with an output voltage dependent on the relay pattern. This device is similar to the device in the D/A transceiver feedback function, so that when the relay pattern is reproduced, a voltage which equals the original analog input is produced.

The reproduced analog voltages representing the rectangular coordinates transmitted from a remote radar are corrected for parallax and amplified. The parallax corrected d-c x, y, and z coordinates are then applied to a plotboard or to a C/P coordinate converter. The C/P converter slaves a remote radar. For a simplified block diagram of the D/A transceiver, refer to Fig. 4-11.

4.4.2 Analog-to-Digital Transceiver (Fig. 4-10 and 4-14)

The analog-to-digital (A/D) transceiver converts each of the d-c x, y, and z analog voltages to a 15-bit digital code for transmission to a remote point. The A/D transceiver has one channel for each of the x, y, and z rectangular coordinate analog voltages. The operation of each channel is identical.

The input analog voltage is compared with a discontinuous varying comparison voltage. The resulting d-c voltage is amplified and applied as an error signal to the sensing function. The sensing function senses the polarity of the error signal and commands the feedback function to generate a new discrete feedback voltage. The input analog is compared with the new feedback voltage, by the comparison function, and a new error voltage is produced and the feedback function is commanded to generate an additional discrete comparison voltage. This process continues until the error signal approaches zero. The process resembles that of a closed servo loop.

The sensing function senses the polarity of the error signal and commands relays in the feedback function to adjust the comparison

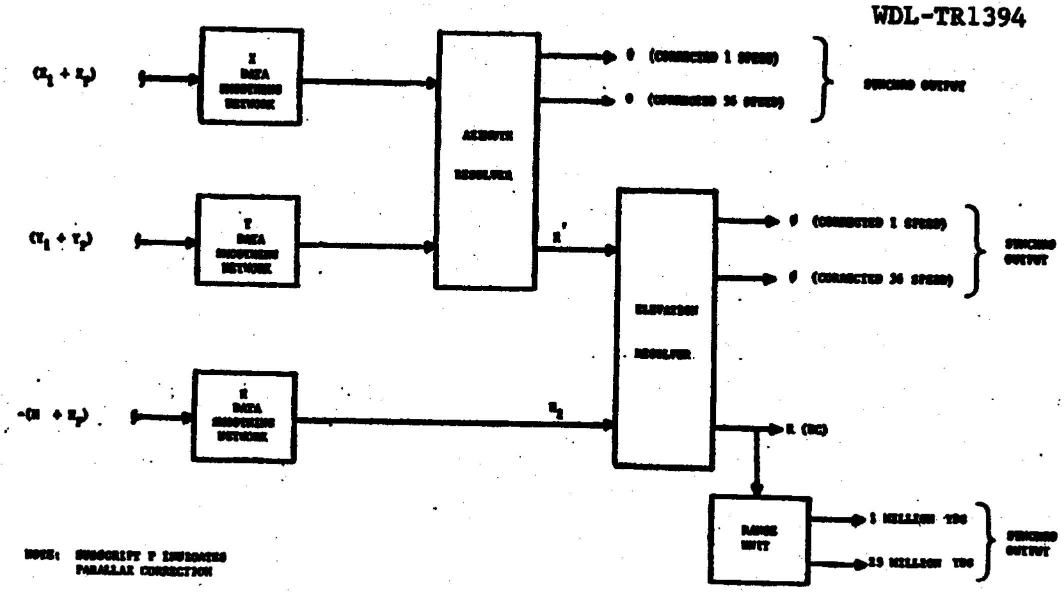


Fig. 4-13 Cartesian/Polar Converter Block Diagram

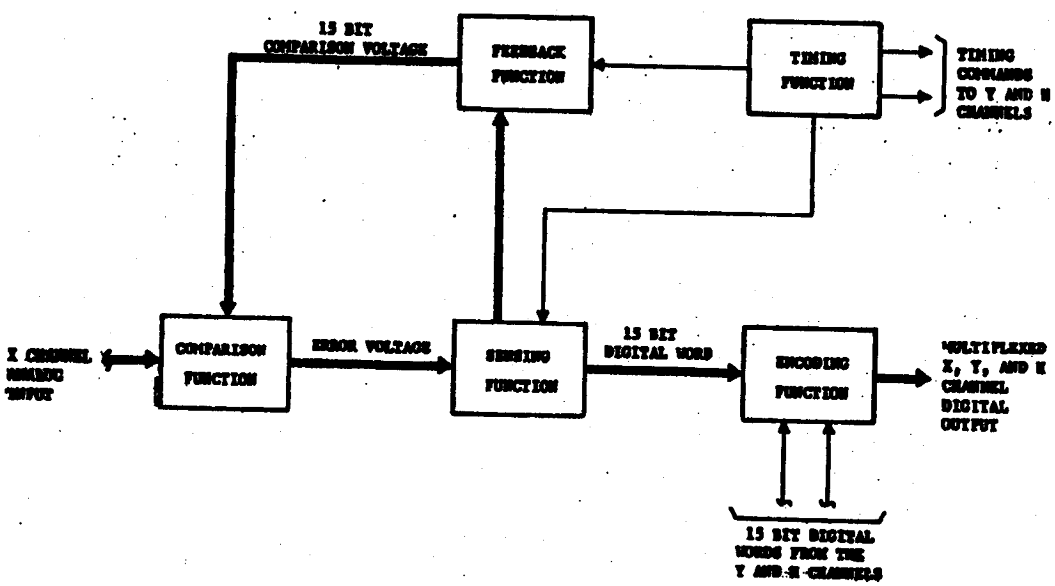


Fig. 4-14 Analog-to-Digital Transceiver, Simplified Block Diagram

voltage. The relays are closed at the beginning of a sampling period and opened in sequence by commands from the sensing function. The relay commands from the sensing functions are timed by the timing function. At each command, a relay opens and the comparison voltage increases by a factor of one-half. The error-voltage polarity is sensed and the relays are commanded to increase the feedback voltage until the polarity of the error voltage goes negative. When the error-signal polarity goes negative, the voltage increase switched in by the feedback function is too large to null the input voltage; the relay causing that increase is reclosed; and the next finer relay is opened. The resulting error-signal polarity is then sensed and the process continues until each increase in the feedback signal is too large to null the input voltage and a negative-polarity error signal is generated. Fifteen relays are operated to generate a comparison voltage.

The relay pattern commanded by the sensing function which duplicates the analog input is transmitted to the encoding function. The encoding function generates a 1920-cps tone burst each time a negative-polarity error signal is sensed.

The timing function synchronizes the sampling of the x, y, and z A/D converter channels so that they are multiplexed. The encoding function transmits the first digit of the three channels serially, then the second digit of the three channels serially, and so on until the 15-bit words for all channels are transmitted. The process occurs about 10 times each second. For a simplified block diagram of the A/D transceiver, refer to Fig. 4-14.

4.4.3 Acquisition Programmer (Fig. 4-15 and 4-16)

The purpose of the acquisition programmer is to record and store the teletype coordinates and time data sent from the central computer and to provide this information to the preplot and vehicle acquisition phases of the operation.

Digital signals are carried from the computer over standard teletype lines to the recorder-playback unit. The play-back may be synchronized with real-time signals from the timing unit. The data

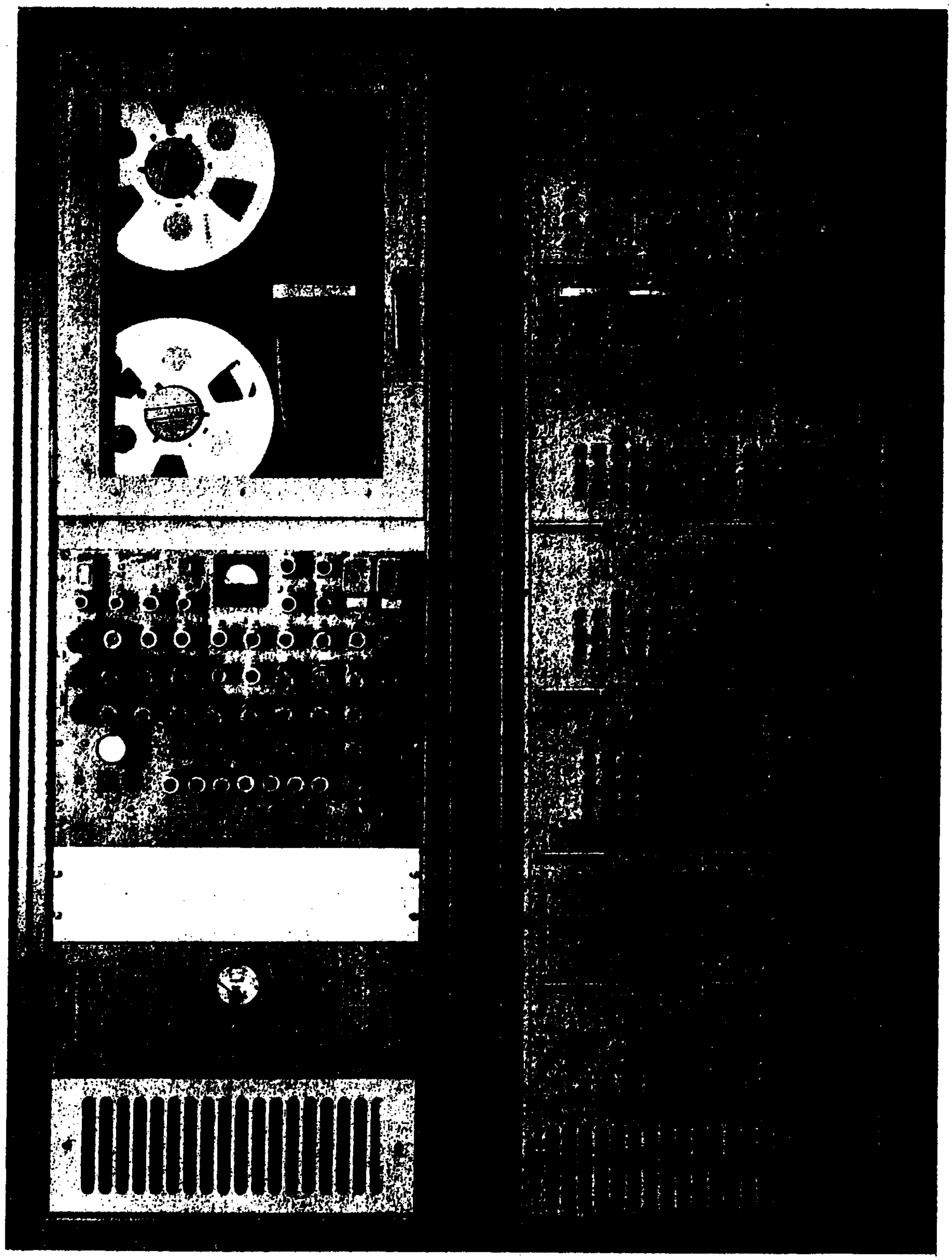


Fig. 4-15 Acquisition Programmer

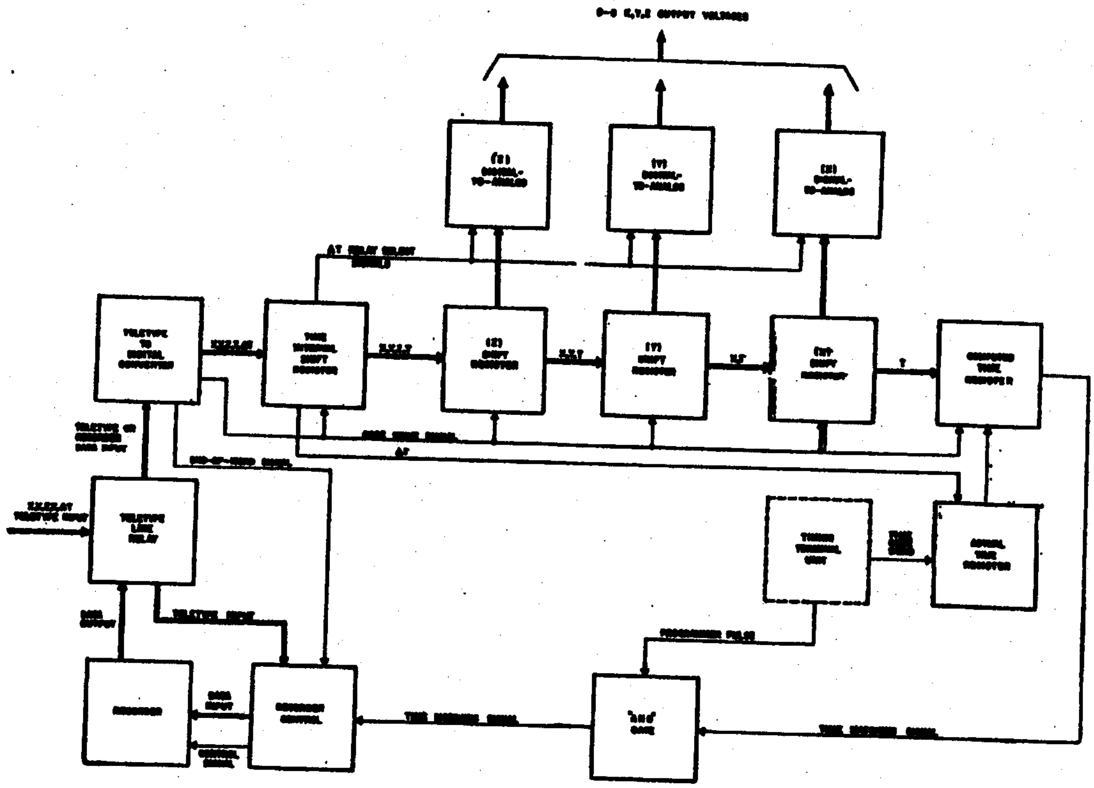


Fig. 4-16 Acquisition Programmer, Simplified Block Diagram

converter section accepts digital signals from the playback unit and converts these to d-c analog voltages proportional to x, y, and z predicted positions of the vehicle.

Programmed timing signals are also received from the playback unit and compared with real-time signals from the timing unit to provide an indication of the time differential (ahead, behind, or matched) between programmed time and real time. Manual facilities are provided for adjusting playback speed to provide "matched" synchronization between program time and real time. The data converter is keyed to allow sampling at 4-, 8-, 12-, 16-, 20-, 24-, or 28-second intervals. Four seconds is the normal sampling interval.

Recorder-Playback Unit. The magnetic tape recorder accepts and records binary-coded information received from a digital computer over standard telephone or teletype lines. Programmed time is compared to real time and facilities provided for manual synchronization. The time differential information is received from the time comparator circuit.

Data Converter. Binary-coded, serially-received pulses are applied to a series of magnetic core storage elements in the data converter. A complete data word containing t, x, y, and z information is received every 4 seconds. At 4-second intervals, this stored information is read out, and real time and programmed time are compared. The playback portion of the recorder can be made to speed up or slow down as necessary to achieve coincidence of real and programmed times. The x, y, and z information is converted to d-c voltages of polarity and amplitude proportional to the programmed vehicle position, and these d-c analog voltages are smoothed to provide uninterruped motion of the display servo system between readouts. Outputs provided to the display servo system are as follows:

a. Reference (+ 140v)
b. Reference (- 140v)
c. Latitude (-140v to +140v)
d. Longitude (-140v to +140v)
e. Altitude (-140v to +140v)
f. High quality ground

Each of the conductors are separately scheduled. The high quality ground is a return for each of the other lines and is not connected to chassis ground. The load between each line and high quality ground must be constant, resistive, and greater than 200,000 ohms, preferably more.

Time Comparison System. (Computed time unit) A 16-bit serial time code word is received once every 4 seconds from the magnetic tape playback unit. This time code word is applied to a magnetic core register which is read out at 4-second intervals causing a group of 16 relays to close and open in a combination corresponding to a time code word.

Real-Time Unit. The real-time unit provides a time code word (16-digit binary) from the timing terminal unit. The real-time code word is related to real-time WWV time signals.

Time Comparator Function. The time code word from the real-time unit is compared with the output of the computed time unit. Switches located on the panel allow advance or retard of the tape to control the speed of playback and produce close synchronism of the program with real time.

For a simplified block diagram of the acquisition programmer, see Fig. 4-16.

4.4.4 Digital-to-Teletype Converter (Fig. 4-17 and 4-12)

The digital-to-teletype (D/TT) converter converts radar range, azimuth, and elevation data and telemetry tracker azimuth and elevation data from cyclic-binary code to teletype code for transmission via 100-wpm teletype to the central computer. Time, station identification, synchronizing data, and quality information are also transmitted.

Since the operation of the radar and telemetry tracker D/TT converters are similar, only the radar D/TT converter is discussed here. Range, elevation, and azimuth data are transmitted from the radar in cyclic binary code, gated into magnetic core shift registers, and stored for subsequent serial readout. Continuous digital range data are produced by two 10-bit code wheels, one coarse and one fine, that

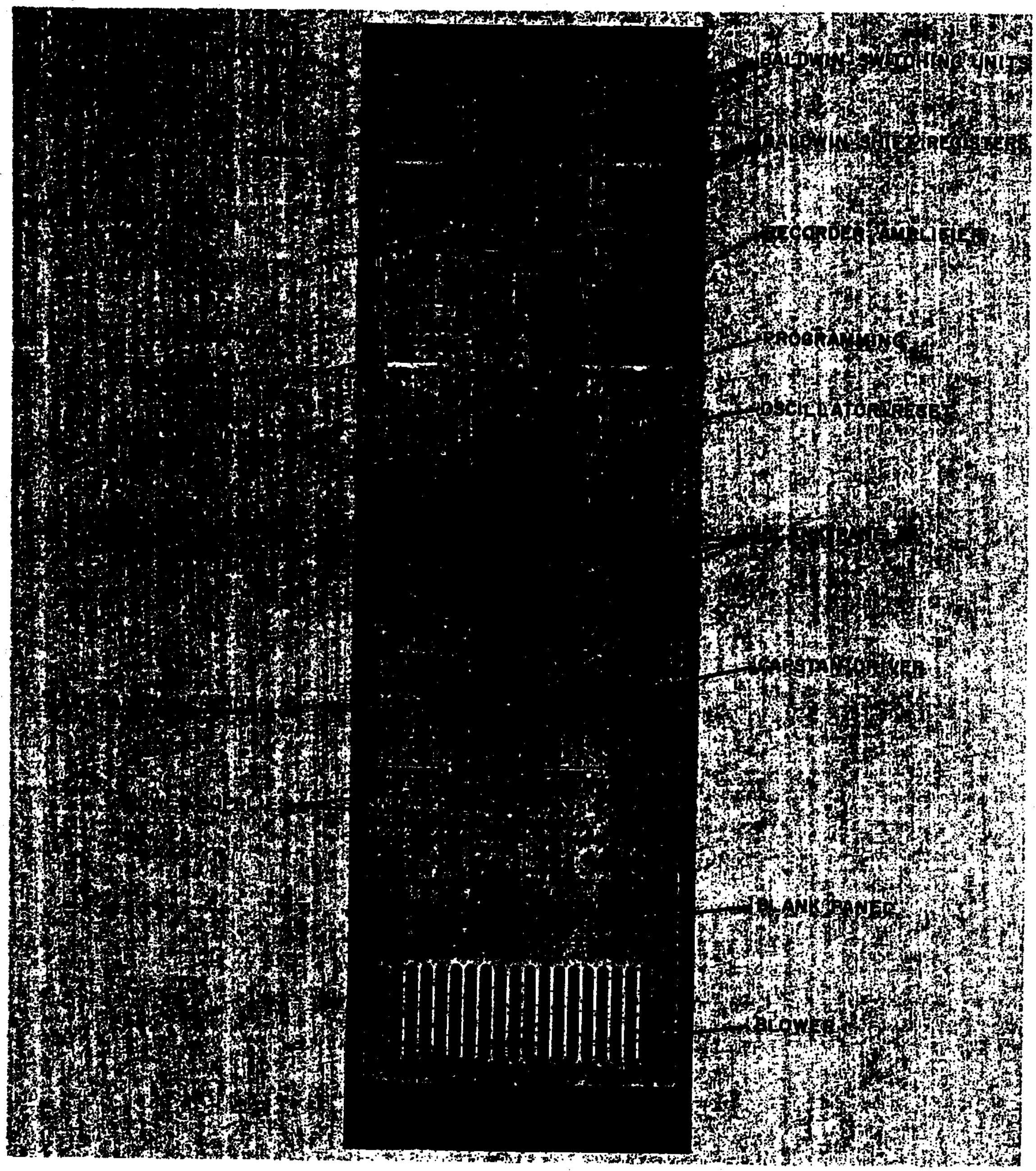


Fig. 4-17 Digital-to-Teletype Converter

produce a range resolution of 9.76 yards per bit. Twenty information bits are available, 19 for range encoding and one for ambiguity resolution. Only 18 bits are used for range encoding as a result of the passive track modification which utilizes the least significant (19th) range bit to provide an indication of the passive track mode of Verlort operation. This results in a range resolution of 19.52 yards. Digital azimuth and elevation antenna position data are transmitted by 16-bit code wheels. The azimuth and elevation code wheels are pulsed simultaneously by timing pulses originating at the shift register control unit. The pulses excite the code wheels and gate the input to the shift register simultaneously once every four seconds. As the range information is available continuously from the range code wheels and encoders, the input gate determines the instant of range input sampling. Gating the inputs to the shift registers reduces the probability of noise being stored as data in the magnetic core shift registers. Time words from the central timing unit and synchronizing data are also read into magnetic core shift registers once every four seconds.

The data which are read into the magnetic core shift registers are read out serially into a teletype line converter for 100-wpm transmission to the central computer. The heading information consists of data, station identification, tracking equipment identification, and data quality factor information. The word heading is programmed within the start-of-word, range, and end-of-word shift registers by means of switches controlled by the operator. The next elements to be shifted into the teletype line converter constitute the data word. The data word consists of time, azimuth, elevation, range, quality, and end-of-word information, in that order. During the time the heading is being transmitted, the elevation, azimuth, and time shift registers are removed from the circuit by a control circuit. The outputs from the range, azimuth, and elevation code wheels are in cyclic binary code. These words are changed into binary code prior to transmission by a cyclic binary-to-binary converter inserted between the time shift register and the azimuth shift register. In addition, the azimuth word is inverted because of the method used to mount the angle encoder on the radar. Reinversion of the word to the correct form is accomplished in the cyclic binary-to-binary converter.

A parity bit is inserted after every even bit sequence. This is accomplished by a parity-bit generator which is controlled by reset pulses from the shift register control unit. The pulses out of the registers are counted by the parity-bit generator. A parity pulse is inserted or not inserted, depending on the number of pulses counted during the bit sequence. If an even number of data pulses are counted, a parity bit is inserted to make the total number of pulses transmitted odd. If an odd number of data pulses are counted, no parity pulse is inserted and the total number of pulses transmitted is odd. The parity generator assures that an odd number of pulses are transmitted during each bit sequence on the teletype tape. The central computer senses bit sequences composed of an even number of pulses and rejects that particular sequence. The computer accepts only sequences which contain an odd number of pulses. The computer detects the total number of sequences in a received word and if that total is not correct, that word will be rejected. If a word is rejected, the computer is still able to compute an accurate orbit on the basis of the preceding and succeeding data samples which occur once every 4 seconds.

A sample header and data word of a typical VERLORT tape is shown below. The first seven-bit sequences make up the header. Sequences 1 and 7 are the header "start" and "stop" indicators and the bit sequence must be even, and punched as indicated before the computer will recognize it as valid information. Sequences 2 through 6 are the "identification" bits giving information on the word message to follow; i.e., month, day, station, vehicle, etc.

Line	Header							Data Word																		
1	X							X																		
2	X						X	X																		
*3	X						X																			
4	X						X																			X
**5							X																			X
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

* Sprocket holes appear between lines 2 and 3
** Parity Pulse Line

The bit sequences 8 through 26 make up the data word. Sequences 8 and 26 are the word "start" and "stop" indicators and must be even and punched, as shown, to be recognized as valid. Sequences 9 through 25 are the sequences giving data on time, azimuth, elevation, and range. All sequences must be recognized as valid before the word will be accepted as good.

The signal emanating from the teletype line converter is applied directly to a 100-wpm teletype tape perforator. A magnetic tape recording is made of this signal and it may be played into the line at any time. A separate channel is provided on the tape for a voice description of the data. This makes it possible to go through the tape at a later time to determine orally the data that appears on that section of the tape.

For a simplified block diagram of the D/TT converter see Fig. 4-12.

4.4.5 Cartesian-to-Polar Converter (Fig. 4-18 and 4-13)

The cartesian-to-polar (C/P) converter converts tracking data from cartesian d-c x, y, and z signals. The polar θ, ϕ, and r synchro outputs which are applied to the antenna and range servo systems of the Verlort radars. Polar θ and ϕ outputs are also applied to the acquisition and tracking control and made available to the slave-data bus.

Parallax-corrected Cartesian x, y, and z data from a D/A converter are applied to the input smoothing circuits of the C/P converter. The smoothed x and y data are applied to the azimuth resolver, and the smoothed z data are applied to the elevation resolver. The resolvers perform the necessary operations on the data to produce corrected two-speed θ and ϕ synchro signals and a d-c range voltage. The d-c range voltage is applied to a range unit for conversion to two-speed synchro data. The one-speed θ and ϕ synchro signals are routed to the radar antenna servo or to the acquisition and tracking console for application to the slave-data bus. The 36-speed θ and ϕ data are not used in this application. The

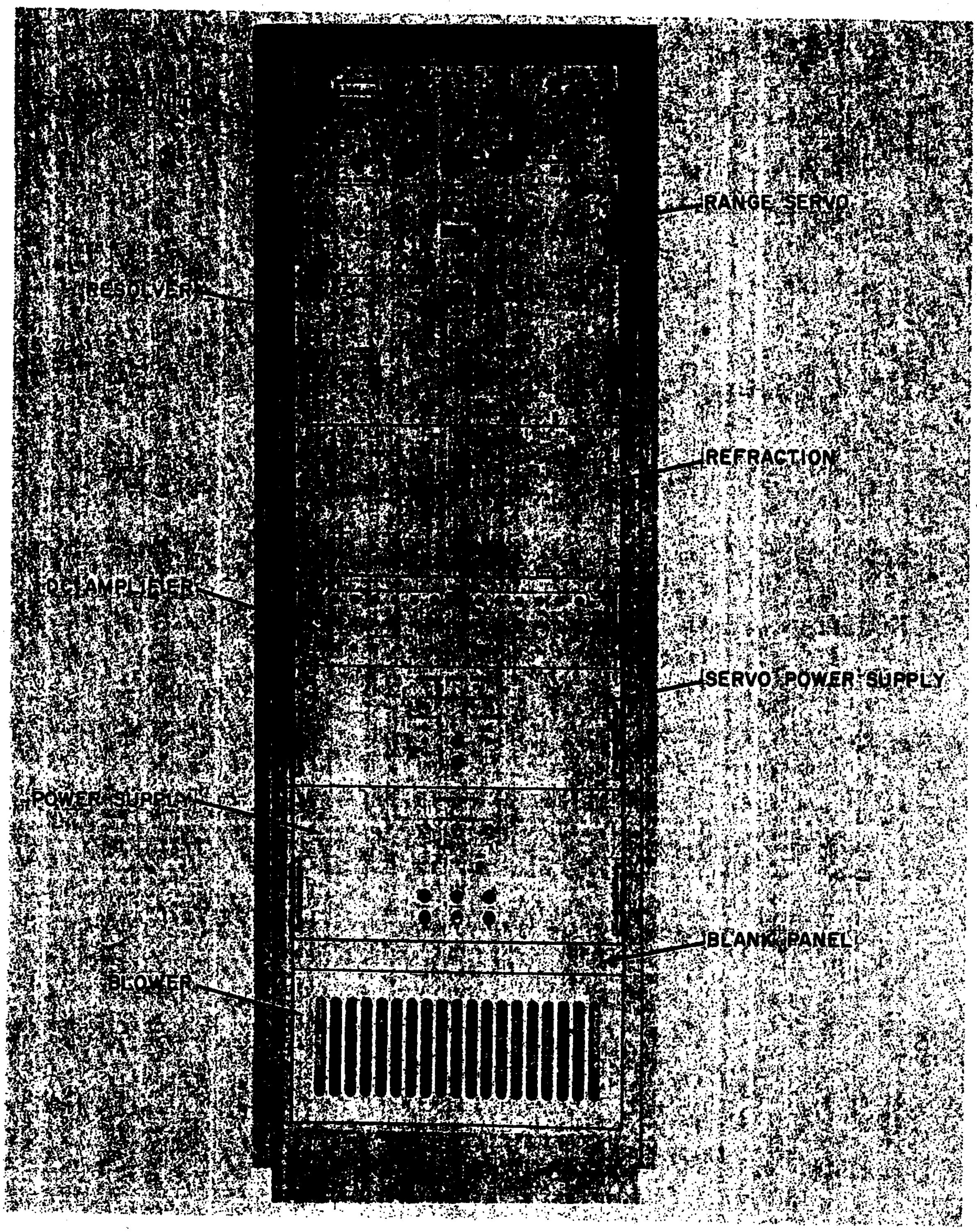


Fig. 4-18 Cartesian-to-Polar Converter

two-speed range synchro data are routed to the radar only to position the radar range gate. See Fig. 4-13 for a simplified block diagram of the C/P converter.

4.4.6 Polar to Cartesian Converter (Fig. 4-19 and 4-20)

The polar-to-cartesian (P/C) converter converts the radar tracking data from polar coordinates to cartesian coordinates. The transmission of polar data requires five channels and complex parallax and earth curvature corrections. Conversion of the data to cartesian coordinates reduces the required transmission channels to three and simplifies the parallax and curvature corrections.

The Verlort radars have three potentiometers which produce voltages proportional to sin θ, and cos θ, sin ϕ, cos ϕ, and r. θ represents the antenna azimuth angle, ϕ represents the antenna elevation angle, and r respresents slant range to the target. The P/C converter interconnects these five radar outputs to produce voltages which represent the target position in the three cartesian coordinates x, y, and z.

The output of the radar range potentiometer is amplified and converted to a double-ended signal which is placed across the elevation potentiometer. The elevation potentiometer multiplies range times the sine and cosine of the elevation angle to produce r sin ϕ and r cos ϕ. The r sin ϕ term is inverted in an amplifier, smoothed and inverted again, and applied as the smoothed z term to the output of the P/C converter. The r cos ϕ term is amplified and converted to a double-ended signal which is placed across the azimuth potentiometer.

The azimuth potentiometer multiplies r cos ϕ times the sine and cosine of the azimuth angle to produce r cos ϕ sin θ, or y, and r cos ϕ cos θ, or x. The two outputs, x and y, are inverted in amplifiers, smoothed and inverted a second time, and applied as smoothed x and y data to the output of the P/C converter.

Refraction Corrector

The refraction corrector corrects the z coordinate for radiation refraction between the vehicle and the radar. The refraction correction is a function of the elevation angle. For this reason,

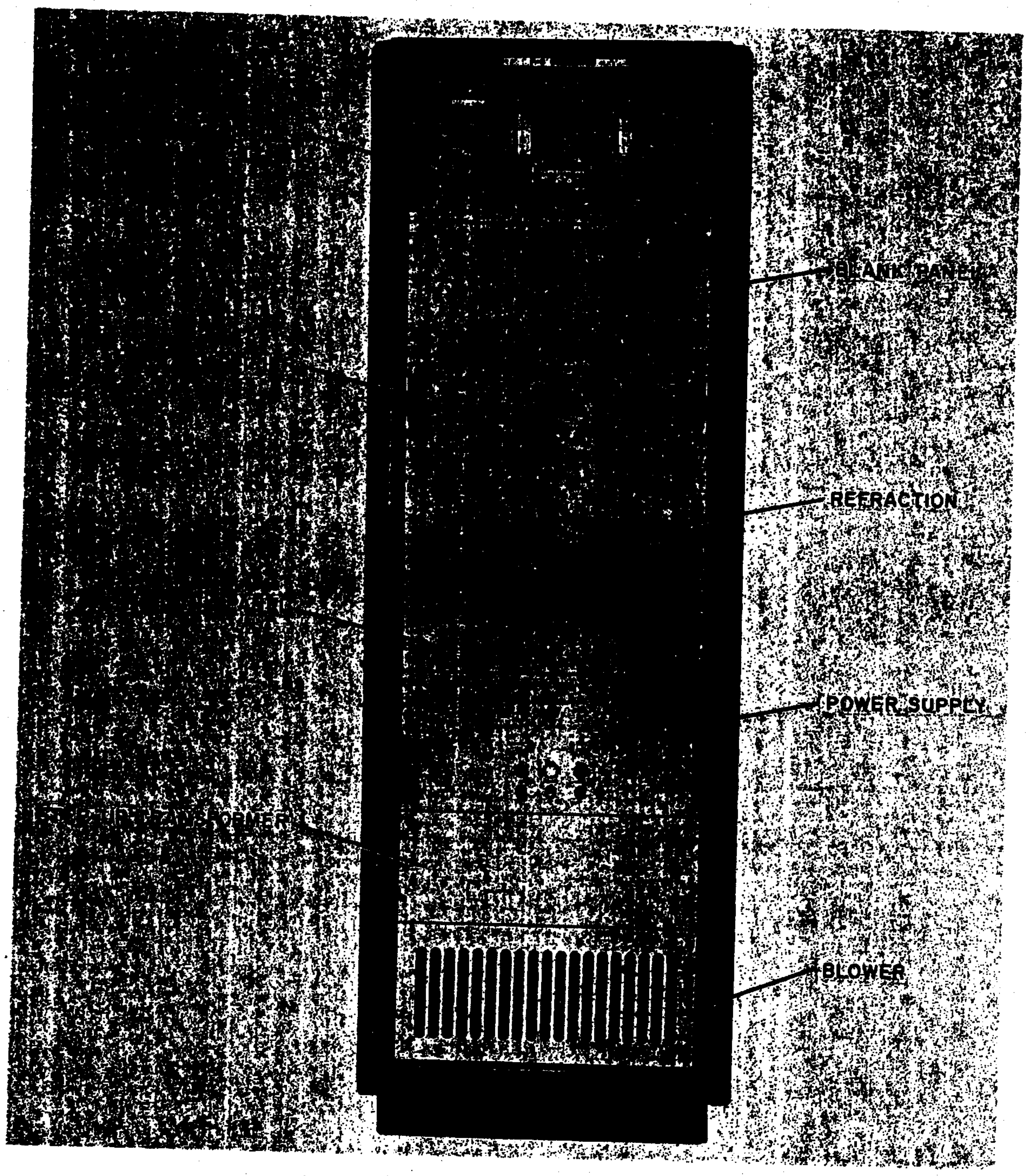


Fig. 4-19 Polar-to-Cartesian Converter

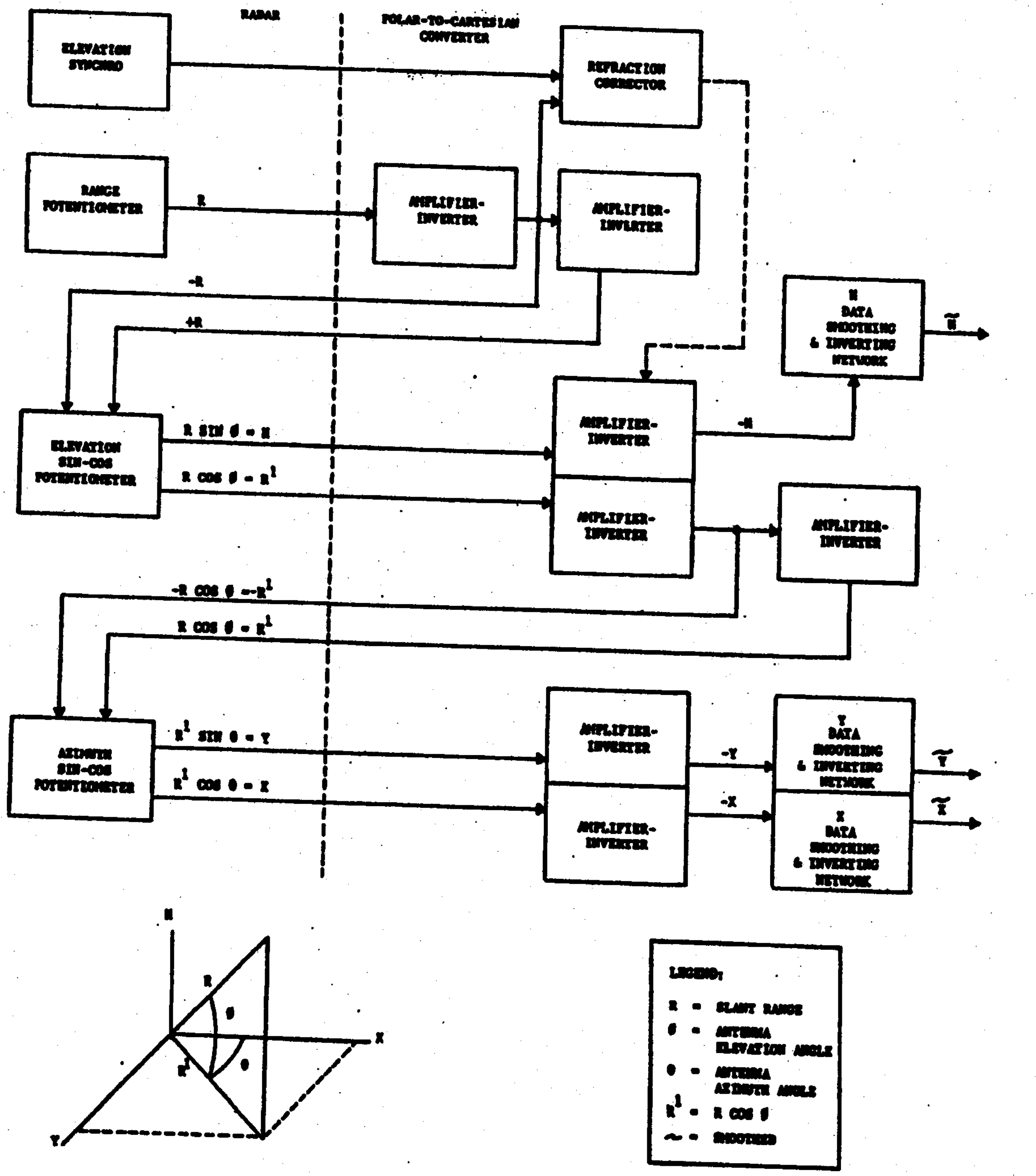


Fig. 4-20 Polar/Cartesian Converter Block Diagram

elevation synchro data from the radar and range data from the range amplifier inverter are supplied to the refraction corrector. The refraction correction is generated and applied to a servo amplifier which rotates a potentiometer to enter the refraction correction in the z channel of the P/C converter. Figure 4-20 is a simplified block diagram of the P/C converter.

4.4.7 Data Van Control Unit (Fig. 4-26 and 4-22)

The data van control unit consists of rack-mounted azimuth and elevation coordinate rotator units, range test simulator, synchro control relays, d-c amplifiers, and associated power supplies.

The prime purpose of this equipment is to provide a range, azimuth, and elevation test data simulation to facilitate testing and calibration of data loops. See Fig. 4-22 for simplified block diagram of the data van control unit.

4.4.8 Coordinate Transformation Unit (Fig 4-23 and 4-24)

The coordinate transformation unit, located at Pt. Mugu applies coordinate rotation and spherical corrections to the slave track data that is transmitted between VAFB and Pt. Mugu. It applies the corrections to both incoming and outgoing data such that incoming data, upon receipt, is translated into Pt. Mugu radar coordinates, and outgoing data is translated into VAFB radar coordinates prior to transmission.

The coordinate transformation unit is housed in a standard rack, and consists of two coordinate transformation sub-units, two spherical computers, a resolver, 30 d-c amplifiers, and associated support equipment.

Coordinate data is transmitted from VAFB to Pt. Mugu in digital form and is received by the D/A transceiver. The D/A transceiver converts the data to analog form and applies parallax correction. This corresponds to a translation of the coordinate system from A to B to C as shown in Fig. 4-25. However, the system must still be rotated to that the antenna at C "looks" in the proper direction. This function is performed by a coordinate transformation subunit which makes a matrix multiplication in three dimensions to rotate the axes. The corrected

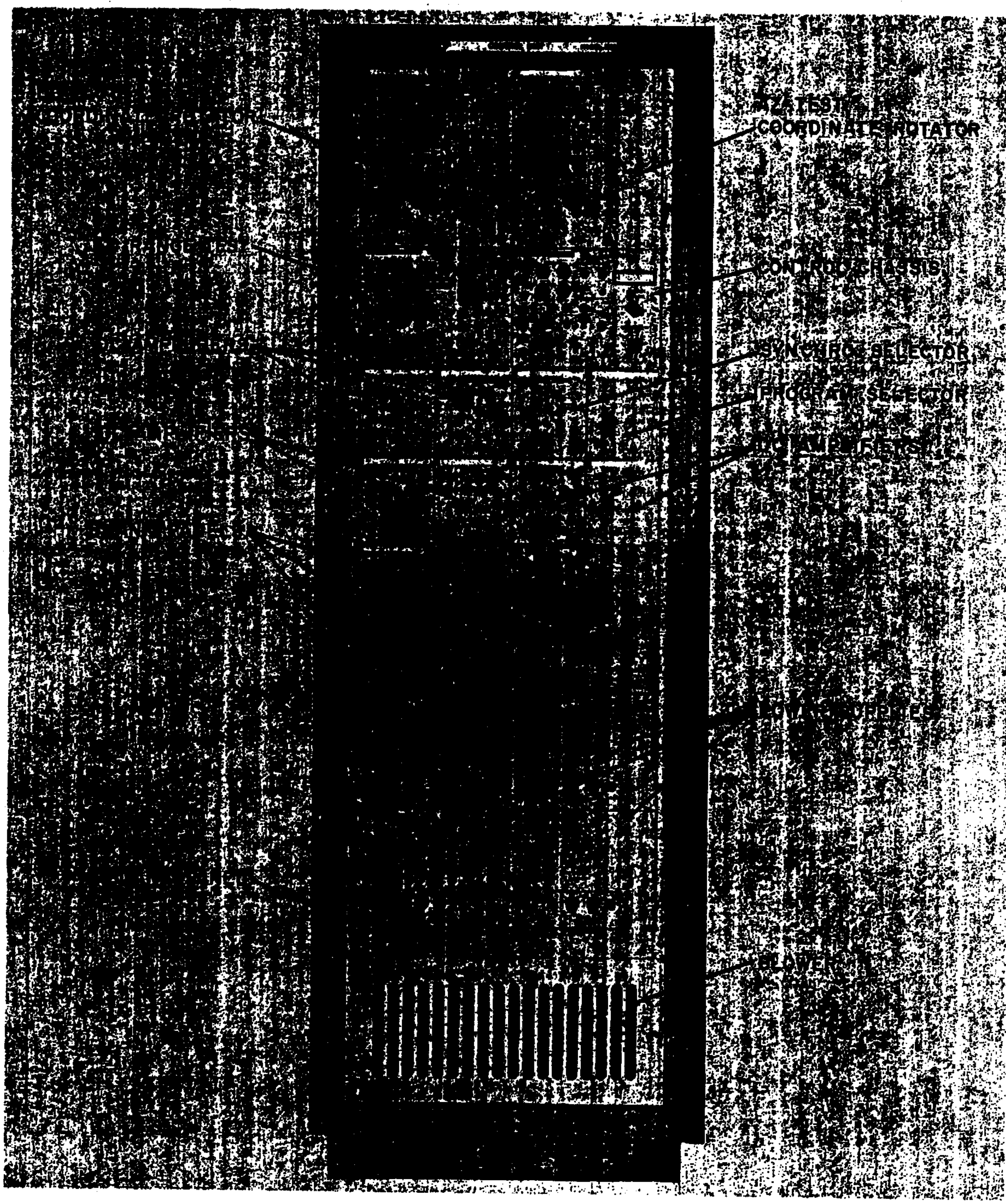


Fig. 4-21 Data Van Control Unit

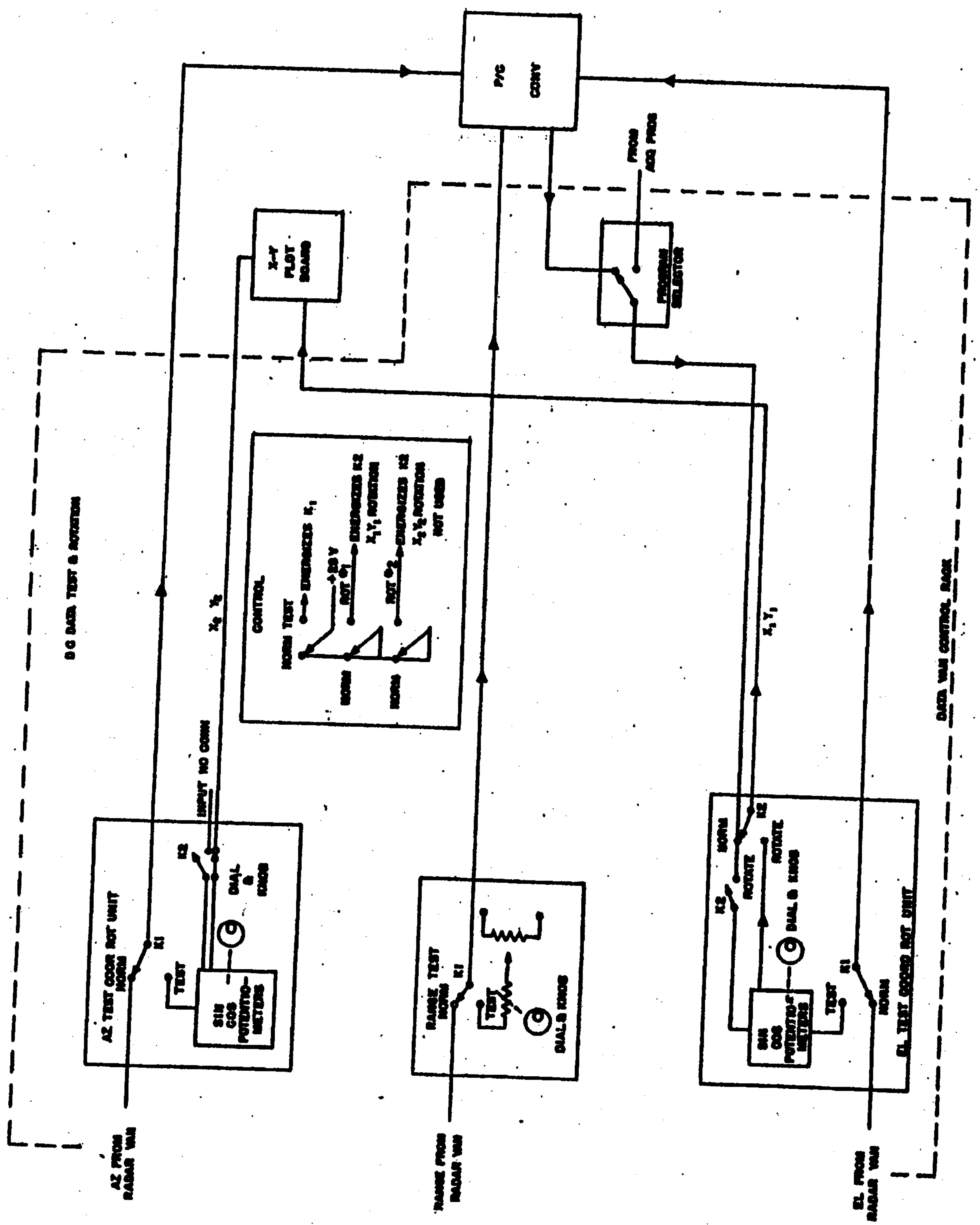


Fig. 4-22a Data Van Control Unit, Simplified Block Diagram (Sheet 1)

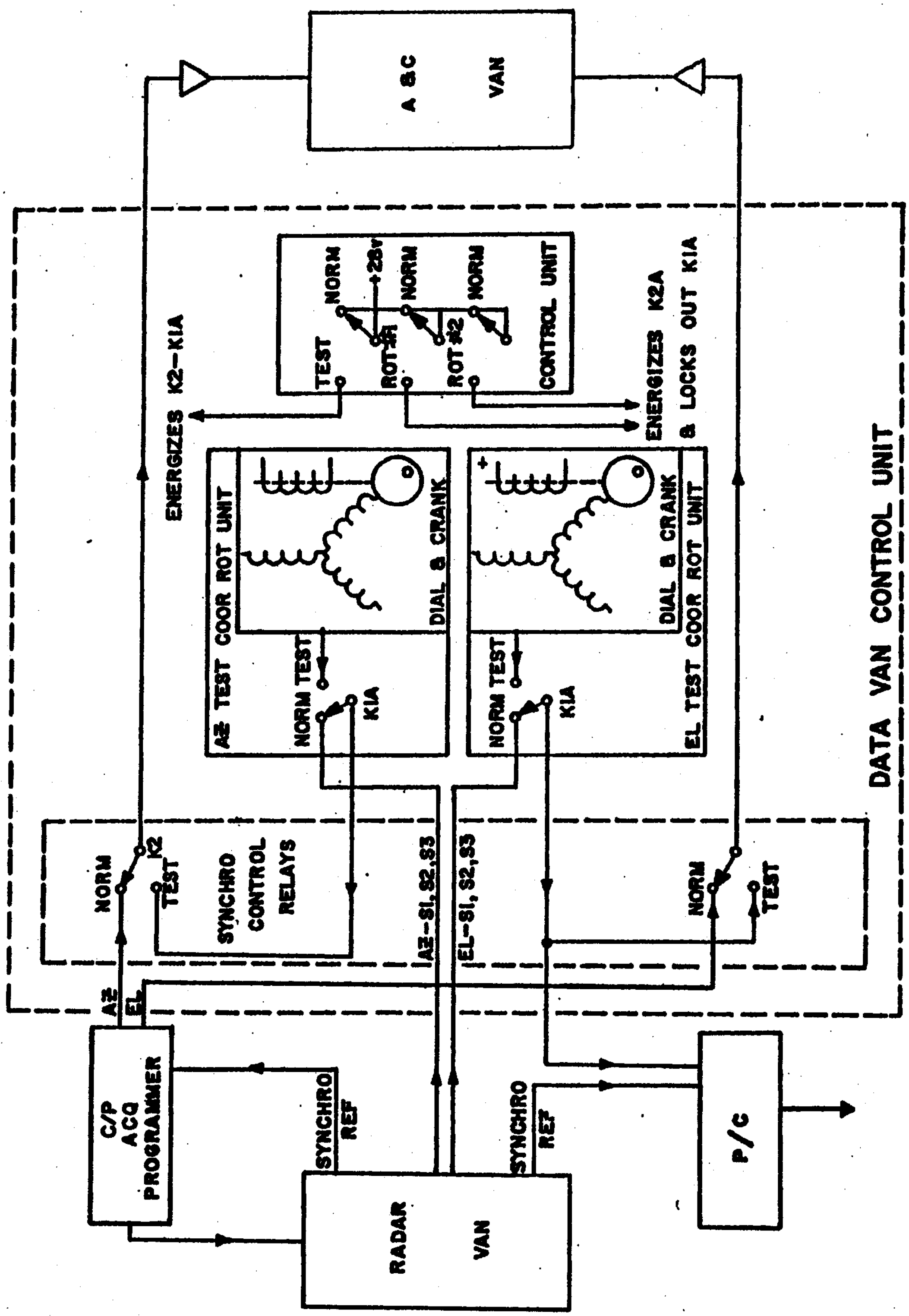


Fig. 4-22b Data Van Control Unit, Simplified Block Diagram

(Sheet 1)

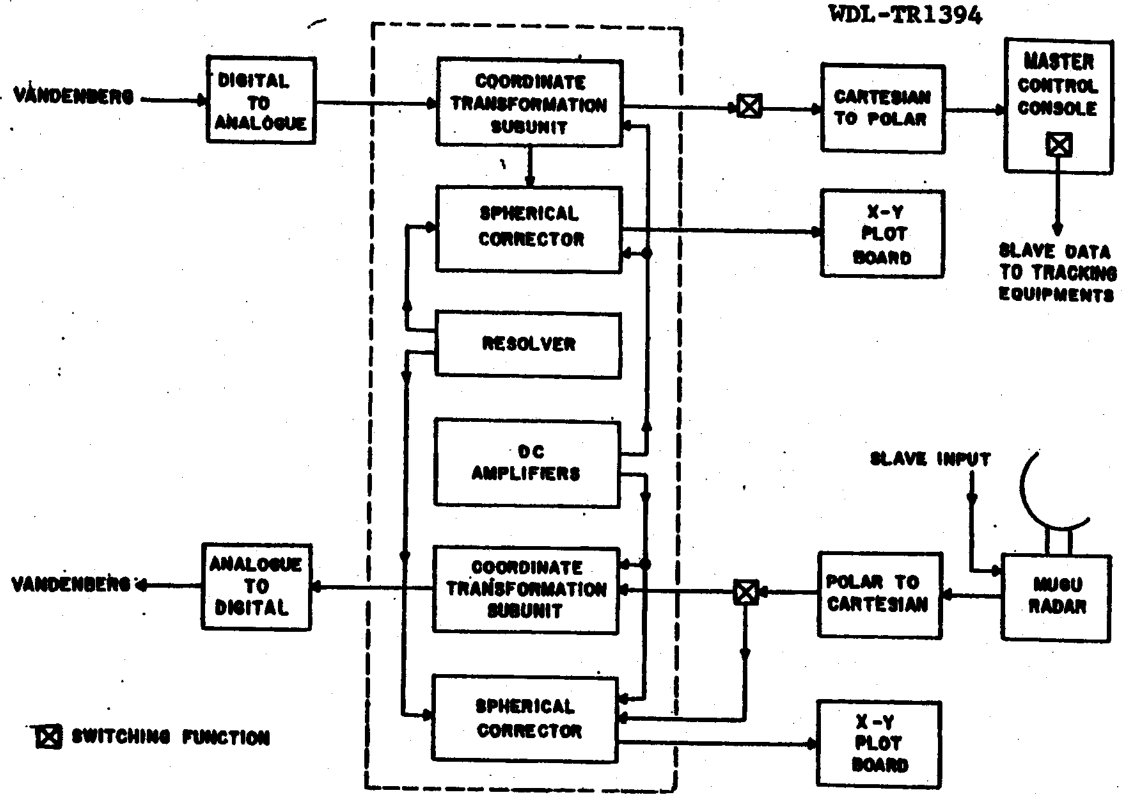


Fig. 4-24 Coordinate Transformation Unit Block Diagram

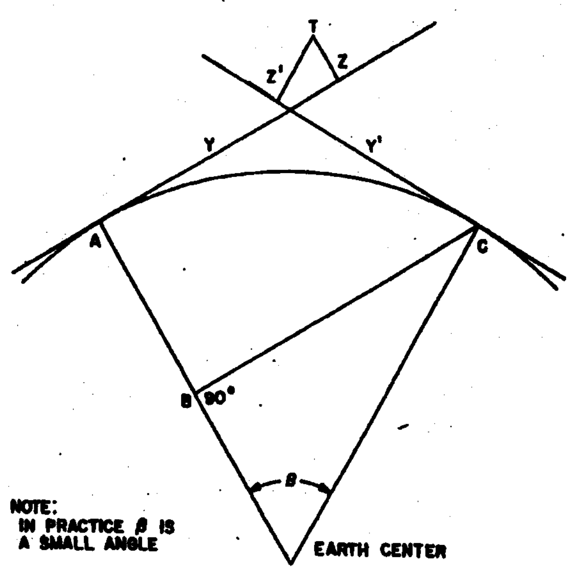


Fig. 4-25 Two Dimensional Coordinate System

information is now fed out through switching to a C/P converter and is then in a form for use in slaving the tracking equipment and for driving various angle indicators. The coordinate transformation subunit also feeds a spherical computer which accounts for earth curvature between the two stations and applies its output to the x-y recorders.

When the VAFB radar is to be slaved to the Pt. Mugu radar, θ, ø and r data are converted to x, y, and z by a P/C converter and fed out to both a spherical computer and a coordinate transformation subunit. The spherical computer applies its correction and feeds x, y, and h to the local plotboard. The coordinate transformer rotates Pt. Mugu coordinates to VAFB coordinates and feeds out to an A/D converter which transmits the information to VAFB in digital form. See Fig. 4-24 for a simplified block diagram of the coordinate transformation unit.

4.4.9 X-Y Recorder (Plotboard) Fig. 4-26 and 4-27)

The x-y recorder (plotboard) is designed to record two y = f (x) plots by moving two pairs of pens. Each plot has two pens available, one to record the function y = f (x), the other to mark time or to mark special events. Normally one plot records the path of the tracked vehicle in x and y coordinates and the other plot records the y and z (radar plane elevation coordinates.

The x-y recorder consists of a control unit, three scale factor and parallax units, a voltage comparator and marker unit, a servo amplifier, a servo supply, and a power supply, as well as the plotting surface.

The x-y recorder provides the following variations in display: parallax correction circuits shift the origin of the plot; scale factor circuits expand or contract the plot; an interchange unit switches the plotted function from one pen arm to the other; and pen lift circuits lift the pen manually or automatically.

The interchange circuit is capable of switching the output of x and y amplifiers to the input of the x_2 and y_2 servo amplifiers and vice versa to permit the plotting of two function y = f (x) on completely across the plotting surface.

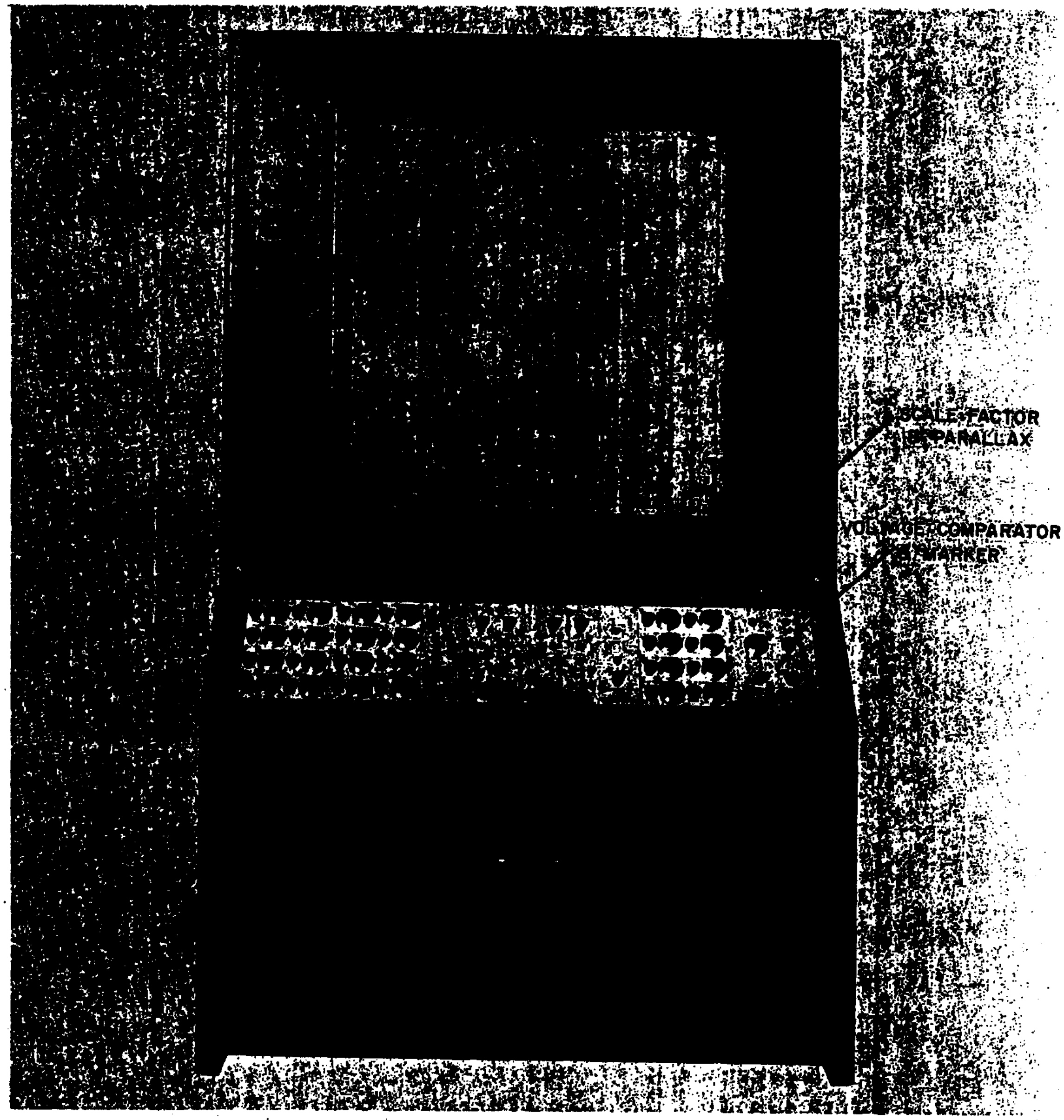


Fig. 4-26 X-Y Recorder Plotboard

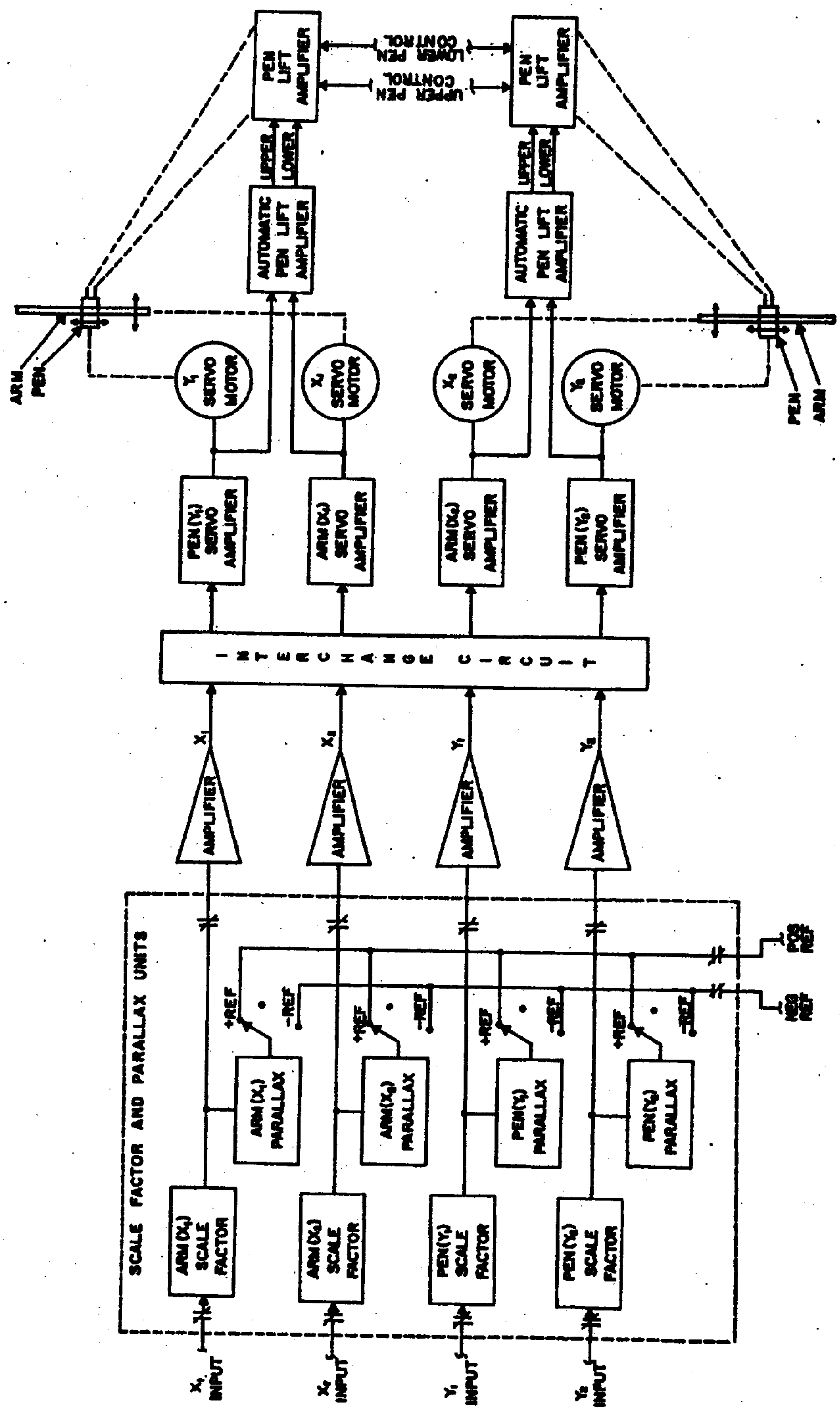


Fig. 4-27 Block Diagram of Plotboard

The servo amplifiers provide power to the servo motors which in turn drive plotboard arms and pens. The servo motors also drive feedback potentiometers which generate voltages for routing back to the input of the servo amplifiers. When the motors are correctly positioned the feedback voltages cancel has input voltages bringing motors, pens, and arms to rest. This condition prevails until the input signal level changes.

The pen lift circuits provide both manual or automatic pen lifting. In the automatic mode, excessively strong signals from the servo amplifiers are amplified by the pen lift amplifiers which lift the pens as they slew rapidly across the plotting surface. Rough signals and excessively strong signal inputs are thus prevented from marking the paper. Manual pen lift is provided as one method of marking special events. For a simplified block diagram of the recorder, see Fig. 4-27.

Figure 4-28 is typical of the type of chart furnished at all tracking stations for plotting the actual or preplot tracks. Each tracking station is provided with a map which covers the range of the station tracking equipment. This map is scaled approximately 80 n. miles to the inch to provide an overall map coverage of 1200 miles in each direction from the site, with the site centered on the map. This map coverage will allow adequate coverage of any passes up to 300 miles altitude down to 3 degrees on the horizon. The map is drawn utilizing the Lambert conformal conic projection with true north being straight up; i.e., the longitudinal line bisecting the site will be a straight line up and down. This is necessary because, with the Verlort equipment base line referenced on a true north-south and east-west, the latitude and longitude lines through the site should be vertical and horizontal in relation to the map so that the pen will trace a true south vertical bearing down the longitudinal line of the map.

At Hawaii and VAFB, the telemtry tracker plotboards require a chart for polar presentation of the vehicle track. This chart (Fig 4-29) consists of a grid of solid and dotted lines, both horizontal and vertical, with unlabeled azimuth and elevation scales on each side of the chart.

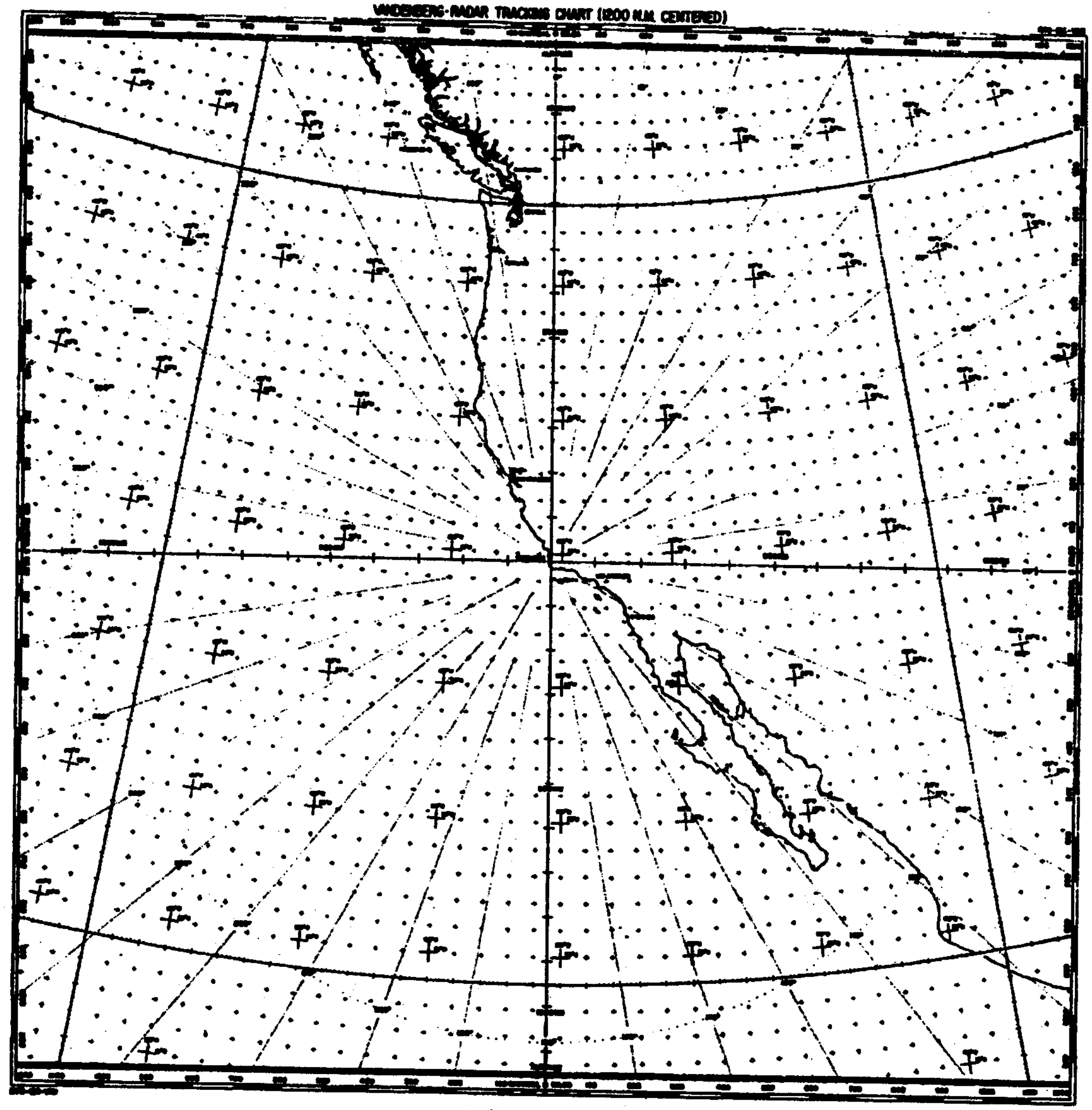


Fig. 4-28 Typical Tracking Station Chart

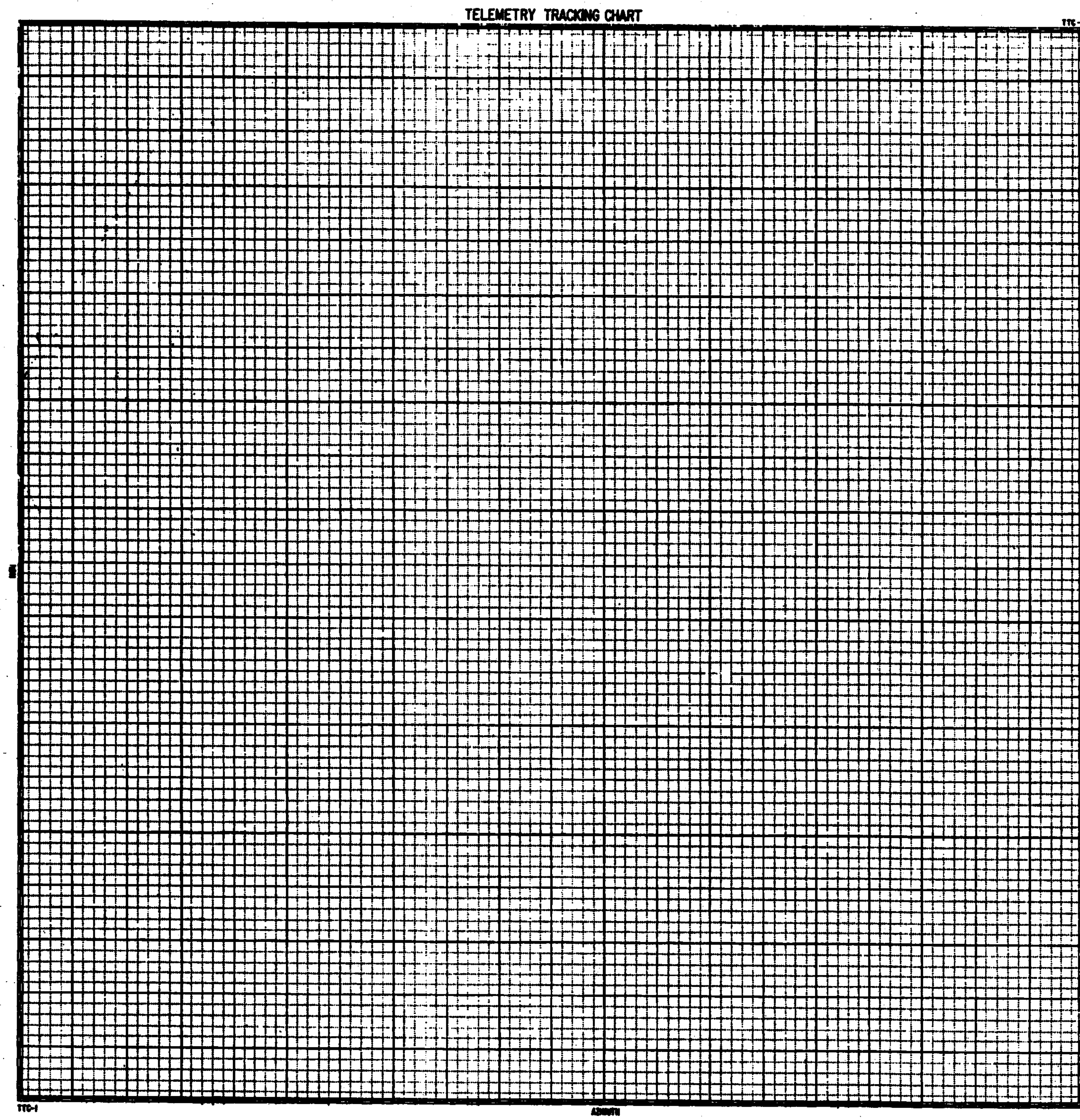


Fig. 4-29 Polar Chart for Telemetry Tracker Plotboard

Additional charts furnished at all stations include radar calibration charts, test charts, and aircraft tracking maps for calibration purposes.

4.4.10 Van Console Control (Fig. 4-30 and 4-31)

The van console control consists of rack-mounted servo indicator amplifiers, synchro line amplifiers, timing terminal unit, and associated power supplies.

The van console control houses the tracking equipment servo amplifiers and the timing terminal unit that delivers timing pulses to the master control and shift supervisor's console. See Fig. 4-31 for a simplified block diagram of the van console.

4.4.11 Building Console Control (Fig. 4-32 and 4-33)

The building console control consists of rack-mounted servo indicator amplifiers, synchro line amplifiers, and synchro-to-dc converter.

The purpose of the building console control is to house the tracking equipment servo and line amplifiers and the synchro-to-dc converter used to drive the telemetry tracker plotting board. See Fig. 4-33 for a simplified schematic of the building console control.

4.4.12 D-C Analog Data Line Amplifier System (Fig. 4-34 and 4-35)

The analog data line amplifier system (ADLA) is a part of the real-time telemetry system, and provides: (1) isolation between telemetry decommutator and instruments and circuitry of the vehicle control console, (2) remote monitoring of VCC instrument indications and levels, (3) level control of input signals to VCC, and (4) signal processing.

The analog data line amplifier consists of eleven modulator panel-mounted d-c amplifiers and a panel meter which is used to monitor the input or output of any of the eleven channels. Inputs to these channels from the telemetry decommutators are in the form of d-c staircase analog voltages within the range of 1 to 10 volts with a staircase sample rate of a least 10 samples per second. In operation, each channel level is preset with the built-in calibration circuitry to assure proper relay operation and meter indication at the VCC.

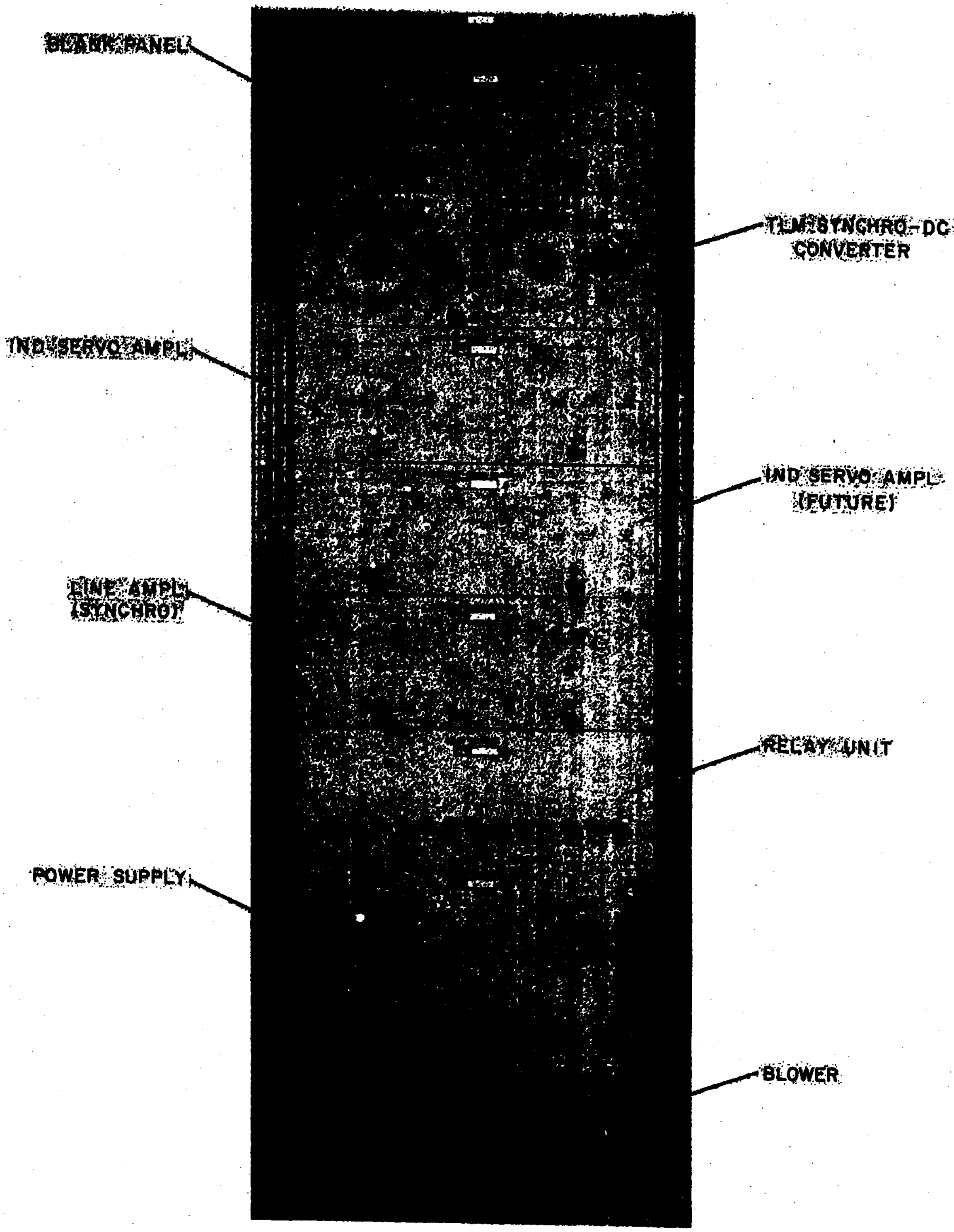


Fig. 4-32 Building Console Unit

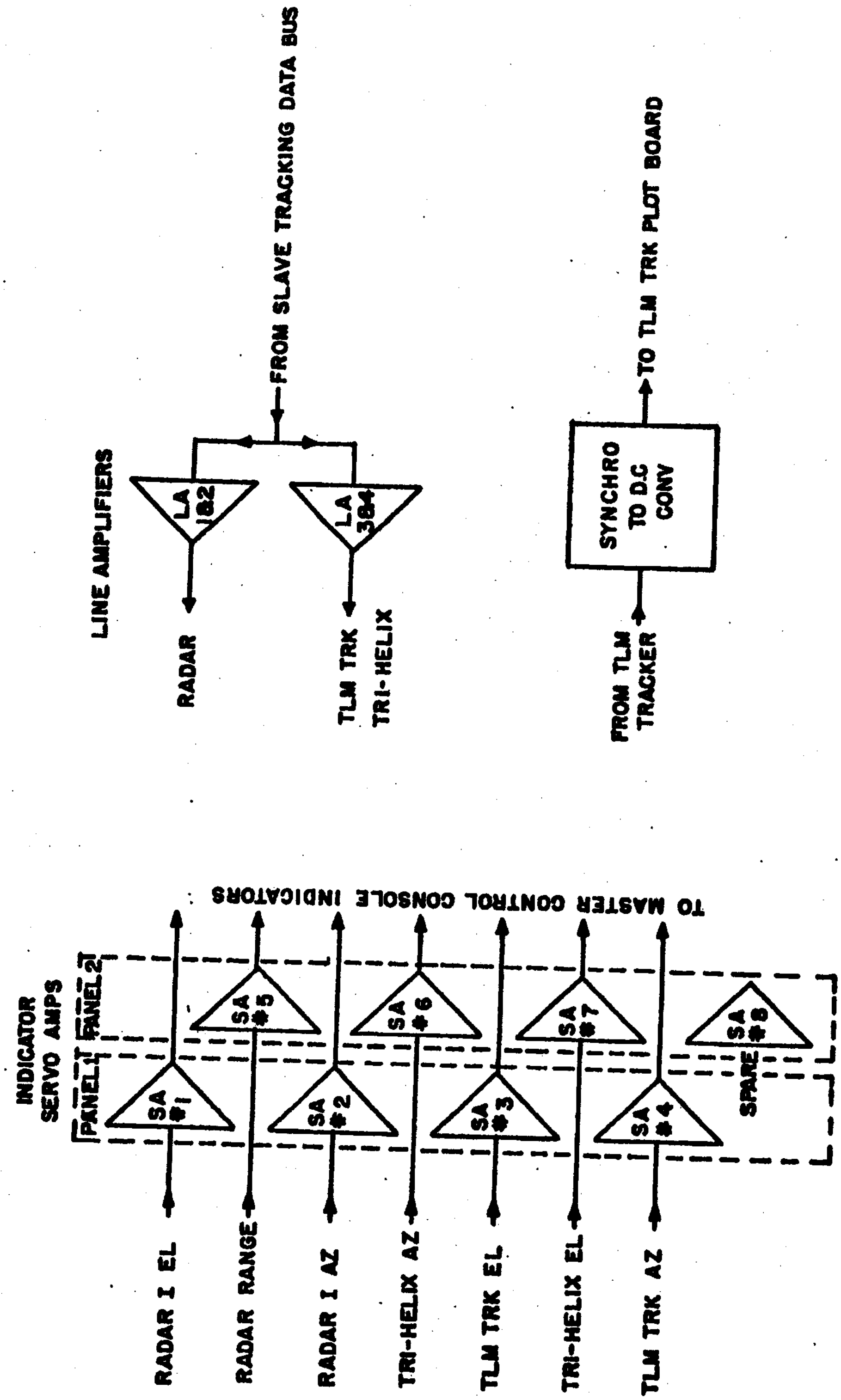


Fig. 4-33 Building Console Unit Simplified Block Diagram

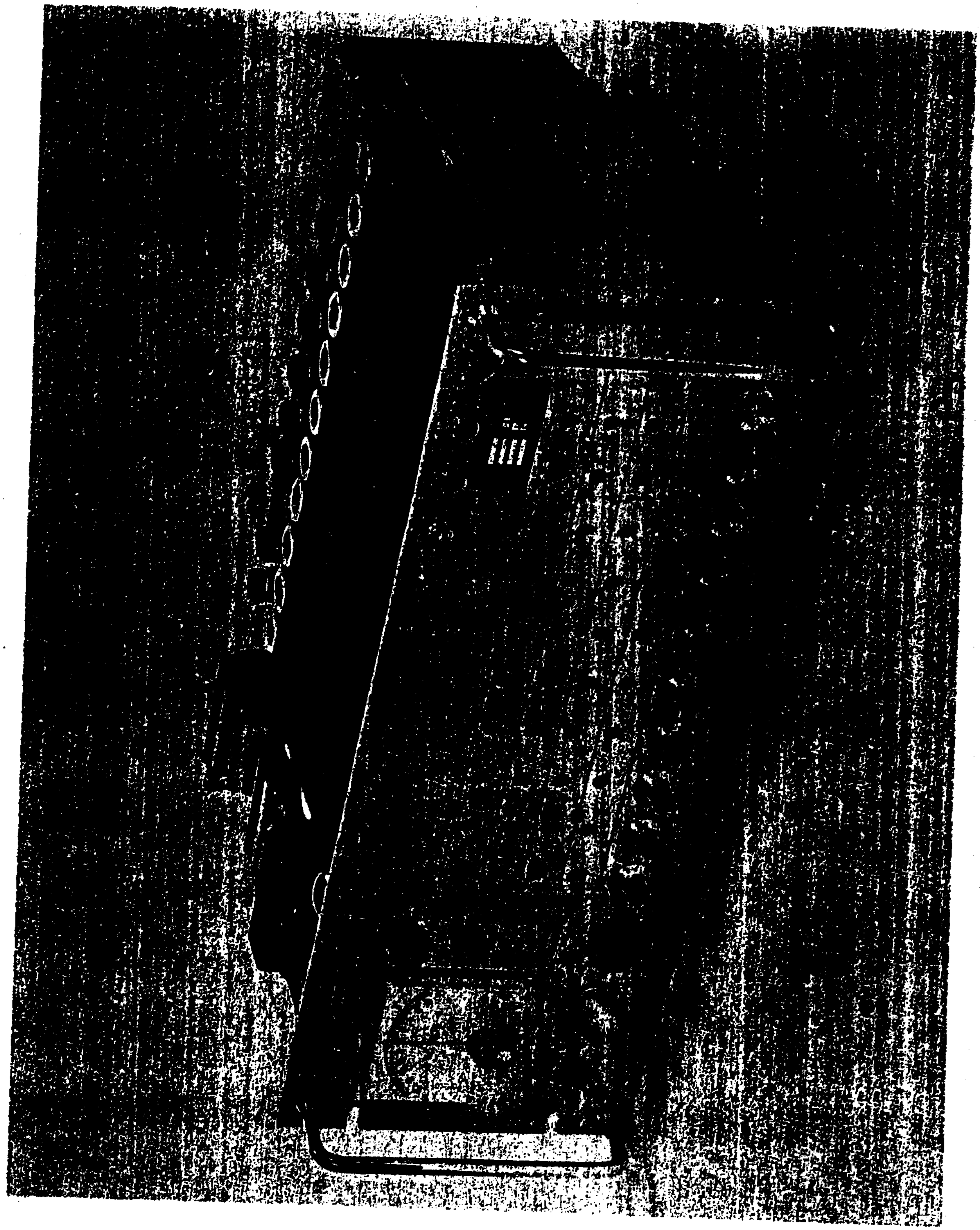


Fig. 4-34 D-C Analog Data Line Amplifier

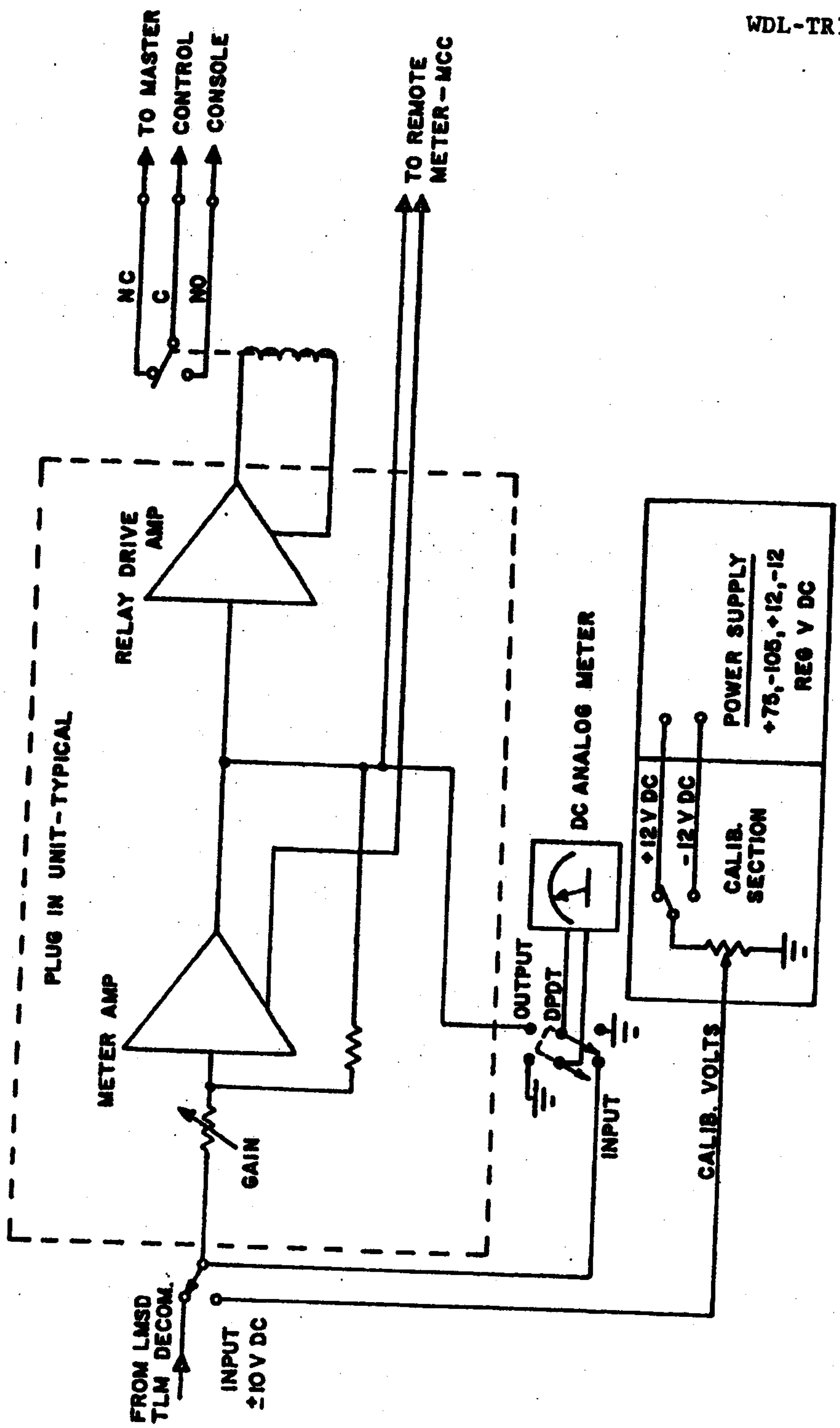


Fig. 4-35 D-C Analog Data Line Amplifier Simplified Block Diagram

The ADLA has the following additional capabilities which increase its versatility and reliability.

a. Calibration meter zero off-set control for each channel

b. Discriminator adjustment for relay operating "set point"

c. Local or remote relay operation for alarm or "on-off" functions

d. Front panel adjustment of amplifier gain, zero off-set, and scale factor adjustments.

The following telemetered readouts of vehicle function are relayed to the Vehicle Command Controller (VCC) console by the analog data line amplifier system:

a. Tone verification, A,B,C and D (4 chan.)

b. Reset monitor signal

c. Command verification 1,2,3 and 4, tone tell tale (4 chan.)

d. Payload function selector setting (4 chan.)

e. Increase/decrease switch position

f. 10-second step position

g. 100- second step position

h. Re-entry selector switch position

i. Transponder signal level

j. Transponder power level.

The SS/L and timer readout panel which provides the VCC indication for c,d,e,f,g and h, above, was not provided at Pt. Mugu. Readouts of these functions at Pt. Mugu are read out at the telemetry equipment, as required.

The following station information is also relayed to the master control console (MCC) by the ADLA system:

a. Sync alarm (T/M decom)

b. Doppler signal strength

c. Tri-helix (T/M) signal strength

d. Telemetry Tracker signal strength (VAFB and Hawaii)

4.5 Function and Description of Shift Supervisor's Console (Fig. 4-36)

The shift supervisor's console consists of the master timing reset panel, the station status panel, and the communications panel.

The purpose of the shift supervisor's console is to provide a supervisory operating position which monitors and controls total station activity.

4.5.1 Master Timing Reset Panel

See Fig. 5-8 for photograph of the master timing reset panel. This panel contains three clocks which display system time, estimated time to acquisition (ETA), and estimated time of track (ETT), respectively. System time is displayed as a six-digit number and is correlated with WWV time; ETA is displayed as a six-digit number expressing hours, minutes, and seconds; and ETT is displayed as a four-digit number indicating minutes and seconds. All three clocks have STOP, START, SET, RETARD, and ADVANCE controls.

4.5.2 Station Status Panel

See Fig. 4-37 for an outline drawing of the station status panel. This panel consists of two banks of indicator lights, energized by switches located at the equipment, which show the operative or inoperative status of the following equipment:

a. Acquisition and tracking controller
b. Vehicle command controller
c. Station data system
d. Timing system
e. Acquisition program
f. Long lines
g. Telemetry system.

4.5.3 Communications Panel

This panel is similar to the communication panels in the master control console.

4.6 Master Control Console (Fig. 4-38)

The master control console (MCC) consists of the acquisition and tracking console and the vehicle command control console.

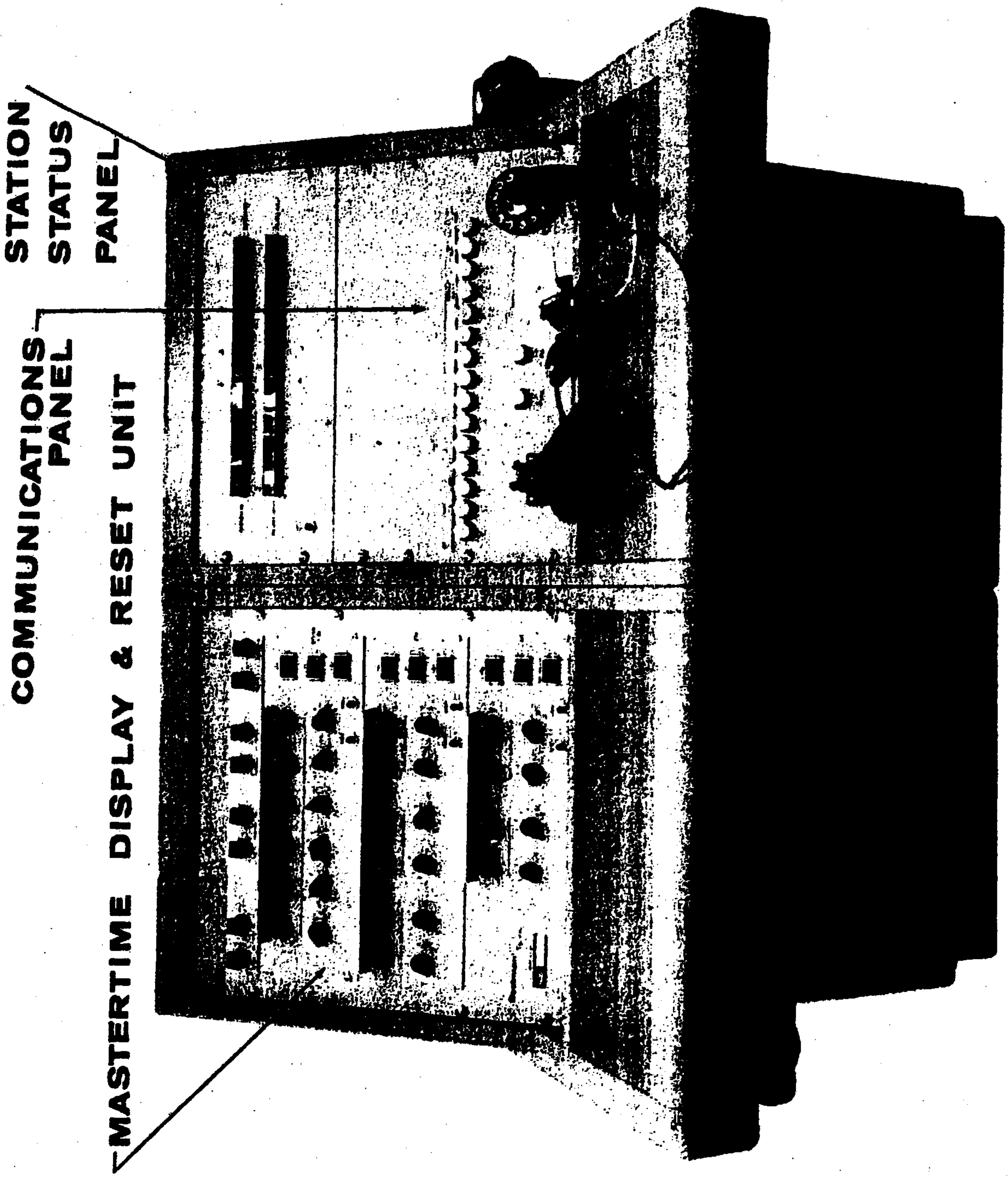


Fig. 4-36 Shift Supervisor's Console

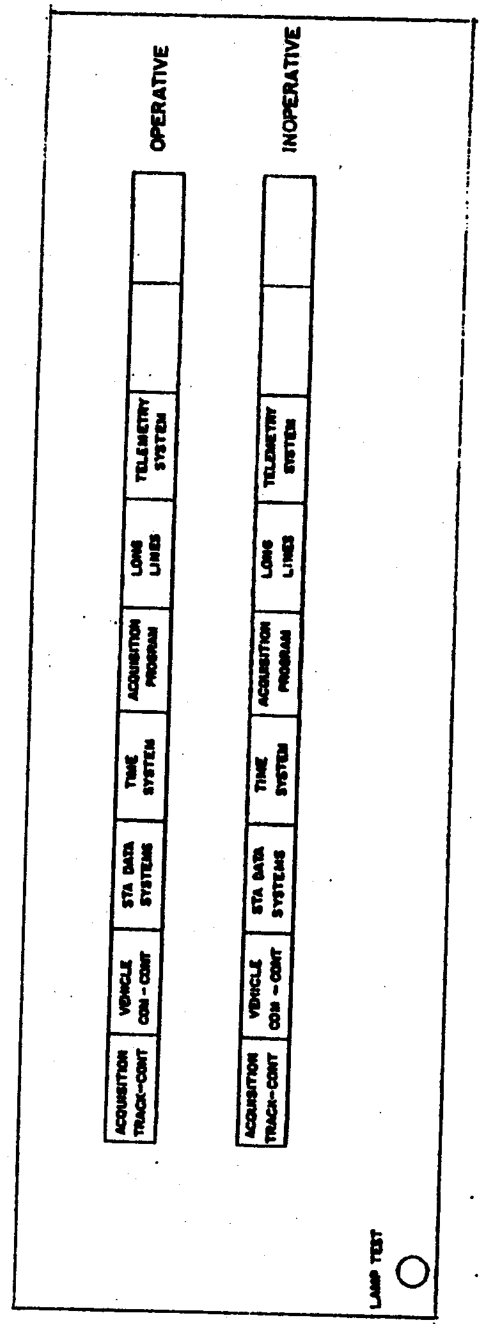


Fig. 4-37 Station Status Panel

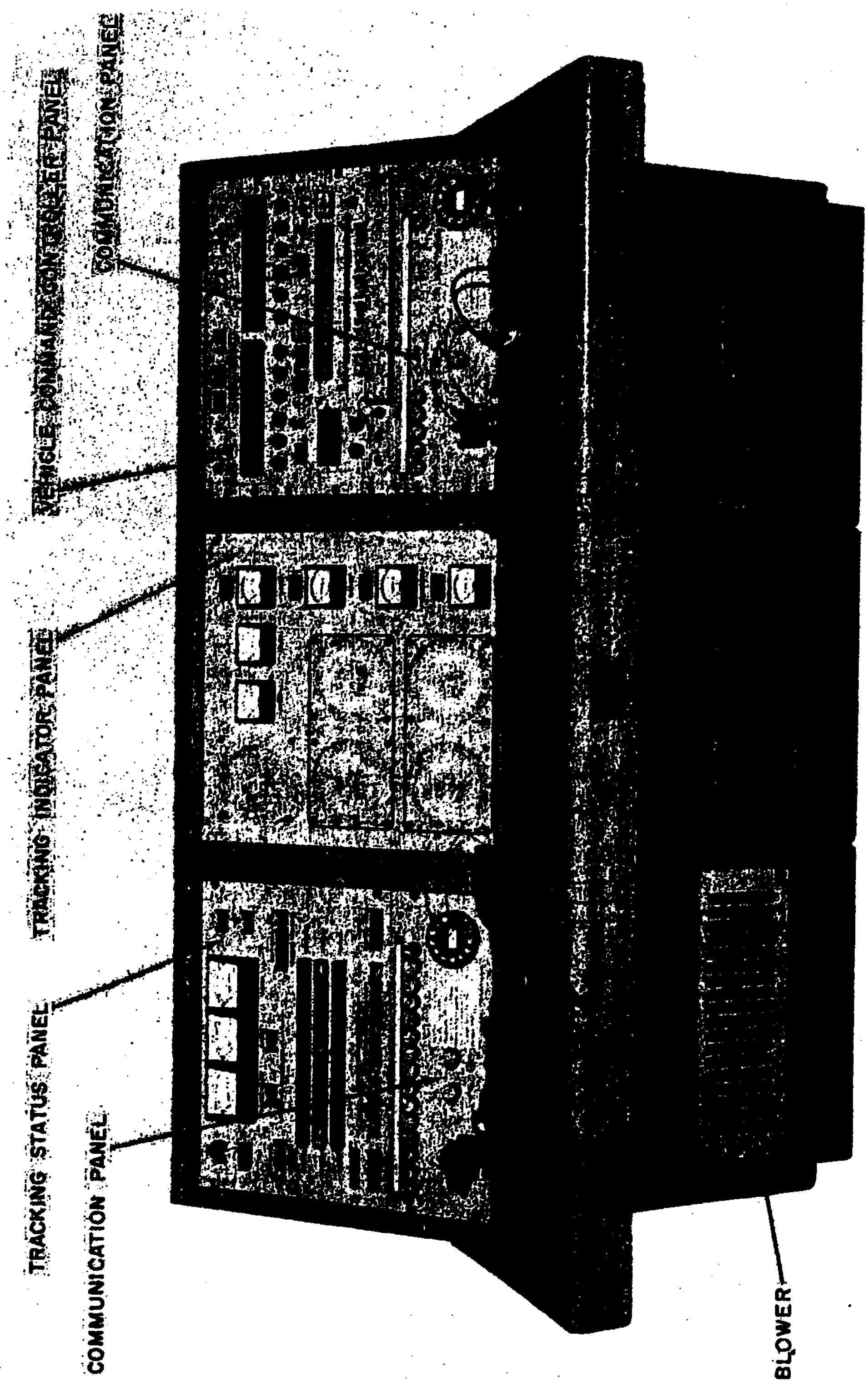


Fig. 4-38 Master Control Console

The purpose of the master control console is to:

a. Provide a display and control position for the status of the tracking equipment

b. Provide a display and control position for operating tracking equipment

c. Provide the necessary intrastation communications for the control operators

d. Provide a display and control position for commands sent to and received from the vehicle.

4.6.1 Acquisition and Tracking Console

The acquisition and tracking console provides control facilities and display features which enable the operator to evaluate the condition and progress of each tracking system, and to control the intrastation and interstation flow of tracking information.

The acquisition and tracking console is one of the three major supervisory operating positions. It is a part of the master control console and is located within the administration and control area at each tracking station. The configuration of the console is identical at all tracking stations for purposes of standardization. Because of the difference in size of the various stations, some of the controls and displays provided by the console are not connected. For example, switches and lights associated with the optical tracker and angle tracker (Remote I) are used only at Vandenberg AFB, and telemetry tracker controls and displays functions only at Vandenberg AFB and Hawaii since this system is not installed at other sites.

The following main panels make up the acquisition and tracking console: (1) tracking status panel, (2) tracking indicator panel, and (3) communications panel.

Tracking Status Panel (Fig. 4-39). This panel contains status lights which indicate the operating condition of station tracking systems; self-illuminated, magnetically-held, pushbutton switches which control the flow of tracking data; and signal level indicators which show r-f signal strength as received at the telemetry and doppler receiving equipment. Miscellaneous control and display functions are provided in addition to the major ones listed above. See Fig. 4-39.

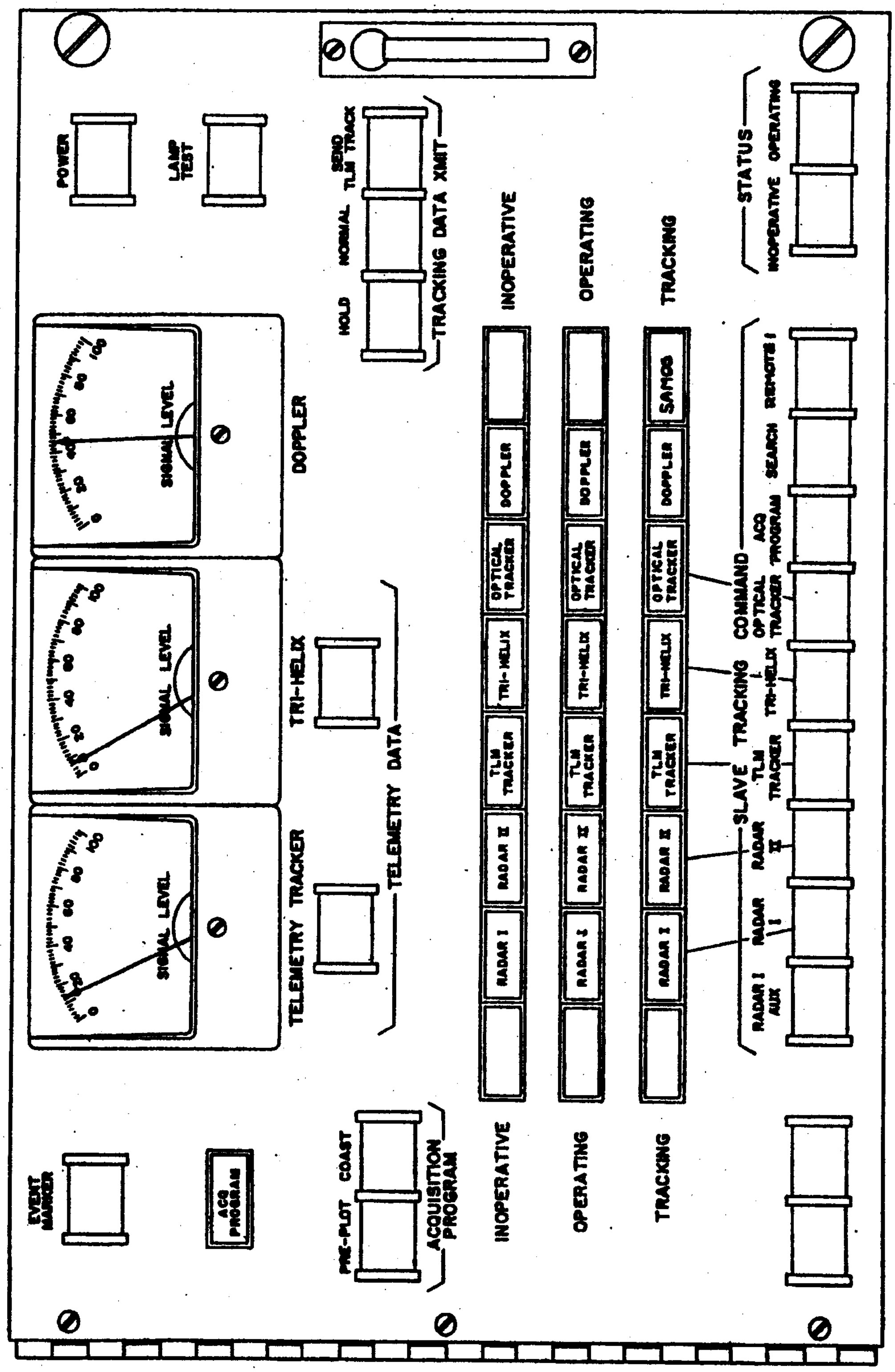


Fig. 4-39 Tracking Status Panel

a. Slave Tracking Command Switches.

The basic function of each of the nine mutually exclusive slave tracking command switches is described below. The magnetic holding coils of the pushbuttons are interlocked so that only the last one depressed is held down, and the others are released automatically.

(1) Radar I Auxiliary.

The RADAR I AUX control is used at the Vandenberg AFB and Hawaii stations only. Depressing this pushbutton actuates a relay that connects RADAR I synchro outputs to a slave-data bus. The slave-data bus is a circuit which interconnects all local tracking systems at each station through the control switching of the acquisition and tracking console. Other contacts energize corresponding tracking-data lights at the radar, telemetry tracker, and tri-helix control positions.

(2) Radar I.

At Vandenberg AFB and Hawaii, depressing the RADAR I pushbutton actuates relays that connect synchro data derived from the d-c potentiometer outputs of the radar antenna to the slave-data bus. This information is converted to digital form for transmission from the radar to the station control point. Digital techniques are used because of the distance involved between these two sites. The digital data are converted back to analog form for utilization at the control positions. At Point Mugu, Kodiak, and New Boston stations, depressing the RADAR I pushbutton connects radar synchro outputs to the slave data bus. Other contacts energize Radar I tracking-data lights at the radar, telemetry tracker, and tri-helix control positions.

(3) Radar II.

At the Kodiak, New Boston and Hawaii stations, the RADAR II control is not connected. At Vandenberg AFB, depressing the RADAR II pushbutton actuates relays which connect synchro data from the Point Mugu radar to the slave-data bus. These data are derived from the real-time digital transmission circuit between Vandenberg AFB and Point Mugu, and permit real-time slaving of the Vandenberg AFB radar in three parameters (θ, ϕ, r) to the Point Mugu radar and vice versa. Other relay contacts energize corresponding tracking-data lights at the local radar, telemetry tracker, and tri-helix control positions. At Point Mugu, depressing the pushbutton labelled RADAR II actuates relays which connect three parameter (θ, ϕ, r) slaving data from the Vandenberg AFB radar to the Mugu slave-data bus. These data are derived from the real-time digital transmission link between Vandenberg AFB and Point Mugu.

(4) Telemetry Tracker.
The TLM Tracker control applies to the Vandenberg AFB and Hawaii sites only. Depressing the TLM TRACKER pushbutton actuates a relay that connects synchro data (θ, ϕ) from the telemetry track antenna to the slave-data bus. Other contacts energize corresponding tracking-data lights at the radar, telemetry tracker, and tri-helix control positions.

(5) Tri-helix.
Depressing the TRI-HELIX pushbutton actuates a relay which connects synchro data (θ, ϕ) from the tri-helix antenna pedestal to the data bus. Other contacts energize corresponding tracking-data lights at the radar, telemetry tracker, and tri-helix operating positions.

(6) Optical Tracker.
(Vandenberg only.) The OPTICAL TRACKER pushbutton actuates a relay which connects synchro data (θ, ϕ) from the optical tracker to the remote synchro inputs of the local radar. Other contacts connect the radar synchro data (θ, ϕ) to the slave-data bus. Tracking-data lights labelled OPTICAL TRACKER at the local radar, telemetry tracker, and tri-helix control positions are energized by additional relay contact closures.

(7) The ACQ PROGRAM pushbutton actuates a relay that connects synchro data (θ, ϕ), as derived from the acquisition programmer in the data transmission area, to the slave-data bus. Other relay contacts energize tracking-data lights labeled ACQ PROGRAM at the radar, telemetry tracker, and tri-helix control positions.

(8) Search.
Depressing the SEARCH pushbutton actuates relays which energize indicator lights marked SEARCH at the radar, telemetry tracker, and tri-helix control positions, and indicates that tracking systems should operate independently in a search mode.

(9) Remote I (VAFB only)
The Remote I button actuates a relay which places two-axis SAMOS angle tracker synchro data (θ, ϕ) on the slave track bus. (See Para. C-1.2)

b. Tracking Status Indicators.
Operational status of the tracking equipment is indicated in three levels on separate banks of lights. The first condition, INOPERATIVE, indicates that the equipment is not able to function as part of the system. The second, condition, OPERATING, indicates that equipment is turned on and operating, or searching. The third condition, TRACKING, indicates that the system is actually tracking the vehicle. The indicator lights are energized automatically when the received signal strength reaches a predetermined value.

c. Acquisition Program Status.
The status light marked ACQ PROGRAM is energized by a switch labeled OPERATING located near the acquisition programmer in the data transmission van. When energized, this light indicates that the acquisition program has arrived from the central computer and is stored on magnetic tape in the acquisition programmer and is available for read-out upon command.

d. Acquisition Program Control.
Two other controls are provided for utilizing the acquisition program, in addition to the ACQ PROGRAM slave tracking command pushbutton. These are the pushbuttons (non-holding) marked PRE-PLOT and COAST. Their functions are as follows:

(1) Preplot.
A preplot of the acquisition program may be run out at high speed on the plot board prior to an actual pass, by depressing the pushbutton labeled PRE-PLOT. This actuates relays starting the acquisition programmer and connecting its output to the plot board input selector switch.

(2) Coast.
The COAST control is used to smooth the operation of tracking systems which are slaved to the acquisition program by passing over errors or discrepancies in the program which become apparent during the preplot. This is done by depressing the pushbutton labeled COAST which actuates relays in the acquisition programmer, disconnecting its output from the slave-data bus as long as the pushbutton is held down.

e. Event Marker Control.
Depressing the non-holding pushbutton labeled EVENT MARKER places a reference mark on the plot board at any time during a preplot or actual real-time plot during a pass.

f. Signal Level Indicators.

Three signal level indicators, labled TELEMETRY TRACKER, TRI-HELIX, and DOPPLER, are provided. These are panel meters used as remote signal level indicators for the telemetry tracker, tri-helix, and doppler systems.

(1) Telemetry Tracker.

At Hawaii and Vandenberg AFB only, the TELEMETRY TRACKER meter presents an analog indication of the relative signal level of the FM telemetry signal as derived from the agc voltage of the telemetry tracker receiver.

(2) Tri-helix.

The TRI-HELIX meter presents an analog indication of the relative signal level of the FM telemetry signal received by the tri-helix antenna. This indication is derived from the agc voltage of an active or standby telemetry receiver located in the LMSD telemetry van or building.

(3) Doppler.

This meter presents an analog indication of the relative signal level of the c-w acquisition signals as derived from the agc voltage of the doppler receiver.

g. Telemetry Data Controls.

Pushbutton switches directly below the TELEMETRY TRACKER and TRI-HELIX indicators activate relays which energize light indicators in the LMSD telemetry receiving area indicating which of the two systems (telemetry tracker or tri-helix) is receiving the strongest or most reliable signal. Holding circuits of these two pushbuttons are interlocked so that only the last one depressed is held and the other is automatically released.

h. Tracking Data Transmission.

Three TRACKING DATA XMIT pushbuttons, labeled HOLD, NORMAL, and SEND TLM TRACK, actuate light indicators in the communications area indicating to the teletype operator which tracking data are to be sent to the central computer. Pushbutton holding circuits are interlocked so that only the last one depressed is held and the other two are released automatically.

(1) Hold.

Depressing the HOLD pushbutton indicates the initial condition when no tracking data are available, or that data being received are not to be transmitted to the control computer.

(2) Normal.

Actuating the NORMAL pushbutton indicates that the normal routine of data transmission is to be followed. This routine is to send radar data, telemetry tracker data, and doppler data, in that order.

(3) Send Telemetry Tracker.
Actuating the SEND TLM TRACKER pushbutton indicates to the teletype operator that he is to transmit tracking data received from the telemetry tracker.

i. Status.
STATUS pushbuttons labelled INOPERATIVE and OPERATING energize lights on the shift supervisor's console which indicate the summarized condition of all local tracking systems as either inoperative or operating. Holding circuits are interlocked so that only the last pushbutton depressed is held and the other is automatically released.

j. Power.
Actuating the POWER pushbutton turns on all power supplies associated with the lights, relays, and synchro indicators of the tracking status panel and tracking indicator panel.

k. Lamp Test.
Actuating the LAMP TEST pushbutton (non-holding) connects the open side of all tracking status panel lights to ground, energizing all good lamps.

Tracking Indicator Panel (Fig. 4-40). Slaved synchro-operated indicators on the tracking indicator panel display angular azimuth and elevation information from the radar, telemetry tracker, and tri-helix, and range information from the radar. Elevation and azimuth information from the radar and telemetry tracker is display on dual-channel indicators, one indicator showing radar and telemetry tracker azimuth, and the other showing radar and telemetry tracker elevation. The inner indicator (open diamond cursor) is driven by a signal from the local radar synchro bus. The outer indicator (solid diamond cursor) is driven by a signal from the telemetry tracker synchro bus. Tri-helix azimuth and elevation information is displayed on single-channel indicators.

Other displays, such as BEACON SIGNAL LEVEL, BEACON POWER, and the various temperature indicators installed on the tracking indicator panel, are a part of the vehicle command control console function which occupies the other half of the master control console.

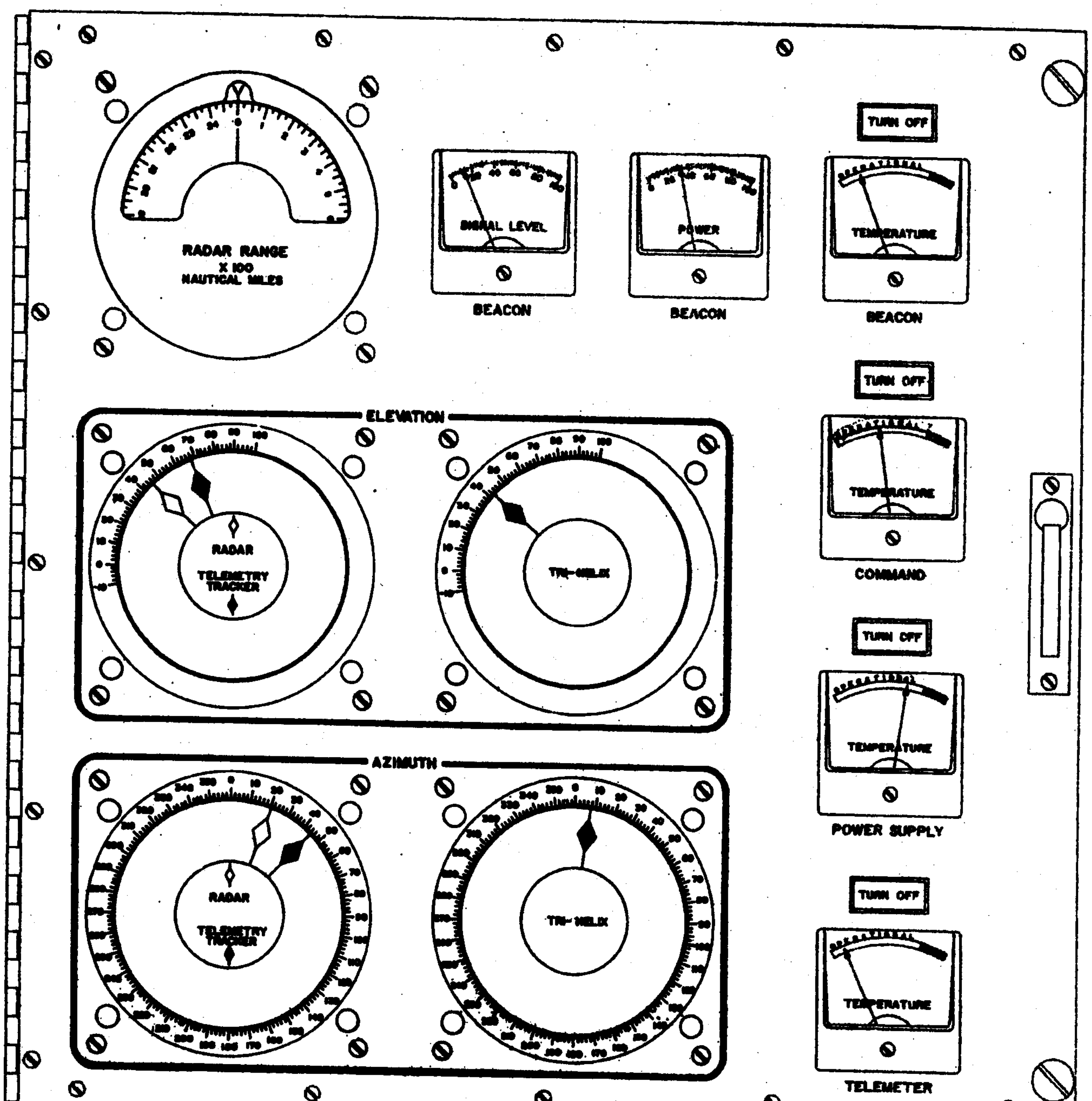


Fig. 4-40 Tracking Indicator Panel

Communications Panel. The third panel on the acquisition and tracking console is a standard communications panel, providing switches and a telephone dial which permit the operator at this position to utilize the intrastation voice communication facilities and the dial telephone system. See Fig. 7-3.

4.6.2 Vehicle Command Control Console

See paragraph 2.2.1.

SECTION 5
TIMING

5.1 General

The timing function provides a time base for all Subsystem H activities. A ground timing system is used to synchronize activities at all stations to a single time reference known as system time (ST). Station acquisition, tracking, and telemetry data are labeled with system time. Tracking data correlated with system time and furnished to the central computer allows prediction of vehicle position as a function of time. This is used to provide acquisition data to the stations for future passes and determines the necessity for adjusting the vehicle timer by command to ensure continued contact. Vehicle functions are also precisely programmed with respect to system time. The vehicle timer programs operation of the vehicle pulse beacon, the telemetry transmitter, and recovery capsule ejection. The vehicle timer may be adjusted by ground command.

5.2 Ground Timing System

The ground timing system generates, distributes, and displays the timing signals which synchronize station activities. The ground timing system consists of dual central timing units at each site that generate the basic timing signals, remote timing terminal units that distribute the timing signals, and remote time indicators that display the timing signals. Because of the similarity of the station timing systems, only the VAFB timing system block diagram is used to illustrate equipment distribution. See Fig. 5-1. The Subsystem H time base, or system time, is identified at one-second intervals by decimal time displays located at appropriate operating and control positions. Four-second intervals of the system time base are identified by 16-bit digital time words used to label the tracking data from the tracking devices. Both the decimal and digital time counts start at system time zero and accumulate until they count to maximum. At 24 hours, they reset to zero automatically and start counting again. The counting cycles of both the decimal and digital time counts are identified by a date expressed in Greenwich Civil Time.

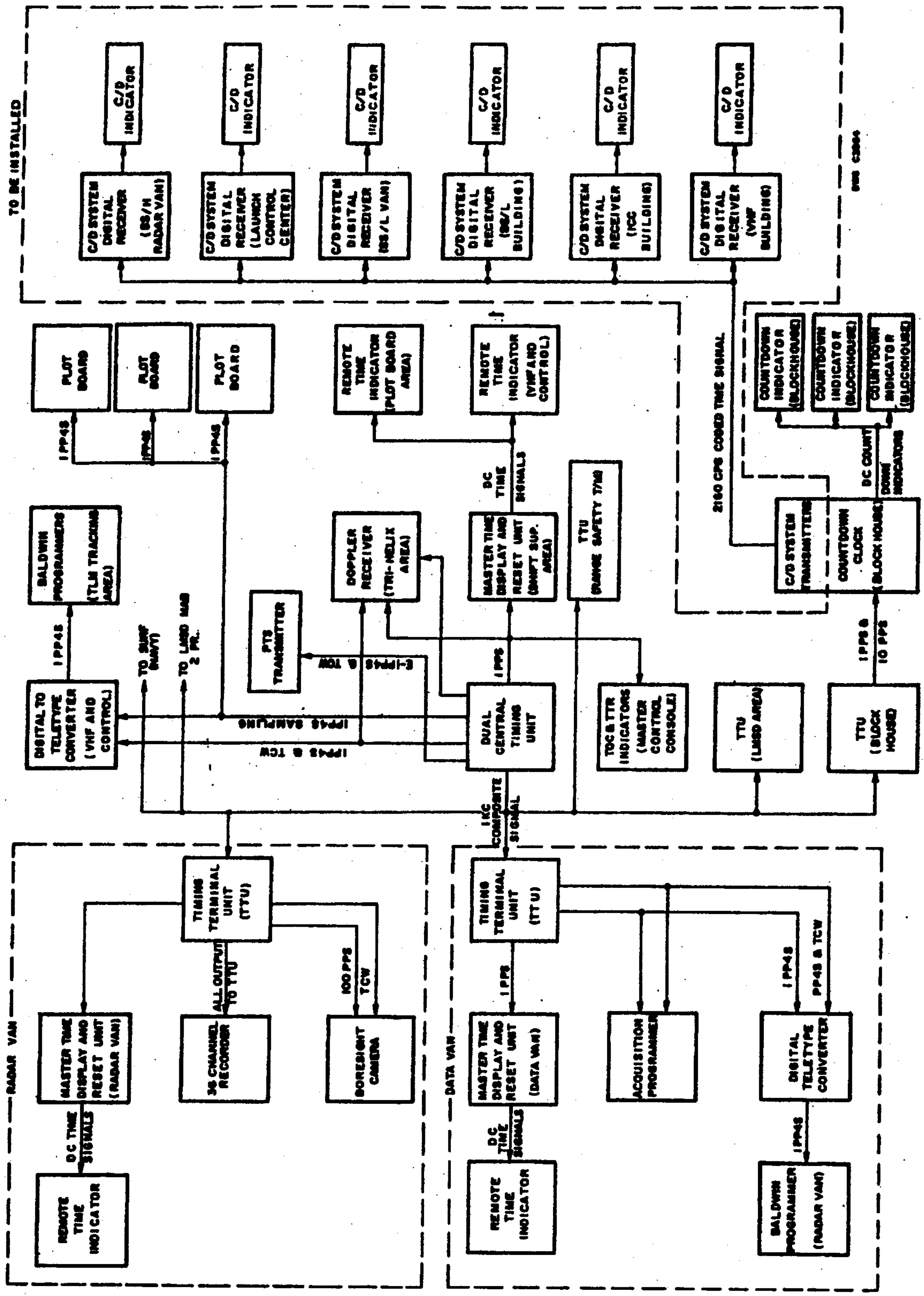


Fig. 5-1 VAFB Ground Timing System Block Diagram

Each of the dual central timing units is synchronized with a one-second signal from radio station WWV. Provision is made at each of the central timing units to compensate for the differences in propagation time from station WWV to each of the sites. This correction permits the central timing units at each of the stations to indicate time within 8 milliseconds of each other. The dual central timing system is located in the VHF building at VTS (see Fig. 4-5) and Hawaii (see Fig. 4-6); and in the instrumentation van (see Fig. 3-10) at Kodiak, New Boston,and Pt. Mugu.

The dual central timing unit produces timing signals which are distributed throughout the tracking station. For using equipment and displays located in the same vicinity the timing signals are routed directly from the dual timing system via 75-ohm coax. For using equipment and displays in remote locations the composite timing signal consisting of a 16-bit binary time code word, 10-pps signal, a 1-pps signal, and an early 1-pp4s frame pulse amplitude modulates a 1-kc carrier and is routed via 600-ohm telephone lines to timing terminal units, (TTU). The 1-kc composite signals to the TTU are processed and converted to the timing signal outputs illustrated in Fig. 5-7. Not all of the outputs available from both the dual central timing system and the timing terminal unit are used. Only those outputs which are utilized by the station equipment are shown in Fig. 5-1.

As shown in Fig. 5-1, at VAFB d-c timing signals from the central timing system are routed directly to the telemetry tracker digital-to-teletype (D/TT) converter, the Doppler receiver, the plot boards, the master time display and reset unit in the shift supervisors console, and the time of crossing (TOC) and time to reset (TTC) indicators on the master control console, all in the VHF and control building. The 1-kc composite signal is routed to timing terminal units in the radar van, data van, the LMSD area, and the block house.

The timing terminal unit in the radar van produces a 1-pps signal which is routed to the master time display and reset unit to drive the radar van remote time indicators. The time-code word and 100-pps signals are applied to the boresight camera to identify film section. All of the outputs of the radar van timing terminal unit are available to the 100-channel recorder.

The timing terminal unit in the data van produces a 1-pps signal which is routed to the master time display and reset unit to drive the data van remote time indicators. The 1-pp4s encoder pulse and the composite 1-pp4s early-frame-marker (EFM) and 16-bit time-code-word (TCW) signals are routed to the acquisition programmer and D/TT converter. The D/TT converter also receives an additional 1-pp4s EFM pulse by a separate line.

The timing signals to the acquisition programmer provide a real-time reference to synchronize the application of the stored acquisition program to the radar antenna and range servos, and to the telemetry tracker and tri-helix antenna servos. The acquisition program is labeled with predicted time information every four seconds. When the real-time input from the timing terminal unit is identical to the time label on the acquisition program, conditions exist for the most probable vehicle acquisition, as far as time is concerned. The tracking antennas and the radar range gate are pre-positioned for acquisition at the correct time.

The timing signals applied to the D/TT converter located in the data van provide a time label for the radar tracking data which is transmitted at 100-wpm to the central computer. In addition, a 1-pp4s signal is routed to the Baldwin programmers to program the sampling of the radar azimuth and elevation data and the gating of the radar azimuth, elevation, and range data.

The central timing system in the VHF and control building provides the composite time-code-word, 1-pp4s early-frame-marker (EFM) pulse, a 1-pp4s encoder pulse, and a separate 1-pp4s EFM pulse to the telemetry tracker D/TT converter. These timing signals provide a time label for the telemetry tracker antenna position data which is stored for later transmission to the central computer, as necessary. The 1-pp4s data encoder signal is routed to the Baldwin programmers to program the sampling and gating of the telemetry tracker azimuth and elevation tracking data.

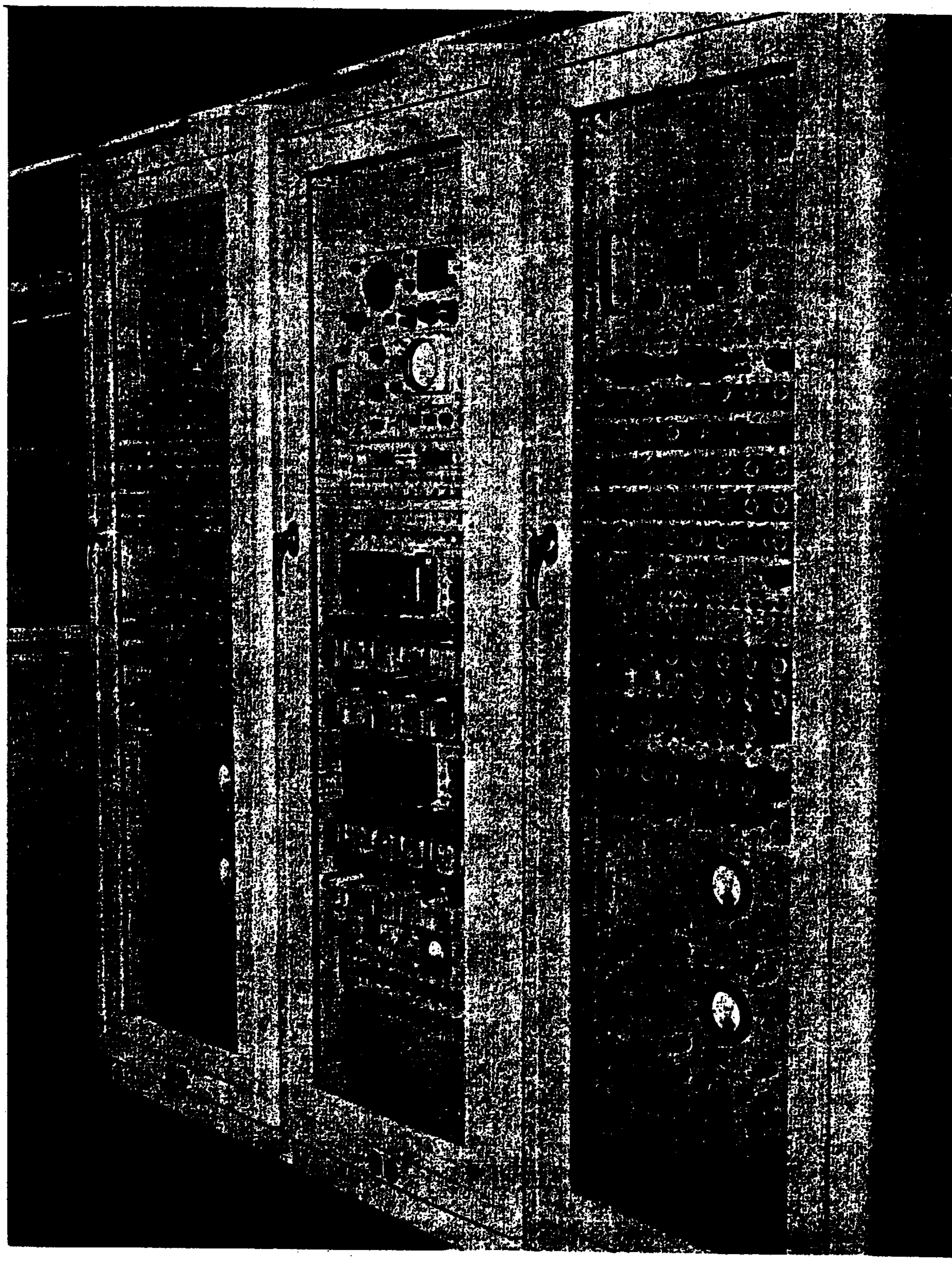
The timing signals applied to the Doppler receiver include the composite time-code-word and early 1-pp4s signal, the 1-pp4s early-frame signal, and the 1-pps signal. The time code-word is read into a shift register and read out serially onto a teletype tape. Sixteen-bit Doppler frequency data is sampled and stored in a shift register at a rate determined by the 1pp4s signal from the central timing unit. The 1-pps pulse from the central timing unit determines the time the stored time and frequency data are read out of their respective shift registers. They are read out one second after they are stored. The frequency and time data are then put on 100-wpm teletype and made available to the central computer.

Plot board timing marks for the real-time plotting of the vehicle orbit are provided by the 1-pp4s signals from the central timing unit.

One second timing signals are applied to a master time display and reset unit in the shift supervisor's area to drive the remote time indicators in the plotboard, VHF, and control areas. One-second timing signals are also routed to the TOC and TTR indicators on the master control console.

5.2.1 Central Dual Timing Generator

Each central dual timing generator (Fig. 5-2, 5-3, and 5-4) consists of two identical time-base generators installed in two standard racks which are separated by a third rack containing equipment common to both of these individual time base generators. Each time base generator is self-sufficient, and is in continuous operation at all times. Output signals are taken from only one time-base generator at a time, but in case of a malfunction in these units, the signal source can be transferred to the back-up time-base generator. The third rack, which has equipment common to both generators, contains a WWV receiver and oscilloscope necessary for making referencing time checks against WWV (or WWVH). Also contained in this



Fig, 5-2 Dual Master Timing Generator

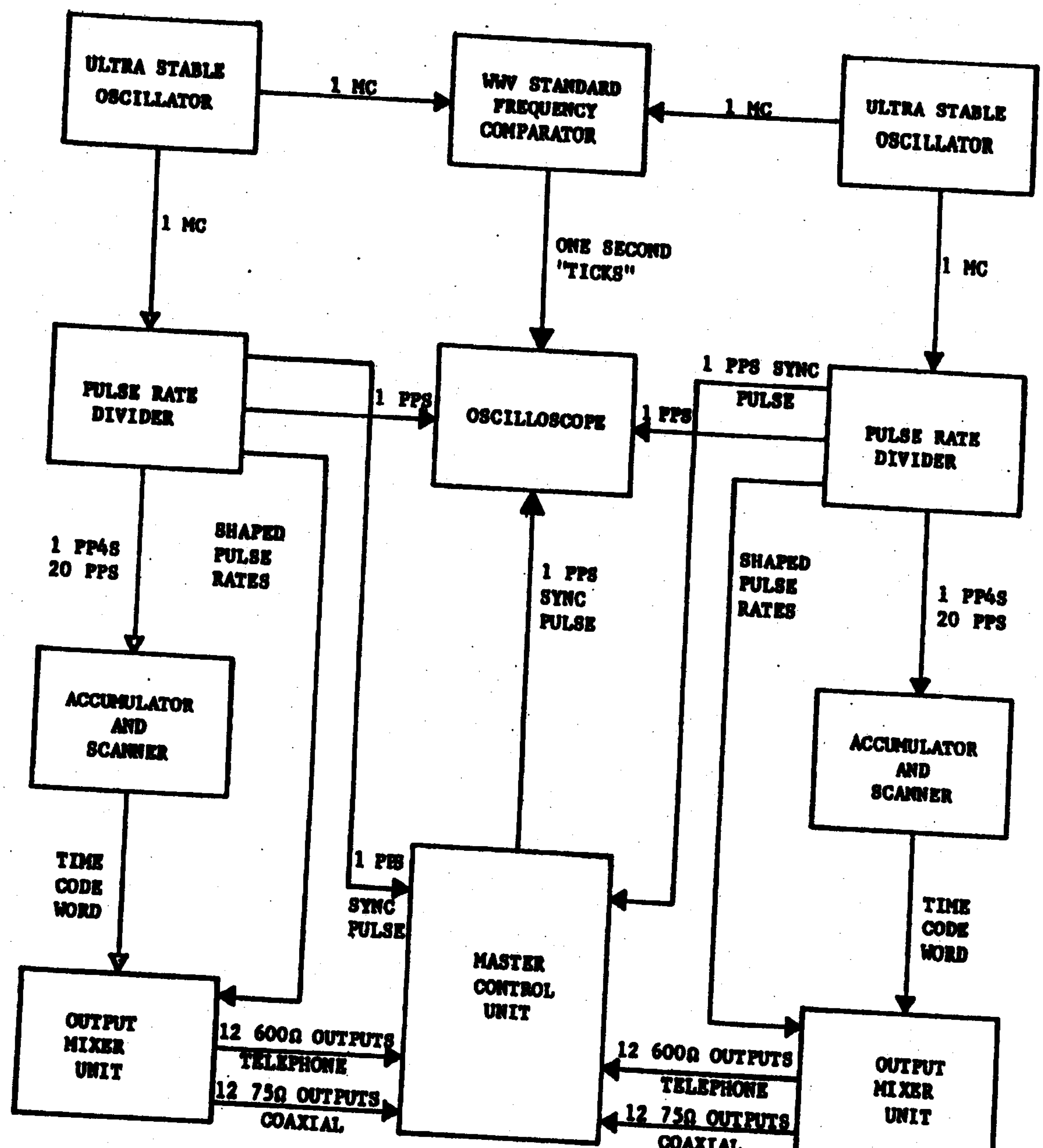


Fig. 5-3 Central Dual Timing Generator Block Diagram

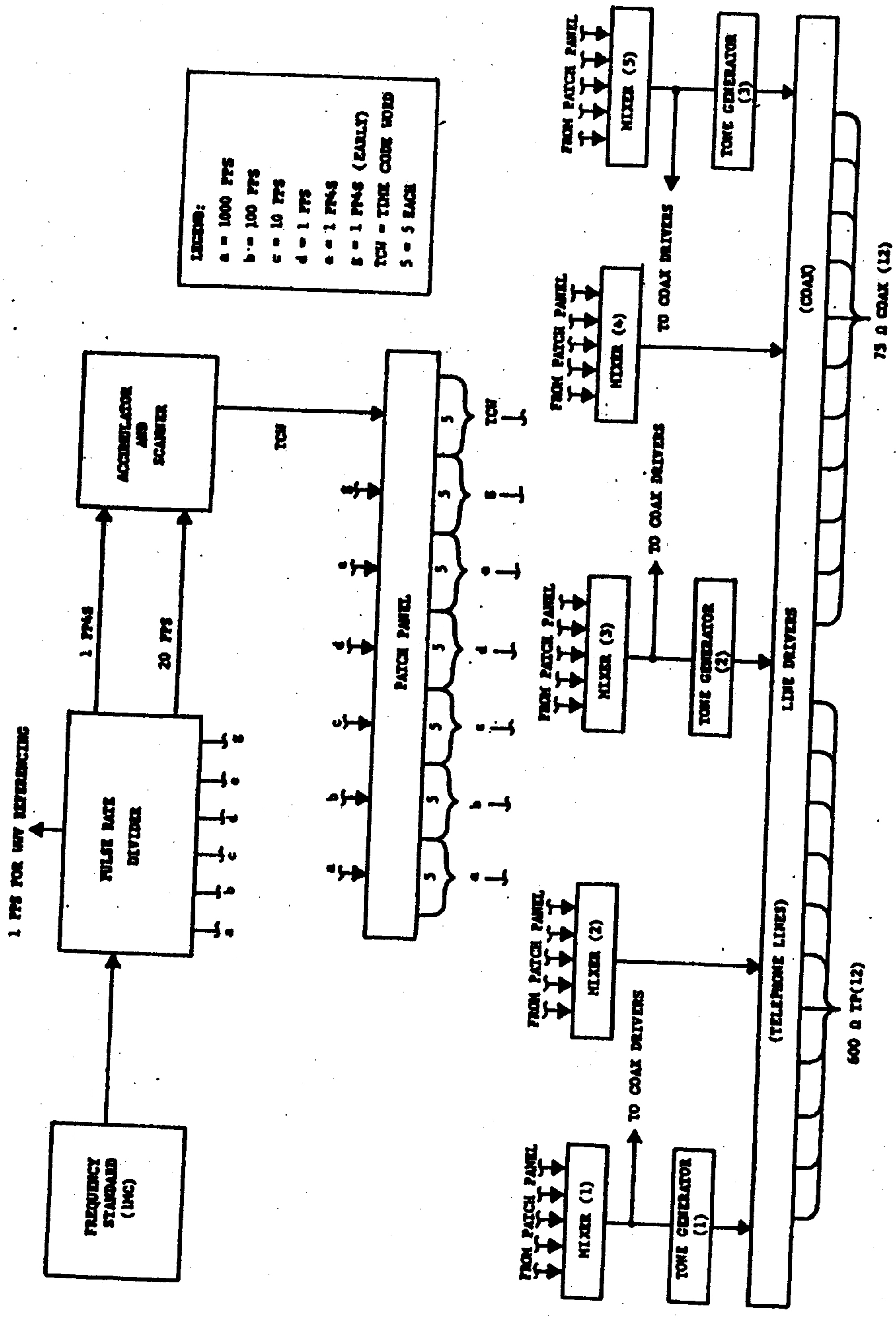


Fig. 5-4 Master Timing Generator Signal Flow Diagram

third rack is a central power control panel, a telephone line driver output panel, and a coaxial line driver output panel.

The ultra-stable oscillator generates a precision 1-mc sine wave which is applied to the pulse rate divider. The pulse rate divider counts down the 1-mc input to produce several output pulses. The divider chain uses flip-flops connected both as N/2 and N/5 dividers. Pulse shapers provide the following pulse width coding:

	PULSE RATE	PULSE WIDTH
(a)	1000 pps	0.5 ms
(b)	100 pps	2.0 ms
(c)	10 pps	5.0 ms
(d)	1 pps	10.0 ms
(e)	1 pp4s (early frame)	50.0 ms
(f)	1 pp8s (early frame)	50.0 ms

The output pulses may be advanced or retarded at either a fine rate of 1-ms per second or a coarse rate of 50-ms per second in reference to the basic 1-pps timing signal from WWV or WWVH. The pulse-rate divider transmits outputs to the patch panel. A 1-pp4s signal, a 20-pps signal, and two code-forming pulses are applied to the accumulator and scanner.

The accumulator and scanner count and store 1-pp4s pulses in a 16-digit binary register which stores up to 21,599 pulses and then recycles to zero at a count of 21,600 (24 hours). At four-second intervals, the pulse count stored in the accumulator is read out serially at a rate of 20 bits per second by the scanner circuitry. The scanner produces a pulse-width coded, 16-digit code word in which a binary "1" is represented by a pulse 30 milliseconds long, and a binary "0" by a pulse 15 milliseconds long. The time code-word is routed through the patch panel to the output mixer unit.

The output mixer unit mixes certain signals from the pulse rate divider and the time code word from the accumulator and scanner and converts the individual and mixed signals into forms suitable for transmission over 600-ohm telephone line and 75-ohm coaxial cable.

All signal inputs to the output-mixer unit, with the exception of the 1-kc sine wave, are accessible at the input patch panel. These signals may be: (1) individually patched to coaxial line drives, (2) patched into mixer inputs, and from mixer outputs to coaxial-line drivers, (3) individually patched to tone generators, and from tone generator outputs to balanced line drivers, or (4) patched to mixer inputs, and from mixer output through tone generators to balanced line drivers.

The 1-kc tone generator is amplitude modulated by the 16-bit time code word, the 1-pp4s early frame pulse, and the 1-pps and 10-pps pulses. The resulting amplitude modulated 1-kc carrier is applied to line drivers and routed to timing terminal units over 600-ohm telephone lines. The amplitude modulated 1-kc carrier is transmitted over telephone lines more efficiently than the digital pulses because the narrow bandpass characteristics of the telephone lines tend to deteriorate the digital pulses. Coaxial-cable drivers amplify the time code word for direct application to coaxial cable for short run distribution.

The WWV standard frequency comparator compares a precisely delayed 1-pps pulse rate from the pulse rate divider with the 1-second signals transmitted by WWV. The precision delay introduced on the 1-pps pulse rate compensates for propagation time from WWV to the tracking station. The WWV signal is used as a reference in adjusting the output of the ultrastable oscillator and the pulse rate divider. The oscilloscope is used to compare the 1-second timing signal from WWV with the delayed 1-pps signal generated by the pulse rate divider.

The master control unit contains switches for (1) transferring output signal lines and synch trigger outputs between system A and B, (2) controlling the accumulator and scanner units, (3) advancing or retarding pulse rates in the pulse rate divider units, and (4) switching balanced-line outputs to an output-level meter.

5.2.2 Timing Terminal Unit

The timing terminal unit (Figs. 5-5 and 5-6) converts the amplitude modulated 1-kc composite signal obtained from the dual timing system to output pulse signals of 1-pps, 10-pps, 100-pps, 1000-pps, an early 1pp4s frame marker pulse and a 1-pp4s frame marker pulse (Fig. 5-7).

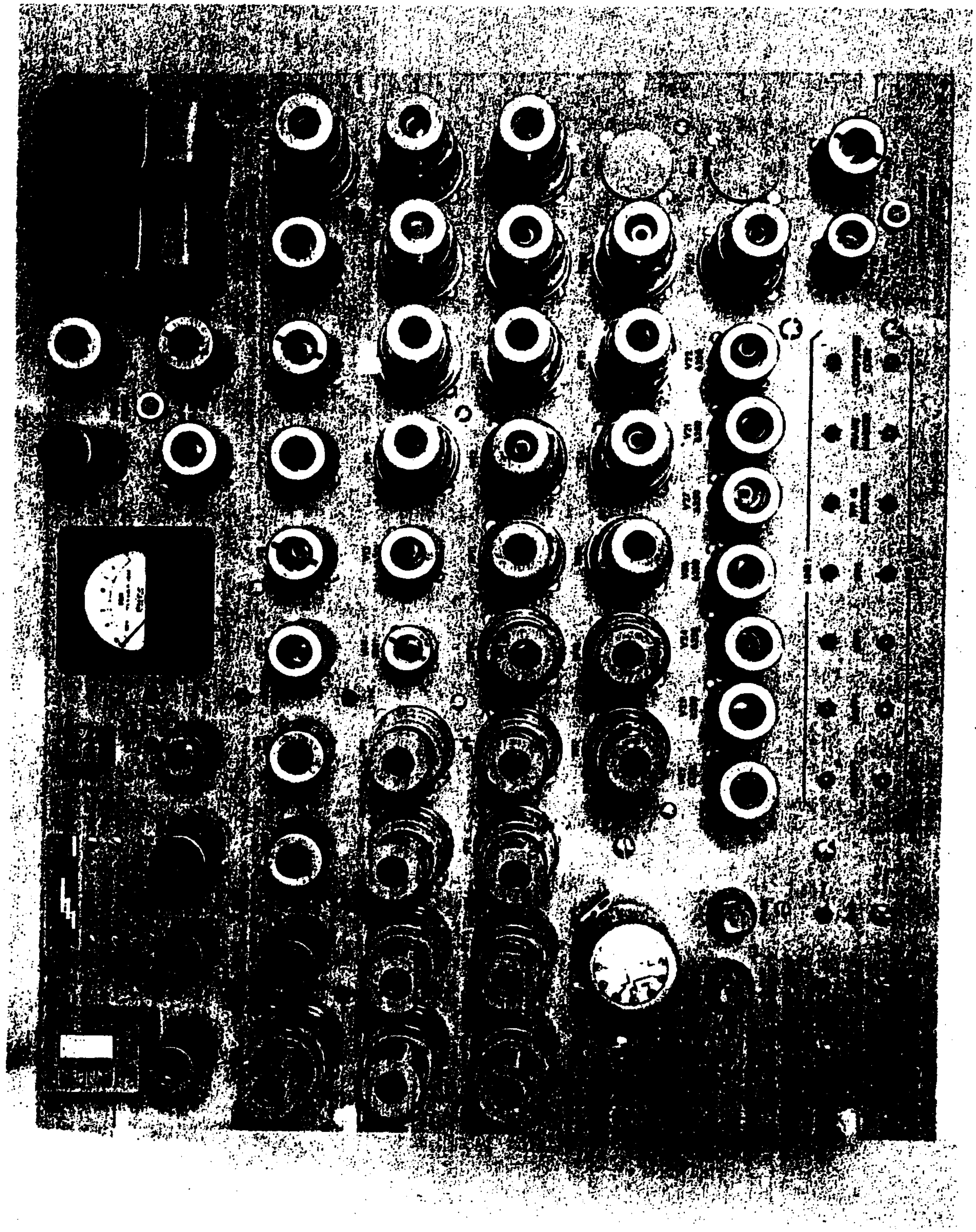


Fig. 5-5 Timing Terminal Unit

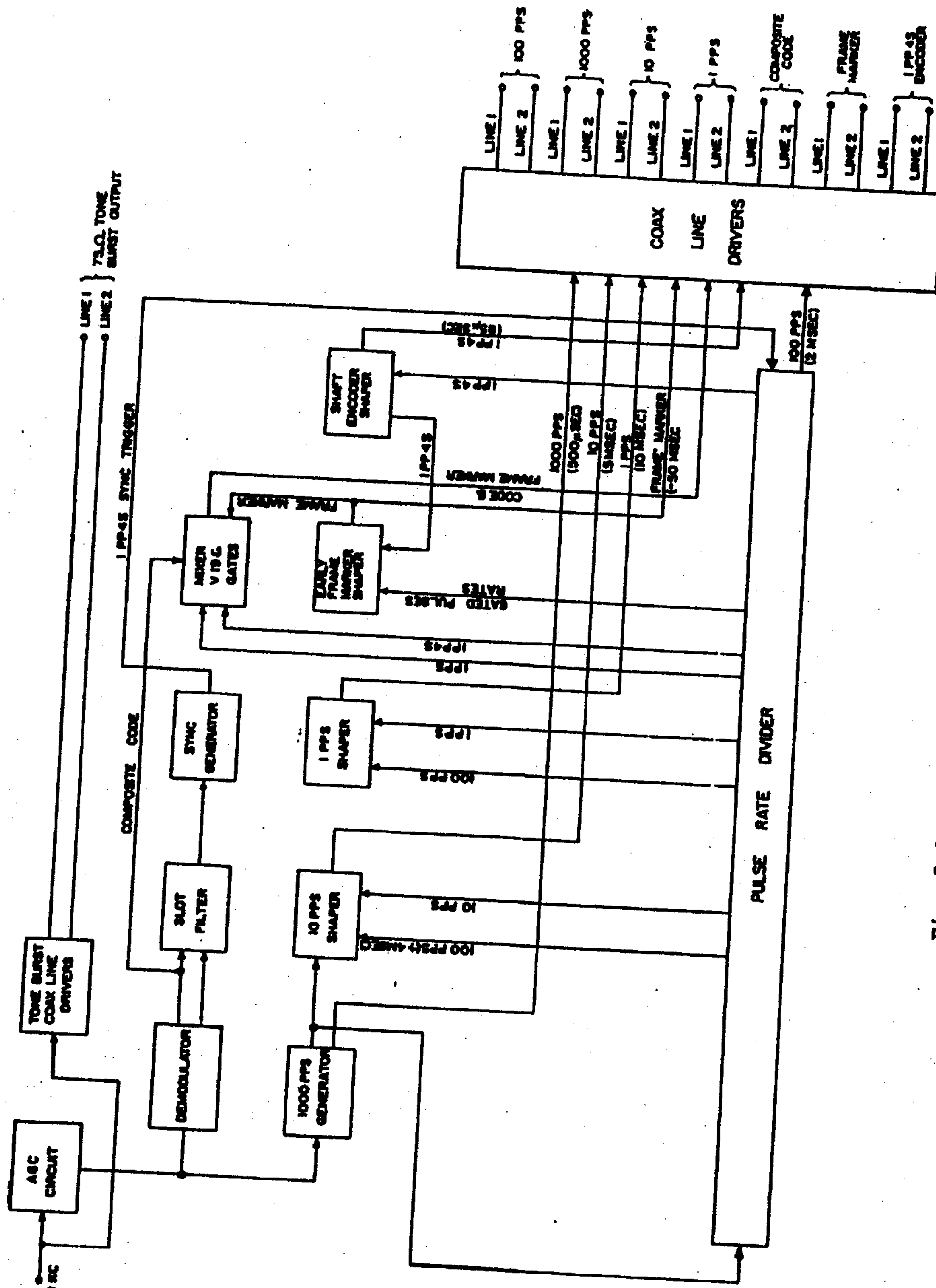


Fig. 5-6 Timing Terminal Unit Block Diagram

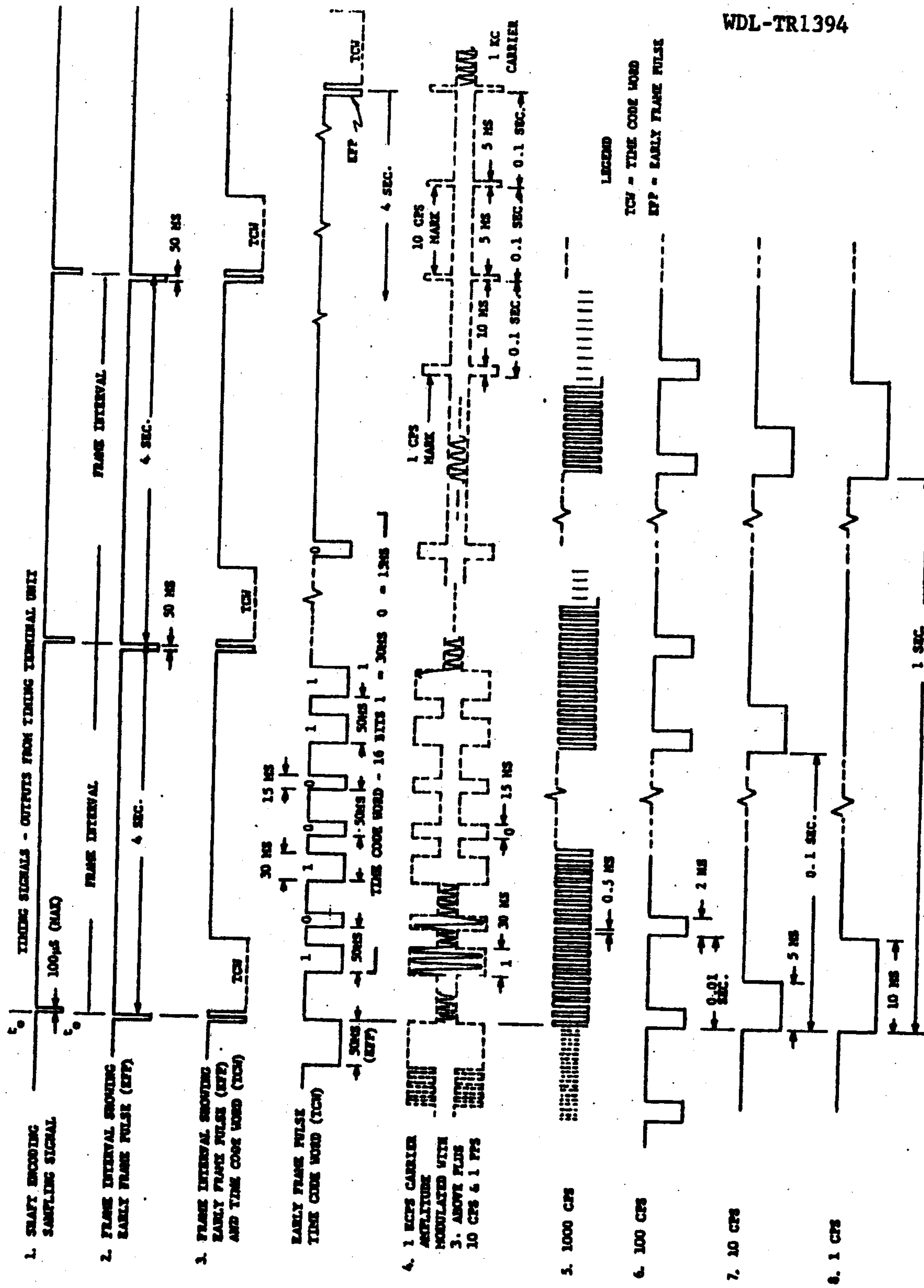


Fig. 5-7 Output Waveforms of Timing Terminal Unit

The amplitude modulated 1-kc input is applied to an automatic gain control circuit which compensates for input signal level variations between +5 dbm and -8 dbm. The input signal then is demodulated to reproduce the two-level d-c composite code which modulates the 1-kc carrier at the central timing equipment.

The 1-kc composite input signal is also applied to a 1000-pps generator where it is clipped to remove modulation, then filtered. The resulting 1-kc sine wave is shaped to form 1000-pps pulses. The 1000-pps signal is applied to a pulse rate divider, which divides the 1-kc signal to produce the lower pulse rate outputs. Each of the two-level d-c output signals is available at two independent output driver circuits. The timing terminal unit also amplifies the modulated 1-kc composite input signal for further distribution over 75-ohm coaxial cables from two independent outputs.

5.2.3 Digital Time-Display Unit

The time display units (Figs. 5-8 and 5-9) display system time, estimated time to acquisition, and estimated time to track in decimal units at key areas within the tracking station. The time displays consist of master time display and reset units and remote time indicators which are slaved to the master time display and reset units. The master time display and reset unit may be driven by a 1-pps pulse from the timing terminal units or by a 1-pps pulse from the dual central timing unit.

The master time display and reset units accumulate 1-pps signals from the timing terminal units and display the accumulated time. The time displays are located locally on the master time display and reset units themselves and remotely on conveniently located wall displays.

The system time display indicates elapsed seconds since system time zero and counts up to a maximum 86,400 seconds or 24 hours. It then resets to zero and resumes counting. System time zero is 0000 Greenwich Civil Time. Time correlation tables (fig. 5-10) are provided to allow conversion of Greenwich Civil Time or Eastern Standard Time as transmitted by WWV to system time and vice versa. The system time display may be preset to any time interval by manually setting in a time using

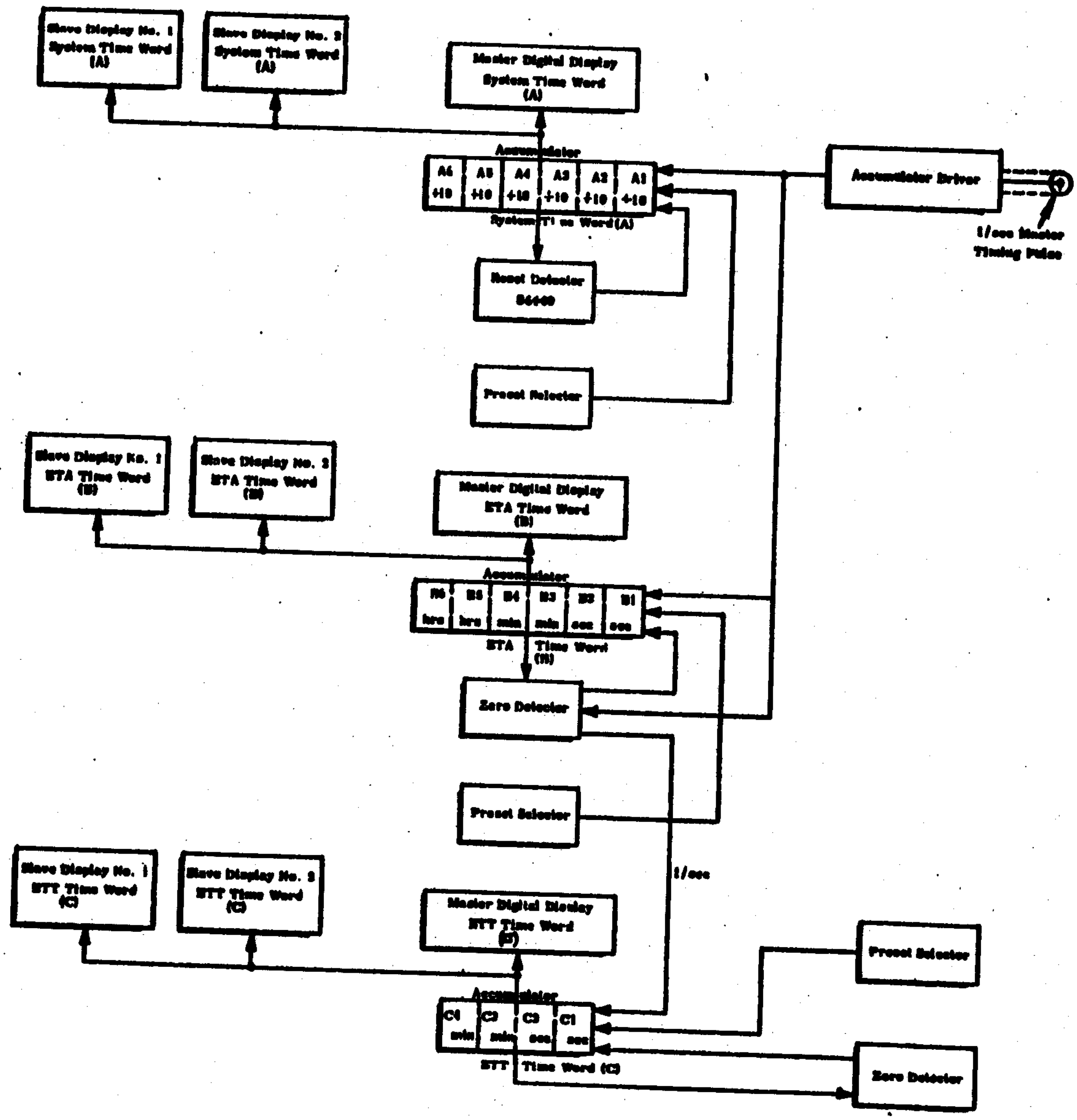


Fig. 5-9 Digital Time Display Block Diagram

UT hrs mins	EST hrs mins	System Time (Binary) 4 secs (Reversed Format)	System Time secs
0 00	19 00	0000000000000000	000000
0 05	19 05	1101001000000000	000300
0 10	19 10	0110100100000000	000600
0 15	19 15	1000011100000000	000900
0 20	19 20	0011010010000000	001200
0 25	19 25	1110111010000000	001500
0 30	19 30	0100001110000000	001800
0 35	19 35	1011000001000000	002100
0 40	19 40	0001101001000000	002400
0 45	19 45	1100010101000000	002700
0 50	19 50	0111011101000000	003000
0 55	19 55	1001110011000000	003300
1 00	20 00	0010000111000000	003600
1 05	20 05	1111001111000000	003900
1 10	20 10	0101100000100000	004200
1 15	20 15	1010011000100000	004500
1 20	20 20	0000110100100000	004800
1 25	20 25	1101111100100000	005100
1 30	20 30	0110001010100000	005400
1 35	20 35	1000100110100000	005700
1 40	20 40	0011101110100000	006000
1 45	20 45	1110010001100000	006300
1 50	20 50	0100111001100000	006600
1 55	20 55	1011110101100000	006900
2 00	21 00	0001000011100000	007200
2 05	21 05	1100101011100000	007500
2 10	21 10	0111100111100000	007800
2 15	21 15	1001011111100000	008100
2 20	21 20	0010110000010000	008400
2 25	21 25	1111111000010000	008700
2 30	21 30	0101001100010000	009000
2 35	21 35	1010100010010000	009300
2 40	21 40	0000011010010000	009600
2 45	21 45	1101010110010000	009900
2 50	21 50	0110111110010000	010200
2 55	21 55	1000001001010000	010500
3 00	22 00	0011000101010000	010800
3 05	22 05	1110101101010000	011100
3 10	22 10	0100010011010000	011400
3 15	22 15	1011011011010000	011700
3 20	22 20	0001110111010000	012000
3 25	22 25	1100000000110000	012300
3 30	22 30	0111001000110000	012600
3 35	22 35	1001100100110000	012900
3 40	22 40	0010011100110000	013200
3 45	22 45	1111010010110000	013500
3 50	22 50	0101111010110000	013800
3 55	22 55	1010001110110000	014100

Fig. 5-10 Time Correlation Table

UT hrs	UT mins	EST hrs	EST mins	System Time (Binary) 4 secs (Reversed Format)	System Time secs
4	00	23	00	0000100001110000	014400
4	05	23	05	1101101001110000	014700
4	10	23	10	0110010101110000	015000
4	15	23	15	1000111101110000	015300
4	20	23	20	0011110011110000	015600
4	25	23	25	1110000111110000	015900
4	30	23	30	0100101111110000	016200
4	35	23	35	1011100000001000	016500
4	40	23	40	0001011000001000	016800
4	45	23	45	1100110100001000	017100
4	50	23	50	0111111100001000	017400
4	55	23	55	1001001010001000	017700
5	00	0	00	0010100110001000	018000
5	05	0	05	1111101110001000	018300
5	10	0	10	0101010001001000	018600
5	15	0	15	1010111001001000	018900
5	20	0	20	0000001101001000	019200
5	25	0	25	1101000011001000	019500
5	30	0	30	0110101011001000	019800
5	35	0	35	1000010111001000	020100
5	40	0	40	0011011111001000	020400
5	45	0	45	1110110000101000	020700
5	50	0	50	0100000100101000	021000
5	55	0	55	1011001100101000	021300
6	00	1	00	0001100010101000	021600
6	05	1	05	1100011010101000	021900
6	10	1	10	0111010110101000	022200
6	15	1	15	1001111110101000	022500
6	20	1	20	0010001001101000	022800
6	25	1	25	1111000101101000	023100
6	30	1	30	0101101101101000	023400
6	35	1	35	1010010011101000	023700
6	40	1	40	0000111011101000	024000
6	45	1	45	1101110111101000	024300
6	50	1	50	0110000000011000	024600
6	55	1	55	1000101000011000	024900
7	00	2	00	0011100100011000	025200
7	05	2	05	1110011100011000	025500
7	10	2	10	0100110010011000	025800
7	15	2	15	1011111010011000	026100
7	20	2	20	0001001110011000	026400
7	25	2	25	1100100001011000	026700
7	30	2	30	0111101001011000	027000
7	35	2	35	1001010101011000	027300
7	40	2	40	0010111101011000	027600
7	45	2	45	1111110011011000	027900
7	50	2	50	0101000111011000	028200
7	55	2	55	1010101111011000	028500

Fig. 5-10 Time Correlation Table (Cont.)

UT hrs mins	EST hrs mins	System Time (Binary) 4 secs (Reversed Format)	System Time secs
8 00	3 00	0000010000111000	028800
8 05	3 05	1101011000111000	029100
8 10	3 10	0110110100111000	029400
8 15	3 15	1000000010111000	029700
8 20	3 20	0011001010111000	030000
8 25	3 25	1110100110111000	030300
8 30	3 30	0100011110111000	030600
8 35	3 35	1011010000J111000	030900
8 40	3 40	00011111007111000	031200
8 45	3 45	1100001101111000	031500
8 50	3 50	0111000011111000	031800
8 55	3 55	1001101011111000	032100
9 00	4 00	0010010111111000	032400
9 05	4 05	1111011111111000	032700
9 10	4 10	0101110000000100	033000
9 15	4 15	1010000100000100	033300
9 20	4 20	0000101100000100	033600
9 25	4 25	1101100010000100	033900
9 30	4 30	0110011010000100	034200
9 35	4 35	1000110110000100	034500
9 40	4 40	0011111110000100	034800
9 45	4 45	1110001001000100	035100
9 50	4 50	0100100101000100	035400
9 55	4 55	1011101101000100	035700
10 00	5 00	0001010011000100	036000
10 05	5 05	1100111011000100	036300
10 10	5 10	0111110111000100	036600
10 15	5 15	1001000000100100	036900
10 20	5 20	0010101000100100	037200
10 25	5 25	1111100100100100	037500
10 30	5 30	0101011100100100	037800
10 35	5 35	1010110010100100	038100
10 40	5 40	0000000110100100	038400
10 45	5 45	1101001110100100	038700
10 50	5 50	0110100001100100	039000
10 55	5 55	1000011001100100	039300
11 00	6 00	0011010101100100	039600
11 05	6 05	1110111101100100	039900
11 10	6 10	0100001011100100	040200
11 15	6 15	1011000111100100	040500
11 20	6 20	0001101111100100	040800
11 25	6 25	1100010000010100	041100
11 30	6 30	0111011000010100	041400
11 35	6 35	1001110100010100	041700
11 40	6 40	0010000010010100	042000
11 45	6 45	1111001010010100	042300
11 50	6 50	0101100110010100	042600
11 55	6 55	1010011110010100	042900

Fig. 5-10 Time Correlation Table (Cont.)

UT hrs mins	EST hrs mins	System Time (Binary) 4 secs (Reversed Format)	System Time secs
12 00	7 00	0000110001010100	043200
12 05	7 05	1101111001010100	043500
12 10	7 10	0110001101010100	043800
12 15	7 15	1000100011010100	044100
12 20	7 20	0011101011010100	044400
12 25	7 25	1110010111010100	044700
12 30	7 30	0100111111010100	045000
12 35	7 35	1011110000110100	045300
12 40	7 40	0001000100110100	045600
12 45	7 45	1100101100110100	045900
12 50	7 50	0111100010110100	046200
12 55	7 55	1001011010110100	046500
13 00	8 00	0010110110110100	046800
13 05	8 05	1111111110110100	047100
13 10	8 10	0101001001110100	047400
13 15	8 15	1010100101110100	047700
13 20	8 20	0000011101110100	048000
13 25	8 25	1101010011110100	048300
13 30	8 30	0110111011110100	048600
13 35	8 35	1000001111110100	048900
13 40	8 40	0011000000001100	049200
13 45	8 45	1110101000001100	049500
13 50	8 50	0100010100001100	049800
13 55	8 55	1011011100001100	050100
14 00	9 00	0001110010001100	050400
14 05	9 05	1100000110001100	050700
14 10	9 10	0111001110001100	051000
14 15	9 15	1001100001001100	051300
14 20	9 20	0010011001001100	051600
14 25	9 25	1111010101001100	051900
14 30	9 30	0101111101001100	052200
14 35	9 35	1010001011001100	052500
14 40	9 40	0000100111001100	052800
14 45	9 45	1101101111001100	053100
14 50	9 50	0110010000101100	053400
14 55	9 55	1000111000101100	053700
15 00	10 00	0011110100101100	054000
15 05	10 05	1110000010101100	054300
15 10	10 10	0100101010101100	054600
15 15	10 15	1011100110101100	054900
15 20	10 20	0001011110101100	055200
15 25	10 25	1100110001101100	055500
15 30	10 30	0111111001101100	055800
15 35	10 35	1001001101101100	056100
15 40	10 40	0010100011101100	056400
15 45	10 45	1111101011101100	056700
15 50	10 50	0101010111101100	057000
15 55	10 55	1010111111101100	057300

Fig. 5-10 Time Correlation Table (Cont.)

UT hrs mins	EST hrs mins	System Time (Binary) 4 secs (Reversed Format)	System Time secs
16 00	11 00	0000001000011100	057600
16 05	11 05	1101000100011100	057900
16 10	11 10	0110101100011100	058200
16 15	11 15	1000010010011100	058500
16 20	11 20	0011011010011100	058800
16 25	11 25	1110110110011100	059100
16 30	11 30	0100000001011100	059400
16 35	11 35	1011001001011100	059700
16 40	11 40	0001100101011100	060000
16 45	11 45	1100011101011100	060300
16 50	11 50	0111010011011100	060600
16 55	11 55	1001111011011100	060900
17 00	12 00	0010001111011100	061200
17 05	12 05	1111000000111100	061500
17 10	12 10	0101101000111100	061800
17 15	12 15	1010010100111100	062100
17 20	12 20	0000111100111100	062400
17 25	12 25	1101110010111100	062700
17 30	12 30	0110000110111100	063000
17 35	12 35	1000101110111100	063300
17 40	12 40	0011100001111100	063600
17 45	12 45	1110011001111100	063900
17 50	12 50	0100110101111100	064200
17 55	12 55	1011111101111100	064500
18 00	13 00	0001001011111100	064800
18 05	13 05	1100100111111100	065100
18 10	13 10	0111101111111100	065400
18 15	13 15	1001010000000010	065700
18 20	13 20	0010111000000010	066000
18 25	13 25	1111110100000010	066300
18 30	13 30	0101000010000010	066600
18 35	13 35	1010101010000010	066900
18 40	13 40	0000010110000010	067200
18 45	13 45	1101011110000010	067500
18 50	13 50	0110110001000010	067800
18 55	13 55	1000000101000010	068100
19 00	14 00	0011001101000010	068400
19 05	14 05	1110100011000010	068700
19 10	14 10	0100011011000010	069000
19 15	14 15	1011010111000010	069300
19 20	14 20	0001111111000010	069600
19 25	14 25	1100001000100010	069900
19 30	14 30	0111000100100010	070200
19 35	14 35	1001101100100010	070500
19 40	14 40	0010010010100010	070800
19 45	14 45	1111011010100010	071100
19 50	14 50	0101110110100010	071400
19 55	14 55	1010000001100010	071700

Fig. 5-10 Time Correlation Table (Cont.)

UT hrs mins	EST hrs mins	System Time (Binary) 4 secs (Reversed Format)	System Time secs
20 00	15 00	0000101001100010	072000
20 05	15 05	1101100101100010	072300
20 10	15 10	0110011101100010	072600
20 15	15 15	1000110011100010	072900
20 20	15 20	0011111011100010	073200
20 25	15 25	1110001111100010	073500
20 30	15 30	0100100000010010	073800
20 35	15 35	1011101000010010	074100
20 40	15 40	0001010100010010	074400
20 45	15 45	1100111100010010	074700
20 50	15 50	0111110010010010	075000
20 55	15 55	1001000110010010	075300
21 00	16 00	0010101110010010	075600
21 05	16 05	1111100001010010	075900
21 10	16 10	0101011001010010	076200
21 15	16 15	1010110101010010	076500
21 20	16 20	0000000011010010	076800
21 25	16 25	1101001011010010	077100
21 30	16 30	0110100111010010	077400
21 35	16 35	1000011111010010	077700
21 40	16 40	0011010000110010	078000
21 45	16 45	1110111000110010	078300
21 50	16 50	0100001100110010	078600
21 55	16 55	1011000010110010	078900
22 00	17 00	0001101010110010	079200
22 05	17 05	1100010110110010	079500
22 10	17 10	0111011110110010	079800
22 15	17 15	1001110001110010	080100
22 20	17 20	0010000101110010	080400
22 25	17 25	1111001101110010	080700
22 30	17 30	0101100011110010	081000
22 35	17 35	1010011011110010	081300
22 40	17 40	0000110111110010	081600
22 45	17 45	1101111111110010	081900
22 50	17 50	0110001000001010	082200
22 55	17 55	1000100100001010	082500
23 00	18 00	0011101100001010	082800
23 05	18 05	1110010010001010	083100
23 10	18 10	0100111010001010	083400
23 15	18 15	1011110110001010	083700
23 20	18 20	0001000001001010	084000
23 25	18 25	1100101001001010	084300
23 30	18 30	0111100101001010	084600
23 35	18 35	1001011101001010	084900
23 40	18 40	0010110011001010	085200
23 45	18 45	1111111011001010	085500
23 50	18 50	0101001111001010	085800
23 55	18 55	1010100000101010	086100

Fig. 5-10 Time Correlation Table (Cont.)

the preset controls. Once preset, the display may be started by pressing the START button. If necessary, the display may be synchronized after starting with the reference source by pressing momentary contact ADVANCE or RETARD buttons which advance or retard the last digit of the display in one-second steps.

The estimated time to acquisition (ETA) display indicates the caluclated time remaining before the next anticipated vehicle acquisition. ETA is computed at each site by the shift supervisor. It is expressed in hours, minutes, and second. The ETA display counts down to zero from a manually preset time. The central computer supplies the predicted time that the vehicle will come into acquisition range. This information is included in the acquisition message transmitted to each site via the 60-wpm teletype system. The ETA displays are manually preset to the computed ETA by adjusting six preset controls. At the system time specified in the acquisition message, the ETA display is started by pressing a START button. The ETA display counts backwards from a maximum of 99 hours, 59 minutes, and 59 seconds to zero and stops automatically. When ETA equals 0, the estimated time to track (ETT) display is started automatically.

The ETT display indicates the calculated time available to track the vehicle starting from ETA equals zero. ETT is computed at each site by the shift supervisor. The central computer supplies the time of beginning and ending track from which ETT is computed. ETT is expressed in minutes and seconds, with a maximum display of 99 minutes and 59 seconds. The ETT display counts down to zero from a manually preset value. When ETT equals 0, the vehicle should be approximately out of range of the tracking equipment.

5.2.4 General Specifications

Dual Timing System

a. Input power requirements
115 V a-c ± 10 per cent, 60 ± 3 cps, 10, 29 amperes

b. Input signals
Two-level, negative d-c signals with amplitude of 1 volt ± 10 per cent peak-to-peak into 75 ohms. Twelve outputs.

One kilocycle signal, amplitude modulated at a ratio of 1:4; output level adjustable from 0 to 10 dbm into 600 ohms. Output balanced to ground. Twelve outputs.

c. Composition of output signals
The following signals, available either individually or compatibly mixed:

1. Code word - 16-digit, pulse-width-coded, 20 bits per second, presented at 4-second intervals. Binary "1" is 30 msec wide; binary "0" is 15 msec wide. First bit begins 50 msec after zero time.
2. 1 pp8s early - pulse width 50 msec, beginning 50 msec prior to zero time.
3. 1 pp4s early - pulse width 50 msec, beginning 50 msec prior to zero time.
4. 1 pps gated - pulse width 10 msec, gated out for one-second period following zero time.
5. 10 pps gated - pulse width 5 msec, gated out for one-second period following zero time.
6. 100 pps gated - pulse width 2 msec, gated out for one-second period following zero time.
7. 1000 pps gated - pulse width 500 usec, gated out for one-second period following zero time.
8. 1 pps - pulse width 10 msec.
9. 10 pps - pulse width 5 msec.
10. 100 pps - pulse width 2 msec.
11. 1000 pps - pulse width 500 μsec.
12. Outputs to timing terminal units consist of: 1-kc sine wave, amplitude modulated by mixed code word, 1-pp4s early, 1-pps gated, and 10-pps gated. Four outputs.

d. Basic accuracy
Better than one part in 10^8 per day.

e. Resolution
1 msec

f. Environmental specifications

1. Ambient temperature
$-20^{\circ}C$ to $54^{\circ}C$ ($-4^{\circ}F$ to $+130^{\circ}F$).
2. Humidity
95 per cent up to temperature of $+54^{\circ}C$ ($+130^{\circ}F$).

Ultra-Stable Oscillator. The ultra-stable oscillator is a 1-mc crystal-controlled signal source designed to provide highly stable reference frequency. Its specifications are as follows:

a. Frequency
1 mc nominal; accurately adjustable over a range of $\pm$ 0.5 cps.

b. Frequency stability
Drift rate less 1 part in 10^9 per day.

c. Sine-wave output
2.5 volts rms minimum open circuit; output impedance approximately 250 ohms.

d. Pulse output
Approximately 1-volt peak

e. Power requirements
$\pm$ 150 volts d-c regulated at: 100 ma max, during warm-up; 60 ma normal

6.3 volts a-c or d-c at 3 amp.

f. Weight
Approximately 30 pounds

g. Mounting
Standard RETMA rack panels 7 x 19 inches

h. Recommended operating temperature limits
0° to 50° centigrade

Timing Terminal Unit.

a. Input power requirements

1. 115 v ac $\pm$ 10 per cent, 60 $\pm$ 3 cps, 1Ø, 1 ampere
2. -200 v dc $\pm$ 1 per cent, 580 milliamperes

b. Input signal
One-kilocycle sine wave, amplitude modulated at a ratio of 1:4 by time-code pulses from central equipment of the dual timing system. Input levels from +5 dbm to -8 dbm (peak level).

c. Output signals

1. Amplified input signal, gain adjustable. Output level 2 v peak-to-peak into 75 ohms. Two outputs.
2. Seven two-level d-c negative pulse outputs. All pulses from 0 V d-c to -1 V d-c into 75 ohms, rise time (with exception of composite code) 10 usec. Outputs as follows:

(a) Early frame marker - 50 msec wide, leading edge at zero time, marking beginning of 4-second (or 8-second) scanning interval. Two outputs.

(b) Composite code - reconstructed modulation envelope of input signal less 1-pps and 10-pps markers. Rise time 100 μsec. Two outputs.

(c) 1000 pps - 500 μsec wide. Two outputs.

(d) 100 pps - 2 msec wide. Two outputs.

(e) 10 pps - 5 msec wide. Two outputs.

(f) 1 pps - 10 msec wide. Two outputs.

(g) 1 pp4s encode - 1-pp4s pulse, 85 usec wide. Two outputs.

d. Power Supply

1. Input power requirements
115 v ac ± 10 per cent, 60 ± 3 cps, 1Ø, 5 amperes.

2. Output voltage
-200 v dc, regulated, 1 ampere

Digital Time Display.

a. Power requirements
115 volts ± 10 per cent, 60 cps, single phase ac, 300 watts maximum.

b. Accuracy
Cumulative error in counting input pulses of not more than 1 part in 20,000 nor in excess of 4 seconds in 24 hours.

5.2.5 Countdown Timing System

A countdown timing system is located at VAFB (see Fig. 5-1) to provide timing control information and display indication of minutes and seconds remaining before T_0. The countdown timing system is designed to allow remote starting, stopping, and resetting of all remote slave countdown indicators throughout the system complex as dictated by the progress of the countdown. The system has a total timing capacity for control and indication of 999 minutes and 59 seconds before T_0 and 10 minutes and 00 seconds after T_0.

The countdown clock, located in the blockhouse, generates and supplies time to the countdown transmitter and local countdown indicators in the form of 36 d-c voltage signals. Each of 36 separate lines carries a presence or absence signal to the transmitter. Seven signals are required to represent each numeral in the display and one to represent the + or - sign, making a total of 36. Presence signal is represented by 28 volts d-c on the line; absence by 0 volts. The parallel inputs to the countdown transmitter are converted to a digital time code word and read out serially to amplitude modulate a 2-kc carrier. This modulated carrier is sent over telephone lines to a remote countdown receiver. The receiver takes the serial digital information and converts it so it is read out as 36 d-c voltages which are applied to a countdown indicator that displays countdown time.

The countdown clock installed in the VAFB blockhouse would have to be relocated to the Point Arguello blockhouse at the start of utilization of the Arguello launch complex for the Discoverer operations.

5.2.6 Ground Timing System Performance

The ground timing system has adequately met Subsystem H ground timing requirements with but minor changes to the original 3 day, 49 minutes and 4 second period. The 24 hour recycle period has the following advantages:

a. It is compatible with the SAMOS Program.
b. Only one system time correlation table need by prepared. The original tables needed continuous updating.
c. System operation is simplified.
d. Use of data by operators is simplified in handling and filing.

Other modifications (RP-04 and RP-06) reduced the susceptibility of the timing terminal units to telephone line noise and provided filters to the timing terminal unit and digital display unit power supply inputs to suppress interference.

Operational experience has confirmed the adequancy of the 4-second time interval for the prime requirement of vehicle orbit prediction. More frequent sampling would be desirable to provide tracking data on tumbling vehicles, during short time periods such as the initial recovery phase, and in tracking analysis efforts. In the case of a tumbling vehicle, the capability of sampling during Verlort "lock-on" would be desirable.

The wide range and multiplicity of outputs available to the ground timing system has been useful in meeting additional timing requirements as they arose. If necessary, additional line drivers can be added when the demand exceeds the original equipment capability. Also, if necessary to meet future requirements, the basic time interval count may be changed to eight seconds and the binary code word extended to 19 digits, making it possible to extend the total time interval count of the system to 524,288 over a period of 48 days, 12 hours, 5 minutes, and 4 seconds.

The accuracy with which the WWV correlation of the ground timing system can be maintained is dependent upon two factors: (a) timing generator stability, and (b) time referencing accuracy. The indicated system time will be in error with respect to the WWV standard by the error introduced by the referencing process and by the accumulated generator error caused by inherent instabilities or inaccurancies. The accumulated error is normally small compared to the expected referencing error.

The ground timing system specifications require the basic accuracy of the timing generator to be within 1 part in 10^8. This would allow a total timing generator error accumulated during a 24-hour period of ± 0.864 milliseconds. The error introduced into the referencing process is the result of propagation effects. The time of propagation of a radio signal from WWV to a tracking station varies in accordance with the path the signal assumes between the earth and the ionosphere. This is estimated to vary from 6 to 8 milliseconds per thousand miles. Including the accumulated 24 hour timing generator error, correlation with WWV of a west coast tracking station 3000 miles distant is estimated to fall within the limits of $\pm$ 4 milliseconds. This allows a possible deviation in system time between two tracking stations of from 0 to 8 milliseconds. At the extreme, this represents 200 feet of vehicle travel, which is not considered significant. Propagation delays between WWV, WWVH, and the tracking stations are listed in Table 5-1. These are based upon a nominal propagation delay of 7 milliseconds per thousand miles, which considers ionospheric reflections.

TABLE 5-1

NOMINAL WWV AND WWVH PROPAGATION DELAYS

SITE	NOMINAL PROPAGATION DELAY	
	From WWV	From WWVH
Vandenberg	16.7 ms	16.6 ms
Point Mugu	16.3 ms	17.1 ms
Kodiak	24.2 ms	17.8 ms
Hawaii	-------	1.0 ms
New Boston	2.8 ms	-------
T/M Ship	16.2 ms	20.5 ms

5.3 Orbital Programmer (Vehicle Timer)

The information that follows is based on data applicable to recent configurations. However, the functions of the orbital programmer are subject to change as dictated by the procedures utilized for a particular operation.

Orbit operations are programmed primarily by the orbital programmer. This programmer operates from a prepunched tape program to turn on the radar beacon transponder and telemetry transmitting equipment within possible reception range of tracking stations and to turn this equipment off at other times to conserve battery power. The orbital programmer also controls payload functions and the enabling and disabling of the tape reset mechanism as programmed. Midway in the recovery pass, the orbital programmer restarts the SS/D timer, which was turned off at the end of the launch phase. The SS/D timer then controls vehicle reorientation operations, nose capsule separation, and initiation of the capsule re-entry operations.

The orbital programmer is adjustable by ground commands transmitted via the S-band radar link during flight. Commands dictate the number and direction of discrete step changes in programmer cyclic rate to match the programmer period to the Discoverer Satellite orbit period. A reset command is also used to shift the tape program instantaneously to preselected and programmed reset index points corresponding to specified reset latitudes.

The heart of the timer is a 35mm mylar tape driven past a row of 13 electrical contact brushes at a controlled linear rate of movement. Perforations spaced in the tape make electrical contacts which position relays according to a planned program of events. Twelve of the contact brush circuits position six relays either up or down. The thirteenth contact is used only to provide alternate re-entry sequence initiation if the alternate re-entry circuit has been selected. The minimum on-or-off duration for one function is 30 seconds with a positioning accuracy of ± 10 seconds.

A synchronous motor drives the program tape sprocket drum through suitable reduction gears. Motor speed, and hence tape linear speed, is controlled as a function of the variable frequency output of a tuneable oscillator. The oscillator is tuned by positioning two 10-position (decade) stepping switches which connect graded resistors into the oscillator circuitry. The second stepping switch moves one step for each revolution (10 steps) of the first stepping switch, thus providing 99 steps. Each step varies the programmer cycle period by 11 seconds with the total period adjustable from 90 to 108.15 minutes. With the orbital programmer cyclic period set to match the satellite orbit period, the tape will travel exactly 4.5 inches during each complete orbit.

The position of the increase/decrease switch and the period setting in the programmer are transmitted to the ground station via telemetry. The increase position indicates that step commands will increase the period setting. The existing period setting in the orbital programmer is telemetered both as a function of the position of the two stepping switches and as a function of the input frequency to the synchronous motor driving the tape. The stepping switch positions are displayed in nixie lights on the command console from which the period setting can be determined in units of seconds, or minutes and seconds, by using a conversion table. The programmer setting at launch represents the nominal orbital period.

A definite relationship between program tape position and terrestrial latitude is required for proper spacing of readout periods and initiation of the recovery sequence. Correction of tape misalignment is provided by a reset function. Tape index points are predetermined for selected reset latitudes. An indexing disc is clutched into the gear train at reset enable, 16 degrees latitude (approximately four minutes) ahead of the index point on the tape, and remains clutched in until reset disable. Transmission of Command 3 (Reset) at any time while the disc is clutched in, will rotate the disc to its index position and, through the gear train, will position the tape to its index position for the specified latitude. Upon release of the clutch at reset disable, the disc is spring-loaded back to its initial position, four minutes before its index point, and is ready to be enabled for another reset point. Reset commands are given only at the specified latitudes unless large orbital programmer deviations make it necessary to give a reset at a different latitude, to move the tape closer to the correct relationship before giving another reset command at the proper latitude.

A reset monitor signal is given by a cam and microswitch arrangement on the indexing disc. Initiation and termination of the reset monitor signal mark specific points in the orbital programmer cycle which can be compared from orbit to orbit as a check on programmer period setting. The reset monitor signal is presented as a light on the command console panel.

In general the orbital programmer tape will be punched to provide readout whenever the vehicle is within reception range of any of the tracking stations during a certain number of orbits. The programmer provides control of beacon and telemetry plate voltage turn-on and turn-off, reset enabling and disabling, location of the reset point, and duration of the reset monitor signal as a function of the terrestrial latitude and orbital pass number. This sequence will be adhered to if the orbital programmer period is set to match the orbit period and the programmer relationship to the terrestrial latitude is maintained by reset commands.

A forward and a reverse high speed capability feature was recently added to the orbital programmer in addition to the adjustable normal speed. Should the actual orbit period differ from the predicted nominal orbit period, on which the programmed events are based, the programmer cycles may be either skipped or repeated. If the programmer receives a SKIP command, the programmer motor will engage the high speed clutch after equipment turnoff and the tape will advance 21/20 programmer passes (4.725 inches of tape) at 20 times the normal speed. If the programmer receives a REPEAT command, the programmer motor will engage the reverse high speed clutch after equipment turnoff and the tape will reverse 19/20 programmer passes (4.275 inches of tape) at 20 times the normal speed. The electrical contact brushes will be lifted during the actual SKIP or REPEAT operation and no programmed events will be effective.

In order to identify the programmer tape pass number, a systematic 30-second reset monitor signal interruption will be programmed to occur at varying times after the reset point. This programmer pass identification will be the only means of verifying a previous SKIP or REPEAT operation.

The re-entry phase is initiated by the orbital programmer by turning on the SS/D timer during the selected recovery pass. Alternate and emergency re-entry sequences can also be initiated as dictated by conditions. These sequences may be initiated by the transmission of Command 5 in accordance with procedures established in the applicable System Test Directive (STD).

SECTION 6
COMPUTATION

6.1 General Description

The central computer for the Discoverer program is the Remington Rand 1103AF computer (1103A computer modified for floating decimal point) located at Lockheed Missiles Space Division, Palo Alto, California. Basically, the computer facility serves to predict and calculate ephemerides for acquisition, training puposes, and control of certain satellite functions. More specifically the applications of the computer functions include the following:

a. Simulation of flight and orbital conditions for orientation and training of tracking station personnel prior to actual Discoverer launches

b. Simulation of tracking operations by automatic control of the tracking radar with computer-generated nominal flight condition data

c. Prediction of nominal satellite acquisition data for each tracking station prior to launch

d. Prediction of nominal ephemeris (almanac of tracking events) data from nominal conditions for planning, test, and tracking operations

e. Simulation of a nominal launch sequence from observed time-of-event data to produce supplemental nominal ascent conditions for use as "best guess" predictions in the event of tracking equipment failures.

f. Repeated recomputation of orbits and ephemeris data from tracking station input to provide better orbit determination and retrorocket timer setting information and to update acquisition and control messages for the tracking stations.

g. Determination of tracking station accuracies and the assignment of statistical weight values to input data from the various tracking input sources.

h. Determination of corrections required to adjust orbital parameters

i. Calculation of best retrorocket ignition time for prediction of re-entry phase

j. Prediction of actual inpact time and location on the basis of retrorocket ignition time

k. Presentation of data is usable forms for tracking or recovery.

The computer program allows monitoring of the computing process in a standard flexowriter output format. The computer can accept instructions to select and store for further calculation and comparison the best values of the orbital parameters.

Figure 6-1 is a flow diagram of the computer.

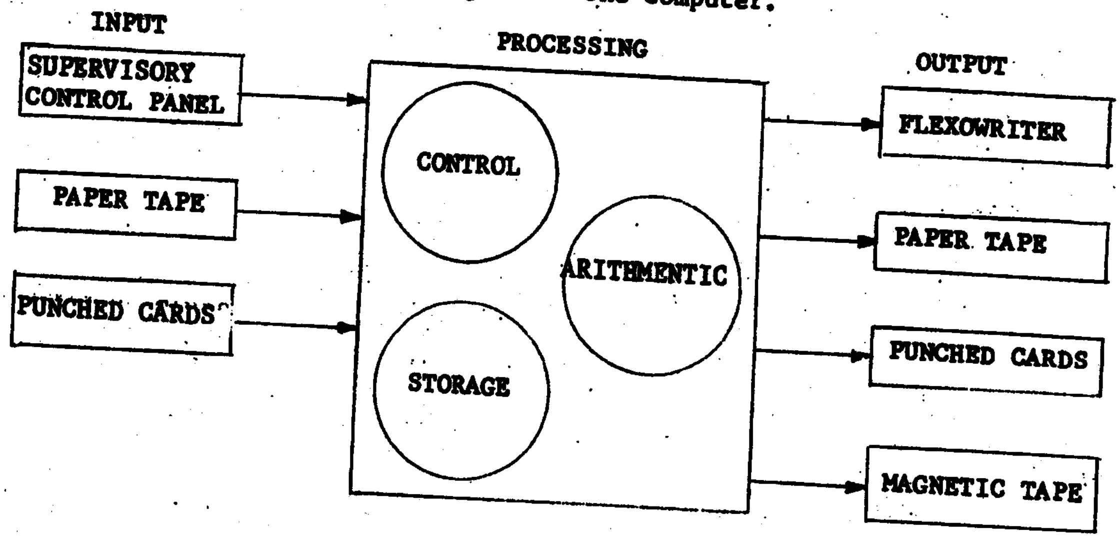


Figure 6-1 1103-AF Automatic Digital Computer System

The inputs and outputs to the computer remain essentially intact even though the internal computer programs undergo change and augmentation. For example, the orbital equations (point by point integration type) will always be supplied with t, x, y, z, $\dot{x}$, $\dot{y}$, and $\dot{z}$ as the input and will always make their output in the same form for the time intervals desired.

6.2 Input Unit

The input unit translates data into the code and format suitable for processing in the computer, and ejects it for manipulation by the computing system.

The following inputs are utilized:

Paper Tape Inputs:

a. Verlort radar data

b. R-1162 tracking data

c. Space track radar data

d. Doppler frequency data

Card Inputs:

a. Time-of-event cards - launch, final burnout, etc.

b. Time to fire - recovery phase

c. Selected data points - a second order input of position and velocity vector data

d. Nominal injection - preflight predictions

e. Run number - first six numbers of a card-bookkeeping operation

f. SS/H timer commands

g. Vehicle parameters - preflight insertion - engine thrust, etc.

In addition, the storage unit in the computer contains the following input items available as needed: a gravity model, an atmospheric model, an earth model, vehicle parameters, and provisions for storage or previous predictions.

6.2.1 Launch Information

Launch information essential for orbital computation is transmitted to the central computer via 60-wpm teletype. This information includes: (1) time of launch, (2) explosive bolt firing, (3) Agena engine ignition, and (4) Agena engine burnout.

6.2.2 Calibration Data

Boresight data are included as part of the tracking tape transmitted via the 100 wpm teletype. The boresight data may be used to insert a correction in the tracking data if required.

6.2.3 Tracking Data

Verlort Radar. The prime tracking data input source is the Verlort radar equipment. The range, azimuth, and elevation of the vehicle as measured by the radar are expressed as digitally encoded shaft positions. The position of these three shafts is sampled at 4-second intervals, as synchronized by the ground timing system, and converted to binary code form. The three binary code words representing range, azimuth, and elevation, and a 16-bit binary code word representing the time at the instant of sampling are then punched on teletype tape and transmitted to the computer. The header format for all 100-wpm teletype data inputs to the central computer is shown in Fig. 6-2, and the Verlort teletype format is given in Fig. 6-3. The computer receives the position of the vehicle in this manner at 4-second intervals during the period in which the vehicle is above the plane tangent to the earth at the tracking station. The flow of Verlort data within the computer is shown in Fig. 6-4. The following alternate systems are used primarily as backup to the Verlort and to provide a statistical weighting factor in the final analysis of data.

R-1162 Receiving Antenna

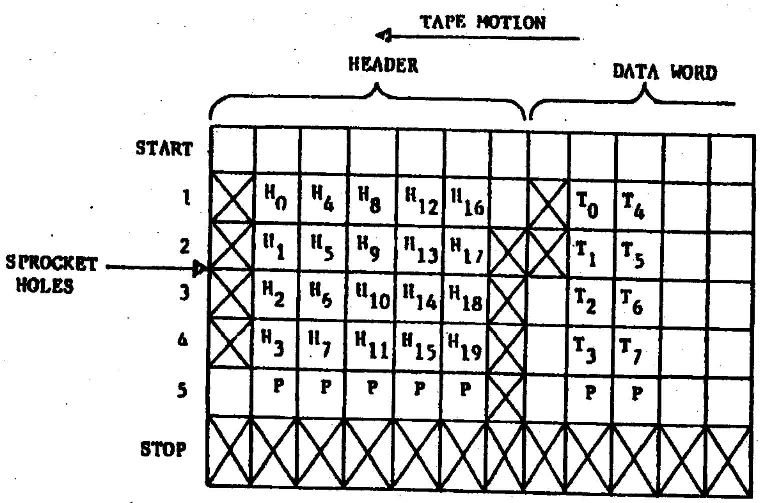
Additional tracking data is obtained from the R-1162 antenna. It is normally locked on to the telemetry signal but it can be locked onto the acquisition beacon as a backup. Alone, the R-1162 does not provide range information; however, range can be predicted by using the predicted location of the orbital plane. The input teletype format is given in Fig. 6-5. A refraction correction must be applied to the elevation measurements of both the Verlort and R-1162 data to compensate for atmospheric bending of the return signals.

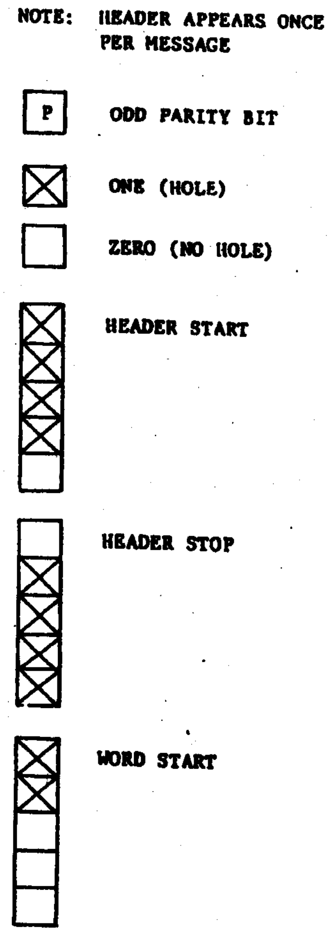
Space-Track Radar

Space track radar is essentially the same as the Verlort radar system, with the exception that it does not make use of the vehicle transponder. This system provides measurements of time, azimuth, elevation, and range as input to the 1102-AF computer program. It also can provide reduced orbital parameters for use as reference in the program.

Doppler

The Doppler system is used to estimate the minimum slant range, relative velocity, and the time of closest approach of an orbital pass. The Doppler system measures frequency shift versus time every two seconds and this provides a measurement of the rate of change in slant range. A typical Doppler tape format is shown in Fig. 6-6.





CHARACTER	DESIGNATION	WEIGHT
H_0 ↓ H_3	MONTH ↓	8 ↓ 1
H_4 ↓ H_8	DAY ↓	16 ↓ 1
H_9 ↓ H_{12}	STATION NO. ↓	8 ↓ 1
H_{13} ↓ H_{15}	IND.SEQUENCE ↓	4 ↓ 1
H_{16} ↓ H_{19}	QUALITY FACTOR ↓	8 ↓ 1

Fig. 6-2 Typical Header Teletype Format to Central Computer

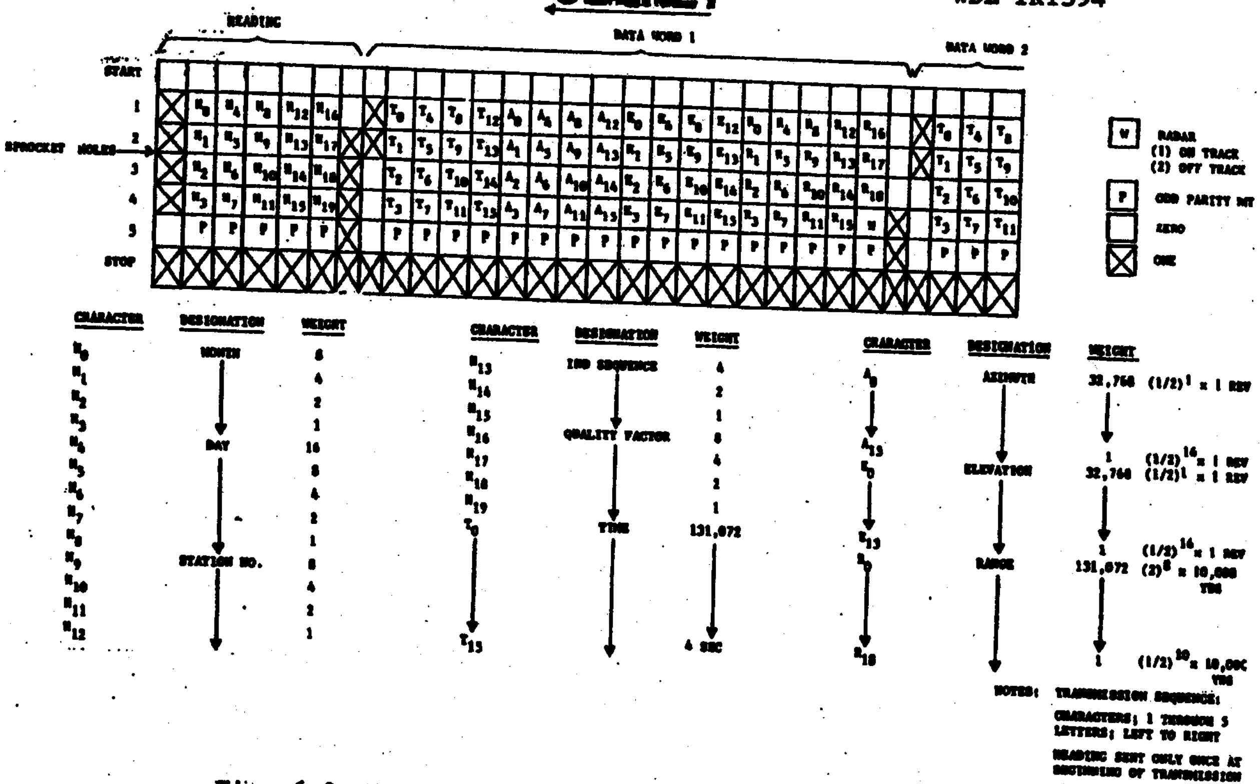


Fig. 6-3 Verlort Teletype Format to Central Computer

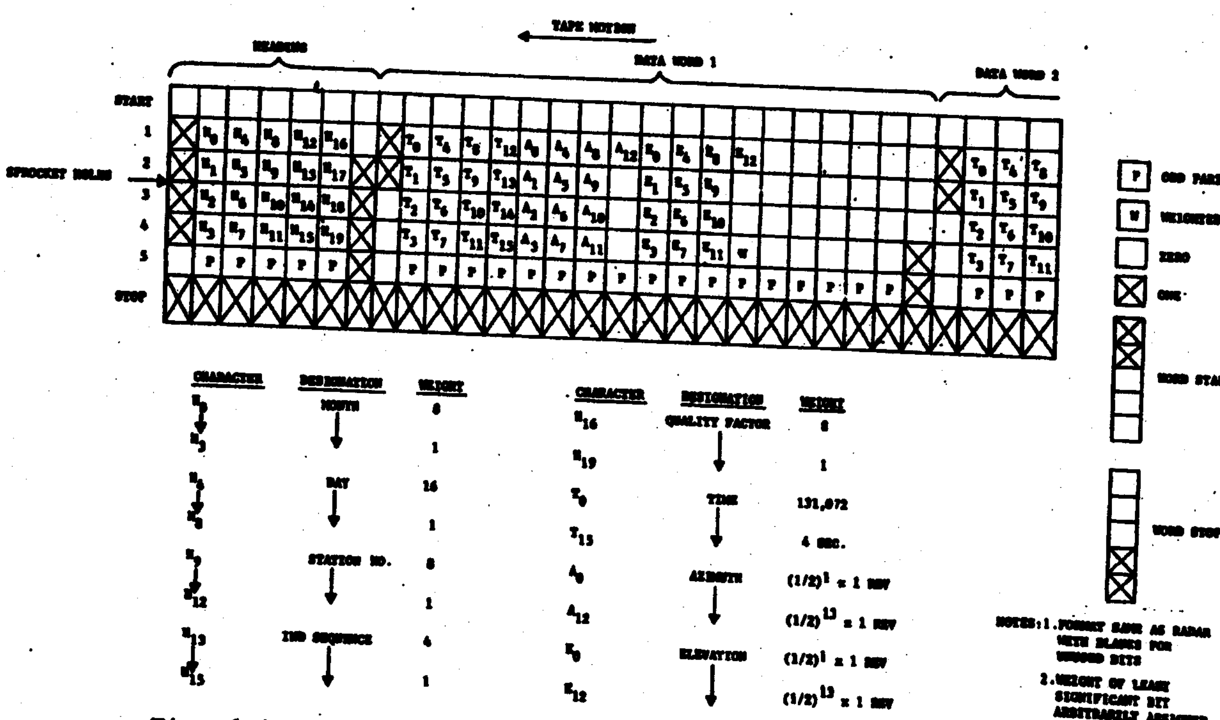


Fig. 6-4 Telemetry Tracker Teletype Format to Central Computer

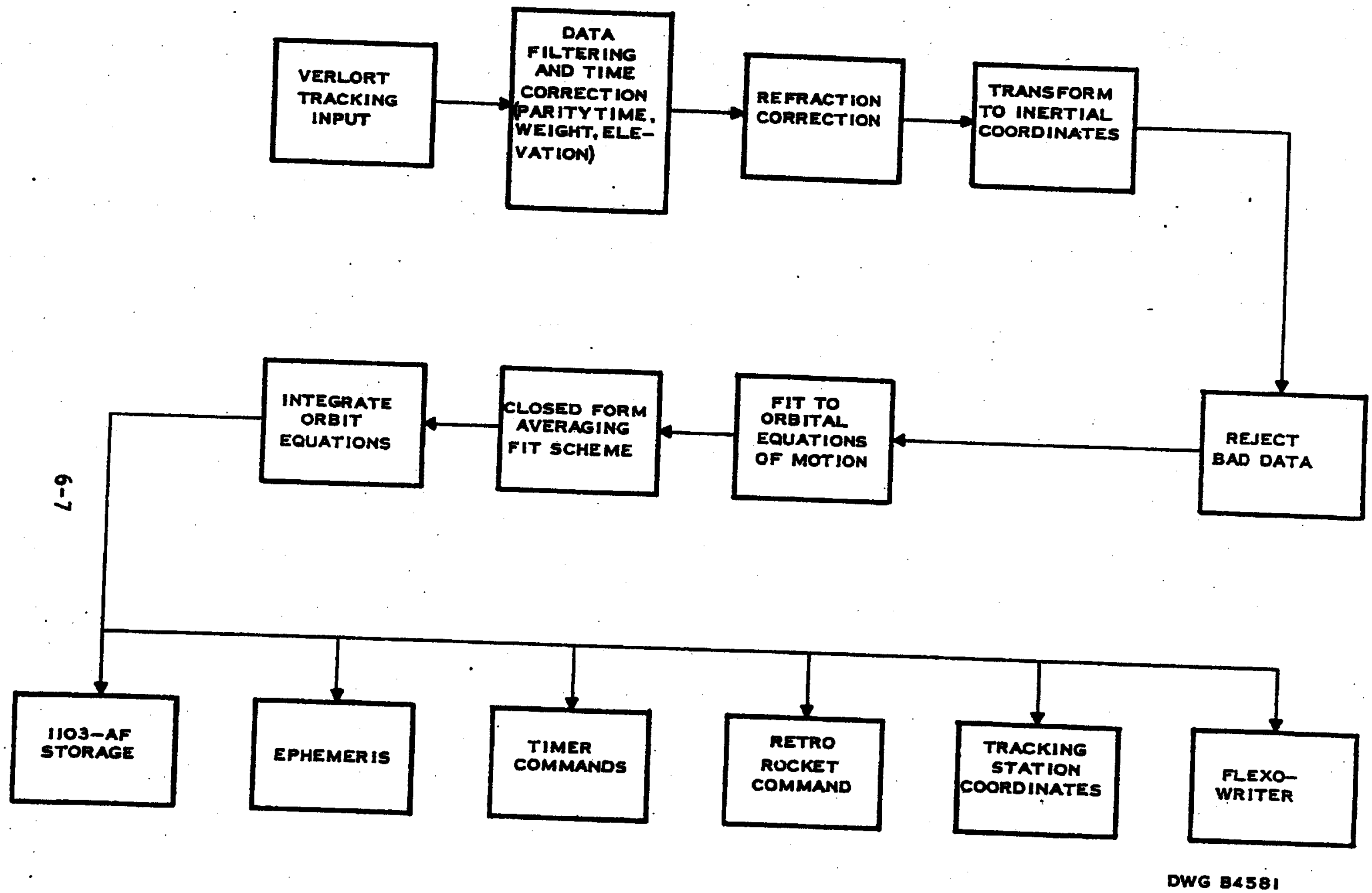


Fig. 6-5 Flow of Verlort Data Within 1103 AF Discoverer Computer Program

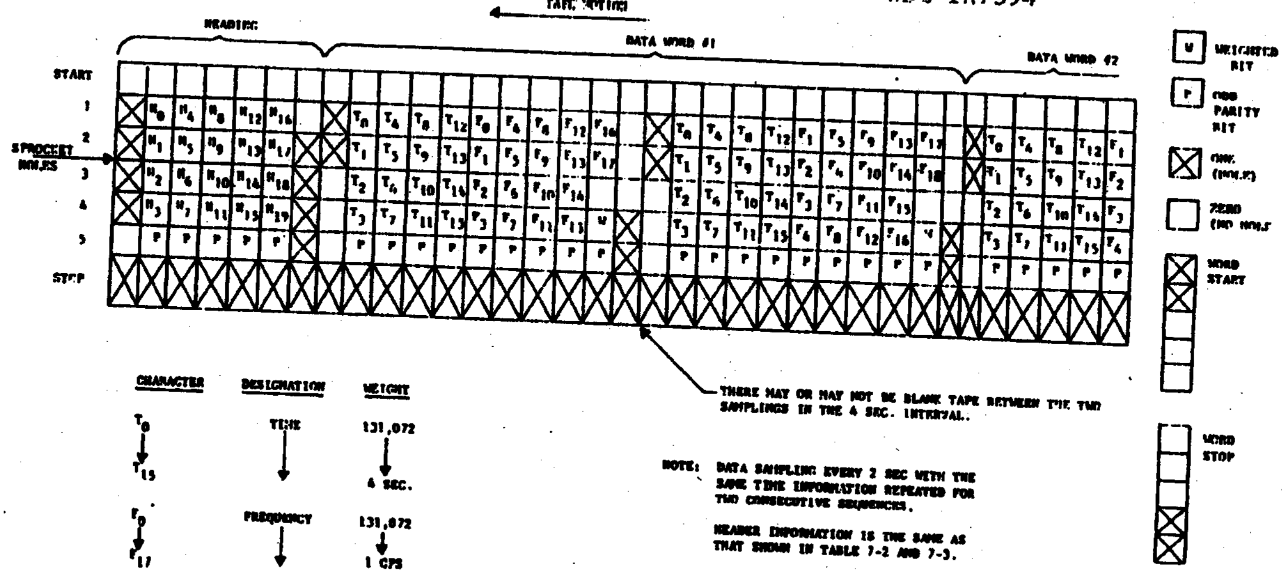


Fig. 6-6 Doppler Teletype Format to Central Computer

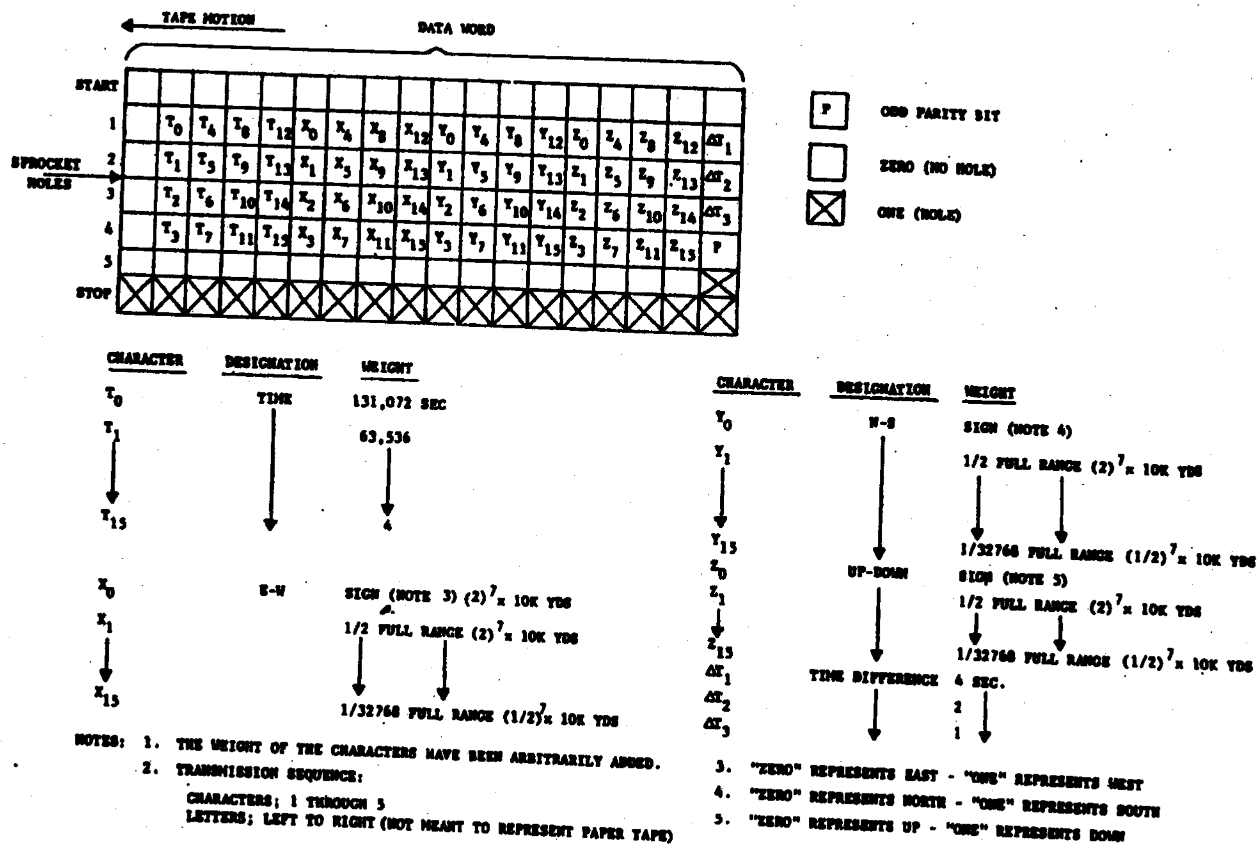


Fig. 6-7 Acquisition Program Teletype Format

6.2.4 Time-of-Events Data

Time-of-events data is sent via 60-wpm teletype as part of the command summary from each tracking station. These events include the launch phase, Stage I and Stage II burnout, injection, etc., and are telemetered from the launch vehicle instrumentation and satellite electronic payload. Time-of-events are used throughout the computer program as a point of reference for computing the satellite flight or re-entry conditions and to predict nominal orbits, timer settings for retrorocket ignition, re-entry time, and point-of-impact.

6.3 Processing Unit

In addition to the basic arithmetic operations as required for equation manipulation, the functions of storage and control are performed in this unit. The storage subsystem holds data, results of computation, and program instruction defining the process to be performed, while the control subsystem contains the instructions of the program.

6.3.1 Storage

The physical models incorporated in the 1103-AF computer program are widely applied throughout the various modes of computation. These models are used to simulate a nominal launch (to be used as backup to ascent tracking instrumentation) and applied in computations of the orbital fit, flight prediction, and retrorocket firing time. The earth model is used in transformation of polar coordinates to inertial coordinates and inertial coordinates to local coordinates.

A brief description of the various models follows:

Atmospheric Model. The elements of the atmospheric model necessary to the ascent and descent phases of the 1103-AF computer program are:

a. Atmospheric density used in computation of drag
b. Local speed of sound used in computation of mach number and, consequently, drag
c. Ambient pressure used in computation of thrust correction for altitude

The local speed of sound and the ambient pressure are given as a function of height and are found in the 1956 ARDC model atmosphere.

Earth Model. The earth model used in the 1103-AF computations is derived from the Hough ellipsoid. The equation representing this ellipsoid is:

$$\frac{U^2 + V^2}{A_e^2} + \frac{W^2}{B_e^2} = 1$$

Where A_e and B_e are defined as the semi-major and semi-minor axis respectively, and U, V, and W are the rectangular coordinates. The earth's eccentricity E_e is defined in the expression

$$E_e^2 = 1 - \frac{B_e^2}{A_e^2}$$

Numberical values associated with the constants in the above expressions are:

A_e = 6,378,270 meters

B_e = 6,356,794.3394 meters

E_e = 0.0819918898

E_e^2 = 0.006722670

Gravity Model. The gravity model is given as

$$G_x = \frac{-\mu}{R^3} X A_1$$

$$G_y = \frac{-\mu}{R^3} Y A_1$$

$$G_z = \frac{\mu}{R^3} Z A_2$$

$$A_1 = 1 + \frac{J a_e^2}{R^2}\left(\frac{1 - 5z^2}{R^2}\right) + \frac{D a_e^4}{R^4}\left(\frac{3}{7} - \frac{6z^2}{R^2} + \frac{9z^4}{R^4}\right)$$

$$A_2 = 1 + \frac{J a_e^2}{R^2}\left(\frac{3 - 5z^2}{R^2}\right) + \frac{D a_e^4}{R^4}\left(\frac{15}{7} - \frac{10z^2}{R^2} + \frac{9z^4}{R^4}\right)$$

where

$D = 1.07 \times 10^{-5}$

$J = 1.638 \times 10^{-3}$

$R^2 = x^2 + y^2 + z^2$

v is velocity

μ is the universal gravitational constant times the mass of the earth

a_e is the semi-major axis of the earth and J and D respectively, are the first and second order expansion terms.

6.3.2 Vehicle Parameters

Certain information pertaining to the characteristics of the launch vehicle and the satellite are required to adequately express the equations of motion and their constraints.

carried out in the computer and operate on data check points supplied by the tracking station. These are known as parity check, time rejection, wight bit rejection, and elevation rejection, and occur in the order listed. Two types of error detection are used: (1) detection of errors of an implausible nature, and (2) detection of possible errors involving plausible but doubtful answers. These are determined by fitting data to established limits under which the system would normally operate.

Parity Check. The parity check is a means of detecting whether or not a machine operation has changed a character's representation. To determine parity, i.e., to test for equivalent values, the machine checks whether the sum of the digits (or bits) of a binary number is an even number, i.e., divisible by two. This simplified test of the quantities recorded by the tracking stations compares the parity to a parity bit of each datum transmitted by the tracking station and rejects those values that do not agree with each check.

Weight Bit. The tracking equipment automatically records a weight bit for its data. This provides a means of determing whether or not a given tracking station was "locked-on" during the time of a satellite pass. Data taken during periods when the tracking station is out-of-lock are rejected from the computations.

Time Rejection Scheme. The time rejection scheme determines the range of values of time acceptable to the computer program. Data points are tested to give a monotone increasing series in time; those points that do not fit the monotone pattern are rejected.

Elevation Check. The elevation check tests whether or not the elevation angle measured at the tracking station is within the limitation of the equipment. Elevation angles less than 6 degrees and those greate than 89 degrees are rejected.

6.4 Flight Prediction

Prediction of the position of the satellite at any given time is achieved by integration of the associated equations of motion. The initial conditions for the motion are provided by the output from the orbital fit and averaging routines in the 1103-AF computer program.

The flight prediction routine is used to:

a. Look ahead in order to compute data for the acquisition messages

b. Compute the vehicle ephemeris

The future position of the satellite can be predicted when numerical values have been obtained for six parameters. Six are required since the equations of motion are three second-order differential equations. There are many sets of parameters, each consisting of six quantities, which can be used to describe the satellite orbit.

The set used for the program is: $x, y, z, \dot{x}, \dot{y}, \dot{z}$, where (x, y, z) are the coordinates of the satellite (at some specified time $t=t$) in a "fixed" or "inertial" coordinate system, and the components of the velocity vector of the satellite at the same time are $(\dot{x}, \dot{y}, \dot{z})$. The members of this set of orbital parameters are called "initial conditions" since we use these six quantities are starting values for the numerical integration of the equations of motion for a close-earth satellite. At first, the set of initial conditions assumed is drawn from launch data or from a nominal orbit. From this an ephemeris, computed using the Runge - Kutta method of numerical integration, gives the prediction of the vehicle position during that period of time when it is above the tangent plane of a tracking station. If the tracking system is a radar, the vehicle position is observed during this time. A least-squares fit is then made between a set of observed positions (say every 4 seconds) and the predicted positions at the time of each of the observations. The results of the least squares method is a set of differential corrections $(\Delta x, \Delta y, \Delta z, \Delta \dot{x}, \Delta \dot{y}, \Delta \dot{z})$ as shown in Fig. 6-8. With this new corrected set of initial conditions the process is repeated. It is repeated again and again until the differential corrections are very small, and then these new initial conditions are used to predict the future position of the vehicle. When another station observes the vehicle, the least-squares fit is made between both sets of observations and this last set of initial conditions . Thus, as more and more stations observe the vehicle, the initial conditions are revised again and again so that prediction is made from initial conditions which produce a trajectory that most closely agrees with all the observations in the least squares sense. This process is depicted in Fig. 6-8.

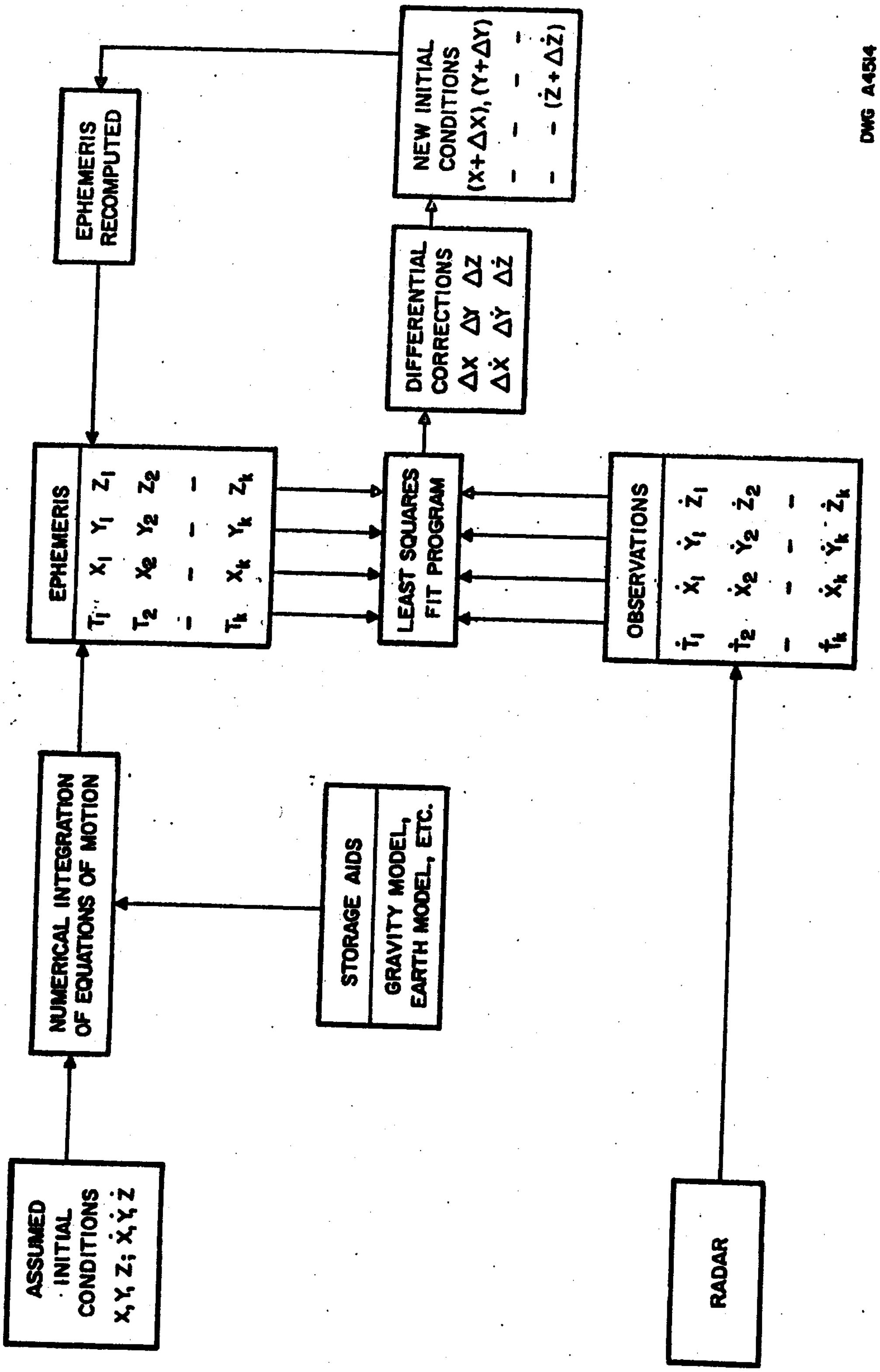


Fig. 6-8 Ephemeris Computation and Prediction

6.5 Output Unit

The output unit can be the same physical unit as that serving as the input unit. The unit serves as a translator of the processed data and transforms data into a format acceptable for use outside of the computer. The output may take the form of flexowriter, paper tape, punched card, or line printer depending on its intended usage. The flexowriter output, for example, can provide information in the following formats:

a.	Time	t
b.	Height or altitude	h
c.	Geocentric latitude	θ
d.	Longitude	λ
e.	Velocity (inertial)	$\lvert\bar{V}\rvert$
f.	Inclination angle	i
g.	Flight path angle	a

The Flexowriter can also give such data as:

a. Revolution number of orbits (counted by the number of descending nodes)

b. Names of the tracking stations

c. Number of data points acquired from any given station

d. Pre-launch card (time of events)

e. Total number of data points

f. Rejection intervals

g. Type of data read into the computer

h. Number of good data points used

i. Orbital parameter obtained from input data by smoothing, rejection, etc.

j. Statistical weight assigned to measure values.

The following outputs are utilized:

Paper Tape Outputs:

a. Local xyz for Verlort radar acquisition tape (a typical acquisition type format as shown in Fig. 6-7.)

b. Space track message

c. Simulated Verlort data - checkout

d. Simulated R-1162 data - checkout

e. Simulated Doppler tracking data - checkout

f. Simulated ship tracking data - checkout

g. Simulated Doppler data - checkout

Card Outputs:

a. Data Cards - single card

b. Program reset cards - position, velocity, vectors, end of revolution - checkout

Listable Magnetic Tape Outputs:

a. SS/H - Timer Summary

b. Data points

c. All card inputs

d. Fits to orbit

e. Ephemeris listings

SECTION 7
GROUND COMMUNICATIONS

7.1 General

Communication circuits are provided for the transmission of data, operating instructions, and administrative orders. The facilities include teletype, telephone, and radio, and they interconnect the launch, tracking, telemetry and control facilities.

The communications function is divided into two separate systems: (1) the interstation communications system, which consists of the circuits and channels provided to connect all of the stations together into an integrated network, and (2) the intrastation communications system, which consists of the circuits and equipment necessary to support on-station activities.

The communications equipment is installed in the operations building at VAFB (see Fig. 4-5), Hawaii (see Fig. 4-6), and Kodiak (see Fig. 4-7). At New Boston, the communications equipment is installed in the A&C van (see Fig. 4-9), and at Point Mugu, in the communications van (Fig. 4-8).

7.2 Interstation Communications System

The interstation communications system (Fig. 7-1) provides a network of communication channels and associated terminal equipment required to coordinate the activities of the Subsystem H tracking stations. The Satellite Test Annex (STA) is the activity control point of the system.

The five Subsystem H tracking stations are connected to the STA Computer complex by half-duplex 60-wpm teletype circuits and alternate voice/100-wpm teletype circuits. The Vandenberg and Point Mugu tracking stations have an additional voice line capability to the STA through the Vandenberg control center. A duplex real-time voice line slave data circuit and an EE-8 terminated voice line also exist between the Vandenberg and Point Mugu tracking stations.

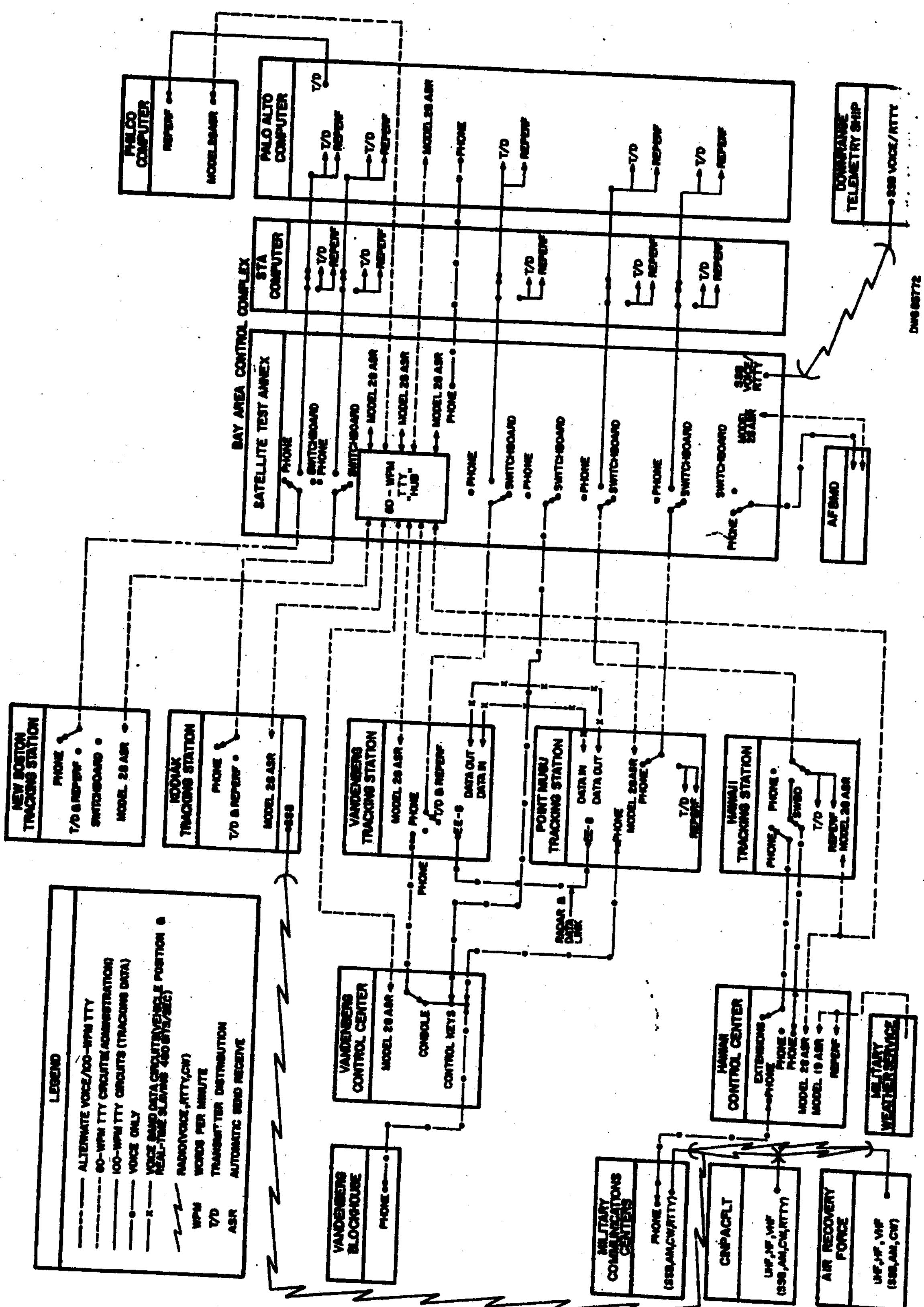


Fig. 7-1 Interstation Communications System

Interstation communications circuits are provided by normal telephone company leased lines, except for those provided by government agencies outside the territorial United States. The down-range telemetry ship is tied in by means of a high frequency, single-sideband (SSB), voice-radioteletype circuit, terminating at the STA. The Kodiak tracking station is linked to the recovery force by SSB.

7.2.1 60-WPM Teletype

The command-administrative 60-wpm teletype circuit terminates on a Model 28 ASR (automatic send-receive) teletypewriter set at each station. The Model 28 ASR consists of a page printer and keyboard, tape perforator and a transmitter-distributor (T/D). Maximum versatility is provided, in that each unit of the teletypewriter set can be used separately or in various combinations. Secure transmissions are possible at each tracking station by use of the Model 131-B on-line crypto equipment in conjunction with the Model 28 ASR.

The 60-wpm circuits from all tracking stations terminate at the STA in a console. From the console, a multiple number of circuits can be patched together into any one of several "hubs" available to the console. The STA decides to which "hub" stations will be assigned during both normal duty hours and operational periods; therefore, if a station desires to transmit a message to a station in another "hub", the station will have to request the STA to make the necessary patch.

The 60-wpm command-administrative net is used for acquisition and command messages, weather and equipment status reports, performance and command summaries, and general information messages and instructions.

7.2.2 Alternate Voice/100-WPM Teletype Net

The alternate voice/100-wpm teletype net consists of separate full-period telephone circuits connecting the tracking stations to the STA. This circuit is used to convey either voice or teletype information on a shared basis. Circuits are normally on voice when not being used for tracking data transmission. When in the teletype mode, the circuit is terminated at the computer.

Teletype Utilization. In the teletype mode, the alternate voice/100-wpm circuit is utilized to route vehicle tracking data in digital-binary form from the tracking stations to the central computer. Antenna positioning data (acquisition program) are routed from the central computer to each tracking station prior to each pass. The circuits are terminated at each end with transmitter-distributors and tape reperforators. The d-c output of the transmitter-distributor is converted to frequency shift tones for routing on the voice frequency telephone carrier channels by Type 43A1 telegraph carrier equipment. At the receiving end, the frequency shift tones are converted back to d-c type impulses by similar equipment. Lines are switched to the central computer equipment by the operator at STA whenever the circuit is utilized for teletype operations. The teletype terminating equipment, consisting of the reperforators, transmitter-distributors, conversion and storage units, is located in the computer area.

Voice Utilization. As a voice circuit, the 100-wpm alternate voice line is used for all voice communications, including countdown status, checks during prelaunch phase, and reporting of real-time readouts during active passes. The STA controls the status of the 100-wpm circuits and selects either the 100-wpm or voice, and conference net or individual station communications.

7.2.3 Launch Coordination Telephone Circuit

A separate full-period telephone circuit is installed which connects the Vandenberg tracking station, Point Mugu tracking station, Vandenberg control center and the STA. This circuit is provided to insure maximum coordination between these stations during prelaunch and launch phases, including the transmission of the lift-off tone.

7.2.4 Real-Time Digital Data Slaving Link

Real-time tracking data is routed between the Vandenberg and Point Mugu tracking stations via a full duplex voice band circuit. This circuit is terminated in D/A and A/D transceivers and permits slaving of tracking equipment between the two stations. A more detailed description is contained in Section 4.2, Data Transmission and Display.

7.2.5 VAFB-Point Mugu Radar Data Voice Line

A voice line terminated with EE-8 telephones in the radar and data transmission areas of both stations is routed between VAFB and Point Mugu. This circuit is used primarily to coordinate activities between the two radars during the launch phase. It is also used in checking out the real-time slaving link during the countdown.

7.3 Intrastation Communications System

The intrastation communications system (Fig. 7-2) provides the communication facilities for coordination of on-site activities. The intrastation communications system consists of (1) an administrative system (2) an operation system (dial) (3) direct operational circuits (hot lines) and (4) an on-station paging system.

7.3.1 Administrative System

At Vandenberg, the administrative telephone system consists of subscriber subsets terminated at the PABX in the new Missile Assembly Building. This system is used for normal administrative calls among the various locations within the launch and tracking complex. Drops are installed in the administrative and operational areas. Access to the commercial telephone system is provided.

At Point Mugu, the administrative system consists of subscriber subsets connected to the Navy (NAMTC) telephone system. Drops are installed in the administrative and operational areas. Access to the commercial telephone system is provided.

Administrative telephone facilities at the Hawaii tracking station terminate on a 100-line PABX. Access to five commercial trunks is provided by dialing "9". Subsets are installed in all administrative and operational areas.

Administrative traffic at the Kodiak station utilizes the station operational dial telephone system (Leich 40-A) for both administrative and operational purposes. Direct dialing access to the local commercial telephone system is provided.

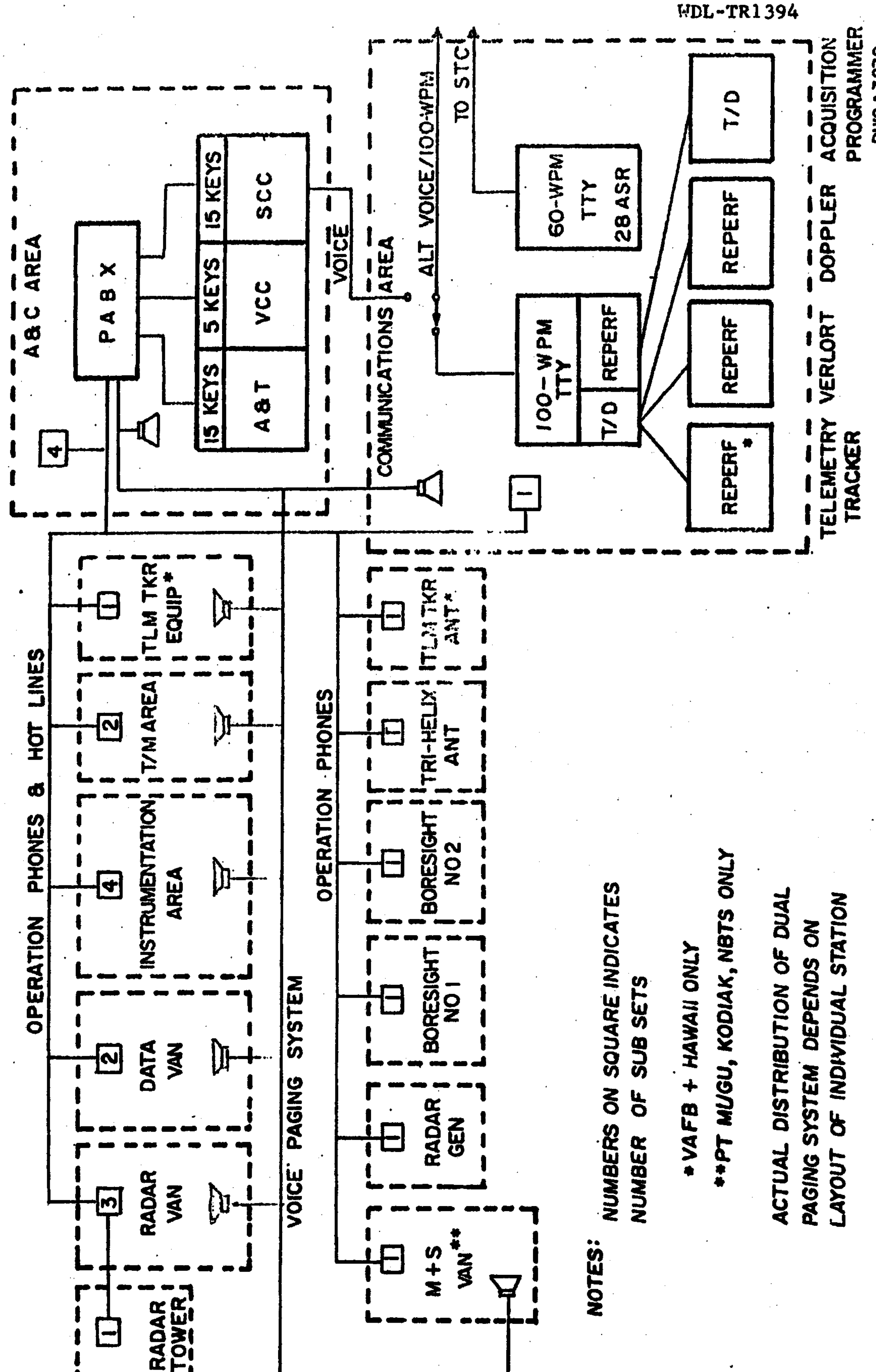


Fig. 7-2 Typical Interstation Communications System

Administrative communications at the New Boston tracking station are provided by New England Bell Telephone facilities installed in administrative and operational areas.

7.3.2 Operational Telephone System (Dial)

The operational telephone system provides dial telephone facilities between all buildings, offices, vans, antenna towers and power-generating facilities within the tracking station. Vandenberg requirements, originally provided by the Kellogg Select-O-Phone System, have been integrated with the SAMOS operational communications system. Point Mugu and Hawaii requirements are met by the Kellogg Select-O-Phone system. The same facilities are provided by a Leich 40-A PABX system at Kodiak and New Boston. Each subset is assigned a number combination and any terminal can be dialed from any other terminal within the system.

The Kellogg Select-O-Phone is strictly an on-station facility since its characteristics make it incompatible with normal commercial facilities. The Leich System is compatible and is utilized at the Kodiak station to dial directly into the off-station telephone system for long distance calls. Both systems provide override features permitting high priority calls to be made at any time.

7.3.3 Direct Operational Circuits

Direct operational circuits (hot lines) are superimposed on the Kellogg dial-system local lines. Separate hot lines are provided with the Leich system. These circuits permit the operator, or the controller at one of the supervisory consoles, to connect his telephone directly onto local lines without the necessity of dialing. The hot lines utilize the switchboard battery, but the switching is independent. The hot lines are controlled by keyed microswitches located on communications panels (Fig. 7-4). At the shift supervisor's console (15 keys), the acquisition and tracking console (15 keys) and the vehicle command console (5 keys). These lines are used during acquisition, tracking, and testing procedures to coordinate the efforts of the master console

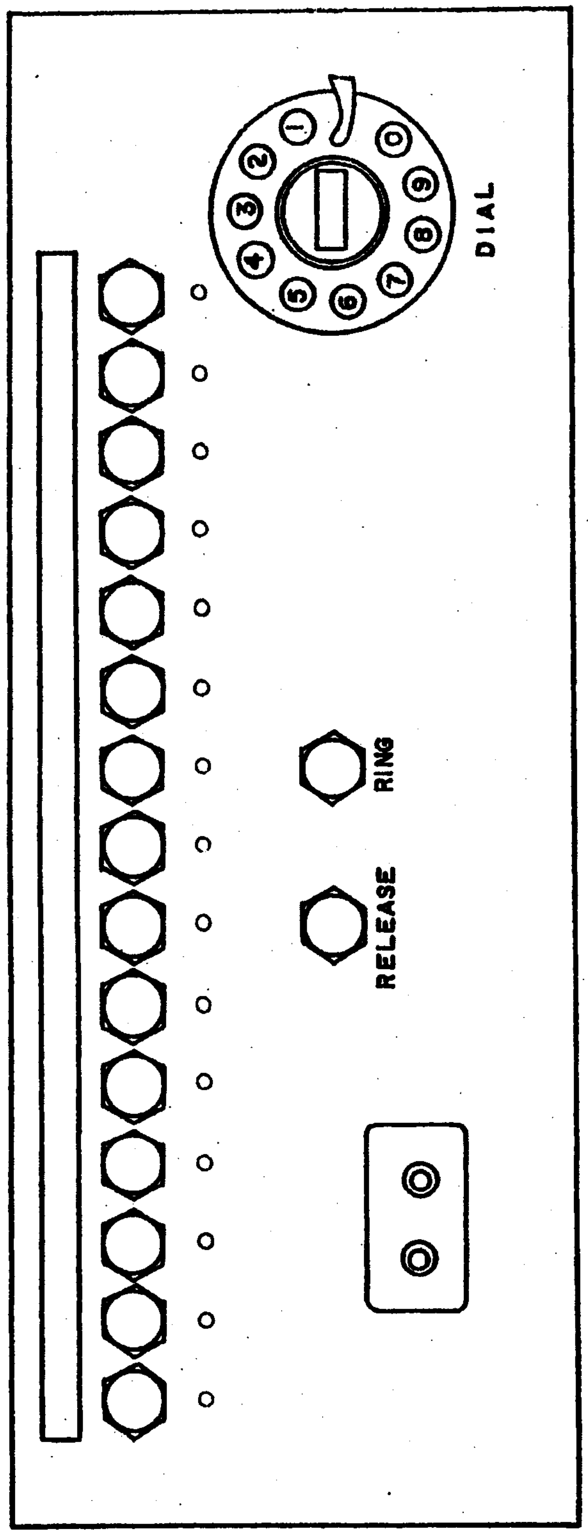


Fig. 7-3 Communications Panel

operators and shift supervisor with the various equipment-operating locations. Contact is initiated by depressing a designated pushbutton switch on the communications panel at any of the three station supervisory consoles. This places the operator's headset directly on the line to the position called. Signalling is provided by a ring button on the panel. Direct hot-line circuits are provided between the following points, subject to revision as dictated by operational requirements:

a. From the SS/H Shift Supervisor's Console to:
   (1) Central Timing Generator
   (2) LMSD Telemetry Equipment
   (3) Data Transmission Van
   (4) Communication Operator's Position
   (5) Acquisition and Tracking Console
   (6) Vehicle Command Console
   (7) Paging System

b. From the Acquisition and Tracking Consoled to:
   (1) Doppler Control Position
   (2) Tri-helix Control position
   (3) Telemetry Tracker Control position (VAFB and Hawaii only)
   (4) Radar Console
   (5) Radar Computer Console
   (6) SS/H Supervisor's Console
   (7) Paging System

c. From the Vehicle Command Console to:
   (1) LMSD Telemetry Equipment
   (2) Radar Operator
   (3) SS/H Supervisor's Console
   (4) Paging System

7.3.4 Voice Paging System

A dual system of voice paging is provided at each tracking station; one system covers the receiving area and the other, the transmitting area. Each area has a separate amplifier and speakers are installed at specified locations in each area. Any dial telephone in the operational telephone system has access to the paging facilities by dialing a preassigned number. The communication panels at the three supervisory positions contain a button switch to provide access to the paging system.

The voice paging system is primarily designed for use by the shift supervisor to conduct operational and general administrative activities. It is used for general announcements, local countdown information and operational instructions prior to and during an operation.

7.3.5 Kellogg Select-O-Phone System

The Kellogg Select-O-Phone system is a 55-line dial telephone system. Present tracking station requirements use approximately 35 lines, leaving an expansion capability of 20 lines with additional selectors. The system is capable of conference calls and dialing up to 3½ miles with long-line equipment. The Select-O-Phone uses a manual ring system; no dial tone is provided.

7.3.6 Leich 40A PABX Telephone System

The Leich 40A private automatic branch exchange is a 40-line dial telephone system featuring a dial tone and automatic ring. A maximum of six local links are available. The Leich equipment is a compatible system and works directly into commercial lines without modification. Ten city trunks terminating on trunk switches are available. The switchboard is designed to operate over a voltage range of 44 to 56 volts with an automatic or common battery central office and may be adapted to work into a magneto office. The trunk loop limit is the central office loop limit or 1500 Ω , (whichever is less).

SECTION 8
SYSTEM OPERATION

8.1 General

Discoverer tracking station operational procedures and requirements are governed by applicable LMSD publications; i.e., System Test Directive (STD) and Station Operating Procedures (SOP). Direct control of system checkout and test operations is exercised by the Satellite Test Annex (STA). Phases of station activity in support of test operations include prelaunch, launch, orbit, and recovery.

8.2 Prelaunch Operations

The objective of the prelaunch procedure is to insure proper functioning of the overall system. Station equipment checks and calibrations are performed in accordance with applicable SOP's. System operation exercises and data transmission checks are conducted to verify proper operation of station equipment. Flybys of aircraft equipped with beacon and telemetry equipment are made at the stations to demonstrate operational readiness. A dress rehearsal involving all stations provides a comprehensive readiness check. Periodic weather reports are submitted from various stations and the effect on flight operations is evaluated by the STA up to the time of launch.

In the final stages of the countdown, periodic communication, station status, and system time checks are performed by STA with each station. Any change in station status, if a malfunction is involved, with an estimated time required for correction, is reported immediately by the station. An acquisition program of the nominal launch or orbit trajectory is transmitted to each station by the central computer. The stations run a preplot of this nominal data and, with the Verlort slaved to the acquisition programmmer, transmit tracking data back to the central computer. From this data, the central computer evaluates the readiness of the tracking data transmission facilities. All r-f interference is reported to the appropriate Frequency Control Center. At the initiation of the terminal count, the blockhouse is placed on the conference voice line to provide a commentary of the progress and the lift-off tone.

8.3 Launch Operations

At lift-off, a 1000 cps tone is transmitted to all stations. The STA immediately provides the down-range telemetry ship with the system time of lift-off via the SSB link.

At lift-off, tracking is initiated by the Vandenberg Verlort, TLM-18 and tri-helix, assisted as necessary by the optical tracker. Two VAFB range safety MPS-19 radars (one active, with its PRF synchronized to the Vandenberg Verlort, and one passive) also begin tracking at lift-off. The Mugu Verlort should lock-on at about t + 40 seconds with the Mugu tri-helix acquiring slightly sooner. Real time Vandenberg slaving link data is available to aid Mugu acquisition if necessary. To avoid lobe tracking, the Vandenberg radars received signal is manually attenuated with the waveguide variable attenuator. The attenuation is gradually removed as the signal strength decreases. At Mugu, anti-lobe-track-operating procedures are utilized. If lobe tracking is suspected due to lower signal strength indication at acquisition, a manual excursion of ± 10 degrees in azimuth and ± 5 degrees in elevation is made at the earliest possible time before T + 90 seconds. Vehicle velocity after this time makes rapid lock-on difficult. Fine PRF synchronization is maintained by Mugu during the time Vandenberg and range safety are actively tracking. To avoid interfering with Mugu Verlort tracking and commanding during PRF changes, the Vandenberg radar will go passive and the two range safety radars will shut down at T + 164 seconds.

The Point Mugu tracking station has the responsibility for determining and transmitting the required time-to-fire and velocity-to-be-gained correction commands to provide engine ignition and cut-off times necessary for achievement of the desired orbit. Computation and transmission of these correction commands will be accomplished automatically by the guidance computer system by sampling and evaluating launch tracking data at two predetermined points. The time-to-fire and velocity-to-be-gained correction commands are normally transmitted automatically as Commands No. 5 and No. 6, respectively. At the option of the computer operator, guidance command control may be switched to the guidance command panel of the VCC which is preset with nominal values of Commands No. 5 and No. 6.

Both Vandenberg and Mugu provide a voice commentary to the STA on equipment tracking status, required real time telemetry readouts, and command transmissions and verifications. Verlort, TLM-18, and Doppler tracking data are recorded on punched teletype tape. Verlort data is transmitted to the central computer via the 100-wpm teletype link as soon as possible. The TLM-18 and Doppler data are transmitted via 100-wpm teletype as directed by the STA. Performance, command, and status summaries are transmitted via 60-wpm teletype following the launch operation. Recorded tracking, telemetry, and plotboard data are packaged up and delivered to STA by courier.

At launch, the downrange telemetry ship will be on station approximately 1300 nm downrange and 75 nm east of the projected launch trajectory. This position optimizes reception of telemetry data beyond the reorientation phase while covering engine burnout and orbit injection. The telemetry ship will automatically track the Doppler transmitter, recording antenna position data and Doppler frequency data on teletype tape. This data, with ship attitude data, is transmitted to the STA by SSB radio teletype at the direction of the STA. The antenna position data, together with the Doppler data, can verify that orbit has been attained or define the trajectory in the event that orbit is not attained. The telemetry data recorded on magnetic tape will normally be delivered upon reaching port, unless an air pickup is directed by the STA.

8.4 Orbit Operations

The tracking stations will go through the prepass checkout for orbit operations as outlined in applicable SOP's. The central computer evaluates exit trajectory data or orbital data as appropriate and transmits an updated acquisition message and acquisition program to the stations via 60-wpm and 100-wpm teletype, respectively. The acquisition message contains Reeves orbit computer parameters; system time of acquisition, midpoint, and fade with positional data in both polar and cartesian coordinates; time of reset; and commands to be transmitted. The acquisition program will be preplotted and then set to start at ETA=0 to assist tracking devices to acquire as necessary.

Tracking will be maintained and tracking and telemetry data recorded from acquisition to fade or actual turn-off of the vehicle S-band transponder and telemetry. Commands will be transmitted as directed by the STA. The anti-beacon capture circuit (see Paragraph 2.2.13) will permit simultaneous Verlort tracking when the vehicle is within range of more than one station. The radar when tracking will normally drive the slave bus. During track, the Reeves orbital computer will be updated continuously, so that if radar track is lost, the computer output can be used to assist in reacquisition. Verlort tracking data will be transmitted to the central computer as soon as possible. The TLM-18 and Doppler data will be transmitted as directed by the STA. Performance and command summaries are transmitted via 60-wpm teletype following the completion of the pass.

If acquisition is not achieved, stations will implement "lost bird" procedures as directed by the STA.

Variations in launch-phase performance of both booster and satellite vehicles may cause the actual orbit period to deviate from the nominal. Since the orbital programmer period was set at launch to agree with the nominal or predicted orbit period, the programmer rate must be changed to agree with the actual orbit period. Once the orbit period has been determined, Command No. 2 can be used to correct the programmer rate in increments of seconds, with Command No. 1 determining the direction (Increase/Decrease) of the change. Command No. 3 is used to reset the on-off timing of the programmer to the proper geographical reference. Proper reset timing is particularly important to the recovery phase.

8.5 Recovery Operations

A primary objective of the Discoverer program is the recovery of a re-entry capsule ejected from orbit on a scheduled recovery pass. The recovery capsule is placed on a re-entry trajectory by a programmed retro-rocket firing. Programmed parachute deployment slows the descent rate of the capsule, and activation of recovery aids enable capsule detection for air recovery by specially equipped aircraft.

On the pass preceding the recovery pass, orbital programmer correction commands are transmitted to the vehicle to refine the timing of the re-entry sequence to place the recovery capsule within a predetermined area in which the recovery force is operating. Acquisition aids contained within the capsule aid both air and surface craft to acquire the capsule during re-entry.

The Hawaii and Kodiak stations are utilized to track the capsule during re-entry and furnish position data to the sea and air recovery forces. Pacific Missile Range (PMR) tracking facilities at South Point, Barking Sands, Christmas Island and Tern Island are also utilized to provide capsule position data. Emergency alternate re-entry procedures also require the support of Vandenberg tracking station and the downrange telemetry ship. The re-entry sequence which is preset into the programmer to occur on a selected pass may be changed by command.

SECTION 9
RELIABILITY

9.1 Station Reliability Analysis (Kodiak)

A reliability study has been conducted on operating time and failure data collected during a 22 month period (from September, 1958 through June, 1960) on Kodiak Tracking Station, Alaska. The data available for this study included equipment operation time and the number of major failures, each listed month by month. Unfortunately there was no record of repair times, so no estimate of availability can be made.

Availability is defined as the ratio of time that equipment is operational to the time it is required. That is, it is the ratio

$$\frac{MTBF}{MTBF + MTR}$$

where MTBF is mean time between failures, i.e., the summation of operating divided by the total number of failures, and MTR is mean time to repair. If repair times are short compared to MTBF's then it follows that availability is high (close to unity).

Reliability is the probability that equipment will perform its required function (operate within specification) for a given period of time. It is expressed as

$$R = e^{-\lambda t}$$

where λ is the failure rate (failures per unit time) and t is the time of required operation.

By assuming that the equipment is operable at the beginning of a required period, the reliability has been calculated for certain essential functions. A vehicle pass duration of seven minutes was assumed, aud the reliabilities for one pass and for seven passes (assuming a total of 17 passes, the vehicle is visible for seven at Kodiak) are calculated. Five functions have been considered:

a. Tracking and command

b. Timing

c. Data transmission

d. Doppler tracking

e. Telemetry

The following equipment was included twice; once in telemetry function and once in Doppler Tracking function:

a. Tri-helix antenna assembly

b. Azimuth drive assembly

c. Elevation drive assembly

d. Base assembly

e. Power supply unit

f. Joystick control unit

All other equipment was assigned only to one function, as shown in Table 9-2. Listed in Table 9-1 are the failure and reliabilities for seven minutes for the functions named. Table 9-2 lists the major equipment components, operation time, number of failures, estimated MTBF, and 90 per cent confidence interval. The MTBF is obtained by dividing operating time by number of failures.* The 90 per cent confidence interval is the interval within which one is 90 per cent certain that the true value lies. That is, in the case of the radar equipment, the antenna pedestal has an estimated MTBF (Table 9-2) of 412 hours and the 90 per cent confidence interval is 228 to 828 hours. This means that by the techniques used, the estimate is correct 90 per cent of the time that the true MTBF is in the range of 228 to 828 hours.

*By failure is meant a fault, the presence of which would cause loss of the function.

TABLE 9-1

SUBSYSTEM FAILURE AND RELIABILITIES

	FUNCTION	FAILURE RATE	RELIABILITY (7 MINUTES)
*1.	Tracking and Command	0.01266	0.9985
*2.	Timing	0.005992	0.9993
*3.	Data Transmission	0.009203	0.9989
*4.	Telemetry	0.01752	0.9980
5.	Doppler Tracking	0.007514	0.9991

Product of 1,2,3,4 = 0.9948

Product of 1,2,3,4,5 = 0.9945
(excluding duplication of tri-helix antenna equipment which is included in each of 4 and 5)

for 7 passes 1,2,3,4 = 0.9755

for 7 passes 1,2,3,4,5 = 0.9585

*Prime importance functions

9.1.1 Summary

Table 9-1 shows the reliability (i.e., the probability that given equipment will perform its function for a stated period of time) for five functions of the Kodiak station based on the operating data. The primary functions of (1) tracking and command, (2) timing (3) data transmission and (4) telemetry have a probability of performing properly during a seven minute pass of 0.9948. For all seven of the 17 Discoverer passes the reliability is 0.9755. For these four functions plus (5) Doppler tracking the reliability for a seven minute pass is 0.9945.

The probability of all the functions performing properly for all seven passes is .9585.

All the above figures are based on the assumption that the equipment is operating satisfactorily at the beginning of each pass. This assumption was made necessary since no repair times were known. The reliability figures should be reduced by an availability factor which would take into account the probability that equipment might be down for repair at the beginning of a pass.

TABLE 9-2

UNIT FAILURE AND RELIABILITIES

UNIT	Operational Hours	Failures	Estimated MTBF	90% Confidence Interval $X \leq MTBF \leq Y$	
Radar Equipment (Command & Tracking)					
Antenna Pedestal - Ser. #DA 2438	3295	8	412	228	828
Transmitter - Receiver #21	1721	8.5	202	114	397
Auxilliary Console #3	3628	5	726	345	1842
Master Console #3	3628	10	363	214	669
Acquisition Console #3	3628	2	1814	576	10209
High Voltage Rectifier #3	2417	0	undetermined	1050	∞
Orbital Computer	3295	0	undetermined	1431	∞
Baldwin Encoders #0019, #0024	3295	2	1648	523	9272
Instrumentation Van Equipt. (Timing)					
Dual Timing System (ZA-22171)	14064	28	512	372	722
Timing Terminal Unit (Radar)	14074	14	1005	643	1662
Digital Time Display System (81)	12825	36	356	270	484
Remote Digital Display Unit (83)	12825	3	4275	1654	15684
Data Equipment					
Control Unit #3	3163	1	3163	667	61663
P-C Converter #3	3068	1	3068	647	59811
C-P Converter #3	3056	3	1017	394	3737

TABLE 9-2 (Continued)

UNIT	Operational Hours	Failures	Estimated MTBF	90% Confidence Interval X ≤ MTBF ≤ Y	
Data Equipment (Continued)					
X-Y Recorder #17	2318	3	773	299	2834
D/TT Converter #1	2911	7	416	221	734
D/TT Converter Tape Transport #3	2631	1	2631	555	51292
Acquisition Programmer #5	2574	8	322	185	50180
Acquisition Programmer Tape Transport Ser. #4	2561	1	2561	540	49927
Doppler Equipment					
Tri-Helix Antenna Assembly	1629	0	undetermined	708	∞
Azimuth Drive Assembly	1629	2	815	259	4584
Elevation Drive Assembly	1159	0	undetermined	503	∞
Base Assembly	1629	4	407	178	1192
Power Supply Unit	1629	0	undetermined	708	∞
Joystick Control Unit	1629	1	1629	343	31758
Phase Coherent Receiver	12632	15	842	511	1366
Pre-Amplifier with Power Supply	3948	8	494	274	992
Telemetry Equipment					
Ampex Tape Recorder	3343	28	119	87	168
*effective failure rate for 2 units in system, where one is required and one is redundant: nil	--	--	--	--	--

TABLE 9-2 (Continued)

UNIT	Operational Hours	Failures	Estimated MTBF	90% Confidence Interval X ≤ MTBF ≤ Y	
<u>Telemetry Equipment (Continued)</u>					
Radio Receiver	2761	10	276	163	509
effective failure rate for 4 units in system, where two are required, two are redundant: nil	--	--	--	--	--
Audio Monitor Panel	3374	3	1125	435	4126
McIntosh Audio Amplifier	1547	2	774	246	4353
effective failure rate for 3 units in system, where one is required, 2 are redundant: nil	--	--	--	--	--
Recording Oscillograph	2277	3	759	294	2785
Low Freq. Standard	14304	0	undetermined	6212	∞
Eput Meter	3374	0	undetermined	1465	∞
Oscilloscope, Tektronix	2905	5	581	276	1475
Subcarrier Discriminator	3060	25	122	87	176
effective failure rate for 18 units in system, where 16 are required, 2 are redundant: nil	--	--	--	--	--
Decommutation Station	3228	30	108	79	150

*by having one or more redundant units, the probability of successful operation for seven minutes is essentially unity, since the MTBF's are much, much greater than seven minutes.

9.2 Reliability Summary

This section presents a brief summary of the reliability effort on the Discoverer Program during the period from December 1958 to November 1960. Machine-processed and analyzed quantitative data on system failures was used in conjunction with failed part analyses to establish a basis for system reliability improvement. Failed part analyses were conducted on a total of 440 representative failed parts which were returned from field and from experimental testing failures. These failure analyses were conducted to determine reliability problem areas and modes of failure. The following data was collected to provide a quantitative basis for analyzing failed parts:

a. The number of failures, including preventive maintenance failures

b. The identity of the failed component, including reporting organization, major system and subsystem, failed part, and manufacturer

c. The cause of failure, if known, including the type of failure

d. The time operated before failure

e. The symptoms of failure; causes and environmental conditions associated with failure.

9.2.1 Reliability Problems

A formal failure analysis was conducted on significant and recurring failures. Such analyses were especially useful because components were examined and histories maintained. The failure analysis group reviewed the failure reports, the failed part analysis report, the tabulation of previous failures, and the associated drawings. It then isolated the causes of failures so that corrective action on reliability problems could be taken to improve system reliability. The following table is an example of the reliability problems encountered in the Discoverer Program.

TABLE 9-3

DISCOVERER PROBLEM SUMMARIES

Beacon Type 449 - Model 3bb2A Subsystem

Receiver/Transmitter Unit

PROBLEM	CAUSE OF FAILURE	CORRECTIVE ACTION
Arcing and loss of power output in the transmitter tube	Plate current and peak current to tube exceeded tube ratings	Reduction of beacon power output requirements within minimum system requirements
Pulse countdown and excessive current drawn by modulator from power supply	Peak current and RMS current at 1230 pps exceeded tube rating	
Inner conductor of cable assembly broke off inside duplexer at soldering terminal	Mishandling of cable during repair	Careful handling and replacement of an excessively handled assembly
Damage to new tubes caused by improper handling	Blistering of the plating in the transmitter cavity	Plating process was corrected with S/N 0030
Air leakage of connector of low pass filter	Ineffective sealing	Sealing process was corrected
Intermittent countdown in vibration and critical code spacing adjustment	Misapplication of part; one sixteenth of a turn on trim pot shaft determined code spacing tolerance	Testing of six Trimpots showed resistance excursions with noise voltage spikes in excess of code spacing tolerance. Modification of circuit required to reduce critical characteristics

TABLE 9-3 (Continued)

Command Decoder Unit

PROBLEM	CAUSE OF FAILURE	CORRECTIVE ACTION
Contact chatter and hangup of armature	Acceleration magnifications result when command decoder was vibrated per specification	Stiffening brace placed across relay mounting board dampened resonances in board
Contacts of relays became welded during checkout of beacon	Incorrect checkout in the field	Modified checkout console to provide fuses to protect relay contacts

Beacon Castings

Porosity, loss of pressure due to air leaks	Incorrect material used in casting: low quality casting workmanship	Casting quality was improved. X-rays and chemical analysis were run on remaining castings

Doppler Subsystem

Tri-Helix Antenna Assembly

Antenna pedestal broke loose from antenna base in high winds aboard tracking ship	Inadequate mounting of antenna to withstand shipboard environment	Strengthened pedestal to base mounting

Antenna

Control relay contacts arced and burned. Water leaked into relay compartment	Contact rating exceeded. Relay compartment leakage.	Replacement of relays with higher rated relays. The relay compartment seals were improved.

TABLE 9-3 (Continued)

Telemetry Tracker Subsystem

Preamplifier

PROBLEM	CAUSE OF FAILURE	CORRECTIVE ACTION
Premature failures of the preamplifier tube	Low signal to noise ratio; "turn on" history and filament voltage variations were major detrimental factors	Installation of power line regulation and reduction of "turn on" hazards

Data Transmission Subsystem

D-C Amplifiers

Premature failure of mechanical chopper caused unbalance and noise in D-C amplifiers	Dirt on contacts caused noise and contact bounce chopper case was not hermetically sealed. Contact adjustment was too critical for field maintenance.	Replacement of chopper with a new chopper designed especially for this application.

9.2.2 Total Reported Failures For Discoverer Ground Tracking System Plus the S-Band Beacon and Command Decoder

The following bar graphs (Figs. 9-1 through 9-9) give a summary of the failures reported from the field during the period of December 1959 to November 1960. This information is indicative, but not conclusive, about overall system failures. It was valuable for indication of equipment warranting further investigation, such as the sub-carrier discriminator in the telemetry ground station components chart.

9.3 Transistorized "S" Band Beacon

The following summarizes the reliability design review performed on the transistorized S-band beacon Type 149-S2 used in Subsystem H on Discoverer and Samos vehicles and is extracted from WDL-TR1333, titled "Reliability Design Review, S-Band Beacon (Transistorized) Type 149-S2, Model RT-5", dated 15 August 1960.

The beacon is composed of an S-band receiver and transmitter (transponder), a transistorized power supply, and a six-command decoder. It receives and acknowledges command signals sent from the tracking site. These command signals are then decoded by the six-command decoder and issued to the vehicle's control facilities. The transponder and the decoder are housed in separate units within the same compartment and are connected by cables to transfer signals or commands from the transponder to the decoder.

9.3.1 Design Review

Reliability Procedures. The following procedures were used to perform the reliability design review:

a. Examination of specifications
b. Review of the parts list
c. Reliability prediction based on parts count
d. Circuit review
e. Review of parts applications
f. Stress value reliability prediction
g. Physical design review
h. Life test results

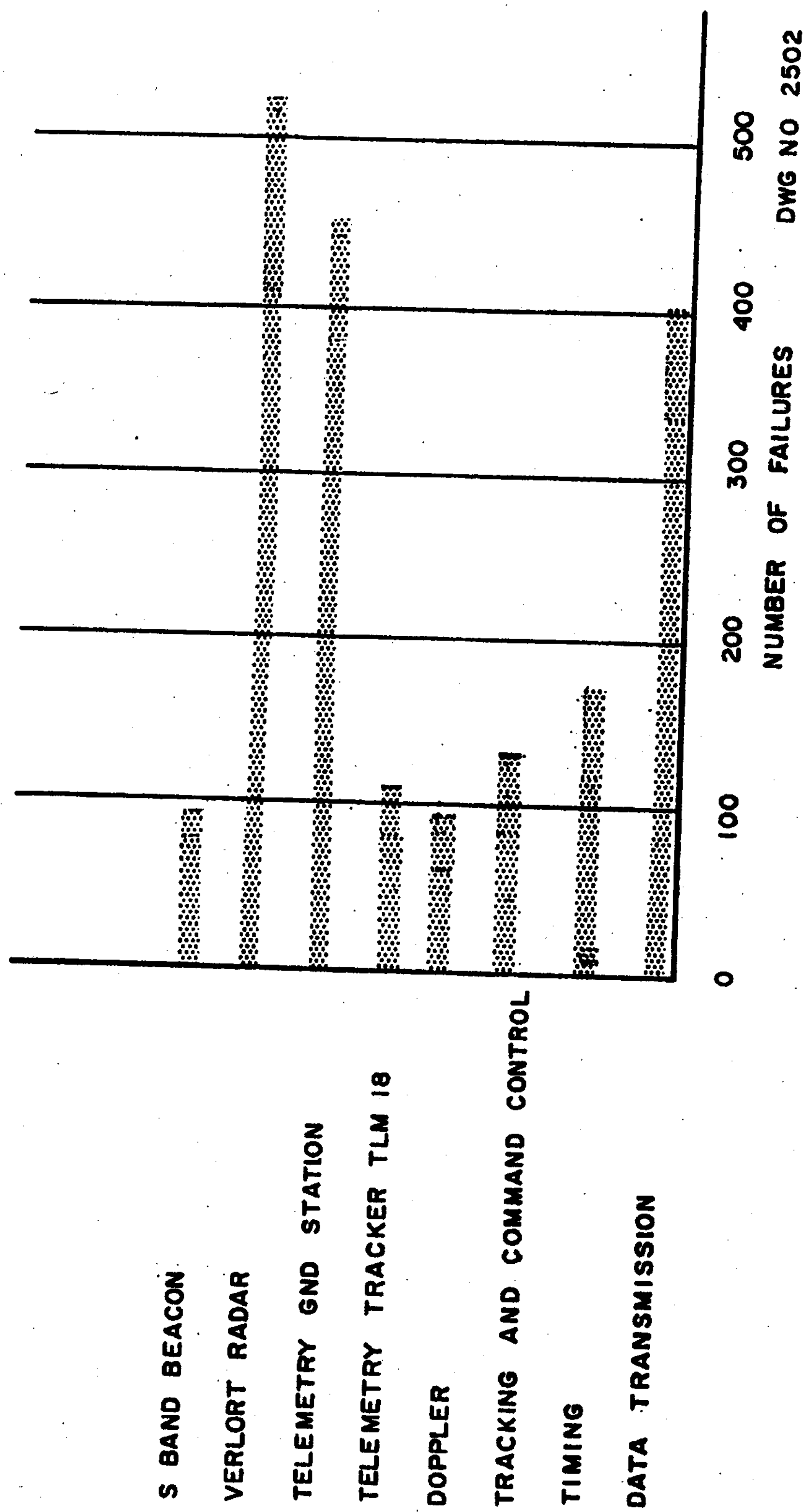


Fig. 9-1 Discoverer Subsystem Failures

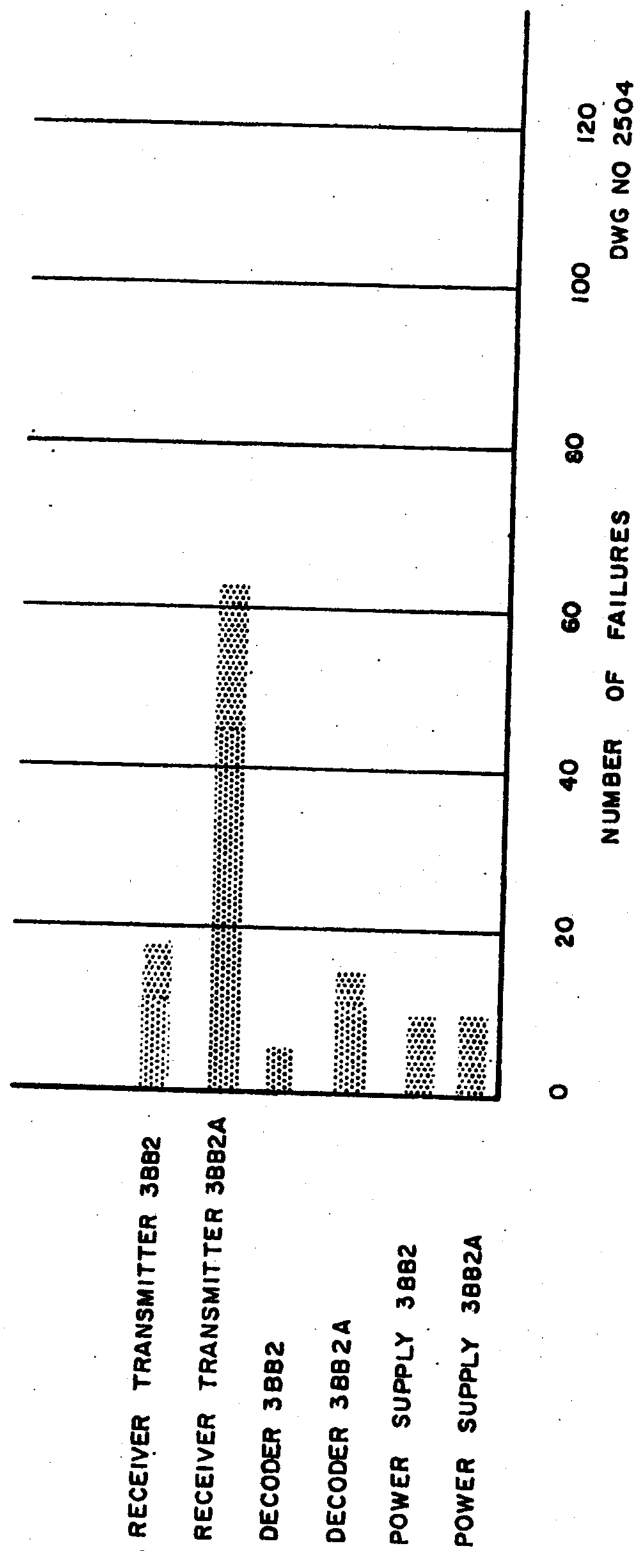


Fig. 9-2 S-Band Beacon Component Failures

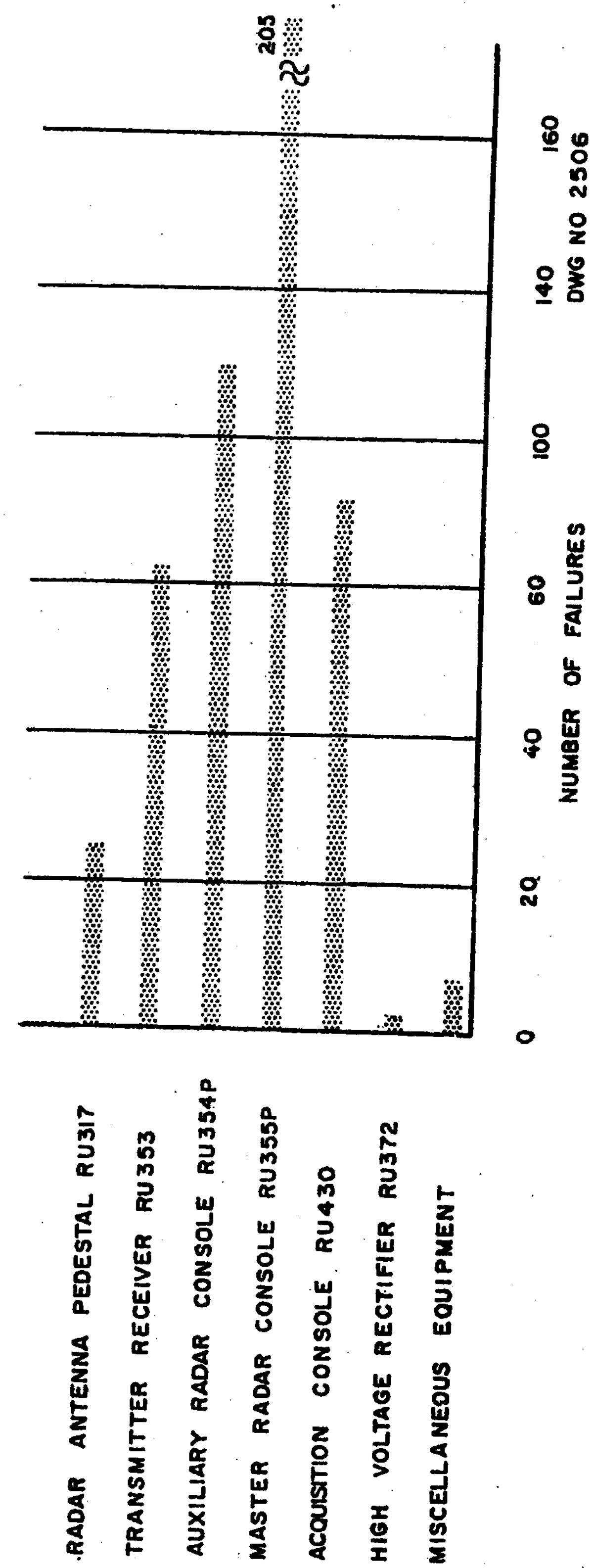


Fig. 9-3 Verlort Component Failures

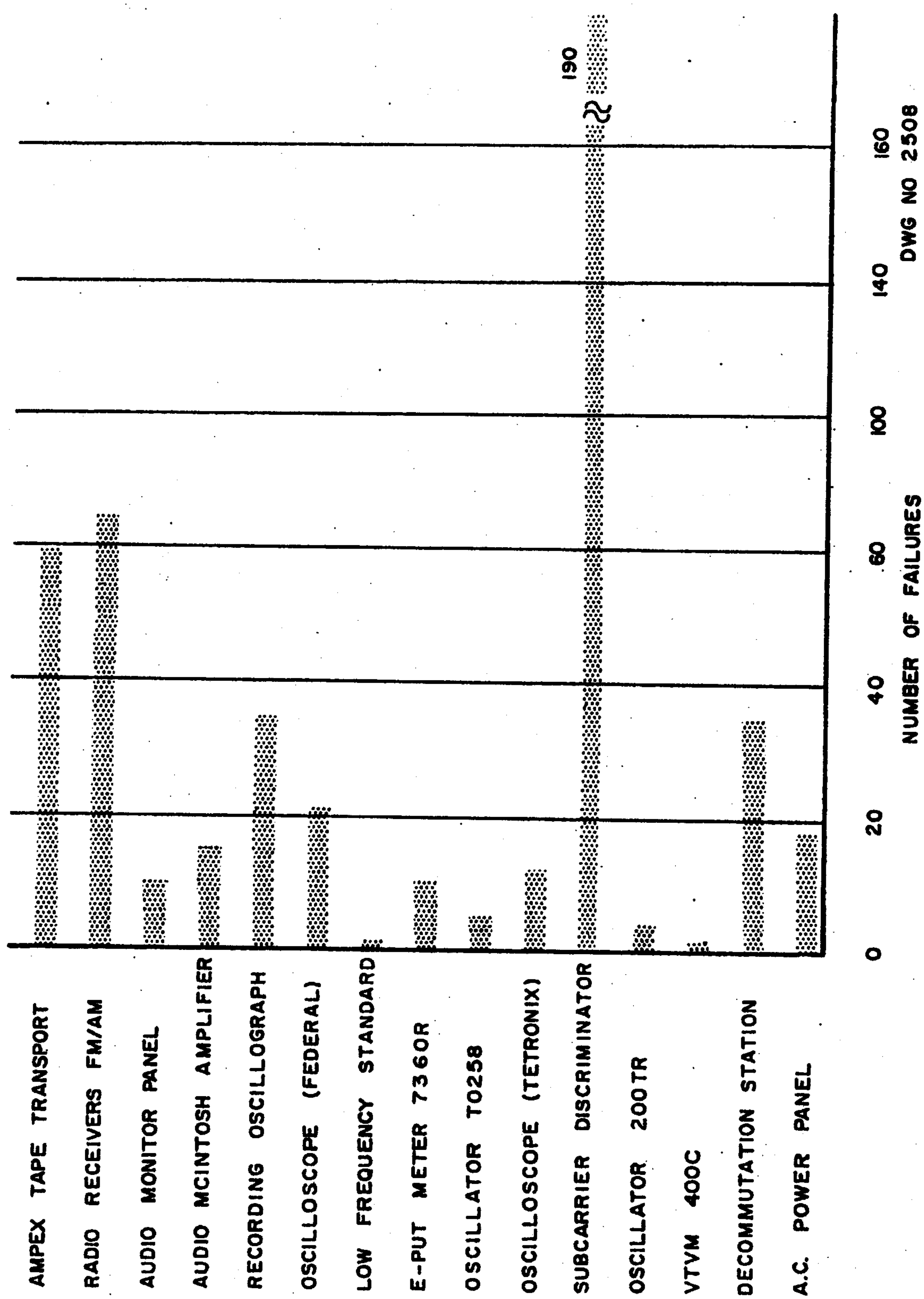


Fig. 9-4 Telemetry Ground Station Component Failures

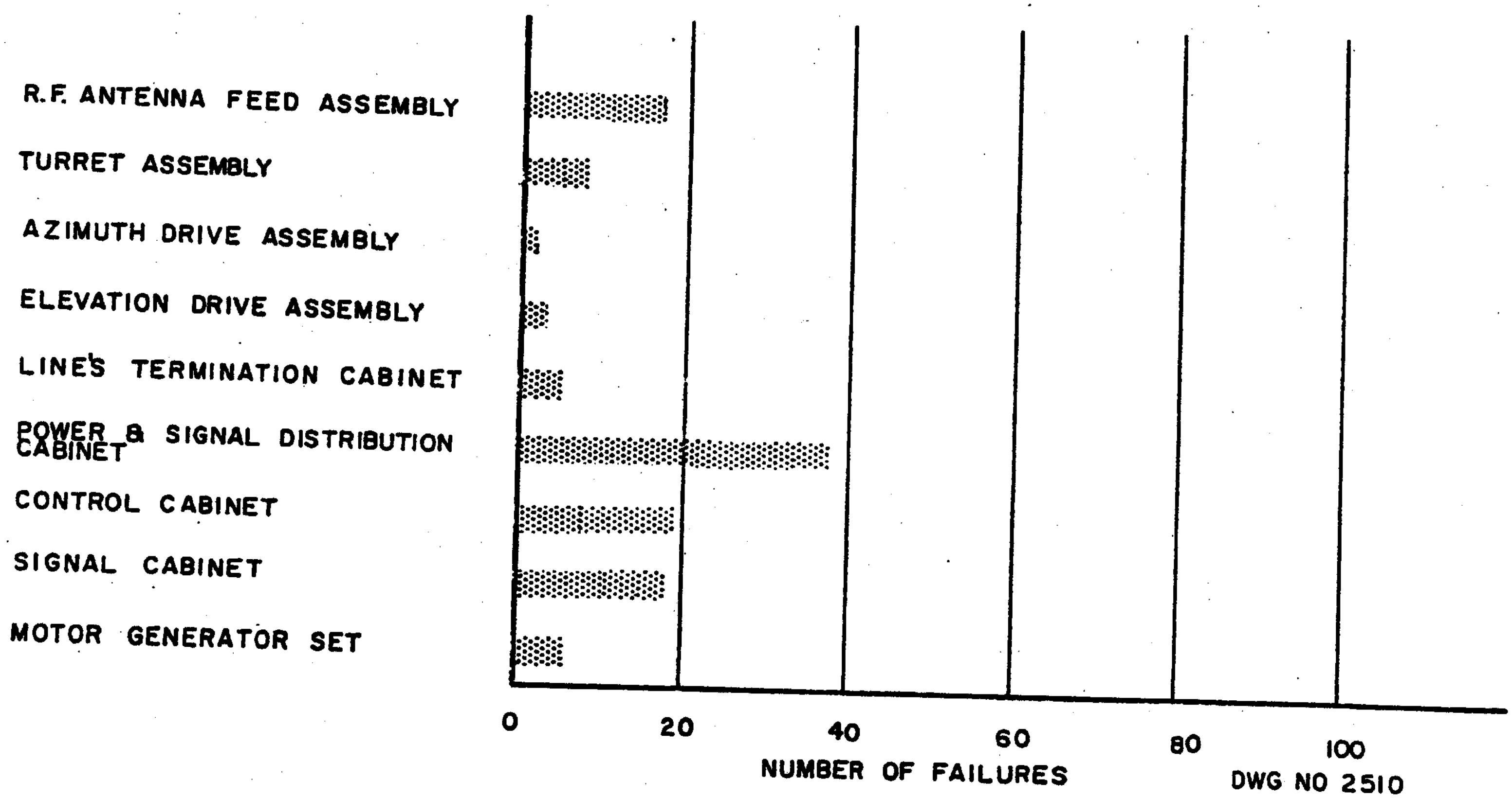


Fig. 9-5 Telemetry Tracker (R-1162) Component Failures

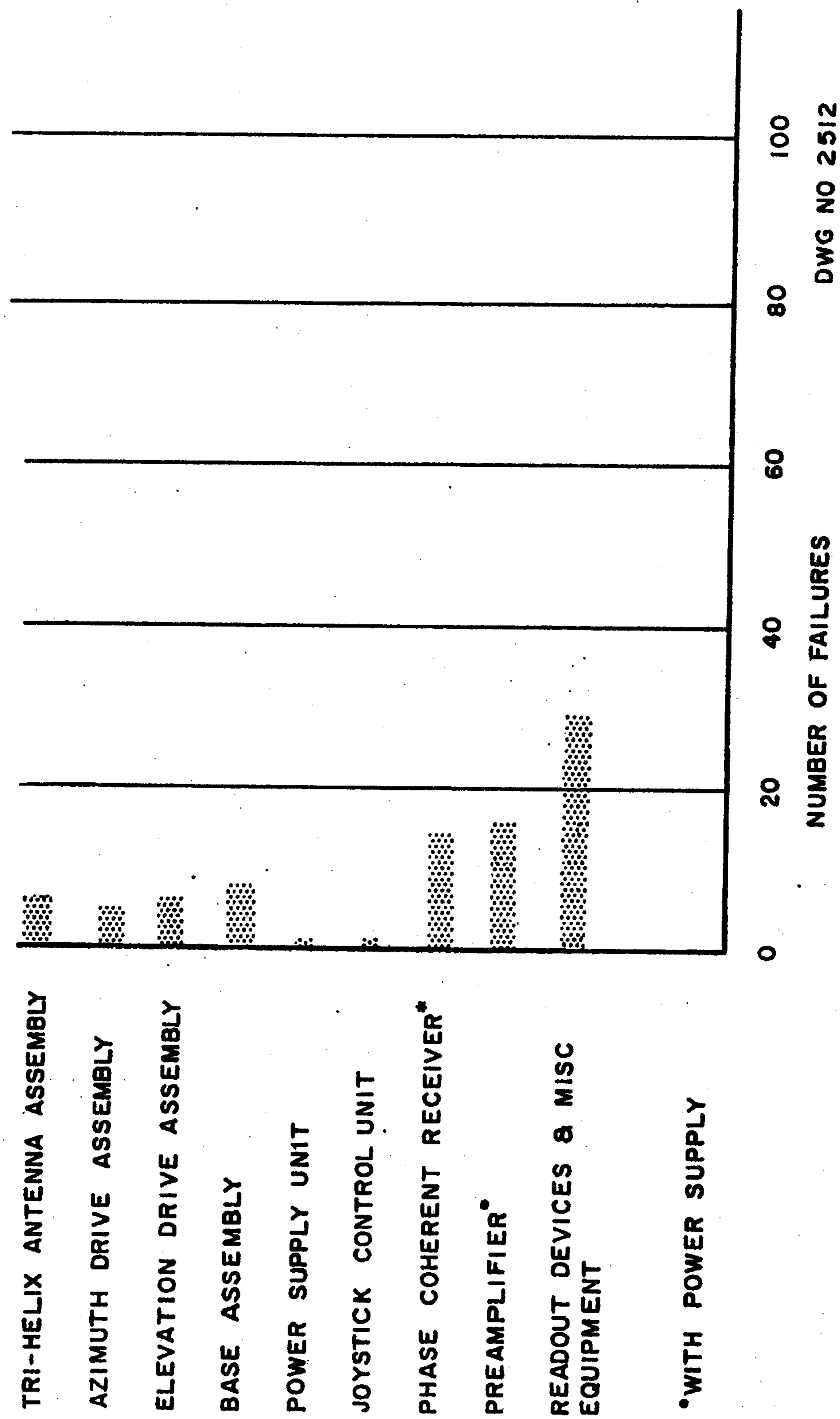


Fig. 9-6 Doppler Component Failures

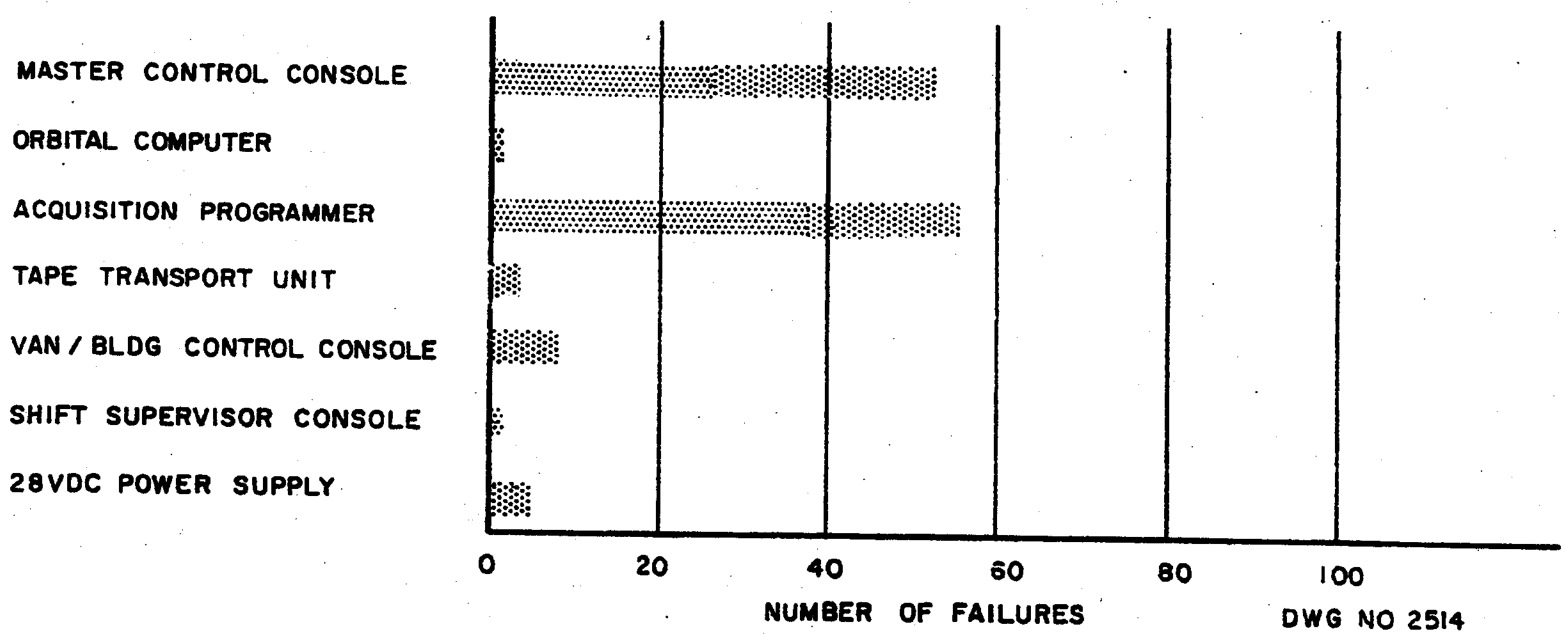


Fig. 9-7 Tracking and Command Control Component Failures

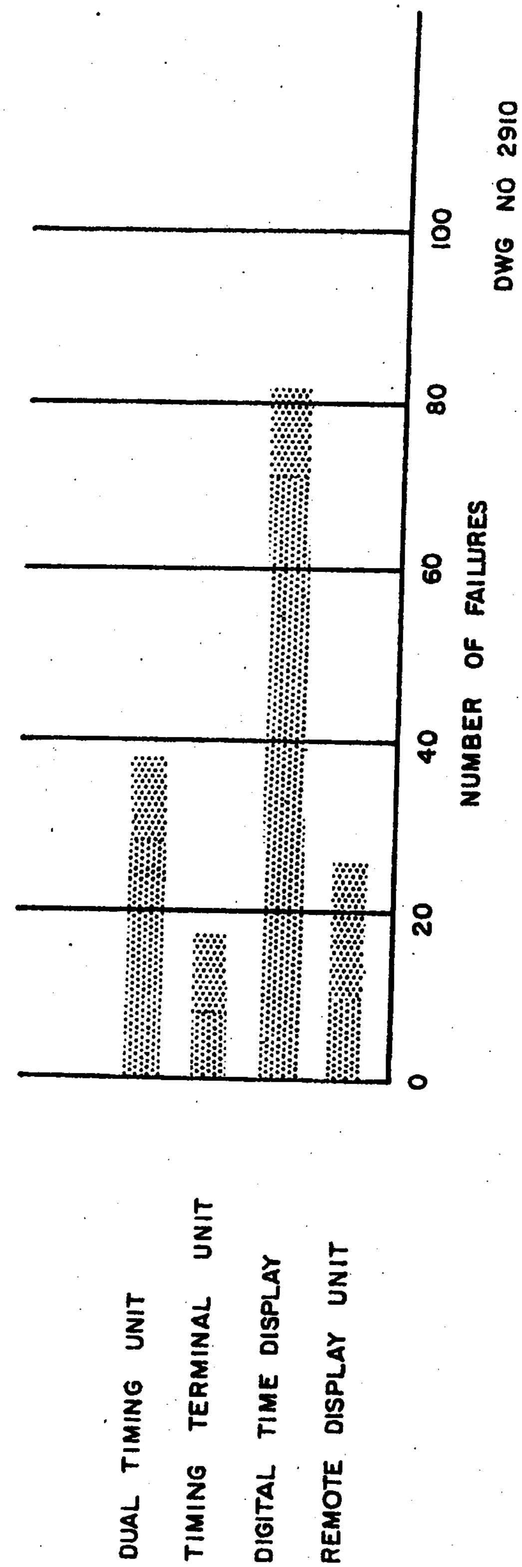


Fig. 9-8 Timing Component Failures

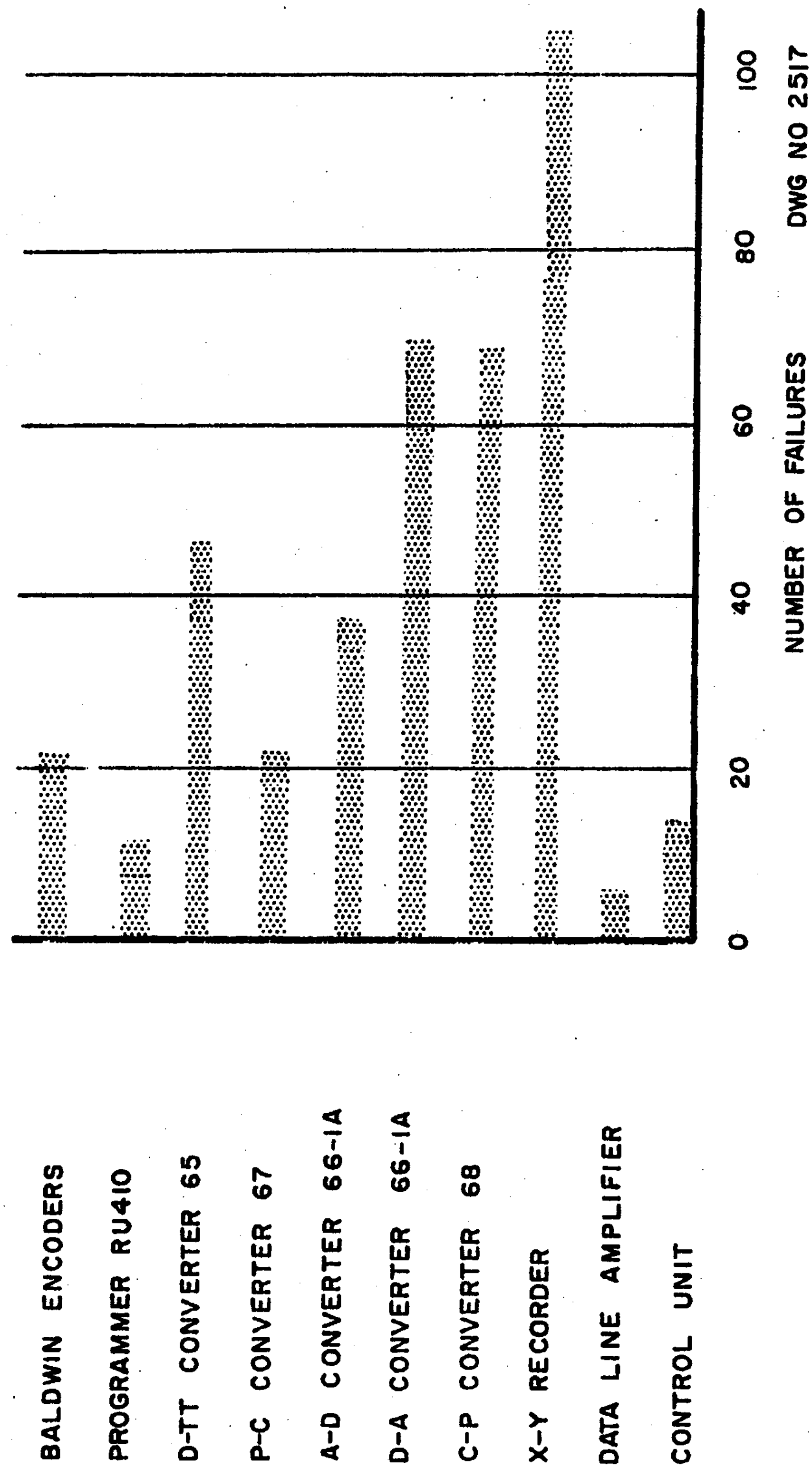


Fig. 9-9 Data Transmission Component Failures

Parts Review. Parts were reviewed and recommendations were offered on all parts that did not meet military standards. Comments were also made in cases where a lack of sufficient information on specific parts was found.

Reliability Prediction. A reliability audit was made based on parts count only. The average failure rates used in making the parts count reliability prediction are listed in Table 9-4. These rates were derived from published literature assuming 70°C ambient temperature and derating to 50 per cent.

Calculation of Electrical Stress Values. Electrical stress values were calculated from preliminary circuit diagrams furnished to Philco WDL by Avion. (Failure rates will vary depending upon the application.) The component failure rates obtained from published literature are based upon per cent of full rated value and a temperature of 70°C.

Reliability Terminology. The terminology listed below applies to Tables 9-5, 9-6, and 9-7 and explains how $R_{(t)}$ is determined:

t = time in hours

Reliability = $R_{(t)} = e^{-\lambda t}$

λ = failure rate in per cent per 1000 hours.

Failure Rate Analysis. Each part in the S-band beacon and the six-command decoder was analyzed. The results of this analysis are given in Tables 9-4 through 9-7. Reliability versus time in hours was computed for the beacon and decoder separately and for the two units combined. See Tables 9-5, 9-6, and 9-7.

Parts Application Review. Suppressor diodes CR2000 through CR2009, located in the relay matrix, are being operated too close to the maximum rating as given by the manufacturer. Work is in progress to find a suitable part having a higher rating. At this writing no replacement part has been found; however no failure has occurred.

9.3.2 Summary of Reliability Problems and Changes Accomplished

Lead Length. High noise level caused false transmitter pulses due to excessive length of lead from terminal 6 on TB 200 to terminal 2 on TB300. To eliminate the noise pickup because of the excessive lead length, the lead has been replaced with a point-to-point jumper effective on Serial Number 509.

Pulse Amplifier. The pulse amplifier gain was found to be critical. High signal level resulted in single pulse operation. Effective on Serial Number 509, the bias on the pulse amplifier was changed to make it less critical to adjustment.

C606 on Serial Numbers 501 and 502. Mounting stud separated from the capacitor case. To correct this, Avion reduced spacer thickness.

Local Oscillator Z1. Crystal current was correct, but insertion loss was high. Effective on Serial Number 502, the type of cable from the local oscillator to the crystal cavity was changed.

Q1300 in Ramp Generator. False commands were generated under threshold signal conditions. To eliminate this, Avion desensitized the multivibrator and improved ramp clamping.

Q1107 and Q1401 on Serial Number 501. Transistor leads broke in vibration at transistor button base. Effective on Serial Number 502, a bonding compound has been coated over the transistors, transistor leads, and sockets. Vibration tests have indicated this fix to be satisfactory.

Relay K2007. This relay failed during altitude test under switching conditions. The failure analysis disclosed a cracked header glass bead which probably existed prior to the start of the test. Avion has initiated a careful magnification inspection of glass beads after assembly of relays to matrix board.

9.3.3 Conclusions

The failure rate for the Model 149-S2 beacon is estimated at .002 failure per hour. For a satellite operational duty cycle of 20 per cent the probability of successful operation for seventeen passes is 0.989. The predicted reliability for 5 hours operating time is 0.9975.

TABLE 9-4

AVERAGE FAILURE RATES

Components	Failure Rate Per cent per 1000 Hours
Resistor	0.122
Capacitor	0.141
Transistor	0.110
Diode	0.084
Relay	0.40
Transformer	0.30
Choke	0.30
Electron Tube	0.84

TABLE 9-5

149-S2 RADAR BEACON

RELIABILITY VERSUS TIME IN HOURS

(based on λ = 31.427 from total failure rate)

Time	$R_{(t)}$	Time	$R_{(t)}$
1	0.9996	160	0.9512
20	0.9940	200	0.9417
40	0.9900	250	0.9231
60	0.9801	300	0.9048
80	0.9782	350	0.8958
100	0.9704	400	0.8780
130	0.9607	450	0.8607
		500	0.8521

TABLE 9-6

SIX-COMMAND DECODER

RELIABILITY VERSUS TIME IN HOURS

(based on λ = 18.780 from total failure rate)

Time	$R_{(t)}$	Time	$R_{(t)}$
1	0.9990	160	0.9704
20	0.9970	200	0.9651
40	0.9950	250	0.9591
60	0.9960	300	0.9447
80	0.9851	350	0.9416
100	0.9821	400	0.9323
130	0.9801	450	0.9231
		500	0.9139

TABLE 9-7

COMBINED RELIABILITY FOR BEACON DECODER

RELIABILITY VERSUS ACTUAL OPERATING TIME IN HOURS

(based on λ = 31.427 + 18.780 = 50.207)

Time	$R_{(t)}$	Time	$R_{(t)}$
1	0.9995	200	0.9054
5	0.9975	300	0.8601
40	0.9802	400	0.8181
100	0.9510	500	0.7778

APPENDIX A
LINK CALCULATION

APPENDIX A-1

VERLORT-BEACON LINK CALCULATION

Radar Power Output	+ 84 dbm
Radar Line and Duplexer Loss	- 2 db
Radar Conical Scan Loss (50% crossover)	- 3 db
Radar Antenna Gain	+ 37 db
Polarization Loss	- 3 db
Fading Margin	- 6 db
Space Loss at 1500 N. Miles; F = 2900 mc	- 170 db
Vehicle Antenna Gain	+ 3 db
Vehicle Receiver Line and Diplexer Losses	- 2 db
Signal Power at Vehicle Receiver	- 62 dbm
Vehicle Receiver Sensitivity	- 65 dbm
Vehicle Signal to Noise Ratio	3 db

BEACON-VERLORT LINK CALCULATION

APPENDIX A-1

VERLORT-BEACON LINK CALCULATION

Radar Power Output	+ 84 dbm
Radar Line and Duplexer Loss	- 2 db
Radar Conical Scan Loss (50% crossover)	- 3 db
Radar Antenna Gain	+ 37 db
Polarization Loss	- 3 db
Fading Margin	- 6 db
Space Loss at 1500 N. Miles; F = 2900 mc	- 170 db
Vehicle Antenna Gain	+ 3 db
Vehicle Receiver Line and Diplexer Losses	- 2 db
Signal Power at Vehicle Receiver	- 62 dbm
Vehicle Receiver Sensitivity	- 65 dbm
Vehicle Signal to Noise Ratio	3 db

BEACON-VERLORT LINK CALCULATION

Vehicle Transmitter Power Output	+ 60 dbm
Vehicle Line and Diplexer Losses	- 2 db
Vehicle Antenna Gain	+ 3 db
Space Loss at 1500 N. Miles; F = 2900 mc	- 170 db
Fading Margin	- 6 db
Polarization Loss	- 3 db
Radar Conical Scan Loss (50% crossover)	- 3 db
Radar Antenna Gain	+ 37 db
Radar Line and Duplexer Losses	- 2 db
Signal Power at Radar Receiver	- 86 dbm
Radar Receiver Sensitivity for Auto Track	- 90 dbm
Radar Signal to Noise Ratio	4 db

APPENDIX A-2

ACQUISITION-TRI-HELIX ANTENNA LINK CALCULATION

Transmitter Power Output	+ 10 dbm
Transmitter Line and Diplexer Losses	- 3 db
Transmitter Antenna Gain	0 db
Space Loss at 1500 Nautical Miles; F = 225 - 240 mc	- 148 db
Polarization Loss	- 3 db
Fading Margin	- 6 db
Receiver Antenna Gain	+ 15 db
Tracking Errors	- 3 db
Receiver Line Losses	- 2 db
Signal at Receiver Input	- 140 dbm
Receiver Noise for 100 cps bw and 5 db N.F.	- 149 dbm
I-F Signal-to-Noise Ratio	9 db

APPENDIX A-3

FM/FM TELEMETRY - TRI-HELIX ANTENNA LINK CALCULATIONS

Transmitter Power Output	+ 39 dbm
Transmitter Line and Diplexer Loss	- 3 db
Transmitter Antenna Gain	0 db
Space Loss at 1500 Nautical Miles; F = 225-240 mc	- 148 db
Polarization Loss	- 3 db
Fading Margin	- 6 db
Receiver Antenna Gain	+ 15 db
Tracking Errors	- 2 db
Receiver Line Losses	- 2 db
Siganl at Receiver Input	- 111 dbm
Receiver Noise for 300 kc bw, 5 db N.F.	- 114 dbm
I-F Signal to Noise	4 db

APPENDIX A-4

TELEMETRY TRACKER LINK CALCULATION

Transmitter Power Output	+ 39 dbm
Transmitter Line and Diplexer Losses	- 3 db
Transmitter Antenna Gain	0 db
Space Loss at 1500 Nautical Miles; F = 225-240 mc	- 148 db
Polarization Loss	- 3 db
Fading Margin	- 6 db
Receiving Antenna Gain	+ 31 db
Conical Scan Loss	- 3 db
Receiver Line Loss	- 2 db
Signal at Receiver Input	- 95 dbm
Receiver Noise for 300 kc bw, 5 db N.F.	- 114 dbm
I-F Signal to Noise	19 db

APPENDIX B
EQUIPMENT MODIFICATIONS

APPENDIX B
EQUIPMENT MODIFICATIONS

B.1 General

A good portion of the Discoverer equipment, as well as the system as a whole, is of a prototype nature; also, the time element of Discoverer implementation did not permit complete equipment integration prior to installation. Because of this, continued engineering effort and operational experience resulted in the development of numerous modifications to improve equipment and system performance.

A listing and description of those modifications proposed and engineered by Philco is included in this appendix.

During the fourth quarter of fiscal year 1960, a general philosophy evolved which limited further Discoverer equipment modifications. The subsequent modifications that are to be considered, will be, generally, those that are mandatory for adaptation to a new program requirement. Modifications that merely improve operating efficiency or refine equipment capabilities generally will not be included. This resulted in cancellation of some proposed modifications.

Work on some modifications has been stopped pending LMSD review. It is anticipated that work on these modifications will be resumed because of the advanced status of the engineering and procurement.

TABLE B-1 (Continued)

No.	Title	Stations Affected	Implemented
RP-			
27	Verlort Elapsed Time Meter	All	Yes
28	Command Tone Recording	All	Yes
29	Launch Pad #5 Intercom	VAFB	Yes
30	Doppler, Recording Equipment Installation	TM Ship	Yes
31	Tape Recorder Doors	All	Yes
32	Additional Calibration Equipment	VAFB, Hawaii	Yes
33	Recorder Tube Shield Mod.	All	Yes
34	Interim Doppler and SSB Installation	TM Ship	Yes
35	Relocation--Baldwin Programmer	All	Yes
36	Record Doppler Signal Strength	Hawaii, Kodiak	Yes
37	Verlort Support Structure Heaters	All	Yes
38	Event Recording Clock		Cancelled
39	SS/G and SS/L Display Console	All, except Mugu	Yes
40	Doppler Receiver Counter Output Circuit Modification	All	Yes
41	Doppler Boresight Beacon	All	Yes
42	Encoder Test Jack Modification	All	Yes
43	Plotting Board Signal Termination		Cancelled
44	Plotting Board Installation Mugu	Mugu	Yes
45	Telemetry Tracker Indicator	VAFB, Hawaii	Yes
46	Tri-Helix Indicator	All	Yes
47	Verlort Boresight Camera	All	Yes
48	X-Y Recorder Servo Mod.	All	Yes
49	Timing Latitude Crossing, Pulse	All	Yes
50	Master Control Console Blower	All	Yes
51	Weather Instrument Shelters	All	Yes
52	Communications Panel Modification	All	Yes
53	Communications Panel Expansion	Hawaii	Yes
54	System Time Clock-Mugu Communications Van		Cancelled
55	Tri-Helix Indicator Wiring Replacement	All	Yes
56	Emergency Power Unit Mugu		Cancelled
57	Milgo Maint Tray		Cancelled
58	TLM-18 for 108 mc Operation		Cancelled

TABLE B-1

DISCOVERER EQUIPMENT MODIFICATION LIST

No. RP-	Title	Stations Affected	Implemented
01	Tri-Helix Signal	All	Yes
02	Power System Hawaii	Hawaii	Yes
03	TLM-18 Safety	VAFB, Hawaii	Yes
04	TTU Mod.	All	Yes
05	Countdown Engr. System	VAFB	Yes
06	TTU Power Supply Mod.	All	Yes
07	Diesel Engineering Service	ANNETTE	Yes
08	Verlort Air Conditioner Access		Cancelled
09	Auto Tracking Status Indication	All	Yes
10	26-1/2 Foot Radome Installation	Hawaii	Yes
11	Emergency Power Study	VAFB, Hawaii, Mugu	Cancelled
11A	Uninterrupted Power-Dual Timing (Mugu)	Pt. Mugu	Cancelled
12	Tri-Helix Synchro Refr. & Rot. Brake	All	Yes
13	Interim Development CCPA		Cancelled
14	Amplifier Muting Relay	All	Yes
15	TLM-18 Boresight Beacon	VAFB, Hawaii	Yes
16	Convenience Outlets	All	Yes
17	Lift Off Tone Oscillator	VAFB	Yes
18	Telemetry Amplifiers	All, except MUGU	Yes
19	Interference Survey Site #6		Yes
20	Simultaneous Nutation and Raster Scan	All	Yes
21	Verlort Two-Pulse Modification	All	Interim, (Permanent, est. date of ship't 1/20/61)
22	Scanner/Programmer	All	Yes
23	TTY Terminal Mod.	Kodiak	Yes
24	Installation of VHF/DF	Kodiak	Yes
25	Test Points Mod. B/TT Converter	All	Yes
26	TLM-18 Reference Voltage Mod.		Cancelled

TABLE B-1 (Continued)

No.	Title	Stations Affected	Implemented
RP-			
59	Verlort Radome Windows	Kodiak	Yes
60	X-Y Recorder Modification	All	Yes
61	Camera Installation, R1162	VAFB, Hawaii	Yes
62	Tape Transport Modification	Kodiak	Yes
63	Telemetry Tracker Carrier Relay	VAFB, Hawaii	Yes
64	Digital Display Equipment	All	Yes
65	Synchro Reference Modification		Cancelled
66	Synchro Line Amplifier	All	Yes
67	Passive Tracking Modification	All	Yes
67A	Quality Bit for Passive Track Modification	All	Yes
68	Anti Beacon Capture	All	Kodi, NED
69	Range Simulator		Cancelled
70	Recorder Standard Channelization	All	Shipped
71	Ground Beacon Verification	All	Shipped
72	Installation of Waveguide Variable Attenuator		Cancelled
73	15 Command Control Relay Unit	VAFB, Hawaii	Yes
74	Tone-Tell-Tale Re-entry Selector	All except Mugu	Yes
75	VCC Rehabilitation		Cancelled
EC-			
* 92	Azimuth and Elevation Servo Response Correction	All	Yes
* 93	Acquisition Programmer Output Control Circuit	Kodiak	Yes
* 94	Command 4 Verification Lamp	All	Yes
* 95	TLM-18 Tracker Preplot Capability	VAFB, Hawaii	Yes
* 96	Time By-pass and Coast and Normal System	All	Yes
* 97	Preplot Pen Control Modification	All	Yes
* 98	Antenna Stowing Mechanism	Hawaii	Yes
* 99	Interchange of Commands 2 and 4	All	Yes
*100	Command 3 Modification to Insure 1 Second Pulsed Commands	All	Yes

* These EC's were accomplished on site with available materials. Directed by TWX's or Specs only.

TABLE B-1 (Continued)

No.	Title	Stations Affected	Implemented
EC-			
101	Re-installation of original TLM-18 Tracker Indicator Panel		
102	Provide 24-Hour Recycling	VAFB, Hawaii	Yes
103	Slave Buss Azimuth & Elevation Indicator, Mod. #23	All	Yes
104	Separation of Synchro Refr. Source		Work Stoppage
105	Synchro Ref. Line Filter at VAFB		Cancelled
106	Plotboard Pen and Arm Motor Replacement		Work Stoppage
107	Addition of Communication Equipment Rack Assembly	All	Yes
108	Boresight Camera Amplifier Supply Voltage Mod.	Kodiak	Yes
109	Switch Controlled Auto-Insertion of "Q's" at end of Data Teletype Tapes	All	Yes
110	Addition of Analog Data Line Ampl. Program Patch Board	Kodiak	Yes
111	ADLA Model 149, Relay Output Monitor	Hawaii, Kodiak	Yes
112	Installation of Synchro Correction Capacitors	All	Yes
113	Scanner Programmer to Eliminate Operational Errors	VAFB, Hawaii	Yes
114	Addition of Coax Line Drivers to Dual Timing System		Cancelled
115	Antenna Balance Adaptor Plates	VAFB, Hawaii	Yes
116	Relocation of D-C Amplitude Balance Control	All	Yes
117	"L" Timer Modification	All	Yes
118	Test Points, Acquisition Programmer	All, except Mugu	Yes
119	Versatility in Selection of Range, Azimuth and Elevation Mods.		Cancelled
120	Active Passive Track Mode of Operation		Cancelled
121	Regulation and Filtering Improvement, Milgo +28 and +44 P.S.		Cancelled
122	TN-24, TN-25, Coupling Modification		Work Stoppage
123	Boresight Camera Cover, R1162		Work Stoppage
124	D/A - 25 Volt Power Supply Cooling		Cancelled
125	Discrete Answer Back--Teletype		Cancelled
126	VCC Extension Test Cable	Kodiak	Yes
127	VCC Command Interrupt Circuit, Mod. No. 18	All	Yes
128	Reticle Illumination for R-1162 and Verlort Boresight Cameras		Work Stoppage
129	TLM-18 Sector-Scan Reset		Cancelled
130	Mod-17 Radar Range Extension		Proposed ECD, 4/29/61

B.2 Discoverer Modification Descriptions

RP-01 Tri-Helix Signal Strength Modification

Modify telemetry and Doppler receiving systems to provide remote indication of telemetry receiver signal strength on tri-helix control rack.

RP-02 Power System Modification at Hawaii

Replace interim power transformers and switchgear at Hawaii transmitting area with permanent weatherproof items.

TP-03 TLM-18 Ground Safety

Improve the safety features of the TLM-18 to provide adequate protection to personnel performing maintenance and calibration of the TLM-18 telemetry tracker.

RP-04 TTU Modification

Modify timing terminal units as described in EE Co. specification, "Modification of Timing Terminal Unit ZA-22247", to improve operation under conditions of excessive telephone line noise.

RP-05 Countdown System Engineering

Furnish the engineering services required to complete installation instructions for the "Countdown Timing System" at VAFB. The installation instructions will consist of:

1. Installation drawings
2. Installation instructions
3. Bill of Materials required to complete the installation.

RP-06 TTU Power Supply Modification

Modify timing terminal unit power supply in accordance with EECo Drawing #A23693 to filter 117 v ac line input.

RP-07 Diesel Engineering Services (ANNETTE)

Provide engineering services required to:

1. Complete minor overhaul of 5 Cummins diesel engines, Model NHRIS, to include replacement of fuel injectors for 1200 RPM operation and exhause valves where required.

2. Supply additional maintenance, tools, and components required for diesel engine maintenance.

RP-08 Verlort Air Conditioner

Design and install a mechanism for extending and retracting the Keco Industry Model F-11a air conditioner in the Verlort radar van. A screw type jack is recommended by J. Harding, Range Operations. After a successful prototype has been developed and is operational, 5 additional units will be fabricated for installation at all IIA sites.

RP-09 **Auto Tracking Status Indication**

Modify RU-406 and RU-310P Verlort radar units to provide for automatic indication of tracking status on SS/H Shift Supervisor's Console.

RP-10 **26-1/2 Foot Radome Installation**

Install 26-1/2 foot rigid radome on existing Verlort radar at Hawaii. Modify existing 18' x 18' steel platform on radar structure to permit 19' 10" diameter base of radome to be installed. Brace radar structure by installation of 4 upright supports to 4 corners of platform structure.

RP-11 **Emergency Power Study**

Perform engineering study of existing auxiliary power systems to determine modifications necessary to insure capability of maintaining the operation of (at least) enough equipment to continue generation of correct time code word without resynchronization of master timing generator with WWV and to take, and preserve, radar tracking data in digital form in the event of primary power failure.

RP-12 **Tri-Helix Synchro Reference and Rotator Brake Modification**

Install synchro reference and rotator brakes on tri-helix antenna systems per Sentry Engineering memo, subject: "Synchro Reference and Rotator Brake Modification for Tri-Helix", dated 16 February 1959.

RP-13 **Interim Development Control Center, Palo Alto**

Not applicable to tracking stations.

RP-14 **Amplifier Muting Relay**

Provide the installation engineering for replacing the paging amplifier muting relay with an Iron Fireman Type R-408-B-1K relay at Vandenberg, Hawaii, and if not completed, at Mugu. The new relay is required to provide more sensitive operation when the paging amplifier is included as part of a conference connection. The amplifier to be modified is part of the Kellogg-Select-O-Phone operational communications system.

RP-15 **TLM-18 Boresight Beacon**

Modify and reinstall the TLM-18 Boresight Beacon at Vandenberg and Hawaii. This modification will include:

1. Replacement of R-67, 15K bleeder resistor.
2. Add a 1/2 amp fuse to the input a-c power leads.
3. Provide a separate weatherproof a-c power connector for a-c power input.
4. Mount an r-f attenuator internally in the r-f output cable.

RP-16 Convenience Outlets

Provide engineering and installation for convenience outlets on Milgo-supplied racks at all locations for the operation of test equipment. If possible, both twist lock and "U" type grounding receptacles providing 115 volts a-c should be provided.

RP-17 Lift Off Tone Oscillator

Engineer, procure, and install a lift off tone oscillator in the VHF Building at Vandenberg. The tone is to be controlled via a telephone pair with 24 volts d-c applied at the block house.

RP-18 Telemetry Amplifiers

Provide, engineer and install line-driving amplifiers for telemetry readout. The line amplifiers will consist of five d-c line amplifiers at each station to be located in the telemetry equipment to the VCC panel for command verification.

RP-19 Interference Survey Site #6, Location Philco WDL.

Not applicable to tracking stations.

RP-20 Modification of Verlort for Simultaneous Nutation and Raster Scan

Install jumper between terminals #4 and 5 of TB-430102 to provide nutating power during raster scan mode of operation.

RP-21 Verlort Two-Pulse Modification

Provide appropriate switching device to convert Verlort radar to two-pulse operation during normal tracking with automatic transfer to three-pulse operation when required for transmission of commands.

RP-22 Scanner/Programmer Modification

Modify scanner/programmer as required to prevent damage to R25 and K-10 when equipment is transferred from "operate" to "standby" condition with stepping relay stopped on Step 19.

RP-23 TTY Terminal Modification

Provide and install switches for by-passing selective calling and cryptographic (131B-2) facilities when required for equipment testing and line monitoring.

RP-24 Installation of VHF Direction Finder

Prepare drawings and specifications for installation of VHF Direction Finder equipment at Kodiak Station.

RP-25 Test Point Modification, D/TT Converter

Modify wiring to pins #45 and 50 of test jack strip J-2 to provide convenient means of checking operation of line flip-flop, parity flip-flop, teletype reperforator and local teletype line.

RP-26 R-1162 Synchro Reference Voltage Modification

Provide automatic switching of the synchro "r" leads to console power in case of loss of the reference voltage from the transmitter area.

RP-27 Verlort Elapsed Time Meter

Provide and install an elapsed time meter on the main power circuit of the Verlort radar for maintenance scheduling and reliability studies. Subject meter is to be located above the door on the front panel of Junction Box, RU-347E.

RP-28 Command Tone Recording

Provide and install a resistive mixing network for recording command tones, launch closure TTF computer tone (Mugu only), and binary time code word on Channel #6 of the radar van recorder.

RP-29 Launch Pad #5 Intercom

Engineer and install a fifteen station, ten channel, inter-communications system on Sentry Launch Pad #5 similar to that currently is use on Launch Pad #4. Equipment requirements are described in WDL-SW-1082, dated February 17, 1959, and WDL-PS-1122, dated February 18, 1959, which should be used as guides for system engineering.

RP-30 Doppler Receiving Equipment Installation, Telemetry Ship

Accomplish temporary installation of following items of Station 6 Doppler Receiving and Doppler Checkout Equipment on MSTS Ship, "Joe E. Mann."

1. Motorola Phase Coherent Receiver
2. Lambda Power Supply, Model C-280
3. Hewlett-Packard Counter, Model 524BR
4. Hewlett-Packard Digital Recorder, Model 560AR
5. Hewlett-Packard Low Frequency Function Generator, Model 202AR
6. Tektronix Oscillograph, Model RM-45
7. Boonton Signal Generator, Model 202F
8. Equipment Rack for items "5" through "7".

RP-31 Tape Recorder Doors

Provide and install windowed doors to cover the tape recorder section of the D/TT converters and acquisition programmers for dust protection.

RP-32 Additional Calibration Equipment

Procure additional calibration equipment for data transmission system to preclude current necessity for constantly transporting certain items of precision calibration equipment between widely separated transmitting and receiving areas.

RP-33 Verlort Recorder Amplifier Tube Shield Modification

Provide and install International Electronic Research Corp. "TR" series high efficiency heat dissipating tube shields on tubes in Verlort Recorder Amplifier Unit, RU-360, in place of existing tube shield to reduce high tube failure rate.

RP-34 Interim Doppler and SSB Installation--"King County"

Accomplish interim installation of VHF Doppler Receiver helical antenna and SSB communications equipment on USNS "King County."

RP-35 Relocation of Verlort Radar Baldwin Programmers

Relocate Verlort Radar Baldwin Programmer to inside wall of radar antenna support structure to improve access to programmers and other units remaining in pedestal.

RP-36 Modification to Record Doppler Signal Strength

Modify wiring of Doppler Receiver to make output of V-703 available for recording of received signal strength of external high impedance recorder. An external low-pass filter should be provided at recorder input to minimize transmission of hum and noise components to recorder and provide signal strength integration.

RP-37 Verlort Support Structure Heaters

Install heaters in Verlort pedestal support structures and weather stripping on all access doors and other openings to eliminate current conditions of moisture condensation and subsequence corrosion of radar pedestal components.

RP-38 Event Recording Clock

Prepare design and detailed cost estimate for fabrication of two similar event recording clocks to be installed at the "Van" Tracking Station per requirements outlined in enclosure to F. Hawkinson memo, Subject: "Event Recording Clock," dated April 6, 1959. This E.O. authorizes design services only. Procurement and fabricating costs will be authorized by separate E.O. subsequent to formal authorization to proceed by LMSD.

RP-39 SS/G and SS/L Display Console

Install new console section and associated equipment to provide display of SS/G and SS/L information adjacent to the vehicle command control console at Vandenberg, Hawaii, and the two Alaska stations. The equipment except installation hardware will be provided by the data handling section.

RP-40 Doppler Receiver Counter Output Circuit Modification

Design, procure and install a modification kit for the Motorola Phase coherent Doppler receiver to improve compatibility between receiver output and Dymec DY-5182A-1 counter input circuits.

RP-41 Doppler Boresight Beacons

Accomplish installation engineering and physical installation of boresight beacons for VHF Doppler receiving system.

RP-42 Baldwin Encoder Test Jack Modification

Install test jacks for monitoring pulse input, pulse output, +800 volts and +28 volts on front panel of Baldwin encoder power supply.

RP-43 Plotting Board Signal Terminations

Modify MCC and plotting board wiring to accomodate latitude crossing panel. Accomplished by vendor.

RP-44 Plotting Board Installation Mugu

Complete installation of d-c data circuits between Data Van D/A Converter and Radar II plotting boards in Administration and Control Van.

RP-45 Telemetry Tracker Indicator Modification

Remove existing angle indicator panel and replace with Milgo supplied servo amplifier indicator panel.

RP-46 Tri-Helix Indicator Modification

Install tri-helix servo indicator conversion kit and assoicated servo amplifiers.

RP-47 Verlort Boresight Camera

Install boresight camera on Verlort radars.

RP-48 X-Y Recorder Modification

Modify X-Y recorder servo amplifier E15A31A and servo supply E15A72A as required to provide additional circuit protection and improve reliability. Modification consists of the replacement of six resistors and eight semi-conductor diodes.

RP-49 Timing and Latitude Crossing Pulse Modification

Modify timing and latitude crossing pulse unit to prevent interaction between timing relay K-1 and collector supply voltage to timing section and latitude crossing section.

RP-50 Master Control Console Blower

Investigate means of improving air circulation in Master Control Console to reduce high ambient temperature of air surrounding transistors in VCC module. Provide intake or exhaust blowers and/or additional air baffling as required.

RP-51 Weather Instrument Shelters

Install weather instrument shelters adjacent to Data Transmission Vans.

RP-52 Communications Panel Modification

Modify communications panel to provide for individual release of parties from conference network. Present mode of operation with common "release key" results in necessity for re-establishing conference each time one or more parites desires to be released from network.

RP-53 Communications Panel Expansion (Hawaii)

Provide material for activation of ten additional switch positions on VCC communications panel (this will result in expansion of panel to full switch position capability).

RP-54 System Time Clock - Mugu Communications Van

Provide and install remote digital time display unit at teletype operators position in communications van to display system time only.

RP-55 Tri-Helix Indicator Wiring Replacement

Replace microswitch wiring in tri-helix indicator unit with wire of increased durability to preclude fatigue breaks and insulation breakdown.

RP-56 Emergency Power Unit Mugu Timing System

Accomplish necessary engineering for installation of 30 kc mobile power unit adjacent to instrumentation van to be utilized as backup power for the dual timing system only.

RP-57 Milgo Maintenance Tray Modification

Add stud and retaining nut assembly to Milgo maintenance trays to prevent slipping of tray and disconnection of connector assembly while in use.

RP-58 Modification of TLM-18 for 108 mc Operation

Measure gain of Vandenberg and Hawaii TLM-18 at 108 mcs. If gain at 108 mcs is too low to be usable, accomplish temporary modifications to antenna as required to provide usable gain at 108 mcs without excessive interaction or loss of performance at 235 mcs.

RP-59 Verlort Radome Windows

Design and install one radome window for testing and operation of the Verlort radar boresight camera.

RP-60 X-Y Recorder Modification

Install minor modification kits on Milgo Model 3010 X-Y Recorders to improve reliability of servo motors and facilitate maintenance of inkwells.

RP-61 Camera Installation (R-1162)

Install boresight camera on R-1162 telemetry trackers.

RP-62 Tape Transport Modification

Modify tape Transports for digital/teletype (D/TT) converter and acquisition programmer to provide for control a-c line power independent from associated equipment.

TP-63 Telemetry Tracker Carrier Relay Modification

Replace R-2201 in both r-f amplifiers with 30K resistors to increase sensitivity and adjustment range of "carrier relay".

RP-64 Digital Display Equipment Modification

Install noise elimination kits on the Beckman digital time display unit.

RP-65 Synchro Reference Modification

Modify synchro reference power distribution system to eliminate presence of "hot lines" within tri-helix control rack and A&T console when a-c line power switches for subject units are in "OFF" position.

RP-66 Synchro Line Amplifier Modification

Modify the existing Milgo synchro line amplifiers to convert from reversed phase to direct phase amplification of synchro system control signals and to present a high degree of system data line isolation.

RP-67 Passive Tracking Modification Kit

This modification provides for the selection of either the automatic range tracking gate or the beacon video return, to trigger the early and late track gates. This in turn makes the angle track gate. The video in the remote video and agc chassis will be delayed 1.0 μ second in order that it be coincident with the angle track gate when the beacon video return is used to trigger the early and late gate. Only the video in the range gate is used.

RP-67A Quality Bit for Passive Track

Provide an additional punched "quality bit" on the teletype tape output of the D/TT converter when the Verlort is in the "passive track" mode of operation.

RP-68 Verlort--Installation of Anti Beacon-Capture Circuit

The anti beacon-capture circuit allows the gated beacon video signals to reset a free running phantastron circuit. If a selected number of gated pulses are missed, the phantastron will run down and allow a reset pulse to fire the magnetron approximately half a PRF cycle early.

RP-69 Verlort--Addition of Range Simulator

This modification will provide a pulse to the "S" band signal generator (HP Model 616) which moves out in time at a time rate of up to 20K yd/second. The r-f signal from the HP-616 is fed into the duplexer and a target is simulated.

RP-70 Verlort--Recorder Standard Channelization

Provides standard channelization of existing functions in the six and 30-channel recorders and adds several new channels.

RP-71 Verlort--Ground Beacon Radar Verification

Provides display facility for local monitoring of command relay operation in an S-band beacon mounted in and integrated by the Verlort. Hardware provided.

RP-72 Verlort--Verlort Wave Guide Variable Attenuator (VTS)

Provides a variable attenuator in the wave guide to minimize side lobe lock on during launch phase and allow launch pad beacon checkout without spurious results due to saturation signals. LMSD will handle this modification and supply hardware.

RP-73 15 Command Control Relay Unit

Provide Discoverer-to-Midas switching of the KY-94 coder inputs. Also provides relay repeaters for the Radar tone verification lines. Switchover of the KY-94 command inputs is accomplished by switching +300 volts (provided by the coder) from the VCC to the 15-command panel.

RP-74 Tone Tell-Tale and Re-entry Selector Indicator Lights for "L" Timer Panel.

Provides a more reliable means of command tone verification independent of the telemetry decommutators. Upon receipt of a command verification tone, telemetry circuits provide a relay closure completing the 28 volt DC circuit to the appropriate tone tell-tale indicator on the "L" timer panel.

The re-entry selector indicator provide a NORMAL indication when the external +28 volt DC supply is turned on, until a signal on telemetry channel 16 activates a relay in the "L" timer chassis. At this time, the NORMAL light is turned off and the ALTERNATE light is turned on.

RP-75 VCC Rehabilitation

Rewire all relays and switches in the command panel.

EC-92 Verlort--Elevation Servo Sensitivity

Change in the torque limiter so that elevation servo sensitivity is the same as azimuth sensitivity. This simplifies alignment and trouble-shooting procedures.

EC-93 Acquisition Programmer--Output Control Circuit

By-pass control relays so that acquisition programmer is always connected to the C/P converter.

EC-94 VCC--Command 4 Verification Lamp, Lock-on Disconnect

Modification to Command #4 verification lamp indicator to momentarily flash, approx. 1/2 second, from a continous lighted lamp indication upon verification. This requires disconnecting ground wire from relay K-216A, terminal 6. This allows K216 to release after operation on the pulsed verification signal.

EC-95 X-Y Recorder--TLM-18 Tracker Pre-Plot Capability

Modify station wiring to allow the plotboard synchro/dc input to be switched automatically from the tracker antenna position synchros to the acquisition programmer synchro output when the acquisition programmer is in the pre-plot mode.

EC-96 Acquisition Programmer--Addition of Time By-Pass and Coast and Normal Switches and Lamps

Addition of time by-pass switch for maintenance and also to allow run through on an "operation" if necessary. Not applicable to Vandenberg.

EC-97 X-Y Recorder--Pre-Plot Pen Control Mod.

Addition of repeat relay in plot board in lieu of direct control of the +300v by the acquisition programmer, as it is inadvisable to have the +300V in the inter-area telephone cable.

EC-98 Tri-Helix--Antenna Stowing Mechanism

Installation of straps and angle brackets to provide antenna stowing mechanism. No applicable to Vandenberg.

EC-99 VCC--Interchange of Commands 2 & 4

Provide increased insurance for stepped command of vehicle timer period, the tone assignaments of commands #2 and #4 were interchanged. Command #2 (formerly tones A & C) will be tones B & C and Command #4 (formerly tones B & C) will be tones A & C.

EC-100 VCC--Command 3 Modification to Insure 1-Second Pulsed Commands

Modification of Command 3 circuitry to insure a 1-second duration pulse when Command 3 is depressed, and when Command 3 is held down, a repeated pulse of 1-second duration spaced at 1-second intervals is transmitted.

EC-101 Re-installation of Original TLM-Tracker Indicator Panel

Installation of the new Milgo Bug Indicator Panel has provided a complete spare indicator panel which is installed in Rack #4 and connected to the 36:1 or 1:1 synchros, as desired, installed in Az & El synchro gear boxes. This provides numerous operational advantages.

EC-102 Modification to Provide 24-hour Automatic Recycling

Digital time display system--modify both the recycle and alarm functions of the system time word to a 24-hour period.

Dual timing system--modify to recycle the accumulator after a count of 21,600 4-second intervals.

EC-103 Slave Bus Azimuth and Elevation Indicator

Conversion of the existing tri-helix azimuth and elevation signal indicators to double indicators using station spare components, allowing slave bus data to be presented on the MCC.

EC-104 Separation of Synchro Reference Source

Separation of the synchro reference source into three circuits, each separately fused and switched, to the MCC, tri-helix, and telemetry-tracker.

EC-105 Synchro Reference Line Filter at VAFB

Minimize 5th & 7th power line harmonics on the synchro indicator servo amplifiers of the MCC to achieve a satisfactory null of the control transformer input to the servo amplifiers.

Install a 300 & 420 cycle series resonant filter across the synchro reference line and a transformer to isolate the synchro load from the other distribution.

EC-106 Plot Board Pen & Arm Motor Replacement

Replacement of the four pole pen and arm motors with eight pole motors to reduce maximum speed.

4 pole: R112-2B Kearfott
8 pole: R111-2B Kearfott

EC-107 Addition of Communication Equipment Rack Assembly (Kodiak)

Install an equipment rack to assemble and mount the Friden tape punch, Doppler repeater and power supply, transmitter-distributor (100 wpm T/D) and digital to teletype (D/TT) reperforator.

This installation will provide additional space to locate the AN/FGC-25 teletype equipment associated with the SSB system.

EC-108 Boresight Camera Amplifier Supply Voltage Modification

Power supply voltage will be increased from a regulated 105 v dc to a regulated 150 v dc. This modification will increase the reliability of the camera data recording unit with regard to neon lamp firing and amplitude of input signal required.

EC-109 Switch Controlled Automatic Insertion of "Q" at End of Data Teletype Tapes

This modification provides for a simple and quick method to insert computer-required "Q"s at the end of a perforated teletype tape for transmission of tracking data from a tracking station to IDCC.

This modification is applicable to Kodiak only.

EC-110 Installation of Analog Data Line Amplifier Program Patch Board

Modification to provide a means of patching the Parsons demodulator outputs to the analog data line amplifiers and the ADLA's outputs to the VCC. This would also provide a means of breaking information to the VCC when not in use.

EC-111 Analog Data Line Amplifier Model 149, Relay Output Monitor

To provide a convenient method of relay output adjustment by adding a third deck to switches S12 and tying pin one of the relay outputs to its taps and replacing S13, toggle switch, with a 5-position switch tying the wiper of S12D to the 3rd position of the new S13--thus allowing the relay outputs to be monitored by the front panel meter.

EC-112 Installation of Correction Capacitors to C/P Refraction Unit

To reduce system inaccuracies synchro correction capacitors are added to the stators of the differential generators in the C/P refraction units.

EC-113 Modification of Scanner/Programmer to Eliminate Operational Errors

Provides for automatic homing of the stepper switch, activation of the header data circuitry with the equipment in "standby" status, and elimination of the data word during the time that header information is being given to the tape punch.

EC-114 Addition of Coax Line Drivers to the Dual Timing System

This modification will provide 12 additional Coax line Drivers to the dual timing system at Vandenberg and Hawaii. The demand for 1pps-4pps and 10pps outputs at these tracking stations now far exceeds the equipment capabilities. Addition of the line drivers would take care of these demands and provide spares for future requirements.

EC-115 Verlort Antenna Balance Adapter Plate

A new adapter plate was fabricated which is four inches longer and two inches wider than the original, with the weight mounting holes shifted two inches toward the outside to insure clearance and slotted the added four inches to allow the weight to be shifted. With the new adapter plate installed, it is not difficult to locate the weight to obtain a very near dynamic balance of the antenna.

EC-116 Relocation of D-C Amplifier Balance Controls

Relocate d-c amplifier balance controls to the front panel for ease in adjustment and to eliminate the requirement to remove the scale factor for units each time an adjustment is required.

EC-117 "L" Timer Panel Modification

Convert timer period readout to step counter to allow display of timer period in numerical step position by indicating the telemetered position of a 1-second and 10-second stepper switch in the vehicle timer. The period may vary from 00 to 99.

EC-118 Test Points, Acquisition Programmer

Installation of test points to facilitate testing and trouble shooting.

EC-119 Versatility in Selection of Range, Azimuth and Elevation Modes

Provide a more versatile system for selection of Range, azimuth and elevation modes.

EC-120 Active Passive Track Mode of Operation

The above modification provides a more rapid transfer from the passive mode to the active mode of operation. With the modification installed the system may have a passive track with the transmitter on or off. To be utilized at the inital acquisition.

EC-121 Regulation and Filtering Improvement, Milgo +28 and +44 Power Supplies

Modification to improve output filtering and voltage regulation by installing new transformer and redesign of regulator circuits.

EC-122 TN-24, TN-25 Coupling Modification

Change from direct to capacitor coupling between TN networks and correct bias levels to reduce failures of TN-24's, TN-25's and MN-13's.

EC-123 R-1162 Boresight Camera Cover

Provide a moistureproof hard cover to replace the existing canvas cover not suitable for use with input from dehydrator unit.

EC-124 D/A-25V Power Supply Cooling, Milgo

To provide blower operation (cooling) to the 25v power supply during standby or power on conditions.

EC-125 Discrete Answer Back Arrangement (Kodiak)

Modification will allow each station to have a function to automatically answer back whenever a STC operator desires this. He will transmit 4 "N"s, conditioning distant station to "select non print". The station letters (CDC list) (KO=Kodiak) will cause distant machine to verify with:

1. Carriage return
2. Line feed
3. Letters
4. Answer back (DI=Kodiak)

EC-126 VCC Extension Test Cables.

To facilitate maintenance of the individual components of the Vehicle Command Control Unit. By utilizing the appropriate extension test cables, a particular chassis or panel may be brought out of the console and worked on with power applied.

EC-127 VCC Command #2 Interrupt Circuit

Modification of the VCC precedence circuit to prevent interruption of Command #2 during a 1-pps duty cycle.

EC-128 Verlort and R1162 Reticle Illumination

To provide a simpler and more precise means of adjusting the intensity of the reticle illumination on the boresight camera.

EC-129 R-1162 (TLM-18) Antenna Sector Scan Reset Modification

To prevent this large antenna from slewing rapidly when switched back to the sector scan mode. The amount of slew would depend upon the amount of stored offset from zero contained in the sector scan differential generator.

EC-130 Extended Range Verlort Radar.

To extend Verlort range to 5,000 miles.

APPENDIX C

INTER-RELATION WITH OTHER PROGRAMS

APPENDIX C

INTER-RELATION WITH OTHER PROGRAMS

C.1 General

The Discoverer C & CS facilities are used in support of other programs, the most significant of these being the Midas, Samos and Advent Programs. Additionally, the Hawaii station supported Tiros I; a detailed description of this support is contained in WDL TR-1187A.

C.2 Midas and Samos

Support of the Midas and Samos programs include Verlort tracking and commanding and VHF telemetry and Doppler reception for the past Midas Phase I and forthcoming hybrid Midas and Samos flights. A detailed description of Midas Phase I is contained in WDL TR-1184. Detailed description of hybrid Midas operations is contained in WDL TR-1416 and of hybrid Samos in WDL TR-1390. Support of these programs required or will require certain modifications and augmentation of the basic Discoverer equipment. The major modifications are:

a. Extension of Verlort range to 5,000 miles at all stations in support of hybrid Midas flights.

b. Installation of a Hybrid Data System for the exchange of Discoverer and Samos cynchro position slaving data at VAFB. A digital slaving link between the Verlort and the D/R antenna is presently planned for NBTS.

c. Installation of 15-command panels at VAFB and Hawaii to expand the Verlort command capability from 6 to 15 commands in support of Midas Phase I. These same 15-command panels, modified to permit a variable, "long command", will be utilized in support of hybrid Samos flights for transmission of auxiliary real time commands (ATCs) as backup for UHF commands on payload and data-link functions.

C.2.1 Verlort Range Extension

Action is being taken (EC-130) to extend the maximum tracking capability of the Verlort radar from 2,300 miles to 5,000 miles to permit tracking of high altitude Midas flights. The extended range modification involves the following changes in Verlort characterisitics:

a. Incorporation of a fourth pulse-recurrent frequency of approximately 630 cps for either automatic or manual selection. The 630 PRF represents a division ratio of

130 from the 82-kc timing oscillator. The additional pulse recurrence frequency is required to eliminate interference between transmitted and received pulses.

b. Extension of the range ambiguity resolution function of the long range display to 5,000 miles. This involves providing the vertical positioning control with an index of approximate range to permit selection of any 2,500 mile portion of interest.

c. Changing the frequency of the 28-cps oscillator to approximately 14-cps in order to cover the extended range. The rundown slope of the strobe sweep generator is reduced approximately half to compensate for the doubling in sweep time.

d. Changing the gearing of the range analog data potentiometer so that a voltage representation of range from 0-5,000 miles can be obtained with a linearity of .007% or better.

In addition to the foregoing Verlort changes, the following modifications are necessary in data and display system characteristics:

a. C/P Converter. Changing the Veeder-Root counter drive gear so that the counter is capabile of reading 9,999 K yards. Change range output synchro drive gear to increase range of unit.

b. D/TT Converter. Changing the wiring between the Verlort range encoder and the D/TT converter so that the most significant range bit is connected to the D/TT R_o range bit location and the least significant bit is connected to the R_{18} range bit location. This allows utilization of 19-bit range data providing a maximum range of approximately 10,224 K yards without changing the resolution (19.53 yards). The passive track bit is removed from the R_{18} location to the T_o (zero) location. The T_o (zero) location became vacant with the 24 hour recycle modification. The required changes in teletype format are shown in Fig. C-1. This change in format will require a revision in central computer programming.

c. MCC. Installing a new range dial graduated to accommodate the extended range.

d. Control Rack. Changing the Veeder-Root counter drive gear to permit the counter to read to 9,999 K yards.

e. P/C Converter. Changing the input circuit of d-c amplifier Number 1 to compensate for the new gear ratio of the Verlort range potentiometer.

EXISTING

X	T_0	T_4	T_8	T_{12}	A_0	A_4	A_8	A_{12}	E_0	E_4	E_8	E_{12}	R_0	R_4	R_8	R_{12}	R_{16}	
X	T_1	T_5	T_9	T_{13}	A_1	A_5	A_9	A_{13}	E_1	E_5	E_9	E_{13}	R_1	R_5	R_9	R_{13}	R_{17}	
	T_2	T_6	T_{10}	T_{14}	A_2	A_6	A_{10}	A_{14}	E_2	E_6	E_{10}	E_{14}	R_2	R_6	R_{10}	R_{14}	PT	
	T_3	T_7	T_{11}	T_{15}	A_3	A_7	A_{11}	A_{15}	E_3	E_7	E_{11}	E_{15}	R_3	R_7	R_{11}	R_{15}	W	X
	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

PROPOSED

X	PT	T_4	T_8	T_{12}	A_0	A_4	A_8	A_{12}	E_0	E_4	E_8	E_{12}	R_0	R_4	R_8	R_{12}	R_{16}	
X	T_1	T_5	T_9	T_{13}	A_1	A_5	A_9	A_{13}	E_1	E_5	E_9	E_{13}	R_1	R_5	R_9	R_{13}	R_{17}	
	T_2	T_6	T_{10}	T_{14}	A_2	A_6	A_{10}	A_{14}	E_2	E_6	E_{10}	E_{14}	R_2	R_6	R_{10}	R_{14}	R_{18}	
	T_3	T_7	T_{11}	T_{15}	A_3	A_7	A_{11}	A_{15}	E_3	E_7	E_{11}	E_{15}	R_3	R_7	R_{11}	R_{15}	W	X
	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

LEGEND

PT PASSIVE TRACK INDICATOR BIT
W RADAR QUALITY BIT
T TIME BITS
A AZIMUTH BITS
E ELEVATION BITS
R RANGE BITS
P PARITY BIT

DWG A4513

Fig. C-1 Extended Range Modification Data Word Format LMSD Mod. 17(EC130)

C.2.2 Hybrid Data System

The hybrid data system (Fig. C-2) provides intersystem positional slaving on a semi-automatic basis between the Discoverer and Samos tracking equipment at the Vandenberg Tracking Station. A set of tracking status and logic signals is also generated by the system to aid the respective system console operators in establishing optimum tracking and slaving modes. This involves the exchange of Discoverer slave track data and Samos angle tracker data.

Slaving Discoverer to Samos. A Samos tracking status indicator lamp was added at the Discoverer MCC tracking status panel to provide an indication that the angle tracker is automatically tracking. Utilization of Samos data is controlled by a "Remote 1" switch provided at the Discoverer slave track command panel. Actuation of this switch places two-axis angle tracker synchro positional data on the Discoverer slave data bus. Discoverer tracking equipment operators may then use this data as necessary to assist in vehicle acquisition.

Slaving Samos to Discoverer. Discoverer slave data is available to the Samos system at all times, regardless of any particular equipment tracking status; however, the actual decision to use Discoverer slave data is made by the Samos master control console acquisition and tracking operator, based upon indications and status signals furnished by the hybrid data system. Continuous servo indicator dial displays of azimuth and elevation slave data are furnished to the Samos master control console; in addition, a lamp indication of Discoverer tracking status labeled DISCOVERER TRACKING is also provided at the Samos MCC.

The Samos MCC operator has the option of selecting two types of slaving configuration, REMOTE 1 or REMOTE 2, when he wishes to slave the Samos Angle tracker to the Discoverer System. The general control action of both are as follows:

Remote No. 1. On the Samos MCC, if remote slaving of the angle tracker is desired, the normal procedure is to go to the Remote 1 condition first. A system interslaving logic has been established, and signals generated, such that if the console is either in the normal (no remote slave) or in the Remote 1 configuration, the DISCOVERER

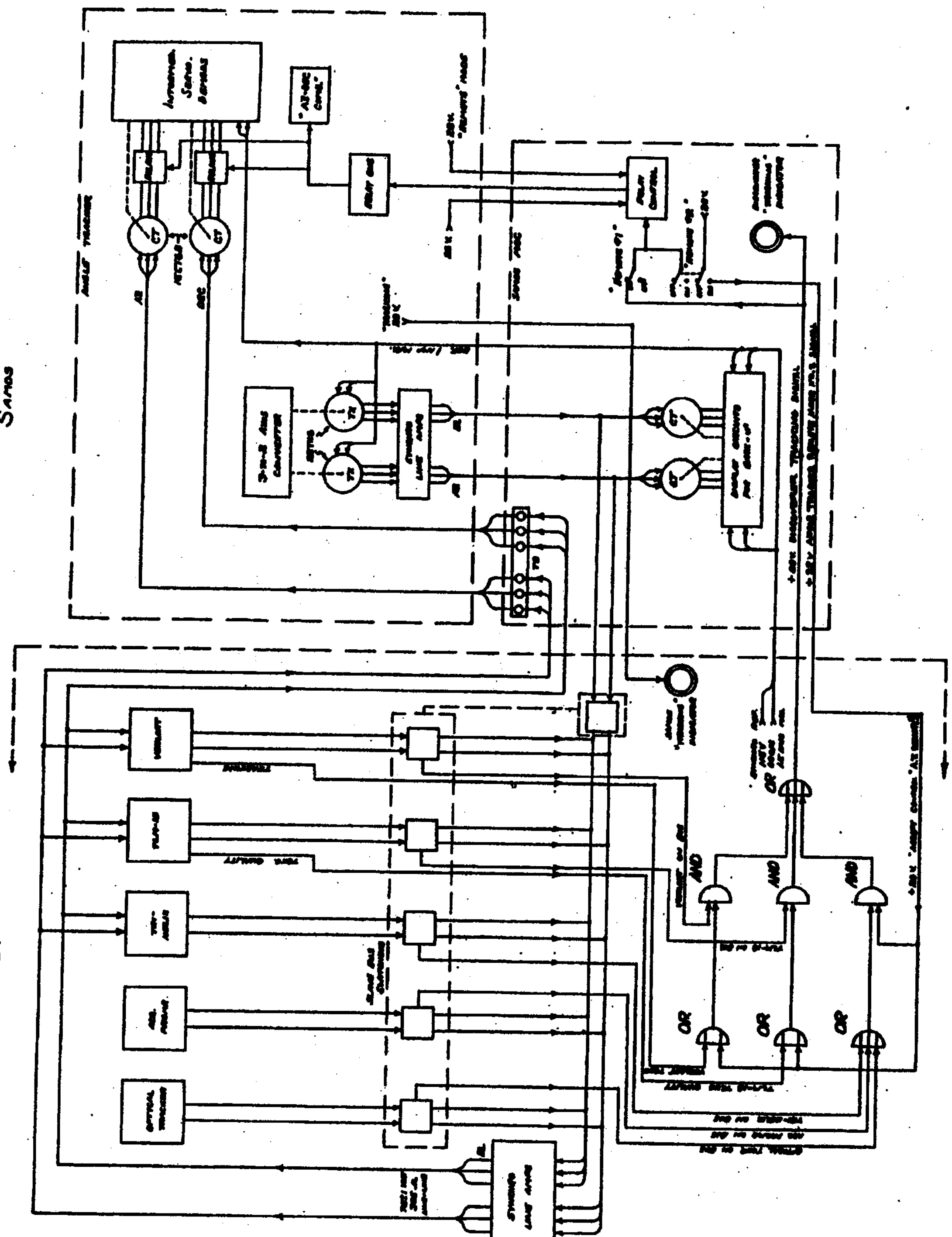


Fig. C-2 Samos-Discoverer Interslaving Simplified Block Diagram

TRACKING lamp will light only if an active track of either the Verlort radar or the telemetry tracker exists, and that particular equipment's slave data is on the bus and directly available to Samos. When the REMOTE 1 push button switch is depressed, the control action to slave the Samos angle tracker to the Discoverer slave data bus will be provided during active track periods to aid the acquisition or tracking capabilities of Samos.

Remote No. 2. If no lamp indication is obtained in the Remote 1 configuration, and a lesser quality of tracking data is desired, the REMOTE 2 button may be depressed. If the DISCOVERER TRACKING lamp lights when the REMOTE 2 push button switch is depressed, it indicates that Discoverer slave data other than radar or telemetry tracker active-track Data is available and is connected to the Samos angle tracker. The slave data sources which will light the lamp in the REMOTE 2 position establish a desired intersystem slaving configuration from Discoverer and are (1) the optical tracker, (2) the acquisition programmer, (3) the tri-helix antenna, (4) the Verlort radar, and (5) the telemetry tracker, the latter two in the non-automatic track mode.

If no "DISCOVERER TRACKING" lamp signal is obtained in either the NORMAL (No Slave), REMOTE 1 or REMOTE 2 switch positions, no tracking slave data of a useful nature to Samos currently exists in the Discoverer system, and tracking and acquisition aids within the Samos system should now be employed to establish Samos acquisition and tracking.

C.2.3 15-Command System

The 15-command system (Fig. C-3) expands the Discoverer command capability from six to fifteen commands. The ground portion include the 15-command panel, (Fig. C-4) which is installed in VCC Bay No. 2 at VAFB and Hawaii. Command control is assumed by the 15-command panel when its power switch is activated. The vehicle portion of the 15-command system is identical to Discoverer except for the addition of a command relay box. This unit contains the latching relays and takes the six-channel output of the decoder, performs the memory logic, and issues the 15 commands to the equipment being controlled.

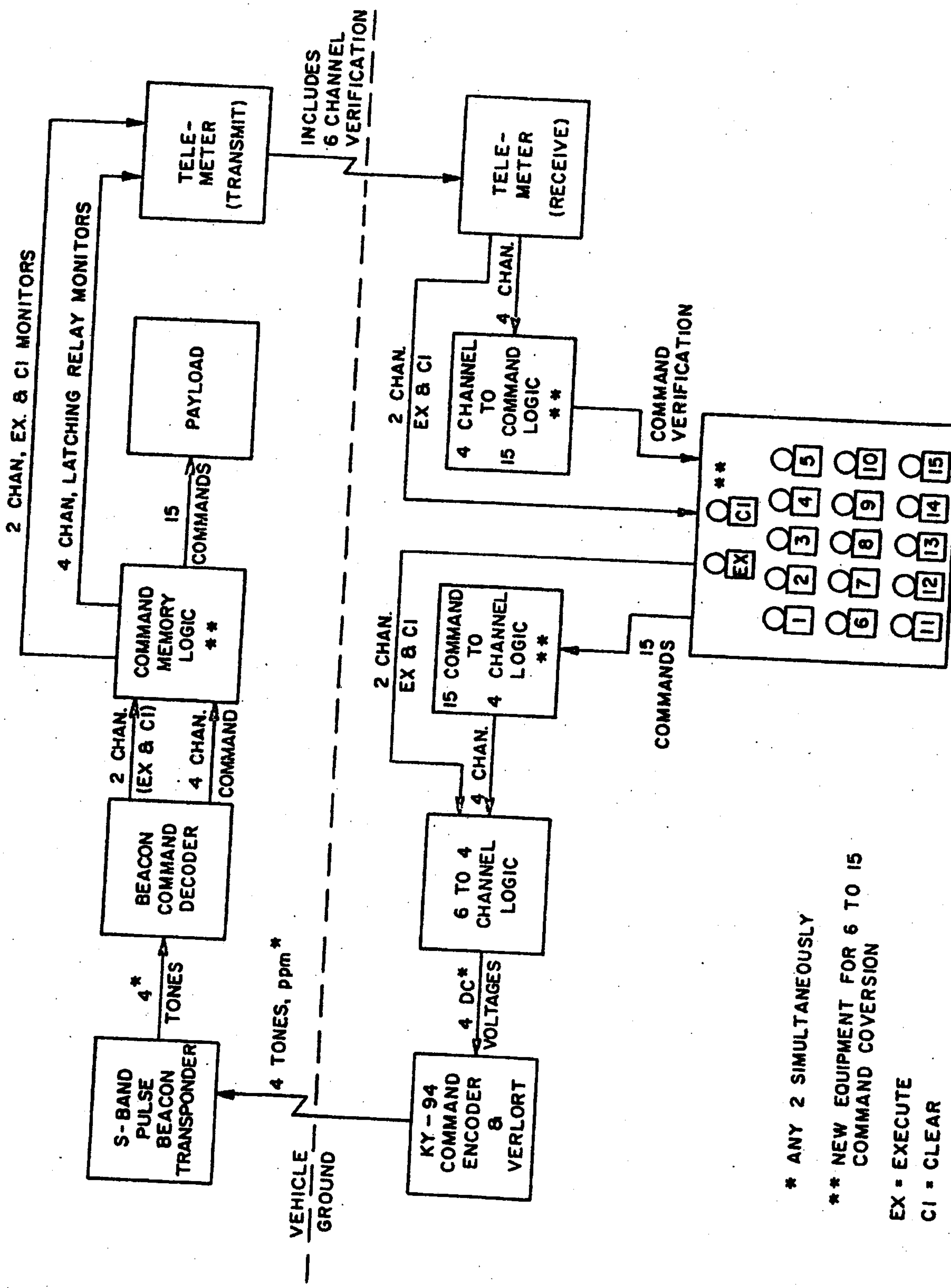


Fig. C-3 15-Command Panel Block Diagram

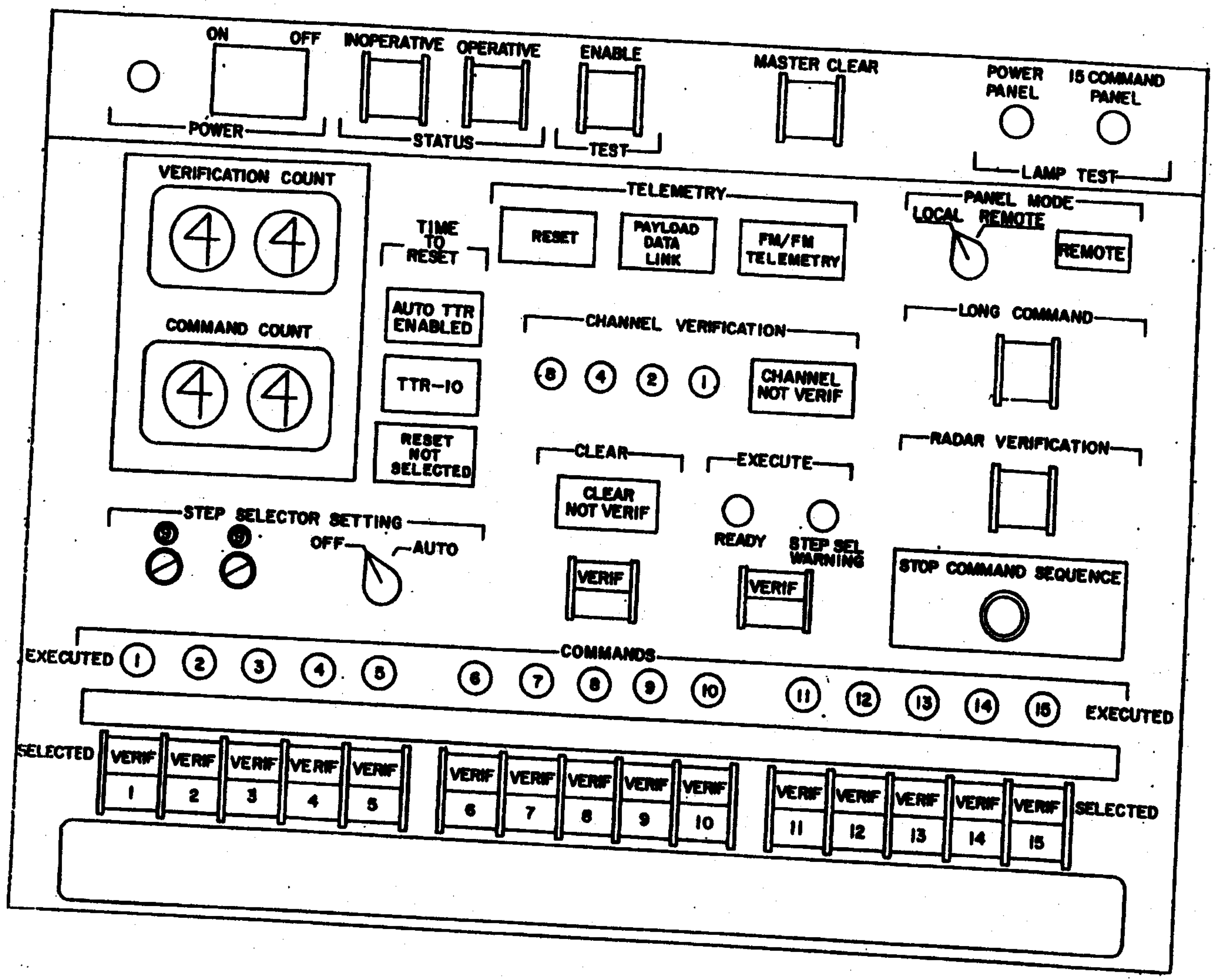


Fig. C-4 15-Command Panel

As in the basic Discoverer six-command structure, six possible pairings of the four tones in the pulse coder are utilized. One pair is used for a clear instruction that prepares the vehicle equipment to receive a new command. Four of the remaining pairs are used, one pair for each digit, to designate to the vehicle equipment the binary equivalent of the decimal number of the command selected. The sixth pair is used for an execute instruction, which instructs the vehicle equipment to carry out the selected commands.

The command control circuits generate tone control signals in the order listed above and supply them to the pulse coder. The pulse coder generates tones for modulating the command pulse. Each control signal is usually generated one time for one second if verified or is repeated until verified.

There are two modes of verification, telemetry and radar. In the telemetry mode, the mode that is normally used, the vehicle equipment transmits a verification signal by means of the telemetry link when a command is received and decoded. In the radar mode, the radar provides the verification signal, which in this case merely indicates that a command is being transmitted.

The execute instruction is ordinarily initiated manually, resulting in a single command of one second duration. However, other modes of execute instruction are possible. If desired, execute can be automatically repeated (one second on and one second off) a predetermined number of times by use of the step selector. Execute can also be transmitted continuously for 40 seconds by use of the "long command" mode. Provision for automatic execution is made with the vehicle timer reset command. When it is desired to reset the vehicle timer, the reset command is manually initiated at some time prior to time-to-reset (TTR). The TTR clock in the VCC is set to automatically generate a signal at TTR minus 10 seconds to start a ten second counter in the 15-command panel control circuit. The execute instruction is automatically transmitted at the end of the counter cycle.

Selection of the remote mode of operation permits operation of certain command control circuits from the Aeroject control panel.

It is possible to transmit the fifteen commands to the vehicle fifteen-command system using the Discoverer six-command panel. The functions performed by each command and tone combination are:

Command	Tone Combination	Function
1	A & B	Execute
2	B & C	Enable 1
3	A & D	Clear
4	A & C	Enable 2
5	B & D	Enable 4
6	C & D	Enable 8

The binary enabling commands are transmitted sequentially to obtain the binary representation of the desired "15-command."

C.3 Advent

The Hawaii Discoverer tracking station will be used in support of the secondary tracking station requirements of the Advent Tracking, Telemetry, and Command Sub-System (TT&CS). A complete description of the TT&CS is contained in WDL TR-1386. The TT&CS performs the following Advent program functions:

a. Provides accurate tracking data in order to determine an ephemeris with an error compatiable with orbit control requirements.

b. Provides an instrumentation system to monitor the performance of the final stage vehicle (FSV) under both normal and emergency (i.e. failure) conditions to provide information about the space environment.

c. Provides the command link for the orbital control of the FSV and for functional control of the vehicle communications payload and other satellite equipment.

The Hawaii Discoverer tracking station equipment planned for utilization in support of Advent are the R-1162 (telemetry tracker), timing, and communications systems.

The R-1162 will be modified to permit dual Discoverer-Advent use with the following capabilities:

a. Receive and track a right-hand circularly-polarized signal in the 215-to-260 mc band with an antenna gain of 28 db. (Discoverer).

b. Receive and track a 401 (±1.5)-mc right-hand circularly polarized signal with an antenna gain of 34 db. (Advent).

c. Transmit at 375 (±1.5) mc at either 100 watts or 20 KW, a right-hand circularly polarized signal, with an antenna gain of 33 db. (Advent).

The following modifications to the R-1162 are being considered to provide the capability indicated above:

a. Replacing the existing feed with a dual horn with 10-cps conical scanning, with an inner horn designed to operate over the frequency band from 375 to 400 mc and an outer horn designed to operate over the frequency band from 215 to 260 mc.

b. Installing a diplexer and band rejection filters to isolate the 275-mc transmit channel and the 401-mc receiver channel. The input to the 215 and 260 mc preamps are to be short circuited during transmission.

The desired tracking accuracy is 8 milliradians rms error unsmoothed in winds to 50 knots, but the current practive is to stow the antenna when the wind velocity reaches 35 mph. There is considerable doubt as to the ability of the R1162 to meet the desired accuracy in winds, so a radome may be required to meet the 20 hours per day operational duty requirements.

The Hawaii Discoverer timing system can be used in support of Advent TT&CS timing requirements. The need includes a time index word which is synchronized with GMT and an accurate and stable set of pulse trains.

For communications, the existing voice and 60-wpm circuits to STA can be used for administration and logistics. An additional full duplex 60-wpm TTY circuit to STA will be required for transmission of data to STA and receipt of STA commands. Data transmitted will be digital azimuth, elevation, Doppler, and "near real-time" telemetry. The existing intrastation communications circuit will require modification and augmentation to support the Advent program.

APPENDIX D

DISCOVERER FLIGHT SUMMARY

APPENDIX D

DISCOVERER FLIGHT SUMMARY

The following table is a tabulation of the Discoverer flights. Eccentricities and periods were taken from NASA Space Track Data.

Disc* Flight No.	Launch Date	Veh. No.	Period (Minutes)	Eccen-tricity	Angle of Inclin'n (Degrees)	Height Apogee (nm)	Height Perigee (nm)
0	1/59	1019	No Orbit	—	—	—	—
I	2/28/59	1022	Possible Orbit	—	—	—	—
II	4/13/59	1018	90.43	0.007	89	189	138
III	6/3/59	1020	No Orbit	—	—	—	—
IV	6/25/59	1023	No Orbit	—	—	—	—
V	8/14/59	1029	94.5	0.04	80	419	122
VI	8/19/59	1028	95	0.05	85	470	98
VII	11/7/59	1051	94.5	0.0492	80.7	453	88
VIII	11/20/59	1050	103.65	0.1005	80.6	903	110
IX	2/4/60	1052	No Orbit	—	—	—	—
X	2/19/60	1054	No Orbit	—	—	—	—
XI	4/15/60	1055	92.3	0.03	80.4	322	103
XII	6/29/60	1053	No Orbit	—	—	—	—
XIII	8/10/60	1057	94.13	0.03279	82.85	382	140
XIV	8/18/60	1056	94.54	0.0459	79.65	442	102
XV	9/13/60	1058	94.23	0.0405	80.90	414	114
XVI	10/26/60	1061	No Orbit	—	—	—	—
XVII	11/12/60	1062	96.45	0.05785	81.86	539	104
XVIII	12/7/60	1103	93.81	0.03326	80.82	375	130
XIX	12/20/60	1101	92.98	0.03105	82.80	345	117

* NOTE: Discoverer Flight

Discoverer Flight	
Flights V, VI, VII, XI, XV	Capsule not recovered
Flights XIII, XIV, XVII, XVIII	Capsule recovered
Flight XIX	No recovery attempted

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