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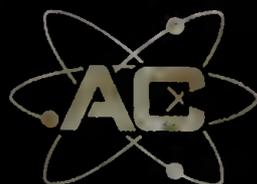


APOLLO

COMMAND MODULE

**PRIMARY GUIDANCE, NAVIGATION,
AND CONTROL SYSTEM MANUAL**

VOLUME 1



AC ELECTRONICS

Division of General Motors, Milwaukee, Wisconsin 53201

ND-1021043

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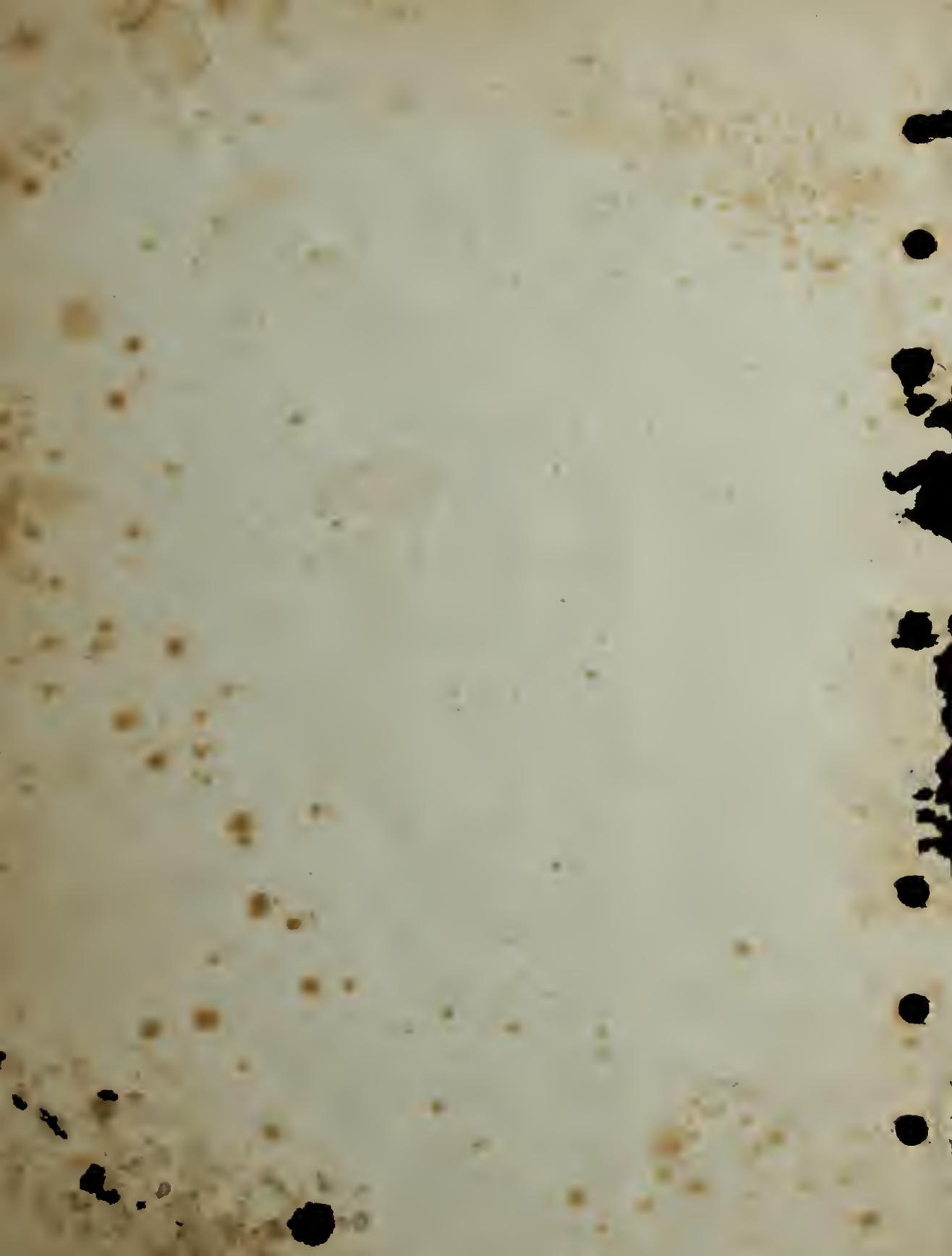
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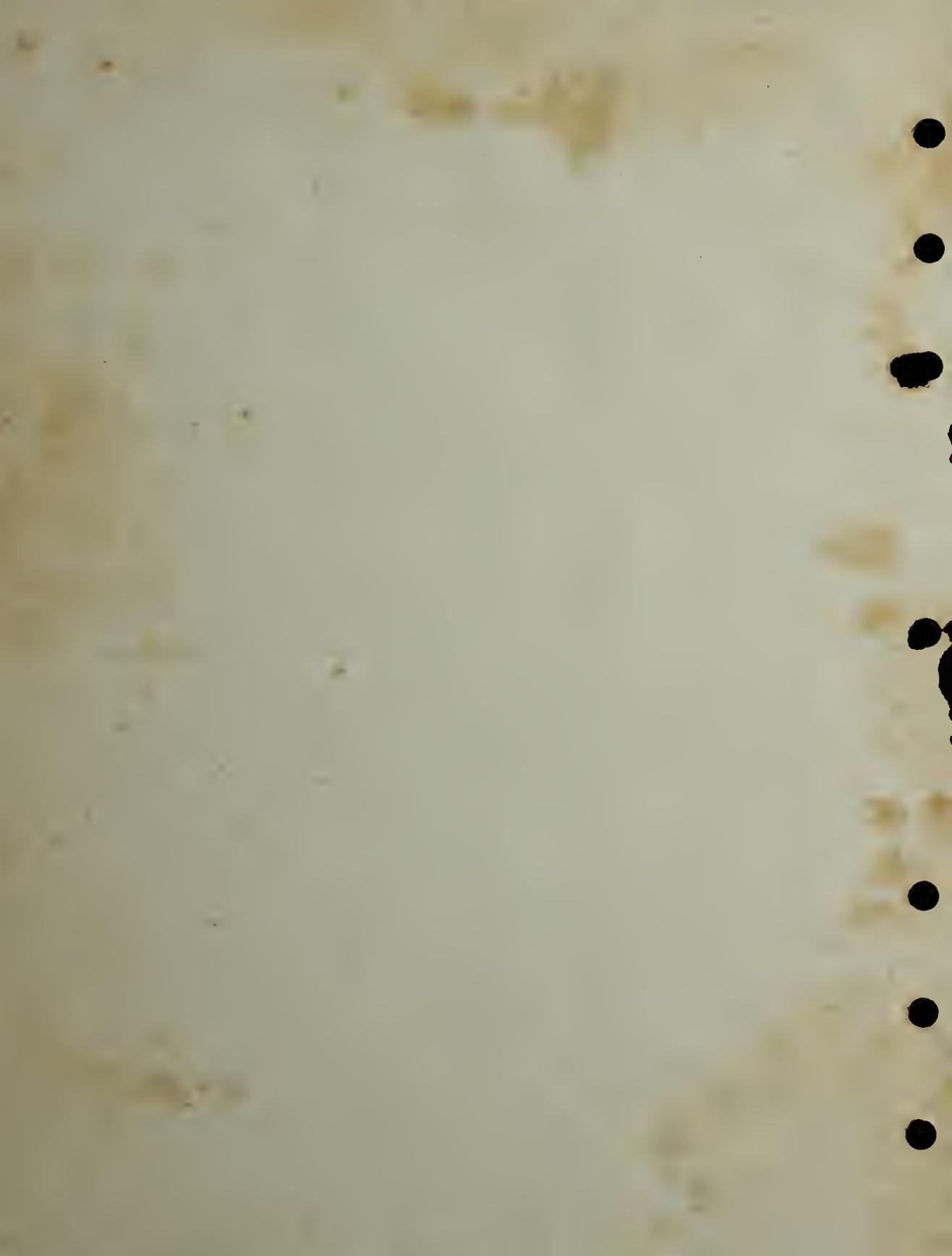
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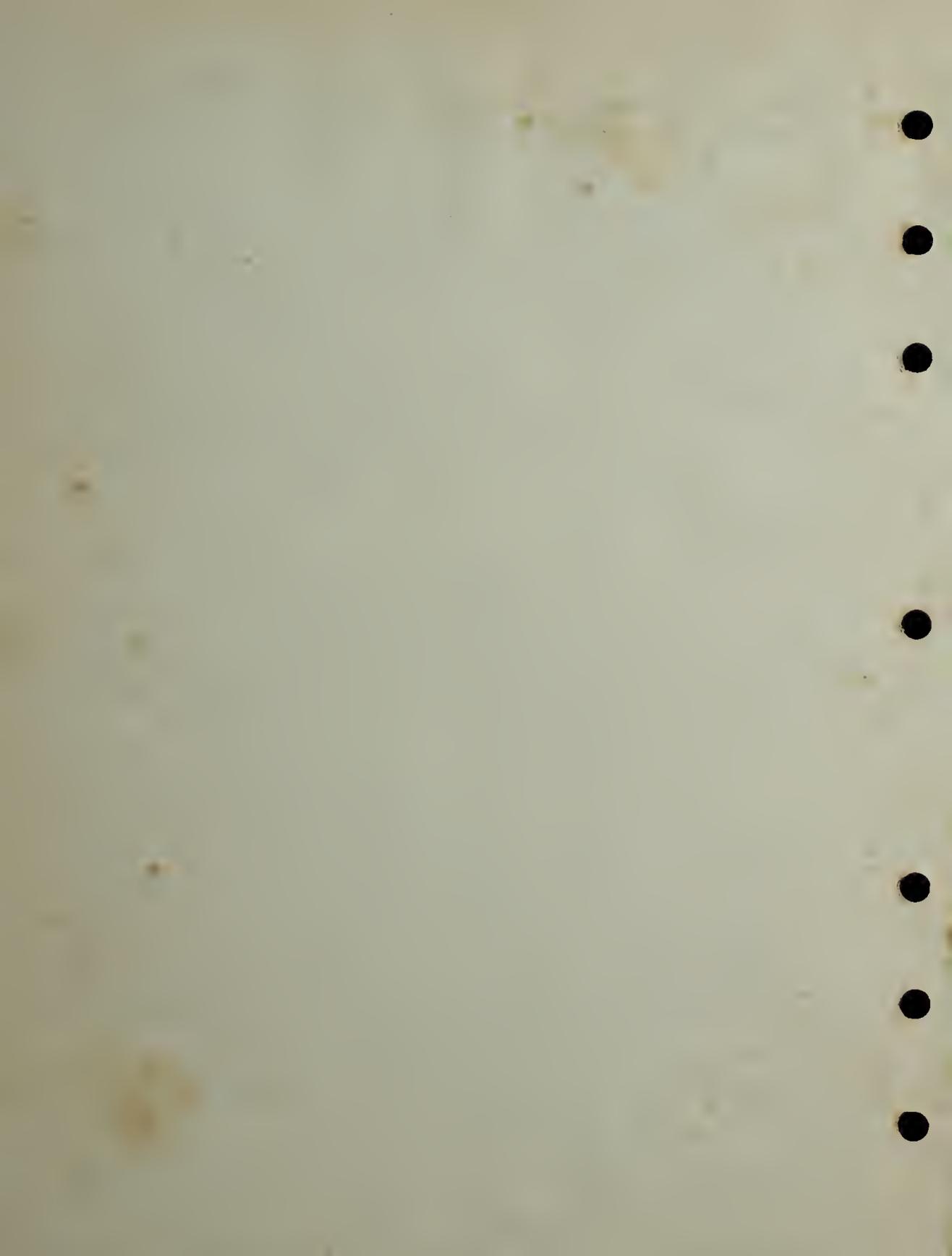
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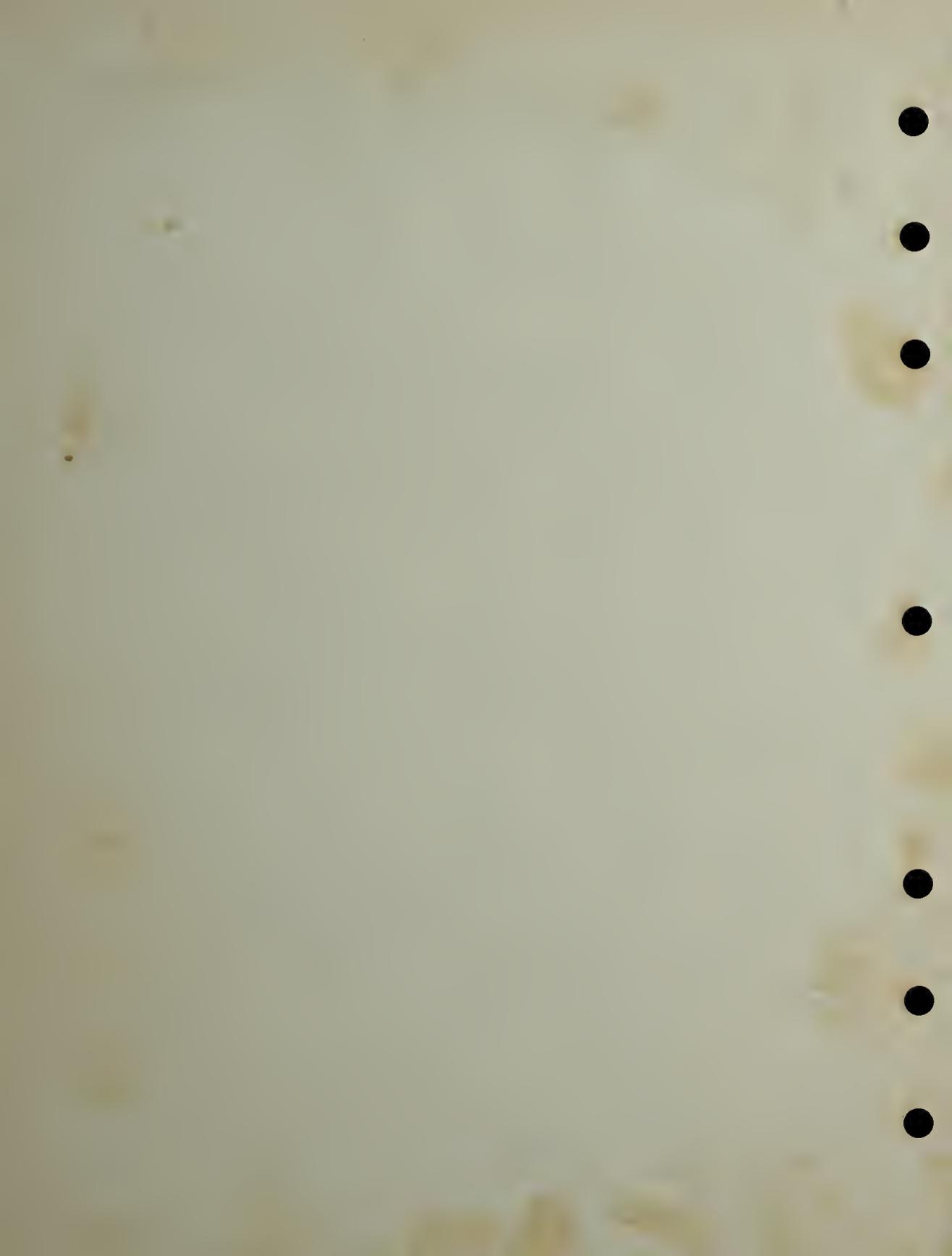
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LIST OF RELATED MANUALS

ND-1021038	Packing, Shipping and Handling Manual
ND-1021039	Auxilliary Ground Support Equipment Manual
ND-1021040	Bench Maintenance Ground Support Equipment Manual
ND-1021042	LEM Primary Guidance, Navigation and Control System Manual

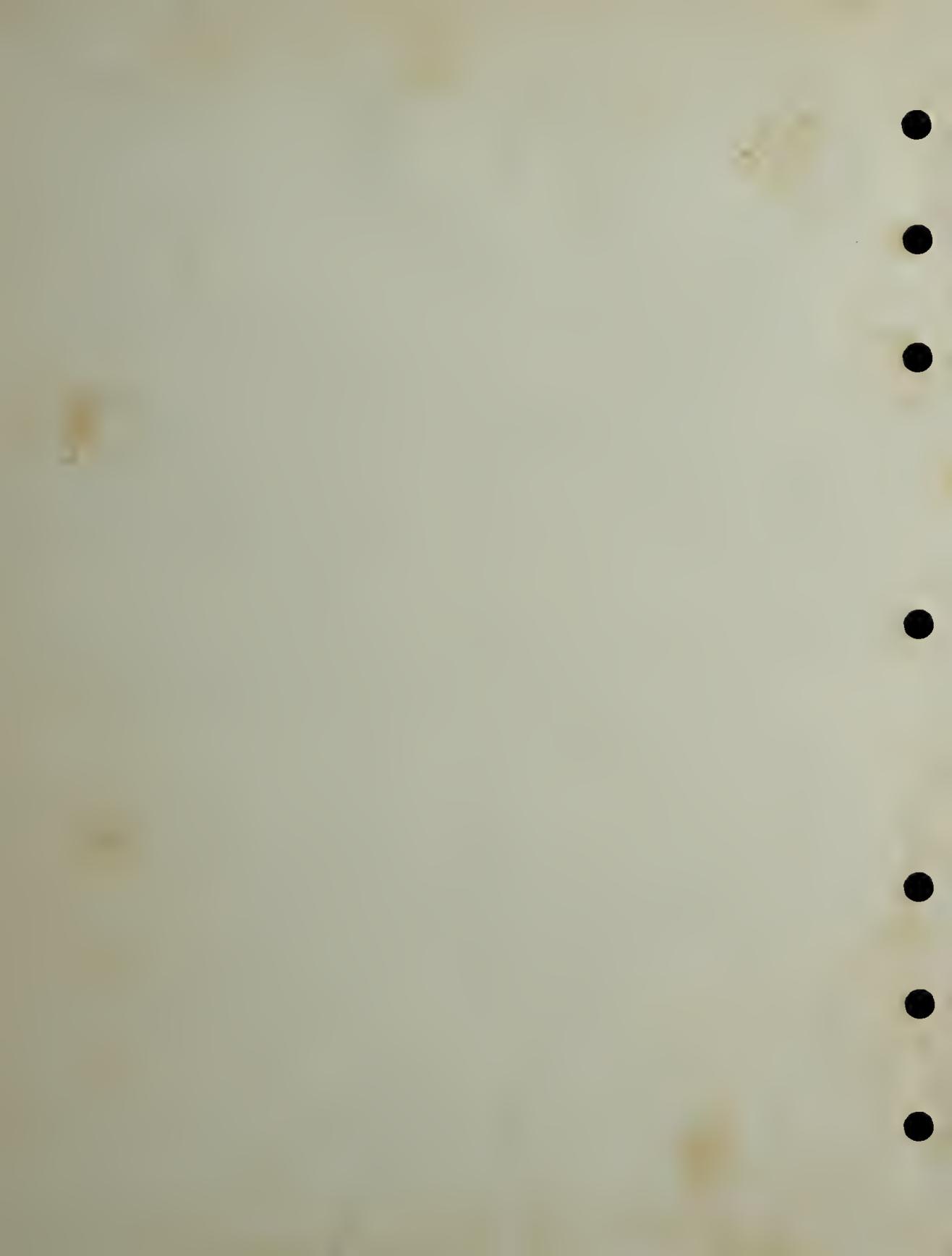


BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

LIST OF ENGINEERING CHANGE PROPOSALS

Engineering change proposals (ECP's) which affect this manual and from which pertinent data has been incorporated are listed below. Unless otherwise specified, the ECP number listed is an AC Electronics ECP number.

ECP No.	Functional Description	Retrofit Instruction Bulletin (RIB) No.	Incorporated In Manual Revision
204	Block II Temperature Control Change	-	Basic



INTRODUCTION

This manual provides information necessary for checkout, maintenance, and repair of the command module Block II primary guidance, navigation, and control system (PGNCS) (figure 1-1). The manual provides an introduction and complete familiarization with the PGNCS. Included in the manual are system tie-in, functional analysis, component description, detailed theory of operation, and description of flight operations.

Job Description Cards (JDC's) containing detailed step-by-step procedures are contained in separate supplementary volumes. This manual lists support equipment required for the JDC procedures and provides tabular and diagram references to the JDC's to insure that the preparation for checkout, checkout analysis, and repair and replacement procedures are performed in sequence and conform to all program requirements.

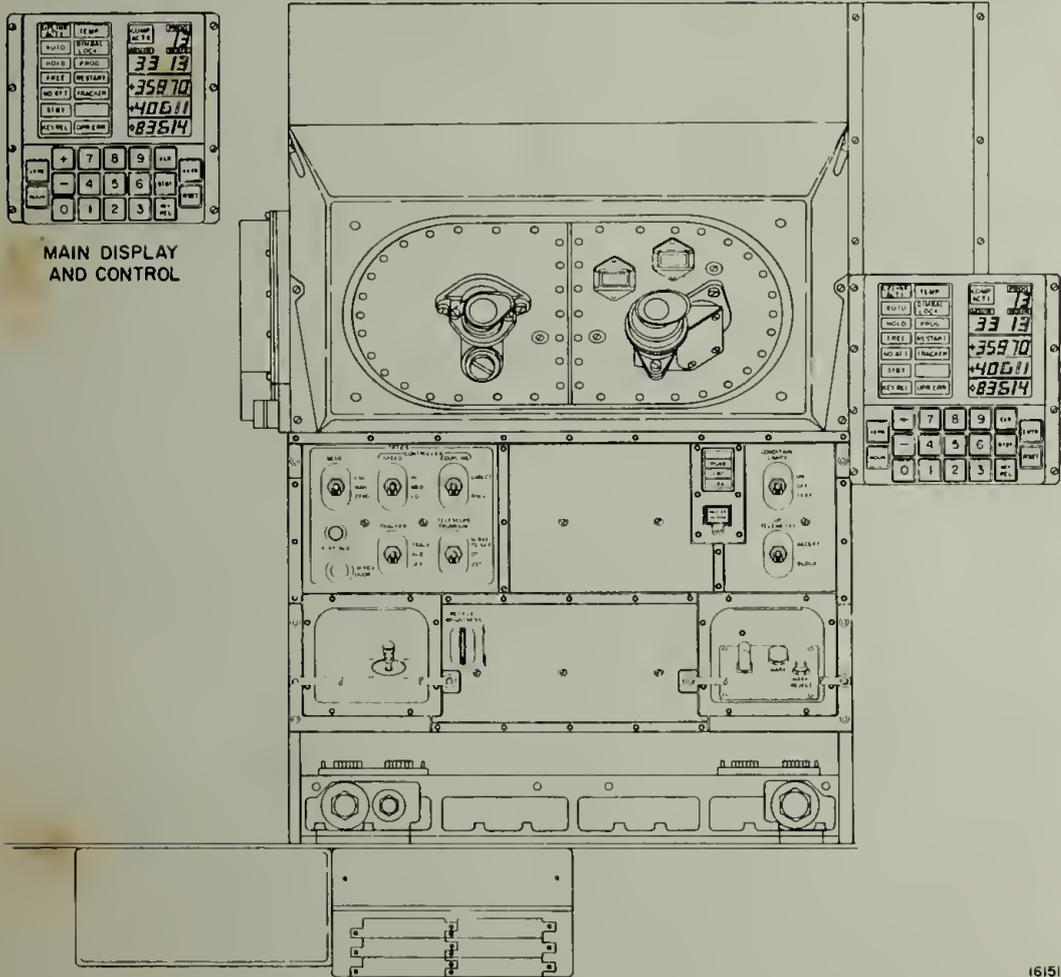
This manual and its JDC's cover PGNCS, part numbers 2015000-011 and 2015000-021 and shall be used in the laboratories at North American Aviation (NAA), Manned Spacecraft Center (MSC), and Kennedy Space Center (KSC). Source data available 4 February 1966 was used in preparation of the basic issue of this manual.

This manual is prepared in accordance with E-1087 Documentation Handbook and National Aeronautics and Space Administration (NASA) contract NAS 9-497, exhibit D.

Appendix A is a listing of technical terms and abbreviations used in the manual. Appendix B explains the function and relationship of the System Identification Data List (SIDL) to the manual.

Changes to the Block II PGNCS manual are requested by sending a completed Technical Data Change Request (TDCR) form to:

Apollo Field Service Publications, Department 38-01
AC Electronics Division GMC
PLT M1
Milwaukee, Wisconsin 53201



MAIN DISPLAY
AND CONTROL

NAVIGATION STATION
(LOWER DISPLAY AND CONTROL)

161518

Figure 1-1. Primary Guidance, Navigation and Control System

Chapter 1

SYSTEM TIE-IN

1-1 SCOPE

This chapter presents the concepts of the Apollo mission. The chapter also describes the functional interface between the Block II primary guidance, navigation, and control system (PGNCS) and the other spacecraft systems.

1-2 APOLLO MISSION AND PROGRAM

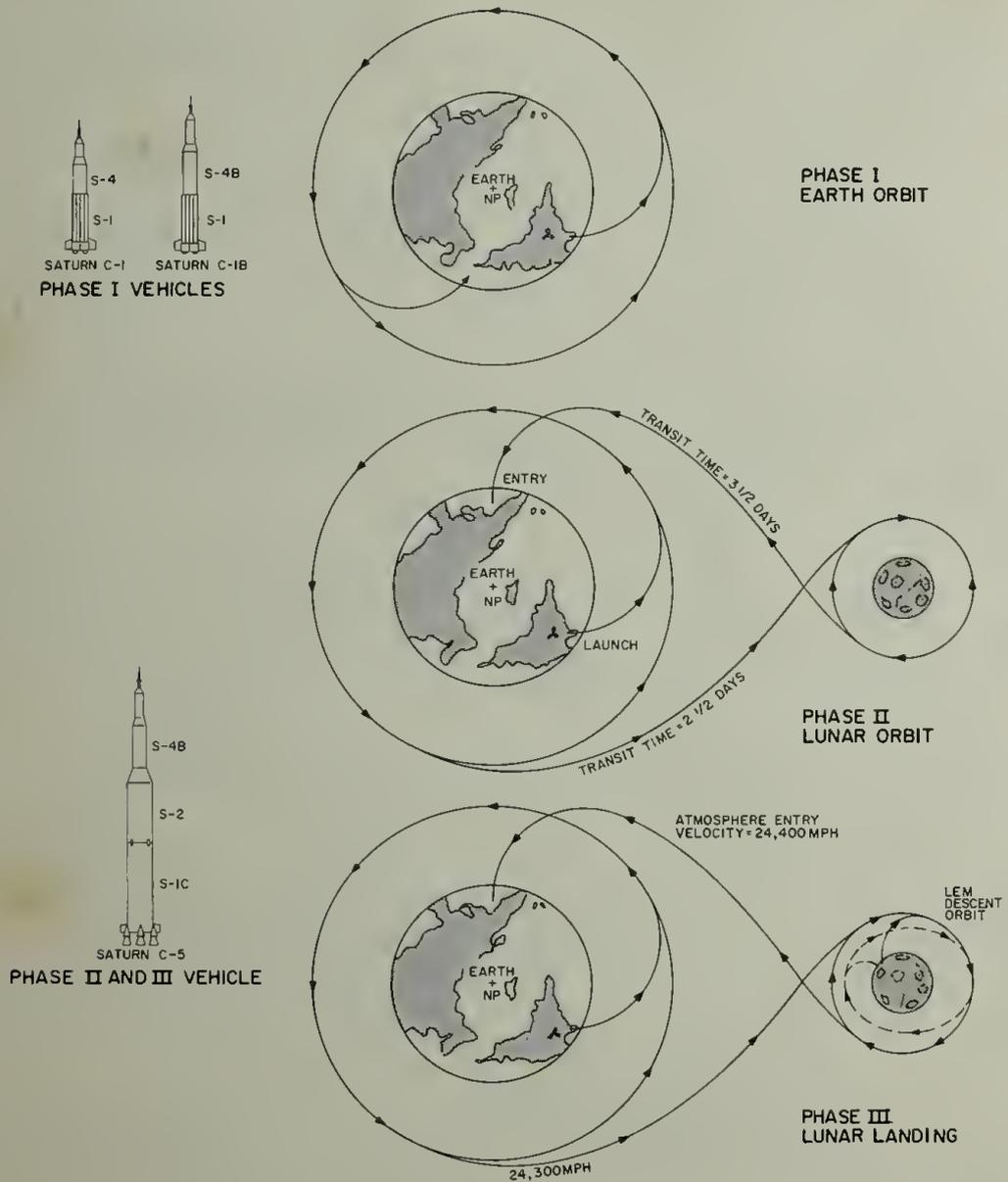
The purpose of the Apollo program is to land two astronauts on the moon. Before a lunar landing is attempted, the spacecraft hardware must be proven, the astronauts must be trained, and a capability for extended space flight must be demonstrated. To attain these objectives the Apollo program has been divided into the following phases (figure 1-2):

- Phase I Earth Orbit.
- Phase II Lunar Orbit.
- Phase III Lunar Landing.

1-2.1 EARTH ORBIT. Phase I consists of unmanned and manned earth orbital flights. The unmanned flights are designed for performance and interface testing of spacecraft systems under flight conditions. Manned earth orbital flights are designed for the astronauts to develop navigation, rendezvous, and entry techniques using the Apollo hardware.

Rendezvous practice in earth orbit will develop lunar excursion module (LEM) (a two man vehicle for lunar landing) separation and docking techniques which will be used in the lunar landing phase.

Entry practice in earth orbit requires acceleration of the spacecraft into a parabolic entry trajectory to simulate the flight path and speed of the spacecraft returning from the lunar orbit or lunar landing phases. Earth landing for all Apollo flights will be by parachute descent of the command module (figure 1-3).



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Figure 1-2. Three Phases of Apollo

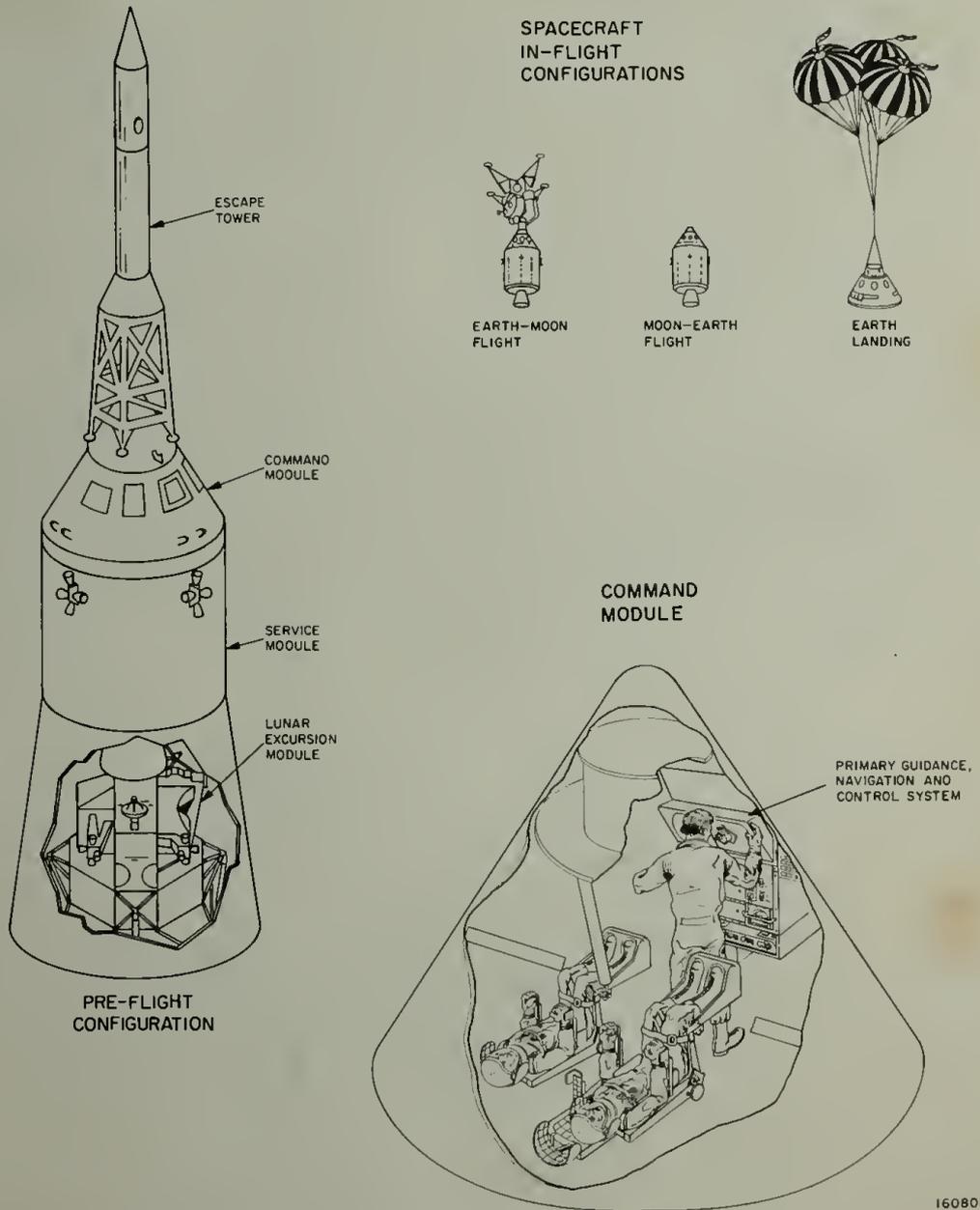


Figure 1-3. Apollo Spacecraft

Phase I will use two launch vehicles. The two stage Saturn C-1 will place the spacecraft and a three man crew into earth orbit. The larger two stage Saturn C-1B will orbit the spacecraft and LEM simultaneously. Physical characteristics of the Apollo vehicles are given in table 1-I.

1-2.2 LUNAR ORBIT. Phase II is a manned flight around the moon and return to earth. The flight requires about six and one half days and employs techniques of navigation and entry practiced during the earth orbit phase. The astronauts will make scientific observations during the lunar voyage, and will view the lunar landscape from a relatively close position. These observations, combined with astronomical and lunar probe findings, will determine a suitable landing site for the lunar landing phase.

The launch vehicle for the lunar orbit phase will be a Saturn C-5.

1-2.3 LUNAR LANDING. Phase III consists of landing two astronauts and scientific equipment on the moon, performing scientific experiments on the moon, and returning lunar samples and the three astronauts to earth.

The flight requires about eight days. Landing on the moon will be accomplished by separating the LEM from the spacecraft and deorbiting the LEM to a predetermined lunar landing site. Two astronauts will descend in the LEM and one astronaut will remain in the spacecraft orbiting the moon. Rendezvous techniques perfected in the earth orbit phase will be applied when the LEM returns to lunar orbit and the two astronauts transfer to the command module. The spacecraft then will be injected into a transearth trajectory.

The Saturn C-5 will be the launch vehicle for the lunar landing phase.

1-3 APOLLO SPACECRAFT

The spacecraft (figure 1-3) consists of a command module and a service module. The LEM is attached to the top of the S-4B stage behind the service module, and an escape tower is mounted atop the command module. Solid fuel motors in the escape tower inject the command module into an escape trajectory if an abort occurs on the pad or any time during the first 3 minutes of flight. The escape tower is jettisoned shortly after a satisfactory launching and only the spacecraft, LEM, and S-4B stage are inserted into earth orbit. After the spacecraft is injected from earth orbit into a lunar trajectory, the LEM and the S-4B are separated from the command and service module. The command module and LEM dock and the S-4B is separated from the LEM. The LEM is carried to lunar orbit where it is detached for lunar landing.

1-3.1 COMMAND MODULE. The command module contains crew accommodations, all controls and displays which the astronauts use to control the spacecraft, and systems for spaceflight and earth entry.

Table 1-I. Spacecraft and Launch Vehicle Physical Characteristics

Vehicle	Stage	Nominal Thrust (pounds)	Propellants and Oxidizers	Height (feet)	Diameter (feet)
Spacecraft	Command module	N/A	Aerozine 50 Nitrogen tetroxide	12	13
	Service module	21,900	Aerozine 50 Nitrogen tetroxide	23	12.8
	LEM	10,000 on landing 4,000 on takeoff	Aerozine 50 Nitrogen tetroxide	17	10
Saturn C-1	First (S-1)	1,500,000	Kerosene Liquid oxygen	81.6	21.6
	Second (S-4)	90,000	Liquid hydrogen Liquid oxygen	40	18
Saturn C-1B	First (S-1)	1,500,000	Kerosene Liquid oxygen	81.8	21.6
	Second (S-4B)	200,000	Liquid hydrogen Liquid oxygen	60	22
Saturn C-5	First (S-1C)	7,500,000	Kerosene Liquid oxygen	138	33
	Second (S-2)	1,000,000	Liquid hydrogen Liquid oxygen	82	33
	Third (S-4B)	200,000	Liquid hydrogen Liquid oxygen	60	22

The command module has a heat shield for entry into the earth's atmosphere, parachutes for final descent, and a reaction control system for attitude control after separation from the service module. The command module has several windows for general observation, rendezvous, horizon reference and earth landing reference.

The PGNCS is located in the command module lower equipment bay area, frequently referred to as the navigation station. Additional displays and controls associated with the operation of the PGNCS are located on the main display and control (D and C) panel above the astronaut couches.

1-3.2 SERVICE MODULE. The service module houses a propulsion system, reaction control system, radar, fuel cells, and other gear and supplies that do not need to be pressurized. Until separation occurs just prior to entry, the service module provides the spacecraft with thrust, attitude control, and electrical power.

1-4 SPACECRAFT SYSTEMS

Functionally, there are seven spacecraft systems associated with the command and service module. Four of these systems are used for control of the spacecraft. The PGNCS or the stabilization and control system (SCS) receive manual inputs from the crew and electrical inputs from inertial sensors to generate commands that result in rotation and translation maneuvers. The reaction control system (RCS) or service propulsion system (SPS) provide all the external forces and mechanical couples to maneuver the spacecraft under the control of the PGNCS or the SCS. The crew obtains information from the on board computer (part of the PGNCS), Manned Space Flight Network (MSFN), or displays that indicate the necessity to initiate one or more of the basic spacecraft motions. The remaining three spacecraft systems are indirectly related to spacecraft control in that they provide power through the electrical power system (EPS), environment through the environmental control system (ECS), and communications through the communications and instrumentation system (CIS).

The PGNCS can also be considered a functional system of the S-4B stage since the astronaut can select the PGNCS as the guidance source for S-4B thrusting. The PGNCS uses manual inputs from the crew, electrical inputs from inertial sensors, and S-4B interface signals to generate steering and thrust commands to the S-4B instrumentation unit (IU).

1-4.1 PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM. The PGNCS performs three basic functions: inertial guidance, optical navigation, and spacecraft control. The PGNCS makes astronaut manual inputs, reaction control system operation, service propulsion system operation and spacecraft operation compatible.

The inertial measuring unit (IMU) is the primary element used for inertial guidance. It consists of three gyros and three accelerometers mounted on the innermost member of a three degree-of-freedom gimbal structure. Angular orientation of this inner platform is obtained from resolvers mounted on the gimbals. The IMU senses velocity and attitude changes and provides these changes to a computer.

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

For optical navigation, a scanning telescope and sextant are used to take sightings on celestial bodies and landmarks. The sightings are used to determine spacecraft position and velocity, and to establish proper alignment of the stable member. Communications with ground tracking stations also provide information for spacecraft navigation.

A digital computer, command module computer (CMC) in the PGNCS is the primary spacecraft data processing element. The CMC, which contains a catalog of celestial objects, is programmed to calculate thrust and steering commands using information obtained from optical sightings and from the IMU. The computer issues on/off thrust discretes to the SPS, RCS, and S-4B IU. Data on gravitational fields and celestial movements are used in the CMC to calculate future position and velocity of the spacecraft.

The PGNCS provides the following spacecraft capabilities:

(1) Rate stabilization of command module during high altitude abort, after separation from the booster, stabilization of the command module after escape tower jettison, and during entry.

(2) Attitude and stabilization control about three axes in response to either manual or automatic rotation commands.

(3) Translational control along three axes in response to manual commands for ullage maneuvers, transposition, and docking.

(4) Translational control along three axes in response to manual commands as a backup mode to the LEM-controlled rendezvous and docking operation.

(5) Translational control along three axes in response to manual commands for small changes in velocity.

(6) Thrust vector control for the SPS.

(7) SPS engine thrust on/off functions.

(8) Guidance control of S-4B engine.

(9) Displays for visual indication of control parameters.

1-4.2 STABILIZATION AND CONTROL SYSTEM. The SCS, as a backup system to the PGNCS, can sense and control spacecraft attitude and velocity changes during flight.

The SCS is located in the command module and consists of a reaction jet and propulsion solenoids driver assembly, electronics control assembly, electronics display assembly, gyro display coupler, thrust vector position servo amplifier, two gyro assemblies, and various displays and controls. The SCS can hold the spacecraft to a

local vertical attitude during earth or lunar orbit by using orbital rates, or to a specific attitude by using reference gyros mounted in the spacecraft. Information about spacecraft attitude and rate of attitude change is displayed to the astronaut. Steering and thrust signals can be sent to operate the reaction control and service propulsion systems.

1-4.3 SERVICE PROPULSION SYSTEM. The SPS provides thrust to control spacecraft velocity. It is normally controlled and operated by the PGNCs sending SPS signals through the SCS, but can be operated manually through the SCS in emergencies.

The SPS is utilized for mission abort, midcourse velocity corrections, and orbital injections. The SPS is located in the rear of the service module and consists of helium, fuel, and oxidizer tanks; gimbaled thrust chamber; propellant control valves; and propellant distribution system.

1-4.4 REACTION CONTROL SYSTEMS. Two reaction control systems are used for attitude control and stabilization of the spacecraft. One RCS is required for the service module and the other for the command module. Both systems can be operated by the PGNCs or the SCS. Each RCS consists of helium, fuel and oxidizer tanks; propellant control valves; fixed thrust chambers; and distribution subsystem.

Spacecraft attitude, rate of rotation, and small translational velocity changes are normally controlled by an automatic RCS loop, but also may be controlled by a direct RCS loop. Each RCS fuel valve and oxidizer valve contains one solenoid winding controlled by the direct RCS loop.

The automatic RCS loop is activated by signals from the PGNCs, SCS, or by signals from hand controls. The RCS jets fire to rotate the spacecraft and, when the rotational command is removed, jets are automatically fired in the opposite direction to stop the spacecraft rotation.

The direct RCS loop bypasses the automatic circuits to provide direct astronaut control of the RCS jets. After the hand control is released, the spacecraft continues to rotate until the astronaut commands an opposite rotation.

1-4.4.1 Service Module Reaction Control System. The service module RCS provides thrust to control spacecraft attitude during all phases of flight except launch and entry. The service module RCS consists of four hypergolic-propellant-pressurized reaction jet subsystems. The subsystems are mounted in the forward section of the service module and are located 90 degrees apart. Eight of the 16 nozzles are used for roll control, four for pitch, and four for yaw. Each nozzle produces a nominal thrust of 100 pounds in space.

1-4.4.2 Command Module Reaction Control System. The command module RCS is used only during entry after separation of the command and service modules. The RCS of the command module consists of two independent subsystems, which are operated simultaneously and provide three axis control of the command module. If one subsystem fails, the remaining reaction jet subsystem provides the control necessary for safe entry.

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

1-4.5 ELECTRICAL POWER SYSTEM. The primary power required to operate the PGNCS is supplied by a hydrox fuel cell in the service module and is used during all mission phases except entry and recovery. Three zinc-silver oxide storage batteries in the command module furnish power for entry and recovery.

The hydrox fuel cell contains three independent modules operating in parallel and capable of producing a 27 to 31 vdc output. In any emergency, any two fuel cell modules could meet all power requirements. Three solid state inverters change the fuel cell output into 115 volt, 400 cps power. The fuel cell dc output and the inverter ac output are both used to provide power for normal PGNCS operation. The 115 volt, 400 cps power is also used to produce 5 volt, 400 cps power for PGNCS operation.

Each fuel cell module contains 31 fuel cell units. The fuel cells utilize hydrogen and oxygen as reactants and potassium hydroxide as an electrolyte. The reactants are stored in tanks furnished as a part of the ECS. The water formed by operating the fuel cells is collected and delivered to the ECS, for potable water.

Two of the storage batteries in the command module can be used to supply supplementary power during peak loads on the fuel cell. The third battery is isolated from the EPS and is used only for post-landing loads. A solid state battery charger is provided to recharge any of the three batteries after normal or emergency discharge.

1-4.6 ENVIRONMENTAL CONTROL SYSTEM. An ECS is used to sustain life in space by providing breathable atmosphere, acceptable temperatures, radiation protection, humidity and pressure control, water, food, and waste disposal. In addition, a water-glycol coolant fluid is circulated about temperature sensitive components of the PGNCS system to aid in maintaining constant operating temperatures. The fluid temperature at the input to the IMU is 45 degrees Fahrenheit and is circulated at a rate of 33 pounds per hour. The ECS includes oxygen tanks and space radiators in the service module, and a distribution system, connections for spacesuit oxygen lines, sensors, regulators, cabin blowers, and heat exchangers in the command module.

1-4.7 COMMUNICATIONS AND INSTRUMENTATION SYSTEM. The Apollo CIS provides voice, television, and telemetry communication with the earth; voice communication among crew members; tracking radar; and communication between the command module and the LEM. A closed loop television system permits viewing external sections of the spacecraft during flight.

Data is transmitted to earth or received from earth by Apollo telemetry. Telemetry data can be stored when direct communication with the earth is not possible because of the location of earth stations or because the spacecraft is behind the moon. Earth stations can determine spacecraft position and transmit this information through telemetry to the PGNCS computer to supplement information obtained from the PGNCS. Critical signals of the PGNCS and other spacecraft systems are conditioned and supplied to pulse code modulated (PCM) equipment for transmission to ground stations.

After earth landing, a recovery beacon in the command module transmits a VHF signal to direct aircraft and ships to the landing area.

1-5 PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM INTERFACE

PGNCS operation during the Apollo mission requires the interface of the PGNCS with other spacecraft systems and with the displays and controls on the main D and C panel.

1-5.1 SYSTEMS. Four spacecraft systems (SCS, SPS, RCS, and EPS) have direct interface with the PGNCS and two systems (ECS and CIS) have indirect interface with the PGNCS. The functional interface between the PGNCS and the other systems is shown in figure 1-4.

The direct interfaces of the PGNCS with the SCS include attitude signals, attitude error signal display, and control signals. The function of each signal depends on the mode of operation of the guidance and control systems. During primary guidance and control, the PGNCS provides attitude and attitude errors to the flight director attitude indicator (FDAI) for display. During backup guidance and control, the SCS body mounted attitude gyro's (BMAG's) can be used to provide attitude data to the CMC by means of the gyro display coupler (GDC). See table 1-11 for SCS and PGNCS interface signals.

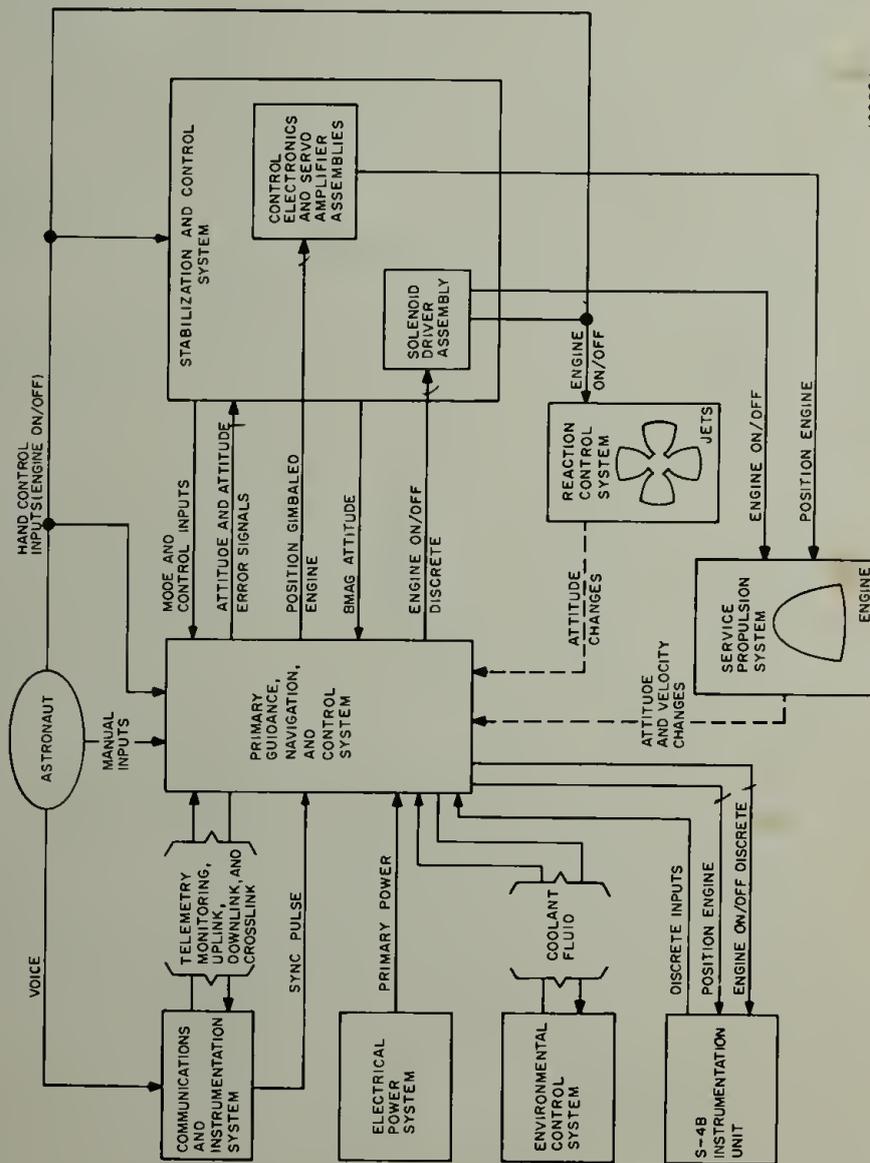
The CMC of the PGNCS generates SPS engine on/off commands and positions the SPS gimbaled engine in pitch and yaw through the generation of steering signals.

The CMC also has direct interface with the RCS of both the command and service modules. The output signals from the CMC, which can be generated by a digital autopilot program, or the output of the CMC resulting from the operation of one of three hand controls is used to turn the RCS jets on and off. The same computer outputs used for command module RCS control are used for service module RCS control. Switchover from the service module to command module operation is external to the PGNCS.

The EPS provides 28 vdc, 5 vac 400 cps, and 115 vac 400 cps power to the PGNCS.

The ECS circulates an ethylene glycol-water coolant about the temperature sensitive electronic equipment in the PGNCS.

The CIS telemetry can transmit spacecraft positional data to the PGNCS computer to supplement the information obtained from the optics and inertial subsystems. Critical signals of the PGNCS are conditioned and supplied to the PCM equipment for transmission to ground stations. The PGNCS can also update the LEM computer through the CIS. See table 1-111 for CIS and PGNCS interface signals.



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Figure 1-4. PGNC Functional Interface, Block Diagram

Table 1-II. SCS Interface Signals

Signal Name	Source	Description
Manual translation commands ($\pm x$, $\pm y$, $\pm z$)	SCS	Signals from translation control which fire jets by CMC control.
Manual rotation commands (roll, pitch, yaw)	SCS	Signals from rotation control which fire RCS jets by CMC control.
BMAG attitude (roll, pitch, yaw)	SCS	BMAG attitude information to the CMC.
RCS jet selection	CMC	RCS jet on/off commands (16 signals).
SPS engine on/off command	CMC	Initiates and terminates SPS thrusting.
Total attitude (roll, pitch, yaw)	ISS	IMU 1X gimbal angle information (IG, MG, OG).
Attitude error (roll, pitch, yaw)	ISS	CDU error signals (roll, pitch, and yaw).
Thrust vector control error (pitch, yaw)	OSS	SPS steering signals from the CMC through the OSS CDU channel.

The PGNCS also has an interface with the S-4B guidance IU. The S-4B guidance provides moding signals to the CMC and the CMC issues thrust maneuver signals to the S-4B stage. See table 1-IV for S-4B and PGNCS interface signals.

Table 1-III. CIS Interface Signals

Signal Name	Source	Description
Downlink data	CMC	Computer words to be transmitted to MSFN.
Crosslink data	CMC	Computer words to be transmitted to LEM PGNCS.
Downlink end pulse	CIS	Synchronizes downlink word transfer from CMC to CIS.
Downlink start	CIS	Indicates to CMC that CIS is ready for downlink data.
Downlink bit sync	CIS	Synchronizes bit transfer from CMC to CIS.
Uplink 1	CIS	Transmitted to uplink counter in CMC. Adds one to uplink counter and shifts counter one increment.
Uplink 0	CIS	Transmitted to uplink counter in CMC. Shifts counter one increment.

Table 1-IV. S-4B Interface Signals

Signal Name	Source	Description
S-4B injection sequence start	CMC	Initiates S-4B thrust maneuver during PGNCS control of Saturn.
S-4B cutoff	CMC	Terminates S-4B thrust maneuver during PGNCS control of Saturn.
Attitude error (roll, pitch, yaw)	ISS	PGNCS steering error during PGNCS control of S-4B thrust maneuver.
Liftoff	IU	Indicates to CMC that liftoff has occurred.
Guidance reference release	IU	Indicates to CMC that IU stable platform is inertial.
S-4B separation/abort	IU	Indicates to CMC that S-4B separation/abort has been initiated.
Ullage thrust present	IU	Indicates to CMC that an ullage maneuver will occur.

1-5.2 CONTROLS AND DISPLAYS. Controls and displays on the main D and C panel, figure 1-5, either have a direct interface with the PGNCS, modify the operation of the PGNCS, or modify the display of data generated by the PGNCS. The rotation control and the translation control have an indirect interface with the PGNCS. Descriptions of the controls and displays are provided in table 1-V.

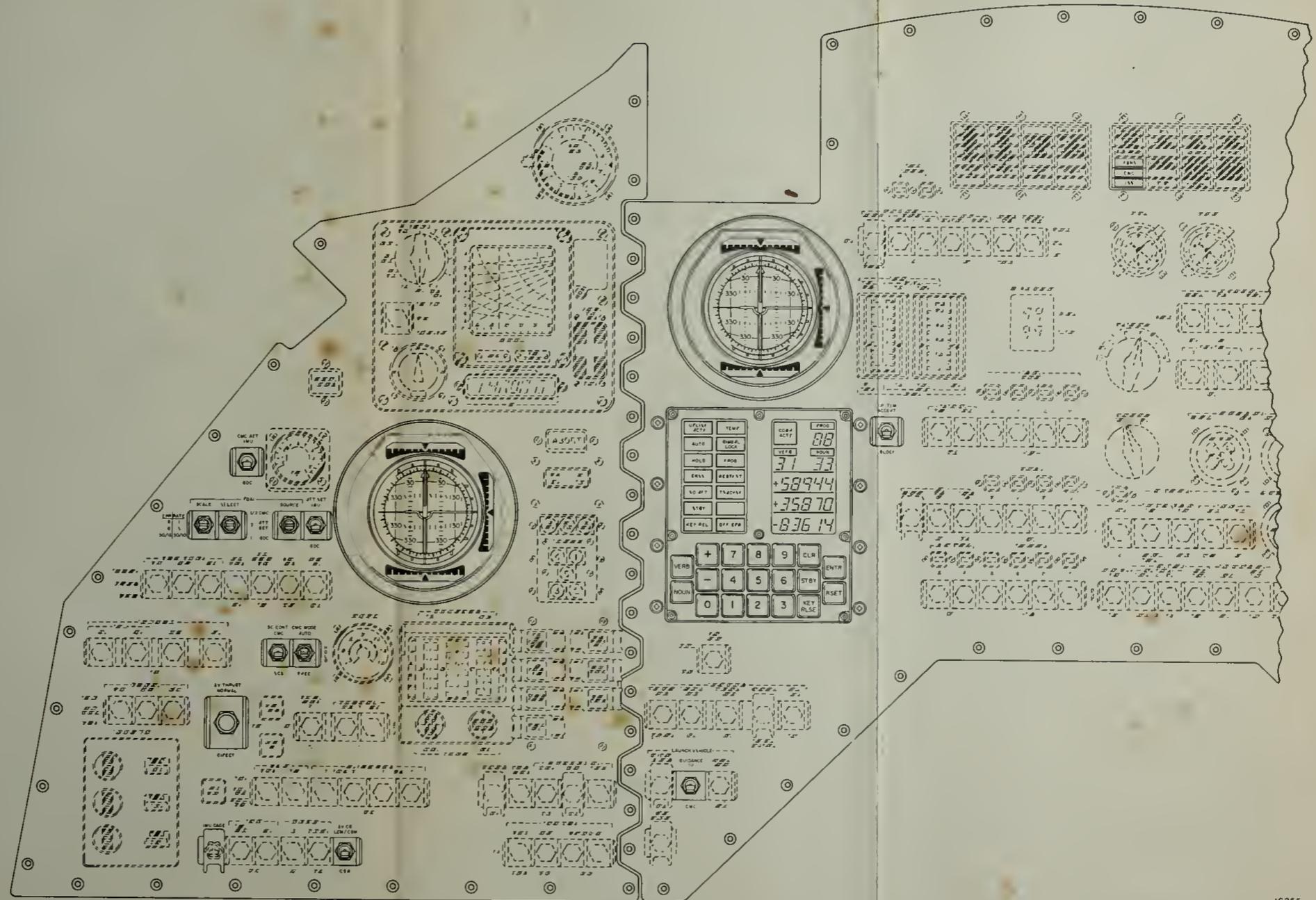


Figure 1-5. Main D and C Panel

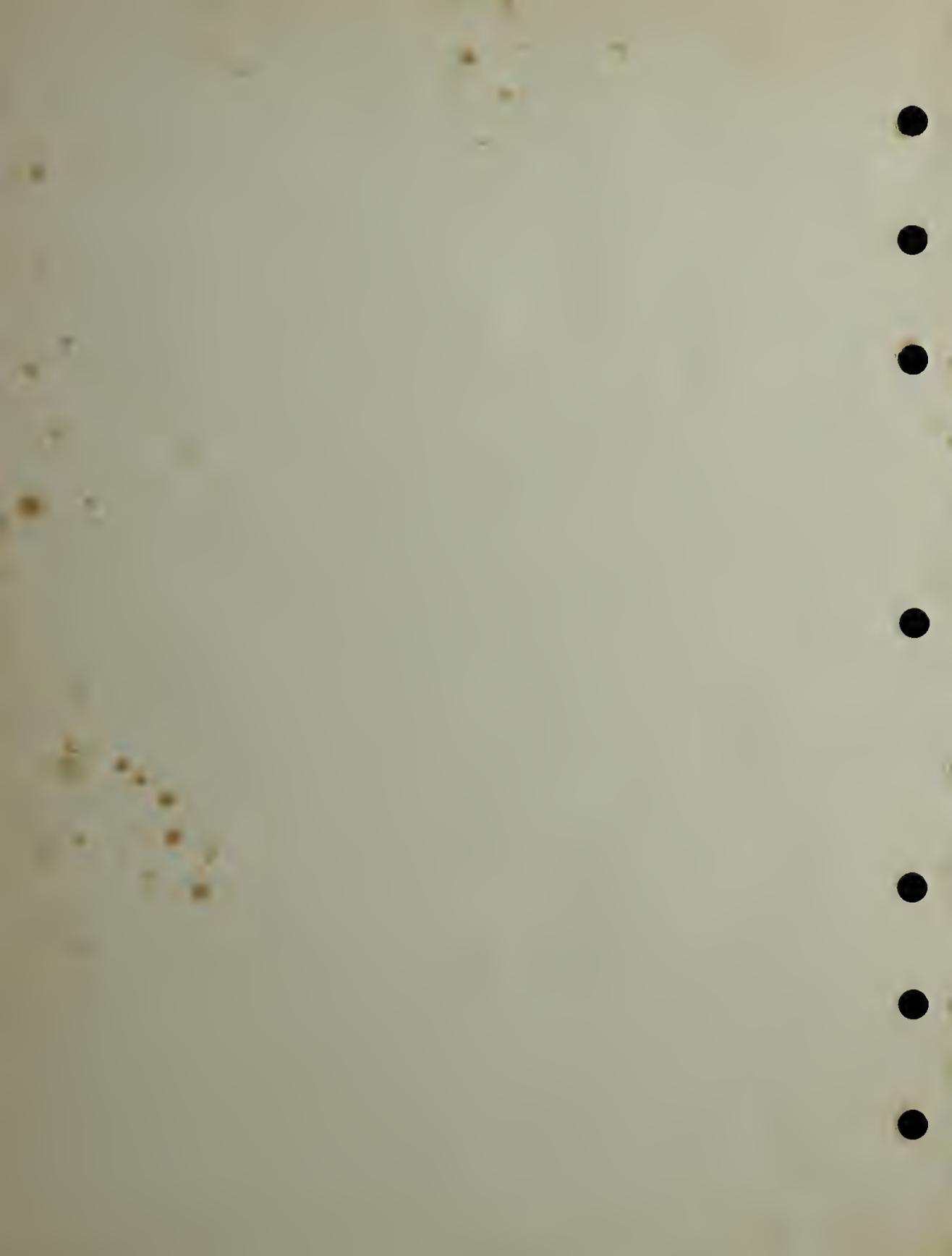


Table 1-V. Displays and Controls

Displays or Controls	Function
IMU CAGE	Causes IMU to be coarse aligned to its zero position, independent of CMC operation.
UPTLM	Allows or blocks telemetry data from ground stations to be entered into CMC.
LAUNCH VEHICLE GUIDANCE	Selects either launch vehicle (IU) or CMC control of S-4B guidance. During command module control, CMC executes a STAB control program.
ΔV CG	Position of switch indicates whether LEM is attached to command module or not. This permits CMC to take into account change in center of gravity for spacecraft maneuvers.
SC CONT	Three position switch which is used to select controlling source for spacecraft attitude control. Switch allows either CMC or SCS to control spacecraft attitude and thrust vector. In a third position, CMC computed attitude errors are routed through the SCS to generate attitude steering signals.
CMC MODE	<p>Three position switch which is used to select manner in which spacecraft attitude is controlled by CMC.</p> <p>AUTO position - computer program can automatically control spacecraft and rotation control can be utilized to change spacecraft attitude.</p> <p>HOLD position - computer set in an attitude hold configuration, it cannot perform automatic functions except to maintain attitude. Spacecraft attitude can be controlled by rotation control inputs to digital autopilot program. When rotation control is released, CMC will maintain selected attitude.</p>

(Sheet 1 of 5)

Table 1-V. Displays and Controls

Displays or Controls	Function
CMC MODE (cont)	<p>FREE position - computer cannot generate commands to maintain spacecraft attitude or to control spacecraft angular drift rate. Computer can issue RCS on/off commands in response to rotation control or minimum impulse control commands. Upon release of controls, spacecraft is free to drift to any attitude.</p>
ΔV THRUST	<p>Three position switch to remove, enable or directly apply power to SPS propellant valves.</p> <p>NORMAL position - indicates that procedures in engine start checklist have been completed and SPS is ready for firing. This switch position enables normal SPS ignition through CMC or THRUST ON switch. CMC will control RCS ullage firing cycle prior to SPS ignition. When this switch position is selected, a SPS ready discrete is received by CMC.</p> <p>OFF position - removes all ability to energize propellant valves.</p> <p>DIRECT ON position - applies power directly to solenoids bypassing CMC.</p>
CMC ATT	<p>CMC attitude is a two position switch used to select attitude reference for spacecraft.</p> <p>IMU position - spacecraft attitude is referenced to PGNCs stable member.</p> <p>GDC position - GDC provides single axis attitude data to CMC. CMC is not capable of firing SPS engines or RCS jets in GDC position if CMC ATT switch has been selected.</p>
FDAI SOURCE	<p>Selects source of signals displayed on FDAI.</p> <p>CMC position - IMU gimbal angles and PGNCs attitude error signals are selected for display.</p>

(Sheet 2 of 5)

Table 1-V. Displays and Controls

Displays or Controls	Function
FDAI SOURCE (cont)	<p>ATT SET position - difference between attitude set dials and total attitude reference selected by ATT SET (IMU or GDC) is displayed.</p> <p>GDC position - IMU angles are displayed on FDAI ball and BMAG error signals are displayed as attitude errors on error needles.</p>
ATT SET	<p>Used to select source of total attitude input signal to attitude set resolvers.</p> <p>IMU position - IMU gimbal angles 1X resolver signals are used as reference. FDAI error needles display difference between IMU gimbal angles and attitude set angles. Error signals can be zeroed by moving the spacecraft around IMU or changing settings of attitude set dials.</p> <p>GDC position - GDC resolvers provide attitude reference.</p>
FDAI SELECT	<p>Used to select either or both of FDAI's for display of data.</p> <p>1/2 position - permits both FDAI's to receive and display attitude and attitude errors. FDAI 1 would be driven by PGNCS inputs and FDAI 2 would be driven by SCS inputs.</p> <p>1 position - permits signal selected by SOURCE switch to be displayed on FDAI 1, other FDAI is inoperative.</p> <p>2 position - permits signal selected by SOURCE switch to be displayed on FDAI 2, other FDAI is inoperative.</p>
FDAI SCALE	<p>Used to select scales used on FDAI for display of attitude error and attitude rate. Attitude error signals provided by PGNCS are scaled in following manner. Pitch and yaw attitude errors represent plus and minus</p>

(Sheet 3 of 5)

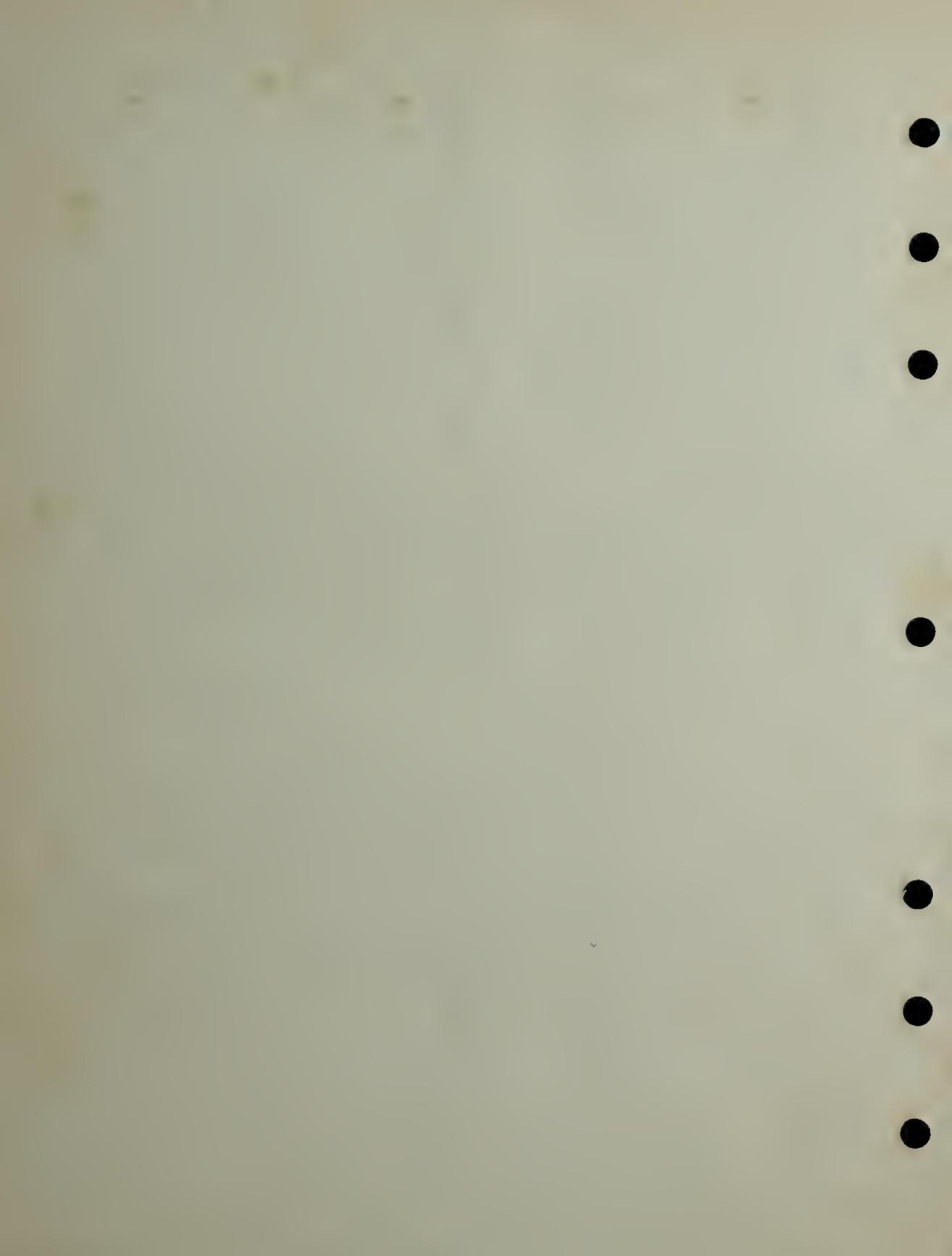
Table 1-V. Displays and Controls

Displays or Controls	Function
FDAI SCALE (cont)	<p>15 degrees full scale during guidance monitor and entry and plus and minus 5 degrees during all other modes. Roll attitude error needle represents plus and minus 50 degree full scale deflection in entry and guidance monitor and plus and minus 5 degrees under all other positions.</p> <p>1st and 2nd position - maintain plus and minus full scale deflection for pitch, yaw and roll attitude error.</p> <p>3rd position - selects plus and minus 50 degree full scale deflection for roll and plus and minus 15 degree full scale deflection for pitch and yaw attitude errors.</p>
FDAI	<p>Attitude Indications. FDAI displays total spacecraft attitude with respect to reference source (CMC, ATT SET, GDC) as selected by SOURCE switch. Spacecraft attitude is displayed on gimballed attitude ball. Inputs to FDAI from PGNCS are 800 cps signals representing sine and cosine of gimbal angles. These signals are taken from 1X gimbal resolvers.</p> <p>Attitude Error Displays. Spacecraft attitude errors are displayed by three attitude error needles on FDAI. If SOURCE switch is in CMC position, the attitude error signal is fed to FDAI from CDU. Attitude error signal is proportional to difference between a desired angle and an actual angle.</p> <p>If SOURCE switch is placed in ATT SET position and ATT SET switch is in IMU position, the difference between attitude set dials and IMU gimbal angles will be displayed on attitude error needles. These signals are generated by using 800 cps signals representing sine and cosine of gimbal angles as a reference for attitude set resolvers. When resolver dials read out gimbal angles, attitude error needles indicate zero. If attitude set dials are set at some angles other than</p>

(Sheet 4 of 5)

Table 1-V. Displays and Controls

Displays or Controls	Function
FDAI (cont)	gimbal angles, attitude error needles of FDAI will display difference between attitude set angles and gimbal angles. Error signal can be driven to zero by movement of spacecraft or by resetting attitude set dials. Attitude Rate Displays. PGNCS does not generate attitude rate signals for display on FDAI.
Rotation Controls (2)	Three degree-of-freedom device for manual attitude control of spacecraft. When positioned at more than 1.5 degrees from normal position, supplies switching inputs to CMC input channels. Six lines, one each for plus and minus pitch, roll and yaw make up interface between rotation controls and CMC. Rotation controls are designed so that attitude control signals can be inserted in either direction into any one axis, and any two axes, or all three axes simultaneously. Rotation controls can also be used directly with SCS and RCS.
Translation Control	'T' handle configuration which is capable of being moved up-down, right-left, and in-out simultaneously. Translation control has one line for each direction of motion for each of X, Y, and Z spacecraft axes. Motion of the translation control in two or three directions simultaneously will cause composite spacecraft maneuvers. The translation control, when rotated in a counterclockwise direction will initiate a mission early termination during high altitude and translunar injection phases of the mission. An abort during launch will occur if launch escape tower is attached. A clockwise rotation of the translation control will disable the PGNCS (digital autopilot control of spacecraft).



Chapter 2

SYSTEM AND SUBSYSTEM FUNCTIONAL ANALYSIS

2-1 SCOPE

This chapter provides functional descriptions of the PGNCS, the three subsystems and the signal conditioner. The chapter describes how the three subsystems and the displays and controls work together to perform the PGNCS operations.

2-2 PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

The PGNCS is functionally divided into inertial, optical, and computer subsystems. These subsystems, with control by the astronaut, can perform the following functions for providing inertial guidance, optical navigation, and spacecraft control:

- (1) Periodically establish an inertial reference for measurements and computations.
- (2) Align the inertial reference by precise optical measurements.
- (3) Calculate the position and velocity of the spacecraft by optical or inertial techniques.
- (4) Generate attitude control and thrust commands to maintain the spacecraft on a satisfactory trajectory.
- (5) Display pertinent data about the status of guidance equipment.

For inertial guidance, the PGNCS employs an IMU containing accelerometers mounted on a stabilized, gimbal-mounted platform. The inertial guidance system senses acceleration and attitude changes instantaneously and provides the resulting data to a computer which generates attitude control and thrust control signals to the SPS and RCS. The IMU, portions of the coupling data unit (CDU), pulsed integrating pendulum (PIP) electronics assembly (PEA) and portions of the power and servo assembly (PSA) form the inertial subsystem (ISS) of the PGNCS.

For optical navigation, the PGNCS employs an optical unit assembly (OUA) consisting of a scanning telescope (SCT) and a sextant (SXT). The OUA is used to sight celestial bodies and lunar and earth landmarks. The sightings are used by the computer to determine spacecraft position and velocity and to establish proper alignment of the stable member. The OUA, portions of the CDU, portions of the PSA, and indicator control panel form the optical subsystem (OSS) of the PGNCS.

The CMC, a digital computer, serves as the central data processing element of the PGNCS. It contains a catalog of celestial bodies and is programmed to calculate steering, thrust, and alignment commands using the information obtained from the optical sightings and the IMU. The computer uses data on gravitational fields and celestial perturbations to calculate future position and velocity of the spacecraft. The CMC and two display and keyboard's (DSKY's) form the computer subsystem (CSS) of the PGNCS.

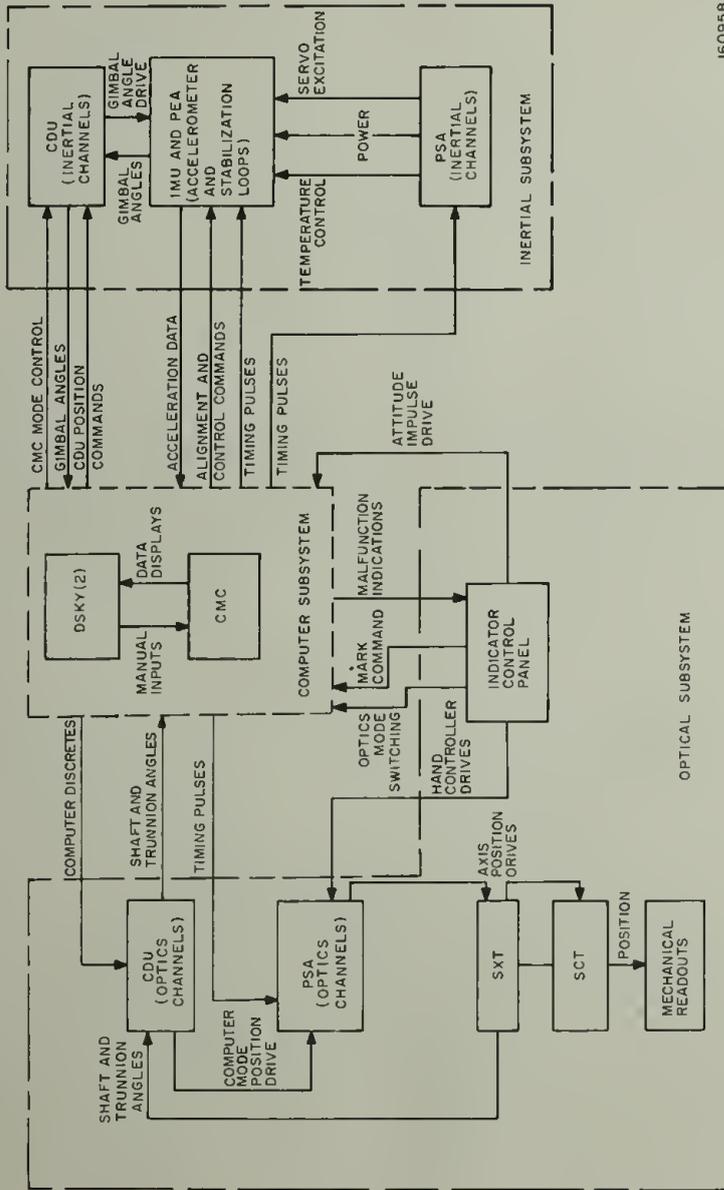
The spacecraft control portion of the PGNCS uses information from the inertial guidance portion to keep the axes that are fixed to the spacecraft structure aligned to the stabilization reference axes. The control portion also keeps the spacecraft velocity vector approximately aligned with the stabilization reference velocity vector. The control portion manages spacecraft rotational and translational orientation.

Figure 2-1 illustrates the signal flow and interface between the PGNCS subsystems.

2-3 BLOCK II PGNCS AXES

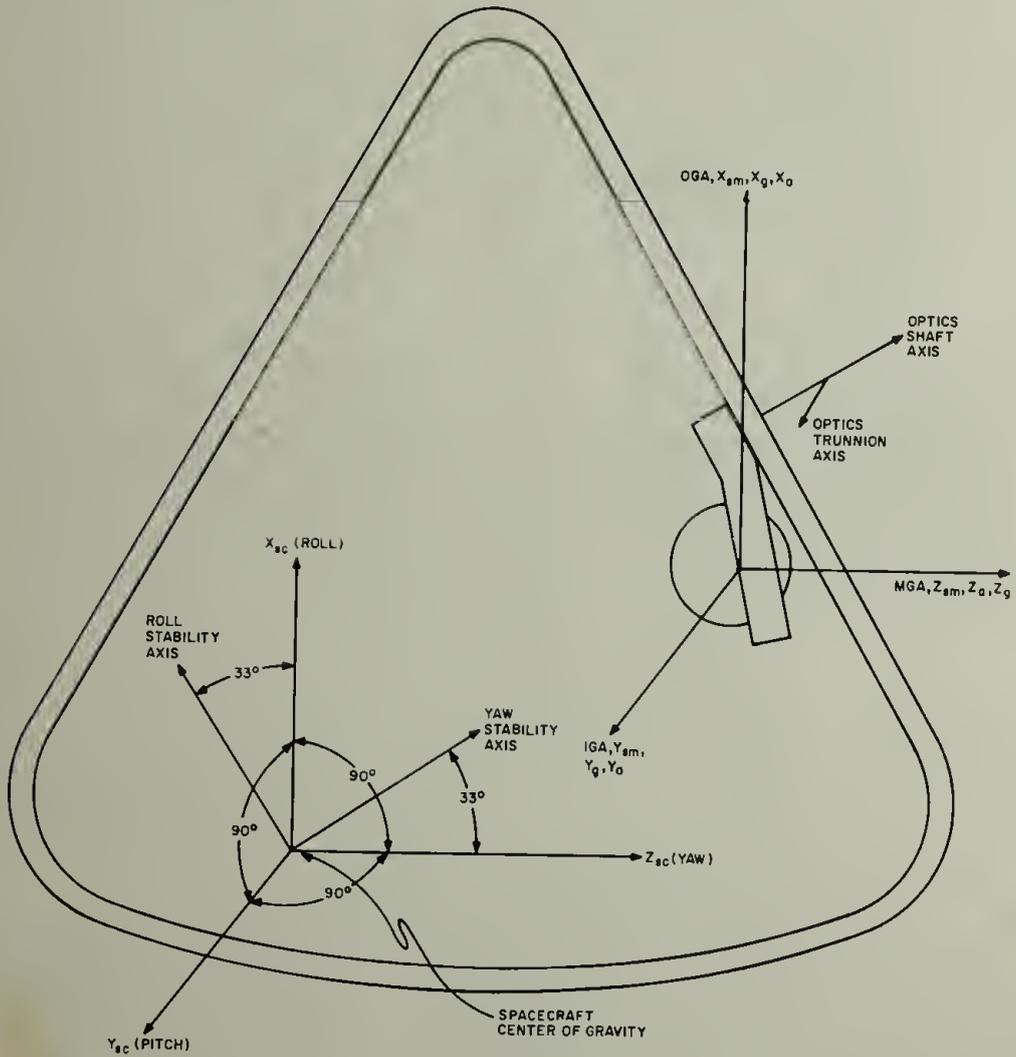
Command module and PGNCS axes are illustrated in figure 2-2. Each set of axes illustrated and discussed are orthogonal with positive rotation defined by the advancing right hand rule.

2-3.1 SPACECRAFT AXES. The spacecraft axes have two functions: they provide a reference for all other sets of Apollo axes and they define the point about which attitude and thrust maneuvers are completed. These two functions are accomplished with definition of the spacecraft symmetry axes and the spacecraft body axes. The spacecraft symmetry axes (X, Y, Z) have a fixed relationship to the spacecraft. The X symmetry axis passes through the geometric center of the command module circular base and through the apex of the command module. The Y and Z symmetry axes are perpendicular to one another and lie in the plane of the command module base. The Z axis points along the downrange centerline of the spacecraft. The spacecraft body axes (X_{SC} , Y_{SC} , Z_{SC}) are parallel to the symmetry axes and are located at the spacecraft center of gravity. Rotation about the X_{SC} , Y_{SC} , and Z_{SC} axes (attitude changes or corrections) is defined as roll, pitch, and yaw respectively.



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Figure 2-1. PGNCs, Functional Block Diagram



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Figure 2-2. Command Module and PGNCS Axes

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

The spacecraft center of gravity is a movable point. Its location depends on the amount of fuel consumed, the astronauts' locations in the command module, and the stages of the Apollo spacecraft attached to the command module. The center of gravity must be determined for accurate attitude and thrust maneuvers.

2-3.2 INERTIAL AXES. Four sets of inertial axes provide references for measuring changes in velocity and attitude. The inertial axes are parallel to the spacecraft axes at zero degrees. The PGNCs senses changes in the alignment of the inertial axes in order to determine the relationship of the inertial axes to the spacecraft axes during flight. Comparison of the alignment of the inertial axes with the spacecraft axes is used in calculating spacecraft attitude changes.

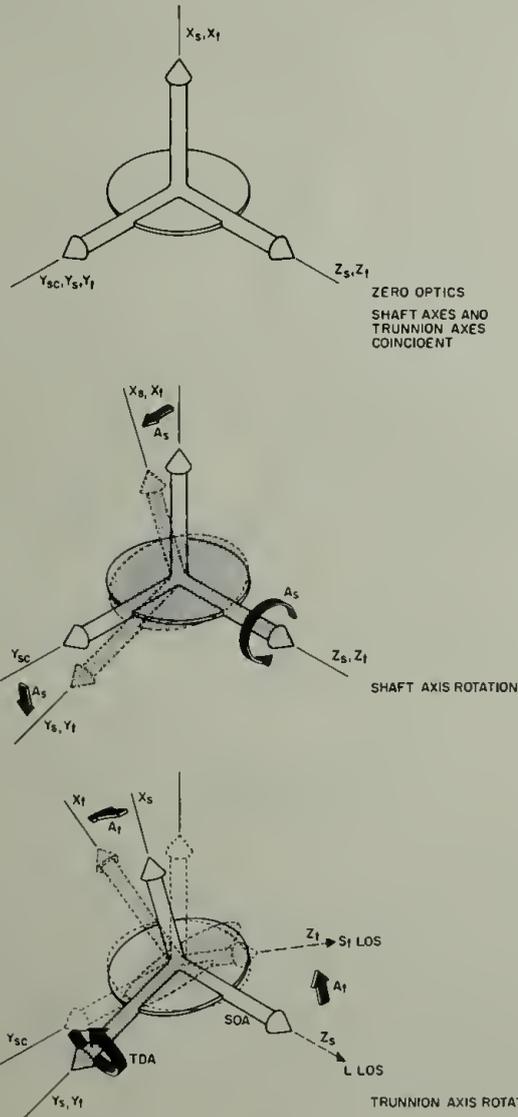
2-3.2.1 Stable Member Axes. The stable member axes (X_{sm} , Y_{sm} , Z_{sm}) provide a reference for aligning the inertial components and for defining the angular orientation of the inertial axes during flight.

2-3.2.2 Gyro Axes. The gyro axes (X_g , Y_g , Z_g) define the positive input axes of the gyros and are parallel to the stable member axes. If the attitude of the stable member is changed with respect to space, each gyro senses the change about its input axes and the circuitry associated with the gyros realigns the stable member to its original position.

2-3.2.3 Accelerometer Axes. The accelerometer axes (X_a , Y_a , Z_a) define the positive input axes of the accelerometers and are parallel to the stable member axes. Velocity changes are measured along the accelerometer input axes. The velocity data is used to determine spacecraft position and velocity.

2-3.2.4 Gimbal Axes. The gimbal axes, outer (OGA), inner (IGA), and middle (MGA) are the axes of the movable gimbals. The gimbal angles are zero when the gimbal axes and the stable member axes are parallel. The attitude of the spacecraft with respect to the stable member is measured by gimbal resolvers.

2-3.3 OPTICAL AXES. The optical axes (figure 2-3) provide a reference for measuring the attitude of the command module and for aligning the IMU. The shaft axis is perpendicular to the conical surface of the command module and is displaced 33 degrees from the Z_{sc} (yaw) axis. The trunnion axis is parallel to the Y_{sc} (pitch) axis when the shaft angle (A_s) is at zero degrees. The shaft drive axis (SDA) is coincident with the Z component of the shaft axis (Z_s) and the trunnion drive axis (TDA) is coincident with the Y component of the trunnion axis (Y_t). The Z_s axis has a fixed orientation and is used to direct the optics line of sight (LOS) toward landmark targets; therefore, the Z_s axis is also referred to as the landmark LOS (LLOS). The Z_t axis is used to direct the optics LOS toward star targets; therefore, the Z_t axis is also referred to as the star LOS (S_t LOS).



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Figure 2-3. Orientation of Optical Axes to Nav Base Axes

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

2-4 INERTIAL SUBSYSTEM

The ISS performs three major functions: measures changes in spacecraft attitude, assists in generating steering commands, and measures spacecraft velocity due to thrust. To accomplish these functions, the IMU provides an inertial reference consisting of a stable member gimbaleed in three degrees of freedom and stabilized by three integrating gyros. Note: During normal operation, the middle gimbal angle is not allowed to exceed ± 70 degrees. The IMU stable member is aligned to a predetermined reference each time the ISS is energized and during prolonged use. Prior to launch, the alignment is accomplished by vertical erection and azimuth alignment controlled by a computer gyro compassing program. During flight, alignment can be accomplished by sighting the optical instruments on celestial objects or it can result from information transmitted through MSFN.

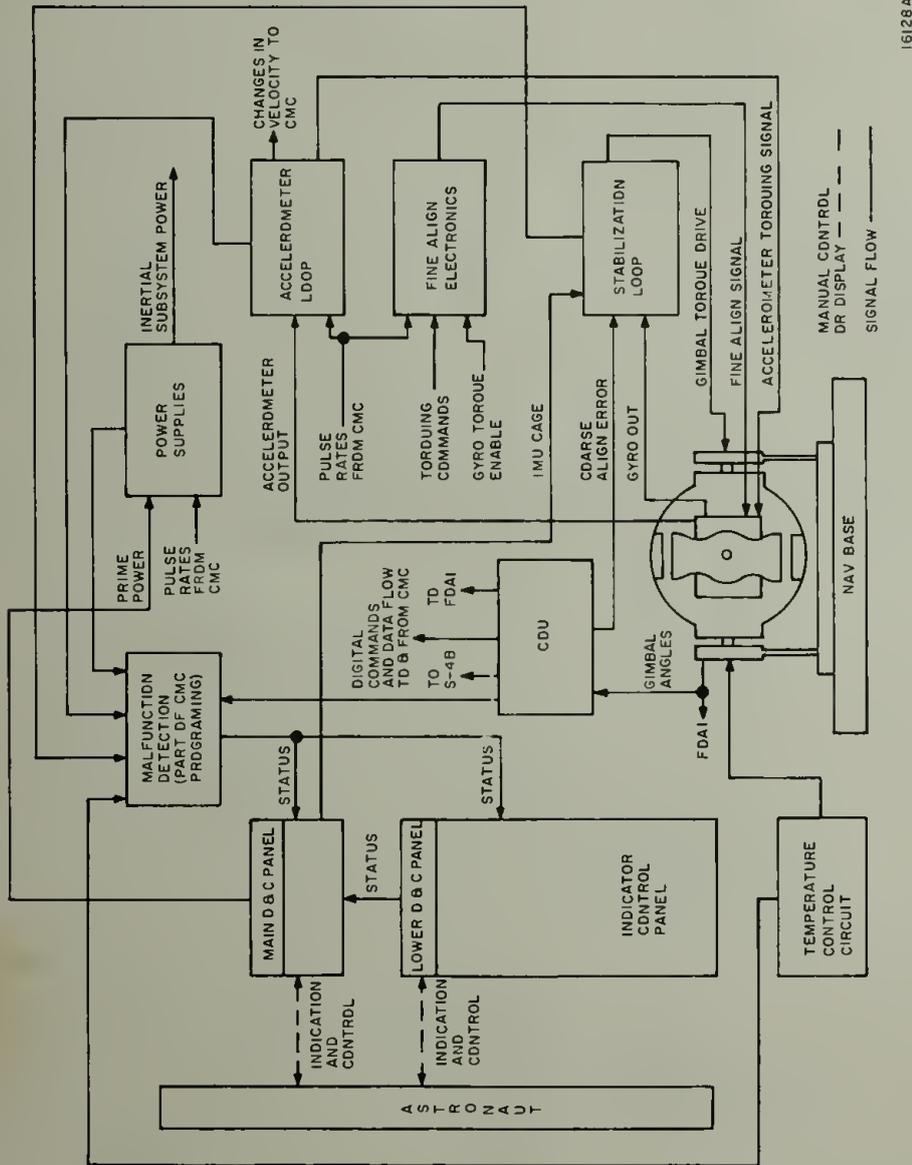
Once the inertial subsystem is energized and aligned, any rotational motion of the spacecraft will be about the stable member, which remains fixed in space. Resolvers, mounted on the gimbal axes, act as angular sensing devices and measure the attitude of the spacecraft with respect to the stable member. These angular measurements are displayed to the astronaut by the FDAI and angular changes are sent to the CMC through the CDU. Desired spacecraft attitude is calculated by the CMC and is compared with the actual IMU gimbal angles. Any difference between the actual gimbal angles and the desired gimbal angles, as calculated by the computer, results in attitude error signals which change spacecraft attitude through the SPS or RCS.

Three pendulous accelerometers mounted on the stable member sense changes in velocity along the axes of the IMU stable member and supply incremental velocity data to the computer. The CMC uses the incremental velocity data to calculate spacecraft total velocity.

The modes of operation of the inertial subsystem can be initiated automatically by the CMC or by the astronaut selecting computer programs through the computer keyboard. The status or mode of operation is displayed on the display and keyboard as determined by data from the computer.

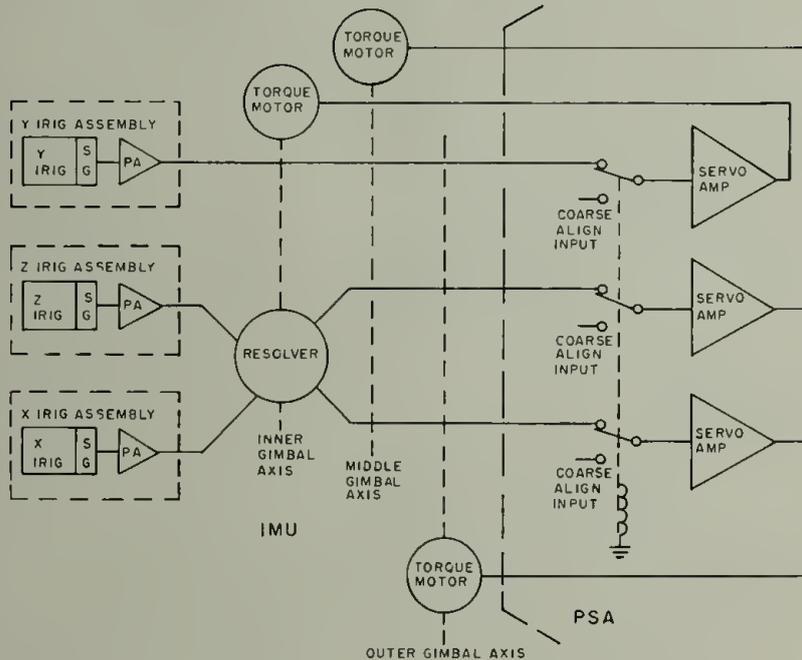
For explanation purposes, the ISS is divided into functional blocks as shown in figure 2-4.

2-4.1 STABILIZATION LOOP. The stabilization loop (figure 2-5) maintains the stable member in a specific spatial orientation so that three mutually perpendicular 16 PIP accelerometers can measure the proper components of command module acceleration with respect to the coordinate system established by the stable member orientation. An input to the stabilization loop is created by any change in spacecraft attitude with respect to the spatial orientation of the stable member. With near zero



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Figure 2-4. Inertial Subsystem, Block Diagram



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Figure 2-5. Stabilization Loop, Block Diagram

gimbal angles, the inertia of the stable member tends to maintain the stable member in a fixed spatial orientation. Because of gimbal friction and unbalances, motion of the spacecraft relative to the stable member produces a torque on the stable member which tends to change its orientation. This change is sensed by the stabilization gyros. When the gyros sense an input, they issue error signals which are amplified, resolved (if necessary) into appropriate components, and applied to the gimbal torque motors. The gimbal torque motors then drive the gimbals to maintain the stable member in fixed spatial orientation.

The stabilization loop consists of three pre-aligned Apollo II inertial reference integrating gyro (IRIG) assemblies, a gyro error resolver, three gimbal servo amplifiers, three gimbal torque motors, three gimbals, and circuitry associated with these components. The inner gimbal is the stable member upon which the three stabilization gyros are mounted. The gyros are mounted with their input axes oriented in an orthogonal configuration. Movement of any gimbal tends to result in a movement of the stable member and rotation about the input axes of one or more of the stabilization gyros.

The stabilization loop contains three parallel channels. Each channel starts with a stabilization gyro (X, Y, or Z) and terminates in a gimbal torque motor. The torque motor drives gimbals resulting in a movement of the stable member and a movement of the stabilization gyros. When a movement of the IMU support gimbal attempts to displace the stable member from its erected position, one or more of the stabilization gyros senses the movement and issues error signals. The phase and magnitude of the 3,200 cps gyro error signal represents the direction and amount of rotation experienced by the gyro about its input axis. The error signal is fed from the gyro signal generator ducosyn to the associated IRIG preamplifier, which is a part of the prealigned Apollo II IRIG assembly. Amplification of the error signal is required to achieve a high signal-to-noise ratio through the gimbal slip rings.

The amplified gyro error signals also represent motion of the stable member about its axis since the stable member axes (X_{SM} , Y_{SM} , Z_{SM}) and the gyro axes (X_g , Y_g , Z_g) are parallel to one another. If the middle and outer gimbal axes remain parallel with the stable member axes, then movement of the outer gimbal (a roll movement of the spacecraft) is sensed by only the X gyro and movement of the middle gimbal (yaw movement of the spacecraft) is sensed by only the Z gyro. Movement of the stable member about the inner gimbal axis (Y_{SM}), however, changes the relationship of the X and Z gyro input axes to the outer and middle gimbal axes. As a result, a movement of the middle or the outer gimbal is sensed by both X and Z gyros. The input required by the gimbal servo amplifiers to drive the gimbals and move the stable member back to its original position must be composed of components of both the X and Z gyros. The required gimbal error signals are developed by the gyro error resolver. The gyro error signals, $E(X_g)$ and $E(Z_g)$, are applied to the stator windings of the gyro error resolver. The rotor windings are connected to the inputs of the outer and middle gimbal servo amplifiers. Movement of the stable member about the inner gimbal axis (pitch movement of the spacecraft) changes the position of the resolver rotor relative to the resolver stator. This change corresponds electromagnetically to the change in the relationship of the stable member axes to the outer and middle gimbal axes. The outputs taken from the rotor are the required middle and outer gimbal error signals (E_{mg} and E_{og}). Since the inner gimbal torque motor axis and the Y axis of the stable member are the same axis, the Y gyro error signal, $E(Y_g)$, is equal to the inner gimbal error signal, (E_{ig}), and is fed directly to the inner gimbal servo amplifier.

The three identical gimbal servo amplifier modules are located in the PSA and each contains a phase sensitive demodulator, a filter, and a dc operational power amplifier. The phase sensitive demodulator converts either the 3,200 cps gimbal error or 800 cps coarse align error, zero or pi phase, signals into a representative positive or negative dc signal. The dc signal is filtered and applied to a dc operational amplifier with current feedback. The compensation network in the feedback circuit of the amplifier controls the response characteristics of the entire stabilization loop. The output of the dc amplifier has an operating range between +28 volts dc and -28 volts dc and drives the respective gimbal torque motor directly in either angular direction.

The gain required for each stabilization loop differs. This difference compensates for the differences in gimbal inertia. The proper gain is selected by the connections to the gimbal servo amplifier module. A single torque motor is mounted on each gimbal at the positive end of the gimbal axis. The torque motors drive the gimbals to complete the stabilization loop.

The orientation of the stable member can be changed in either the coarse align, fine align, or IMU cage modes. Signals to reposition the gimbals are injected into the gimbal servo amplifiers from the CDU during the coarse align and IMU cage modes and into the stabilization gyros from the fine align electronics during the fine align mode. During the IMU cage mode and the coarse align mode, the reference signal for the demodulator in the gimbal servo amplifier is externally switched from 3,200 cps to 800 cps.

2-4.2 FINE ALIGN ELECTRONICS. The fine align electronics (figure 2-6) provides torquing current to the stabilization gyros to change the orientation of the IMU gimbals during the fine align mode. The operation of the fine align electronics is controlled by the CMC.

The components of the fine align electronics are common to the three stabilization gyros. The fine align electronics provides torquing signals to the stabilization gyros one at a time on a time shared basis. The fine align electronics consists of a gyro calibration module, a binary current switch module, and a dc differential amplifier and precision voltage reference module; all are located in the PSA.

The fine align electronics is enabled and controlled by CMC inputs to the gyro calibration module. The CMC inputs are torque enable pulses, gyro select pulses, a torque set command, and a torque reset command. The fine align electronics is enabled by the torque enable pulses. The torque enable pulse is a train of pulses three microseconds in width and occurring at 102.4 kpps. The torque enable pulses are applied through a relay driver to energize the torque enable relay in the calibration module. When the torque enable relay is energized, system 28 vdc is applied to the precision voltage reference (PVR) and regulated 120 volts dc from the pulse torque power supply is applied to the dc differential amplifier and the binary current switch. The torque enable pulse train is received 20 milliseconds prior to any gyro set command.

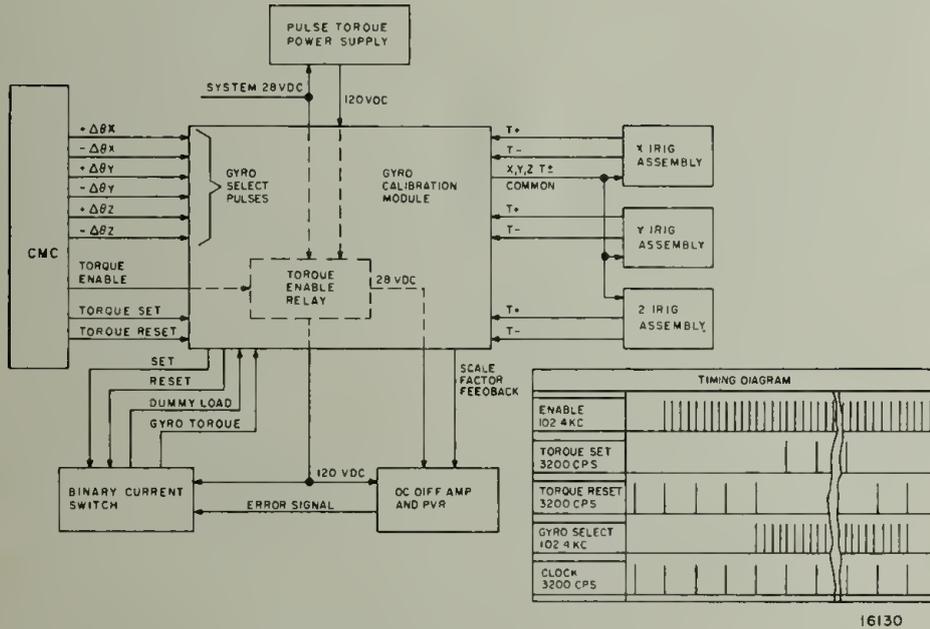
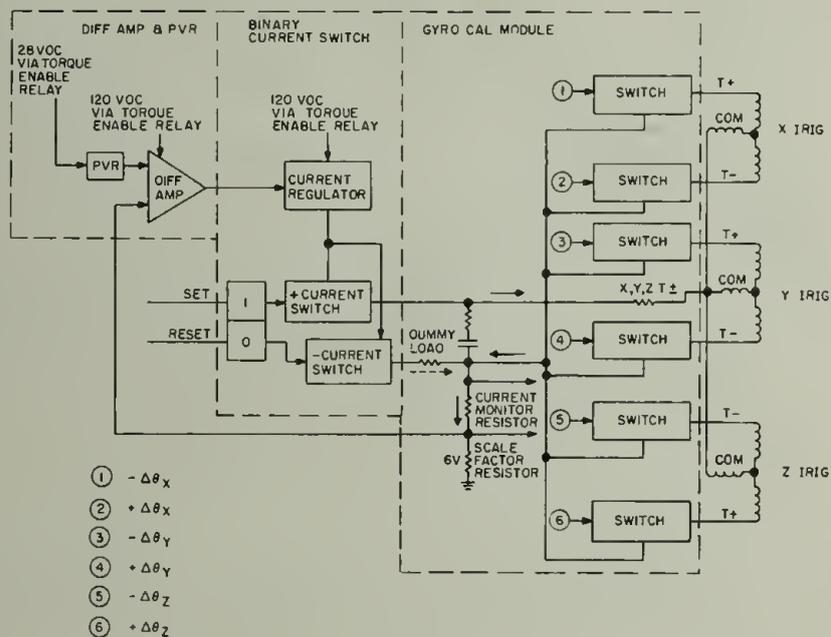


Figure 2-6. Fine Align Electronics - Computer Inputs

The gyro to be torqued and the direction it is to be torqued is selected by the CMC sending gyro select pulses to one of the six $+\Delta\theta$ or $-\Delta\theta$ inputs. (See figure 2-7.) The gyro select pulse is a train of pulses three microseconds in width and occurring at 102.4 kpps. The pulse train activates a transistor switch network which controls current through the T+ or T- coils of the torque generator ducosyn in the gyro selected. The gyro select pulse train is received 312.5 microseconds (one CMC clock time at 3,200 pps) prior to any torque set command.

The torque set and reset commands are 3,200 pps pulse trains containing pulses that are three microseconds in width. A 3,200 pps pulse train will be present on the torque set line when any gyro is to be torqued. A 3,200 pps pulse train is present on the torque reset line at all other times. This ensures that the binary current switch is in the reset condition prior to receipt of a torque enable command from the CMC. When the gyro has been torqued the proper amount, a torque reset command is issued which

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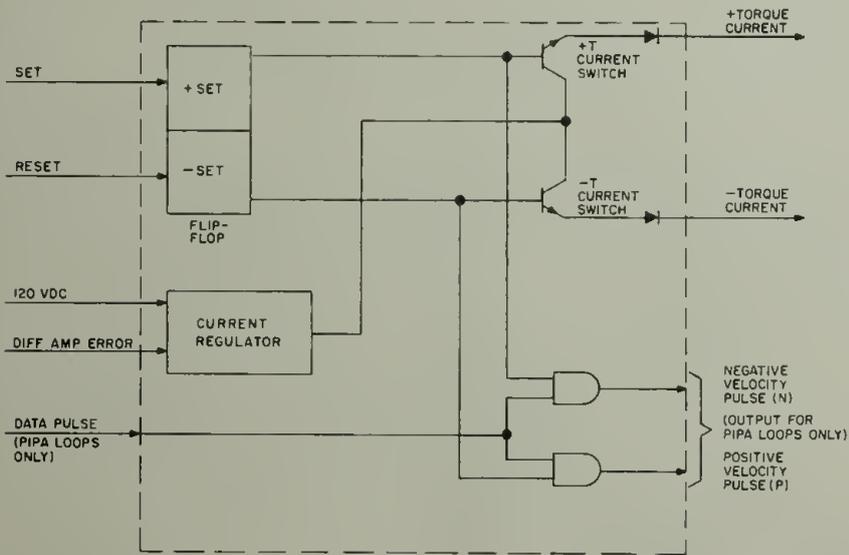
Figure 2-7. Fine Align Electronics - Gyro Selection

cuts off the torque current. The gyro select pulse train is removed 312.5 microseconds after the torque reset command is issued. The torque set and torque reset pulses feed through a 1:2 step-up transformer in the calibration module to the set and reset inputs of the binary current switch.

The torque current from the binary current switch is applied through a tuned resistive-capacitive compensation network in the calibration module to make the torque generator ducosyn windings appear as a pure resistive load to the binary current switch. The torque current to the gyros is through the T±(common) line. Current will flow only through the selected torque generator coils, the current monitor resistor, and the scale factor resistor. The voltage drop developed across the scale factor resistor is used as a feedback to the differential amplifier to regulate the torquing current. The voltage drop across the current monitor resistor is applied to PSA test points for external monitoring of gyro torque current.

When no gyro is being torqued, the binary current switch provides current flow through a dummy load resistor and through the current monitor and scale factor resistors. In this manner, the binary current switch maintains a continuous flow of torque current. The dummy load resistor simulates the impedance of the torque generator coil and a compensation network.

The torque set and torque reset pulses trigger a flip-flop (bi-stable multivibrator) in the binary current switch. See figure 2-8 for a block diagram of the binary current switch. If the flip-flop is in the +set condition, the +set condition will remain until a reset command resets the flip-flop. The outputs of the flip-flop control two transistor switches. If the flip-flop is in the +set condition, the +set output is present at the base of the +torque current switch, and causes the switch to turn on. The +torque current switch closes the path from the 120 volt supply through the current regulator to the proper T+ or T- winding of the selected gyro through the calibration module. If the flip-flop is in the -set condition, the -torque current switch will turn on to close the current path through the dummy load resistor.

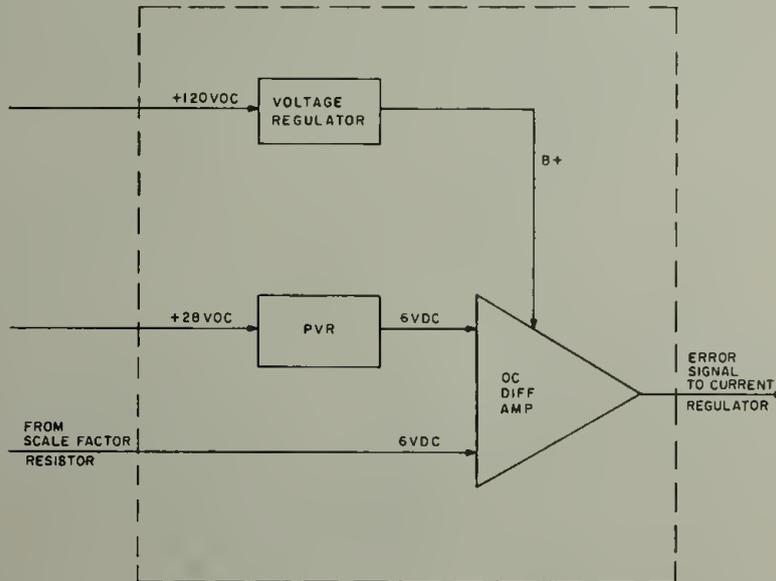


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Figure 2-8. Binary Current Switch

The binary current switch used in the fine align electronics is identical to the binary current switch used in the accelerometer loops. The portion of the binary current switch used only for the accelerometer loops is disabled in the fine align electronics application. In the accelerometer loop application, current to the accelerometer T+ torque generator coil is provided by the +torque current switch and current to the T- torque generator coil is provided by the -torque current switch. Therefore, the +torque and -torque designations of the switches have significance. In the fine align electronics application, the switch designations have no significance since current to both the T+ and T- coils of the gyro torque generators is provided by the +torque current switch while the -torque current switch provides only the dummy load current.

The dc differential amplifier and PVR module (figure 2-9) maintains the current through the windings of the torque generator ducosyn at 84 milliamperes. The PVR is supplied with 28 volts dc and, through the use of zener diode circuits, develops an accurate 6 volts dc for use as a reference voltage. The scale factor resistor in the



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Figure 2-9. DC Differential Amplifier and Precision Voltage Reference

calibration module also has 6 volts developed across it when 84 milliamperes of current flows through it. A comparison is made by the dc differential amplifier of the PVR 6 volts and the scale factor resistor 6 volts. Any deviation from the nominal 84 milliamperes of torquing current will increase or decrease the voltage developed across the scale factor resistor and cause an output error signal from the dc differential amplifier. This error signal controls the current regulator in the binary current switch. The current regulator, which is in series with the torque generator coils of the selected gyro and the 120 volt dc source, will maintain the torquing current at 84 milliamperes.

The current flow through the windings of the torque generator ducosyn causes the gyro float to rotate about the gyro's output axis. A $+\Delta\theta$ gyro select command from the CMC will allow torque current to flow through a T- torque generator coil which results in a positive rotation of the gyro float about the output axis. A $-\Delta\theta$ gyro select command produces a negative float rotation. Float rotation results in an error output from the signal generator ducosyn. The error signal is applied to the stabilization loop to reposition the gimbals and the stable member. The change in gimbal angles is transmitted by the CDU read counters to the CMC.

2-4.3 ACCELEROMETER LOOP. The three accelerometer loops measure the acceleration of the stable member along three mutually perpendicular axes. This data is integrated by the CMC to determine velocity which is used by the CMC to determine the spacecraft velocity vector. Figure 2-10 is a functional diagram of an accelerometer loop.

The three accelerometer loops contain three prealigned 16 PIP assemblies, three PIP preamplifiers, three ac differential amplifier and interrogator modules, three binary current switches, three calibration modules, three dc differential amplifier and precision voltage reference modules, a pulse torque isolation transformer, and associated electronics.

The three mutually perpendicular PIP's are acceleration sensitive devices which, in closed loops with their associated accelerometer loop electronics, become integrating accelerometers. The PIP is basically a pendulum-type device consisting of a cylinder with a pendulous mass unbalance (pendulous float) pivoted with respect to a case. The pivot axis defines the PIP output axis. A signal generator at the positive end of the output axis provides electrical outputs indicative of the rotational float position. A torque generator, at the other end of the float acts as a transducer to convert electrical signals into torque about the float shaft.

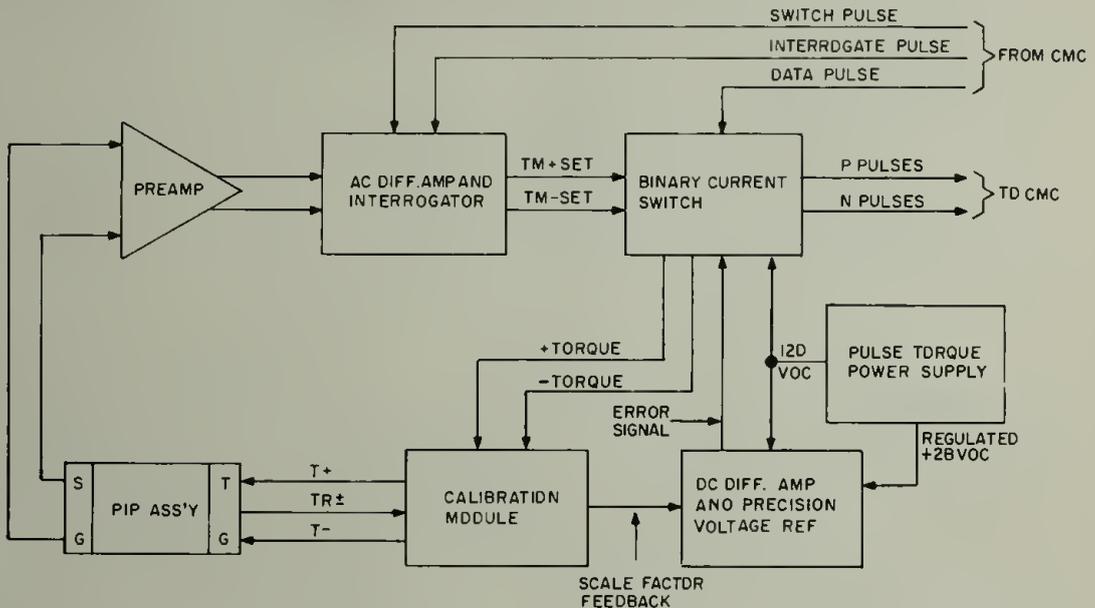


Figure 2-10. Accelerometer Loop

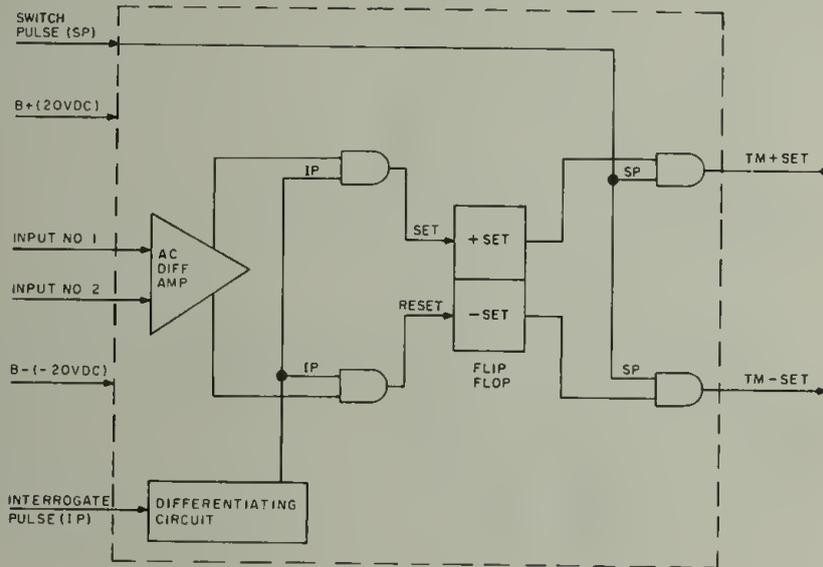
A PIP accelerometer loop can be mechanized to operate in a ternary (three state) or binary (two state) mode. The Block II loops are designed to operate in the binary mode with the PIP pendulous float in continuous oscillatory rotation. The oscillation is produced by alternate positive and negative torquing from the torque generator. The torque generator has two windings, one to produce torque in a positive direction, the other to produce torque in a negative direction. Only one winding is energized at any one time. The windings are energized alternately by the setting of a flip-flop in the binary current switch (figure 2-7). When the accelerometer loop is first energized, the interrogator sets the flip-flop to route torquing current to the winding which will rotate the float to null. As the float passes through null, the phase of the output signal generator changes so that the interrogator issues pulses to reset the flip-flop in the binary current switch and thus route torquing current to the other torque winding. The float is then torqued in the opposite direction until the signal generator output again changes phase as the float passes through null which reinstates the cycle.

The output of the signal generator, after being amplified by the PIP preamplifier, is interrogated 3,200 times a second by the interrogate pulse. The binary current switch flip-flop can be reset only when the interrogate pulse is present and the signal generator output is of the proper phase.

The PIP pendulous float oscillates about its null point at a frequency near the natural resonant frequency of the loop. The resonant frequency is dependent upon float damping, signal and torque generator sensitivity, and other loop characteristics. In Block II accelerometers loops, this resonant frequency is approximately 500 cps. Since the accelerometer loop is designed with a torque winding selection rate of 3,200 pulses per second, the loop will oscillate at a frequency equal to $3,200 \div x$ where x is any even number. Solving the equation $f = 3,200 \div x$, the frequency closest to 500 is $533\frac{1}{3}$. In this case, the value of x is six. Thus one complete pendulum cycle will occur during six torque selection pulses. Dividing the time for the six pulses into the time required for positive and negative rotations, it is seen that the PIP functions in a 3-3 mode (positive rotation for three torque selection pulses, negative rotation for three torque selection pulses).

In its 3-3 mode and sensing no acceleration, the PIP pendulous float rotates an equal angular distance on both sides of an electrical and mechanical null. The 2 volt rms, 3,200 cps, one phase signal generator excitation voltage is synchronized with the CMC clock. The signal generator has a center tapped secondary winding which provides a double ended output, one side having a zero phase reference with respect to the 3,200 cps excitation and the other side a pi phase reference. The center tap is connected to ground. The output signal is representative of the magnitude and direction of the rotation of the pendulous float about the output axis. The error signal is routed to the preamplifier mounted on the stable member. The phase of the output signal from the preamplifier is shifted -45° from the reference excitation. The output signal is then in phase with the interrogate pulse. The phase shifted zero or pi phase signals from the preamplifier are applied as separate inputs to the ac differential amplifier. The ac differential amplifier outputs are routed to the interrogator.

The ac differential amplifier and the interrogator are packaged in the same module located in the PEA. The interrogator analyzes the ac differential amplifier outputs to determine the direction of the 16 PIP float movement and to generate appropriate torquing commands. See figure 2-11 for a block diagram of the ac differential amplifier and interrogator module. The two amplified signals from the ac differential amplifier go to two summing networks and threshold amplifiers (represented in figure 2-11 by AND gates). Interrogate pulses (IP) are continuously being received by the interrogator from the CMC. An interrogate pulse is a two microsecond pulse occurring at 3,200 pps and timed to occur 135 degrees after the positive going zero crossing of the reference excitation. (See figure 2-12.) With this phasing, the interrogate pulse occurs at the 90 degree peaks of the phase shifted zero or pi phase input signals from the PIP preamplifiers. The interrogate pulse occurs at a positive 90 degree peak of the zero phase signal if the float angle is positive and at a positive 90 degree peak of the pi phase signal if the float angle is negative. The zero and pi phase signals and the interrogate pulses

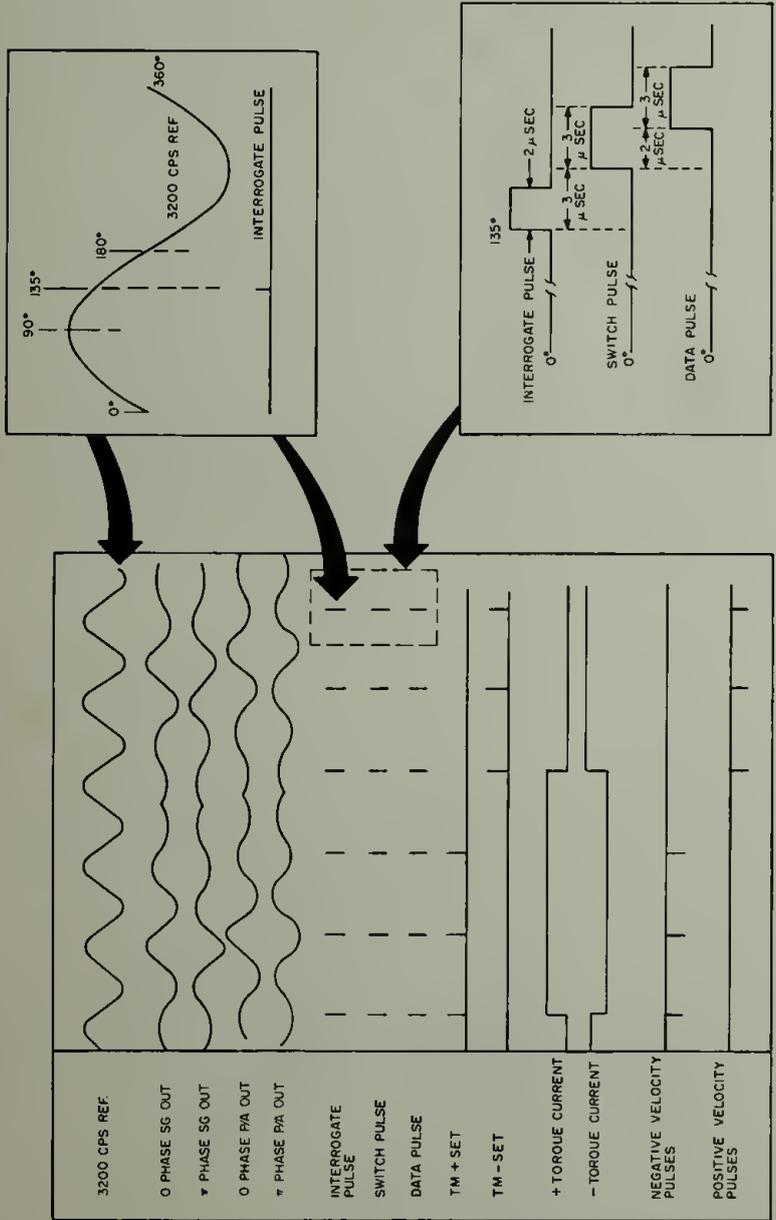


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Figure 2-11. AC Differential Amplifier and Interrogator Module

are ANDed by the summing network and threshold amplifier. The gated outputs of the threshold amplifier are applied to a flip-flop as set or reset pulses. If the flip-flop is in the +set condition, a succession of set pulses will maintain the +set condition. The +set condition will remain until the float angle passes through null. At this time a reset pulse will be produced to cause the flip-flop to go to the -set condition.

The outputs of the flip-flop are applied to two AND gates which are also driven by switch pulses received from the CMC. The switch pulses are a train of clock driven 3,200 pps pulses three microseconds in width that are timed to occur three microseconds after the leading edge of the interrogate pulse. The flip-flop enables only one output gate at any switch pulse time. The outputs of the AND gates are called the TM+ set pulse and the TM- set pulse.



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Figure 2-12. Accelerometer Timing

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The binary current switch utilizes the TM+ set and TM- set outputs of the interrogator to generate 16 PIP torquing current and velocity change pulses. See figure 2-8 for a block diagram of the binary current switch. The TM+ set and the TM- set pulses furnish the input to a flip-flop. If the flip-flop is in the +set condition, a succession of TM+ set pulses will maintain the +set condition. The +set condition will persist until the float passes through null. The phase change will cause the flip-flop of the ac differential amplifier and interrogator module to reset to the -set condition. At this time, a TM- set pulse will be developed and will cause the binary current switch flip-flop to go to the -set condition. The outputs of the flip-flop control two transistor current switches. If the flip-flop is in the +set condition, the +set output will be at the base of the +torque current switch and will turn it on. The +torque current switch closes the path from the current regulated 120 volt dc supply through the PIPA calibration module to the 16 PIP T+ torque generator coils. If the flip-flop is in the -set condition, the -torque current switch will be turned on, closing the path through the T- torque generator coils.

An acceleration along the PIP input axis causes the pendulous mass to produce a torque which tends to rotate the float about the output axis in proportion to the magnitude of the acceleration. The acceleration produced torque aids and opposes the torque generator forces causing changes in the time required for the float to be torqued back through null. A change in velocity (ΔV) is the product of acceleration and incremental time (Δt); the torque is proportional to an incremental change in velocity (ΔV).

$$T_{ACCEL} = K_1 a \Delta t = K_1 \Delta V$$

With the float in motion due to loop torquing, additional torque is required to overcome the acceleration torque and to keep the pendulous float in its oscillatory motion. Torque current at any one time is a constant. Additional torque is obtained by supplying torque current through the torque windings longer. To determine the amount of acceleration sensed by the PIP, it is necessary only to measure the time that torque current is applied to each torque winding. The amount of acceleration is derived from the following identity:

$$ACCEL_{IND} = K_2 \Sigma [(T+) - (T-)] \Delta t$$

From the above identity, it is seen that torquing time (Δt) is proportional to the change in velocity (ΔV).

$$K_1 \Delta V = K_2 \Sigma [(T+) - (T-)] \Delta t$$

$$\Delta V = \frac{K_2}{K_1} \Sigma [(T+) - (T-)] \Delta t$$

The time (Δt), representative of the ΔV , is sent to the CMC in the form of P and N pulses (figure 2-9).

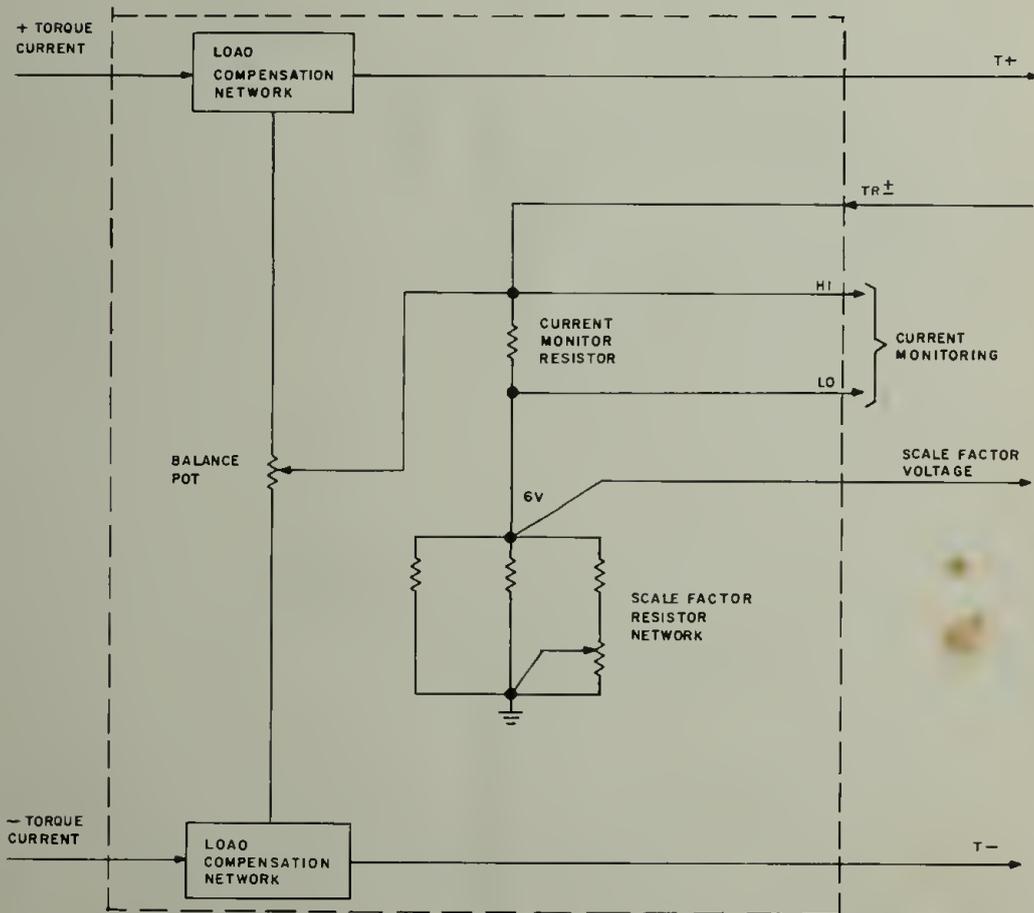
In addition to selecting the proper torque generator winding, the outputs of the binary current switch flip-flop also go to two AND gates where they are ANDed with the 3,200 cps data pulses from the CMC. The data pulse is three microseconds in width and is timed to occur two microseconds after the leading edge of the switch pulse. (See figure 2-11). Since the data pulse and switch pulse are both 3,200 cps, the CMC receives either a P pulse or an N pulse once every $1/3,200$ second. When the PIP is sensing no acceleration, the pendulum is oscillating at a frequency of $533-1/3$ cps and the CMC is receiving three P pulses and three N pulses once every cycle or once every $\frac{1}{533-1/3}$ seconds. The CMC contains a forward-backward counter which receives the velocity pulses and detects any actual gain in velocity.

The counter counts forward on the three P pulses and then backward on the three N pulses. The counter continues this operation and generates no ΔV pulses. With an acceleration input to the PIP, however, the loop no longer operates at the 3-3 ratio and the counter exceeds its capacity and reads out the plus or minus ΔV pulses which are then stored and used by the CMC. The pulses above the 3-3 ratio are representative of the additional torque supplied by the torque generator to compensate for the acceleration felt by the spacecraft. Each pulse indicates a known value of ΔV due to the loop scale factor.

The PIPA calibration module (figure 2-13) compensates for the inductive load of the 16 PIP torque generator ducosyns and regulates the balance of the plus and minus torques. The calibration module consists of two load compensation networks for the torque generator coils of the 16 PIP. The load compensation networks tune the torque generator coils to make them appear as a pure resistive load to the binary current switch. A variable balance potentiometer regulates the amount of torque developed by the torque generator coils. Adjustment of this potentiometer precisely regulates and balances the amount of torque developed by the T+ and T- torque generator coils. This balancing insures that for a given torquing current an equal amount of torque will be developed in either direction.

The calibration module also includes a current monitor resistor and an adjustable scale factor resistor network in series with the torque generator coils. A nominal six volts is developed across the scale factor resistor network due to the torquing current and is applied as an input to the dc differential amplifier and precision voltage reference module. The voltage drop across the current monitor resistor is used for external monitoring purposes.

The dc differential amplifier and PVR are identical to those used in the fine align electronics. (See figure 2-9.) The dc differential amplifier and PVR module maintain the current through the ducosyn torque generator coils at 100 milliamperes. The PVR is supplied with regulated 28 volts dc and, through the use of precision circuits, develops an accurate 6 volts for use as a reference voltage. The scale factor resistor in the calibration module also develops 6 volts when 100 milliamperes of current flows through it. A comparison is made by the dc differential amplifier of the PVR 6 volts and the scale factor 6 volts. Any deviation of the binary current switch torquing current



15192C

Figure 2-13. PIPA Calibration Module

from the nominal 100 milliamperes will increase or decrease the scale factor resistor voltage and result in an output error signal from the dc differential amplifier. This error signal controls the current regulator in the binary current switch. The current regulator, which is in series with the 120 volt dc source and the ducosyn torque generator coils, will maintain the torque current at 100 milliamperes.

2-4.4 IMU TEMPERATURE CONTROL SYSTEM. The IMU temperature control system (figures 2-14 and 2-15) maintains the temperature of the stabilization gyros and accelerometers within the required temperature limits. The system supplies and removes heat to maintain the proper IMU temperature with minimum power consumption. Heat is removed by convection, conduction, and radiation. The natural convection used during IMU standby mode changes to blower controlled, forced convection during IMU operating modes. The IMU internal pressure is maintained between 3.5 and 15 psia to enable the required forced convection. To aid in removing heat, a water-glycol solution from the spacecraft coolant system at approximately 45 degrees Fahrenheit passes through the coolant passages in the IMU case.

2-4.4.1 Temperature Control Circuit. The temperature control circuit maintains the gyro and accelerometer temperature. The temperature control circuit consists of a temperature control thermostat and heater assembly, a temperature control module, three IRIG end mount heaters, three IRIG tapered mount heaters, two stable member heaters, and three accelerometer heaters. The thermostat and heater assembly is located on the stable member and contains a mercury-thallium thermostat, a bias heater, and an anticipatory heater. Except for the bias heater, all heaters (a total of 12) are connected in parallel and are energized by 28 volts dc through the switching action of transistor Q2, which completes the dc return path. The thermostat which senses the temperature of the stable member controls switching transistors Q1 and Q2.

When the temperature falls below 130 (± 0.2) degrees Fahrenheit, the thermostat opens, transistors Q1 and Q2 conduct, and current flows through the twelve heaters. Because of the large mass of the stable member, its temperature will increase at a relatively slow rate as compared to the gyros which have a heater in each end mount. The anticipatory heater improves the response of the thermostat to insure that the magnitude of the temperature cycling of the gyros and the accelerometers is as small as possible. When the temperature rises above 130 (± 0.2) degrees Fahrenheit, the thermostat closes and the base of transistor Q1 is shorted to ground, cutting off transistors Q1 and Q2 and deenergizing the heaters. The thermostat has a 0.5 degree deadband which is the difference between contact closing with rising temperature and contact opening with falling temperature. The temperature control circuit will maintain the average of the gyro temperatures at 135 (± 1) degrees Fahrenheit and the average of the accelerometer temperatures at 130 (± 1) degrees Fahrenheit under normal ambient conditions. The temperature difference between the gyros and the accelerometers is adjusted by properly proportioning the amount of power in each heater. The balance is obtained by decreasing the current through each accelerometer heater by the proper selection of resistor R1.

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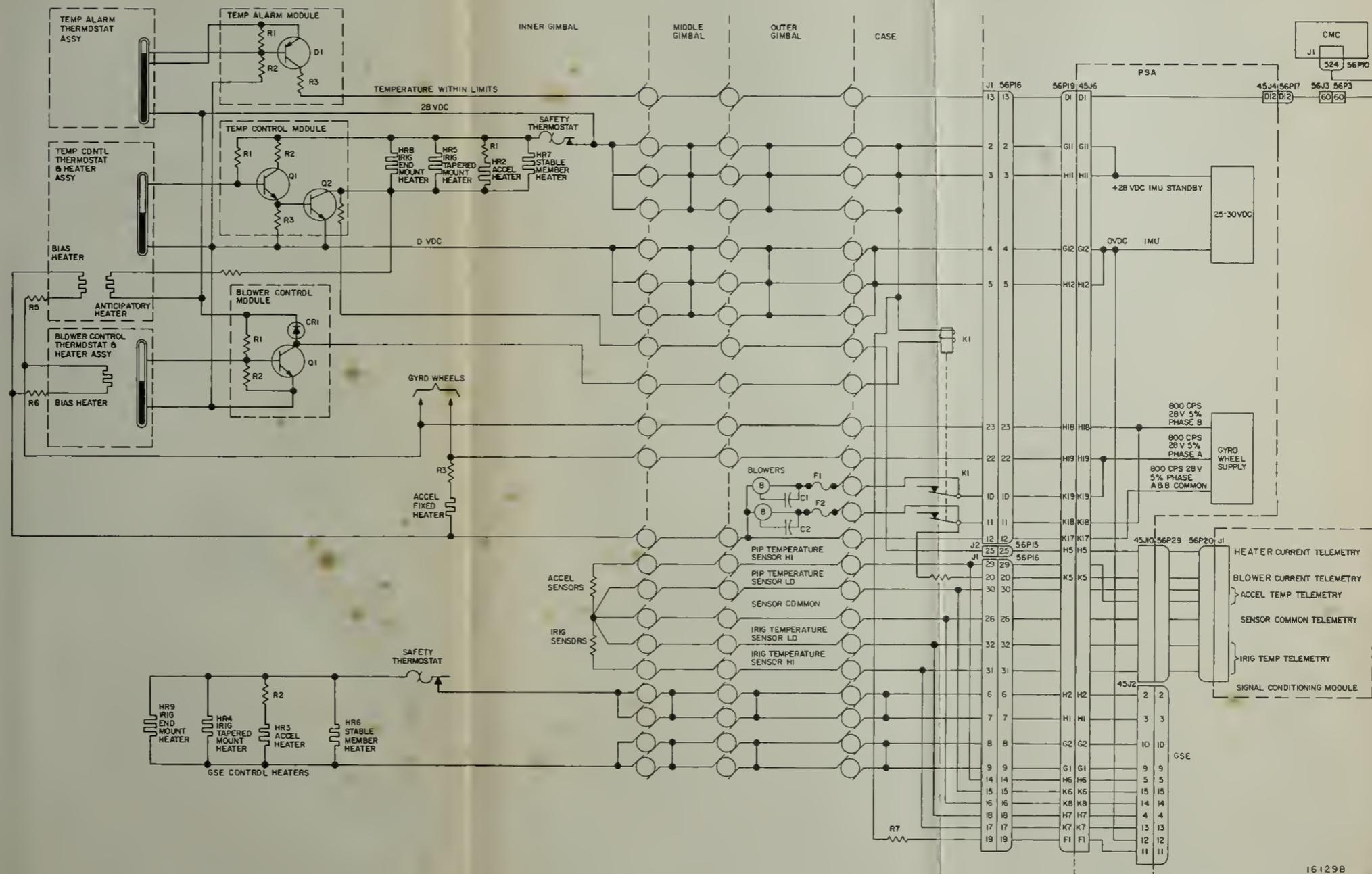
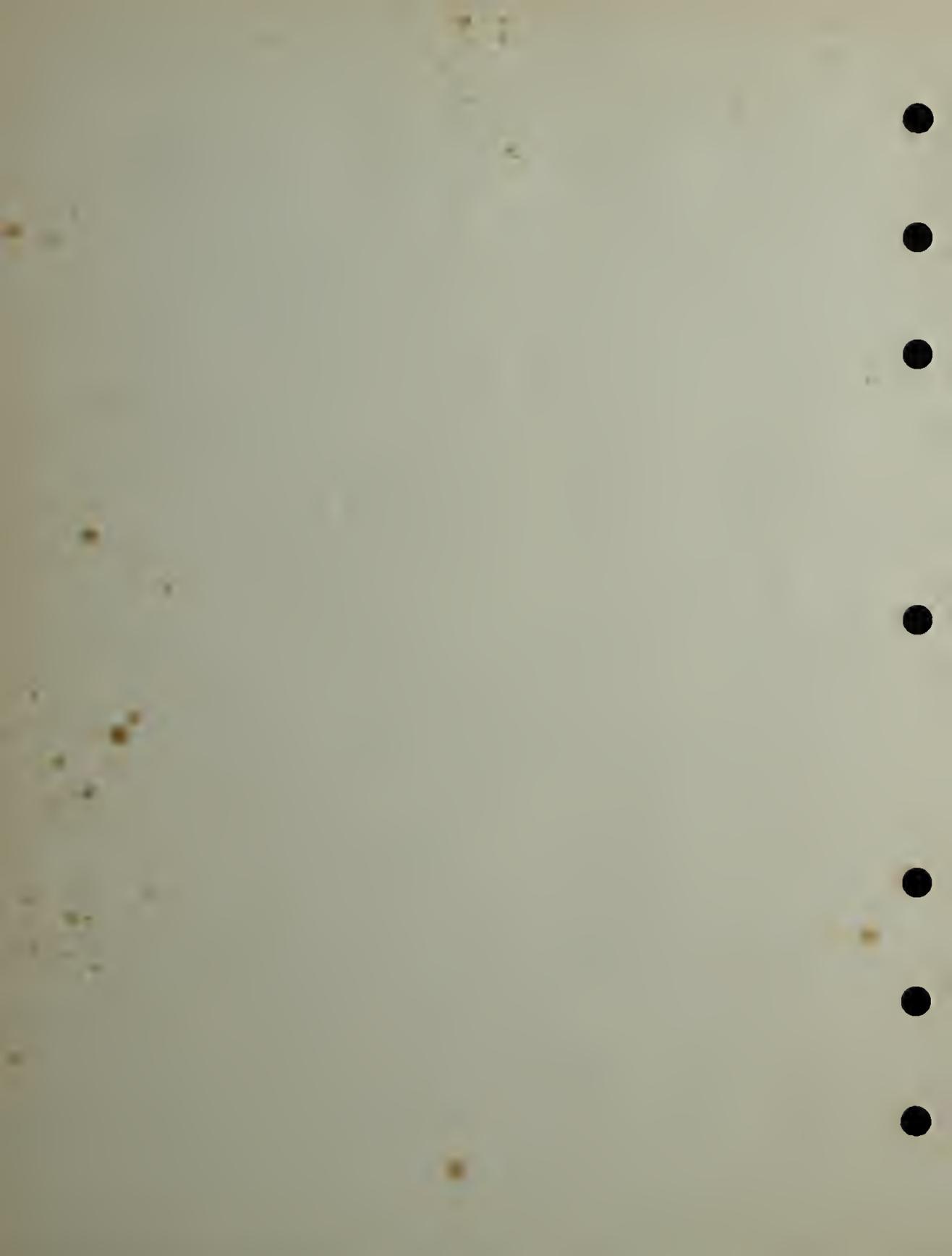
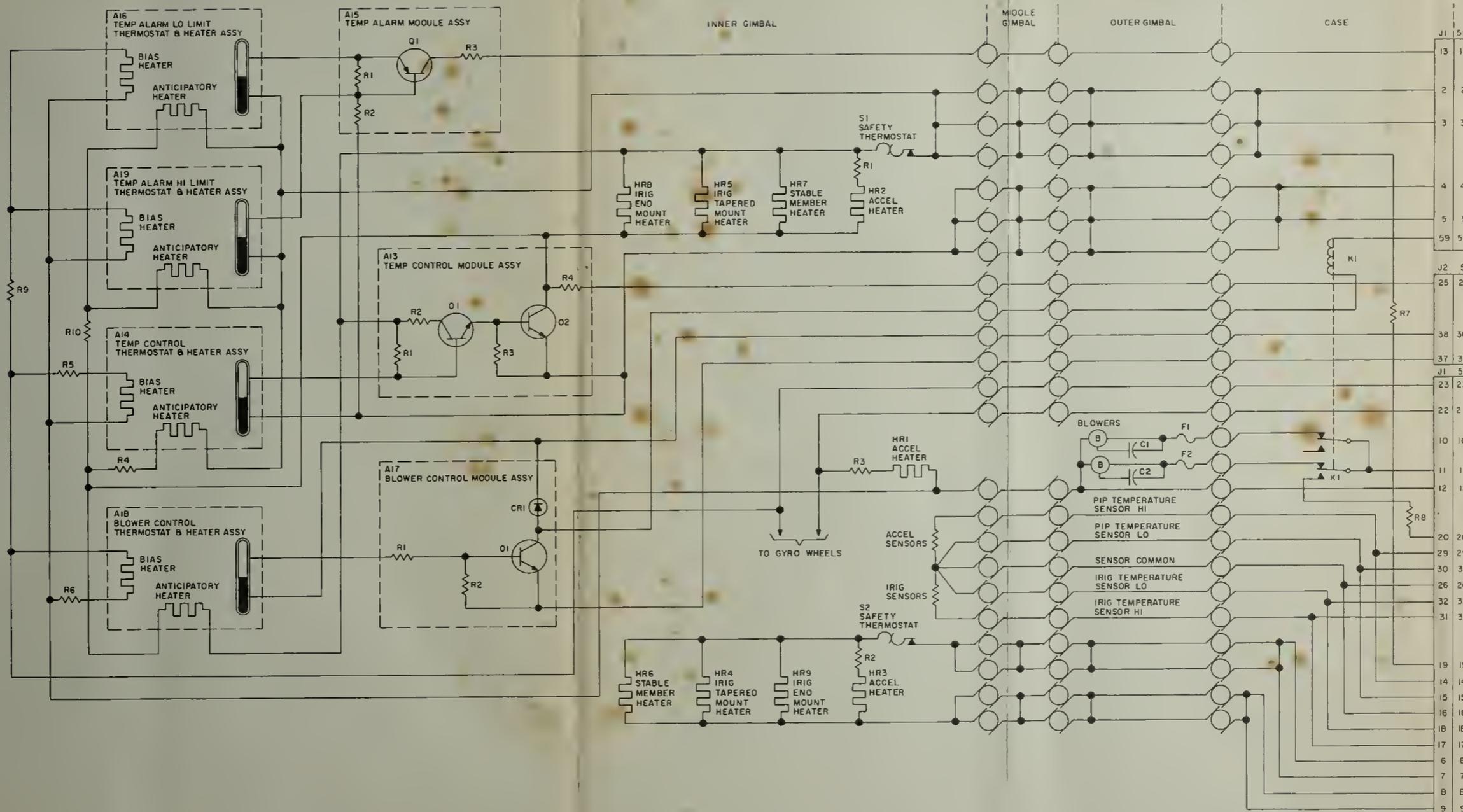


Figure 2-14. IMU Temperature Control System for PGNCs Part Number 2015000-011





J1	56
13	13
2	2
3	3
4	4
5	5
59	59
J2	5
25	25
38	38
37	37
J1	56
23	23
22	22
10	10
11	11
12	12
20	20
29	29
30	30
26	26
32	32
31	31
19	19
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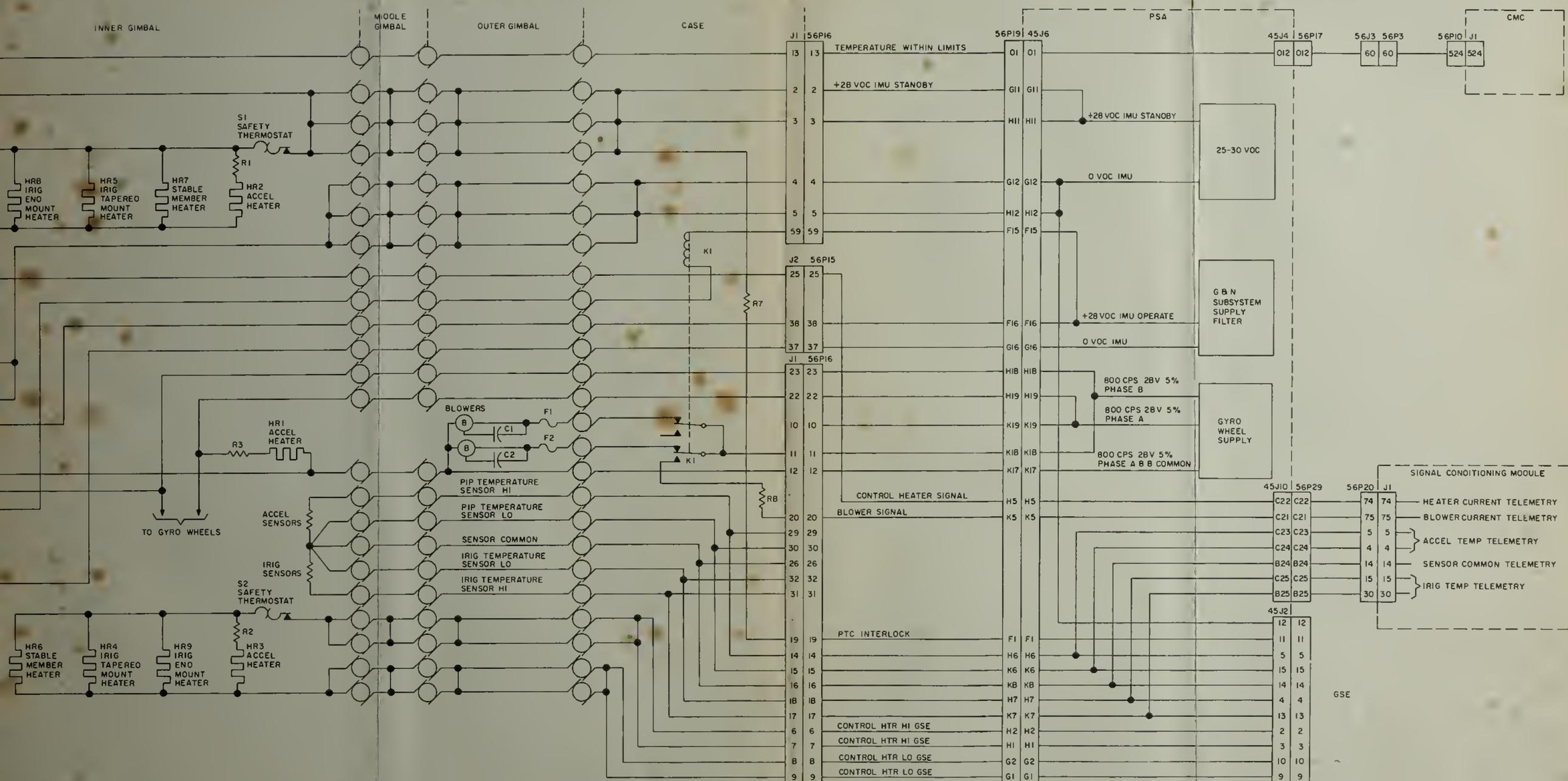
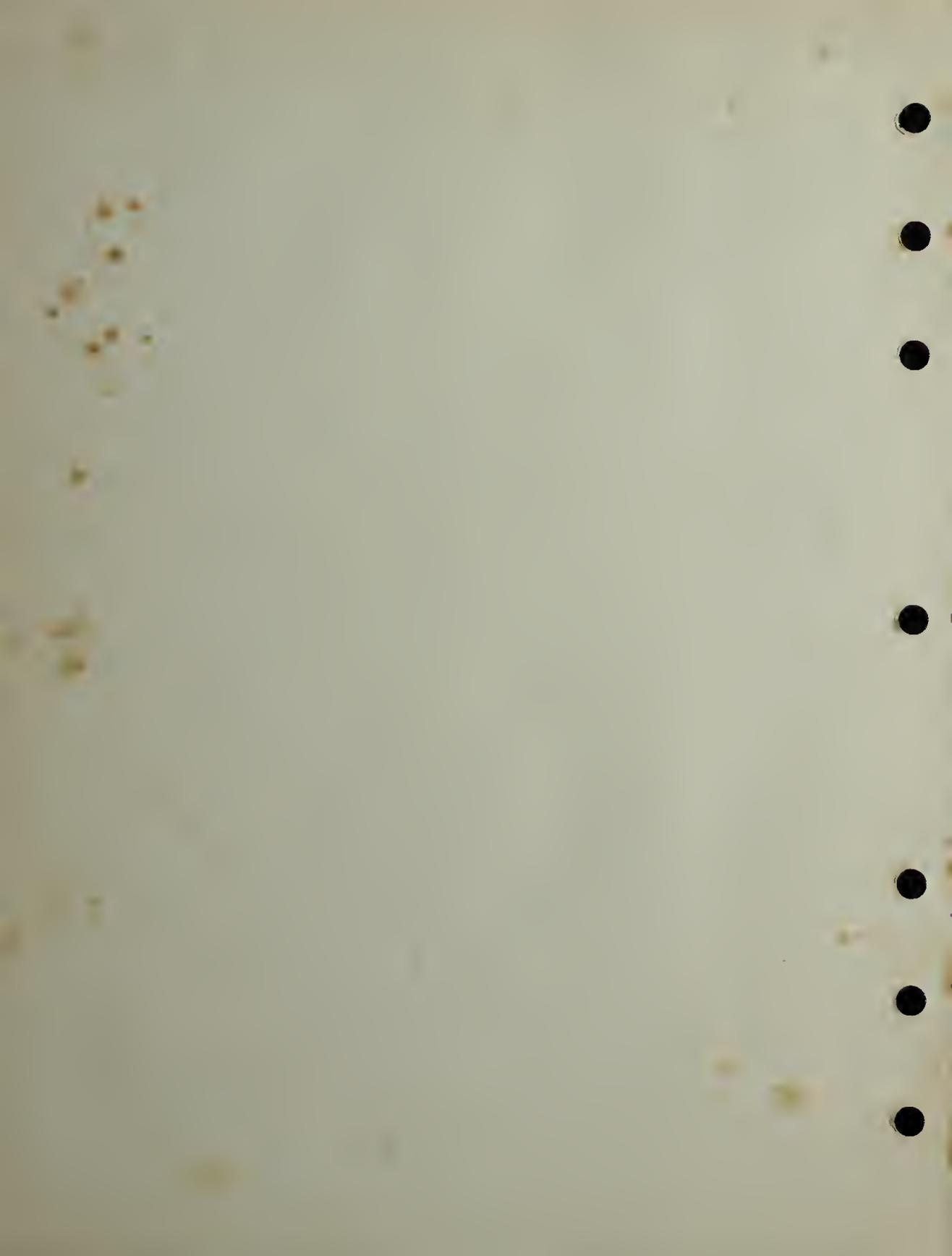


Figure 2-15. IMU Temperature Control System for PGNCS Part Number 2015000-021



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During IMU operation, power is applied to the fixed accelerometer heaters to compensate for the additional heat supplied to the gyros by the gyro wheel motor heat dissipation. Power is also applied to a bias heater on the control thermostat. The bias heater supplies a fixed amount of heat to the control thermostat to maintain the proper absolute temperature level of the gyros and accelerometers. The amount of bias heat is determined by the value of R5. The power for the fixed accelerometer heaters and the thermostat bias heater is the -90 degree output from the 28 vac power supply which is also used for gyro wheel power.

The 28 vdc heater power is applied to the heaters through the contacts of a safety thermostat which provides protection against an extreme overheat condition in case a malfunction occurs in the temperature control circuit. The safety thermostat contacts open at 139.5 (± 3.0) degrees Fahrenheit and close at 137 (± 3) degrees Fahrenheit.

2-4.4.2 Blower Control Circuit for PGNCs Part Number 2015000-011. The blower control circuit (figure 2-14) maintains IMU heat balance by removing heat. The blower control circuit consists of a blower control thermostat and heater assembly, a blower control module assembly, two axial blowers, and a relay. Although the blower control circuit is active, it is not utilized in this system. The power inputs to the blowers by-pass the contacts of K1 to allow the blowers to operate continuously during IMU operate modes.

The blowers are supplied from the -90 degree output of the 28 volt, 800 cps, 5 percent power supply which also provides gyro wheel motor power. Fused phase shift networks are associated with each blower so that excitation and control current can be supplied from the same source.

2-4.4.3 Blower Control Circuit for PGNCs Part Number 2015000-021. The blower control circuit (figure 2-15) maintains IMU heat balance by removing heat. The blower control circuit consists of a blower control thermostat and heater assembly, a blower control module assembly, two axial blowers, and a relay. The contacts of the thermostat contained in the blower control thermostat and heater assembly close at 139 (± 0.2) degrees Fahrenheit and remain closed at higher temperatures. Resistor R6 is provided to limit the current through the bias heater in the blower control thermostat and heater assembly. The amount of heat supplied by the bias heater is a constant. If the duty cycle of the temperature control circuit exceeds 50 percent, enough additional heat will be provided by the anticipatory heater to increase the temperature of the blower control thermostat and heater assembly to 139 degrees Fahrenheit. When the thermostat contacts close, transistor Q1 conducts and relay K1 is energized to remove the power from the blowers. The normal duty cycle of the temperature control circuit, with the IMU in a 75 degree Fahrenheit ambient temperature, is approximately 15 to 20 percent. Under this condition the blowers will operate continuously. Only a very low ambient temperature will cause a blower off condition.

Power to the blowers is supplied from the -90 degree output of the 28 volt, 800 cps, 5 percent power supply which also provides gyro wheel motor power. Fused phase shift networks are associated with each blower so that excitation and control current can be supplied from the same source.

2-4.4.4 Temperature Alarm Circuit for PGNCS Part Number 2015000-011. The temperature alarm circuit which monitors the temperature control system, consists of a temperature alarm thermostat assembly and a temperature alarm module. If a high or low temperature is sensed by the temperature alarm thermostat (located on the stable member) a discrete is sent to the CMC and to the IMU auxiliary module. When the temperature is within the normal range, 28 volts dc is applied through the thermostat to the emitter of transistor Q1 causing the transistor to conduct through a grounding system in the CMC.

When the temperature falls below 126.3 (± 1.0) degrees Fahrenheit, 28 volts dc is removed from transistor Q1 causing it to stop conducting. When the temperature rises above 134.3 (± 0.2) degrees Fahrenheit, 28 volts dc is applied directly to the base as well as to the emitter of transistor Q1 causing it to stop conducting. Non-conduction of transistor Q1 signals the CMC of an alarm condition. There is no differentiation between a high or low temperature alarm. When the CMC senses a temperature alarm, it causes the TEMP and PGNCS lamps to light. When the IMU auxiliary module receives a temperature alarm, it sends the information to telemetry.

2-4.4.5 Temperature Alarm Circuit for PGNCS Part Number 2015000-021. The temperature alarm circuit which monitors the temperature control system, consists of a temperature alarm high limit thermostat and heater assembly, a temperature alarm low limit thermostat and heater assembly, and a temperature alarm module assembly. If a high or low temperature is sensed by the thermostats located on the stable member a discrete is sent to the CMC and to the IMU auxiliary module. When the temperature is within the normal range, the low limit thermostat contacts are closed and the high limit thermostat contacts are open. Transistor Q1 is then properly biased for conduction through a grounding system in the CMC.

At temperatures below 126.0 (± 0.2) degrees Fahrenheit both the low limit thermostat contacts and the high limit thermostat contacts are open. At temperatures above 134.0 (± 0.2) degrees Fahrenheit both the low limit thermostat contacts and the high limit thermostat contacts are closed. In either case, transistor Q1 is not able to conduct. Non-conduction of transistor Q1 signals the CMC of an alarm condition. There is no differentiation between a high or low temperature alarm. When the CMC senses a temperature alarm, it causes the TEMP and PGNCS lamps to light. When the IMU auxiliary module receives a temperature alarm, it sends the information to telemetry.

2-4.4.6 External Temperature Control. External temperature control of the IMU is provided by ground support equipment (GSE) control heater circuits in the IMU. The circuits are controlled externally to the airborne equipment by the portable temperature controller or the temperature monitor control panel of the optics inertial

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analyzer (OIA). The GSE control heater circuitry consists of a safety thermostat, six gyro heaters, two stable member heaters, three accelerometer heaters, temperature indicating sensors, and an IMU standby power sensor which disables the GSE when airborne power is on. The temperature indicating sensors act as the control sensing element of the external control and indicating circuitry. The heaters are connected in parallel. The six gyro temperature indicating sensors (two in each gyro) are connected in series to sense the average temperature of the gyros. The three accelerometer temperature indicating sensors (one in each accelerometer) are connected in series to sense the average temperature of the accelerometers. All of the GSE control heater circuitry is electrically independent of the airborne temperature control system. The GSE heater control circuitry is not available as a backup system in flight.

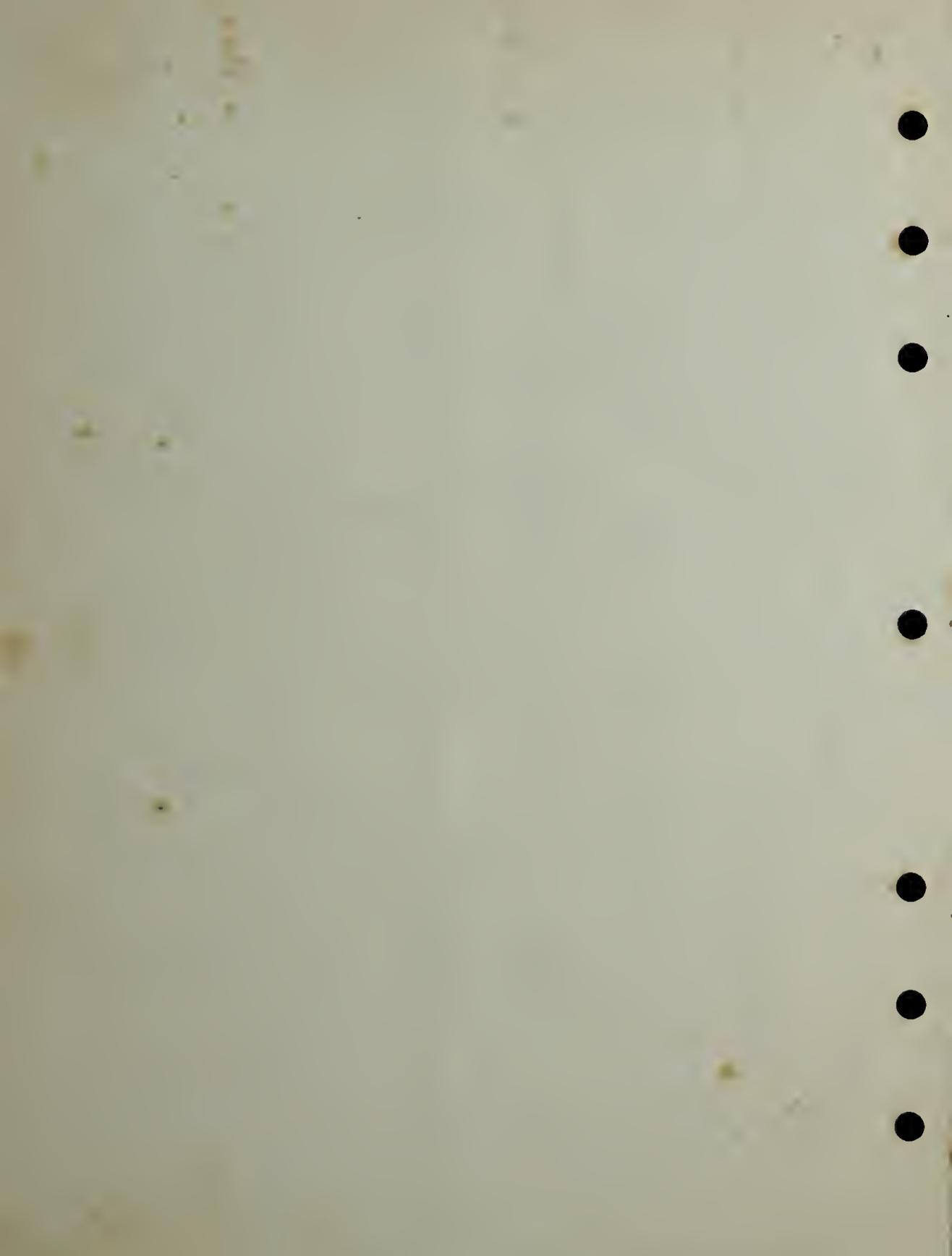
2-4.5 COUPLING DATA UNIT. The coupling data unit (CDU) contains circuits to perform the following functions:

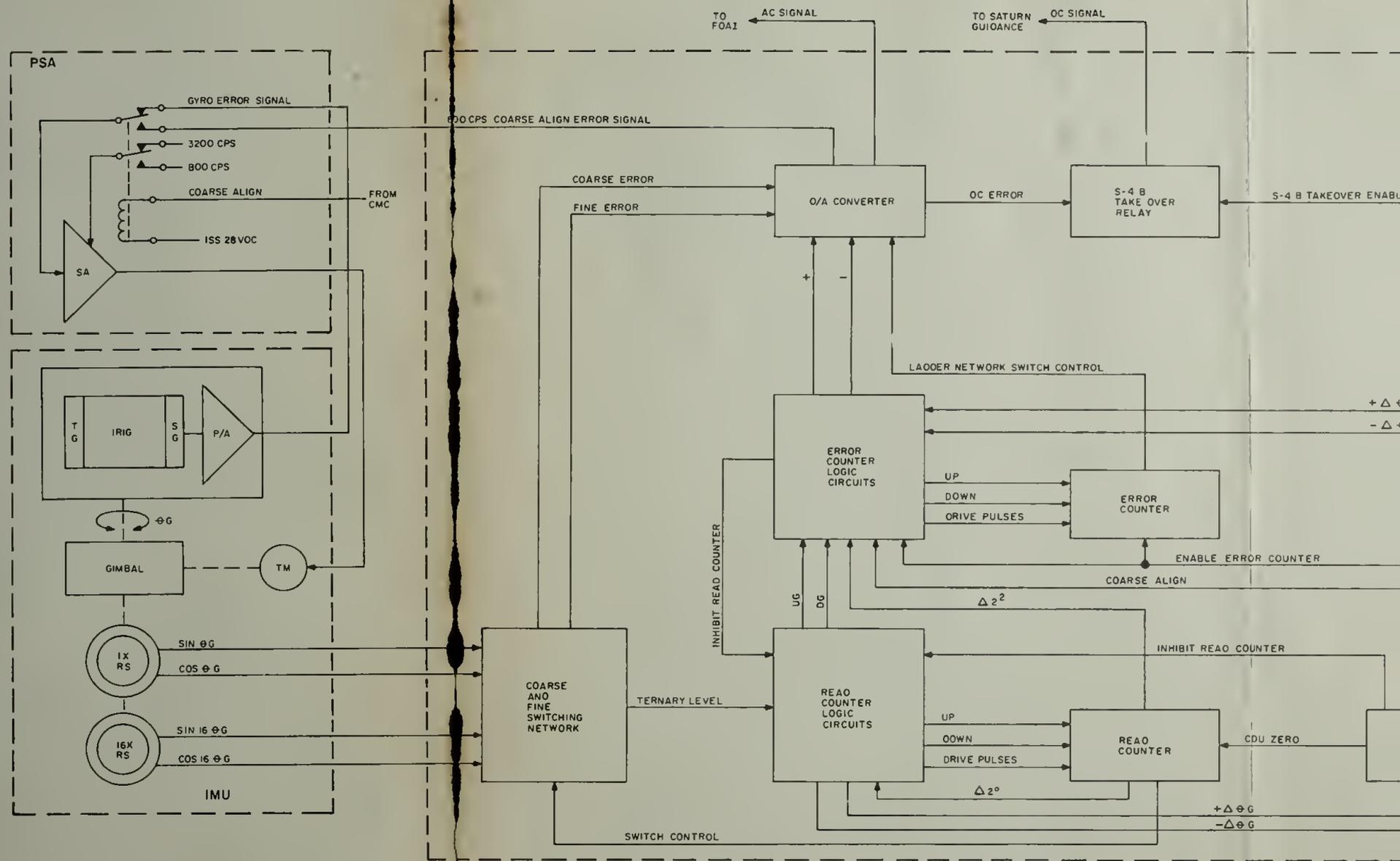
(1) Convert IMU gimbal resolver outputs into digital information which is stored in the read counter and transmitted to the CMC in the form of $\pm \Delta \theta G$ pulses.

(2) Accept $\pm \Delta \theta C$ pulses from the CMC, store these pulses in the binary error counter, and provide one dc and two ac signal outputs proportional to the stored pulses.

Any change in the IMU gimbal angles is sensed by the IMU gimbal resolvers (see figure 2-16) which generate angular information ($\sin \theta G$, $\cos \theta G$, $\sin 16 \theta G$, and $\cos 16 \theta G$) proportional to the IMU gimbal angles. This information is routed to the coarse and fine switching network which provides coarse and fine error signals to the digital-to-analog (D/A) converter as well as a ternary level signal to the read counter logic circuits. The read counter logic circuits provide up or down signals and drive pulses to increment or decrement the read counter as required to contain a digital representation of the gimbal angle. A coarse or fine system is used to increment or decrement the read counter. The coarse system is used if the IMU gimbal resolver signal is greater than 0.1 degree and causes the read counter to be incremented or decremented at a 12.8 kpps rate. The fine system is used if the IMU gimbal resolver signal is less than 0.1 degree and causes the read counter to be incremented or decremented at an 800 pps rate. The read counter can follow the IMU gimbal angles to within ± 20 arc seconds. The read counter transmits $\pm \Delta \theta G$ pulses (equivalent to approximately 40 arc seconds of gimbal angle rotation) to the CMC. The CMC utilizes these signals to determine the actual IMU gimbal angles and to display the angles on the DSKY.

During the IMU coarse align mode, the CMC compares the $\pm \Delta \theta G$ pulses from the read counter logic circuits (actual gimbal angles) with the CMC calculated (desired) gimbal angles and generates $\pm \Delta \theta C$ pulses which are routed to the error counter logic circuits. The CMC also supplies coarse align enable and enable error counter signals to the ISS moding logic to enable these circuits. The error counter logic circuits provide up or down signals and drive pulses to the error counter to cause it to be incremented or decremented as required. The D/A converter accepts ladder network





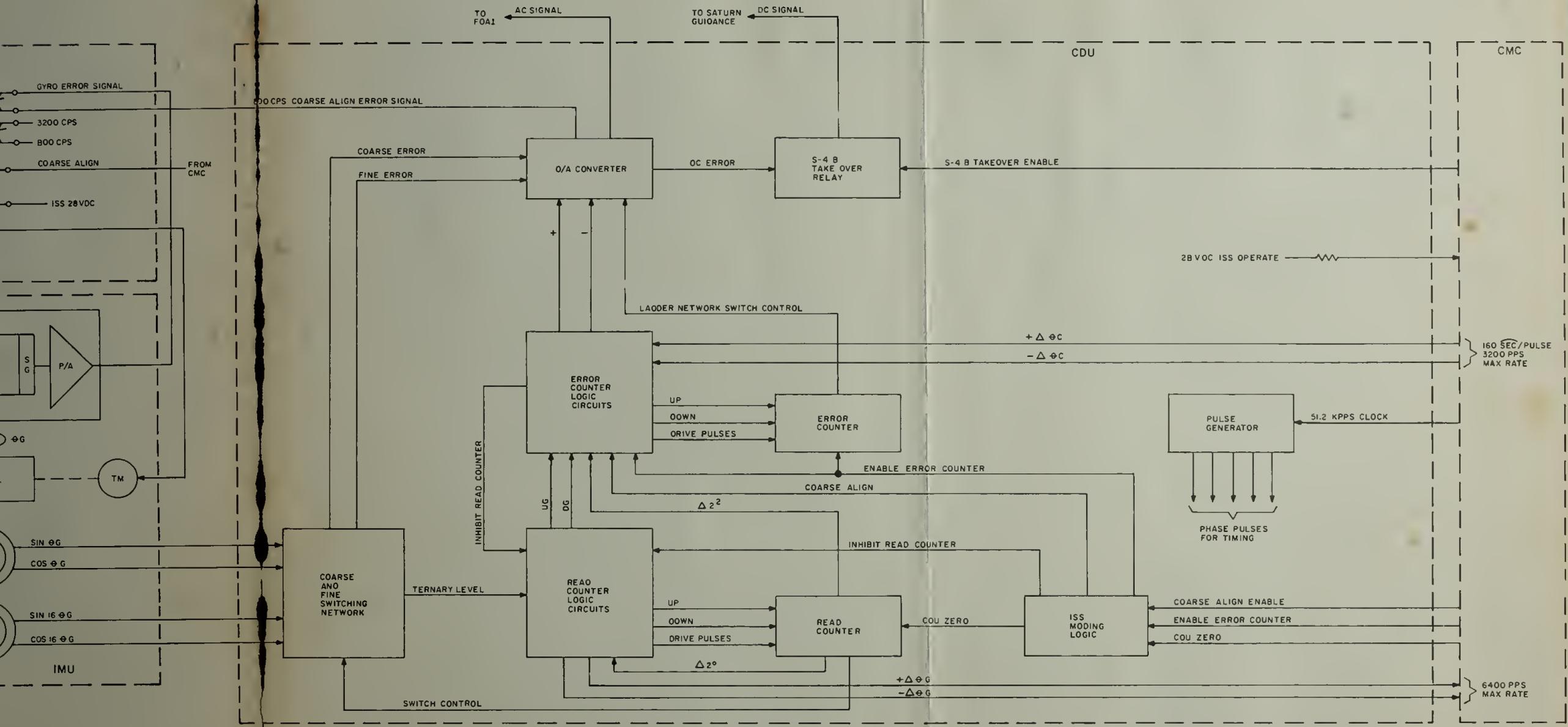
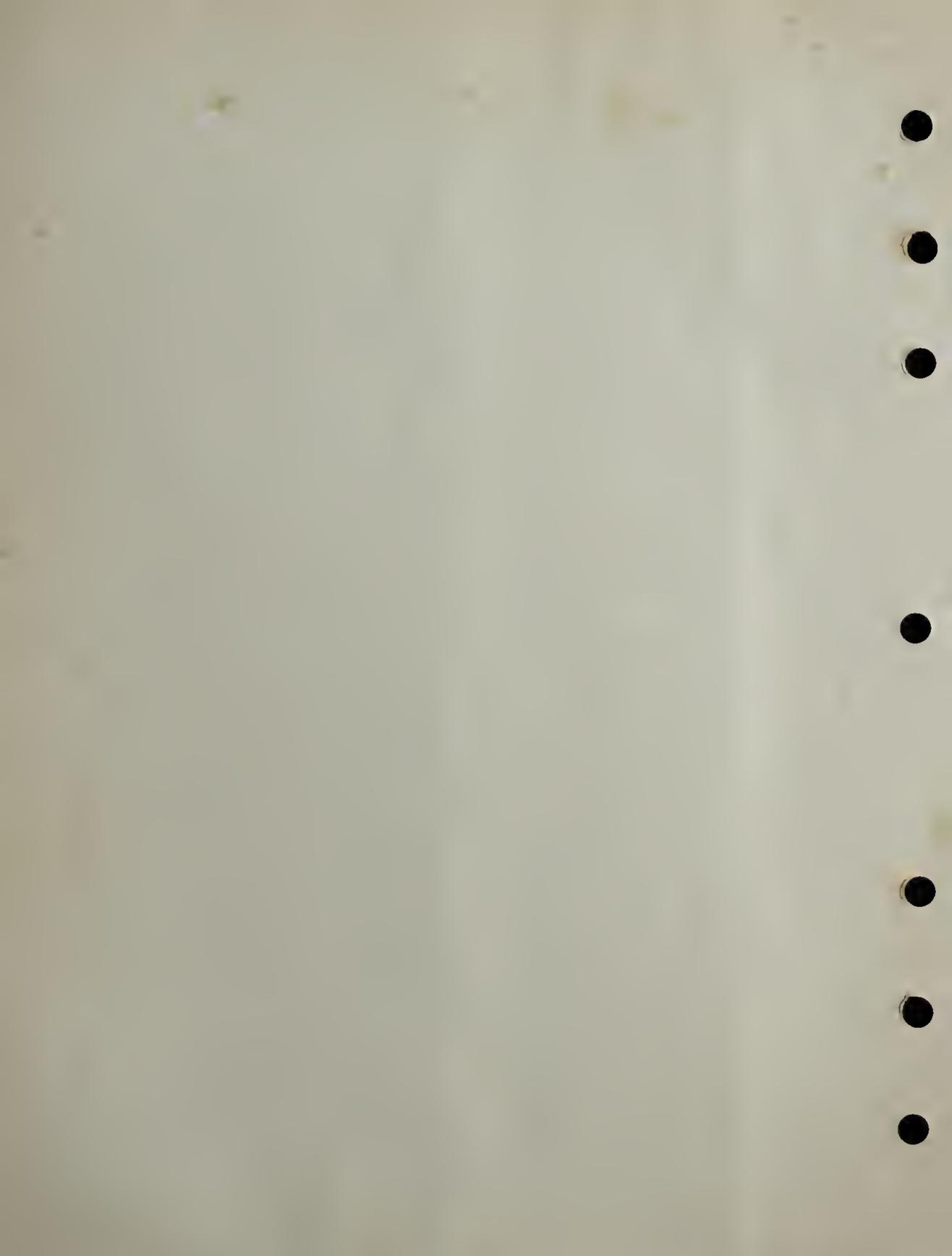


Figure 2-16. ISS-CDU Moding



switch control signals from the error counter and + or - control signals from the error counter logic circuits. The D/A converter provides an 800 cps coarse align error signal to the gimbal servo amplifiers to drive the gimbals to the desired angle. As the gimbals are positioned to the new angles, the change is detected by the resolvers which causes the read counter to be incremented or decremented in proportion to the change. A Δ^2 signal is provided from the read counter to the error counter logic circuits to cause the error counter to be decremented when the read counter is incremented to null or to clear the error counter when the IMU gimbal is at the desired angle. The D/A converter also supplies signals to the FDAI and, if the S-4B take-over relay is enabled by the CMC, to the Saturn guidance system.

2-4.5.1 ISS CDU Discrettes. All CMC discrettes issued to the CDU to initiate and control the various ISS modes or functions are 0 (± 2) vdc, CMC ground, applied through a 2,000 ohm source impedance to the CDU mode module. ISS CDU discrettes supplied by the CMC are: CDU zero, enable error counter, coarse align enable, and S-4B take-over.

2-4.5.1.1 CDU Zero. The CDU zero discrete clears all three CDU read counters simultaneously. It also inhibits the transmission of incrementing pulses to the read counters for the duration of the discrete. The CDU zero discrete is present for as long as the read counters are to be held at zero. The minimum duration is approximately 400 milliseconds. The IMU is not changed by the CDU zero discrete.

2-4.5.1.2 Enable Error Counter. The enable error counter discrete enables all three error counters simultaneously which allows them to accept incrementing pulses ($\pm \Delta \theta C$) from the CMC. The error counters are normally cleared and inhibited. The enable error counter discrete is used in conjunction with the coarse align enable discrete during the coarse align mode, and the S-4B take-over discrete. The enable error counter discrete is used alone only when display of attitude error signals on the FDAI is required.

2-4.5.1.3 Coarse Align Enable. The coarse align enable discrete enables a relay driver which energizes the coarse align and demodulator reference relays located in the PSA. This connects the coarse align error signal to the gimbal servo amplifiers and changes the reference voltage for the demodulator in the gimbal servo amplifiers from 3,200 cps to 800 cps. The discrete also enables the digital feedback pulses from the read counter to the error counter. The presence of the coarse align enable discrete and the absence of the enable error counter discrete inhibit the incrementing pulses to the read counter.

2-4.5.1.4 S-4B Take-over. Prior to the CMC generating the S-4B take-over discrete, the CMC checks to see if the error counters are in use. If the error counters are in use, the CMC removes the enable error counter discrete and, after a 1/2-second delay, issues the S-4B take-over discrete. The CMC generates the enable error counter discrete 40 milliseconds after the S-4B take-over discrete and, after a 4 millisecond delay, can send $\pm \Delta \theta C$ pulses to the error counter. The S-4B take-over discrete energizes the control relays which connect the error counter D/A converter dc outputs to the Saturn guidance electronics for Saturn booster vehicle steering control. During

this mode, the digital feedback pulses from the read counter to the error counter are inhibited and the CMC monitors spacecraft position and velocity by use of the PIPA's and the ISS CDU read counters.

2-4.6 ISS MODES OF OPERATION. The ISS has five major modes of operation which are: IMU turn-on, ISS CDU zero, coarse align, S-4B take-over, and thrust vector control. Sub-modes are: IMU cage, attitude error indication, fine align, inertial reference, and attitude control. All ISS moding is initiated and controlled by CMC discrettes to the CDU. The CMC may send a single discrete, a combination of discrettes, or no discrete at all to select an ISS mode of operation.

2-4.6.1 IMU Turn-on. The IMU turn-on mode is a backup mode used to drive the gimbals to their zero position and hold them there during the IMU turn-on period. (See figure 2-17.) The IMU turn-on mode is enabled upon closure of the ISS OPERATE circuit breaker and allows a 90-second gyro run up period. The ISS OPERATE circuit breaker routes 28 vdc IMU operate power through the deenergized contacts of the ISS turn on control relay, located in the IMU auxiliary assembly module, to the cage relays. The 28 vdc IMU operate power is also routed through the same deenergized contacts to the CMC as a turn on delay request discrete. The cage relays energize and, in turn, cause the coarse align relays to be energized. The cage relays route the 1X gimbal resolver sine winding outputs through the contacts of the coarse align relays to the respective gimbal servo amplifiers. The gimbal servo amplifiers drive the gimbals until the resolver signals are nulled. The operation of the caging loops is discussed further in the IMU cage mode description.

Upon receipt of the ISS turn on delay request discrete, the CMC sends the ISS CDU zero discrete and the coarse align enable discrete to the CDU for a minimum period of 90 seconds. The CDU zero discrete clears the read counters and inhibits the incrementing pulses to the read counters. The coarse align enable discrete provides a redundant means of energizing the coarse align relays.

A second set of deenergized contacts on the ISS turn on control relay routes a ground to the time delay circuit of the pulse torque power supply which inhibits the operation of the power supply and thus prevents accelerometer pulse torquing during the 90 second turn on period. This allows time for the accelerometer floats to be centered and the gyro wheels to run up prior to torquing.

After the 90 second delay has been completed, the CMC sends the ISS turn on delay complete discrete. This discrete acts through a relay driver to energize and latch in the ISS turn on control relay. Energizing the ISS turn on control relay deenergizes the cage relay, removes the ISS turn on delay request discrete, and removes the inhibit from the pulse torque power supply. The computer program can then place the ISS in the inertial reference mode by removing both the CDU zero and the coarse align enable discrettes, or it can initiate the coarse align mode by removing only the CDU zero discrete and sending the ISS enable error counter discrete. The IMU turn on circuit will be reset whenever 28 vdc IMU operate power is turned off.

2-4.6.2 ISS CDU Zero. The purpose of the ISS CDU zero mode is to clear and inhibit the three ISS CDU read counters. The mode is initiated by the CMC sending the CDU zero discrete. The presence of the discrete is maintained for as long as the read counters are to be held at zero.

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2-4.6.3 Coarse Align Mode. The purpose of the coarse align mode is to change the orientation of the gimbals by CMC command. This is accomplished by feeding the CDU error counter CMC pulses equal to the required change in gimbal angles. The mode is initiated by the CMC sending the coarse align discrete (followed in 40 msec by the enable error counter discrete) to the three ISS channels of the CDU. The CMC, knowing the actual gimbal angle registered in the read counters, can calculate the desired amount of change in gimbal angles required to reposition the gimbals to the desired angles. The CMC converts this change into a number of $\pm\Delta\theta C$ pulses and sends these pulses to the error counters. The $\pm\Delta\theta C$ pulses are sent to the error counters at a rate of 3,200 pps in bursts of 60 milliseconds. Bursts of pulses are sent 480 milliseconds apart. Each $\Delta\theta C$ pulse is equal to a change in gimbal angle of 160 arc seconds. The error counter, having been enabled, accepts the pulses and counts up or down as necessary until all the pulses have been registered.

The ladder decoder in the D/A converter module supplies an 800 cps, amplitude modulated analog error signal equivalent to the digital information in the error counter. The ladder decoder signal is summed with a feedback signal and applied through a mixing amplifier, also located in the D/A converter module, to the gimbal servo amplifiers to drive the gimbals to the desired angles. The coarse align error signal output of the mixing amplifier is applied to the gimbal servo amplifiers through the contacts of the coarse align relays located in the PSA. The coarse align relays, which are energized by the coarse align enable discrete acting through a relay driver, switch the input of the gimbal servo amplifiers from the gyro preamplifiers to the coarse align error signal output of the ISS D/A converters. The demodulator reference relay is also energized by the coarse align enable discrete and switches the reference frequency of the demodulator in the gimbal servo amplifiers from 3,200 cps to 800 cps. The coarse align enable discrete also energizes a relay in the gimbal servo amplifiers which switches additional capacitance into the amplifier's compensation networks to tune them for 800 cps operation.

As the gimbals are driven, $\pm\Delta 2^2$ pulses, representing the change in actual gimbal angle, are generated by the read counter and applied to the error counter. The $\pm\Delta 2^2$ pulses are also equal to 160 arc seconds and decrease the $\pm\Delta\theta C$ pulses registered in the error counter. The error counter output to the ladder decoder, therefore, represents the difference between the desired amount of change in gimbal angle and the amount of change actually accomplished. The error counter reaches a null or reads zero, and the gimbals stop moving, when the actual gimbal angle has changed by an amount equal to the total value of the $\pm\Delta\theta C$ pulses sent by the computer to the error counter. The CMC checks the contents of the read counter 2.1 seconds after the CMC has sent the last coarse align torquing pulse to the error counter. If the gimbal angles are not within two degrees of the desired angles, the computer issues an alarm.

The rate at which the gimbals are driven is limited to prevent damage to the gyros and to assure that the read counter can track the gimbal angle accurately. The rate of gimbal movement is limited by feeding back the CDU fine error signal $\sin 16 (\theta - \psi)$ to the input of the mixing amplifier located in the D/A converter module. The coarse error signal is also fed back to the mixing amplifier but is used only during the turn-on mode. The fine error signal is out of phase with the output of the ladder decoder and has an amplitude proportional to the difference between the actual gimbal angle (θ) and the angle registered in the read counter (ψ). The fine error signal is applied through a voltage limiting circuit to the summing junction of the mixing amplifier where it is

summed with the 800 cps ladder decoder output signal. The D/A converter ladder decoder output is applied to the mixing amplifier through a scaling amplifier and a voltage limiting diode network. The scaling amplifier controls the signal gain to produce a scale factor of 0.3 volt rms per degree. The output of the mixing amplifier will be at a null when the D/A converter ladder decoder output, after limiting, is equal to the fine error feedback signal. The fine error signal will be a constant value only when the gimbal and the CDU are going at the same rate and with the gimbal angle leading the CDU angle. Since the CDU is constrained to counting at one of two speeds, the gimbals will be constrained to a rate equal to one of these two speeds. During the coarse align mode, the CDU is constrained to a high counting speed of 6.4 kpps and a low counting speed of 800 cps. At all other times, the high counting speed is 12.8 kpps.

If the gimbals are moving at a faster rate than the rate at which the CDU is counting, the fine error signal will increase causing a retarding torque to be developed by the gimbal servo amplifier. If the gimbals are moving at a rate slower than the rate at which the CDU is counting, the fine error signal will decrease causing the gimbal servo amplifier to apply an accelerating torque to the gimbals. By adjusting the gain of the fine error signal into the mixing amplifier, the gimbal drive rate is limited to either 35.5 degrees per second (6.4 kpps CDU counting rate) or 4.5 degrees per second (800 cps CDU counting rate).

2-4.6.4 S-4B Take-over. During the S-4B take-over mode, the CMC controls spacecraft steering by sending attitude error signals to the Saturn guidance system through the ISS CDU. This mode is a backup for the Saturn guidance system if the Saturn guidance system IMU fails during earth ascent, translunar injection, or earth orbit. The S-4B take-over mode is initiated by the astronaut activating a switch on the main D and C panel. Closure of this switch routes a +28 vdc discrete to the ISS CDU where it arms a set of relays which, when energized, connect the dc outputs of the D/A converters to the Saturn guidance system. The +28 vdc discrete is also routed to the CMC. Receipt of this discrete by the CMC signals the CMC to issue the S-4B take-over discrete. The S-4B take-over discrete energizes the control relays which connect the D/A converters dc outputs to the Saturn guidance system. The CMC issues the enable error counter discrete 40 milliseconds after the S-4B take-over discrete. With the error counters enabled and the D/A converters dc outputs connected to the Saturn guidance system, the CMC can send steering signals to the Saturn guidance system. The CMC calculates the amount of yaw, pitch, and/or roll required for proper spacecraft attitude and determines the amount of $\pm\Delta\theta C$ pulses to be sent to the error counters. The error counters receive the $\pm\Delta\theta C$ pulses and count up or down as required until all pulses have been received. The error counters send this digital information to the D/A converters where it is converted to a dc signal and sent to the Saturn guidance system for attitude control. The CMC monitors the spacecraft response to the attitude signals through the read counters and the PGNCS PIP's. During this mode, the digital feedback signals from the read counters to the error counters are inhibited.

Prior to the CMC issuing the S-4B take-over discrete, the CMC checks to see if the error counters are in use. If the error counters are in use, the CMC removes the enable error counter discrete which inhibits and clears the error counters. The S-4B take-over discrete will then be issued after a 1/2-second delay.

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2-4.6.5 Thrust Vector Control. During the thrust vector control mode, the CMC controls the SPS engine gimbals by sending steering control signals to the SPS engine gimbal amplifiers through the optics CDU. The thrust vector control mode is initiated by the astronaut activating a switch on the main control panel. Closure of this switch routes a +28 vdc discrete to the optics CDU where it arms a set of relays which, when energized, connect the dc outputs of the optics CDU D/A converters to the SPS engine gimbal amplifiers. The +28 vdc discrete is also routed to the CMC. Receipt of this discrete by the CMC, signals the CMC to issue the thrust vector control discrete. The thrust vector control discrete energizes the control relays which connect the optics CDU D/A converters dc outputs to the SPS engine gimbal amplifiers. The CMC issues the optics D/A enable discrete 40 milliseconds after the thrust vector control discrete. With the optics error counters enabled and the optics CDU D/A converters dc outputs connected to the SPS engine gimbal amplifiers, the CMC can send steering control signals to position the SPS engine gimbals. The CMC calculates the amount of pitch or yaw required for proper trajectory and then determines the amount of $\pm\Delta\theta C$ pulses to be sent to the error counters. The error counters receive the $\pm\Delta\theta C$ pulses and count up or down as required until all pulses have been received. The error counters send this digital information to the D/A converters where it is converted to a dc signal and routed to the SPS engine gimbal amplifiers. The CMC monitors spacecraft response to the engine gimbal steering signals through the ISS CDU read counters and the PGNC'S PIP's. During this mode, the digital feedback signals from the read counters to the error counters are inhibited.

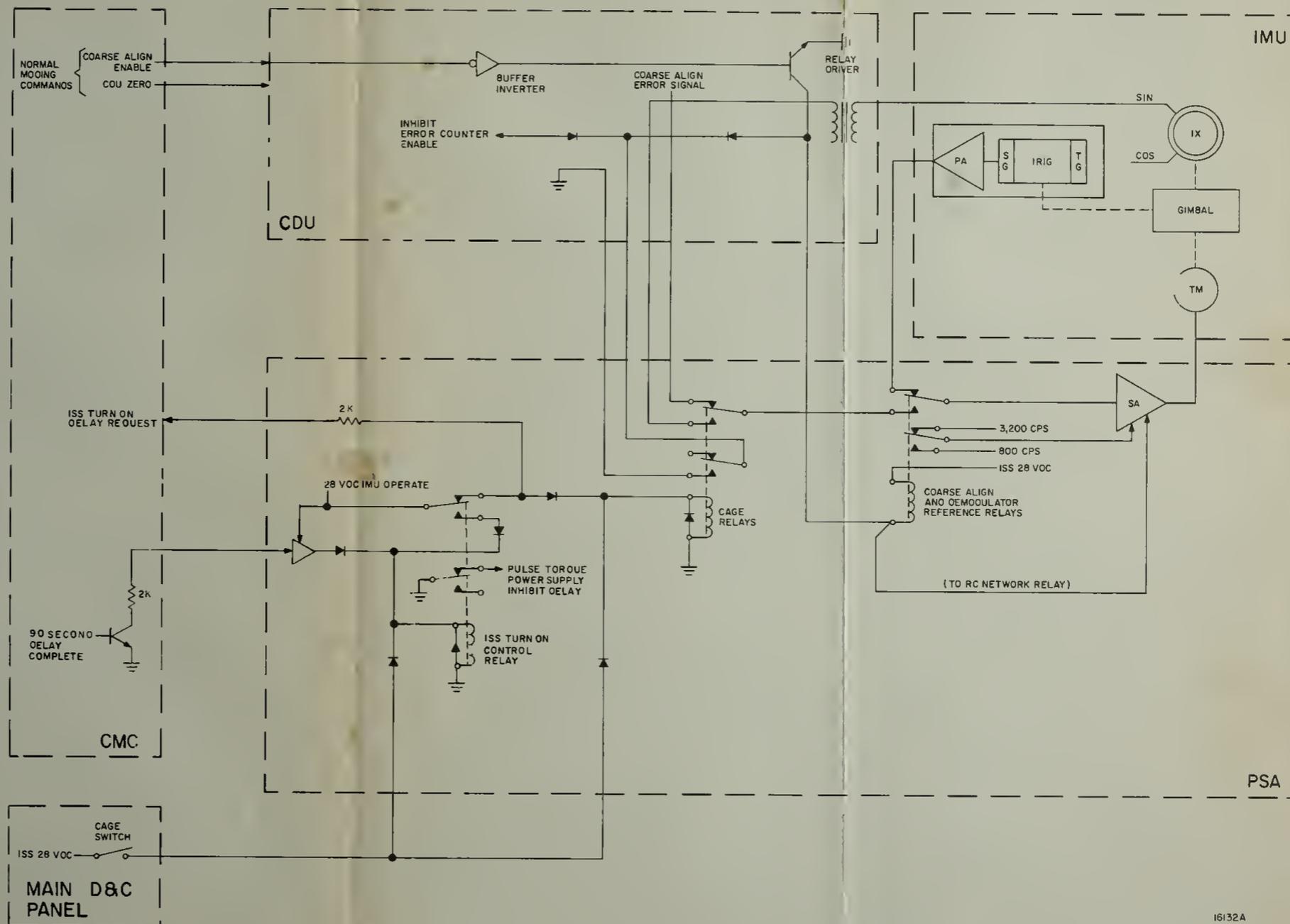
Prior to the CMC issuing the thrust vector control discrete, the CMC checks to see if the optics CDU error counters are in use. If the error counters are being used, the CMC removes the optics D/A enable discrete which inhibits and clears the error counters. The CMC will then issue the thrust vector control discrete.

2-4.6.6 IMU Cage Mode. The IMU cage mode (figure 2-17) is an emergency backup mode which will allow the astronaut to recover a tumbling IMU by setting the gimbals to zero. During this mode, the 1X gimbal resolver sine winding outputs are fed through the CDU's to the gimbal servo amplifiers to drive the gimbals until the resolver signals are nulled.

The IMU cage mode is initiated by the astronaut pressing the IMU CAGE switch. The switch is held until the gimbals settle at the zero position (five seconds maximum). The gimbal position may be observed on the FDAI. The IMU CAGE switch routes a 28 vdc discrete signal to the CMC and to the cage relays located in the PSA. The cage discrete energizes the cage relays which in turn cause the coarse align relays, the demodulator reference relay, and a relay in the gimbal servo amplifiers to be energized. The relay in the gimbal servo amplifiers switches additional capacitance into the RC compensation networks to tune them for 800 cps operation. The demodulator reference relay changes the gimbal servo amplifier demodulator reference signal from 3,200 cps to 800 cps. The cage relays switch the 1X gimbal resolver sine winding outputs through the energized contacts of the coarse align relays into the corresponding gimbal servo amplifier inputs. The gimbal servo amplifiers drive the gimbals until the resolver signals are nulled which occurs at zero gimbal angle.

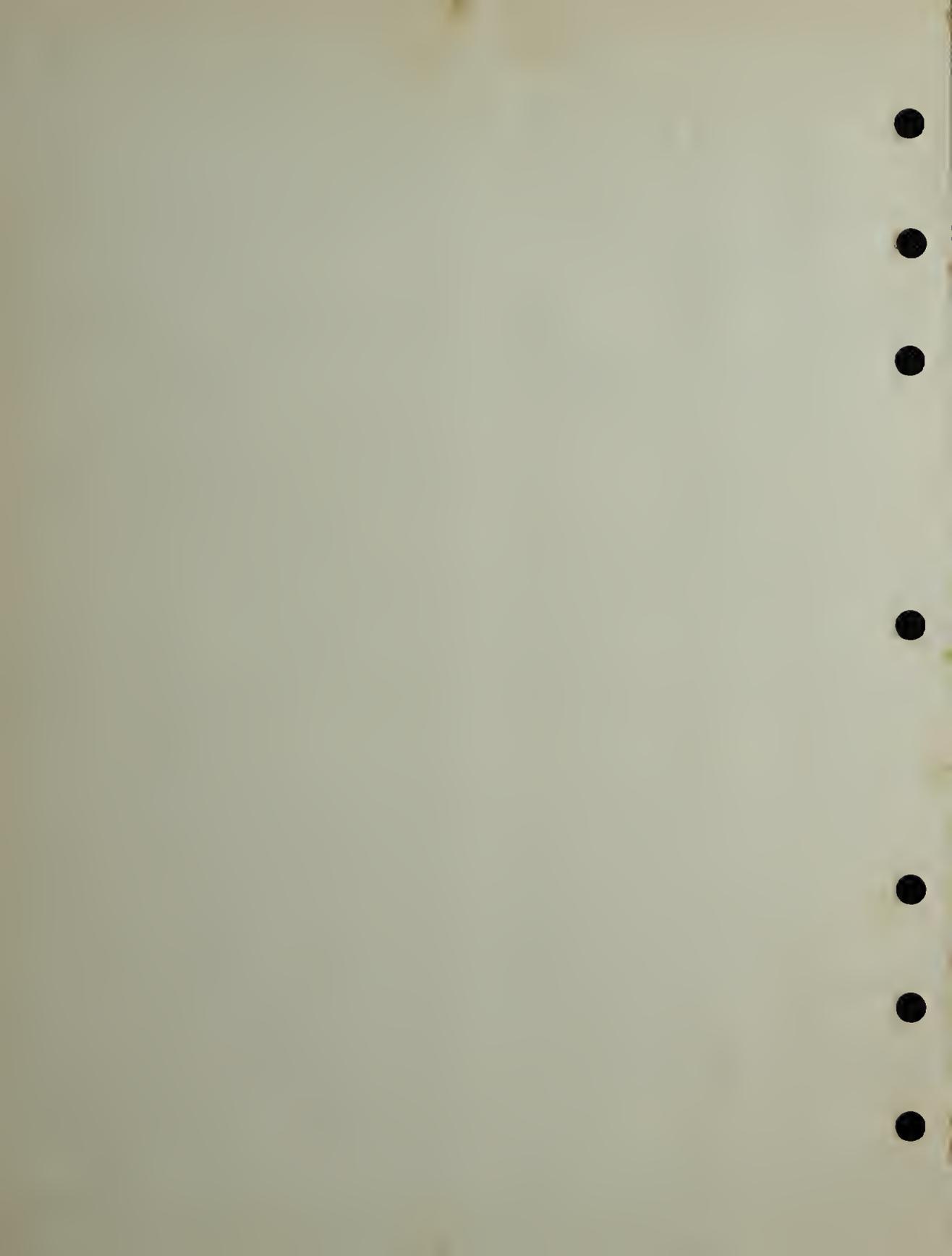


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Figure 2-17. IMU Cage Mode



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Upon receipt of the IMU cage discrete, the CMC will discontinue sending the enable error counter discrete, the coarse align enable discrete, and the incrementing pulses to the CDU. The CMC will also discontinue sending torquing commands to the fine align electronics if any are in process.

After the IMU CAGE switch is released, the CMC will allow the read counters to settle, then will place the PGNCS in an attitude control mode. During the time the IMU cage discrete is present and while the read counters are settling, the NO REFERENCE lamp on the DSKY is lighted.

The IMU cage mode will also be entered automatically whenever the IMU is turned on. During the normal turn on sequence, the closure of the ISS OPERATE circuit breaker will route 28 vdc through the deenergized contacts of the ISS turn on control relay to the cage relays. The cage relays energize and cage the gimbals. After the 90 second turn on time delay has been completed the CMC will (if it is on) send the ISS turn on delay complete discrete which will energize the ISS turn on control relay which, in turn, deenergizes the cage relays. If, however, the CMC is off or in standby when the IMU is turned on, the ISS turn on control relay will remain deenergized and the ISS will remain in the IMU cage mode.

If the IMU cage mode is entered as a result of an IMU turn on with the CMC off or in standby, the ISS may be placed in the inertial reference mode by allowing 90 seconds for gyro runup, then pressing the IMU CAGE switch. The IMU CAGE switch will energize and latch the auto cage relay control which removes the ISS 28 vdc which had been energizing the cage relays. With the auto cage relay control latched, the cage relay will deenergize when the IMU CAGE switch is released. Deenergizing the cage relays causes the coarse align relays to be deenergized which connects the gyro error signals to the respective gimbal servo amplifiers. The stabilization loops will maintain the stable member inertially referenced to the orientation established by the caging loops.

2-4.6.7 Attitude Error Indication. The attitude error indication mode supplies attitude error signals to the FDAI. The attitude error indication mode is initiated by the CMC sending the enable error counter discrete to the CDU. The ISS read counters are enabled and register the IMU gimbal angles which are sent to the CMC as $\pm\Delta\theta_G$ pulses. The CMC calculates the difference between the actual gimbal angles registered in the read counters and the desired IMU gimbal angles and, if any difference exists, converts this difference into $\pm\Delta\theta_C$ pulses which are sent to the error counters. The error counter, having been enabled, accepts the pulses and counts up or down until all pulses are registered. The error counter output is applied to the D/A converters where it is converted into an ac signal proportional to the error counters contents and applied to the FDAI.

Any change in actual gimbal angles causes the read counters to increase or decrease proportionally. If the attitude error increases or decreases, the CMC will send additional $\Delta\theta_C$ pulses to decrease or increase, respectively, the error counter contents. The digital information in the error counters is converted into an 800 cps,

amplitude modulated, analog error signal by the ladder decoder in the DAC's. This ac signal, representing the difference between the actual gimbal angles and the desired gimbal angles, is applied through the scaling amplifiers to the FDAI.

2-4.6.8 Fine Align Mode. The purpose of the fine align mode is to reposition the stable member to a fine alignment by torquing the gyros. The fine align mode is actually a gyro torquing function accomplished during the inertial reference mode. The torquing current to the gyros is provided by the fine align electronics located in the PSA. The fine align electronics are enabled and controlled by CMC pulses sent directly to the fine align electronics. The CMC does not send command discrettes to the ISS CDU during this mode. The ISS is in the inertial reference mode prior to the enabling of the fine align electronics and returns to that mode when the fine align electronics are disabled. The computer accepts the angular data received from the optical measurements, transforms the S_t LOS, into stable member coordinates, and compares the desired coordinates with the actual coordinates. Differences are used to compute the angular rotation about each stable member axis which will move the stable member to the correct orientation. The fine align electronics torques the gyros on a time shared basis. The CMC sends four types of pulse trains to the fine align electronics. The first pulse train to be sent is the torque enable command which enables the fine align electronics. The second pulse train is a gyro select command which selects a particular gyro and the direction it is to be torqued by means of a switching network which closes the current path through the proper torque ducosyn coil. The third and fourth types of pulse trains are the torque set and torque reset commands which control a binary current switch to start and stop the current flow through the selected torque ducosyn coil. The amount of current flow through the torque ducosyn coils is precisely controlled at a fixed value. The amount of gyro torquing to be accomplished is determined by the amount of time torque current is applied, that is, the time duration between the receipt of the torque set and the torque reset commands. The factor is calculated by the CMC based on optical alignment measurements. The torque ducosyn displaces the gyro float causing the ducosyn signal generator to apply an error signal to the stabilization loop. The stabilization loops drive the gimbals to reposition the stable member. Upon completion of the torquing, the stable member remains fixed in inertial space, and in fine align mode, until the torque enable command is removed, after which the ISS remains in inertial reference mode until further change is commanded.

During the fine align mode, the ISS error counters remain cleared and inhibited. The read counters continue to repeat the gimbal angles and send angular data ($\pm\Delta\theta G$) to the CMC.

2-4.6.9 Inertial Reference Mode. The purpose of the inertial reference mode is to provide a coordinate reference system on which attitude and velocity measurements and calculations may be based. During the inertial reference mode, the stable member is held fixed with respect to inertial space by the stabilization loops. The ISS CDU read counters provide the CMC with changes in gimbal angles with respect to the stable member. The ISS is in the inertial reference mode during any operating period in which there is an absence of moding commands. During the inertial reference mode, the fine align electronics is inhibited and the ISS error counters are cleared and inhibited.

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2-4.6.10 Attitude Control. The attitude control mode, a PGNC mode, utilizes the digital autopilot to maintain spacecraft attitude. The ISS stabilization loops maintain an inertial reference from which spacecraft attitude can be determined. The spacecraft attitude is compared to a desired attitude by the digital autopilot. If an error exists, the RCS jets are used to change the spacecraft attitude. Attitude errors are displayed on the FDAI.

During the attitude control mode, the error counter is enabled. The computer sends the desired change in gimbal angle orientation to the error counters. The output of the error counters is developed into an analog error signal (attitude error signal) by the 800 cps ladder network and the output is fed to the FDAI. The computer develops discretes that control the firing of RCS jets and, therefore, change the orientation of the spacecraft. The change in spacecraft orientation is sensed by the IMU stabilization loops and results in changing IMU gimbal angles. The gimbal resolver output is sent to the FDAI to display total attitude and to the summing logic and coarse fine mixing circuit. Resulting digital information is sent to the read counter. The read counter supplies the changing gimbal angle pulses to the CMC. The CMC uses the information in determining when to stop firing the RCS jets. The FDAI error counter is pulsed to zero, nulling the attitude error signal on the FDAI.

2-5 OPTICAL SUBSYSTEM

The OSS allows direct visual sightings to be made and precision measurements to be taken on celestial objects by means of the SCT and SXT. The angular data developed is transferred by the CDU into the CMC, which uses this data to calculate spacecraft position and trajectory. In addition, the results obtained are used to align the IMU to a star framework.

Establishment of a LOS to selected celestial targets generally requires use of the SCT and/or SXT together with spacecraft positioning controls. The astronaut changes spacecraft attitude to direct the optics field of view toward the celestial target area. Direct viewing through the wide 60 degree field of the SCT enables target search and recognition. The SXT is then used to take precise measurements.

After target acquisition, the optical angular measurements and the time of sighting are transferred to the CMC. Data pertaining to the location of targets and programs for navigational calculations stored in the CMC are then compared. The results of the comparisons are used to align the IMU and determine spacecraft position and trajectory.

In case of failure in the optics electronics, the astronaut can operate the SCT manually with a universal tool and read the angles off the SCT counters. In such emergencies, the astronaut will calculate, with possible assistance from the ground, a navigational fix to determine position and required velocity corrections.

The OSS consists of an optical unit, two CDU channels, portions of the indicator control panel, and portions of the PSA. The indicator control panel contains the controls and indicators that are used to establish OSS operating modes.

Figure 2-18 is a functional block diagram of the OSS. The diagram shows the flow of data for the various modes of operation selected by mode switching and the functional relationship among the various blocks. Each functional block is described in subsequent paragraphs.

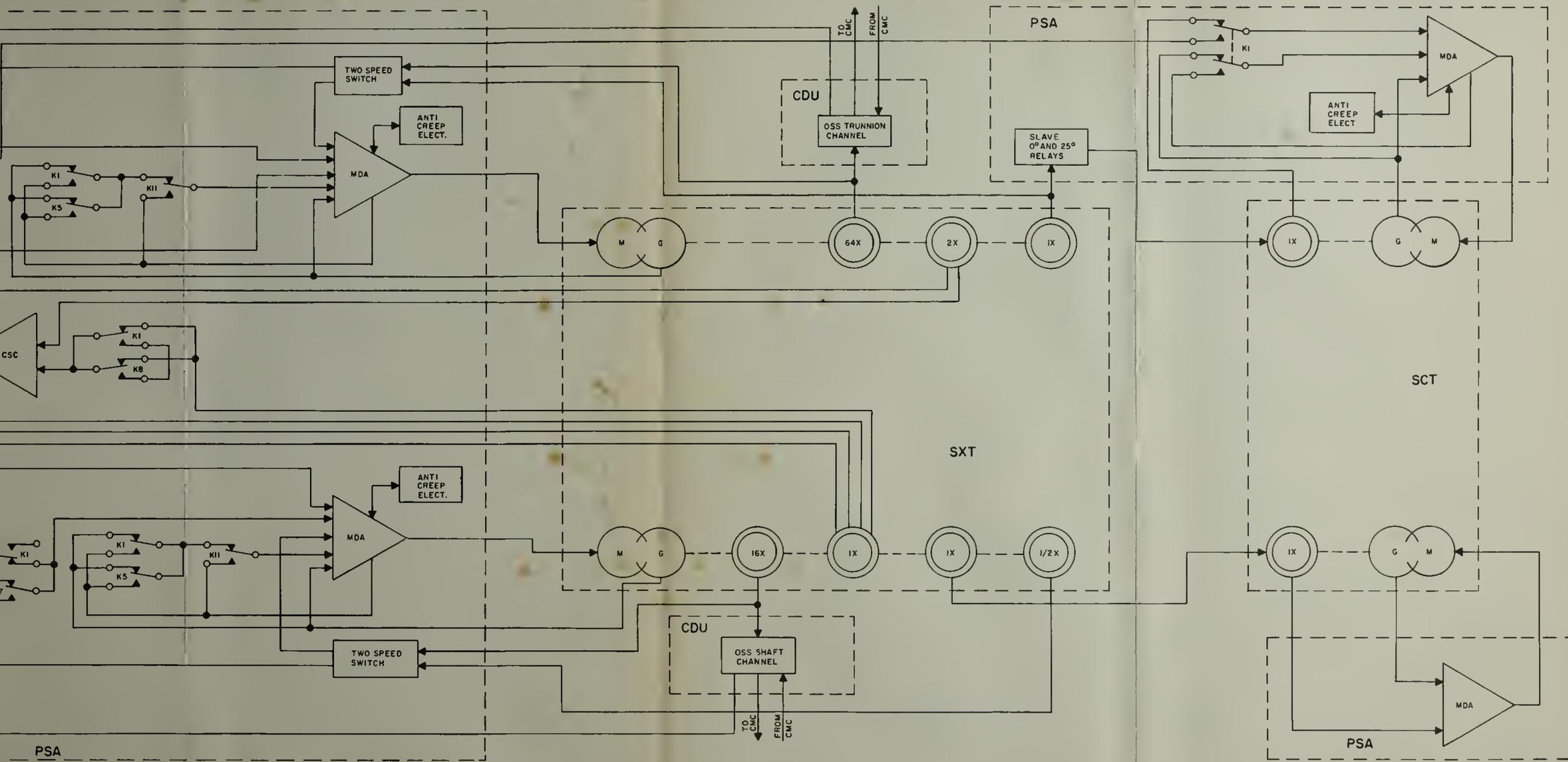
2-5.1 SCANNING TELESCOPE. The SCT is a single LOS, refracting type, low power instrument with 60 degrees instantaneous field of view. The SCT wide field of view is used for general celestial viewing and recognition of target bodies for sighting setups and measurements. In addition, it is used to track landmark points during earth and lunar orbits.

The SCT has two axes of rotational freedom, defined as the shaft and trunnion axes. Rotation about the shaft axis defines increments of shaft angle movement (A_S). Rotation about the trunnion axis defines increments of trunnion angle movement (A_t).

The prime element of the SCT is a double dove prism, (prism), mounted in the head assembly. The prism introduces the target image into the SCT optical system. The prism is positioned about the two axes interpreted as A_S and A_t . Mechanically, this is accomplished by rotation, through a differential, of the complete head assembly and driving of the prism on its mount. A differential gearing system enables independent positioning of A_S and A_t . The independent positioning enables the LOS established through the prism to traverse within the following limits: zero degrees (parallel to shaft axis) to ± 60 degrees at A_t elevation, unlimited 360 degrees in A_S . When the SCT is slaved to the SXT, rotation is limited to 270 degrees due to limit stops along the SXT shaft axis. Due to obstructions created by aperture limitation in the spacecraft frame, the LOS along the trunnion axis has a useful range of approximately 58 degrees. Therefore, the aggregate maximum field that can be viewed by rotating the trunnion and shaft within their respective limits is 116 degrees.

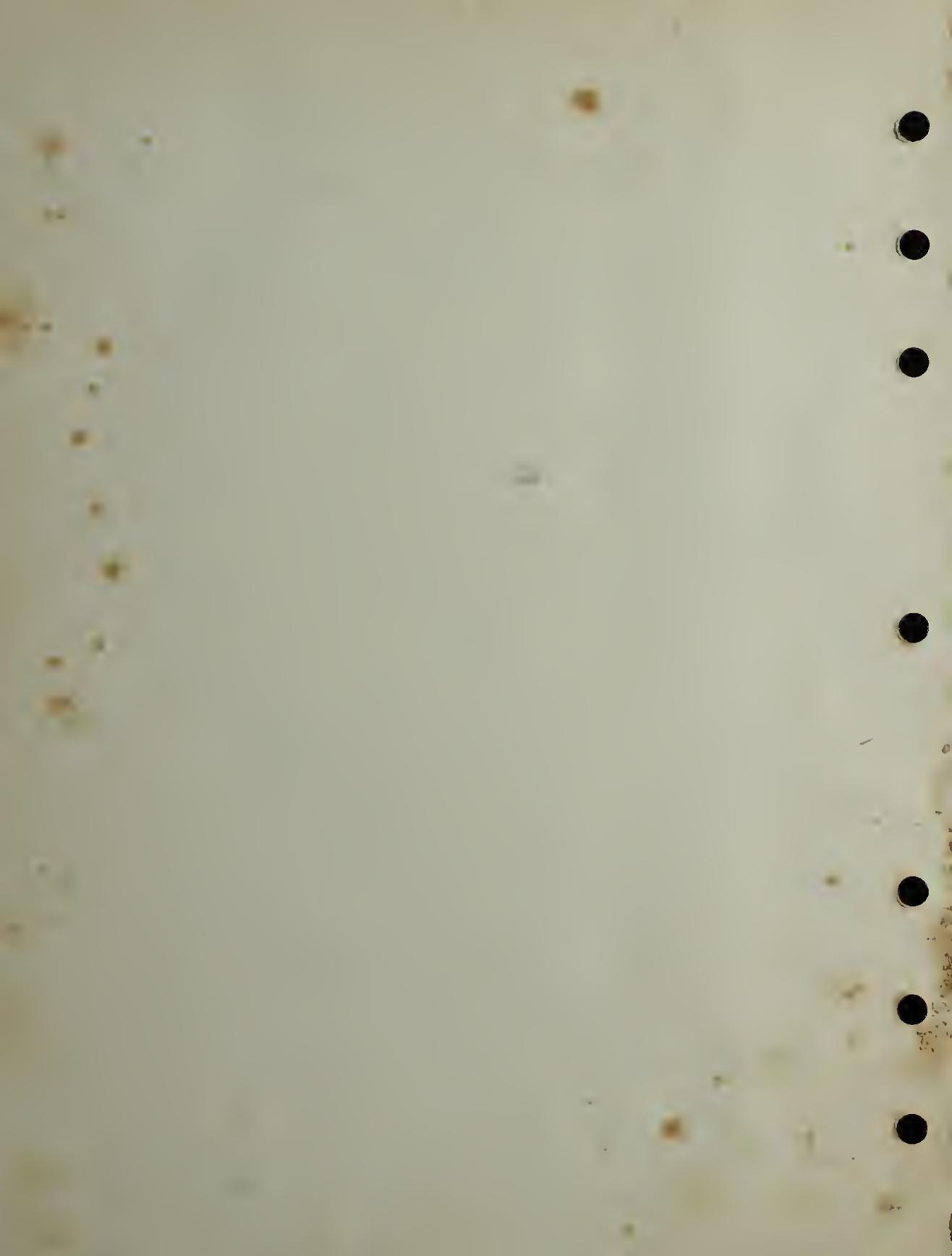
The optics hand controller controls the shaft and trunnion drive rates. The drive rates are integrated by SXT servos which position the SCT LOS. The shaft and trunnion angles can be read directly from the SCT by counters mounted in the face of the optical panel.

2-5.2 SEXTANT. The SXT is a highly accurate, dual LOS, electro-optical instrument with 28 power magnification and 1.8 degrees field of view. It is capable of sighting two celestial targets simultaneously and measuring the angle between them with 10 arc seconds accuracy. One LOS, called landmark LOS (LLOS) is fixed along the shaft axis normal to the local conical surface of the spacecraft. The LLOS is positioned by changes in spacecraft attitude. The other LOS, called star LOS (S_t LOS), has two degrees of rotational freedom about the shaft and trunnion axis. Variation about the trunnion axis is represented by movement of an indexing mirror. S_t LOS positioning is controlled by electro-mechanical integration loops consisting of servos, tachometers, and associated electronics. Control of the servos is determined by operating modes which are selected using indicator control panel switches. The S_t LOS movement is independent of the fixed LLOS. Measurements are made by first sighting into the SXT eyepiece and adjusting spacecraft attitude until the LLOS image is centered on the SXT reticle. Subsequent positioning of the S_t LOS to locate the star image coincident with the LLOS is done to satisfy requirements necessary for measurements to be taken between the two images. (Coincidence must be as near the reticle center as possible.) Positioning accuracies of the SXT trunnion and shaft axes are within 10 and 40 arc seconds, respectively.



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Figure 2-18. OSS, Functional Block Diagram



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2-5.3 SCT SERVO LOOPS. Shaft and trunnion servo loops are used to position the SCT. The shaft and trunnion servo loops function as single speed repeater servos. Trunnion servo loop operation is determined by mode switching.

2-5.3.1 SCT Shaft Servo Loop. A single speed positioning servo loop is used to rotate the SCT optics about the shaft axis. The SXT shaft 1X resolver generates an error signal proportional to the mechanical rotor displacement from electrical null. The electrical input to the SCT shaft 1X resolver is the sine-cosine output signal from the SXT shaft 1X resolver in the SXT shaft servo loop. The SCT resolver error signal is applied to the MDA summing network. Feedback from the motor-generator is applied through a feedback compensation network of the MDA summing network. The amplifier circuit generates the motor drive signals in the phase and magnitude required to drive the rotor of the SCT shaft 1X resolver to null and to position the SCT shaft at a new angle. The SCT shaft movement is thus slaved to SXT shaft movement.

2-5.3.2 SCT Trunnion Servo Loop. Rotation of the double dove prism and mount assembly about the trunnion axis is controlled by the SCT trunnion servo loop. This servo functions as a single speed, positioning servo. The SCT trunnion 1X resolver generates an error signal proportional to the mechanical rotor displacement from electrical null. The electrical input to the SCT trunnion resolver is determined by the configuration of the SLAVE, 0° and 25° relays. These relays are controlled by the position of the TELESCOPE TRUNNION switch on the indicator control panel.

When the TELESCOPE TRUNNION switch is in the 0° position, the 0° and SLAVE relays are energized. This disconnects the input sine-cosine signals from the SXT trunnion 1X resolver; applies a fixed 28 volt, 800 cps, 0 phase reference signal to the sine winding of the SCT trunnion 1X resolver; and shorts out the cosine winding to establish a zero electrical reference.

When the TELESCOPE TRUNNION switch is in the 25° position, the 25° and SLAVE relays are energized. This disconnects the input sine-cosine signals from the SXT trunnion 1X resolver; applies a fixed 28 volt, 800 cps, 0 phase reference signal to the sine winding of the SCT trunnion 1X resolver; and applies a fixed reference voltage from the secondary of a transformer to the cosine winding to establish an electrical reference which causes the SCT to move to a fixed 25° trunnion angle offset.

The error signal from the SCT trunnion 1X resolver is applied through relay K1 to the MDA summing network. The feedback from the motor-generator is also applied through relay K1 to the MDA summing network. The amplifier circuit generates the motor drive signals in the phase and magnitude required to drive the rotor of the SCT trunnion 1X resolver to a null and to position the SCT trunnion at a new angle.

2-5.4 SXT SERVO LOOPS. Shaft and trunnion loops are utilized to position the SXT. Either loop may function as a two-speed positioning servo or as an integrating servo loop. The loop function is determined by mode switching.

2-5.4.1 SXT Shaft Servo Loop. Rotation of the SXT index head about the shaft axis is controlled by the SXT shaft servo loop. This loop may function as either a precision two speed positioning servo loop or as an integrating servo loop. In manual and computer modes it is used as an integrating loop; in the zero optics mode the servo loop is set as a two speed, positioning servo.

When the MODE switch is placed in ZERO position, the SXT shaft feedback relay (K5) and the shorting relay (K7) are energized. The output of the secondary winding of the 16X resolver (fine) and the output of the secondary winding of the SXT 1/2X resolver (coarse) is applied to the two speed switch. Relay K5 disconnects the direct tachometer feedback from the MDA input summing network and applies it through the compensation network as required for the positioning servo configuration.

Relay K7 places the rate input to the MDA summing network at zero. Consequently, the error input to the servo is taken from the two speed switch and is proportional to the SXT shaft displacement from the zero electrical reference. The zero reference for 1/2X coarse resolver is obtained from the 28 volt, 800 cps stator excitation supply. The error reference for the 16X fine resolver is more precise and is established by the 28 volt, 800 cps rotor excitation. The two speed servo loop drives the SXT gear train into accurate alignment with the zero reference.

In system modes of operation, other than zero optics and CMC, relays K5 and K7 are deenergized. Deenergizing these relays sets up the servo as an integrating loop. This places the two speed inputs to the MDA summing network at zero. Deenergizing relay K7 removes the zero input to the MDA summing network and switches in the rate error. The rate error is obtained from one of two drive rate sources depending on mode switching.

When the system is in manual resolved mode, the resolved input relay (K6) is energized. The optics hand controller drive rate signal is applied through closed contacts of the relay to the SXT shaft 1X resolver. The output of the SXT shaft 1X resolver goes to the cosecant function generator through relays K1 and K8 and to the MDA summing network through relay K7. The cosecant function generator output also goes to the 2X computing resolver in the SXT trunnion servo loop.

In the manual direct mode, all the relays are deenergized. The source of the drive rate error signal then is the optics hand controller. The signal is fed through the resolver input relay K6 and through contacts of K7 to the MDA summing network.

In the computer mode, the computer input relay (K10) is energized. This connects the CMC to the MDA summing network through the D/A converter in the CDU. Relay K7 disables manual control of the loop.

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2-5.4.2 SXT Trunnion Servo Loop. Rotation of the SXT indexing mirror about the trunnion axis is controlled by the SXT trunnion servo loop. This servo is similar to the SXT shaft servo in that mode relays select a precise two speed positioning servo loop in the zero optics mode and an integrating servo loop in the remaining modes. The same series of input relays switch the input to the MDA summing network from one of two sources: (1) the SXT trunnion hand controller during direct manual mode; (2) the resolved drive rate from the shaft 1X resolver during resolved manual mode. All relays are energized as explained previously.

SXT trunnion and shaft angles are obtained by interpreting displacement of the SXT indexing mirror about both axes. Two pancake resolvers, mechanically linked with the SXT indexing mirror and SXT head assembly, sense and transmit analog equivalents of SXT mirror displacements about trunnion and shaft axes.

2-5.5 MODES OF OPERATION. The OSS incorporates multiple modes of operation to facilitate the taking of precise measurements within short time increments. The specific mode selected effectively adapts the system to fit the needs of the astronaut under varying situations prior to sightings. The OSS operates in one of three prime modes and can be controlled in either of two control modes. Each is selected by switches on the indicator control panel. The modes are:

- (1) Zero Optics
 - (a) 0°
 - (b) 25°
 - (c) Slave to SXT
 - (d) Direct
 - (e) Resolved
- (3) Computer

2-5.5.1 Zero Optics. In zero optics mode, relays convert the SXT trunnion and shaft loops into two speed null sensing servos. The positioning servos then drive the SXT optics into alignment with zero reference inputs. This mode of operation is normally established as a part of a preliminary procedure for taking optical sightings.

The zero optics mode can be selected either manually or by the computer after the computer control mode of operation has been selected. The computer selects zero optics by energizing a relay which in turn energizes the two-speed switch. The computer is notified of the zero optics mode by a signal when the mode control switch is in the zero position.

Entering the zero optics mode causes the bank of SXT input relays to disconnect the SXT loops from all data source drive rate inputs. This switches in zero alignment reference inputs, and serves to mechanize each loop as a positioning servo. (See figure 2-19.)

In the SXT trunnion loop, the 1X and 64X resolver transmitter outputs are switched back to the loop MDA by a two-speed switch. These resolver output signals terminate at zero optics relay contacts whenever the loop functions as an integrating device with rate inputs. In zero optics mode, the relay contacts close and apply the output signals to a two-speed, coarse-fine switch. The resolvers are mechanized as control transformer error detectors for the trunnion integrating loop circuit and generate error signals proportional to the displacement of the mechanical shaft from the electrical zero reference. These error signals are used to drive the mechanical shaft until it is precisely aligned to the zero reference. The zero optics relay also reconnects the tachometer generator from direct to compensated feedback so that the servo characteristics assume the characteristics of a positioning servo.

The SXT trunnion loop accuracy is determined by the 64X resolver. However, since the 64X resolver passes through 64 nulls in 180 degrees of trunnion rotation, the 1X resolver output overrides the 64X resolver output and drives the SXT trunnion near zero. When the SXT Trunnion angle is within 2.8 degrees of zero (5.625 degrees StLOS), the 64X resolver output is switched into the MDA to drive the SXT trunnion to zero. The SXT trunnion CDU read counter will then be cleared by the CMC CDU zero discrete.

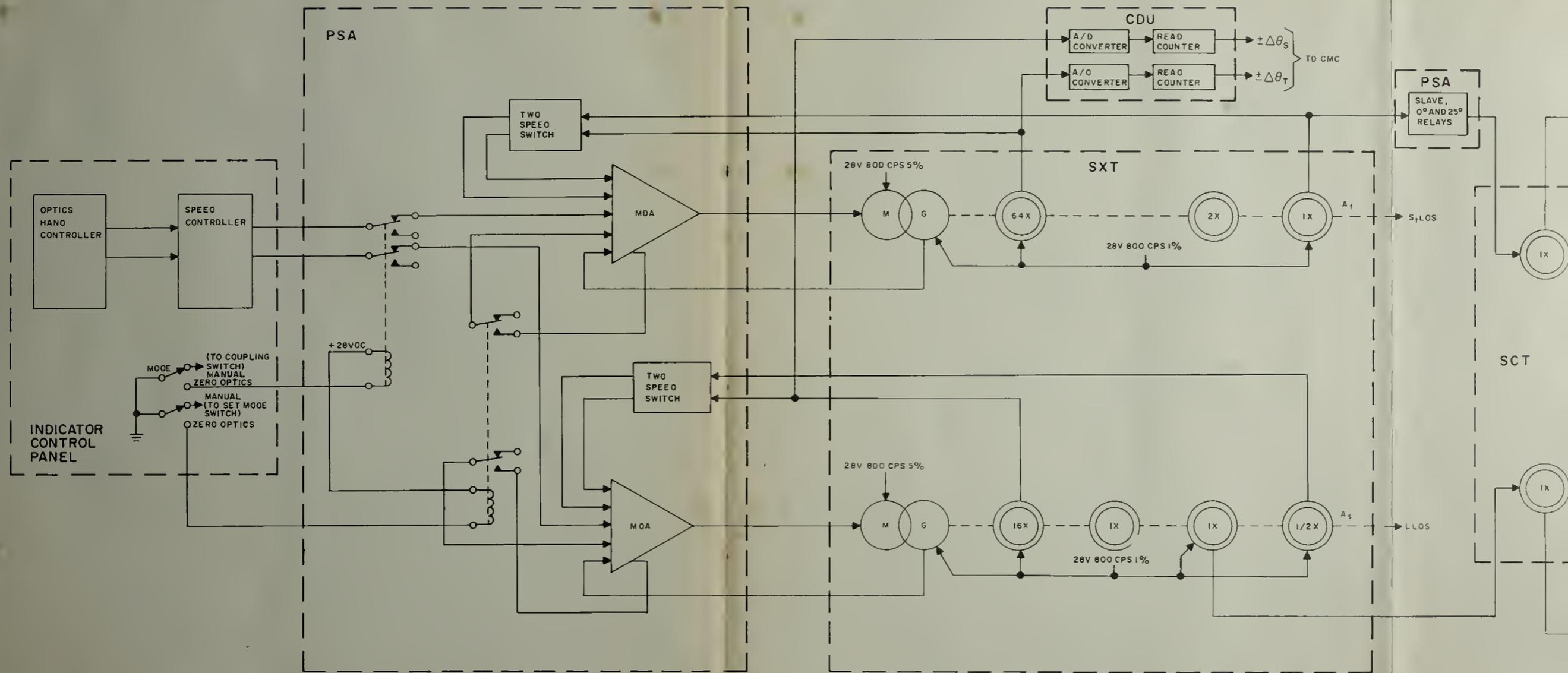
The SXT shaft integrating loop is mechanized identically to that of the trunnion loop. In the SXT shaft loop, the 1/2X and 16X resolvers serve as error detectors for the two-speed, shaft positioning servo.

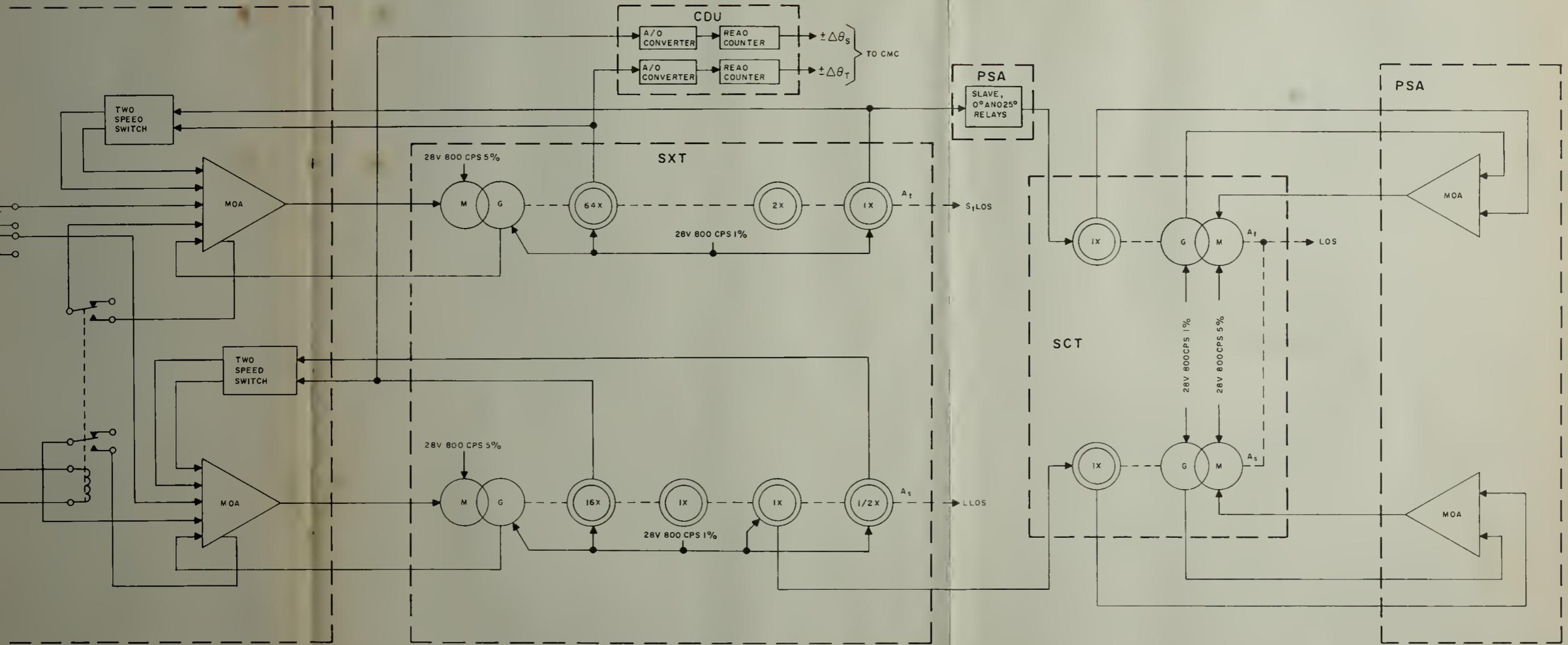
2-5.5.2 Manual Modes. In manual modes of operation, the direction and rate of image motion viewed on the SCT and SXT eyepieces are manually controlled. The optics hand controller and speed selector on the indicator control panel are used for manually acquiring the landmark and star targets. Displacement of the optics hand controller generates SXT trunnion and shaft angular drives (A_t and A_s).

The manual mode provides these three modes of operation associated with the SCT: 0° , 25° , and Slave to SXT.

2-5.5.2.1 0° Manual Mode. In this mode, 28 volt, 800 cps power is applied directly to the SXT trunnion 1X resolver cosine winding limiting the SXT to shaft motion only.

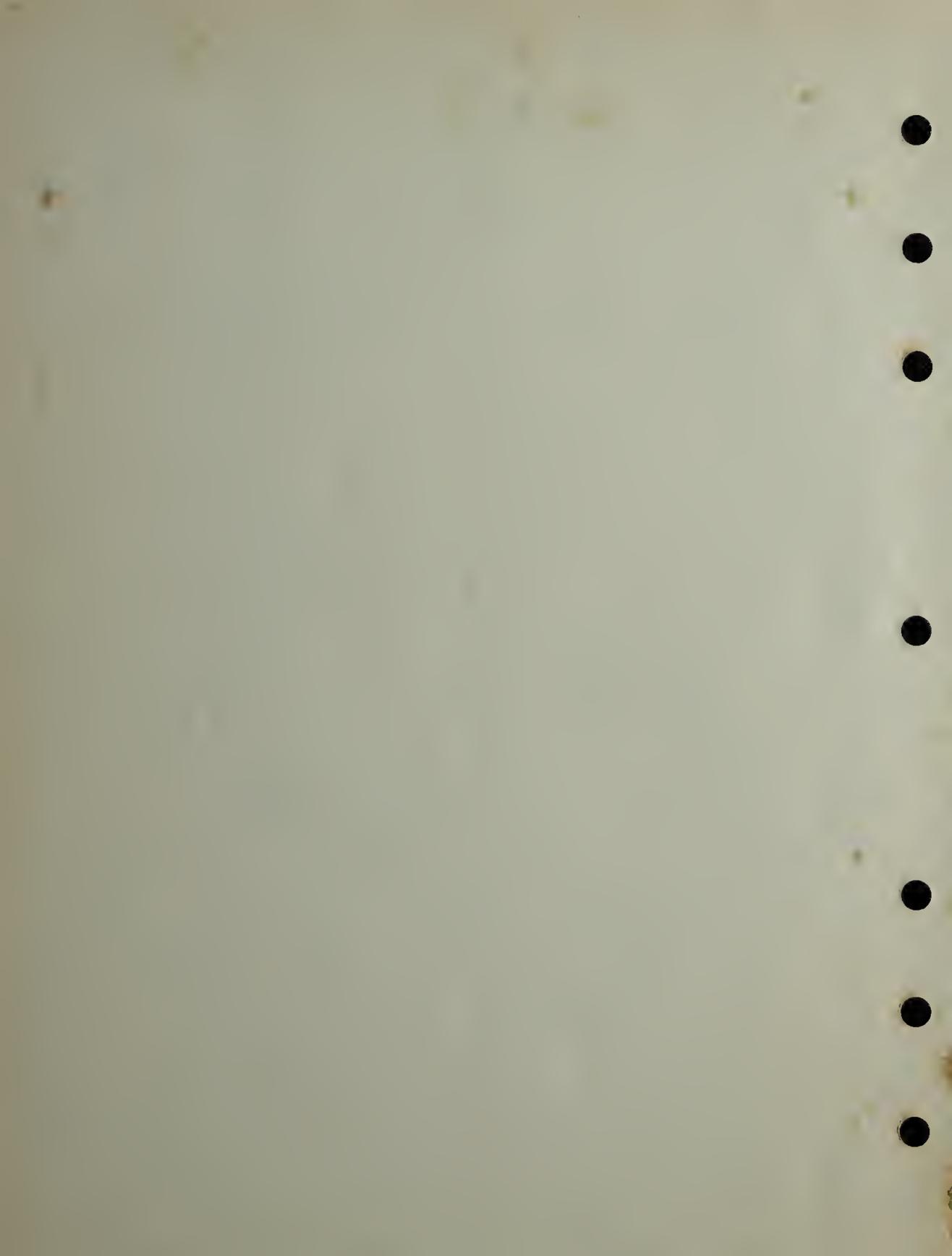
2-5.5.2.2 25° Manual Mode. In this mode, 28 volt, 800 cps power is applied through the 25° offset transformer to the sine winding of the SCT 1X resolver. The SCT trunnion is displaced 25 degrees from the zero position and is capable of scanning a 110 degree cone by rotation of the SCT shaft.





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Figure 2-19. Zero Optics and Manual Direct Modes



2-5.5.2.3 Slave to SXT Manual Mode. In this mode, the SCT trunnion is slaved directly to the SXT trunnion and the following two modes of operation associated with the SXT are provided: manual direct mode and manual resolved mode.

2-5.5.2.4 Manual Direct Mode. The manual direct mode permits image movement in a coordinate system. Figure 2-20 illustrates the direction of image movement as viewed in the SCT and SXT eyepieces using the optics hand controller. Characteristics of the typical image presentations shown in figure 2-20 are:

(1) Position 1. A landmark target is selected by manipulation of spacecraft attitude controls and centered on the SCT reticle. The star target at this point is not in the SCT field of view.

(2) Position 2. By selecting the offset 25° mode, the landmark target is displaced to the edge of the SCT field of view. The selected star target is now positioned in the SCT field of view.

(3) Position 3. The SCT reticle is displaced in shaft to align the star image on the SCT reticle reference line. The included angle between landmark and star image, as measured on the SCT reticle reference line, must be less than 50° to maintain images in the SXT reticle. The SXT trunnion is displaced an amount equal to the included angle.

(4) Position 4. The SXT trunnion angle is driven to the included angle to acquire the star target. When viewed in the SXT eyepiece, both landmark and star images now appear in the field of view. The star image may appear to be misaligned with respect to the shaft axis reticle reference.

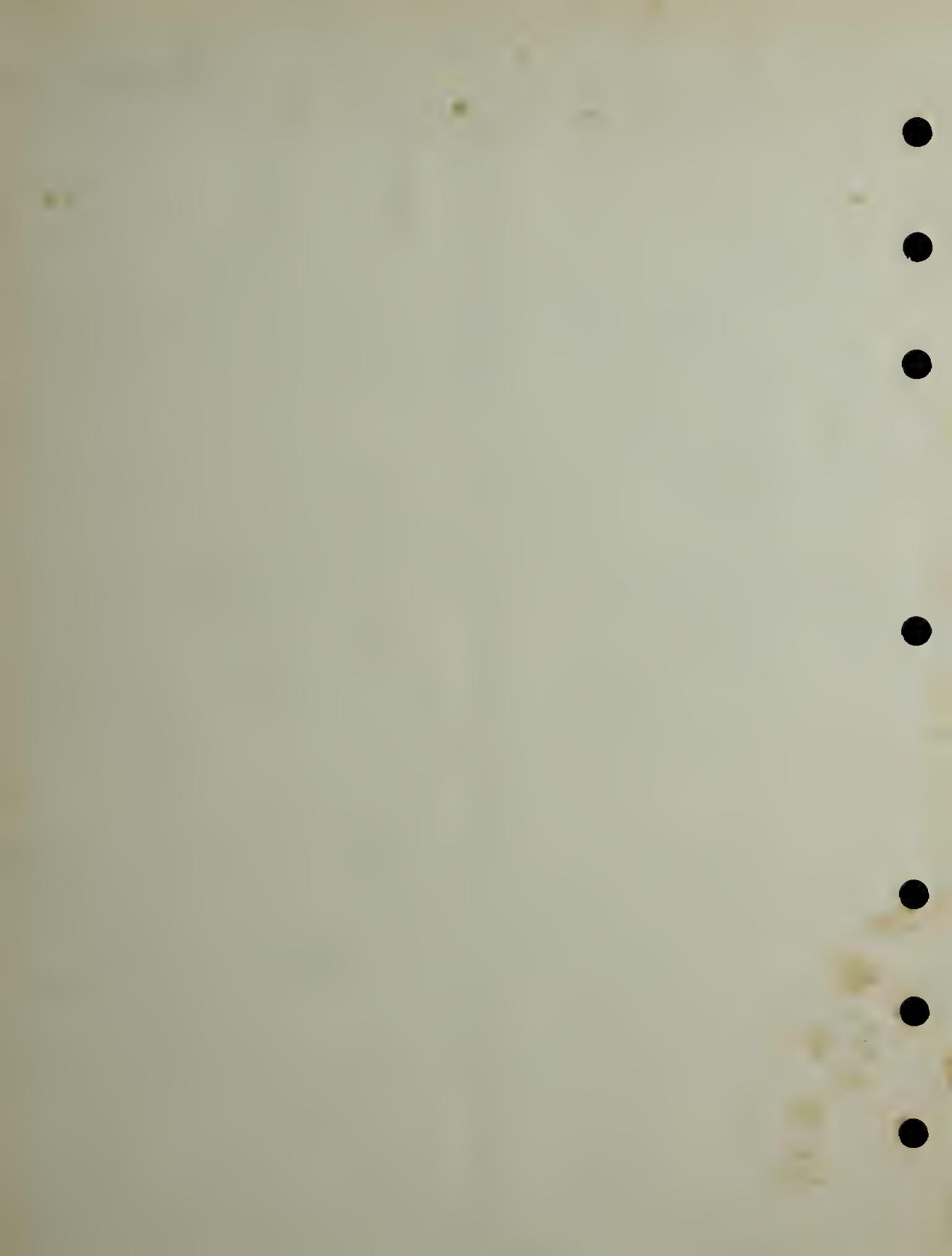
(5) Position 5. Fine alignment of the star image with the shaft reticle reference is accomplished by positioning the optics hand controller.

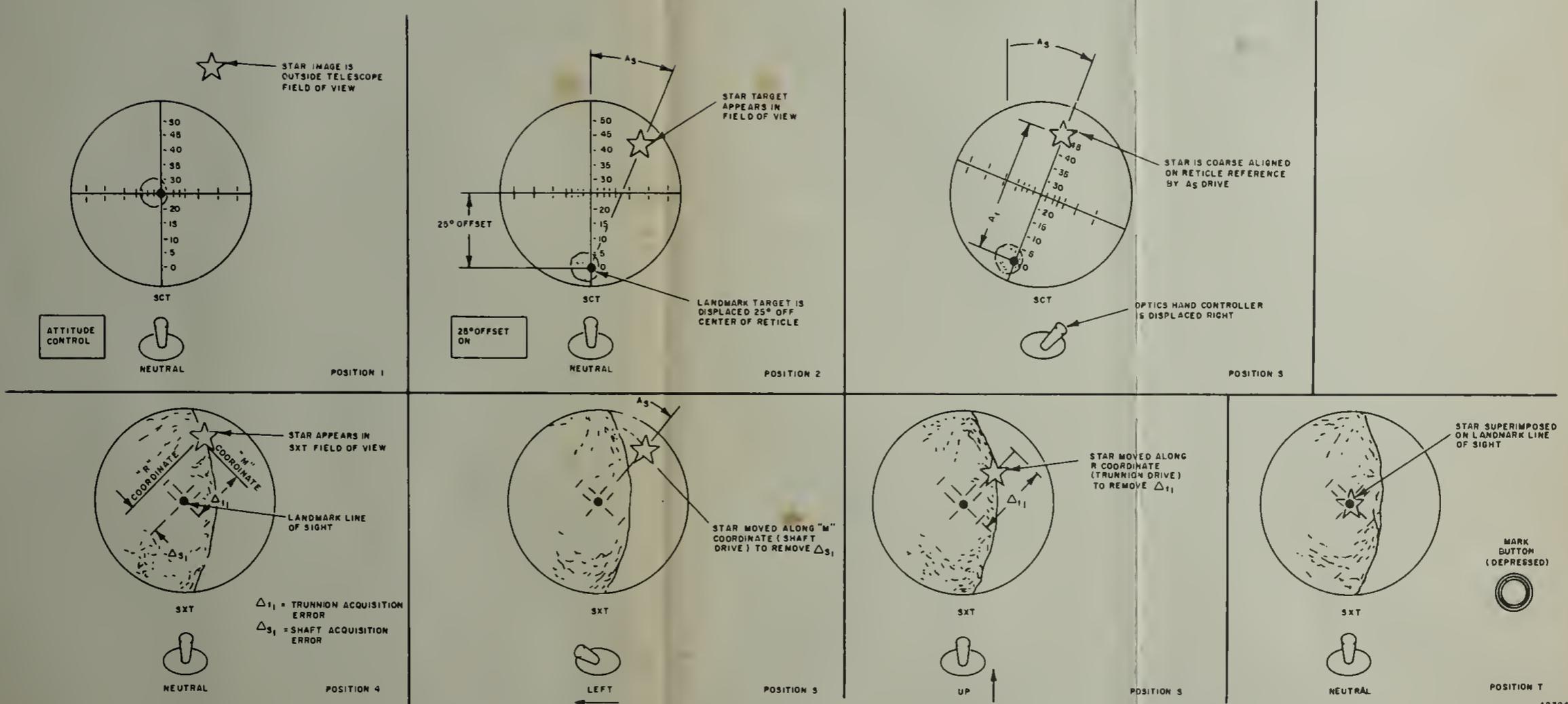
(6) Position 6. The star image is displaced in trunnion angle toward the center of the landmark target aligned on the center of the reticle.

(7) Position 7. Super-imposition of the star target on the landmark target is accomplished and the MARK button depressed.

In manual direct mode, the SXT trunnion and shaft servos are mechanized as rate integrating servo loops. The trunnion and shaft angular drive rate signals (A_t and A_s) are fed through switching relays directly into the MDA of their respective servos.

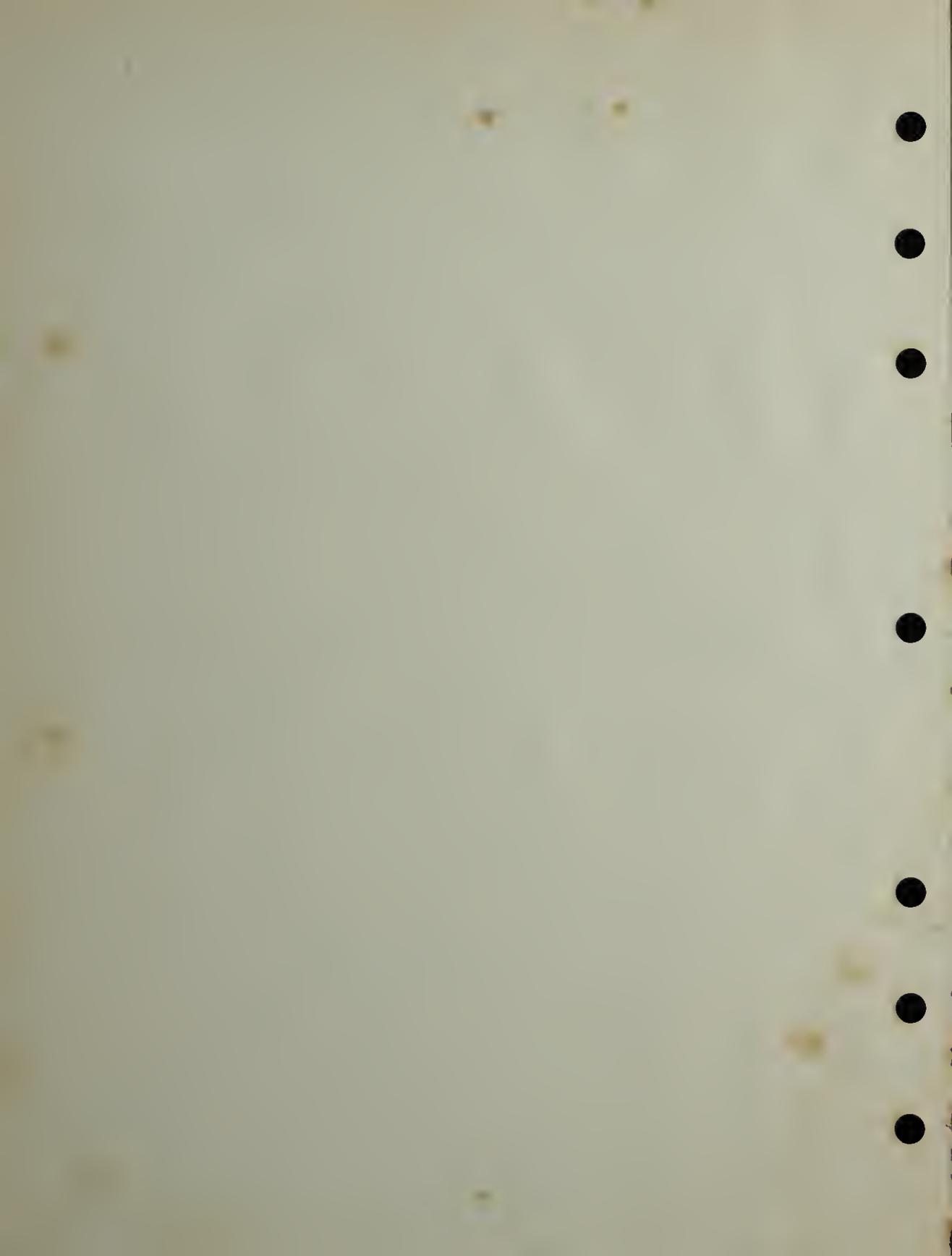
The trunnion drive rate signal (A_t) causes the trunnion servo, located in the SXT optics, to drive the SXT indexing mirror around the trunnion axis in a direction and at a rate proportional to the direction and displacement of the optics hand controller. Similarly, the shaft drive rate signal (A_s) causes the shaft to rotate the entire SXT optics around the shaft axis.





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Figure 2-20. Image Presentations, Manual Direct Mode



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The sin and cos error signals from the SXT trunnion 64X resolver and the SXT shaft 16X resolver are applied through the CDU A/D converter to the read counters. The $\pm\Delta\theta_T$ and $\pm\Delta\theta_S$ pulses from the read counters are sent to the CMC representing the amount of SXT trunnion and shaft angle rotation. The CMC can use this data to display the SXT angles on the DSKY and to determine spacecraft position and trajectory.

During the direct manual mode, the anticreep electronics removes B+ from the MDA's when the optics hand controller output (either trunnion or shaft) drops below 500 mv. This prevents the optics from drifting when the optics hand controller is at null.

2-5.5.2.5 Manual Resolved Mode. The manual resolved mode permits independent movement of the image coordinates relative to a rectangular system. Figure 2-21 illustrates the direction of image movement in the SXT eyepiece using the optics hand controller. Characteristics of the typical SXT image presentations shown in figure 2-21 are:

(1) Position 1. With the landmark and star images coarse aligned by the SCT, both targets are presented in the SXT field of view. At this point, the image is not aligned with the SXT reticle.

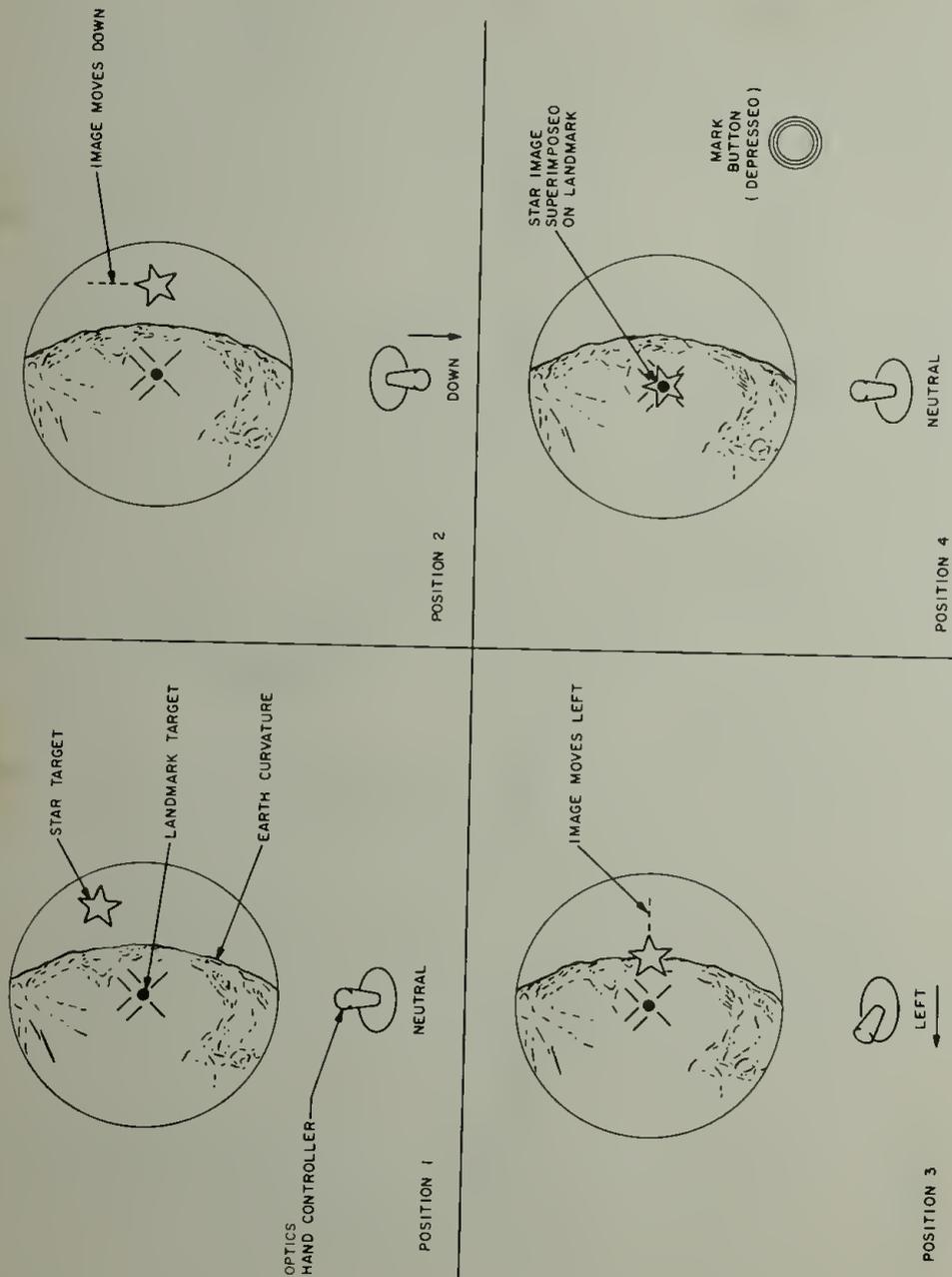
(2) Position 2. When the optics hand controller is positioned up-down or left-right, the image movement appears to follow or is coordinated with controller motion. In this particular operation, the controller is positioned downward and the image is displaced in that direction.

(3) Position 3. With the star target to the right of the landmark, the hand controller is displaced to the left and the image movement follows. Note: the operations covered in positions 2 and 3 can be obtained simultaneously by positioning the hand controller diagonally to the right and down.

(4) Position 4. This presentation depicts the star target superimposed on the landmark target. At this time, the MARK button is pressed and the sighting completed.

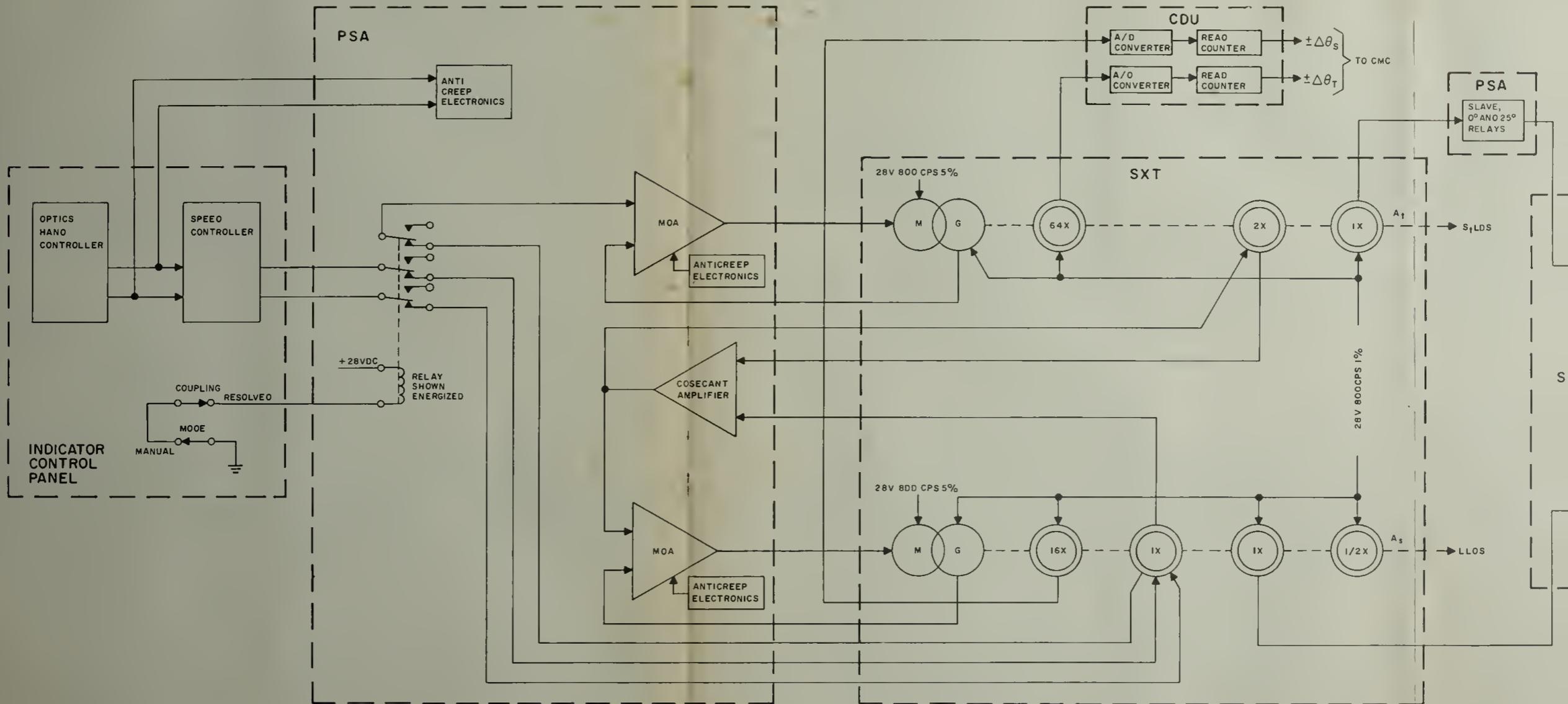
In manual resolved mode, the SXT trunnion and shaft servos are mechanized as rate or integrating loops. Drive rate resolution and variable gain is added to the shaft servo loops to make the rate and direction of the image motion independent of the shaft axis and trunnion angle. (See figure 2-22.)

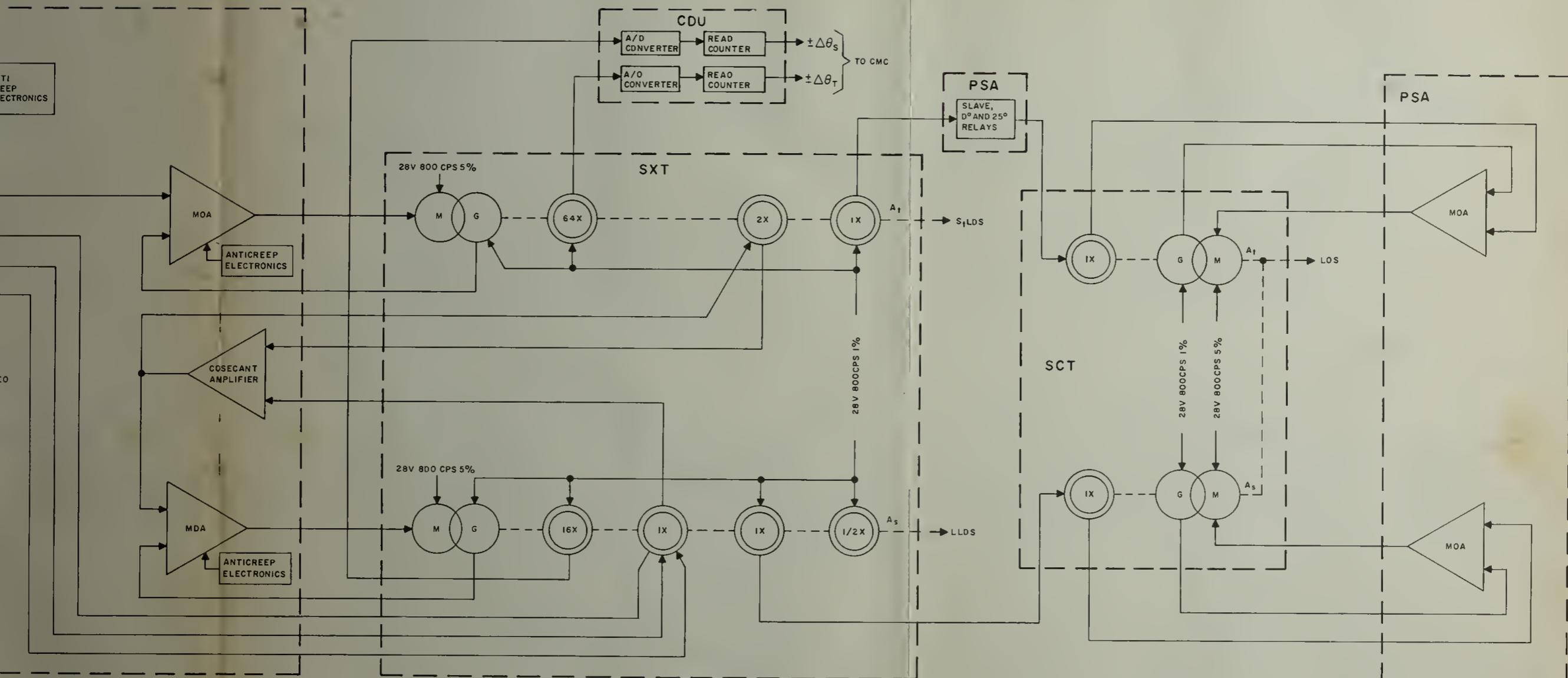
Switching relays direct the drive rate signals (up-down and left-right) from the optics hand controller to the 1X resolver in the SXT shaft. The rotor of the 1X resolver is positioned to the shaft angle (AS). The voltages induced in the stator windings are a function of the two rotor input voltages and the shaft angle. The R and M coordinates



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Figure 2-21. SXT Image Presentations, Manual Resolved Mode





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Figure 2-22. Manual Resolved Mode

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drive rate signals are resolved by the 1X resolver into shaft and trunnion signals. The trunnion signal is fed directly to the MDA while the shaft signal is fed through the cosecant amplifier to the MDA. This servo causes the SXT indexing mirror to rotate around the trunnion axis at a rate and direction proportional to the drive rate signal causing the image to move up or down for an up-down drive rate signal.

The left or right drive rate signal from the 1X resolver is fed to the SXT shaft servo through a cosecant amplifier which is connected in the input circuit by switching relays. This amplifier functions as a variable gain device between trunnion angles of 10 to 60 degrees. The amplifier employs a 2X computing resolver in the SXT trunnion servo as a minor loop. The effect of this cosecant generator is to make the rate of image motion (angular velocity) independent of changes in trunnion angle, by decreasing the shaft speed as trunnion angle increases. The reduction in shaft speed enables a constant rate of trunnion peripheral velocity to be achieved regardless of trunnion angle. This insures that the optics LOS does not sweep past the target before recognition.

One input to the summing network of the cosecant amplifier is the drive rate along the Y axis, which is obtained after resolution by the 1X resolver in the shaft servo. The motion along this axis increases at a rate proportional to the sine of the trunnion angle (A_t). To compensate for this effect, an inverse sine factor (the cosecant) is introduced. A computing resolver in the SXT trunnion gear train is employed to yield the function $0.5C \sin A_t$ to compensate for the gear train ratio. The controlled electrical variable (C) drives the SXT shaft integrating loop so that its angular velocity is independent of the trunnion angle. In this way, a uniform sweep rate along the Y axis is achieved throughout the range of trunnion angles. The resolution of the drive rates onto the Y axis is used as a direct input to the shaft integrating servo loop.

During the manual resolved mode, the anticreep electronics removes B+ from the MDA's when the optics hand controller output (both trunnion and shaft) drops below 500 mv. This prevents the optics from drifting when the optics hand controller is at null.

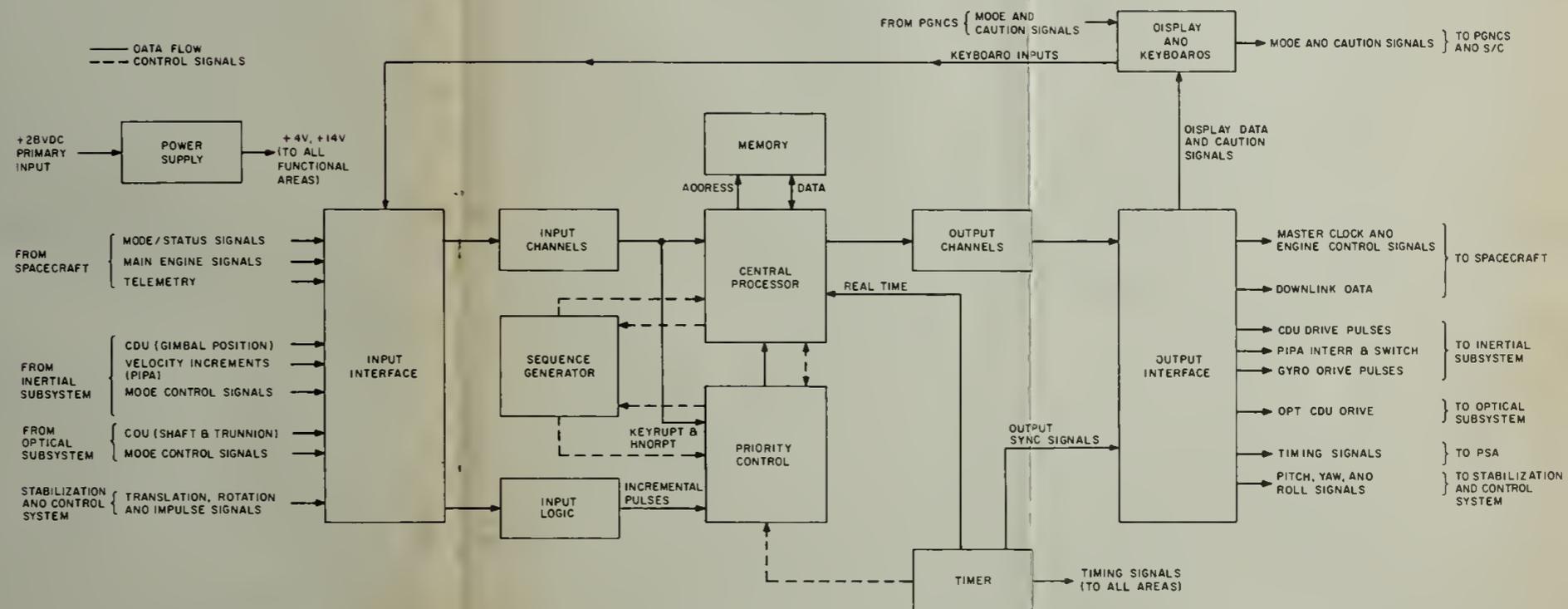
2-5.5.3 Computer Mode. The computer mode is initiated from the indicator control panel by the astronaut. The computer then controls and drives the OSS loops. The computer can initiate zero optics, and computer driving. During the computer mode, the zero optics mode functions the same as in the manual mode. During computer driving mode, the CMC issues the enable error counter discrete which enables the error counters to receive $\pm\Delta\theta_{CT}$ and $\pm\Delta\theta_{CS}$ pulses from the CMC. These pulses represent the desired angle of the optics as computed by the computer. The output of the error counter is fed to the D/A converters where it is converted to an ac signal and used to position the SXT loops through the MDA. As the SXT is driven, the CDU read counters receive the trunnion and shaft resolver error signals and register the SXT angles. A feedback circuit from the read counter to the error counter reduces the error counter contents as the read counter increases and nulls the error counter and SXT stops driving. The CMC receives the $\pm\Delta\theta_T$ and $\pm\Delta\theta_S$ pulses from the read counter and determines when the optics are at the desired angles.

2-6 COMPUTER SUBSYSTEM

The CSS is the control and processing center of the PGNCS. It consists of the CMC, a main panel DSKY and a navigation panel DSKY. The CSS processes data and issues discrete outputs and control pulses both to the PGNCS and to the other Apollo spacecraft systems. The CMC is a parallel digital control computer with many features of a general purpose computer. As a control computer, the CMC aligns the IMU, positions the optics (SXT), and issues control commands to subsystems of the spacecraft. As a general purpose computer, the CMC solves the guidance and navigation equations required for the round trip to the moon. In addition, the CMC monitors the operation of the spacecraft, including the CSS.

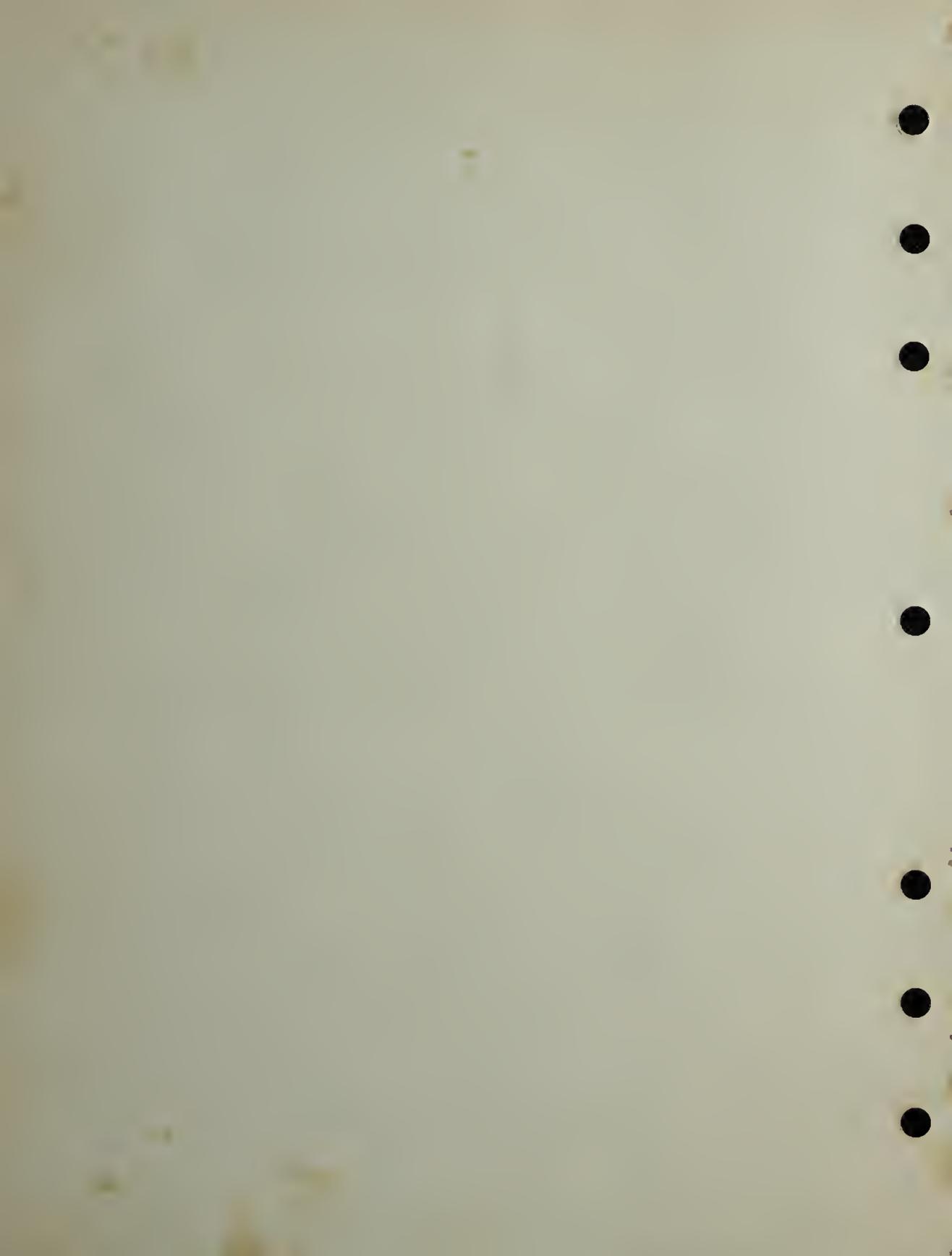
The main functions of the CMC (see figure 2-23) are implemented through the execution of the programs stored in memory. Programs are written in a machine language called basic instructions. A basic instruction contains an operation (order) code and a relevant address. The order code defines the data flow within the CMC, and the relevant address selects the data that is to be used for computations. The sequence generator controls data flow. The order code of each instruction is entered into the sequence generator, and the sequence generator produces a different sequence of control pulses for each instruction. Each instruction is followed by another instruction. In order to specify the sequence in which consecutive instructions are to be executed, the instructions are normally stored in successive memory locations. By adding the quantity one to the address of an instruction being executed, the address of the instruction to be executed next is derived. Execution of an instruction is complete when the order code of the next instruction is transferred to the sequence generator and the relevant address is in the central processor.

The central processor consists of several flip-flop registers. It performs arithmetic operations and data manipulations on information accepted from memory, the input channels, and priority control. Arithmetic operations are performed using the ONE's complement number system. Values of 14 bits, excluding sign, (up to 28 bits during double precision operations) are processed with an additional bit produced for overflow or underflow. All operations within the central processor are performed under control of pulses generated by the sequence generator (indicated by dashed lines in figure 2-23). In addition, all words read out of memory are checked for correct parity, and a parity bit is generated for all words written into memory within the central processor. Odd parity is used; therefore, all words stored in memory contain an odd number of ONE's including the parity bit. The central processor also supplies data and control signals through the output channels and interface to the various spacecraft subsystems.



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Figure 2-23. Computer Subsystem Block Diagram



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The CMC has provision for ten program interrupts. These ten interrupts are: T6 RUPT, T5 RUPT, T3 RUPT, T4 RUPT, KEYRUPT 1, KEYRUPT 2, UPRUPT, DOWNRUPT, RADAR, and HAND CNTRL RUPT. The T6 RUPT through T4 RUPT programs are initiated by the CMC. The DOWNRUPT program is initiated at the completion of every parallel-to-serial conversion for downlink operation. The remaining priority programs are initiated by external inputs to the CMC. The KEYRUPT programs are initiated when a DSKY pushbutton is depressed or when priority control receives a MARK signal (discrete bit) from the OSS to indicate a sighting. The UPRUPT program is initiated when a complete UPLINK word is received. The HAND CNTRL RUPT program is initiated as soon as the hand controller is moved out of detent by the astronaut.

Before a priority program can be executed, the current program must be interrupted: however, certain information about the current program must be preserved. This includes the program counter and any intermediate results contained in the central processor. Priority control produces an interrupt request signal, which is sent to the sequence generator. This signal, acting as an order code, causes the execution of an instruction that transfers the current contents of the program counter and any intermediate results to memory. In addition, the control pulses transfer the priority program address in priority control to the central processor, and then to memory via the write lines. As a result, the first basic instruction word of the priority program is entered into the central processor from memory, and execution of the priority program is begun. The last instruction of each priority program restores the CMC to normal operation, provided no other interrupt request is present. This instruction transfers the previous program counter and intermediate results from their storage locations in memory back to the central processor.

Certain data pertaining to the flight of the spacecraft is used to solve the guidance and navigation problems required for the round trip to the moon. This data, which includes real time, acceleration, and IMU gimbal angles, is stored in memory locations, called counters. The counters are updated as soon as new data becomes available. An incrementing process is implemented, by priority control between the execution of basic instructions, and changes the contents of the counters. Data inputs to priority control are called incremental pulses. Each incremental pulse produces a counter address and a priority request. The priority request signal is sent to the sequence generator, where it functions as an order code. The control pulses produced by the sequence generator transfer the counter address to memory through the write lines of the central processor. In addition, the control pulses enter into the central processor the contents of the addressed counter to be incremented.

Real time plays a major role in solving guidance and navigation problems. Real time is maintained within the CMC in the main time counter of memory. The main time counter provides a 745.65 hour (approximately 31 days) clock. Incremental pulses are produced in the timer and sent to priority control to increment the main time counter. The Apollo mission requires that the CMC clock be synchronized with the KSC clock. The CMC time is transmitted once every second by downlink operation for comparison with the KSC clock.

Incremental transmissions occur in the form of pulse bursts from the output channels to the CDU, the gyros, the RCS of the spacecraft and to the radar. The number of pulses and the time at which they occur are controlled by program. Discrete outputs originate also in the output channels under program control. These outputs are sent to the DSKY's and various other subsystems. Continuous pulse trains originate in the timing output logic for synchronization of other systems.

The uplink word from the spacecraft telemetry system is supplied as an incremental pulse input to priority control. As this word is received, priority control produces the address of the uplink counter in memory and requests the sequence generator to execute the instructions which perform the serial-to-parallel conversion of the input word. When the serial-to-parallel conversion is completed, the parallel word is transferred to a storage location in memory by the uplink priority program. The uplink program also retains the parallel word for subsequent downlink transmission. Another program converts the parallel word to a coded display format and transfers the display information to the DSKY's.

The downlink operation of the CMC is asynchronous with respect to the spacecraft telemetry system. The telemetry system supplies all the timing signals necessary for the downlink operation. These signals include start, end, and bit sync pulses.

The CSS contains two identical DSKY's. With either keyboard, the astronaut can load information into the CMC, retrieve and display information contained in the CMC, and initiate any program stored in memory. A keycode is assigned to each keyboard pushbutton. When a keyboard pushbutton on either DSKY is depressed, the keycode is produced and sent to an input channel. A signal is also sent to priority control, where it produces both the address of a priority program stored in memory and a priority request signal, which is sent to the sequence generator. This results in an order code and initiates an instruction for interrupting the program in progress and executing the KEYRUPT priority program stored in memory. A function of this program is to transfer the keycode, temporarily stored in an input channel, to the central processor, where it is decoded and processed. A number of keycodes are required to specify an address, or a data word. The program initiated by a keycode also converts the information from the DSKY keyboard to a coded display format. The coded display infor-

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mation is transferred by another program to an output channel, and sent to the display portion of each DSKY. The display notifies the astronaut that the keycode was received, decoded, and processed properly by the CMC.

2-6.1 PROGRAMS. A CMC program performs such functions as solving guidance and navigation problems, testing the operation of the PGNCs and monitoring the operation of the spacecraft. Such a program consists of a group of program sections that are classified according to the functions they perform. These functions are defined as mission functions, auxiliary functions, and utility functions. (See figure 2-24.)

2-6.1.1 Mission Functions. Mission functions are performed by program sections that implement operations concerned with the major objectives of the Apollo mission. These operations include erecting the IMU stable member and aligning it to a desired heading while the spacecraft is located on the ground. The stable member is also aligned each time the ISS is re-energized during a flight and after prolonged use. In addition, the mission functions include computation of spacecraft position and velocity during coasting periods of the flight by solution of second-order differential equations which describe the motions of a body subject to the forces of gravity.

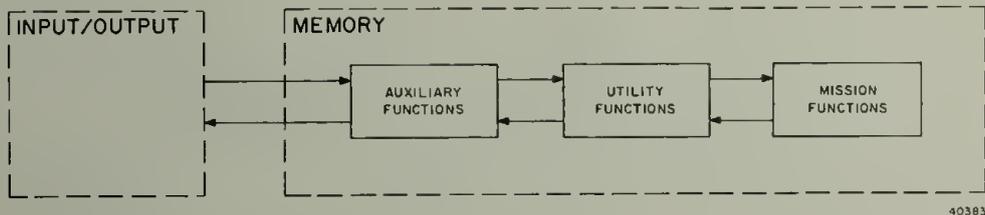


Figure 2-24. Program Organization

2-6.1.2 Auxiliary Functions. Auxiliary functions are executed at the occurrence of certain events, requests, or commands. These functions are performed by program sections that provide a link between CMC and other elements of the PGNCS. This link enables the CMC to process signals from various devices and to send commands for control and display purposes. In addition, the auxiliary functions implement many and varied operations within the CMC in support of the mission functions.

2-6.1.3 Utility Functions. Utility functions are performed by program sections that coordinate and synchronize CMC activity to guarantee orderly and timely execution of required operations. These functions control the operation of the mission functions and schedule CMC operations on either a priority or a real-time basis. The utility functions also translate interpretive language to basic machine language which allows complex mathematical operations such as matrix multiplication, vector addition, and dot product computations to be performed within the framework of compact routines. In addition, the utility functions save the contents of registers A and Q during an interrupt condition and enable data retrieval and control transfer between isolated banks in the fixed-switchable portion of fixed memory.

2-6.2 MACHINE INSTRUCTIONS. The CMC has three classes of machine instructions - regular, involuntary, and peripheral (table 2-I). Regular instructions are programmed and are executed in whatever sequence they have been stored in memory. Involuntary instructions (with one exception) are not programmable and have priority over regular instructions. One involuntary instruction may be programmed to test computer operations. No regular instruction can be executed when the computer forces the execution of an involuntary instruction. The peripheral instructions are used when the CMC is connected to the peripheral equipment. During the execution of any peripheral instruction, the CMC is in the monitor stop mode and cannot perform any program operation.

Table 2-I. Instruction Classes

Class	Type	Control
Regular	Basic Extracode Channel Special	Program
Involuntary	Interrupt Counter	Priority
Peripheral	Keyboard Tape	Operator

2-6.2.1 Regular Instructions. Four types of instructions comprise the regular instruction class. They are the basic, channel, extracode, and special instructions. Basic instructions are the most frequently used instructions. The instruction words stored in memory are called basic instruction words. They contain an order code field and an address field. Special instructions have predefined addresses and order codes whereas basic instructions have only predefined order codes. The special instructions are used to control certain operations in the computer. For example, one special instruction is used to switch the computer to the extend mode of operation. This mode extends the length of the order code field and converts basic instruction words to channel or extracode instruction words. Channel instructions can only be used with input/output channel addresses. Extra code instructions perform the more complex and less frequently used arithmetic operations.

Regular instructions can also be functionally subdivided into the following:

- (1) Sequence changing.
- (2) Fetching and storing.
- (3) Modifying.
- (4) Arithmetic and logic.
- (5) Input/output.
- (6) Editing.

The sequence changing instructions alter the sequence in which the instructions stored in memory are executed. One group, called transfer control instructions, changes the program path as defined by the programmer. The other group, called decision making instructions, branches to alternate program paths in response to predefined conditions.

The fetching and storing instructions move data, without alteration, from one location to another. One group called copy instructions provides a nondestructive transfer of data from memory to the central processor. Another group called exchange instructions transposes data between memory and the central processor. One instruction provides a nondestructive transfer of data from the central processor to memory.

The modifying instructions alter the next instruction to be executed by changing the contents of the order code field, address field, or both.

The arithmetic and logic instructions perform numerical computations. One group called the basic arithmetic instructions performs addition, subtraction, multiplication, and division in the ONE's complement number system. Another group called the add and store instructions performs single or double precision addition, and transfers the

resultant from the central processor to memory. The incrementing instructions increment a signed quantity, increment its absolute value, or diminish its absolute value by one. One instruction performs subtraction in the TWO's complement number system for angular data and one instruction performs the Boolean AND operation.

The input/output or channel instructions link the interface circuits to the central processor. One group called read instructions transfers the total or partial contents of any channel (register) location to the central processor either directly or accompanied by the Boolean AND, OR, or EXCLUSIVE OR operation. Another group of instructions transfers all new or partially new information to any channel location in the same manner.

The editing or special instructions are address-dependent and control the operation of the program. One special instruction, as mentioned previously, controls the extend mode of operation. Other instructions prevent a program from being interrupted and shift and cycle data to the left or right.

2-6.2.2 Involuntary Instructions. The involuntary instruction class contains two types of instructions - interrupt and counter. The interrupt instructions use the basic instruction word format just as the regular instructions do. However, the interrupt instructions are not entirely programmable. The contents of the order code field and the address field are supplied by computer logic rather than the program. The counter instructions have no instruction word format. Signals which function as a decoded order code specify the counter instruction to be executed and the computer logic supplies the address. The address for these instructions is limited to one of 29 counter locations in memory.

There are two interrupt instructions. One instruction initializes the computer when power is first applied and when certain program traps occur. The other interrupt instruction is executed at regular intervals to indicate time, receipt of new telemetry or keyboard data, or transmission of data by the computer. This interrupt instruction may be programmed to test the computer.

There are several counter instructions. Two instructions will either increment or decrement by one the content of a counter location using the ONE's complement number system. Two other instructions perform the same function using the TWO's complement number system. Certain counter instructions control output rate signals and convert serial telemetry data to parallel computer data.

2-6.2.3 Peripheral Instructions. There are two types of peripheral instructions. One type deals with memory locations and the other type deals with channel locations. The peripheral instructions are not used when the computer is in the spacecraft. They are used when the computer is connected to peripheral equipment during subsystem and preinstallation system testing. The peripheral instructions are not programmable and are executed when all computer program operations have been forcibly stopped. These

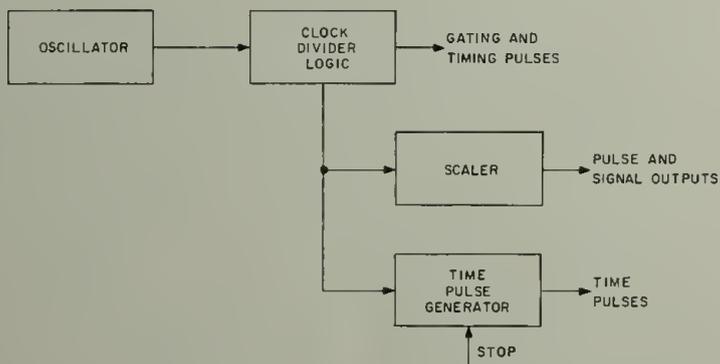
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instructions are used to read and load any memory or channel location, and to start the computer program at any specified address. The peripheral instructions and counter instructions are processed identically.

2-6.3 TIMER. The timer generates the timing signals required for operation of the CMC and is the primary source of timing signals for all spacecraft systems.

The timer is divided into the areas indicated in figure 2-25. The master clock frequency is generated by an oscillator and is applied to the clock divider logic. The divider logic divides the master clock input into gating and timing pulses at the basic clock rate of the computer. Several outputs are available from the scaler (which further divides the divider logic output into output pulses and signals for gating) to generate rate signal outputs and for the accumulation of time. Outputs from the divider logic also drive the time pulse generator which produces a recurring set of time pulses. This set of time pulses defines a specific interval (memory cycle time) in which access to memory and word flow take place within the computer.

The start-stop logic senses the status of the power supplies and specific alarm conditions in the computer, and generates a stop signal which is applied to the time pulse generator to inhibit word flow. Simultaneously, a fresh start signal is generated which is applied to all functional areas in the computer. The start-stop logic and subsequent word flow in the computer can also be controlled by inputs from the Computer Test Set (CTS) during pre-installation systems and subsystem tests.



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Figure 2-25. Timer Block Diagram

2-6.4 SEQUENCE GENERATOR. The sequence generator carries out the instructions stored in memory. The sequence generator processes instruction codes and produces control pulses which regulate the data flow of the computer. The control pulses are responsible for performing the operations assigned to each instruction in conjunction with the various registers in the central processor and the data stored in memory.

The sequence generator (figure 2-26) consists of the order code processor, command generator, and control pulse generator. The sequence generator receives order code signals from the central processor and priority control. These signals are coded by the order code processor and supplied to the command generator. The special purpose control pulses are used for gating the order code signals into the sequence generator at the end of each instruction.

The command generator receives instruction signals from priority control and peripheral equipment and coded signals from the order code processor. The command generator determines the input signals and produces instruction commands which are supplied to the control pulse generator.

The control pulse generator receives twelve time pulses from the timer. These pulses occur in cycles and are used for producing control pulses in conjunction with the instruction commands. There are five types of control pulses: read, write, test, direct exchange, and special purpose. Information in the central processor is transferred from one register to another by the read, write, and direct exchange control pulses. The special purpose control pulses regulate the operation of the order code

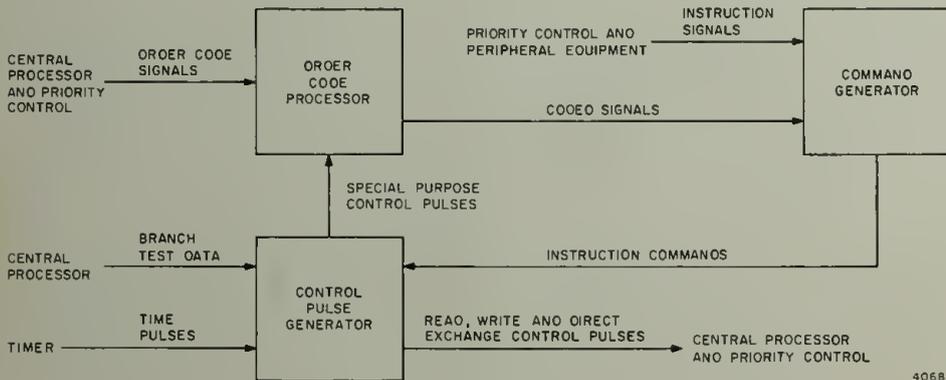


Figure 2-26. Sequence Generator Block Diagram

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processor. The test control pulses are used within the control pulse generator. The branch test data from the central processor changes the control pulse sequence of various instructions.

2-6.5 CENTRAL PROCESSOR. The central processor, figure 2-27, consists of the flip-flop registers, the write, clear, and read control logic, write amplifiers, memory buffer register, memory address register and decoder, and the parity logic. All data and arithmetic manipulations within the CMC take place in the central processor.

Primarily, the central processor performs operations indicated by the basic instructions of program stored in memory. Communication within the central processor is accomplished through the write amplifiers. Data flows from memory to the flip-flop registers or vice-versa, between individual flip-flop registers, or into the central processor from external sources, In all instances, data is placed on the write lines and routed to a specific register or to another functional area under control of the write,

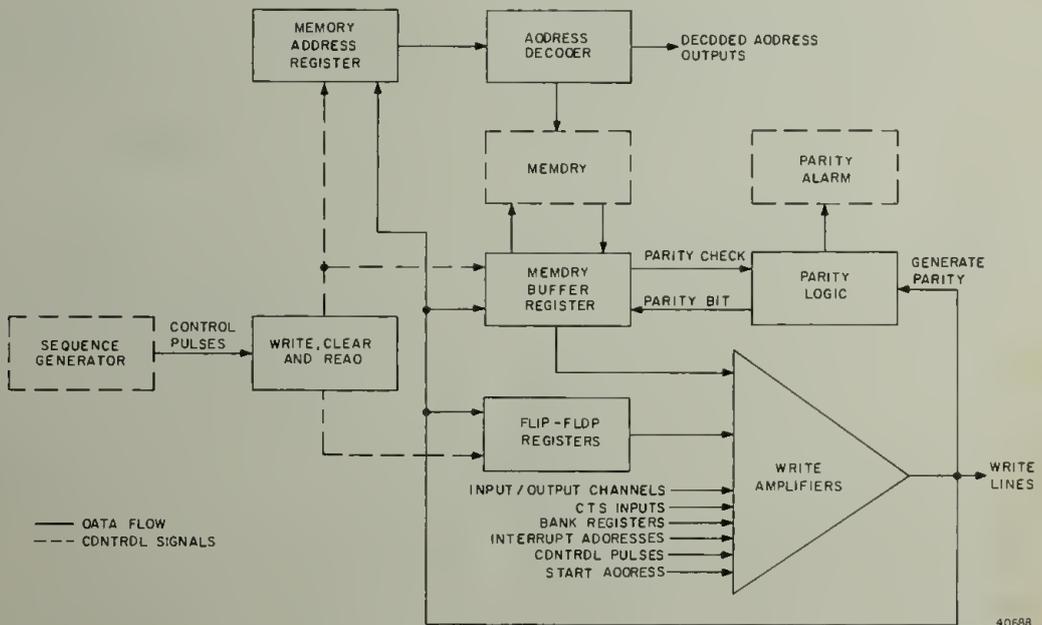


Figure 2-27. Central Processor Block Diagram

clear, and read logic. This logic section accepts control pulses from the sequence generator and generates signals to read the content of a register onto the write lines, and write this content into another register of the central processor or to another functional area of the CMC. The particular memory location is specified by the content of the memory address register. The address is fed from the write lines into this register, the output of which is decoded by the address decoder logic. Data is subsequently transferred from memory to the memory buffer register. The decoded address outputs are also used as gating functions within the CMC.

The memory buffer register buffers all information read out or written into memory. During readout, parity is checked by the parity logic and an alarm is generated in case of incorrect parity. During write-in, the parity logic generates a parity bit for information being written into memory. The flip-flop registers are used to accomplish the data manipulations and arithmetic operations. Each register is 16 bits or one computer word in length. Data flows into and out of each register as dictated by control pulses associated with each register. The control pulses are generated by the write, clear, and read control logic.

External inputs through the write amplifiers include the content of both the erasable and fixed memory bank registers, all interrupt addresses from priority control, control pulses which are associated with specific arithmetic operations, and the start address for an initial start condition. Information from the input and output channels is placed on the write lines and routed to specific destinations either within or external to the central processor. The CTS inputs allow a word to be placed on the write lines during system and subsystem tests.

2-6.6 PRIORITY CONTROL. Priority control is related to the sequence generator in that it controls all involuntary or priority instructions. Priority control processes input-output information and issues order code and instruction signals to the sequence generator and twelve-bit addresses to the central processor.

Priority control (figure 2-28) consists of the start, interrupt, and counter instruction control circuits. The start instruction control initializes the computer if the program works itself into a trap, if a transient power failure occurs, or if the interrupt instruction control is not functioning properly. The computer is initialized with the start order code signal, which not only forces the sequence generator to execute the start instruction, but also resets many other computer circuits. When the start order code signal is being issued, the T12 stop signal is sent to the timer. This signal stops the time pulse generator until all essential circuits have been reset and the start instruction has been forced by the sequence generator. The computer may also be initialized manually when connected to the peripheral equipment and placed into the monitor stop mode. In this mode, the time pulse generator is held at the T12 position until the monitor stop signal is released.

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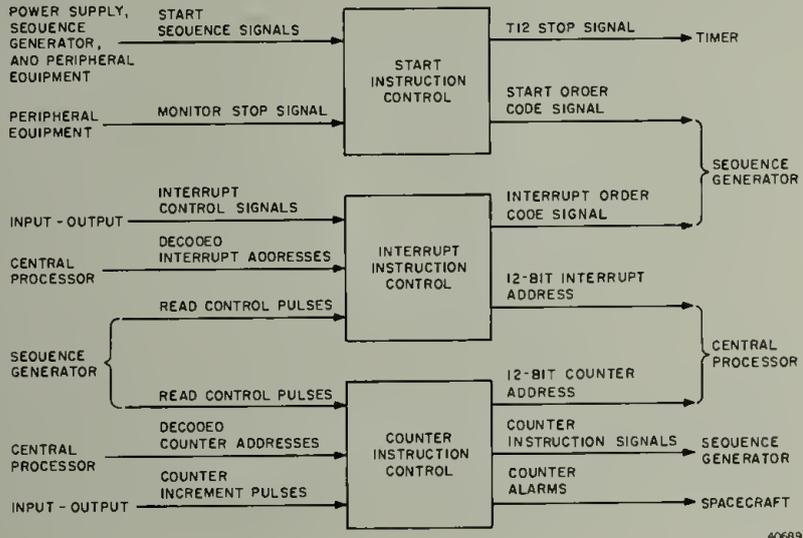


Figure 2-28. Priority Control Block Diagram

The interrupt instruction control can force the execution of the interrupt instruction. This is done with the interrupt order code signal which is sent to the sequence generator and the twelve-bit address sent to the central processor. There are ten addresses each of which accounts for a particular function that is regulated by the interrupt instruction control. The interrupt instruction control links the keyboards, telemetry, and time counters to program operations. The interrupt addresses are transferred to the central processor by read control pulses from the sequence generator. The source of the keyboard, telemetry, and time counter inputs is the input-output circuits. The interrupt instruction control has a built-in priority chain which allows sequential control of the ten interrupt addresses. The decoded interrupt addresses from the central processor are used to control the priority operation.

The counter instruction control is similar to the interrupt instruction control in that it links input-output functions to the program. It also supplies twelve-bit addresses to the central processor and instruction signals to the sequence generator. The instruction signals cause a delay (not an interruption) in the program by forcing the sequence

generator to execute a counter instruction. The addresses are transferred to the central processor by read control pulses. The counter instruction control also has a built-in priority of the 29 addresses it can supply to the central processor. This priority is also controlled by decoded counter address signals from the central processor. The counter instruction control contains an alarm detector which produces an alarm if an incremental pulse is not processed properly.

2-6.7 INPUT-OUTPUT. The input-output section accepts all inputs to, and routes to other systems all outputs from, the computer. The input-output section, (figure 2-29) includes the interface circuits, input and output channels, input logic, output timing logic, and the downlink circuits.

Most of the input channels and the output channels are flip-flop registers similar to the flip-flop registers of the central processor. Certain discrete inputs are applied to individual gating circuits which are part of the input channel structure. Typical inputs to the channels include keycodes from the DSKY's, signals from the PGNCS proper and other spacecraft systems as shown. Input data is applied directly to the input channels; there is no write process as in the central processor. However, the data is read out to the central processor under program control. The input logic circuits accept inputs which cause interrupt sequences within the computer. These incremental inputs (acceleration data from the PIPA's etc.) are applied to the priority control circuits and subsequently to associated counters in erasable memory.

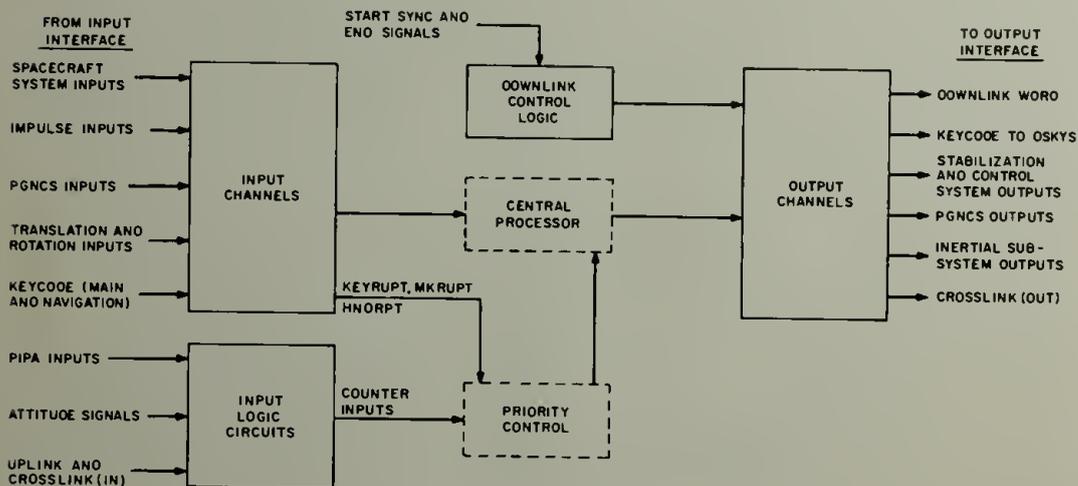


Figure 2-29. Input-Output Block Diagram

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Outputs from the computer are placed in the output channels, and are routed to specific systems through the output interface circuits. The operation is identical to that in the central processor. Data is written into an output channel from the write lines and read-out to the interface circuits under program control. Typically, these outputs include outputs to the stabilization and control system, the DSKY's, the PGNCs, etc. The downlink word is also loaded into an output channel, and routed to the spacecraft telemetry system by the downlink circuits.

The output timing logic gates synchronization pulses (fixed outputs) to the PGNCs and the spacecraft. These are continuous outputs since the logic is specifically powered during normal operation of the computer and during standby.

2-6.8 MEMORY. Memory (figure 2-30) consists of an erasable memory with a storage capacity of 2,048 words, and a fixed core rope memory with a storage capacity of 36,864 words. Erasable memory is a random-access, destructive-readout storage device. Data stored in erasable memory can be altered or updated. Fixed memory is a nondestructive storage device. Data stored in fixed memory is unalterable since the data is wired in and readout is nondestructive.

Both memories contain magnetic-core storage elements. In erasable memory, the storage elements form a core array; in fixed memory, the storage elements form three core ropes. Erasable memory has a density of one word per 16 cores; fixed memory has a density of eight words per core. Each word is located by an address.

In fixed memory, addresses are assigned to instruction words to specify the sequence in which they are to be executed, and blocks of addresses are reserved for data, such as constants and tables. Information is placed into fixed memory permanently by weaving patterns through the magnetic cores. The information is written into assigned locations in erasable memory with the CTS, the DSKY's, uplink, or program operation.

Both memories use a common address register (register S) and an address decoder in the central processor. When register S contains an address pertaining to erasable memory, the erasable memory cycle timing is energized. Timing pulses sent to the erasable memory cycle timing then produce strobe signals for the read, write, and sense functions. The erasable memory selection logic receives an address and a decoded address from the central processor and produces selection signals which permits data to be written into or read out of a selected storage location. When a word is read out of a storage location in erasable memory, the location is cleared. A word is written into erasable memory through the memory buffer register (register G) in the central processor by a write strobe operation. A word read from a storage location, is applied to the sense amplifiers. The sense amplifiers are strobed and the information is entered into register G of the central processor. Register G receives information from both memories.

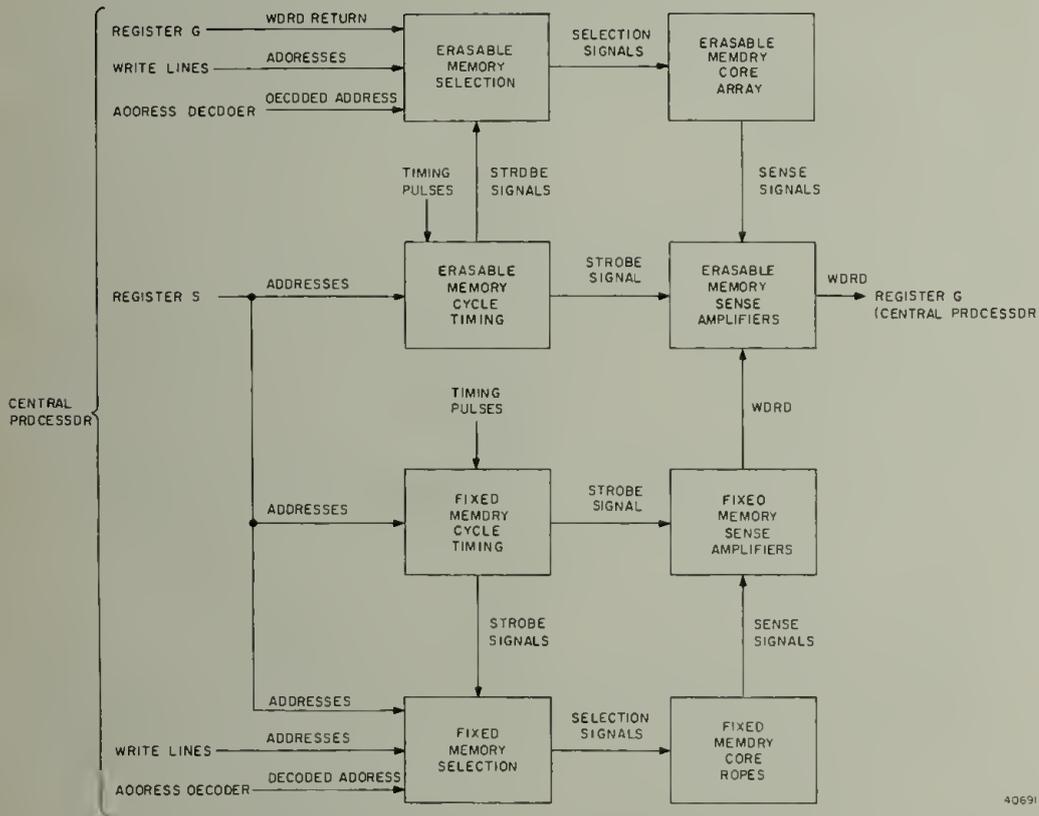


Figure 2-30. Memory Block Diagram

The address in register S energizes the fixed memory cycle timing when a location in fixed memory is addressed. The timing pulses sent to the fixed memory cycle timing produce the strobe signals for the read and sense functions. The selection logic receives an address from the write lines, a decoded address and addresses from register S, and produces selection signals for the core rope. The content of a storage location in fixed memory is strobed from the fixed memory sense amplifiers to the erasable memory sense amplifiers and then entered into register G of the central processor.

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

2-6.9 POWER SUPPLIES. The two power supplies (figure 2-31) furnish operating voltages to the CMC and the DSKY's. Primary power of 28 vdc from the spacecraft is applied to both power supplies. Regulator circuits maintain a constant output of (+4 volts) and (+4 volts switched) from one supply, and (+14 volts) and (+14 volts switched) from the other. The regulator circuits are driven by a sync signal input from the timer, each power supply having a different sync frequency. During system and subsystem test, inputs from the CTS can be used to simulate power supply failures.

The standby mode of operation is initiated by pressing the standby (STBY) button on the DSKY. During standby, CMC is put into a RESTART condition and the switchable +4 and +14 voltages are switched off thus putting the CMC into a low power mode where only the timer and a few auxiliary signals are operative.

The voltage alarm circuits monitor the +28, +14, and +4 volt outputs and produce a CMC restart signal (fresh start) should any of the voltages deviate from nominal by more than a predetermined amount. The oscillator alarm produces a CMC restart

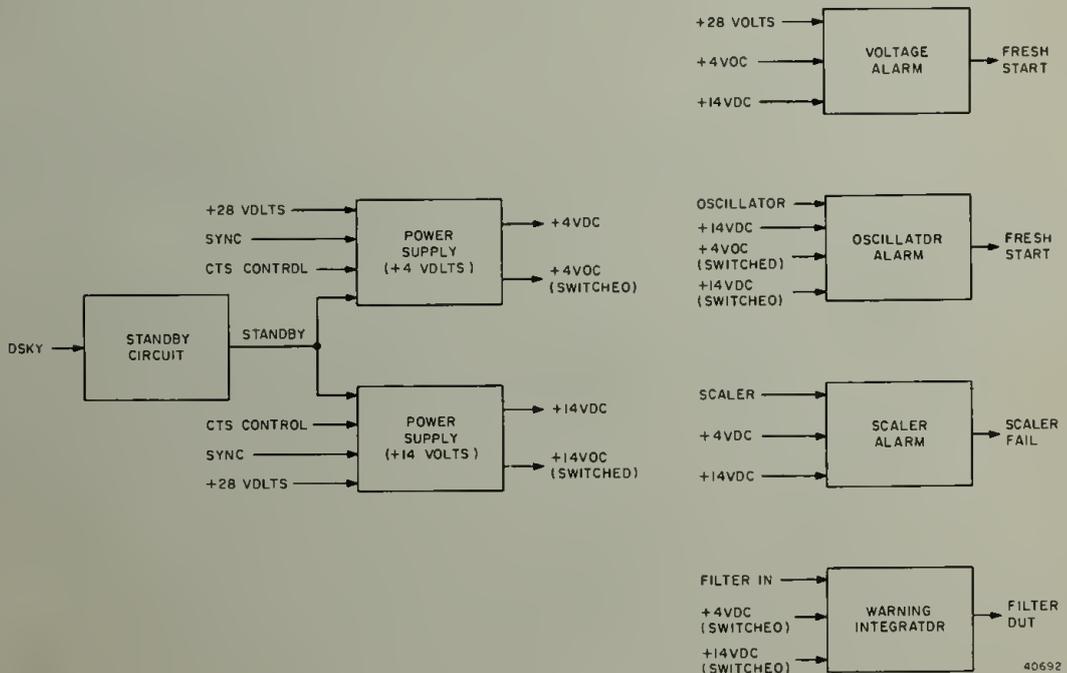


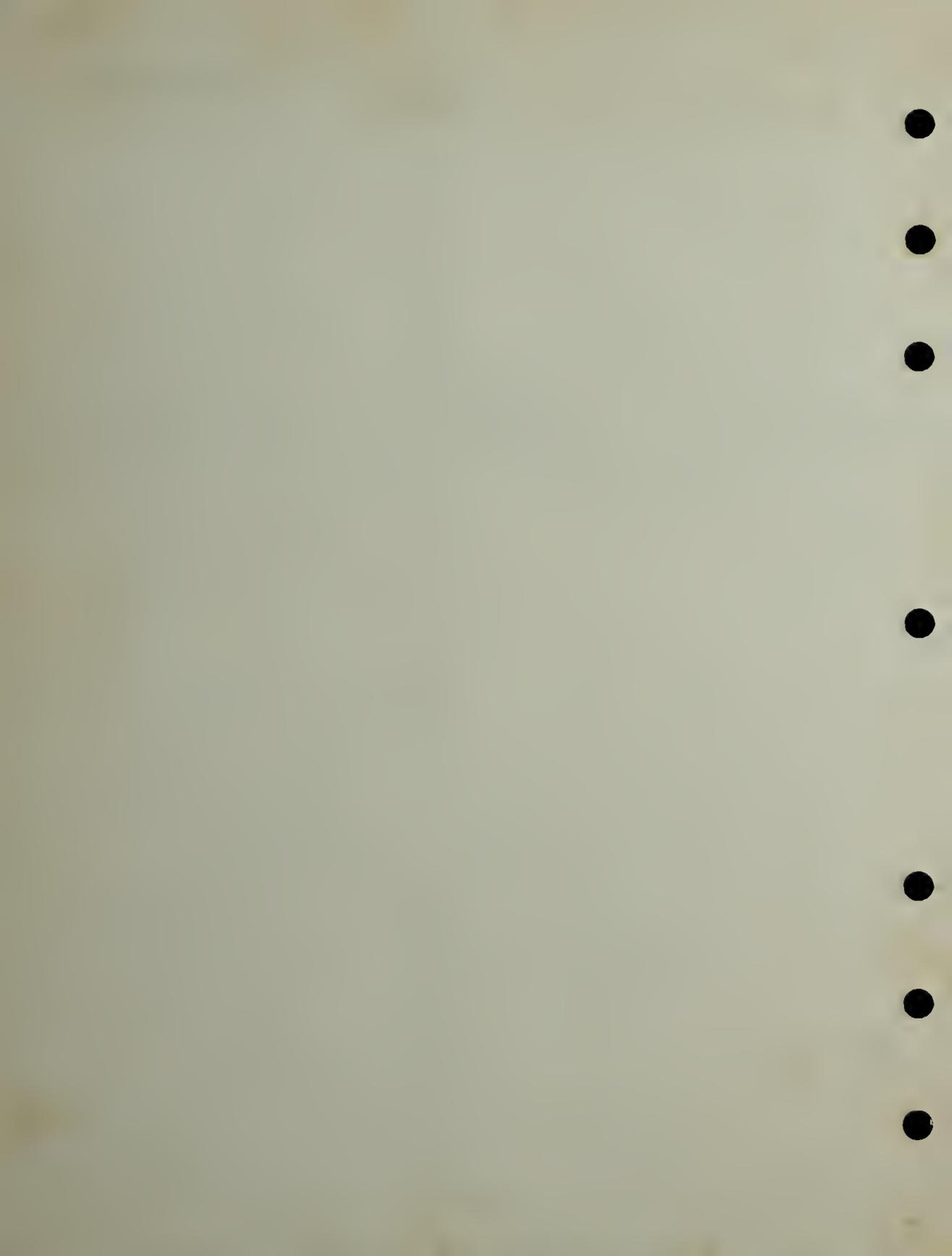
Figure 2-31. Power Supplies Block Diagram

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

which contains several numerical, sign, and other control keys, allows the astronaut to communicate with the CMC. The inputs from the keyboard are entered into an input channel and processed by the CMC.

The inputs entered from the keyboard, as well as other information, appear on the displays after processing by program. The display of information is accomplished through the relay matrix. A unique code for the characters to be displayed is formed by 15 bits from output channel 10 in the CMC. Bits 12 through 15 are decoded by the decoding circuits, and, along with bits 1 through 11, energize specific relays in the matrix which causes the appropriate characters to illuminate. The information displayed is the result of a keycode punched-in by the astronaut, or is computer-controlled information. The display characters are formed by electroluminescent segments which are energized by a voltage from the power supply routed through relay contacts. Specific inputs from the PGNCS are also applied, through CMC, to certain relays in the matrix through output channel 10 of the CMC. The resulting relay-controlled outputs are caution signals to the PGNCS.

The mode and caution circuits accept direct input signals from channels 11, 12, and 13, without being decoded. The resulting outputs can give an indication to the astronaut on the DSKY and/or route the output signal to the PGNCS and spacecraft.



Chapter 3

PHYSICAL DESCRIPTION

3-1 SCOPE

This chapter describes PGNCS components. The purpose and capabilities of each component are discussed. Module locations and location and functions of operating controls are illustrated. Figure 3-1 shows the location of units in the PGNCS. Table 3-1 lists Block II PGNCS components and their part numbers.

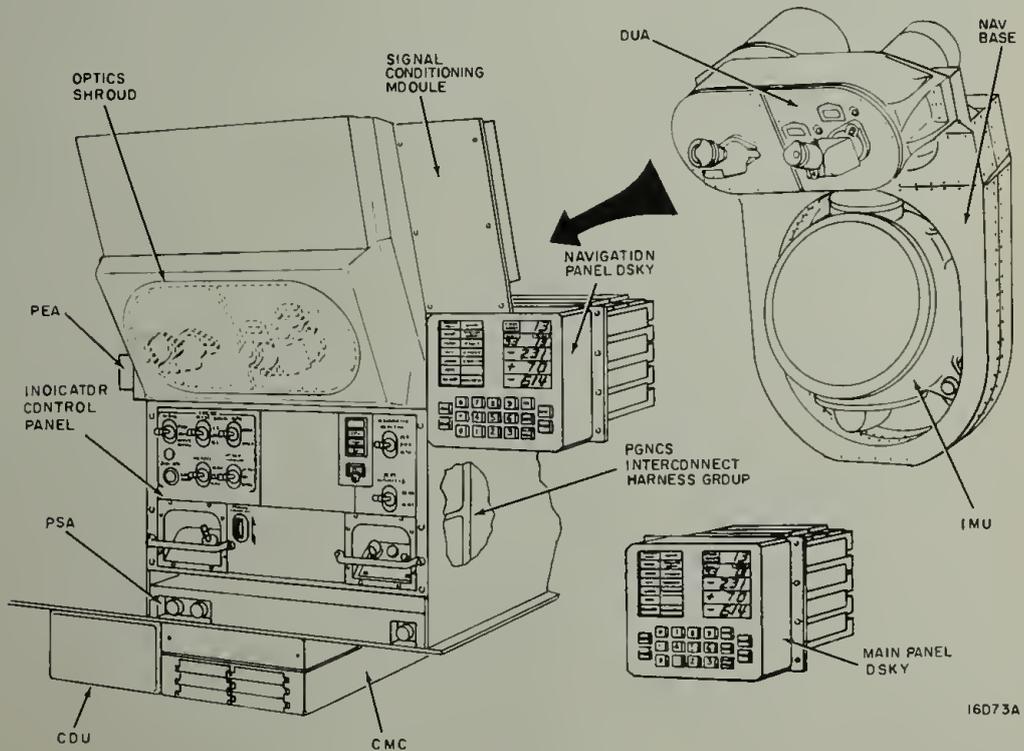


Figure 3-1. Primary Guidance, Navigation, and Control System

Table 3-I. PGNCS Components

Component	Part Number
CDU	2007222-031
CMC group	2003101-021
CMC	2003100-021
Main panel DSKY	2003985-051
Navigation panel DSKY	2003985-051
D and C group	2014623-011
Indicator control panel	2014578-011
Optics shroud	2014576-011
Flexible hose assembly (2 required)	2018820-011
IMU and PEA (System 2015000-011)	2007203-011
IMU	2018601-011
PEA	2007201-011
IMU and PEA (System 2015000-021)	2007203-021
IMU	2018601-021
PEA	2007201-011
Nav base	2899982-011
Nav base, OUA, and bellows installation kit	2899950-011
OUA	2011000-031
PGNCS interconnect harness group	2014567-011
Interconnect harness A	2014641-011
Interconnect harness B	2014642-011
Interconnect harness C	2014643-011
Interconnect harness D	2014644-011
Interconnect harness E	2014645-011
Interconnect harness F	2014646-011
Interconnect harness G	2014647-011
Interconnect harness H	2014648-011
PSA	2007200-021
Signal conditioning module	

3-2 COUPLING DATA UNIT

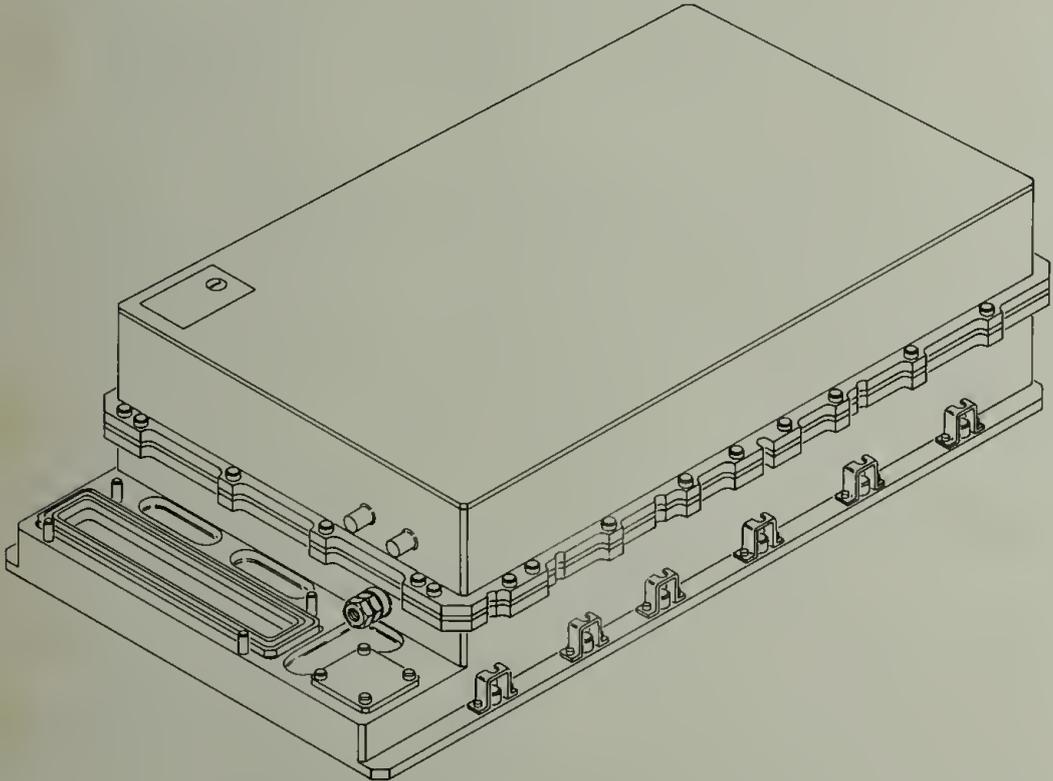
The CDU (figure 3-2) consists of two tray assemblies containing a total of 32 modules. The two tray assemblies, tray X and tray S, are bolted together, module sides facing. The unit is then mounted to a coldplate in the command module. The assembled unit, constructed mainly of magnesium, measures approximately 5.5 inches high, 11.3 inches wide, and 20 inches deep.

Tray X has a connector used only for component level testing, a connector, J53, used to connect to the PGNCS interconnect harness A, and a filler valve used to pressurize the CDU.

The modules in the CDU provide five separate channels to couple the CMC to the IMU and the OUA. In addition to the five separate channels, the CDU contains four modules which are shared by all channels. Basic CDU functions are as follows:

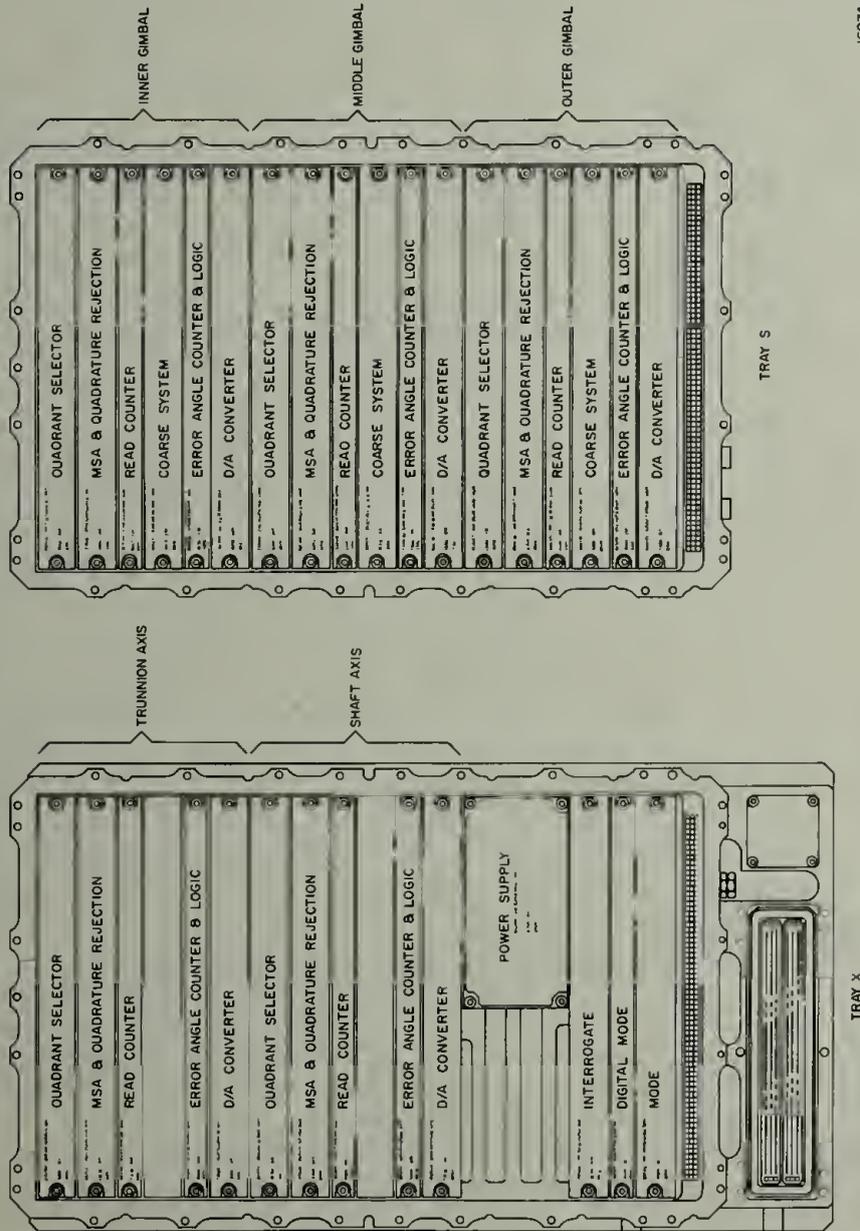
- (1) Interpret commands (digital) from the CMC and convert them to IMU gimbal positioning signals (analog).
- (2) Interpret gimbal positions (analog) and transmit the information to the CMC (digital).
- (3) Couple the IMU to the FDAI.
- (4) Interpret OUA shaft and trunnion angles (analog) and transmit the information to the CMC (digital).
- (5) Interpret commands (digital) from the CMC and convert them to OUA positioning signals (analog).

Module locations are illustrated in figure 3-3 and their functions are described in table 3-II.



16072

Figure 3-2. Coupling Data Unit



16074

Figure 3-3. CDU Module Locations

Table 3-II. Function of CDU Modules

Nomenclature	Part Number	Function
Coarse system (three)	2007236-011	Provides coarse switching and attenuation circuitry necessary to increment angles.
Digital mode	2007141-031	Provides pulse commands which are used throughout CDU for synchronization, switching, and strobing.
D/A converter (five)	2007237-011	Converts digital information in error counter into dc analog signal and two ac analog signals.
Error angle counter & logic (five)	2007139-041	Accumulates pulses representing angular error and provides logic circuitry to control operation of other CDU modules.
Interrogate	2007263-011	Generates a portion of the timing pulses required for CDU operation, produces 14 vdc power, and provides circuitry for data and pulse transmission.
MSA & quadrature rejection (five)	2007238-011	Provides fine switching and attenuation circuitry necessary to increment angles.
Mode	2007254-011	Buffers signals and monitors CDU operations.
Power supply	2007142-011	Supplies 4 vdc logic power to digital logic portions of CDU.
Quadrant selector (five)	2007243-011	Converts sin and cos resolver signals to phase relationships required by main summing amplifier.
Read counter (five)	2007140-031	Accumulates pulses representing angles, and controls switching of coarse system module and main summing amplifier.

3-3.1.1 Logic Tray A. Tray A assembly (figure 3-5) contains 31 modules: 24 logic modules, five interface modules, and two power supply modules. All modules are mounted on the tray and then potted with a silastic compound.

Tray A has three intertray connectors: A61, A62, and A63; and two connectors on the rear. A 360 pin rear connector (A51) connects the CMC through PGNCs interconnect harness A to the main power source of 28 vdc, to the DSKY's, to other parts of the PGNCs, and to other spacecraft systems. A 144 pin rear connector (A52) provides interface with ground support equipment used in testing the CMC.

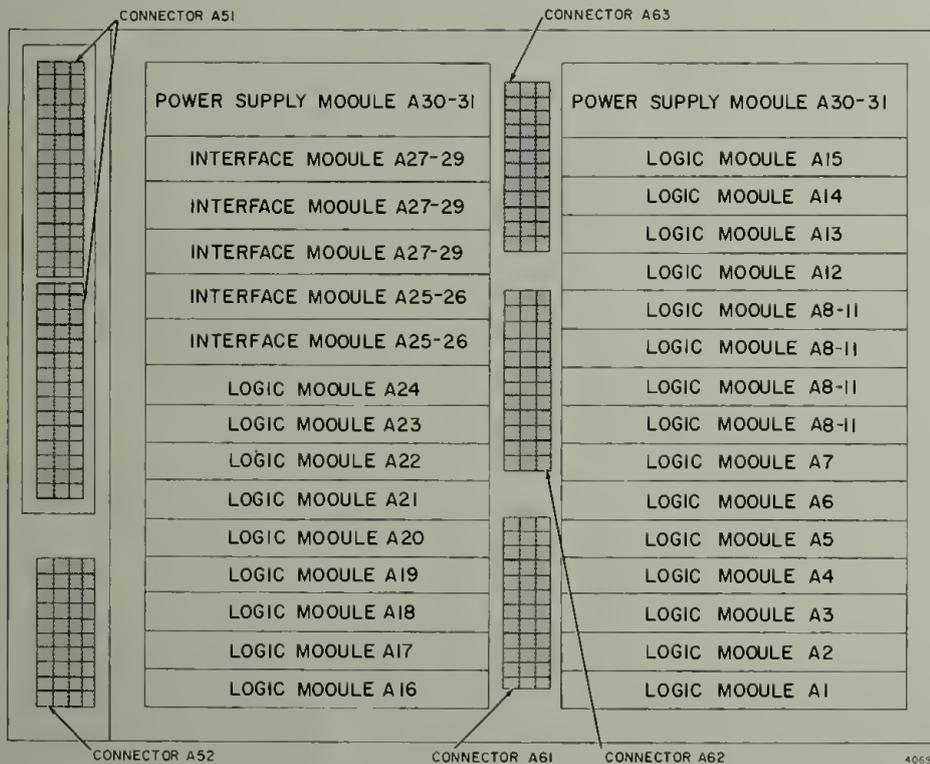


Figure 3-5. Tray A Module Side

3-3.1.2 Tray B. Tray B assembly (figure 3-6) contains 17 modules, including 6 rope modules. All modules are potted into the tray except the rope modules which are plugged into the front of the CMC. Tray B has three intertray connectors: B61, B62, and B63.

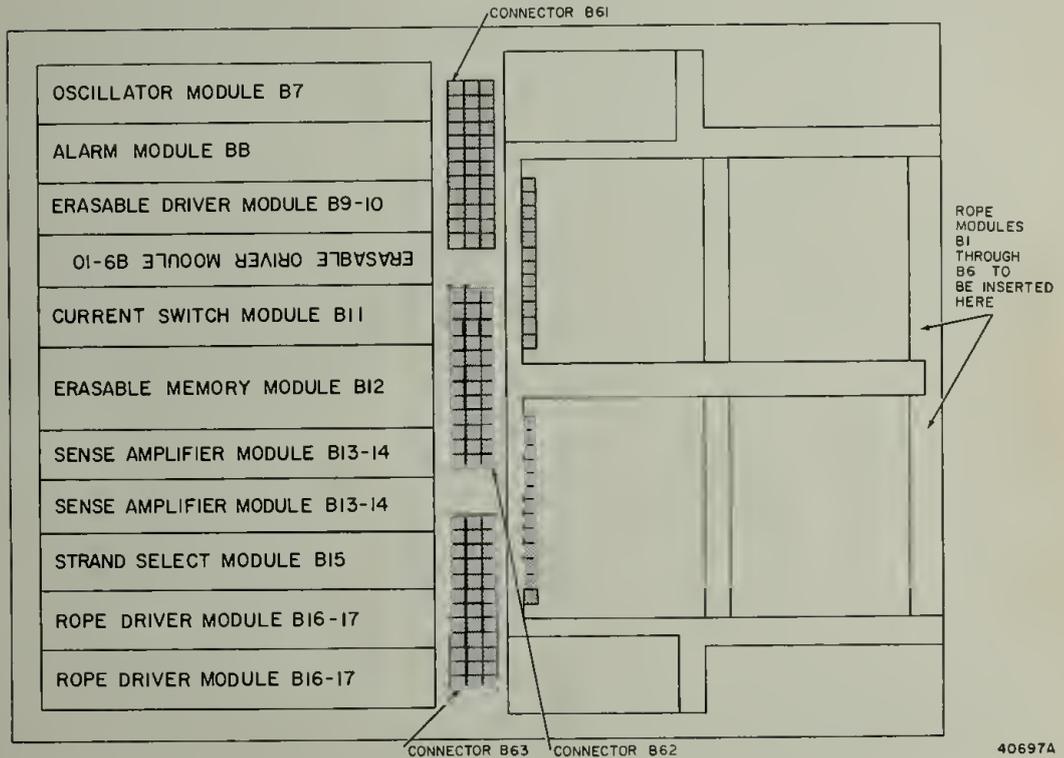


Figure 3-6. Tray B Module Side

3-3.2 DISPLAY AND KEYBOARD (DSKY). There are two identical and interchangeable DSKY's associated with the CMC, the main panel DSKY and the navigation panel DSKY (figure 3-7). Each DSKY measures approximately 8 inches high, 8 inches wide, and 7 inches deep.

Each DSKY is divided into two sections: one section for displays and one section for the keyboard. The display section contains 14 caution and alarm indicators, 4 operation display indicators, and 18 data display indicators. The words PROG, VERB, and NOUN associated with the operation display indicators, and the lines separating the three groups of data display indicators, are always illuminated. Six interchangeable indicator driver modules are mounted at the rear of the display section. The keyboard section contains 19 keys. The word, sign, or number of a key is always illuminated.

A 91 pin connector, a filler valve, and a power supply are also mounted on the rear of each DSKY. The 91 pin connector (J9) connects the DSKY to the CMC, PGNCS, and other spacecraft systems. Connections are through PGNCS interconnect harness A for the main panel DSKY and through PGNCS interconnect harness H for the navigation panel DSKY. The filler valve is used for pressurizing the DSKY to one atmosphere. The power supply module supplies the voltage required to light the display indicators.

The operating controls and indicators, and their functions, are listed in table 3-III.

3-4 DISPLAY AND CONTROL GROUP

3-4.1 INDICATOR CONTROL PANEL. The indicator control panel (figure 3-8) provides displays and controls, equipped with electroluminescent lamps, for the following functions:

- (1) Manual spacecraft maneuvering.
- (2) Manual optics positioning.
- (3) Optics mode control.
- (4) Warning, caution, and status lamps.

The indicator control panel is approximately 12.6 inches high, 23.5 inches wide, and 4.1 inches deep. An electrical connector (J1) provides connections between the indicator control panel and the PSA through PGNCS interconnect harness E.

3-4.2 OPTICS SHROUD. The optics shroud is manufactured from laminated fiberglass cloth and is used as protection and as a cover for the OUA. The optics shroud is approximately 12.75 inches high, 23.5 inches wide, and 6 inches deep.

3-5 FLEXIBLE HOSE ASSEMBLY

The flexible hose assemblies connect the IMU to the spacecraft environmental control system which provides the necessary coolant solution. The flexible hose assemblies are approximately 9.75 inches long and are equipped with quick disconnects. The connections to the environmental control system are welded.

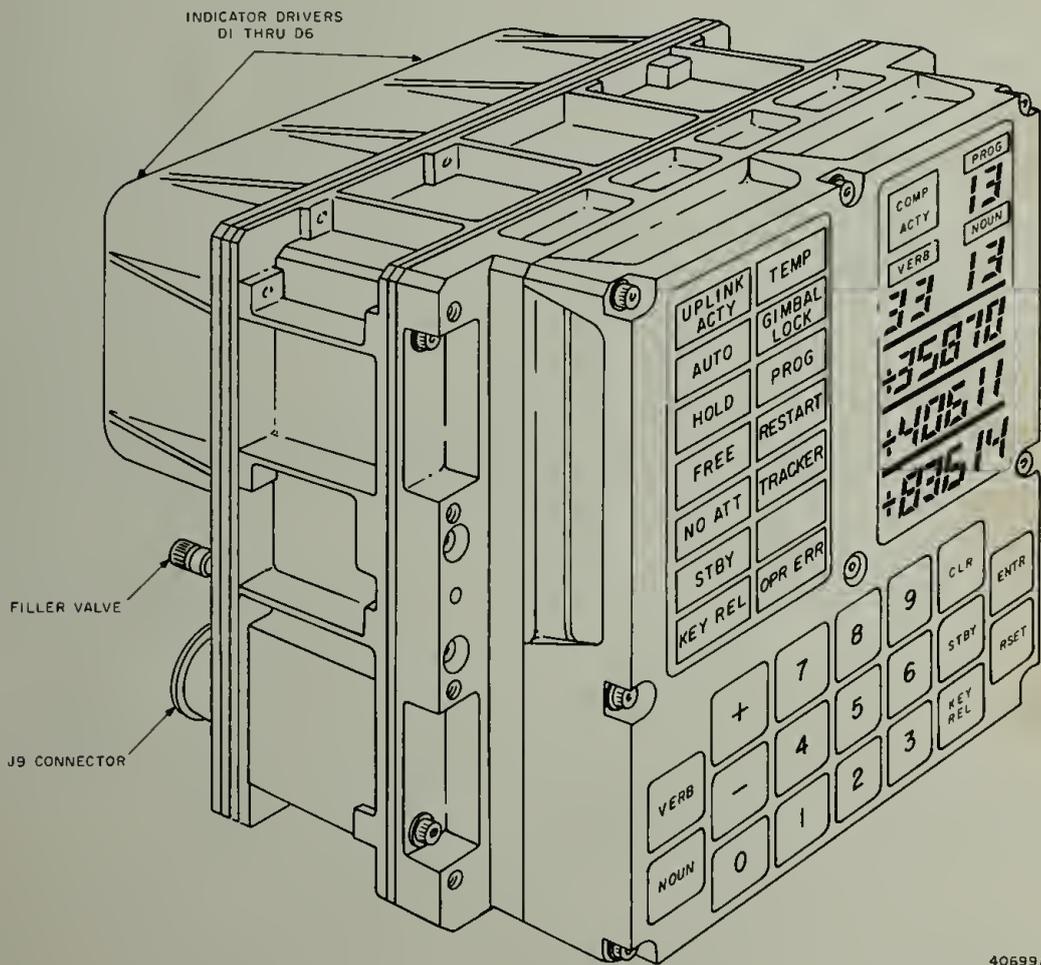


Figure 3-7. Main Panel and Navigation Panel DSKY

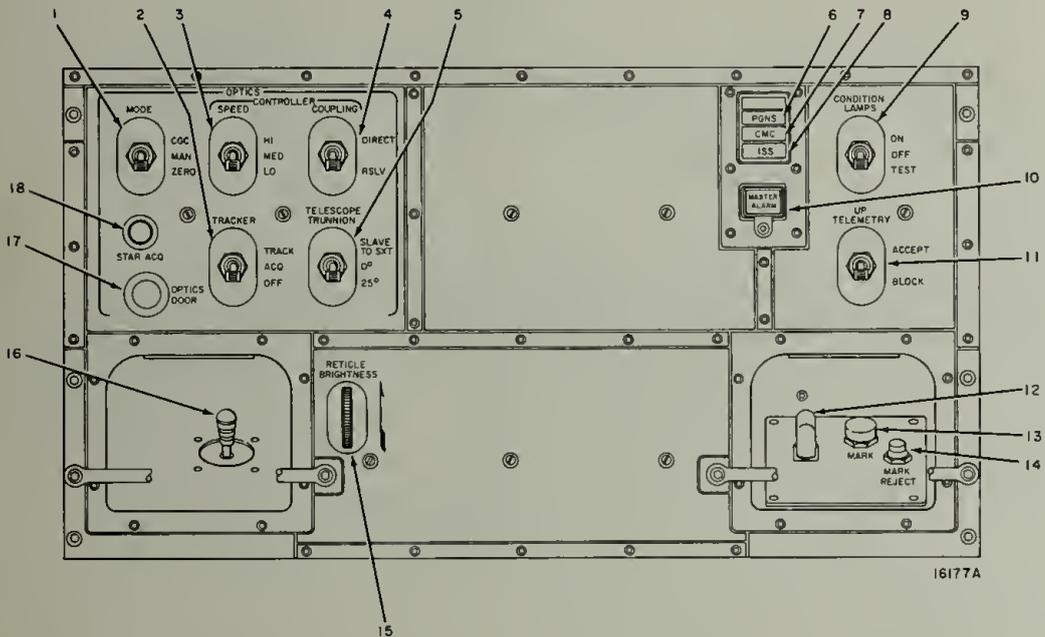
Table 3-III. DSKY Operating Controls and Indicators

Controls and Indicators	Function
Caution and Alarm Indicators	
UPLINK ACTY STBY KEY REL RESTART OPR ERR AUTO HOLD FREE NO ATT TEMP GIMBAL LOCK PROG TRACKER SPARE	Indicates information is being received via UPLINK. Indicates CMC is in restart condition and low power mode. Indicates that program information wishes to be displayed. Indicates CMC is in restart condition. Indicates illegal keyboard operation. Not used. Not used. Not used. Indicates that ISS is not suitable for use as attitude reference. Indicates overheat or underheat condition of IMU stable member. Indicates middle gimbal angle in excess of 75 degrees. Indicates that program check has failed. This indicator is controlled by CMC program. Not used. Spare.
Operation Display Indicators	
COMP ACTY PROG VERB NOUN	Indicates that CMC is in operation. Indicates function or functions of program being executed in CMC. Indicates verb code entered at keyboard. Indicates noun code entered at keyboard.

Table 3-III. DSKY Operating Controls and Indicators

Controls and Indicators	Function
Data Display Indicators	
Data display indications	A plus or minus sign signifies data displayed is decimal; no sign signifies data is octal.
Keyboard Keys	
KEY REL	Releases control of keyboard so that information supplied by program action may be displayed.
STBY	Initiates CMC restart condition and puts CMC into low power mode. Normal operation may be resumed by pressing STBY again.
RSET	Clears caution indicators and OPR ERR indicator.
CLR	Clears data contained in data register currently in use.
VERB	Conditions CMC to interpret next two numerical characters as action request.
NOUN	Conditions CMC to interpret next two numerical characters as address code.
ENTR	Informs CMC that assembled data is complete; execute requested function.
+ key	Enters positive sign for decimal data.
- key	Enters negative sign for decimal data.
0 through 9	Enters data, address code, and action request code into CMC.

(Sheet 2 of 2)



Index Number	Control or Indicator	Function
1	OPTICS MODE selector	Selects circuitry for either zeroing optics, manual control of optics, or CMC control of optics.
2	OPTICS TRACKER selector	Not used.
3	OPTICS SPEED CONTROLLER	Varies voltage for optics hand controller use.
4	OPTICS COUPLING CONTROLLER	Selects either direct or resolved positioning of optics.

Figure 3-8. Indicator Control Panel (Sheet 1 of 2)

Index Number	Control or Indicator	Function
5	OPTICS TELESCOPE TRUNNION selector	Slaves SCT to SXT S _t LOS or SXT LLOS, or off-sets SCT 25° in trunnion angle from SXT LLOS.
6	PGNS condition lamp	Indicates malfunctions in PGNS equipment.
7	CMC condition lamp	Indicates malfunctions in CMC equipment.
8	ISS condition lamp	Indicates malfunctions in ISS equipment.
9	CONDITION LAMPS selector	Enables condition lamp circuitry or lights condition lamps for test.
10	MASTER ALARM lamp and pushbutton	Indicates failure in PGNS and allows resetting of alarm circuitry.
11	UP TELEMETRY switch	Allows or blocks telemetry data from ground stations to be entered into CMC.
12	Attitude impulse hand control	Supplies signals to reaction control system to position the spacecraft in attitude.
13	MARK pushbutton	When pressed, sends signals to CMC to record time and optics and gimbals angles.
14	MARK REJECT pushbutton	Cancels input initiated by MARK pushbutton.
15	RETICLE BRIGHTNESS control	Varies voltage to change reticle lamp brightness.
16	Optics hand controller	Supplies signal to drive optics about shaft axis and/or trunnion axis in manual mode.
17	OPTICS DOOR	Opening through which tool can be inserted to manually open optics door in case of mechanical failure.
18	STAR ACQ lamp	Not used.

Figure 3-8. Indicator Control Panel (Sheet 2 of 2)

3-6 INERTIAL MEASURING UNIT AND PIP ELECTRONICS ASSEMBLY

3-6.1 INERTIAL MEASURING UNIT. The IMU (figure 3-9) is a three-gimbal system. The command module has unrestricted movement about all axes of the gyro-stabilized inner gimbal (stable member). During normal operation, the middle gimbal angle is not allowed to exceed ± 70 degrees. The inner gimbal is held stable by three Apollo II IRIG's. Accelerations along any component of the three orthogonal axes of the stable member are sensed by one or more of the three 16 PIP accelerometers. Intergimbal assemblies physically support the gimbals and pass electrical signals between them. The temperature of the IMU is maintained at the desired level by a system of heaters, blowers, thermostats, and coolant passages. The IMU is sealed to maintain one atmosphere pressure as an aid in convection cooling when the IMU is subjected to pressures of less than one atmosphere.

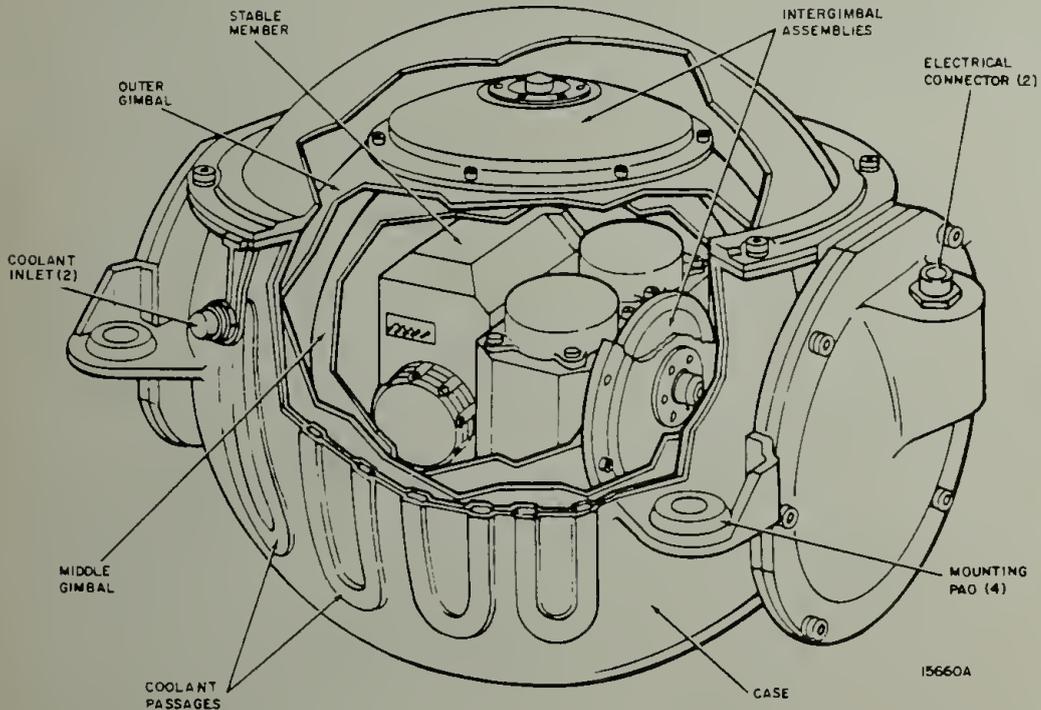


Figure 3-9. Inertial Measuring Unit

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

3-6.1.1 Stable Member. The stable member is suspended by two intergimbal assemblies inside the middle gimbal. It is free to rotate without restriction about the inner gimbal (IG) axis. The stable member is machined from a solid block of beryllium 6.5 x 5.9 x 5.2 inches. Holes are machined to receive the three Apollo II IRIG's and the three PIP's. Accelerometer preamplifiers, stable member heaters, temperature control circuitry and thermostats, a ducosyn transformer, and two safety thermostats are attached to the stable member.

3-6.1.1.1 Gyroscopes. Three Apollo II IRIG's are mounted on the stable member (figure 3-10).

Ducosyns are used for magnetic suspension of the gyro rotor and for signal and torque generation. The signal generator ducosyn is located at the positive output axis end of the float; the torque generator ducosyn is located at the negative output axis end.

The gyro wheel assembly operates as a hysteresis synchronous motor. The hub of the wheel is made of beryllium and the rim is made of heavy steel. This method of construction concentrates the weight at the rim giving the wheel a high inertial moment.

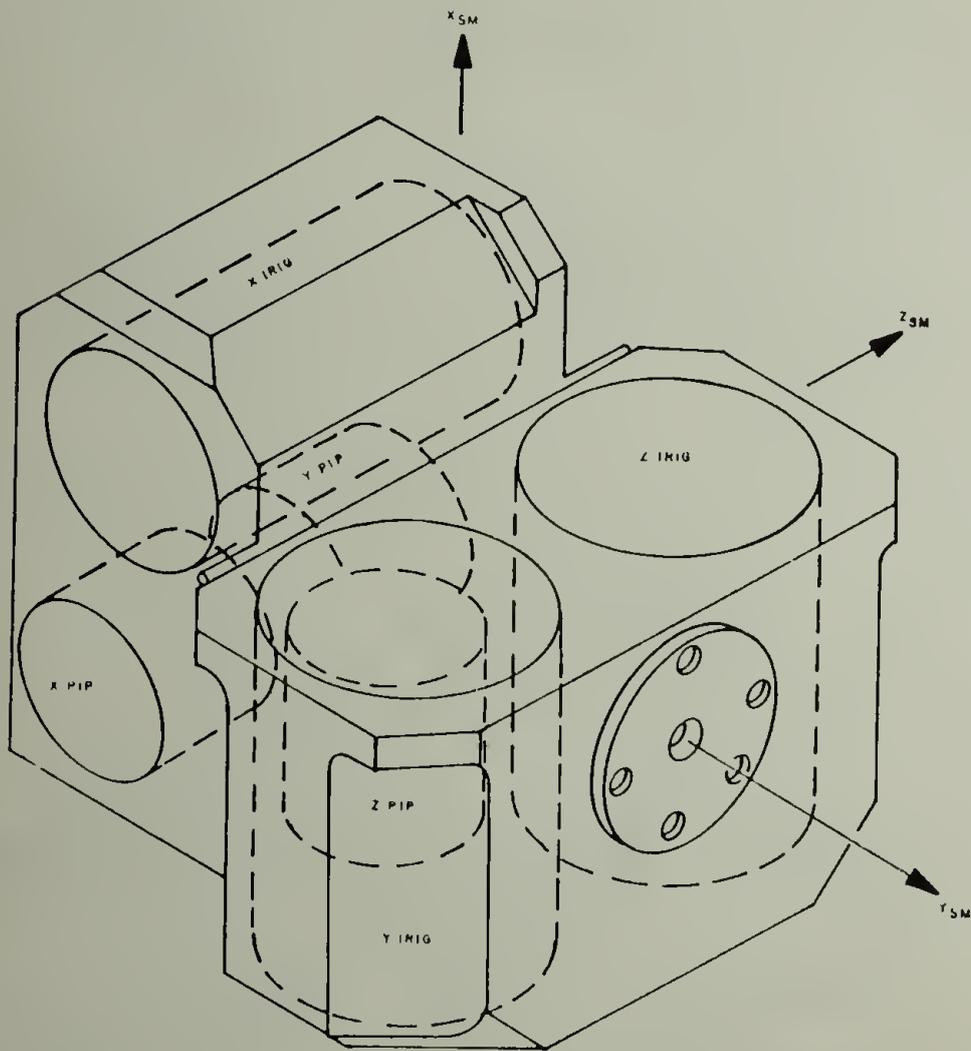
3-6.1.1.2 Accelerometers. The Block II IMU uses three 16 PIP accelerometers for sensing acceleration. Figure 3-10 shows the orthogonal placement of the 16 PIP's on the stable member. The 16 PIP is basically a cylindrical float with a pendulous mass unbalance and is pivoted with respect to a case. Ducosyns are located at each end of the float for magnetic suspension and signal and torque generation.

3-6.1.1.3 Stable Member Mounted Electronics. Table 3-IV gives the location and functions of electronics modules which are mounted on the stable member.

3-6.1.2 Middle Gimbal. The middle gimbal is suspended by two intergimbal assemblies inside the outer gimbal. It, in turn, supports the stable member. Slip ring assemblies in the intergimbal assemblies provide a means of carrying electrical signals between the outer gimbal and the stable member. The middle gimbal is approximately 9.5 inches in diameter.

3-6.1.3 Outer Gimbal. The outer gimbal is similar in configuration to the middle gimbal, being suspended inside the supporting gimbal by two intergimbal assemblies. The outer gimbal has two thermostatically controlled axial-flow blowers mounted in its walls to force air from the vicinity of the middle gimbal to the walls of the case, where heat is transferred to a water-glycol coolant solution circulating through passages in the case. The outer gimbal is approximately 10.6 inches in diameter.

3-6.1.4 Supporting Gimbal. The supporting gimbal (case) is a spherical enclosure which supports the three gimbals described in the preceding paragraphs. The outer gimbal is suspended inside the case by two intergimbal assemblies which allow complete freedom of rotation. The walls of the case contain coolant passages through which a water-glycol solution is circulated to dissipate heat generated by inertial components and electrical modules. Two quick disconnect fittings connect the coolant passages to the Block II command module coolant supply. The case is surrounded by insulating material to prevent condensation on the coolant passages. The case is approximately 12.6 inches in diameter.



16136

Figure 3-10. Stable Member

Table 3-IV. Location and Functions of IMU Electronics

Nomenclature	Part Number	Location and Function
Blower control module assembly	2007171-011 (System 2015000-011) 2007172-011 (System 2015000-021)	Stable member (SM): Removes power from blower control relay in response to request from blower control thermostat and heater assembly.
Blower control relay	1010353-10 (System 2015000-011) 1010353-13 (System 2015000-021)	Outer gimbal resolver intergimbal assembly: Removes power from blower motors at request of blower control module assembly.
Blower control thermostat and heater assembly	2018635 (System 2015000-011) 2018825-011 (System 2015000-021)	SM: Controls on-off action of blower motors on outer gimbal.
Ducosyn transformer assembly	2007019-011	SM: Reduces 28 volts ac to 2 volts and 4 volts for signal generator excitation of PIP and IRIG ducosyns, respectively.
PIP preamplifier assembly	2007060-011	SM: Amplifies signals generated by PIP signal generator to prevent loss in slip ring assemblies. Also provides 45 degree phase shift from reference voltage.
Precision resolver alignment assembly	2007204-011	Outer gimbal resolver intergimbal assembly: Compensates for design anomalies in intergimbal assembly resolvers.
Safety thermostat (2)	1001485	SM: Disables all IMU heaters if extreme overheat condition exists.
Stable member heater assembly (2)	2018641	SM: Supplements and stabilizes heat generated by inertial component heaters.

(Sheet 1 of 2)

Table 3-IV. Location and Functions of IMU Electronics

Nomenclature	Part Number	Location and Function
Temperature alarm module assembly	2007170-011	SM: Signals CMC that overheat or underheat condition exists.
Temperature alarm thermostat assembly	2018636 (System 2015000-011)	SM: Controls operation of temperature alarm module assembly.
Temperature alarm thermostat and heater assembly (high)	2018823-011 (System 2015000-021)	SM: Controls operation of temperature alarm module assembly during overheat conditions.
Temperature alarm thermostat and heater assembly (low)	2018824-011 (System 2015000-021)	SM: Controls operation of temperature alarm module assembly during underheat conditions.
Temperature control module assembly	2007064-011	SM: Applies power to heaters in IRIG's, PIP's, and on SM, in response to request from temperature control thermostat and heater assembly.
Temperature control thermostat and heater assembly	2018637 (System 2015000-011) 2018826-011 (System 2015000-021)	SM: Controls operation of temperature control module to maintain proper heat in inertial components.

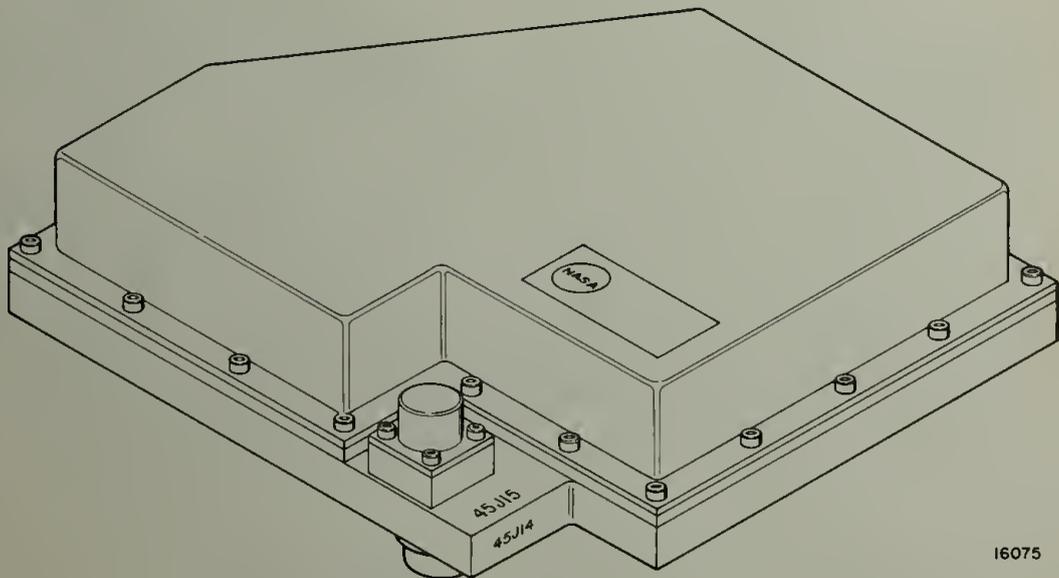
(Sheet 2 of 2)

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

Electrical interface between the IMU and the remainder of the PGNCS is accomplished by two electrical connectors (J1 and J2) on the case. A precision resolver alignment assembly module and a blower control relay are mounted on the resolver intergimbal assembly of the outer gimbal. The resolver alignment assembly is accessible from outside the case.

3-6.1.5 Intergimbal Assembly. The intergimbal assemblies serve four basic purposes: the duplex ball bearings support the gimbal with a minimum of friction, the torque motor drives the gimbal in response to an error signal, the multispeed resolver furnishes signals which represent the angular position of the gimbal, and the gyro error resolver (inner gimbal only) transforms gyro error signals into gimbal angle error signals. Slip rings are also mounted in each intergimbal assembly providing a means of transferring electrical signals from the stable member and intergimbal assemblies and allowing 360 degrees of freedom for each gimbal.

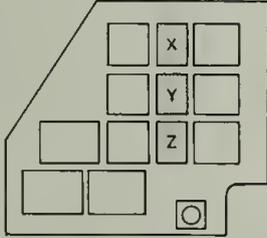
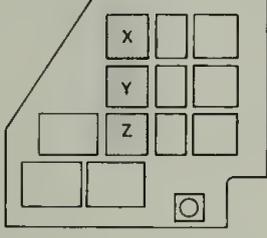
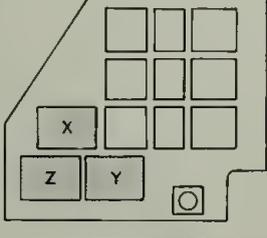
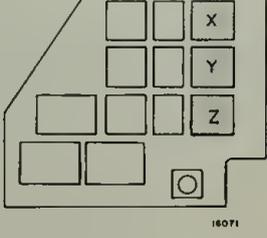
3-6.2 PIP ELECTRONICS ASSEMBLY. The PEA (figure 3-11) consists of a group of modular electronic assemblies whose functions are related to inertial components in the IMU. The PEA is mounted close to the IMU to avoid line loss in low-level signals. Table 3-V identifies and lists the functions of the PEA modules. The PEA has two connectors: an 85 pin connector (J14) used to connect the PEA to the IMU and PSA, and a 44 pin connector (J15) used as a PIP test connector. The PEA measures approximately 9.1 inches high, 10 inches wide, and 2.6 inches deep.



16075

Figure 3-11. PIP Electronics Assembly

Table 3-V. Location and Functions of PIP Electronics Assembly Modules

Module Part Number	Module Assembly Name and Function	Location
2007101-011	DC differential amplifier and PVR (three) Regulates torquing current supplied through binary current switches.	
2007103-011	Binary current switch (three) Switches constant current pulses between PIPA torque generators to null PIPA loops. Supplies pulses to CMC forward backward counter to indicate velocity change.	
2007104-011	AC differential amplifier and interrogator (three) Amplifies signals from PIPA signal generator and converts them to plus and minus torque pulses.	
2007105-011	C/M PIPA calibration (three) Compensates for differences in inductive loading of PIPA signal generator windings and regulates balance of plus and minus torques.	

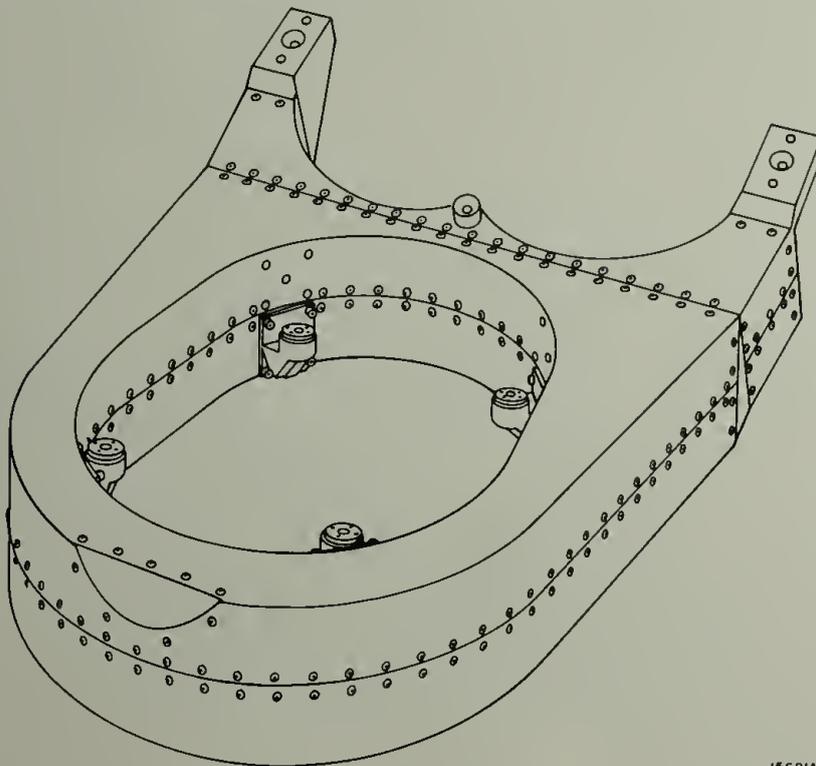
3-7 NAVIGATION BASE

The nav base (figure 3-12) provides a mounting surface for the IMU and OUA.

The outer shell is constructed by riveting and bonding anodized preformed sheet aluminum alloy panels together. The shell is filled with polyurethane foam.

Precisely machined mounting surfaces insure that the plane formed by the IMU mounts is $32^{\circ} 32' 23''$ from the plane formed by the OUA mounts. The nav base is positioned behind the indicator control panel with the OUA along the conical surface of the command module.

The nav base is constructed with a 20° offset and is approximately 27 inches long, 22 inches wide, and 4.5 inches high.



15681A

Figure 3-12. Navigation Base

3-8 NAVIGATION BASE, OPTICAL UNIT ASSEMBLY, AND BELLOWS INSTALLATION KIT

The nav base, OUA, and bellows installation kit consist of nav base mounting assemblies (fixed, line, and plane) for shock mounting the nav base to the spacecraft; OUA to spacecraft seal assemblies to provide seals between the inner shell of the spacecraft and the housings of the SXT and SCT; and hardware for mounting the OUA and IMU to the nav base.

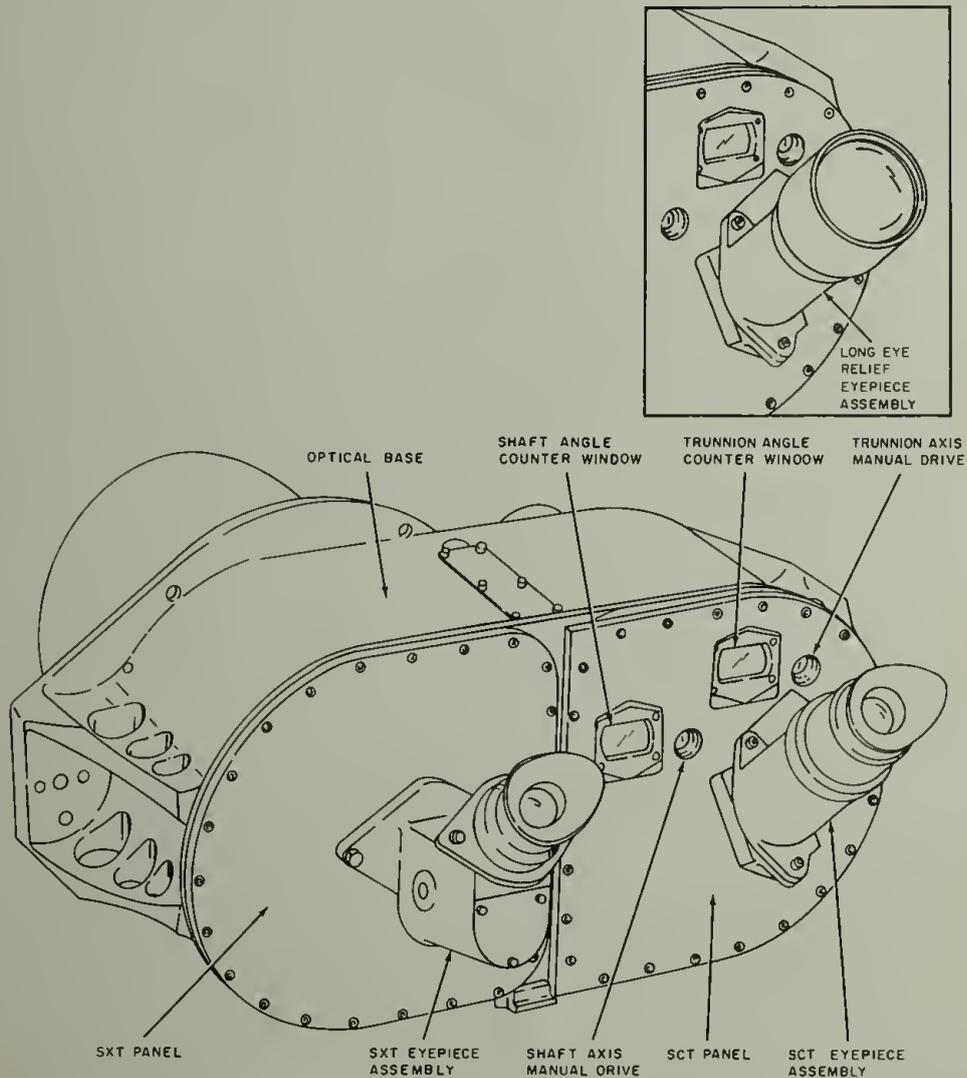
3-9 OPTICAL UNIT ASSEMBLY

The OUA consists of two optical instruments, a SXT and a SCT, mounted on a common optical base. (See figure 3-13.) The base is rigidly mounted on the nav base above the IMU. Three precision ball mounts on the optical base provide for mounting the OUA on the nav base. Two bellows function as flexible seals between the inner shell of the spacecraft and the housings of the SXT and SCT.

3-9.1 OPTICAL BASE. The optical base, a precisely machined beryllium casting, provides a mount for the SCT and SXT and houses the shaft axis drive and control components of the SXT and SCT. Internal components of the base are sealed by the SXT and SCT panels (figure 3-13), which provide mountings for the SXT and SCT eyepiece assemblies. SCT shaft and trunnion mechanical angle counters are located in the SCT panel assembly. The SCT panel is equipped with adapters to allow manual positioning of the SCT trunnion and shaft axes in the event of servo positioning loop failure.

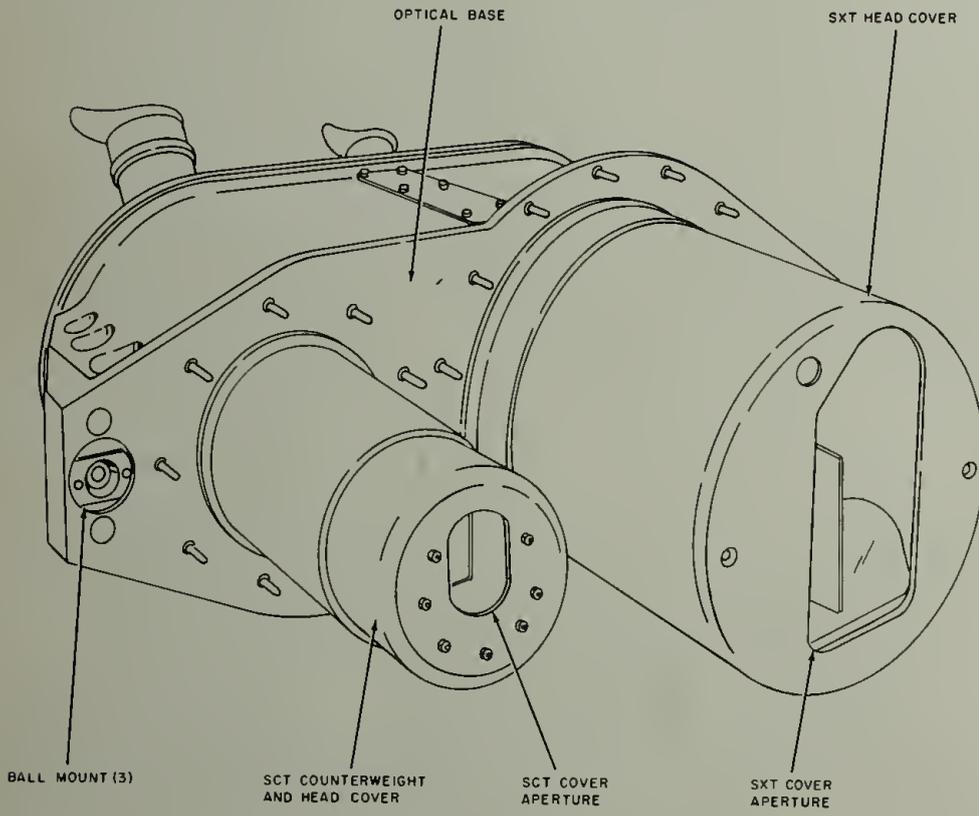
3-9.2 SEXTANT. The SXT assemblies are contained in a cylindrical housing which protrudes outward from the optical base. (See figure 3-14.) The housing contains optical components and trunnion drive assemblies. The SXT head assembly is protected by an aluminum alloy head cover. An elongated aperture extending to the periphery of the cover permits unobstructed lines-of-sight for the SXT through its entire operating range.

3-9.3 SCANNING TELESCOPE. The SCT assemblies are mounted in a cylindrical housing which protrudes outward from the optical base. (See figure 3-14.) The housing contains optical components and trunnion drive assemblies. The SCT head assembly is protected by a counterweight and cover assembly. This assembly has an aperture which allows an unobstructed line-of-sight through the entire SCT operating range.



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Figure 3-13. Optical Unit Assembly, Front View



16260

Figure 3-14. Optical Unit Assembly, Rear View

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

3-10 PGNCS INTERCONNECT HARNESS GROUP

The PGNCS interconnect harness group connects the PGNCS to the spacecraft power supplies and electrically interconnects PGNCS components. These connections are made through eight wiring harnesses. Component interconnections are listed in table 3-VI.

3-11 POWER AND SERVO ASSEMBLY

The PSA (figure 3-15) contains encapsulated electronic circuitry for the inertial and optical subsystems of the PGNCS. The PSA contains 37 modules mounted on a common frame which in turn is mounted on a coldplate. The coldplate dissipates heat generated by the electronic components. Table 3-VII gives the location and functions of the PSA modules.

The PSA has 10 connectors: two 61 pin connectors (J1 and J3) which are used for test and monitor; one 19 pin connector (J2) used to connect the portable temperature controller to the PSA for GSE control of IMU temperature; one 323 pin connector (J4) which connects the PSA to the CMC, CDU, and main panel DSKY through PGNCS interconnect harness D, and also used for test and monitor; one 116 pin connector (J5) which connects the SXT to the PSA through PGNCS interconnect harness B; one 193 pin connector (J6) which connects the IMU and PEA to the PSA through PGNCS interconnect harness C; one 114 pin connector (J7) which connects the indicator control panel to the PSA through PGNCS interconnect harness E; one 68 pin connector (J8) which connects the nav panel DSKY to the PSA through PGNCS interconnect harness H, and also used for test and monitor; one 66 pin connector (J9) which connects the SCT to the PSA through PGNCS interconnect harness F; and one 192 pin connector (J10) which connects the signal conditioning module to the PSA through PGNCS interconnect harness G, and also used for test and monitor.

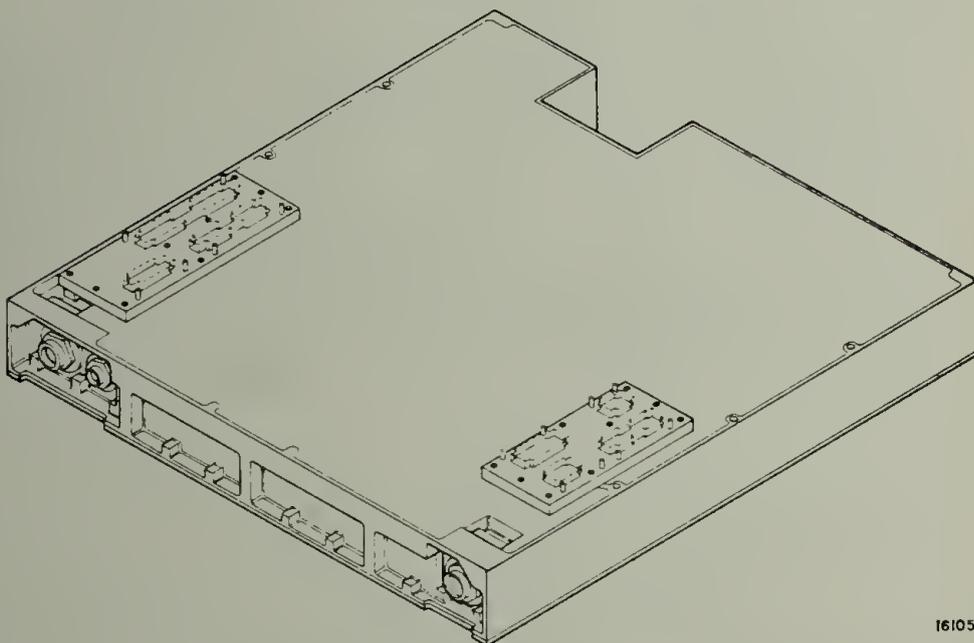
The PSA is approximately 2.75 inches high, 23.1 inches wide, and 22.6 inches deep.

3-12 SIGNAL CONDITIONING

This paragraph will give a physical description of signal conditioning and will be supplied when information is available.

Table 3-VI. PGNCS Interconnect Harness Group Connections

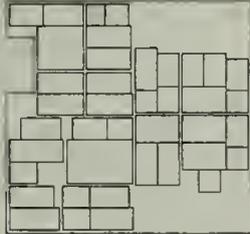
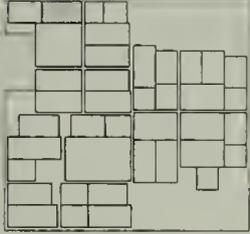
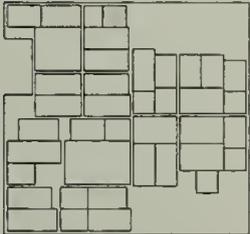
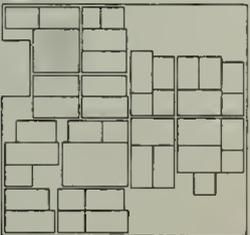
PGNCS Interconnect Harness		Connects to	
Number	Plug	Jack	Component
A (2014641)	P1	J1	PGNCS interconnect harness D
	P2	J2	PGNCS interconnect harness D
	P3	J3	PGNCS interconnect harness D
	P4	J4	PGNCS interconnect harness D
	P5	J5	PGNCS interconnect harness H
	P6		Interface, CMC signals
	P7		Interface, ISS signals
	P8		Interface, main panel DSKY signals
	P9	X53	CDU
	P10	A51	CMC
B (2014642)	P13	J1	SXT
	P14	J2	SXT
	P18	J5	PSA
C (2014643)	P12	J14	PEA
	P15	J2	IMU
	P16	J1	IMU
	P19	J6	PSA
D (2014644)	J1	P1	PGNCS interconnect harness A
	J2	P2	PGNCS interconnect harness A
	J3	P3	PGNCS interconnect harness A
	J4	P4	PGNCS interconnect harness A
	P17	J4	PSA
E (2014645)	P24	J1	Indicator control panel
	P26	J7	PSA
F (2014646)	P23	J1	SCT
	P28	J9	PSA
G (2014647)	J6		OUA eyepiece heaters
	J7		OUA eyepiece heaters
	P20	J1	Signal conditioning module
	P21	J2	Signal conditioning module
	P22	J3	Signal conditioning module
	P29	J10	PSA
	P32		Interface, PCM signals
H (2014648)	J5	P5	PGNCS interconnect harness A
	P25	J9	Navigation panel DSKY
	P27	J8	PSA
	P30		Power bus A
	P31		Power bus B



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Figure 3-15. Power and Servo Assembly

Table 3-VII. Location and Functions of PSA Modules

Module Part Number	Module Assembly Name and Function	Location
2007101-011	DC differential amplifier and precision voltage reference Supplies precision reference voltage for IRIG pulse torquing current control.	
2007102-011	Gyro calibration Applies plus or minus torque pulses to IRIG's as directed by CMC.	
2007103-011	Binary current switch Switches current pulses to one of IRIG torque generators to control gimbal position.	
2007106-011	Pulse torque power supply Supplies +120 vdc to PIPA loops and to fine align electronics. Also supplies +28, +20, and -20 vdc to PIPA loops.	

(Sheet 1 of 9)

Table 3-VII. Location and Functions of PSA Modules

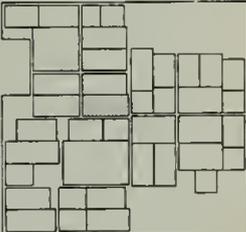
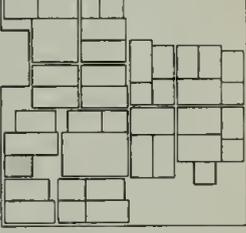
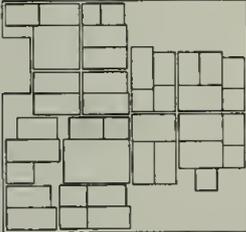
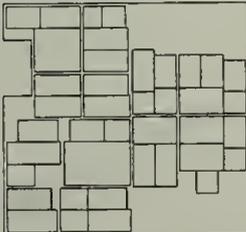
Module Part Number	Module Assembly Name and Function	Location
2007107-011	<p>-28 volts dc power supply Supplies power to three gimbal servo amplifiers in stabilization loop and to pulse torque power supply to generate -20 vdc for accelerometer loops.</p>	
2007108-011	<p>3,200 cps 1% amplifier Supplies 3,200 cps ducosyn excitation and magnetic suspension voltage. Also used as reference for gimbal servo amplifier demodulator in all modes of operation except coarse align mode.</p>	
2007109-011	<p>3,200 cps AAC, filter and multivibrator Regulates operation of 3,200 cps 1% amplifier.</p>	
2007110-011	<p>800 cps 1% amplifier Provides IMU resolver excitation and reference for 800 cps 5% amplifier.</p>	

Table 3-VII. Location and Functions of PSA Modules

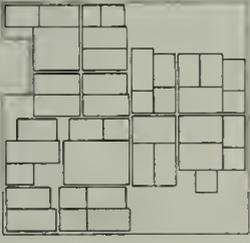
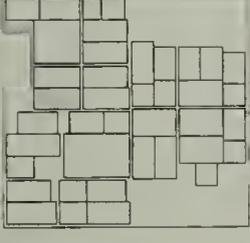
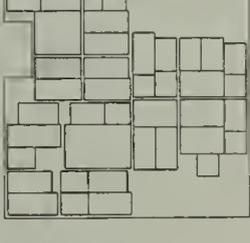
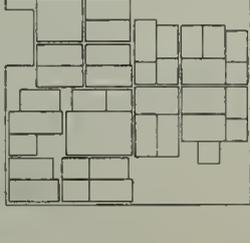
Module Part Number	Module Assembly Name and Function	Location
2007110-011	800 cps 1% amplifier Provides resolver and tachometer excitation for OSS, and reference for 800 cps 5% amplifier.	
2007111-011	800 cps 5% amplifier Supplies 28 volts 800 cps for IMU blowers and PIP heaters and 28 volts 800 cps phase A IRIG wheel power.	
2007111-011	800 cps 5% amplifier Supplies 28 volts 800 cps for IMU blowers and PIP heaters and 28 volts 800 cps phase B IRIG wheel power.	
2007111-011	800 cps 5% amplifier Supplies excitation for trunnion and shaft motors in SXT and SCT.	

Table 3-VII. Location and Functions of PSA Modules

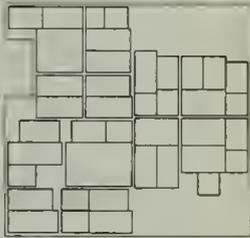
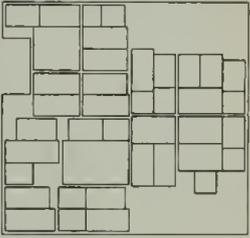
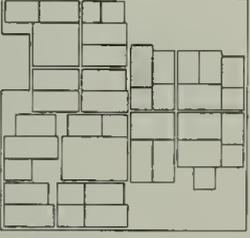
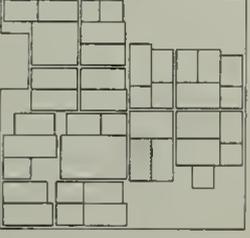
Module Part Number	Module Assembly Name and Function	Location
2007112-011	800 cps aac, filter and multivibrator Supplies and regulates 800 cps voltage to IMU 1% power amplifier.	
2007112-011	800 cps AAC, filter and multivibrator Supplies and regulates 800 cps voltage to optics 1% power amplifier.	
2007113-011	G and N subsystem supply filter Filters 0, 27.5, and 28 vdc power supplies for ISS standby power.	
2007113-011	G and N subsystem supply filter Filters 0, 27.5, and 28 vdc power supplies for ISS operate power.	

Table 3-VII. Location and Functions of PSA Modules

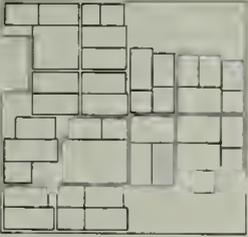
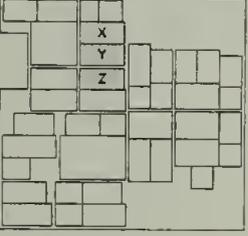
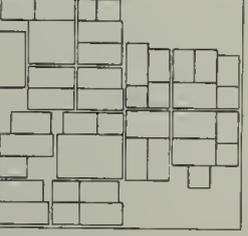
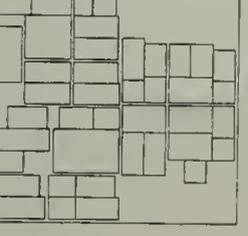
Module Part Number	Module Assembly Name and Function	Location
2007113-011	G and N subsystem supply filter Filters 0, 27.5, and 28 vdc power supplies for OSS operate power.	
2007114-011	Gimbal servo amplifier (three) Amplifies outer gimbal (X), middle gimbal (Y), and inner gimbal (Z) error and supplies correction signals to gimbal torque motors.	
2007117-011	IMU auxiliary Indicates out of tolerance conditions on 3,200 cps 28 v rms, 800 cps 28 v rms, and resolved IRIG preamplifier output; provides IMU turn-on moding discrete; and indicates IMU temperature out of tolerance to telemetry.	
2007118-011	Motor drive amplifier Drives SXT trunnion motor.	

Table 3-VII. Location and Functions of PSA Modules

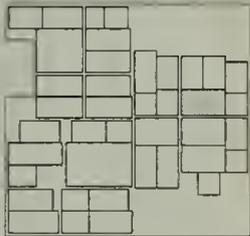
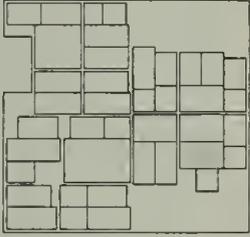
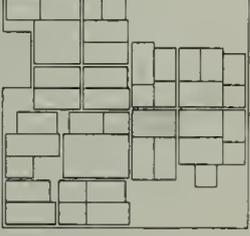
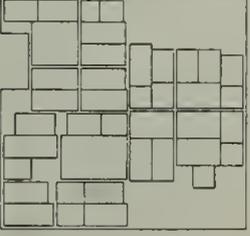
Module Part Number	Module Assembly Name and Function	Location
2007118-011	Motor drive amplifier Drives SXT shaft motor.	
2007118-011	Motor drive amplifier Drives SCT trunnion motor.	
2007118-011	Motor drive amplifier Drives SCT shaft motor.	
2007120-011	Optics load compensation Provides power factor correction for 800 cps 1% and 5% power supplies.	

Table 3-VII. Location and Functions of PSA Modules

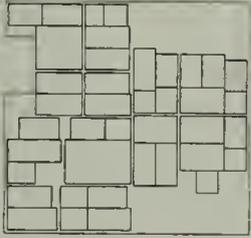
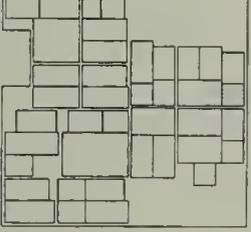
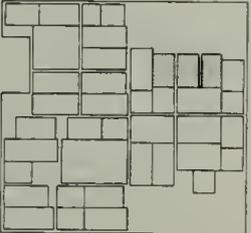
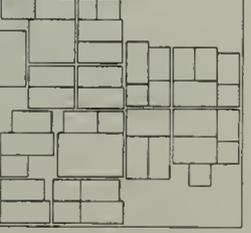
Module Part Number	Module Assembly Name and Function	Location
2007121-011	<p>Two speed switch Provides signal selection for switching null seeking servo loops from coarse to fine resolver error detection.</p>	
2007122-011	<p>Cosecant generator Maintains image trace of optics at constant rate regardless of trunnion angle in resolved mode.</p>	
2007123-011	<p>Relay (three) Provides relay switching for optics control.</p>	
2007123-011	<p>Relay Provides relay switching for IMU control.</p>	

Table 3-VII. Location and Functions of PSA Modules

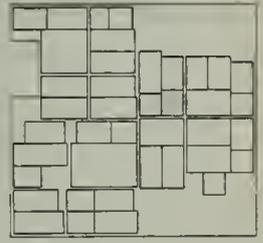
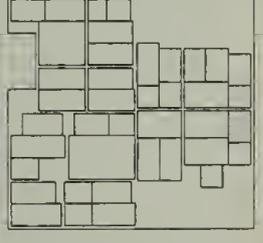
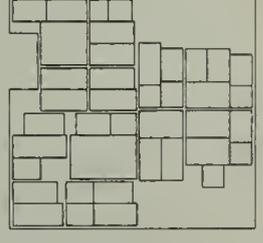
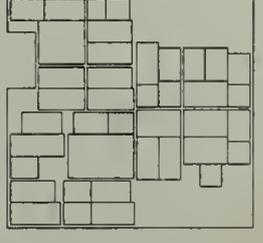
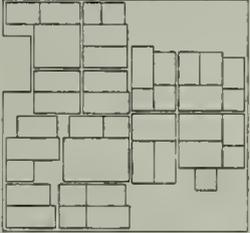
Module Part Number	Module Assembly Name and Function	Location
2007124-011	<p>Anti-creep electronics Removes B+ from motor drive amplifiers when optics hand controller output drops below certain limits and thus prevents optics from drifting.</p>	
2007126-011	<p>Optics automatic operate relay Provides signals to STAR PRESENCE and STAR ACQ lamps and contains relays for computer control of optics.</p>	
2007128-011	<p>SCT moding Provides fixed input to SCT 1X resolver corresponding to 25° offset in SCT and provides optics moding capability.</p>	
2007132-011	<p>IMU load compensation Provides power factor correction for 800 cps 1% and 5% power supplies.</p>	

Table 3-VII. Location and Functions of PSA Modules

Module Part Number	Module Assembly Name and Function	Location
2007161-011	Reticle light dimmer Provides circuitry for controlling brightness of SXT and SCT reticle lamps.	

(Sheet 9 of 9)

Chapter 4

COMPONENT THEORY OF OPERATION

4-1 SCOPE

This chapter discusses the operation of individual assemblies by explaining, in detail, the operation of components or circuits in the assemblies. The detailed discussions are generally limited to those components or circuits whose operation is not apparent in the functional descriptions presented in chapter 2.

4-2 APOLLO II INERTIAL REFERENCE INTEGRATING GYRO

The Apollo II IRIG stabilization gyro (figure 4-1) is a fluid and magnetically suspended, single-degree-of-freedom, integrating gyro. It is one of the 25-series of inertial instruments. The 25 designation denotes the case diameter in tenths of inches. The stabilization gyros are the sensing elements of the stabilization loop. Three such gyros are mounted on the stable member so that their input axes are mutually perpendicular. Any change in the attitude of the stable member is sensed by one or more of the gyros. The gyros convert this displacement into an error signal which is amplified and fed into the gimbal torque motors. The gimbal torque motors reposition the stable member until the error signals are nulled and the original orientation of the stable member is re-established.

The Apollo II IRIG consists of a wheel assembly, a spherical float, a cylindrical case, a signal generator ducosyn, and a torque generator ducosyn. The wheel is mounted within the sealed float on a shaft perpendicular to the float axis and spins on preloaded ball bearings. The wheel is driven as a hysteresis synchronous motor in an atmosphere of helium. The float is mounted within the case on a shaft axially coincident with the longitudinal axes of both float and case. Precision hard-alloy pivots and bearings are located at each end of the float shaft, with the bearing being part of the float assembly. The torque generator ducosyn is mounted on one end of the float shaft, while the signal generator ducosyn is mounted on the opposite end. The space between the float and case is filled with a suspension and damping fluid.

Four axes (input, spin, spin reference, and output) are associated with the Apollo II IRIG. While the wheel is spinning, the gyro tends to maintain its attitude with respect to space. If the gyro is forced to rotate about the input axis (perpendicular to the wheel

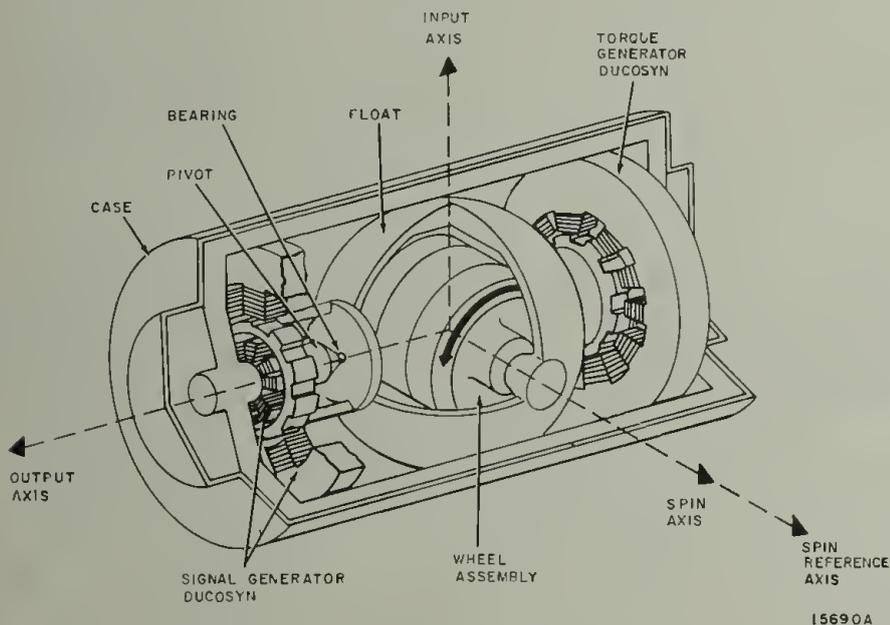


Figure 4-1. Apollo II IRIG, Simplified Cutaway View

spin axis), it will respond with a torque about the output axis (perpendicular to both spin and input axes). The spin axis is displaced from its normal or null alignment with the spin reference axis by an amount equal to the angle through which the output axis has rotated. The spin reference, input, and output axes are always mutually perpendicular. The rotation produced about the output axis in response to a rotation about the input axis in a single-degree-of-freedom gyro is called gyroscopic precession. The output axis is along the float shaft. Rotation of the gyro about its input axis results in a precession of the float.

The signal generator ducosyn is mounted on the positive output axis end of the float to provide magnetic suspension of the float with respect to the case, and to serve as a transducer for providing an electrical analog signal which indicates the amount and direction of the angular rotation of the float about the output axis. The torque generator ducosyn is mounted on the negative output axis end of the float to provide magnetic suspension, and to serve as a transducer for converting electrical error signals to a torque about the output axis when desired.

Since float movement is a measure of angular displacement of the gyro, friction on the float shaft (output axis) is a critical factor of gyro sensitivity. To reduce this friction to a negligible level, the space between the float and case is filled with a fluid which has the same density (specific gravity) as the float. This fluid causes the float to be suspended with respect to the case. Density of the fluid is kept equal to the density of the float by the controlled application of heat. Heating coils attached to the Apollo II IRIG end mounts maintain the density of the fluid. Two sensors submerged in the fluid indicate the temperature of the fluid. The fluid also provides viscous damping of float movement. The fluid suspension is supplemented by magnetic suspension which keeps the pivot centered in the bearing. The magnetic suspension forces are created by the signal and torque generator ducosyns. Under normal environmental conditions the pivot never touches the bearing. Polished precision hard-alloy bearings and pivots are used to minimize the friction which may result if the pivot touches the bearing under extreme environmental conditions.

Since oxygen would rust the ferrous parts in the wheel assembly, the float is filled with helium which will conduct heat away from the wheel motor. Because helium is a light gas it generates little windage, resulting in the additional advantage of low windage losses in the wheel motor. The float is filled with helium at a pressure of one-half atmosphere to further reduce windage losses.

4-2.1 GYRO WHEEL ASSEMBLY. The gyro wheel assembly consists of a wheel, a shaft, hysteresis ring, ball bearings and bearing retainer. The wheel consists of a beryllium hub with a steel rim. The purpose of the composite wheel is to concentrate as much weight as possible in the outside rim, providing the wheel with a high moment of inertia. The hollow steel shaft has female threads on each end and is machined to serve as the inner race for the ball bearings. Preloading of the wheel is achieved and controlled by bolting the bearing retainers to the hub. The bearing retainers press on the outer bearing race exerting a wedging action on the balls. As a result, a deliberate load (preload) is imposed on the wheel bearing to insure that the wheel rotates precisely at a right angle to the shaft. The amount of preload is carefully determined since excessive preload will introduce excessive bearing friction that would limit bearing life. The hysteresis ring, constructed of laminated, specially hardened steel, is fitted on the wheel hub and serves as a rotor for the hysteresis synchronous motor which drives the wheel.

4-2.2 FLOAT ASSEMBLY. The float assembly consists essentially of the float gimbal, two hemispheres, hysteresis motor stator, and bearings. The wheel assembly is bolted to the float by threaded rings. The rings also hold together the float gimbal and the float hemispheres, both of which are made of beryllium. The hysteresis motor stator is placed inside the float gimbal with the power leads brought out through each end of the float gimbal. The float shaft is an integral part of the float gimbal and extends outward from the float to serve as a mount for the float bearings and ducosyn rotors. The bearings, when placed on each end of the float gimbal, define the output axis. The float gimbal also has a hole fitted with a ball and screw seal through which the float is evacuated and filled with helium. Preliminary balance weights are placed on the float gimbal

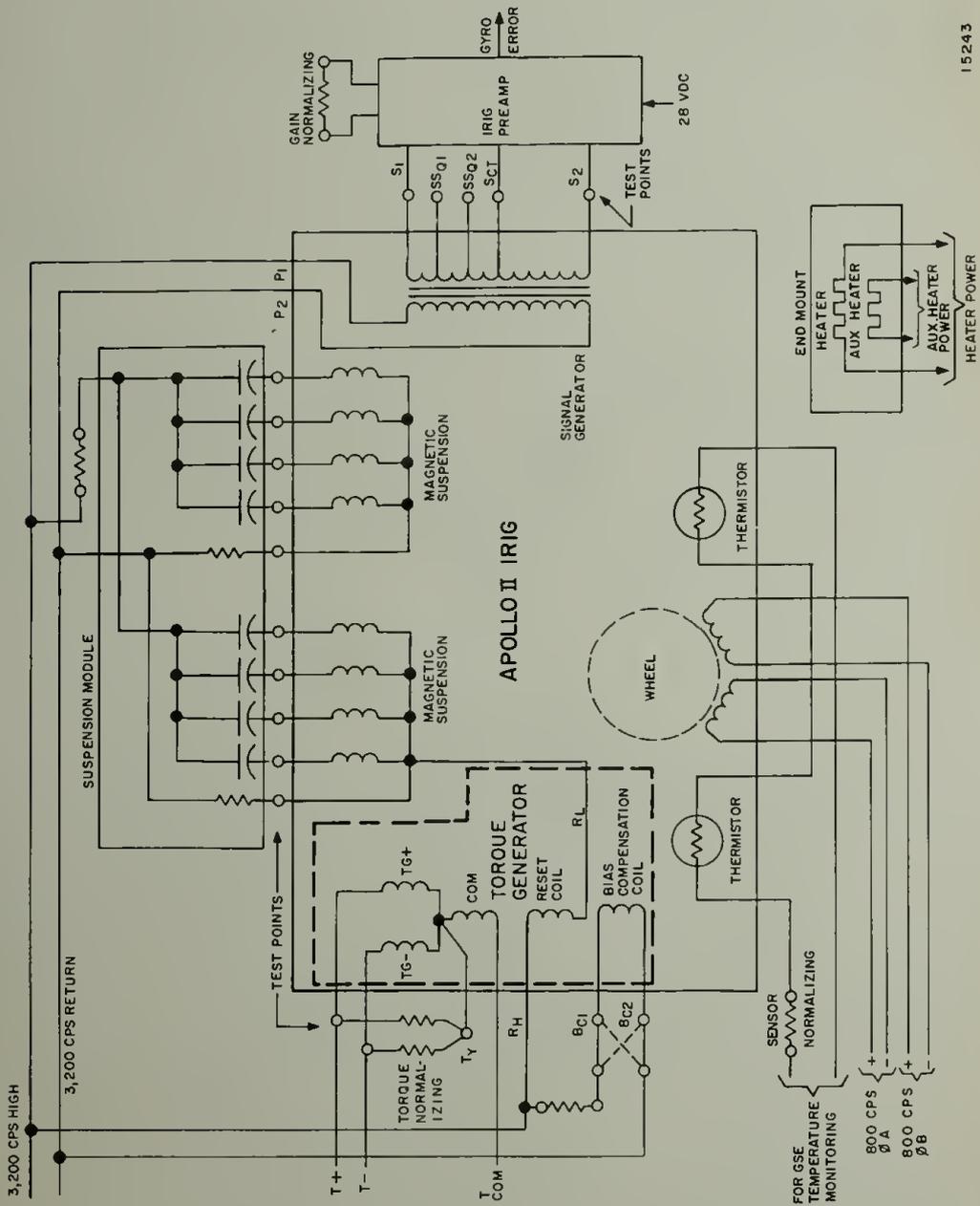
for rotational balancing prior to the float being inserted into the case. Balance weights along the spin axis and the input axis are accessible from outside the case and are used for rotational balancing after final assembly.

4-2.3 CASE. The case consists essentially of main housing and damping block assemblies, end housing assembly, and main cover assembly. The float assembly is encased by the main housing assembly and is supported with respect to the end housing by the pivot assemblies. Beryllium damping blocks fill the space around the float. These blocks provide the necessary control of the damping gap (the width of the gap between the float assembly and case), thereby controlling the damping coefficient. The end housings are held to the main housing by clamping caps. The end housings contain the pivot assemblies, ducosyn stators, bellows to take up the expansion and contraction of the suspension fluid, and a setscrew and ball seal to allow filling with the suspension fluid. Four balance adjusters, provided in the main housing assembly, allow access to the adjustable balance weights along the spin axis and the input axis. After hermetic sealing and balancing of the unit, the Apollo II IRIG is covered by a main cover assembly which provides a magnetic shield plus a second hermetic sealing.

4-2.4 NORMALIZING NETWORK. The normalizing network (figure 4-2) contains the magnetic suspension capacitors, torque generator normalization resistors, temperature sensor normalization resistor, main heater, auxiliary heater, and signal generator preamplifier with gain normalization resistor attached. The pre-alignment package is added to the signal generator end of the gyro case during final assembly, making the gyro a pre-aligned gyro. The gyro is pre-aligned on a test stand with the input axis aligned about the output axis relative to a slot in the mounting ring. This alignment is carried over to the stable member where a pin is precisely located to pick up the slot. When the gyro is mounted in the stable member, an additional main heater and an additional auxiliary heater are placed on the torque generator end.

The signal generator preamplifier is an ac amplifier with transformer coupled input and output which amplifies the gyro output signal prior to transmission from the stable member to the PSA.

4-2.5 APOLLO II IRIG DUCOSYNS. The Apollo II IRIG uses ducosyns for magnetic suspension of the float, signal generator action, and torque generator action. The ducosyn is a separate magnetic suspension microsyn and separate transducer microsyn in a single unit. The unit contains two separate stators mounted in the end housing and two separate rotors mounted on a common mounting ring of the float assembly. The inside stator assembly consists of eight outwardly projecting tapered poles which are wound and excited to provide magnetic suspension. The outer stator assembly consists of twelve inwardly projecting poles which are wound to provide either signal generator or torque generator action. The outer rotor is the transducer rotor and consists of eight unwound salient poles projecting outward. The inner rotor, which is the magnetic suspension rotor, is cylindrical, tapered, and unwound. A beryllium ring separates the two rotors to reduce cross-coupling effects.



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Figure 4-2. Apollo II IRIG Normalizing Network

4-2.5.1 IRIG Signal Generator Ducosyn. The signal generator ducosyn is mounted on the positive output axis end of the gyro to provide magnetic suspension and to serve as a transducer to provide an electrical analog signal representing the position of the float relative to the case. (See figure 4-3.) Poles 1, 4, 7, and 10 are wound with primary windings which induce a voltage into the secondary windings on the pole pieces on either

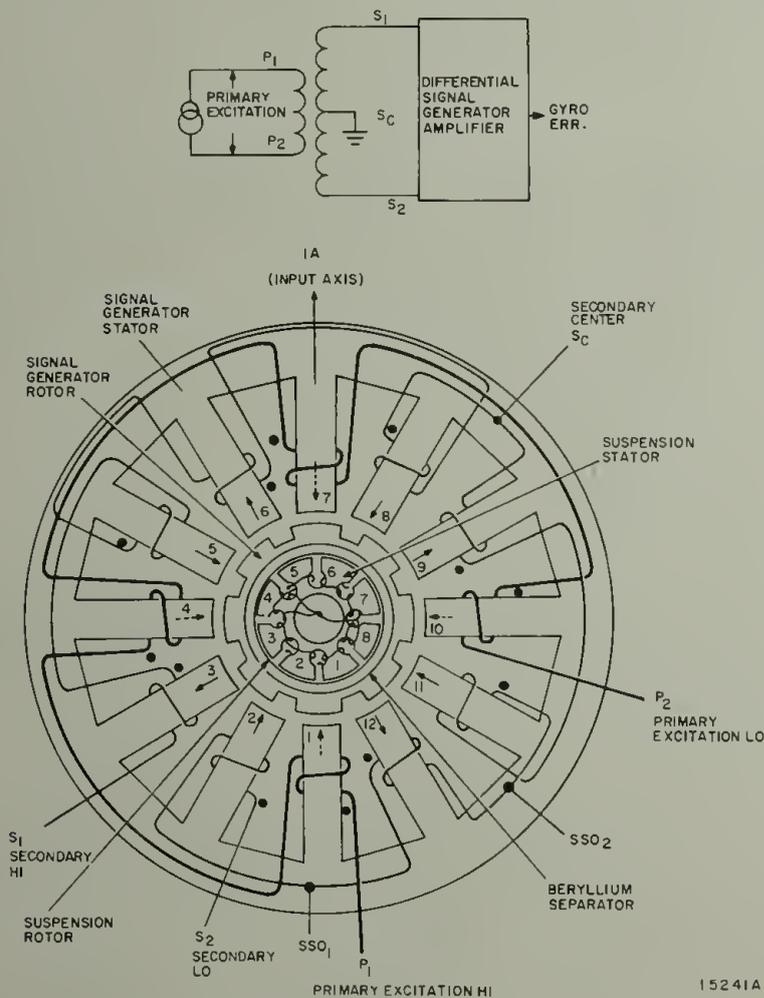


Figure 4-3. IRIG Signal Generator and Suspension Microsyn

side of the primary winding poles. All secondary windings are wound with equal turns. The secondary windings (2-12, 3-5, 6-8, and 9-11) on either side of each primary pole are wound in opposition to each other. When the rotor pole pieces are symmetrically located between the pairs of secondary poles, the flux density in the secondary poles is equal and equal voltage is induced in the secondary windings. Since the secondary windings are wound in opposition, the induced voltages cancel and the net output voltage is zero. This is the null position of the rotor. When the rotor is rotated from the null position as a result of float displacement, the equality of air gap reluctance is disrupted resulting in unequal flux density in the pairs of secondary poles and therefore unequal induced voltages in the windings. The magnitude of the net output voltage depends on the degree of air gap reluctance unbalance; the greater the rotor displacement from null, the greater the net output voltage. The phase of the net output voltage is determined by the direction of rotor rotation. As a result of counterclockwise rotation, higher voltages are induced in the secondary windings that are wound in phase with the primary windings, causing the net output voltage to be in phase with the primary excitation. In the same manner, clockwise rotation produces a net output voltage that is out of phase with the primary excitation.

The Apollo II IRIG ducosyns require a 4 volt, 3,200 cps, single phase excitation for the signal generator primary windings and for the magnetic suspension portions.

4-2.5.2 IRIG Torque Generator Ducosyn. The Apollo II IRIG torque generator ducosyn is mounted on the negative output axis end of the float to provide magnetic suspension and to serve as a transducer to convert an electrical error signal into a torque about the output axis. Figure 4-4 shows the torque generator with the rotor in the null position. To develop torque, current is allowed to flow through the common winding and through either the T+ or the T- winding. The direction of torque is determined by the winding through which current flows. The torque generator stator may be considered as divided into four symmetrical groups of three poles. The center pole of each group (1, 4, 7, and 10) has a common winding only and will always be a north pole when energized. The poles on either side (2-12, 3-5, 6-8, and 9-11) of the center poles have both T+ and T- windings with the polarity of the poles determined by which of the two windings is energized. In either case, one pole in each group will become a north pole and the other a south pole. Since the center pole is always a north pole, each group of three poles will consist of two north poles and one south pole whenever the windings are energized. The rotor will tend to align itself symmetrically between the north and south poles, creating a torque. When the T- winding is energized, pole 12 will become a south pole and pole 2 will become a north pole. The rotor, in attempting to align itself, will tend to rotate clockwise until rotor pole 8 is directly opposite stator pole 12 and rotor pole 1 is directly between stator poles 1 and 2, since 1 and 2 are both north poles. When the T+ winding is energized, stator pole 2 will become a south pole and stator pole 12 will become a north pole. The rotor will tend to rotate counterclockwise attempting to align rotor pole 2 opposite stator pole 2, and rotor pole 1 between stator poles 1 and 12. The other poles attempt to align themselves in the same manner.

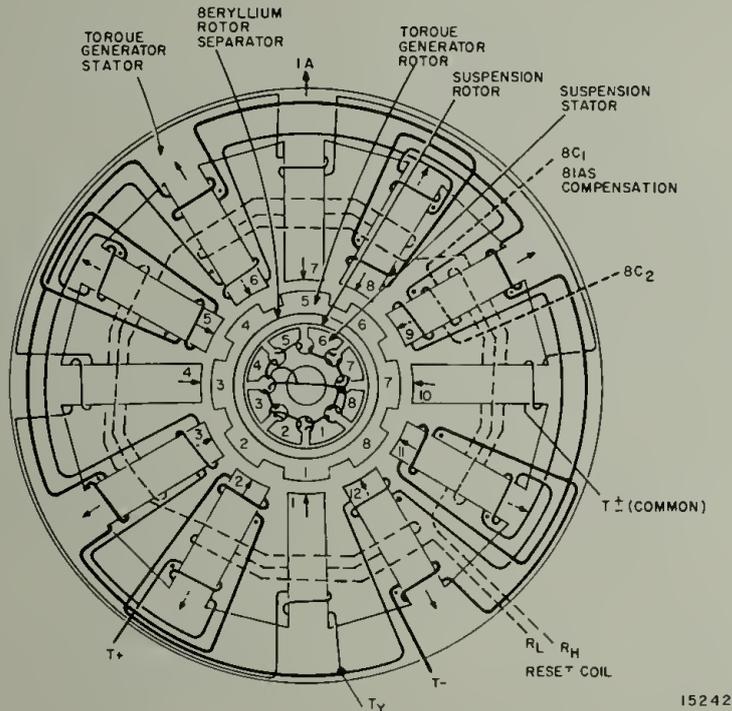


Figure 4-4. IRIG Torque Generator and Suspension Microsyn

The direction of the desired torque is controlled by gyro select pulses from the CMC. The pulses act through a switching network in the gyro calibration module to close the torque current path through either the T+ or the T- winding. The magnitude of the torque current is held constant to develop a constant torque. Torque on the rotor produces torque on the gyrofloat. The resulting float displacement creates an error signal from the ducsyn signal generator. Thus, the position of the IMU stable member is changed by the compensating reaction from the stabilization loops.

The torque generator stator also has a reset coil and a bias compensation coil, both of which are continuously energized by the 4 volt, 3,200 cps magnetic suspension and signal generator excitation voltage. The reset coil serves to keep the magnetic state of the magnetic material constant following any torque commands. This degaussing action prevents the storage of residual magnetic dipoles in the rotor and stator which would create torque. A winding around each group of three stator poles acts as a reset coil

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for both rotor and stator. The bias compensation coil creates a torque equal and opposite the non-gravity torques which produce bias drift, such as the torque due to flex leads. In this manner, the bias drift due to these sources may be reduced to zero.

4-2.5.3 IRIG Ducosyn Magnetic Suspension Unit. The Apollo II IRIG ducosyn magnetic suspension units have a tapered cylindrical rotor and tapered stator poles that develop radial and axial magnetic suspension of the gyro float.

Each stator winding is part of a series resistance inductance capacitance (RLC) circuit. (See figure 4-5). Although the equivalent circuit illustrated shows only two poles, it is representative of any of the four pairs of diametrically opposed stator poles. Inductances L_1 and L_2 represent the total inductances of the stator windings. Resistances R_1 and R_2 represent the total resistance of each stator circuit. Capacitors C_1 and C_2 are the external fixed capacitors in series with the resistance and inductance. The values of L_1 and L_2 vary inversely with the size of air gaps A and B respectively.

The excitation to the magnetic suspension unit is maintained at precisely 3,200 cps; the inductance is the only circuit variable. When the inductance is adjusted so the inductive reactance equals and cancels the capacitive reactance, circuit resonance is achieved. At resonance, the total circuit impedance is at a minimum, consisting only of resistance, and the current is thus at a maximum. During construction and testing, a fixed suspension capacitor is selected that develops a value of capacitive reactance that is less than the value of inductive reactance present when the rotor is at null. The resulting impedance allows a current flow that is less than the maximum or resonant current. In operation, translational movement of the rotor from its null point alters the inductance to bring the circuit closer to or further from resonance.

The current flow through the R_1 , L_1 , and C_1 circuit of figure 4-5 increases or decreases according to the inductance which is controlled by air gap A. At some position of the rotor (or value of A) L will produce resonance and maximum current. As the rotor moves in either direction from the resonant point, the current falls off sharply because the value of L (and inductive reactance) changes to make the circuit impedance greater. The current in the stator winding determines the amount of magnetic energy in the stator pole. The attracting force on the rotor is equal to the change in magnetic energy divided by the change in air gap. This relationship of force versus air gap is such that as the rotor moves away from the stator (increasing A), the attracting force rises to a maximum, then decreases sharply as the rotor passes through the resonant point. A negative or repelling force is developed as the rotor is moved beyond the resonant point. In operation, the movement of the rotor is limited by the float pivots so the attracting force only increases as the rotor is moved away from the stator to its maximum allowable displacement. Conversely, as the rotor moves closer to the stator, decreasing the air gap, the attracting force decreases.

As the rotor moves right, air gap A increases and air gap B decreases, and vice-versa. The attracting force at one stator pole changes inversely to the change in attracting force at the other stator pole. When the rotor is displaced from its null point (where

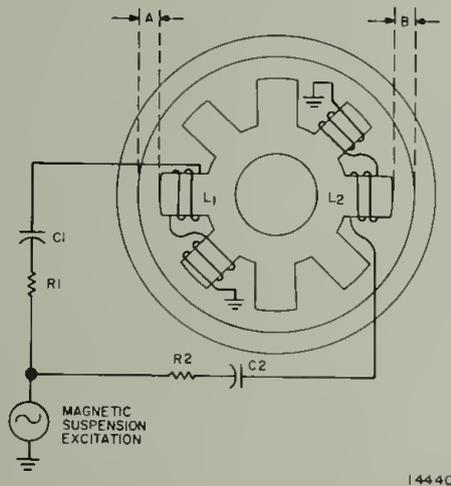


Figure 4-5. Ducosyn RLC Equivalent Circuit

the forces on the rotor from both poles are equal), the force from the pole the rotor is approaching decreases, and that of the opposite pole increases. The direction of the resultant force moves the rotor back to the null position. This action magnetically clamps the rotor between its operating limits. Since the four pairs of stator poles are arranged in a circle within the rotor, their simultaneous action effectively suspends the rotor.

Since the rotor and the stator poles are tapered, end play on the float tends to increase or decrease the air gaps of the magnetic suspension units located at each end of the float. The two magnetic suspension units act together to develop a component of force that supports the float axially.

4-3 16 PULSED INTEGRATING PENDULUM

The 16 PIP's are used as accelerometers in the IMU. The 16 PIP in itself is not an accelerometer, but an acceleration sensitive device. In its associated accelerometer loop, the 16 PIP becomes an integrating accelerometer.

The 16 PIP is basically a cylinder with a pendulous mass unbalance (pendulous float) and is pivoted with respect to a case. The pendulous float has no electrical power

requirements as it is completely mechanical in operation. The space between the pendulous float and case is filled with a fluid. A signal generator ducosyn, located at one end of the float, provides magnetic suspension of the float with respect to the case and acts as a transducer to convert mechanical rotation of the float with respect to the case into electrical analog signals. A torque generator ducosyn, located at the other end of the float, provides magnetic suspension of the float with respect to the case and acts as a transducer to convert electrical signals into mechanical torque about the float shaft. A 2 volt rms, 3,200 cps, single phase excitation is required for the magnetic suspension portion of each ducosyn and for the transducer portion of the signal generator ducosyn.

The output axis of the 16 PIP is defined by the axis of the pivots which support the float with respect to the case. (See figure 4-6.) The pendulum axis is defined by a line which passes through the mass unbalance and intersects the output axis at a right angle. The input axis is the axis along which the 16 PIP is sensitive to acceleration. The input axis and pendulum axis form a plane that is perpendicular to the output axis. When the float rotates about the output axis, the pendulum axis is displaced proportionately from its normal or null position (pendulum reference axis). The pendulum reference, input, and output axes are always mutually perpendicular.

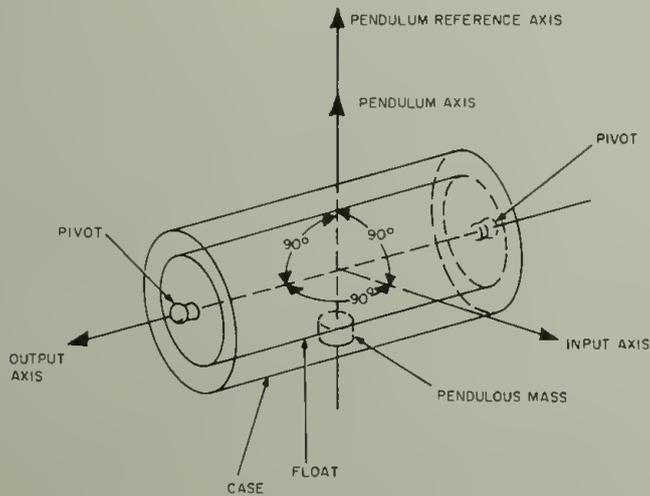


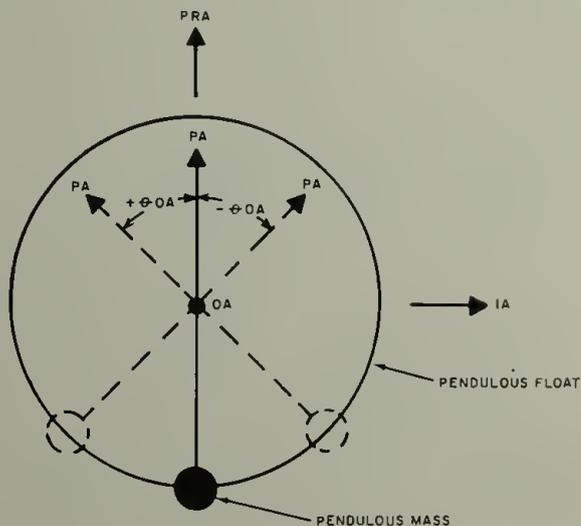
Figure 4-6. Definition of 16 PIP Axes

The mass unbalance hangs below the output axis and is forced by loop torquing to swing like a pendulum. The torquing required to keep the pendulum action oscillatory at no acceleration is a known value. When acceleration is sensed along the input axis, an additional torque is felt by the pendulum and the loop compensates for the acceleration torque by supplying torquing current for additional time.

Figure 4-7 illustrates the direction the pendulous mass tends to swing due to acceleration torque as viewed from the positive end of the output axis or signal generator end of the PIP.

Acceleration in the direction of the positive input axis (the direction in which the arrowhead points) results in a torque on the float about the output axis which tends to rotate it in the negative angular direction ($-\theta_{OA}$) about the output axis. Conversely, acceleration in the direction of the negative input axis produces a torque on the float tending to rotate it in the positive angular direction ($+\theta_{OA}$) about the output axis. When no acceleration is being felt along the input axis, the summation of the angular displacement about the output axis is zero; and by definition, the PIP is at a null.

Maximum sensitivity and linearity of the 16 PIP occur near null. To assure maximum sensitivity and linearity, the accelerometer loop in which the 16 PIP is used restricts the angular displacement about the output axis to very small excursions in either direction from null. The accelerometer loop is designed so that the torque developed



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Figure 4-7. Result of Acceleration Along Input Axes

by the torque generator is equal to and opposite the pendulous torque resulting from applied acceleration. The signal generator, located at the positive end of the output axis, senses an angular displacement of the float about the output axis. The phase and magnitude of the output signals from the signal generator secondary winding are determined by the direction and amount of float displacement. The error signals are processed by the accelerometer loop into incremental velocity pulses to the CMC and into torquing current to the torque generator.

4-3.1 FLOAT ASSEMBLY. The float is a hollow beryllium cylinder fitted with a shaft on which the float pivots are located. On both ends of the float are salient four pole transducer rotors and cylindrical magnetic suspension rotors with tapered inside diameters. The rotor itself is a solid one piece device. The pendulous mass screws into and protrudes slightly from the float. A pin and screw which provides pendulousity adjustment also serves as a stop to limit float rotation about the output axis to ± 1 degree. Adjustable balance weights for rotational balancing of the float are located along the pendulum axis and the input axis. The completed float assembly is placed in a main housing assembly filled with a suspension fluid. The suspension fluid provides fluid suspension of the float with respect to the case and viscous damping of the float.

4-3.2 HOUSING ASSEMBLY. The housing assembly consists of a main housing assembly and two end housings. Damping blocks line the inner diameter of the main housing so as to surround the float. Four bellows assemblies are located within the damping blocks and take up the expansion and contraction of the suspension fluid resulting from variations in the temperature of the fluid. Each end housing contains a pivot bearing, an eight pole magnetic suspension stator, and either an eight pole signal generator stator or an eight pole torque generator stator. The two end housings are called the signal generator end housing (on the +OA end) and the torque generator end housing (on the -OA end). The magnetic suspension microsins have tapered stator poles and a tapered rotor, developing magnetic suspension forces in both radial and axial directions.

4-3.3 OUTER CASE ASSEMBLY. The housing assembly is completely covered by an outer case which provides magnetic shielding and a hermetic seal for the unit. Heating coils are placed between the main housing and the outer case to heat the suspension fluid to the proper temperature for fluid suspension of the float. All electrical connections for signal generator, torque generator, magnetic suspension microsins, and heaters are brought out through the torque generator end of the case.

4-3.4 NORMALIZING NETWORK. The 16 PIP normalizing network module contains the suspension capacitors, torque generator normalizing resistors, and temperature sensor normalizing resistors. This module is mounted over the 16 PIP and bridges the 16 PIP end cap. However, to avoid PIP alignment problems this module is fastened to the stable member instead of the 16 PIP.

4-3.5 PIP DUCOSYNS. The 16 PIP ducosyn signal generator and torque generator differ from the Apollo II IRIG units in both construction and operation. The 16 PIP signal generator and torque generator have eight pole stators. The 16 PIP ducosyn rotor is constructed from a solid piece of ferrite. Flats are ground onto the outer diameter of the rotor to create pseudo-salient poles which serve as the transducer rotor. The inner

diameter of the rotor is tapered and serves as the magnetic suspension rotor. There is no magnetic separation between the transducer rotor and the suspension rotor; therefore, the magnetic suspension rotor degausses the torque generator rotor. The degaussing prevents the storage of residual magnetic poles in the magnetic material which could cause unwanted torques to be created.

The torque generator stator has a single winding per pole. (See figure 4-8.) The windings on the even poles develop negative torque and the windings on the odd numbered poles develop positive torque. The accelerometer loop applies constant dc current to either the odd or even poles. The torque generator stator also has a reset winding which degausses the stator, thus preventing the storage of residual magnetic poles which could create unwanted torque.

The signal generator stator poles have both a primary and secondary winding per pole. The secondary windings are wound in opposition so that when the rotor is at null

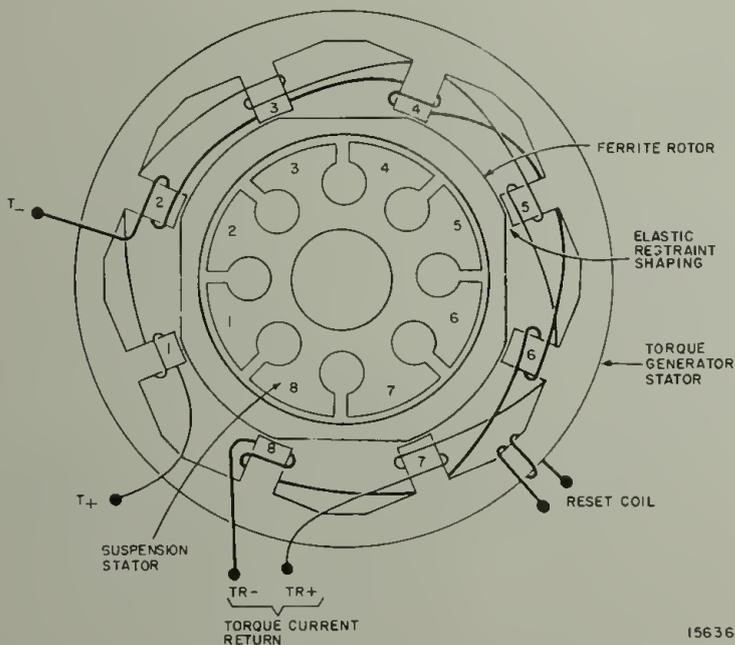


Figure 4-8. PIP Torque Generator

the air gap reluctance at each pair of stator poles is equal and the net output voltage is zero. When the rotor is displaced from null, the air gap reluctance becomes unequal and a net output voltage proportional to the direction and magnitude of the float displacement is developed. The output of the signal generator is amplified, phase shifted, and applied to the interrogator module in the accelerometer loop which detects the direction of float displacement.

4-4 COUPLING DATA UNIT

The CDU is an electronic device used as an interface element between the PGNCSS subsystems, the PGNCSS, and various displays and controls. The CDU is a sealed unit containing 32 modules of ten types. The ten module types make up five, almost identical, channels; one each for the IMU inner, middle, and outer gimbals and one each for the OUA SXT shaft and trunnion axes. Several of the CDU modules are shared by the five channels.

The CDU functions primarily as an analog to digital (A/D) converter and as a digital to analog (D/A) converter. The A/D converter converts resolver signals into digital information which is stored in a 16 stage binary counter called the read counter. The D/A converter accepts pulses from the CMC, stores them in a 9 stage binary counter called the error counter, and provides ac and dc output signals proportional to the stored pulses. A digital feedback path between the read counter and the error counter is provided to count up as the read counter counts down and vice versa.

The CDU converts the IMU gimbal angular information from 1X and 16X resolver signals into digital information. The resolver angle is digitized into bits, equal to 20 arc seconds each, and stored in the read counter. An error signal proportional to the difference between resolver angle and the CDU angle (the angle registered by the read counter) causes the read counter to count until the error signal is nulled. If the difference between the resolver angle and the CDU angle is greater than 0.1 degree, the read counter will be incremented at a 12.8 kpps rate. The incrementing rate will be 800 pps if the difference is less than 0.1 degree. As the read counter is incremented, the overflow output of the first stage (equivalent to 40 arc seconds per pulse) is sent to the CMC to indicate the change in resolver angles.

The CDU converts the optics SXT shaft and trunnion angular information from the shaft 16X and the trunnion 64X resolver signals into digital information. The resolver angle is digitized into bits equal to 2.5 arc seconds for trunnion and 20 arc seconds for shaft and stored in the read counters. The read counters are incremented at the same rate as the read counters used for the ISS gimbal angles. As the read counter is incremented, the overflow output of the first stage (equivalent to 5 arc seconds per pulse for the trunnion and 40 arc seconds per pulse for the shaft) is sent to the CMC to indicate the change in resolver angles.

4-4.1 COARSE SYSTEM MODULE. The coarse system module functions with the read counter to form the coarse analog to digital conversion system. The coarse module is used only in the three IMU CDU channels. The coarse module receives the $\sin \theta$ and $\cos \theta$ signals from the 1X gimbal angle resolver and switches them through attenuation

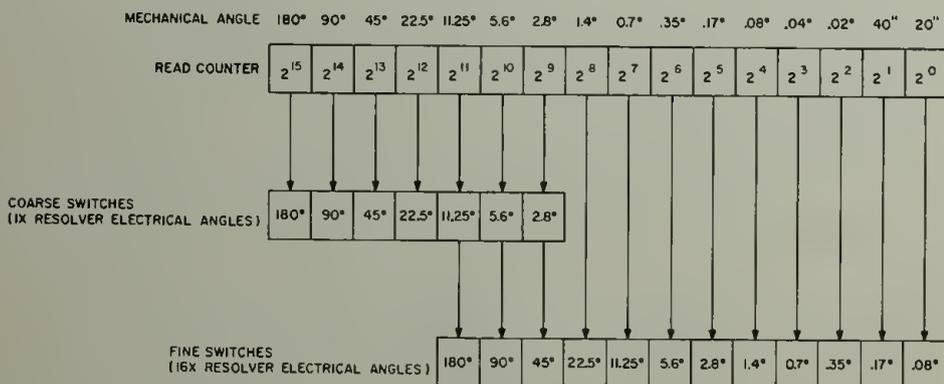
resistors which represent various values of $\sin \psi$ and $\cos \psi$. The resolver angle is compared with the angle registered by the read counter through the mechanization of the following trigonometric identity:

$$\pm \sin (\theta - \psi) = \pm \sin \theta \cos \psi \mp \cos \theta \sin \psi$$

where θ is the gimbal angle and ψ is the CDU angle represented by the accumulation of bits registered by the read counter. The value of ψ can be considered the gimbal angle indicated by the read counter. When θ and ψ are equal, the equation goes to zero. If θ does not equal ψ , an error detector in the coarse module produces an output that causes the sending of incrementing pulses to the read counter. As the read counter counts up or down, changing the value of ψ , it sends switch control signals from its seven most significant stages to the coarse module. The switch control signals operate switches in the coarse module changing the arrangement of the attenuation resistors for different values of $\sin \psi$ and $\cos \psi$ until a null output from the error detector is obtained. For each read counter angle ψ there is a corresponding switch arrangement which produces a null.

The accumulation of ψ is controlled by three modules within the CDU: the coarse module, the main summing amplifier and quadrature rejection module (MSA&QR), and the quadrant selector module. The coarse module is used in conjunction with the 1X gimbal angle resolver inputs. The other two modules are used in conjunction with the 16X gimbal angle resolver inputs and function with the read counter to form the fine analog to digital conversion system.

Figure 4-9 illustrates the mechanical angles of the gimbals, read counter bit positions associated with the mechanical angles, and coarse and fine system switching



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Figure 4-9. Read Counter Relationship to Coarse and Fine System Switching

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associated with each read counter bit position. Note that bits 2^0 through 2^{11} are associated with fine system switching and bits 2^9 through 2^{15} are associated with coarse system switching. The three bit overlap of the coarse and fine systems provides a smooth transition from one system to the other. The angles above the read counter blocks are the mechanical angles through which the 1X gimbal angle resolver shaft rotates. Note also that 180 electrical degrees of 16X resolver rotation is equal to 11.25 degrees of the 1X resolver angle.

Figure 4-10 provides a functional block diagram of the coarse module. The 1X resolver output signals, 26 v (rms) $\sin \theta$ and 26 v (rms) $\cos \theta$ are applied through transformers which have a transformation ratio of 26:4. A 28 v (rms) 800 cps reference signal is applied through a transformer which has a transformation ratio of 28:4. The maximum voltage available, high to center tap, is 4 v (rms). The gimbal angle is represented by the amplitude of the $\sin \theta$ and $\cos \theta$ signals and by their phase with respect to the 800 cps reference signal. If the gimbal angle were 150 degrees, for example, the $\sin \theta$ and $\cos \theta$ signals at the transformer secondaries would be equal to:

- (1) $(4 \text{ v rms}) (\sin 150^\circ) =$
 $(4 \text{ v rms}) (0.5) = 2.0 \text{ v (rms)}$
- (2) $(4 \text{ v rms}) (\cos 150^\circ) =$
 $(4 \text{ v rms}) (-0.866) = -3.46 \text{ v (rms)}$

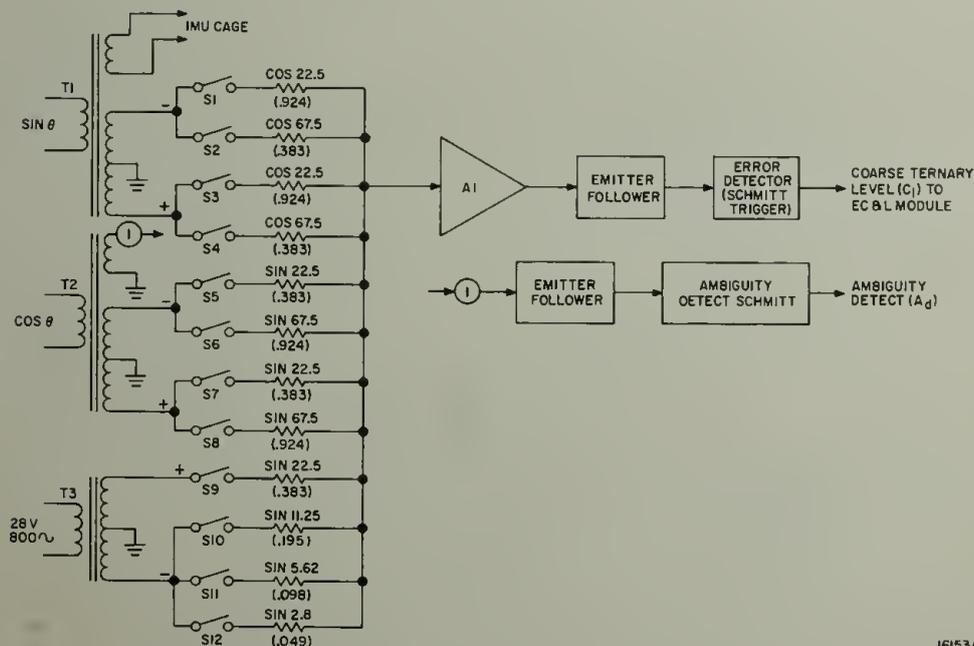
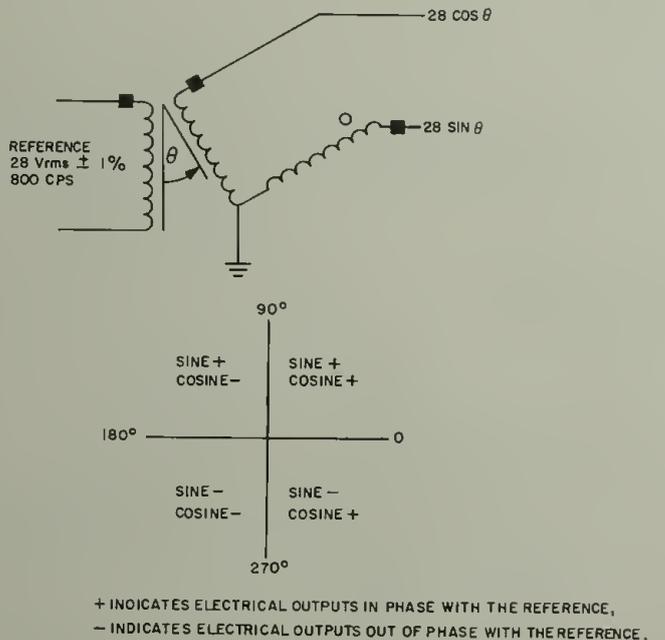


Figure 4-10. Coarse System Module Block Diagram

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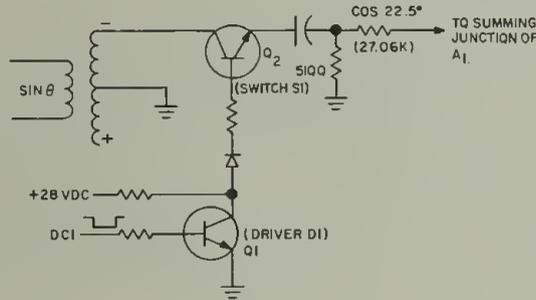
The $\sin \theta$ signal would be in phase with respect to the 800 cps reference. The $\cos \theta$ signal would be out of phase with respect to the 800 cps reference, as is signified by the minus sign. Figure 4-11 shows the phase relationship of the 1X resolver sine and cosine output signals with respect to the 800 cps reference.

Each center tapped secondary of the transformers provides both an in phase and an out of phase signal of equal amplitude, as signified by the plus or minus sign shown on each portion of the secondary winding. (See figure 4-10.) Thus, if the $\cos 150$ degrees signal were to be taken from the out of phase secondary, the signal would be equivalent to $(-4 \text{ v rms}) (-0.866) = 3.46 \text{ v (rms)}$, and would be in phase with respect to the 800 cps reference. The minus sign in front of the 4 v (rms) signifies that the out of phase portion of the transformer secondary was used. The signal from each portion of the T2 and T3 secondary windings is applied to two transistorized switches. The circuit for one of the switches, S1, is shown in figure 4-12. The circuit consists of switching transistor Q2 and the transistor driver Q1. When the logic equation for switch control signal DC1 is not satisfied, DC1 is at a positive voltage level allowing Q1 to conduct to saturation and keeping the base of Q2 grounded. With its base



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Figure 4-11. Resolver Sine and Cosine Phase Relationship



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$DC1 = \frac{2^{15}}{2^{15}} 2^{14} 2^{13} + \frac{2^{15}}{2^{15}} \frac{2^{14}}{2^{13}}$	$DC7 = 2^{15} (2^{14} 2^{13} + \frac{2^{14}}{2^{13}})$
$DC2 = \frac{2^{15}}{2^{15}} 2^{14} 2^{13} + \frac{2^{15}}{2^{15}} \frac{2^{14}}{2^{13}}$	$DC8 = \frac{2^{15}}{2^{15}} (2^{14} 2^{13} + \frac{2^{14}}{2^{13}})$
$DC3 = \frac{2^{15}}{2^{15}} 2^{14} 2^{13} + \frac{2^{15}}{2^{15}} \frac{2^{14}}{2^{13}}$	$DC9 = 2^{12}$
$DC4 = \frac{2^{15}}{2^{15}} 2^{14} 2^{13} + \frac{2^{15}}{2^{15}} \frac{2^{14}}{2^{13}}$	$DC10 = 2^{11}$
$DC5 = \frac{2^{15}}{2^{15}} (2^{14} 2^{13} + \frac{2^{14}}{2^{13}})$	$DC11 = 2^{10}$
$DC6 = \frac{2^{15}}{2^{15}} (2^{14} 2^{13} + \frac{2^{14}}{2^{13}})$	$DC12 = 2^9$

Figure 4-12. Coarse Switch Circuit and Logic Equations

grounded, Q2 is turned off (open) preventing the transformer output signal from being applied to the attenuator resistor circuit labeled $\cos 22.5^\circ$. When its logic equation is satisfied, DC1 drops to 0 vdc and Q1 stops conducting, allowing the base of Q2 to rise toward +28 vdc causing Q2 to conduct to saturation. With Q2 turned on, the transformer output is applied through the attenuator resistor circuit to the summing junction of operational amplifier A1. All of the coarse system module switches (S1 through S12) operate in an identical manner. The logic equations for the switch control signals (DC1 through DC12) that activate the switches are given in figure 4-12.

Switches S1 through S8 mechanize the system's nulling identity, $\pm \sin(\theta - \psi) = \sin \theta \cos \psi \mp \cos \theta \sin \psi$, directly by switching the $\sin \theta$ and $\cos \theta$ signals from the transformer secondaries through the attenuator resistors which represent values of $\sin \psi$ and $\cos \psi$. At the same time the switches select either the in phase or out of phase transformer output so that the attenuated signals will always be out of phase with respect to each other at the summing junction, and thus, be consistent with the requirements of the nulling identity. To develop the signal equivalent to the $\sin \theta \cos \psi$ term of the identity, a single switch from the S1 through S4 group of switches will be closed to select either the in phase or out of phase $\sin \theta$ signal and connect it to an attenuator resistor circuit representing either $\cos 22.5$ degrees or $\cos 67.5$ degrees. The $\cos \theta \sin \psi$ signal is developed in the same manner by a single switch in the S5 through S8 group. The transformer outputs selected in each case will cause the $\sin \theta \cos \psi$ and the $\cos \theta \sin \psi$ signals to be out of phase with respect to each other at

the summing junction. When the attenuated signals are summed together at the summing junction, a difference or resultant voltage is developed which represents the $\sin(\theta - \psi)$ side of the identity. The S1 through S8 switches can select values of ψ to match the gimbal angle to within 22.5 degrees. The resultant voltage, therefore, may be a maximum of $(\pm 4 \text{ v rms}) (\sin 22.5^\circ) = 1.53 \text{ v (rms)}$.

The resultant voltage can be nulled out by summing it with voltage increments of proper phase supplied by the voltage ladder formed by switches S10, S11, and S12. The ladder, in effect, performs a linear interpolation to match the difference angle $(\theta - \psi)$ to within 2.8 degrees in steps of 2.8 degrees. The ladder switches are activated by switch control signals from the 2⁹, 2¹⁰, and 2¹¹ stages of the read counter. The signal input to the ladder switches is from the out of phase secondary of the 800 cps reference transformer T3. The remaining switch, S9, is controlled by the 2¹² stage of the read counter and supplies an in phase reference signal to the summing junction. The operation of the S9 switch will be discussed in more detail later.

The coarse system switches activated at any particular gimbal angle can be determined by first determining what read counter stages will have accumulated bits (see figure 4-9) and applying this information to the logic equations given in figure 4-12 to determine what switch control signals will be generated. A simpler more convenient method is provided by the coarse switching diagram given in figure 4-13. The coarse switching diagram illustrates the range of gimbal angles over which each switch is closed. The S and C designations indicate a sine and cosine attenuator resistor, respectively, with the value of the attenuator resistor given after the designator. The plus and minus signs signify the polarity of the transformer secondary that the attenuator resistor is connected to. The R designation indicates the closure of switch S9. The L designation indicates the closure of one or more of the ladder switches.

A gimbal angle which illustrates the operation of switches S1 through S8 is 67.5 degrees. A gimbal angle of 67.5 (45 + 22.5) degrees places a bit in read counter stages 2¹² and 2¹³ (see figure 4-9) and satisfies the logic equations for DC4 and DC6 (see figure 4-12), which close switches S4 and S6. The coarse switching diagram verifies the closure of a +C67.5 and a -S67.5 switch which correspond to switches S4 and S6. The voltages present at the summing junction as a result of the closure of switches S4 and S6 are:

$$(S4) \quad (4 \text{ v rms}) (\sin 67.5^\circ) (\cos 67.5^\circ) = \\ (4 \text{ v rms}) (0.924) (0.383) = 1.42 \text{ v (rms)}$$

$$(S6) \quad (-4 \text{ v rms}) (\cos 67.5^\circ) (\sin 67.5^\circ) = \\ (-4 \text{ v rms}) (0.383) (0.924) = -1.42 \text{ v (rms)}$$

The two voltages are equal in amplitude but opposite in phase and therefore cancel, producing a null.

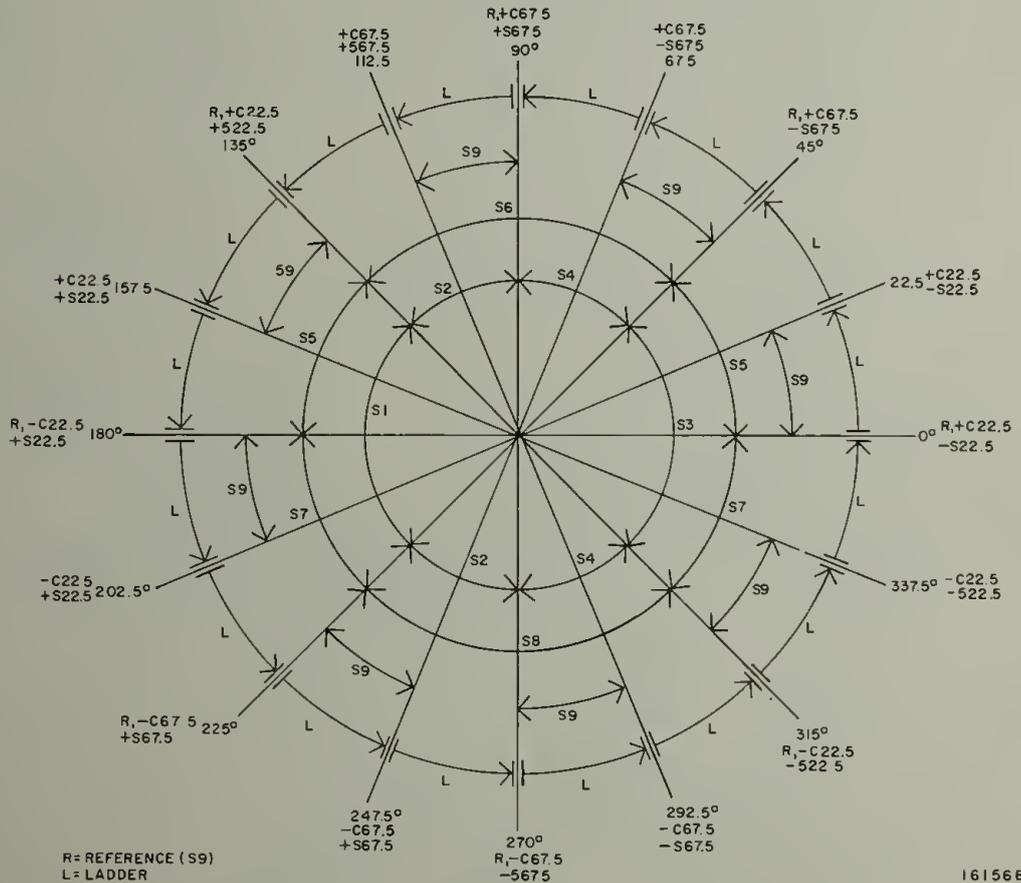


Figure 4-13. Coarse Switching Diagram

A gimbal angle which illustrates the use of the ladder is 28.1 degrees. A gimbal angle of 28.1 (22.5 + 5.6) degrees places a bit in read counter stages 2¹² and 2¹⁰ satisfying the logic equations for DC3, DC5, and DC11 which close switches S3, S5, and ladder switch S11, respectively. The coarse switching diagram verifies that switch S3 (+ cos 22.5°), S5 (-sin 22.5°), and the ladder are actuated. The voltages present at the summing junction as a result of the closure of switches S3 and S5 are:

$$(S3) \quad (4 \text{ v rms}) (\sin 28.1^\circ) (\cos 22.5^\circ) = \\ (4 \text{ v rms}) (0.471) (0.924) = 1.74 \text{ v (rms)}$$

$$(S5) \quad (-4 \text{ v rms}) (\cos 28.1^\circ) (\sin 22.5^\circ) = \\ (-4 \text{ v rms}) (0.882) (0.383) = -1.35 \text{ v (rms).}$$

The resulting in phase voltage from the S3 and S5 closure is 0.39 v (rms). To null the system this in phase voltage must be summed with an out of phase signal. With ladder switch S11 closed an out of phase voltage equivalent to (-4 v rms) (sin 5.62) = -0.39 v (rms) is applied to the summing junction to establish a null.

When the resultant signal at the summing junction (S1 through S8 switch closures) is an out of phase voltage, operation of the ladder switches will affect the out of null condition. An in phase signal is required at the summing junction with which the ladder signals can be summed to obtain a null. This required in phase signal is provided by switch S9 and the + reference side of transformer T3 as shown in figure 4-10. Switch S9 is activated on alternate 22.5 degree segments, as shown on the coarse switching diagram, because it is in those segments that switches S1 through S8 can produce an out of phase resultant. Switch S9 provides a signal equivalent to (4 v rms) (sin 22.5°) = 1.53 v (rms) which, in effect, inverts the out of phase resultant to an in phase signal so that the out of phase ladder signals can accomplish a null. Expressing the function of switch S9 in another way would be to say that it creates the effect of a 22.5 degree shift in gimbal angle.

A gimbal angle which would illustrate the use of switch S9 as well as the ladder is 239.1 degrees. A gimbal angle of 239.1 (180 + 45 + 11.25 + 2.8 = 239.05) degrees places a bit in read counter stages 2¹⁵, 2¹³, 2¹¹, and 2⁹. Bits in these positions satisfy the logic equations for DC2, DC8, DC10 and DC12, closing switches S2, S8, S10 and S12. The absence of a bit in read counter stage 2¹² satisfies the logic equation for DC9 which closes switch S9. The sine and cosine of 239.1 degrees are both negative since the angle lies in the third quadrant. The voltages present at the summing junction as a result of switches S2 and S8 being closed are:

$$(S2) \quad (-4 \text{ v rms}) (-\sin 239.1^\circ) (\cos 67.5^\circ) = \\ (-4 \text{ v rms}) (-0.8581) (0.383) = 1.35 \text{ v (rms)}$$

$$(S8) \quad (4 \text{ v rms}) (-\cos 239.1^\circ) (\sin 67.5^\circ) = \\ (4 \text{ v rms}) (-0.5135) (0.924) = -1.90 \text{ v (rms).}$$

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The resultant out of phase voltage from the S2 and S8 closure is -0.55 v (rms). Summing this voltage with the out of phase voltages from the ladder switches (S10 and S12) will increase the out of phase resultant at the summing function. The closure of switch S9, however, provides the necessary in phase voltage value to obtain a null. Summing the in phase S9 voltage with the out of phase resultant provides a new resultant of $1.53 - 0.55 = 0.98$ v (rms). The voltages present as a result of the S10 and S12 closures are:

$$\begin{aligned} \text{(S10)} \quad & (-4 \text{ v rms}) (\sin 11.25^\circ) = \\ & (-4 \text{ v rms}) (0.195) = -0.78 \text{ v (rms)} \end{aligned}$$

$$\begin{aligned} \text{(S12)} \quad & (-4 \text{ v rms}) (\sin 2.8^\circ) = \\ & (-4 \text{ v rms}) (0.049) = -0.20 \text{ v (rms)}. \end{aligned}$$

Summing the total ladder signal with the S2, S8 and S9 resultant ($0.98 - 0.98 = 0$ v rms) establishes a null.

In order for the system to be nulled the voltage at the summing junction of amplifier A1 must be low enough to keep the amplifier output ($E_{\text{out}} = E_{\text{in}} \times \text{gain}$) below the triggering level of the schmitt trigger error detector. The amplifier output is referred to as the coarse error signal. When the system is not nulled, the coarse error is large enough (1.58 volts peak-peak nominal) to cause the error detector to fire and to generate an 800 cps square wave output. The 800 cps output, referred to as the coarse ternary level signal (C_1), is sent to the read counter logic section of the error counter and logic module. The coarse ternary level will exist when the error ($\theta - \psi$) is greater than approximately 7 degrees. The logic within the error counter and logic module sends pulses at 12.8 kpps to count the read counter up or down. If the coarse ternary level signal is out of phase with respect to an 800 cps square wave reference signal in the logic, the logic causes the read counter to be counted up and if the coarse ternary level signal is in phase, the read counter is counted down. The read counter in turn will change the configuration of the coarse system switches, choosing different attenuation values ($\sin \psi$ and $\cos \psi$) until $\theta - \psi = 0$ and the system is nulled. The coarse error signal is also supplied to the mode module fail detect circuits where it is monitored internally and to the CDU test point connector for external monitoring. The coarse system module also performs two additional functions: generates the ambiguity detect signal (A_d) and the IMU cage signal. The IMU cage signal is taken from a separate secondary winding of the $\sin \theta$ transformer, T3, and is used during the IMU cage mode to drive the gimbals to their zero positions. To develop the ambiguity detect signal, the output of a separate secondary winding on the $\cos \theta$ transformer, T2, is applied through an emitter follower to a schmitt trigger which fires when its input exceeds a nominal value of approximately 6 volts peak-peak. The schmitt trigger output is an 800 cps square wave, which exists when the gimbal angle is between 125 and 235 degrees. The ambiguity detect signal is sent to the ambiguity logic circuit in the digital mode module to prevent the CDU from nulling at an ambiguous angle.

4-4.2 QUADRANT SELECTOR MODULE. The quadrant selector module functions with the MSA&QR and with the read counter module to form the fine analog to digital conversion system. The quadrant selector module inverts the 16X resolver sine or cosine signals as necessary, depending on the quadrant the resolver angle lies in, so that they are always out of phase with respect to each other. A second function of the quadrant selector module is the generation of an 800 cps reference signal.

In order to implement the nulling identity $\pm \sin(\theta - \psi) = \pm \sin \theta \cos \psi \mp \cos \theta \sin \psi$ for the fine analog to digital conversion system, the $\sin \theta$ and $\cos \theta$ signals from the 16X gimbal angle resolver must be switched so that they are always out of phase with respect to each other. Figure 4-11 shows that the resolver signals are out of phase with each other only in quadrants II and IV. The quadrant selector inverts the $\sin \theta$ signal in quadrants I and IV, and the $\cos \theta$ signal in quadrants III and IV. Figure 4-14 is a block diagram of the quadrant selector module. The switch driver circuits and associated switch control signals which operate the various quadrant selector switches are not shown.

The inversion of the $\sin \theta$ signal is accomplished by operational amplifiers A1 and A2 and switches S5 and S6 in the following manner. Switch S6 is closed and S5 is opened to provide a feedback path around A2 through R9 and to disconnect the output of A2 from the input of A1. The $\sin \theta$ signal, applied to A1 through R1, is inverted by the normal operation of A1 and the desired inverted $\sin \theta$ signal is made available at its output. When no inversion is required, the switch configuration is changed to S5 closed and S6 opened. The feedback path around A2 is closed through R4 and the output of A2, which is also inverted, is applied to the input of A1 through R2. Since the resistance of R2 is half that of the feedback resistor of A1, an inverted $\sin \theta$ signal of twice normal amplitude is applied to the summing junction input of A1. When this signal is summed with the in phase $\sin \theta$ signal from R1, the resultant is an inverted $\sin \theta$ signal of normal amplitude. The inverted $\sin \theta$ signal is again inverted by A1 to re-establish an in phase $\sin \theta$ signal at its output.

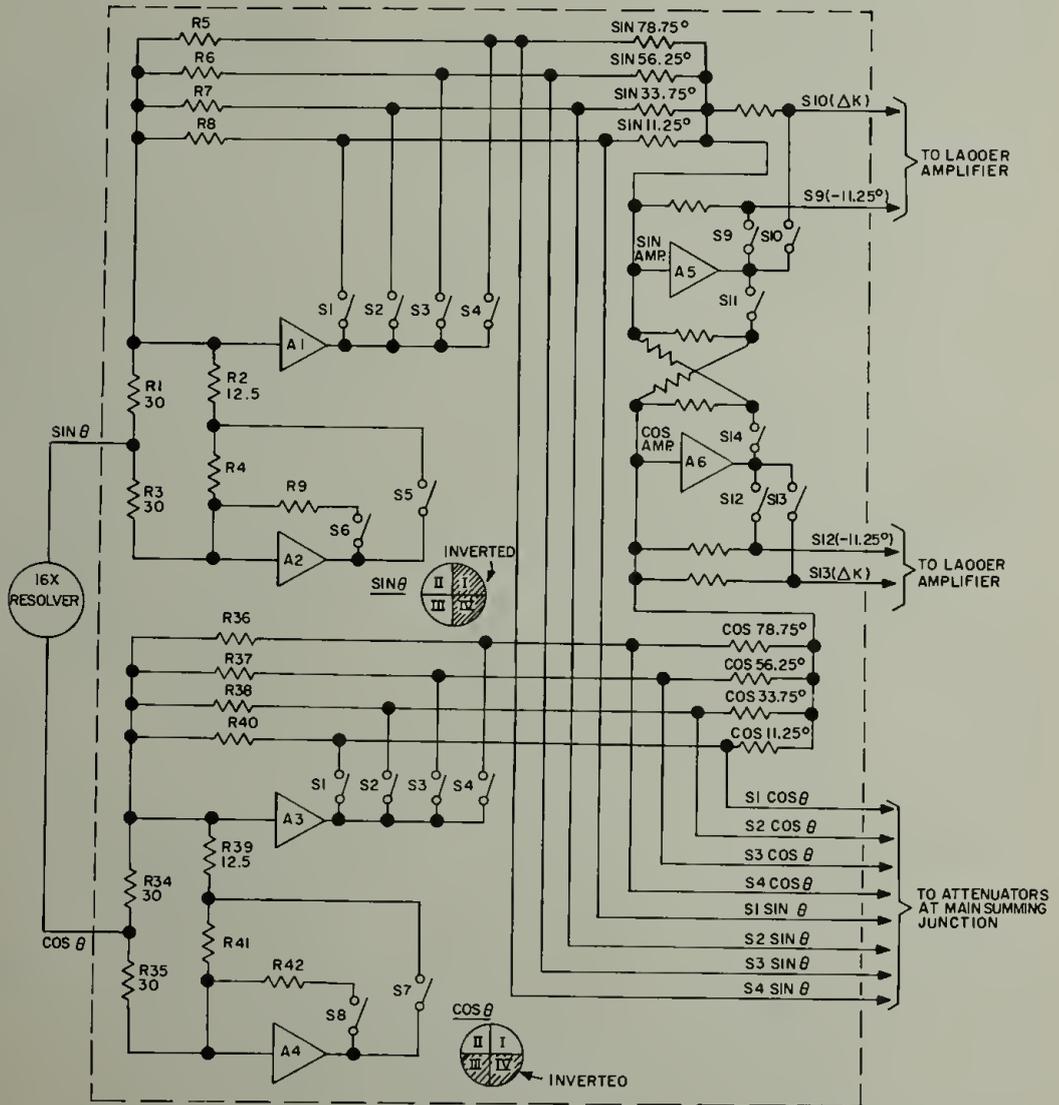
Switches S5 and S6 are closed when the following logic equations are satisfied:

$$S5 = 2^{10} \overline{2^{11}} + 2^{10} 2^{11}$$

$$S6 = 2^{10} 2^{11} + 2^{10} \overline{2^{11}}$$

The 2^{11} stage of the read counter corresponds to 180 electrical degrees and the 2^{10} stage corresponds to 90 electrical degrees in the fine system. The logic equations then state that S5 is closed when the angle ψ is between 90 and 180 degrees ($2^{10} \overline{2^{11}}$) or between 180 and 270 degrees ($2^{10} 2^{11}$) which are the II and III quadrants, respectively. S6 is closed when ψ is between 270 and 360 degrees ($2^{10} 2^{11}$) or between 0 and 90 degrees ($2^{10} \overline{2^{11}}$) which are the IV and I quadrants, respectively.

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ALL UNSPECIFIED RESISTORS ARE
25K ALL VALUES ARE IN K Ω.
REFERENCE DESIGNATIONS
CORRESPOND TO SCHEMATIC
2010059.

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Figure 4-14. Quadrant Selector Module Block Diagram

Phasing of the $\cos \theta$ signal is performed in the same manner as the $\sin \theta$ signal using A^3 , A^4 , S7, and S8. The $\cos \theta$ signal is inverted in the III and IV quadrants. The logic equations for S7 and S8 are:

$$S7 = \overline{2^{11}}$$

$$S8 = 2^{11}$$

S8 will be closed and S7 will be open when ψ is between 180 and 360 degrees (2^{11}) providing an inverted $\cos \theta$ signal at the output of A^3 . S7 is closed and S8 is open when ψ is between 0 and 180 degrees (2^{11}) providing a non-inverted signal at the output of A^3 . Figure 4-15 illustrates which of the S5 through S8 group of switches are closed over the various segments of 360 electrical degrees of 16X resolver rotation.

Switches S1 through S4 select resistance values located in the MSA&QR which attenuate the properly phased sine and cosine signals at the inputs of the MSA&QR. The accumulation of bits in the twelve least significant stages of the read counter controls all switches in the fine system. At any angle one and only one switch of the four (S1 through S4) is on, selecting the appropriate value of attenuation. The values of attenuation selected by each switch is given below:

- (S1) $\sin 11.25$ degrees and $\cos 11.25$ degrees
- (S2) $\sin 33.75$ degrees and $\cos 33.75$ degrees
- (S3) $\sin 56.25$ degrees and $\cos 56.25$ degrees
- (S4) $\sin 78.75$ degrees and $\cos 78.75$ degrees.

If the resolver angle θ were equal to any of the exact values given above or quadrature multiples, a null would be accomplished at the summing junction of the main summing amplifier in the MSA&QR without the benefit of any additional signals. As an example, assume an angle of 213.75 degrees (equivalent to 33.75 degrees) exists at the resolver. The $\sin 213.75$ degrees signal is a negative quantity (out of phase) as is the $\cos 213.75$ degrees signal. The sine is not inverted in quadrant III and therefore remains as an out of phase voltage. The cosine is inverted in quadrant III and the out of phase $\cos 213.75$ degree signal becomes an in phase voltage. At this value of θ , switch S2 shall be closed, the result at the main summing junction shall be:

$$(\sin 213.75^\circ) (\cos 33.75^\circ) - (\cos 213.75^\circ) (\sin 33.75^\circ) = 0,$$

and the desired null shall be accomplished. If the resolver angle is not equal to any of the attenuation values or their quadrature multiples, the required attenuation cannot be accomplished by switches S1 through S4 alone. Additional switching is then performed in the MSA&QR module ladder circuits.

The logic equations mechanized to control the operation of switches S1 through S4 are as follows:

$$\begin{aligned}
 S1 &= 2^8 2^9 2^{10} + \overline{2^8 2^9 2^{10}} \\
 S2 &= \overline{2^8 2^9 2^{10}} + 2^8 \overline{2^9 2^{10}} \\
 S3 &= 2^8 \overline{2^9 2^{10}} + \overline{2^8 2^9 2^{10}} \\
 S4 &= \overline{2^8 2^9 2^{10}} + 2^8 2^9 \overline{2^{10}}
 \end{aligned}$$

Figure 4-15 illustrates which of the S1 through S4 switches are closed over the various segments of 360 electrical degrees of 16X resolver rotation.

Switches S1 through S4 also select attenuation values at the inputs of the sine and cosine amplifiers for use in generating an 800 cps reference signal. In obtaining a null at the main summing amplifier it is necessary to supply a reference signal to the ladder network that is in phase with respect to the external 800 cps reference input of the resolver. This reference is equivalent to $\cos(\theta - \psi)$ and is generated in the quadrant selector module by solving the trigonometric identity:

$$\cos(\theta - \psi) = \sin \theta \sin \psi + \cos \theta \cos \psi.$$

The reference identity is mechanized by the sine amplifier A5, the cosine amplifier A6, and switches S9 through S14. The reference identity implies that the sine and cosine signals from the resolver must always be in phase with respect to each other, in contrast to the nulling identity which required the signals to be out of phase with respect to each other. In solving the reference identity it is necessary to re-phase the sine and cosine signals so that they are always in phase and consistent with the equation.

The inputs to the sine amplifier are the attenuated $\sin \theta$ signals from switches S1 through S4, the values of which are $\sin \theta \sin 11.25^\circ$, $\sin \theta \sin 33.75^\circ$, $\sin \theta \sin 56.25^\circ$, and $\sin \theta \sin 78.75^\circ$, respectively. The inputs to the cosine amplifier are the attenuated $\cos \theta$ signals from switches S1 through S4, the values of which are $\cos \theta \cos 11.25^\circ$, $\cos \theta \cos 33.75^\circ$, $\cos \theta \cos 56.25^\circ$, and $\cos \theta \cos 78.75^\circ$, respectively. It should be remembered that only one of the four switches can be closed at any particular time and that the sine and cosine signals are always out of phase with respect to each other at the inputs to the sine and cosine amplifier.

The sine and cosine amplifiers each have two outputs which may be switched to the ladder amplifier in the MSA&QR but the switching logic allows the selection of only one of the four outputs at any particular time. Switch S11 switches the output of the sine amplifier to the input of the cosine amplifier and switch S14 switches the output of the cosine amplifier to the input of the sine amplifier. Switches S11 and S14 will never be closed at the same time. Switch S11 is closed when the angle θ is in quadrant I or III;

switch S14 is closed when the angle θ is in quadrant II or IV. Both the sine and cosine amplifiers invert their input signals. The effect is to have one amplifier invert the S1 through S4 input signal that is out of phase with respect to the external 800 cps reference, sum it with the in phase S1 through S4 signal and invert the resultant signal to an out of phase signal at the output of the second amplifier. Switches S9 and S10 switch the sine amplifier outputs to the ladder amplifier and switches S12 and S13 switch the cosine amplifier outputs to the ladder amplifier. Switches S9 and S10 alternate on and off every 11.25 degrees in the second and fourth quadrants (at which time S14 is closed) and switches S12 and S13 alternate on and off in the first and third quadrants (at which time S11 is closed). One output, therefore, is always present at the input to the ladder amplifier. The output signal switched to the ladder amplifier is always out of phase with respect to the external reference and when it is inverted by the ladder amplifier it becomes the in phase $\cos(\theta - \psi)$ reference signal required at the ladder network. The $\cos(\theta - \psi)$ signal is of a nearly constant amplitude for all inputs to the $\cos(\theta - \psi)$ generator circuit.

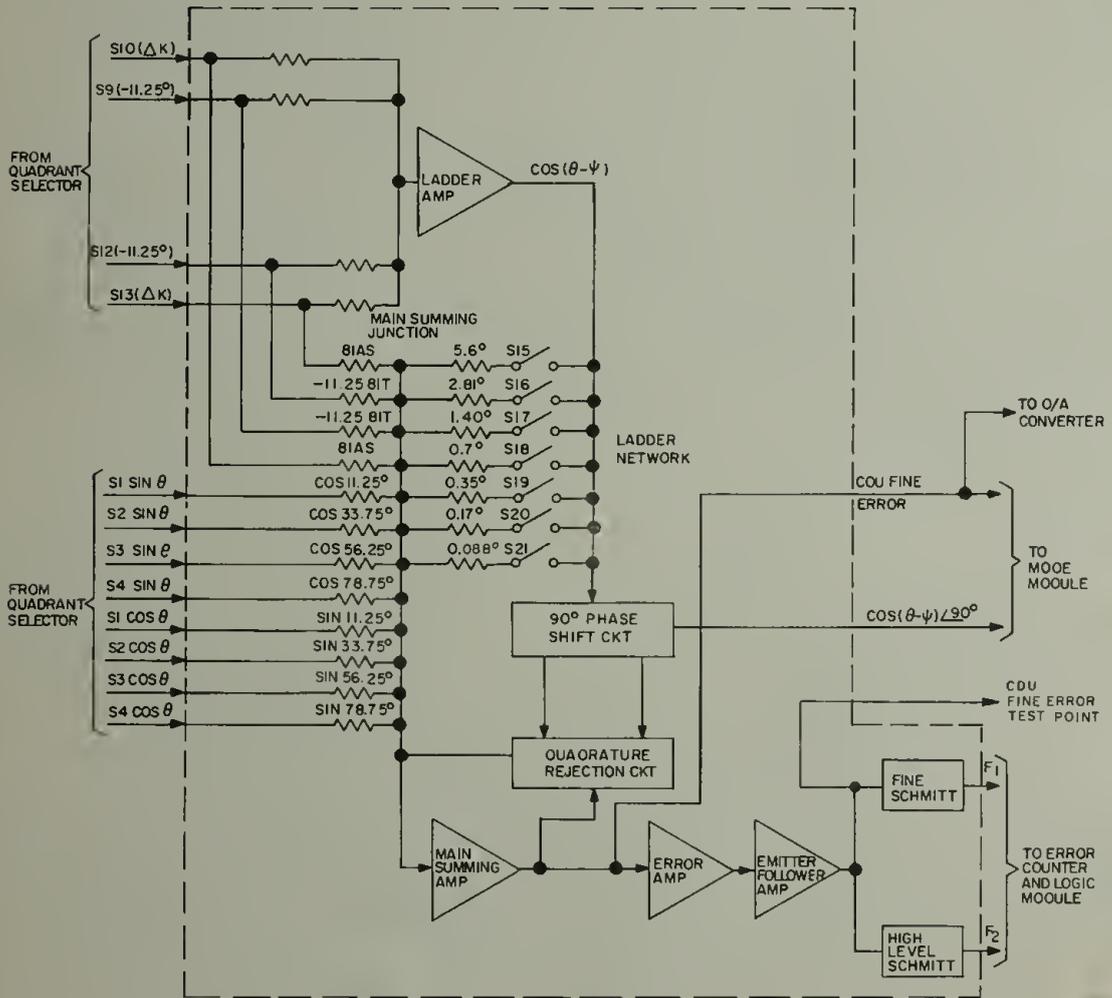
The logic equations mechanized to control the switching in the $\cos(\theta - \psi)$ generator are as follows:

$$\begin{aligned} S9 &= \overline{2^7} 2^{10} & S12 &= \overline{2^7} \overline{2^{10}} \\ S10 &= 2^7 2^{10} & S13 &= 2^7 \overline{2^{10}} \\ S11 &= \overline{2^{10}} & S14 &= 2^{10}. \end{aligned}$$

Figure 4-15 illustrates the operation of these switches through 360 electrical degrees of 16X resolver rotation.

The switches that connect the sine or cosine amplifier outputs to the ladder amplifier also connect these outputs to attenuator resistors at the main summing junction of the main summing amplifier to establish either a bias signal or an out of phase reference signal corresponding to -11.25 degrees at the junction. Switches S9 and S12 provide inputs to the -11.25 degree attenuator resistor. This signal, which is referred to as the -11.25 degree bit, performs a function similar to that performed by the signal from switch S9 in the coarse module. Switches S10 and S13 provide inputs to the bias attenuator. The bias signal, also referred to as a ΔK signal, is applied to the summing junction minimizing any error generated by implementation of the $\cos(\theta - \psi)$ equation. Both the -11.25 degree bit and the bias signal are further discussed in the MSA&QR discussion.

4-4.3 MAIN SUMMING AMPLIFIER AND QUADRATURE REJECTION MODULE. The MSA&QR functions with the quadrant selector module and the read counter module to form the fine analog to digital conversion system. The MSA&QR performs three functions: summing, quadrature rejection, and generation of the F_1 and F_2 ternary level signals. A block diagram of the MSA&QR is given in figure 4-16.



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Figure 4-16. Main Summing Amplifier and Quadrature Rejection Module, Block Diagram

In the summing operation the signals from the quadrant selector are summed at the main summing junction with the output of the ladder network and the output of the quadrature rejection circuit. The signals from the quadrant selector module (two signals supplied through the operation of switches S1 through S4) are always out of phase with respect to each other and either the -11.25 degree bit signal or the bias signal from amplifiers A5 or A6. Both the -11.25 degree bit signal and the bias signal are out of phase with respect to the 800 cps reference. If a gimbal angle θ exists that is not an exact multiple of 11.25 degrees, the main summing junction cannot be nulled by the operation of switches S1 through S4 alone. If this condition exists, an in phase signal from the ladder amplifier is supplied through switches S15 through S21 to null the signal at the main summing junction. Switches S15 through S21 are controlled by the accumulation of bits in the 2^0 through 2^6 stages of the read counter. The in phase signal from the ladder network is the $\cos(\theta - \psi)$ reference generated in the quadrant selector module and inverted by the ladder amplifier. The result of the summation of these signals, with the aid of the quadrature rejection circuit, is about a six millivolt rms null at the output of the main summing amplifier.

To illustrate the summing operation, assume that the angle registered by the read counter (ψ) is between 0 and 11.25 electrical degrees. Since the angle lies in the first quadrant, the in phase and relatively small $\sin \theta$ signal is inverted by the quadrant selector and is attenuated by a factor equivalent to $\cos 11.25$ degrees at the main summing junction. The in phase and relatively large $\cos \theta$ signal is attenuated by a factor equivalent to $\sin 11.25$ degrees at the main summing junction. The resultant voltage of these two signals from the quadrant selector is an in phase voltage which must be summed with an out of phase voltage to obtain a null. If the in phase voltage from the ladder switches were summed with the in phase resultant from the quadrant selector signals, the in phase resultant would be increased, affecting the out of null condition. The out of phase voltage necessary to accomplish a null is provided by the -11.25 degree bit signal. The effect of this signal is to invert the resultant from the quadrant selector signals to an out of phase voltage which may be nulled out with increments of in phase voltage from the ladder. The -11.25 degree bit signal performs the same function as the S9 reference signal in the coarse system module.

If ψ is between 11.25 and 22.50 electrical degrees, quadrant selector switch S12 is open and S13 is closed which removes the -11.25 degree bit signal and applies the bias signal to the summing junction. The resultant voltage of the quadrant selector signals will always be an out of phase voltage. The in phase voltage increments from the ladder switches null out the out of phase resultant and the bias signal minimizes errors.

The bias signal minimizes errors incurred in the implementation of the $\cos(\theta - \psi)$ equation. During those times that the -11.25 degree bit signal is switched in and the bias signal is absent, a similar bias is provided through the gain of the ladder amplifier.

As the angle ψ becomes greater, the operation described repeats the S12 and S13 alternating on and off every 11.25 degrees. In the second quadrant the operation continues with switches S9 and S10 alternating on and off. In the third quadrant switches S12 and S13 again are operational and in the fourth quadrant S9 and S10 regain control.

The resolver signals contain a certain percentage of quadrature (reactive) component which, if large enough, could cause the fine schmitt trigger error detector to fire. To eliminate this possibility, a quadrature reject circuit is incorporated into the MSA&QR. The quadrature component is rejected by taking the $\cos(\theta - \psi)$ output of the ladder amplifier and shifting it 90 degrees in phase to obtain a $\cos(\theta - \psi) \angle 90^\circ$ signal which is used as a reference for a phase sensitive demodulator and a modulator (chopper). The 800 cps output of the main summing amplifier is sampled, amplified, and applied to the phase sensitive demodulator. If the main summing amplifier output contains any quadrature component the output will be demodulated and charge a capacitor in a filter circuit. If the output of the main summing amplifier is an out of phase voltage, the dc charge on the capacitor will be negative. If the output of the main summing amplifier is an in phase voltage, the dc charge on the capacitor will be positive.

The dc charge on the capacitor is applied as an input to the chopper which is keyed by the $\cos(\theta - \psi) \angle 90^\circ$ signal. The modulated output from the chopper is 180 degrees out of phase with respect to the quadrature component. The chopper output is amplified and applied to the main summing junction where it tends to buck any quadrature component present. The $\cos(\theta - \psi) \angle 90^\circ$ signal is also sent to the fail detect circuits in the mode module for internal monitoring purposes.

The main summing amplifier output is applied to an error amplifier. The output of the error amplifier is applied to two schmitt triggers. One schmitt trigger generates an 800 cps square wave output, referred to as the high ternary level signal F_2 , which is applied to the read counter logic section of the error counter and logic module causing the read counter to be incremented at a high rate (12.8 kpps). The second schmitt trigger generates an 800 cps square wave output, referred to as the fine ternary level signal F_1 , which causes the read counter to be incremented at a low rate (800 pps). The high level schmitt trigger will fire whenever the error amplifier output is greater than 4 volts peak-peak nominal. When the read counter is within 20 bits (approximately 0.1 degrees) of reading the gimbal angle, the high level schmitt trigger ceases to fire and the fine schmitt trigger takes over to cause the read counter to be incremented at the low rate. As long as the error signal is large enough (1.5 to 2 bits or greater from null) to fire the fine schmitt trigger, the system will not be nulled and incrementing pulses will be sent to the read counter. The read counter will change the switching configuration to select different values of ψ until ψ is within two bits of equaling θ . When this match occurs, the output of the error amplifier will have been reduced to below the 200 millivolt peak-peak nominal triggering level of the fine schmitt trigger and the system will be nulled.

The output of the main summing amplifier is referred to as the fine error signal and is equivalent to $\sin 16(\theta - \psi)$. This signal is applied to the fail detect circuits in the mode module for internal monitoring purposes, and sent to the D/A converter module where it is used as a gimbal rate limiting signal during the ISS coarse align and turnon modes of operation. The fine error signal is also amplified, buffered, and routed to a test point on the CDU test connector for external monitoring purposes.

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4-4.4 INTERROGATE MODULE. The interrogate module generates a portion of the timing pulses required for CDU operation, produces optics 14 vdc power, and has pulse driver circuitry for data and pulse transmission. The interrogate module provides the following outputs:

- (1) 51.2 kpps pulse train to the digital mode module.
- (2) 1,600 pps interrogate pulse train used in the CDU ISS channels.
- (3) 800 pps $\angle 0^\circ$ reference signal to the ISS inner, middle, and outer error counter and logic module and to the digital mode module.
- (4) 1,600 pps shaft and trunnion interrogate pulses.
- (5) 14 vdc power (optics).
- (6) 25.6 kpps pulse train to 4 vdc trunnion and shaft power supply module.
- (7) 800 pps $\angle 45^\circ$ and 800 pps $\angle 0^\circ$ reference to the optics error counter and logic modules.

4-4.4.1 14 vdc Power Supply. The interrogate module contains two identical 14 vdc power supplies. The input power for the power supplies is 28 vdc. The power supply consists of a single transistor whose bias level is controlled by a zener diode. The 14 volt output is taken from the emitter resistor of the transistor. One 14 vdc power supply provides 14 vdc to the mode module, to the optics D/A converters, and to the CDU test connector for the optics axes. The output of the second 14 vdc supply is used entirely within the interrogate module, providing 14 vdc to the pulse driver circuits.

4-4.4.2 ISS Reference Generator. The ISS reference generator develops an 800 pps square wave voltage of 0 degree phase for use as a reference by the ISS error counter and logic modules and by the digital mode module. The signal input is voltage from the ISS 28 v (rms), 800 cps, 1 percent power supply applied through a 5 to 1 stepdown transformer. The positive half cycles are detected and used to drive a transistor. The output of the transistor is an inverted 800 pps square wave.

4-4.4.3 Optics Reference Generator. The optics reference generator provides 0 degree phase and 45 degree phase reference signals of 800 pps. The 0 degree phase reference signal is supplied to the optics shaft error counter and logic module. The 45 degree phase reference signal is used for the optics trunnion error counter and logic module. The 0 degree phase reference signal is generated in the same manner as the ISS 0 degree phase reference signal. The 45 degree phase reference signal also is obtained in the same manner except that the phase of the 800 cps signal input is first shifted 45 degrees.

4-4.4.4 ISS Interrogate Generator. The ISS interrogate generator provides a 1,600 pps, 3 microsecond pulse width pulse train to the digital mode module and the inner gimbal, middle gimbal, and outer gimbal error counter and logic modules.

The input to the ISS interrogate generator is an ISS 28 v (rms), 800 cps voltage which is applied through a 5 to 1 stepdown transformer. The 5.6 volt signal phase is shifted 90 degrees by a resistance, capacitance, and transistor phase shift network. The phase shifted signal is used to key a square wave generator. The symmetrical square wave output of the square wave generator is applied to a differentiating circuit where the leading edge of the square wave is differentiated and inverted. The trailing edge of the square wave is differentiated only. In this manner two signals are obtained which are then combined to key a transistor output stage that develops the 1,600 pps, 3 microsecond pulse width pulse train output.

4-4.4.5 Shaft Interrogate Generator. The shaft interrogate generator provides a 1,600 pps, 3 microsecond pulse width pulse train to the optics shaft error counter and logic module and to the digital mode module. The operation of the shaft interrogate generator is the same as the ISS interrogate generator.

4-4.4.6 Trunnion Interrogate Generator. The trunnion interrogate generator provides a 1,600 pps, 3 microsecond pulse width pulse train to the optics trunnion error counter and logic module and to the digital mode module.

The input to the trunnion interrogate generator is a 90 degree phase shifted trunnion $\cos(\theta - \psi)$ signal from the main summing amplifier and is used to key a square wave generator. The operation of the trunnion interrogate square wave generator is the same as the ISS interrogate square wave generator.

4-4.4.7 Buffer Transformer. A 2 to 1 buffer transformer located in the interrogate module routes the 51.2 kpps pulse train from the CMC to the clock pulse generator in the digital mode module.

4-4.4.8 25.6 kpps Pulse Driver. The 25.6 kpps pulse driver circuit routes a 25.6 kpps pulse train from the digital mode module to the 4 vdc power supply where it is used for synchronization purposes. The output of the transistor pulse driver is transmitted through a 2 to 1 buffer transformer.

4-4.5 READ COUNTER MODULE. The read counter module consists of the read counter and associated buffer units and switching logic.

The read counter contains 16 identical stages. The output of the first stage is sent to the CMC. The read counter has the capability of counting up or down. The accumulation of bits in the counter represents ψ (CDU angle) which the CDU is attempting to match to θ (gimbal angle). The content of the read counter is buffered and used as inputs to the digitizer switch logic which is contained in the read counter module.

4-4.6 ERROR ANGLE COUNTER AND LOGIC MODULE. The error angle counter and logic module contains the error counter and associated logic, error and rate selection logic, and read counter control logic.

4-4.6.1 Error Selection Logic. The error selection logic tests the fine ternary level (F_1) from the main summing amplifier and the coarse ternary level (C_1) from the coarse module. At interrogate time, the logic produces a selected error signal (S) having the same time phase as the selected ternary level signal but inverted. The coarse ternary level (C_1) has priority and, at interrogation, a high speed clamp signal is produced. The high speed clamp causes the rate select logic to count the read counter at high speed (12.8 kpps). The clamp also initiates the inhibit next interrogate logic which inhibits the interrogation of the coarse ternary level signals at the next interrogate time. The coarse ternary level remains in control until the error angle (difference between CDU angle and gimbal angle) is small enough to allow the fine system to take over control.

4-4.6.2 Inhibit Next Interrogate Logic. The purpose of the inhibit next interrogate logic is to prevent constant interrogation and thus prevent the system from operating erratically up and down when coarse and fine ternary levels of opposite phase are present. The logic provides the error selection logic with a clamp signal at the next interrogate time. Operation of the logic is dependent upon the coarse ternary level detection and phase pulses I_2 and I_3 .

4-4.6.3 Rate Select Logic. The rate select logic provides the proper input pulses for operation of the read counter. The logic selects low speed (800 pps) or high speed (12.8 kpps) inputs to the read counter except in coarse align when the read counter input is 6.4 kpps. The high speed clamp from the error selection logic or high ternary level F_2 from the main summing amplifier will initiate the high speed rate. The low rate is provided by the 800 pps output of the auxiliary clock. Ambiguity override signal A_0 forces the rate select logic into high speed.

4-4.6.4 Read Counter Up-Down Logic. The read counter up-down logic tests the phase of the selected error signal generated in the error selection logic and controls the direction in which the read counter will count. The selected error signal is compared with the 800 cps reference signal. A selected error signal in phase with the reference signal causes the counter to count down while a selected error signal out of phase with the reference signal causes the counter to count up. The presence of ambiguity override signal A_0 forces the counter to count down. Read counter pulses and up-down pulses from up-down logic are ANDed and fed to the CMC. Read counter up-down pulses are fed to the error counter input sync logic.

4-4.6.5 Error Counter Input Sync Logic. The error counter input sync logic accepts pulses from the CMC and the read counter up-down logic. To prevent CMC pulses and read counter pulses from occurring simultaneously, an inhibit function is developed which allows CMC pulses priority. The inhibit function is sent to the error counter drive logic where it is further developed and sent to the rate select logic to inhibit pulses to the read counter. When a pulse is being received from the CMC, the read counter and digitizing operation is inhibited.

4-4.6.6 Error Counter Drive Logic. The error counter drive logic provides pulses to the error counter and an inhibit to the read counter when CMC pulses are being accepted.

Input pulses to the error counter can originate from the CMC or from the read counter. When input pulses originate from the read counter, the output from the third stage of the read counter is used. The CMC pulses and Δ^2 pulses are converted to pulses at $\theta 4$ time for input to the error counter. The change in count direction occurs at $\theta 2$ time and counting occurs at $\theta 4$ time.

4-4.6.7 Error Counter Up-Down Logic. The error counter up-down logic controls the direction in which the error counter will count and determines the phase of the output of the D/A converter. If the error counter is at zero and the next pulse is an up pulse, the D/A converter polarity will be set to "+" and the count-up direction set. If pulses continue, the error counter will continue to count up. When the pulses change to down pulses, the counter will count down, provided the error counter does not contain zero.

4-4.6.8 Error Counter. The error counter has nine identical stages. Its inputs may be CMC pulses or the output of the third stage (2^2) of the read counter. The error counter can count up or down and is controlled by the error counter up-down logic. Error counter $\theta 2$ and $\theta 3$ inputs are control signals which drive the counter. Bit information is fed through buffer circuits in the error counter to the D/A converter as switch commands.

4-4.7 DIGITAL MODE MODULE. The digital mode module consists of a clock pulse generator, auxiliary clock, 25.6 kpps generator, ambiguity logic, and pulses after interrogate pulse logic. The digital mode module provides pulse commands which are used throughout the CDU for synchronization, switching, and strobing.

4-4.7.1 Clock Pulse Generator. The clock pulse generator generates the phase pulses required by the CDU. A 51.2 kpps pulse train from the CMC is divided by four. By ANDing appropriate signals, four 3μ sec, 12.8 kpps pulse trains ($\theta 1$, $\theta 2$, $\theta 3$, and $\theta 4$) of different phases are produced. These signals are used throughout the CDU for strobing and control.

4-4.7.2 Auxiliary Clock. The auxiliary clock receives phases $\theta 1$, $\theta 2$, and $\theta 4$ from the clock pulse generator and generates an 800 pps $\theta 4$ signal. The 800 pps $\theta 4$ signal is generated by dividing the normal 12.8 kpps $\theta 4$ signal by 16. The $\theta 1$ and $\theta 2$ signals are control signals which drive the divider. The 800 pps signal provides a low speed counting rate for the rate select logic in the error angle counter and logic module.

4-4.7.3 25.6 kpps Generator. The 25.6 kpps generator produces a 25.6 kpps drive rate by ANDing two 12.8 kpps pulse trains ($\theta 2$ and $\theta 4$). This 25.6 kpps drive rate is applied to the +4 volt power supply for synchronization.

4-4.7.4 Ambiguity Logic. Because the ambiguity logic prevents the possibility of the CDU indicating a false or ambiguous gimbal position, it is used with the IMU only. Ambiguity detect signal Ad from the coarse system module is ANDed with out-of-phase reference pulse R2 and interrogate pulse I to produce ambiguity override signal A₀.

Signal A_0 is sent to the rate select logic and read counter up-down logic in the error angle counter and logic module. The override signal forces the rate select logic into high speed (12.8 kpps) and the up-down logic into countdown.

4-4.7.5 Pulses After Interrogate Pulse Logic. The pulses after interrogate pulse logic accepts interrogate pulse I from the interrogate module and phases $\phi 1$ through $\phi 4$ from the clock pulse generator. This logic provides the means of synchronizing interrogate pulse I and the 51.2 kpps computer clock pulses by generating phase pulses I_2 and I_3 at $\phi 2$ and $\phi 3$ times respectively, after the occurrence of each interrogate pulse. These synchronized pulses are used in the CDU for synchronization and control purposes.

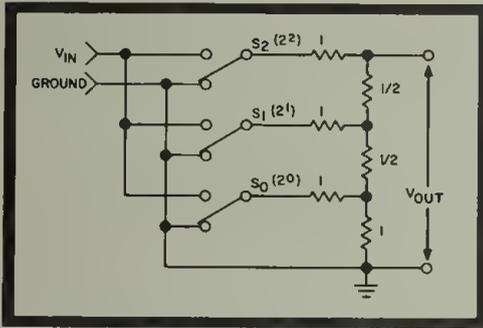
4-4.8 DIGITAL TO ANALOG CONVERTER. The ISS D/A converter converts digital information from the error counter into a dc analog signal and two ac analog signals. One ac signal provides attitude error information to the FDAI. The second ac signal is the coarse align error signal supplied to the gimbal servo amplifiers during the coarse align mode. The dc signal is used during S-4B take-over mode for control of the Saturn booster vehicle by the PGNCs. The OSS D/A converter converts digital information from the error counter into a dc analog signal and an ac analog signal. The ac signal is the positioning signal for the optics shaft and trunnion and is applied to the optics servo loops. The dc signal is used during the thrust vector control mode to provide positioning signals to the service propulsion system engine gimbals.

The D/A converter consists of a voltage ladder decoder, a scaling amplifier, a demodulator, and a mixing amplifier. The conversion of digital information into a dc analog signal by the D/A converter is accomplished in essentially two steps. The digital information is first converted into an 800 cps analog signal by the ladder decoder. The ac signal is then converted to a dc analog signal by a demodulator that rectifies and filters the ac. Before being applied to the demodulator or being used as a direct ac output, the ac signal is routed through the scaling amplifier which controls the gain of the signal. The mixing amplifier combines a feedback signal with the ac analog signal to produce the ac analog output signal.

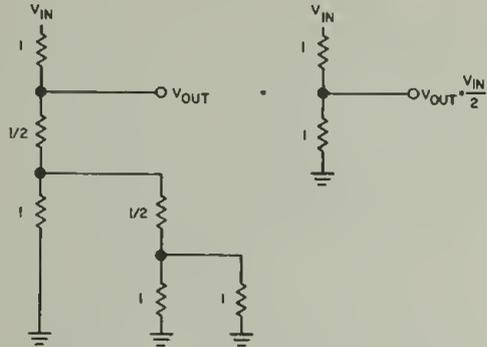
The D/A converter also contains pulse driver circuits and buffer transformers which route the $\pm \Delta \theta G$ pulses from the read counter through the error counter and logic module to the CMC and the $\pm \Delta \theta C$ pulses from the CMC to the error counter and logic module.

4-4.8.1 Ladder Decoder. Accumulated data bits in the error counter control the operation of transistor switches that apply either an ac ground or 800 cps of proper phase to the ladder resistors. In this manner, a voltage proportional to the binary configuration of the switches is developed across the ladder network. For simplicity, the operation will be explained using the 3 bit converter shown at the upper left of figure 4-17; however, the theory of operation presented applies to the 9 bit converter employed by the CDU.

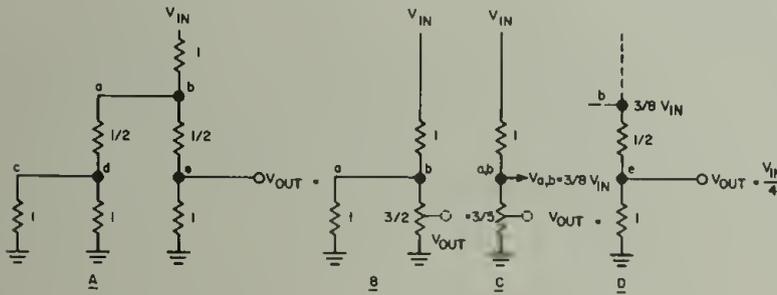
Switches S_2 , S_1 , and S_0 represent transistor switches which are activated by the three data bits from the error counter. (The switch drive circuitry is not shown.)



SIMPLIFIED 3 BIT CONVERTER



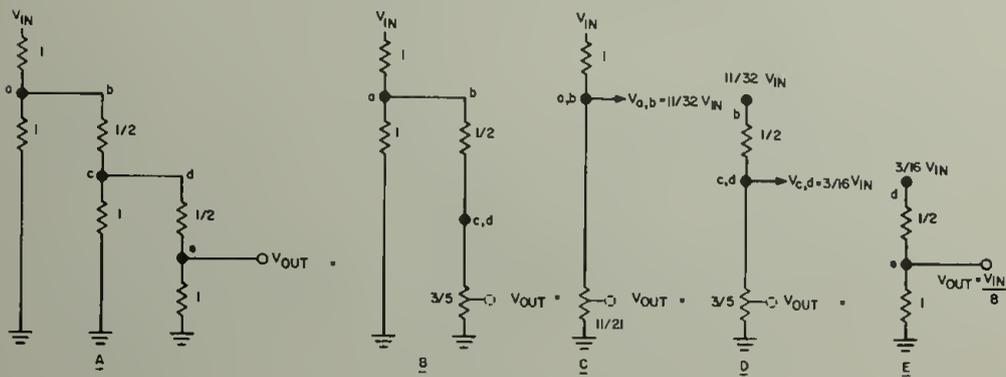
CASE 1. SWITCH S_2 CLOSED



S_2	S_1	S_0	
2^2	2^1	2^0	
0	0	1	$1/8 V_{IN}$
0	1	0	$1/4 V_{IN}$
0	1	1	$3/8 V_{IN}$
1	0	0	$1/2 V_{IN}$
1	0	1	$5/8 V_{IN}$
1	1	0	$3/4 V_{IN}$
1	1	1	$7/8 V_{IN}$

TRUTH TABLE

CASE 2. SWITCH S_1 CLOSED



CASE 3. SWITCH S_0 CLOSED

15755A

Figure 4-17. Simplified 3 Bit Converter and Switch Configurations

Switch S_2 is closed by a logic 1 (0 volt) in the most significant bit position (100) and has a binary weight of 2^2 . Switch S_1 is closed by a logic 1 in the next most significant bit position (010) and has a binary weight of 2^1 . Switch S_0 is closed by a logic 1 in the least significant bit position (001) and has a binary weight of 2^0 .

If the data bits from the error counter are 100, switch S_2 is closed and applies the 800 cps input voltage (V_{IN}) to the ladder. The remaining switches are left in their normally open position and apply ground. The configuration of the ladder resistors is like that shown in Case 1 (A) of figure 4-9. The solution of the series and parallel groups of resistances shows the resistance above and below the output point to be 1 (as shown in the equivalent circuit B). Therefore, the input voltage V_{IN} is divided by 2 and applied to the scaling amplifier.

With data bits 010, switch S_1 is closed and the remaining switches open; the resistor configuration is like that shown in Case 2 (A) of figure 4-9. Combining series and parallel resistances produces the equivalent circuit progression A through D. The voltage at point ab is determined first and applied to point b. The simple divider ratio of resistances above and below the output point is then used to find the output voltage as shown in the final equivalent circuit D. The output voltage shows that V_{IN} is divided by 4 and applied to the scaling amplifier.

With data bits 001, switch S_0 is closed and the remaining switches open; the resistor configuration is like that shown in Case 3 (A) of figure 4-9. Combining series and parallel resistances produces the equivalent circuit progression A through E. The voltage at point ab is found first and applied to point b. In the same manner the voltage cd is found and applied to point d. The output voltage is then found from the divider ratio in the final equivalent circuit E. The output voltage shows that V_{IN} is divided by 8 and applied to the scaling amplifier.

If a combination of switches is closed at the same time, the output voltage will be equal to the sum of the voltages found for each switch individually. For example, if switches S_2 and S_0 are closed simultaneously (by data bits 101), the output voltage would be:

$$\frac{V_{IN}}{2} + \frac{V_{IN}}{8} = \frac{5V_{IN}}{8}$$

The remaining combinations of switch configurations possible from three data bits is shown in the truth table in figure 4-9. In each case the 800 cps output has an amplitude proportional to the data bit controlled switches.

In the actual transistor switching circuit (the remainder of the D/A converter discussion will refer to circuitry shown on schematic 2010028) the data bit inputs to switches (DD0, DD1, etc.) are normally at a positive voltage (logic 0). Therefore, switch driver Q3 is on and ground is applied to the base of switch Q14 to keep it turned off. The ac ground is applied to the ladder resistor network through Q15 which is forward biased by the 3.3 volt zener voltage (applied to the emitter) from CR4 and by

ground applied to the base. If a logic 1 (0 volt) is applied to DD0, Q3 will turn off and Q14 will turn on applying 2.5 v (rms) 800 cps from T₁ to the ladder. The large positive voltage on the base of Q15 will turn off Q7 removing ac ground from the ladder. The theory of operation is the same for the remaining 8 switches.

The D/A converter receives 9 data bits from the error counter as inputs. The error counter also supplies a + and - polarity control signal to the D/A converter. These signals determine whether an in-phase or an out-of-phase 800 cps voltage will be applied to the ladder. This will in turn determine the phasing of the D/A converter ac output signals and the polarity of the D/A converter dc output signals. If a logic 1 is applied to the +D/A polarity input, Q13 turns off and Q12 turns on applying in-phase voltage to the ladder. If a logic 1 is applied to -D/A polarity input, Q1 turns off and Q2 turns on applying out-of-phase voltage to the ladder.

4-4.8.2 D/A Converter Output Stage. The D/A converter output stage consists of the demodulator, the scaling amplifier, and the mixing amplifier. The 800 cps amplitude modulated signal from the ladder is applied to the scaling amplifier and demodulator where the gain is controlled to produce a voltage gradient of 300 mvdc per degree at the output of the D/A converter. In the coarse align mode, the ac voltage from the scaling amplifier is applied as an input to the mixing amplifier.

The scaling amplifier consists of transistors Q33 and Q34 which, along with the feedback network, form an amplifier with an ac gain of approximately 3 to 4. The output of the scaling amplifier is applied to phase sensitive demodulator through transformer T₃. The full wave rectifiers, which consist of both sections of Q38 and Q39, are controlled by an 800 cps reference signal through T₄. If the ladder output is in phase with the reference signal, a positive error voltage will develop at the output of the rectifier. If the ladder output is 180 degrees out of phase with the 800 cps reference signal, a negative error voltage output is produced. The emitter to emitter connection of the transistor sections of Q38 and Q39 produces collector to emitter voltage drops of opposite polarity at each transistor section cancelling the overall voltage drop across the two sections of the transistor. The rectified ac is filtered and applied as the D/A converter dc analog signal. The scaling amplifier also provides an ac analog signal to the FDA1 and to the mixing amplifier in the coarse align mode. Transistor Q32 provides a means of inhibiting the output of the D/A converter in case of 4 volt power supply failure. The inhibit action occurs when a logic 1 is removed from the inhibit D/A converter input causing Q32 to turn on and to short the input of the scaling amplifier to logic ground.

In the coarse align mode, the gimbals are limited to a maximum rate to prevent damage to the gyros and to allow the read counter to track the gimbal angle accurately. The fine error signal, $\sin 16(\theta - \psi)$ from the main summing amplifier, is fed back to rate limit the gimbals. The fine error signal is out of phase with the ladder output and has an amplitude proportional to the difference between the actual gimbal angle and the angle registered in the read counter. The fine error feedback signal is summed with

the ac output from the scaling amplifier to provide the input to the mixing amplifier. The output of the mixing amplifier is the coarse align error signal to be applied to the gimbal servo amplifiers during the coarse align mode.

4-4.9 MODE MODULE. The mode module is utilized as an interface module. The mode module contains circuits to buffer signals and monitor CDU operation. Direct interface is made between the mode module and the CMC and with other modules within the CDU. The mode module provides the following:

- (1) Buffered moding signals.
- (2) Four timing signals.
- (3) ISS and OSS fail signals.
- (4) ISS 14 vdc power supply input.
- (5) Thrust vector control signals.
- (6) Saturn booster vehicle control signals.

4-4.9.1 Moding Buffer Circuits. The moding buffer circuits receive signals from the CMC and from the digital mode module. These signals are inverted, amplified, or otherwise processed into moding signals to be sent to other modules of the CDU.

The signals received from the CMC are five moding discrettes. The discrettes are 0.0 (± 2) vdc CMC ground, applied through a 2,000 ohm source impedance. The buffer circuits for four of the discrettes are identical. These discrettes are the ISS CDU zero, optics CDU zero, ISS error counter enable, and optics error counter enable. In each case the discrete biases a transistor inverter into conduction. The positive dc signal obtained from the inverter is then sent to the moding sync logic of the digital mode module. The fifth discrete, the coarse align enable, has a two stage buffer circuit consisting of an inverter and a relay driver transistor. The inverter has a dual output circuit which provides two positive dc output voltages upon receipt of the coarse align enable discrete from the CMC. One output is sent to the moding sync logic in the same manner as the previous four moding signals. The second output of the inverter stage is applied to the relay driver transistor, causing it to turn on. The relay driver provides a current path to ground which energizes the coarse align relays located in the PSA.

The signals received from the digital mode module are the ISS CDU zero drive and optics CDU zero drive signals. These signals are at positive dc voltage levels. The buffer circuits simply invert the signals and send them to other CDU modules.

4-4.9.2 14 vdc Power Supply. The 14 vdc power supply contained in the mode module is identical to the 14 vdc power supplies described in the interrogate module.

4-4.9.3 Phase Buffer Circuits. The phase buffer circuits receive four phase pulse trains, designated θ_2 drive, $\bar{\theta}_2$ drive, θ_3 drive, and θ_4 drive, from the digital mode module. The buffer circuit for each pulse train is a transistor inverter powered by the 4 vdc power supply. All four inverted signals are sent to the error counter and logic module. The inverted $\bar{\theta}_2$ and θ_3 signals are also sent to the read counter module.

4-4.9.4 ISS-CDU Fail Detect Circuit. The ISS-CDU fail detect circuit monitors the tolerance of critical signals. The fail detect circuits can be considered as three independent failure detect and logic circuits, each monitoring a single type of CDU error. If an out-of-tolerance condition is detected by the circuits, a failure signal is applied to a common output OR circuit.

The first ISS-CDU error detect and logic circuit receives the inner, middle, and outer coarse error signals from the coarse system module, and the inner, middle, and outer fine errors from the main summing amplifier. These six signals are applied to a level detector consisting of six voltage divider networks and a common filter section. The input signals are attenuated, half-wave rectified, and filtered. The voltage level at the output of the filter section controls the conduction of an output transistor. If any of the coarse or fine errors exceed tolerance, the voltage level at the output of the filter section reaches a level sufficient to bias the output transistor into conduction. The output transistor in turn supplies a failure indication input to the common output OR circuit.

The second ISS-CDU failure detect circuit monitors the inner, middle, and outer read counter UP level signals to detect an excessive read counter limit cycle frequency. When the read counter alternately counts up, then down, the input transistor of the failure detect circuit alternately turns on and off. The output of the transistor is differentiated so a number of positive and negative pulses, corresponding to the frequency at which the counter changes direction, are developed. The positive pulses are detected and applied to a common filter section. By integrating the positive pulses the filter section develops an output level proportional to the frequency at which the counter changes direction. When the frequency exceeds tolerance, the output level of the filter section is sufficient to bias an output driver transistor into conduction. The driver transistor in turn supplies a failure indication to the common output OR circuit.

The third ISS-CDU failure detect circuit monitors the three $\cos(\theta - \psi)$ error signals from the inner, middle, and outer main summing amplifiers and also monitors the output of the 14 vdc power supply located in the mode module. Each of the three $\cos(\theta - \psi)$ signals is applied to an input transistor which conducts when the applied signal decreases below tolerance. When any of the three input transistors conduct, they turn off a fourth transistor which had been preventing the conduction of the output transistor. The proper state of each of the transistors in the circuit is established by bias levels derived from the 14 vdc supply. If the 14 vdc input decreases below tolerance, bias levels are changed sufficiently to result in the conduction of the output transistor. When the output transistor conducts, it supplies a failure indication to the common output OR circuit.

The output OR circuit accepts inputs from the three failure detect circuits previously mentioned. The output transistors of those three circuits must conduct through the same resistor network so any of the three will develop a voltage drop across the resistor network. The voltage drop causes the conduction of the input transistor in the OR circuit. When this transistor conducts, it supplies an input to a time delay circuit consisting of a resistance-capacitance network and a zener diode. After approximately 7 seconds, the zener diode conducts, supplying proper bias to the output stage of the circuit which consists of two transistors. When the output transistors conduct, the circuit provides a positive 28 vdc CDU failure indication to the CMC.

4-4.9.5 Optics-CDU Fail Detect Circuit. The optics-CDU fail detect circuit functions in exactly the same manner as the ISS-CDU fail detect circuit. The only difference between the two circuits is that the optics-CDU fail detect circuit monitors the 14 vdc power supply located in the interrogate module and only two each from the $\cos(\theta - \psi)$, fine error, and limit cycle types of signals.

4-4.9.6 Moding Relays. Two sets of two relays are located in the mode module. One set is used to route signals for Saturn steering control after S-4B take-over. The other set of relays is used during the thrust vector control mode. The relays are energized by a CMC discrete acting through a relay driver. The energized relays route the dc error signals from the optics CDU D/A converter to the service propulsion system engine gimbal amplifiers and from the ISS CDU D/A converter to the Saturn guidance system.

4-5 POWER SUPPLIES

The power supplies convert the +28 vdc prime Block II command module power into the various dc and ac voltages required by the PGNCS. The +28 vdc prime power is supplied from the EPS. Prime power will be supplied to the 3,200 cps power supply during both standby and operate modes of the ISS, while it will be supplied to all other power supplies during the operate modes only.

All ac power supplies are synchronized to the CMC clock by means of computer pulses. The dc supplies, using multivibrators as ac sources for transformation, are also synchronized to the CMC. Synchronization is accomplished by a multivibrator which will free run at a lower frequency without the computer pulses, assuring operation of the ISS power supplies in the event of a CMC failure.

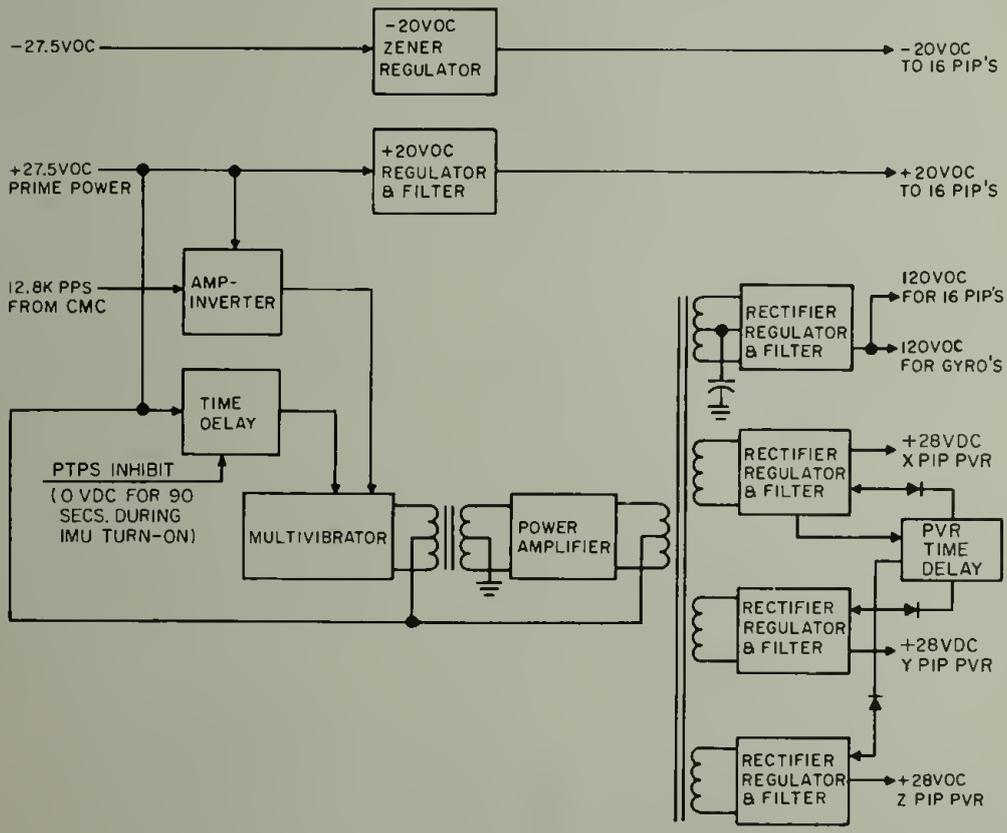
4-5.1 PULSE TORQUE POWER SUPPLY. The pulse torque power supply (figure 4-18) provides 120 vdc to the three binary current switches and three dc differential amplifiers in the accelerometer loops, and the binary current switch and dc differential amplifier in the stabilization loop fine align electronics. The pulse torque power supply also provides three individual 28 vdc outputs to the accelerometer loop PVR's, 20 vdc to the three accelerometer loop ac differential amplifier and interrogator modules and the associated binary current switches, and -20 vdc to the ac differential amplifier and interrogator module in the accelerometer loops.

The -20 vdc output is derived from the -28 vdc power supply by using a zener diode as a voltage divider and regulator. The output is regulated at -20 (± 0.8) vdc.

The 20 vdc output is derived from 28 vdc prime power by the use of a three transistor series regulator which maintains the output voltage at 20 (± 0.55) vdc.

The 120 vdc and 28 vdc outputs are derived from a multivibrator, a power amplifier, and a rectifier and filter. A 12.8 kpps synchronizing pulse is received from the CMC through a buffer transformer in the pulse torque isolation transformer assembly and is applied to an amplifier-inverter. The output of the amplifier-inverter is applied to a multivibrator-chopper causing the multivibrator-chopper to be synchronized at 6,400 cps. A transistorized time delay circuit is incorporated into the emitter circuits of the multivibrator to provide a turnon time delay of approximately 350 milliseconds. During the 90 second IMU turnon mode, 0 vdc is applied through the turnon circuits of the IMU auxiliary assembly module to the time delay circuit which inhibits the 120 vdc and 28 vdc PVR supplies. The multivibrator-chopper output is applied to the primary of a transformer which has 28 vdc prime power applied to its center tap. The secondary of the transformer, which is also center tapped, is coupled to a two stage push-pull power amplifier which operates from 28 vdc prime power. The output of the power amplifier consists of a transformer with four secondary windings; one with center tap return for the 120 vdc power supply, and one each for the X, Y, and Z accelerometer loop 28 vdc PVR supplies. The 120 vdc power supply consists of a full wave rectifier whose output is filtered, regulated, and again filtered. The 28 vdc power supplies are identical and consist of a full wave bridge rectifier whose output is filtered, regulated, and again filtered. The PVR time delay circuit inhibits the operation of the regulator in each 28 vdc PVR circuit to provide a six to eight second time delay in the 28 vdc PVR outputs.

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM



16134A

Figure 4-18. Pulse Torque Power Supply

4-5.2 -28 VDC POWER SUPPLY. The -28 vdc power supply provides input power to the three gimbal servo amplifiers in the stabilization loops and to the pulse torque power supply to generate -20 vdc for use in the accelerometer loops. The -28 vdc power supply consists of a pulse amplifier-inverter, a multivibrator-chopper, a power amplifier, and a rectifier and filter. (See figure 4-19.) The 25.6 kpps synchronization pulse input is amplified and inverted for use in synchronizing the multivibrator-chopper at 12.8 kcps. The multivibrator-chopper output is applied to the primary of a transformer which has 28 vdc prime power applied to its center tap. The secondary of the transformer, which is also center tapped, is coupled to a push-pull power amplifier. The output of the amplifier is transformer coupled to a full wave rectifier and filter whose positive side is referenced to ground to provide a -27.0 (± 1.0) vdc output.

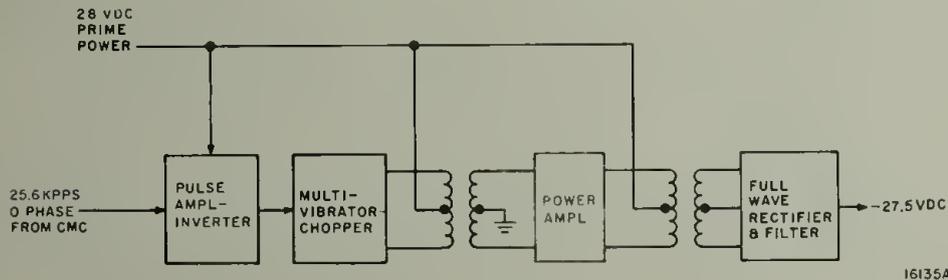


Figure 4-19. -28 VDC Power Supply

4-5.3 ISS 800 CPS POWER SUPPLY. The 800 cps power supply (figure 4-20) consists of four modules: an automatic amplitude control, filter, and multivibrator; a 1 percent amplifier; and two 5 percent amplifiers. The 1 percent amplifier provides IMU gimbal resolver excitation, gimbal servo amplifier demodulator reference, and FDAI and autopilot reference. The two 5 percent amplifiers provide gyro wheel excitation, IMU blower excitation, and accelerometer fixed heater power. The 1 percent amplifier also provides the input to one of the 5 percent amplifiers whose output is phase shifted -90 degrees. The output of this 5 percent amplifier is applied to the second 5 percent amplifier whose output is also phase shifted -90 degrees, or -180 degrees from the output of the 1 percent amplifier. The outputs of the 1 percent amplifier and the 5 percent amplifiers are applied to their respective loads through the IMU load compensation network which provides a power factor correction.

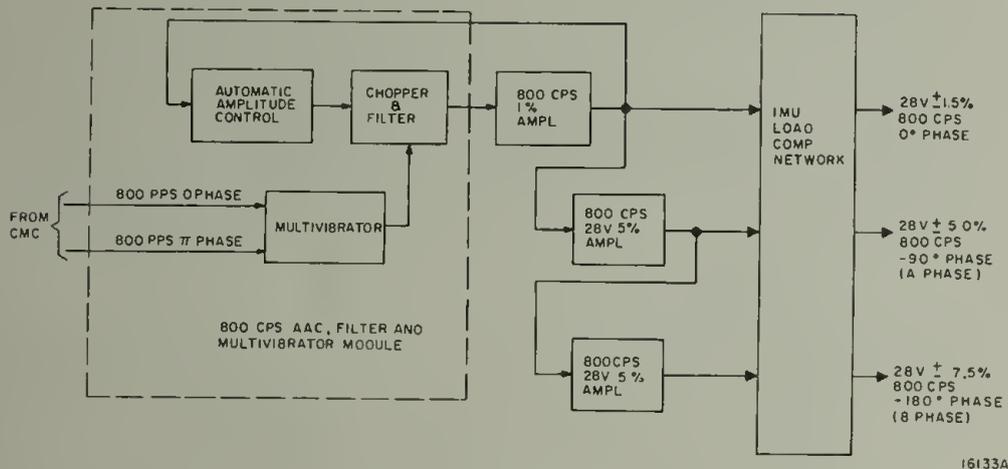


Figure 4-20. 800 CPS Power Supply

Zero and pi phase, 800 cps pulse trains from the CMC synchronize the multivibrator at 800 cps. In the absence of the synchronizing pulses, the multivibrator will free run between 720 and 790 cps. The output of the multivibrator controls the operation of the chopper and filter circuit. The filtered chopper output is applied to the 1 percent amplifier. The output of the 1 percent amplifier, in addition to its direct uses, is a feedback signal to the automatic amplitude control circuit. The positive peaks of this feedback signal are detected and added to a dc reference signal. The sum is filtered and provides a dc bias to the multivibrator driven chopper. The bias controls the amplitude of the chopped signal.

The 1 percent amplifier is push-pull in operation with transformer coupled input and output and with overall voltage feedback for gain and distortion control.

The two 5 percent amplifiers are identical in operation. The amplifiers are push-pull in operation and have transformer coupled inputs and outputs. The input transformer primary center tap is connected to the input signal low. The input signal high is applied directly to one side of the primary winding and is also applied through a phase shift network to the other, or out of phase, side of the primary. A feedback signal from the secondary of the output transformer is also applied to the out of phase side of the input transformer primary where it is mixed with the phase shifted portion

of the input signal. This mixing results in a -90 degree phase shift in the secondary of the input transformer. The output of the first 5 percent amplifier is used as an input to the second 5 percent amplifier to provide an additional -90 degree phase shift.

4-5.4 OSS 800 CPS POWER SUPPLY. The OSS 800 cps power supply consists of three modules: an automatic amplitude control, filter, and multivibrator; a 1 percent amplifier; and a 5 percent amplifier. The 1 percent amplifier provides resolver and tachometer excitation and the input to the 5 percent amplifier. The 5 percent amplifier provides SXT and SCT motor excitation. The outputs of the 1 percent amplifier and 5 percent amplifier are applied to their respective loads through the optics load compensation network which provides power factor correction.

The operation of the OSS 800 cps power supply is identical to the operation of the ISS 800 cps power supply except that it does not have two 5 percent amplifiers.

4-5.5 3,200 CPS POWER SUPPLY. The 3,200 cps power supply provides excitation voltage for the signal generator and the magnetic suspension portions of the IRIG and PIP ducosyns. The 3,200 cps output is also used as a reference for the demodulator in the gimbals servo amplifiers.

The excitation voltage to the signal generators requires both voltage stability and phase stability. To accomplish this stability, the excitation voltage power transmission to the stable member is through a step down transformer on the stable member which reduces the slip ring current and, therefore, voltage drop effects due to slip ring, cable, and connector resistance. In addition, each wire connecting the output of the transformer to the input terminals of each PIP is cut to exactly the same length. The voltage level at the primary of the transformer is fed back to the power supply and is compared to a voltage and phase reference.

The 3,200 cps power supply (figure 4-21) consists of an amplitude control module and a 1 percent power amplifier. The amplitude control module contains an automatic amplitude control circuit, a multivibrator, a chopper, and a filter.

The 3,200 pps pulse trains of zero degree phase and 180 degree phase synchronize a multivibrator. The output of the multivibrator controls the operation of the chopper circuit. The output of the chopper is applied to the 1 percent power amplifier. The 28 v (rms) output of the amplifier is transmitted through the slip rings to the transformer on the stable member where the voltage is stepped down to 2 volts for the accelerometer ducosyns and 4 volts for the gyro ducosyns. A sample of the 28 volt level at the primary of the transformer is fed back through the slip rings to the input of the automatic amplitude control circuit. The positive peaks of the feedback signal are detected and added to a dc reference signal. The sum is filtered and provides a dc bias to the chopper circuit. The dc bias controls the amplitude of the chopper output to the filter.

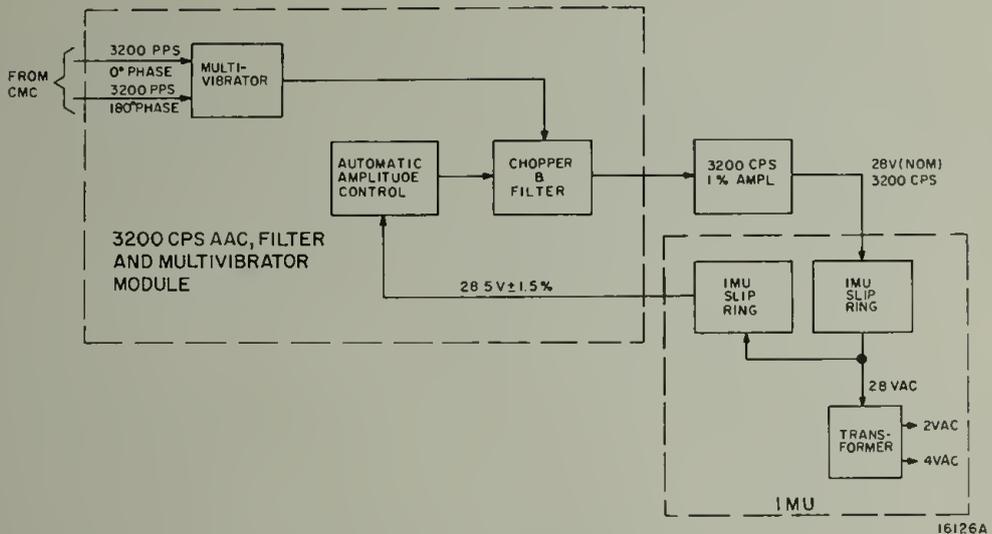


Figure 4-21. 3,200 CPS Power Supply

4-5.6 4 VDC POWER SUPPLY. The 4 vdc power supply (figure 4-22) supplies 4 vdc logic power to the digital logic circuits of the CDU. The 4 vdc power supply is a dc to dc converter type consisting of a pulse amplifier-inverter, a multivibrator-chopper, a power amplifier, a rectifier and filter circuit, and a difference amplifier and series regulator circuit.

A 25.6 kpps synchronization pulse input is amplified and inverted and used to synchronize the multivibrator-chopper, whose natural frequency is 11.5 keps. The multivibrator-chopper drives the primary of a transformer which has 28 vdc applied to its center tap. The secondary of the transformer is also center tapped and is coupled to a push-pull power amplifier. The dc input to the power amplifier is supplied through a series regulator. The power amplifier drives the primary of a transformer to develop a 12.8 keps square wave. The output from the transformer secondary is applied to the rectifier and filter circuit where the 4 vdc output is developed.

The 4 vdc output is fed back to a difference amplifier that produces an IMU output error signal proportional to the difference between the 4 vdc output and a reference voltage level obtained from a zener diode and resistor voltage divider network. The output of the difference amplifier controls the operation of the series regulator to increase or decrease the level of the dc input to the power amplifier as necessary to maintain the power supply output at 4 volts.

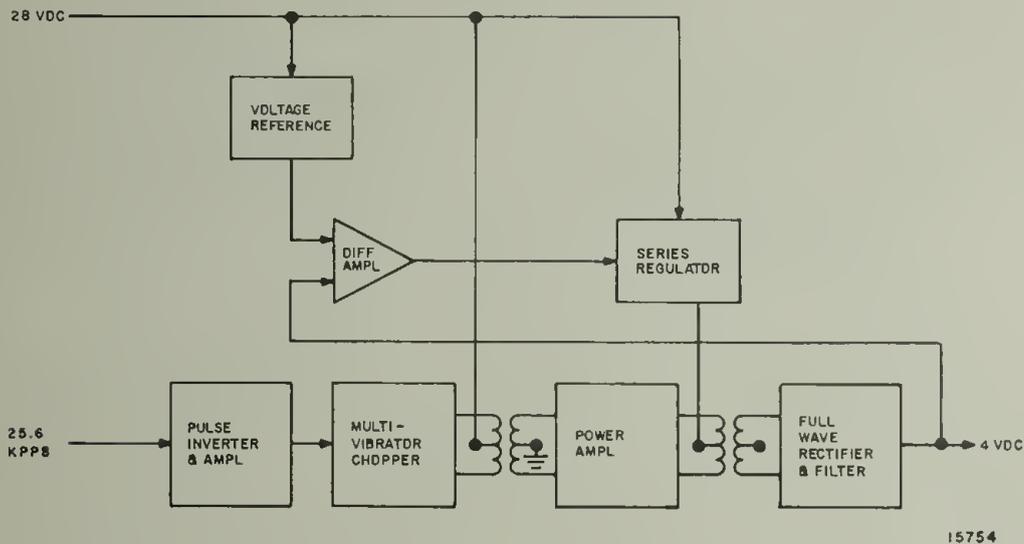


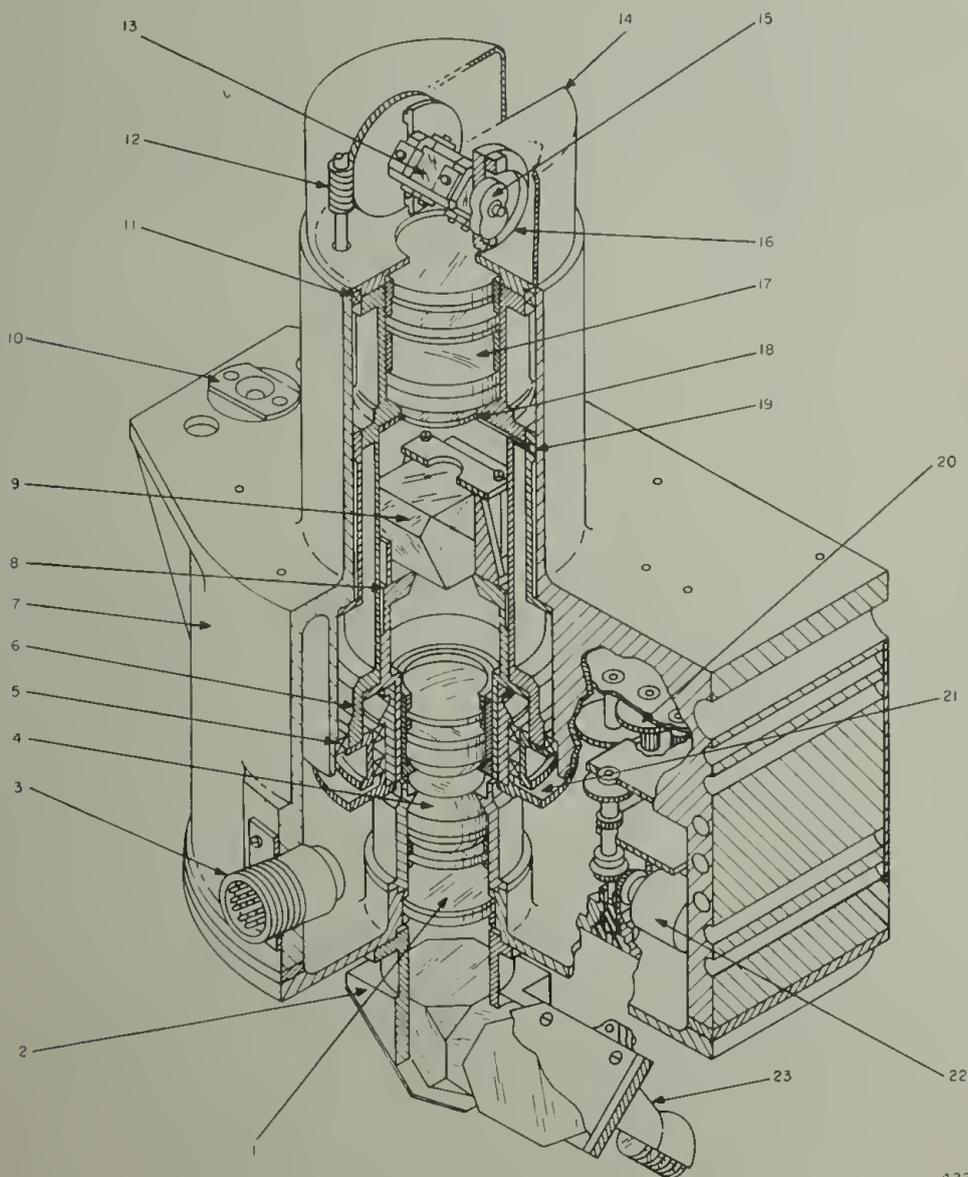
Figure 4-22. 4 VDC Power Supply, Block Diagram

4-6 OPTICAL UNIT ASSEMBLY

The OUA consists of two electromechanical optical instruments, SXT and SCT, mounted on a common base.

4-6.1 SCANNING TELESCOPE. The SCT is a one-power, 60-degree instantaneous field-of-view optical instrument, capable of changing the line-of-sight (LOS) of the viewing field. The LOS is positioned by rotation of a viewing prism about its trunnion axis and by rotation of the outer telescope tube assembly about its shaft axis. Trunnion and shaft are rotated by separate servos, each commanded from the SXT. The SCT is able to scan a conic viewing area of 110 degrees.

The structure of the SCT is shown in figure 4-23. The SCT portion of the optical base contains components of the shaft and trunnion loops (motor-generators, gear trains, resolvers, and mechanical counters) and the housing and lamp assembly. The SCT panel assembly is fastened to the optical base and contains windows to expose shaft and trunnion mechanical counters, input adapters for manual control of the gear trains, eyepiece prism housing assembly, and gas injection valve. The SCT contains an optics head assembly, a rotatable outer telescope tube assembly, a stationary inner telescope tube assembly, an eyepiece prism housing assembly, and an eyepiece housing assembly. The optics head assembly contains a double dove prism and mount assembly, mount, support, cam-follower and spring assembly, and trunnion worm shaft. The outer telescope tube assembly contains the objective lens assembly and the reticle.



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Figure 4-23. SCT, Cutaway View (Sheet 1 of 2)

1. Eyepiece window
2. Eyepiece prism housing assembly
3. Electrical connector
4. Relay lens assembly
5. Ball bearing (outer telescope tube assembly)
6. Outer telescope tube assembly
7. Optical base
8. Inner telescope tube assembly
9. Pechan prism
10. Ball mount (3)
11. Ball bearing (outer telescope tube assembly)
12. Trunnion drive worm shaft
13. Dove prism and mount assembly
14. SCT head cover
15. Anti-backlash cam
16. Anti-backlash spring and cam follower
17. Objective lens assembly
18. Reticle assembly
19. Housing and lamp assembly
20. Shaft drive gear box
21. Cluster gear assembly
22. Shaft angle counter
23. Eyepiece assembly

Figure 4-23. SCT, Cutaway View (Sheet 2 of 2)

A housing and lamp assembly, used to illuminate the SCT reticle, is mounted in the optical base around the outer telescope tube assembly. The inner telescope tube assembly contains a pechan prism and relay lens assembly. Contained within the eyepiece prism housing assembly are two right-angle prisms. The eyepiece housing assembly contains an objective lens assembly. The objective lens assembly and reticle in the outer telescope tube assembly and the pechan prism and part of the relay lens assembly in the inner telescope tube assembly form the optical complex of a minus 4.6-power telescope. The portion of the relay lens assembly in the inner telescope tube assembly, the eyepiece prism housing assembly, and the eyepiece housing assembly form the optical complex of a plus 4.6-power telescope.

Detailed theory of operation is divided into two general areas of discussion: optical complex and drive assemblies.

4-6.1.1 SCT Optical Complex. The SCT optical complex (figure 4-24) consists of a double dove prism and mount assembly, a minus 4.6-power telescope, and a plus 4.6-power telescope.

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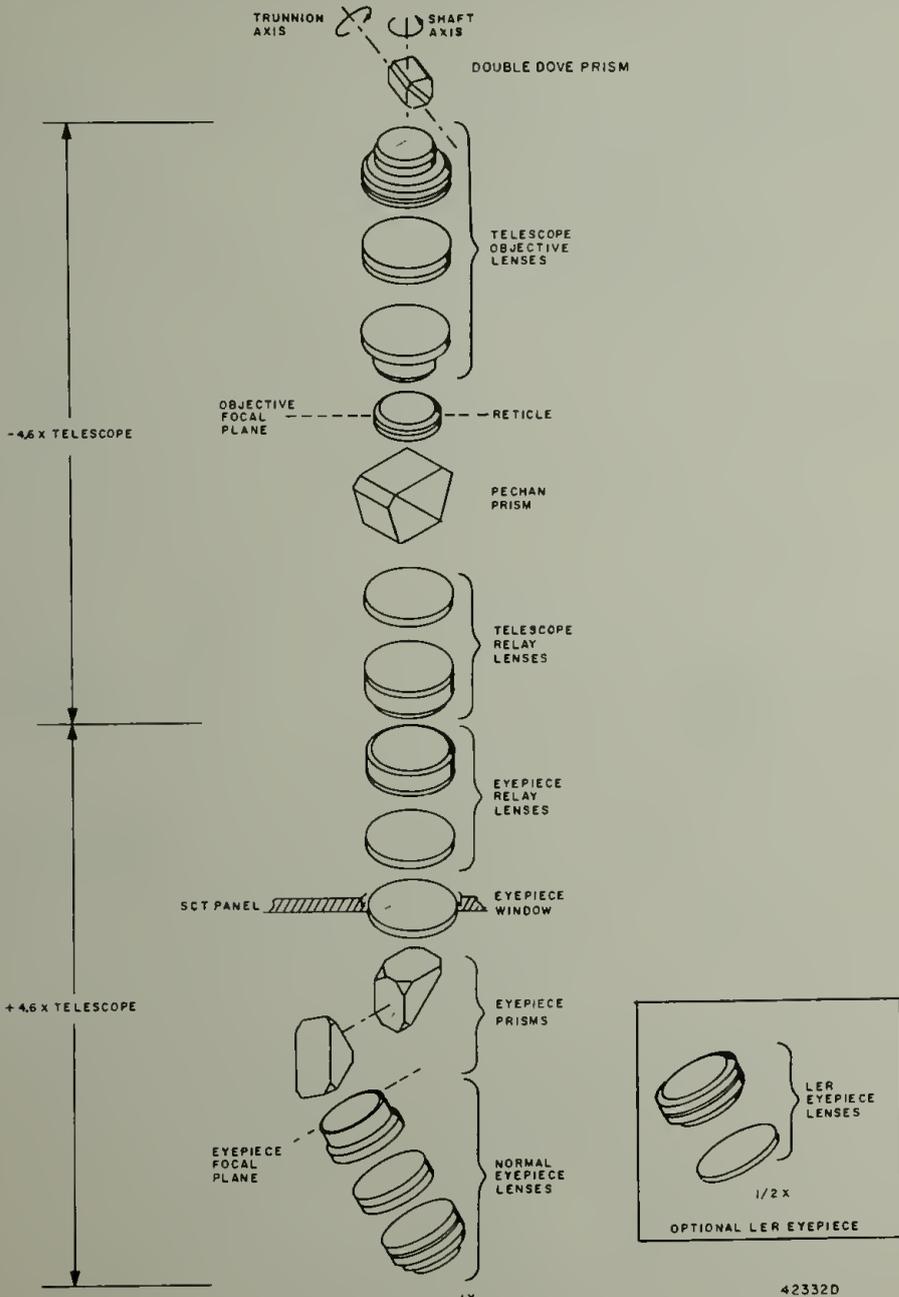
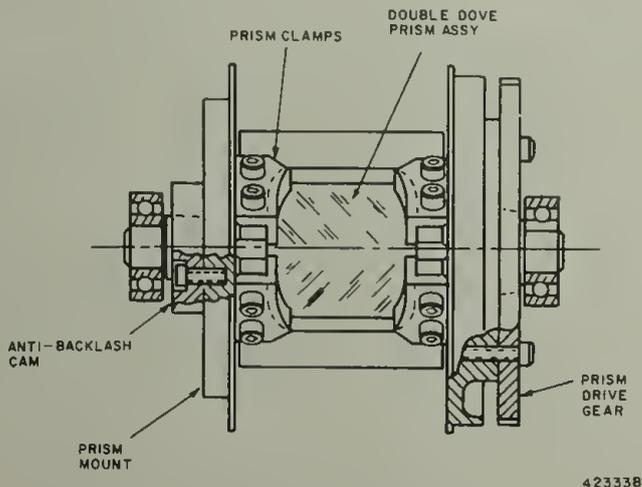


Figure 4-24. SCT Optics

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4-6.1.1.1 Double Dove Prism and Mount Assembly. The double dove prism and mount assembly (figure 4-25) contains two optically matched dove prisms. The prisms are aluminized and cemented together at the hypotenuse and accurately positioned and clamped to a mount. The double dove prism is the first optical element in the SCT optics to pick up the target image. Each dove prism inverts and transmits an image to the objective lens assembly. Optically the prism functions as a compact, wide-angle mirror that is rotatable about two axes, trunnion and shaft. The rotational limitations of the prism about the trunnion axis are from -5 to $+50$ degrees. At zero degrees, the reflective surface of the prism is parallel to the shaft axis and the selected target is centered on the reticle crosshairs. The images of the targets pass through the angular entrance face of the prism, are refracted toward the prism's reflective surface, and are reflected off the prism's mirrored surface at the angle at which they were received, toward the exit face of the prism. At the angular exit face, the images are refracted again and the now inverted image is transmitted parallel to the shaft axis. When the prism is rotated about the trunnion axis, the selected target increases in angular position to the prism's reflective surface. With an increase in angular position of the selected target, the images entering the prism become increasingly inclined to the prism's angular face. As the images entering the prism increase in inclination to the angular face, the degree of refraction caused by the prism decreases until, at perpendicularity, there is no refraction. However, in use, the prism field-of-view is limited by the SCT head assembly, the command module optics opening, and the size of the objective lens. These limitations restrict the useful field-of-view to 60 degrees and the conic scan to 110 degrees. At all useful positions of the prism, the images reflected off the mirrored surface of the prism are transmitted parallel to the shaft axis by the objective lens assembly.



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Figure 4-25. Double Dove Prism

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A worm gear and worm shaft drive the double dove prism and mount. The worm shaft is driven by a motor generator in the SCT trunnion drive gearbox. An angle counter, seen through the SCT panel window, displays the trunnion angle and is mounted in the trunnion drive gearbox. The angle counter is set for a zero reading when a resolver, a component of the trunnion drive gearbox, is at the null setting.

An anti-backlash device is used to improve positional accuracy. The device consists of a cam on the double dove prism shaft, a cam-follower, and a spring assembly. The cam-follower is held against the cam by the spring, thereby minimizing the backlash of the worm drive. Preloaded bearings in the double dove prism mount and in the worm drive also assist in precise operation of the trunnion drive.

4-6.1.1.2 Minus 4.6-Power Telescope. The minus 4.6-power telescope consists of an objective lens assembly and reticle assembly mounted in the outer telescope tube assembly and pechan prism and part of the relay lens assembly mounted in the inner telescope tube assembly.

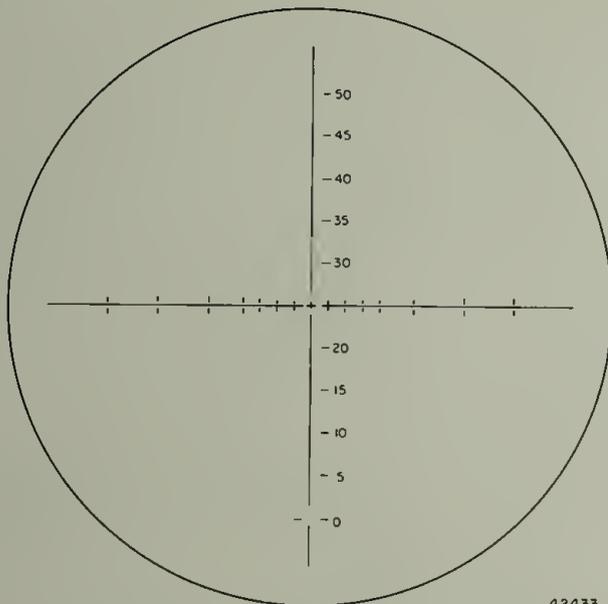
The objective lens assembly consists of three cemented doublets fitted into the upper end of the outer telescope tube assembly. Each doublet is made up of a positive and negative lens. This objective cluster collects light from the double dove prism and produces an image at the reticle plane. A 60-degree field-of-view is obtained with an aperture of approximately 5 millimeters.

The reticle assembly (figure 4-26) is located in the outer telescope tube assembly, is adjacent to the objective lens assembly, and is accurately positioned in the focal plane of the objective lens assembly. The inverted images transmitted by the objective lens assembly are focused onto the reticle. The reticle crosshair intersection is the reference target for the image transmitted from the double dove prism and objective lens assembly.

The reticle is illuminated from the edge by four incandescent lamps located in the housing and lamp assembly. (See figure 4-27.) This assembly is secured to the optical base and envelopes the outer telescope tube assembly. Three light-transmitting rods, assembled 120 degrees apart in the reticle plane, direct the light from the incandescent lamps to the reticle. The rods are fastened to the outer telescope tube assembly and provide uniform illumination at any shaft angle.

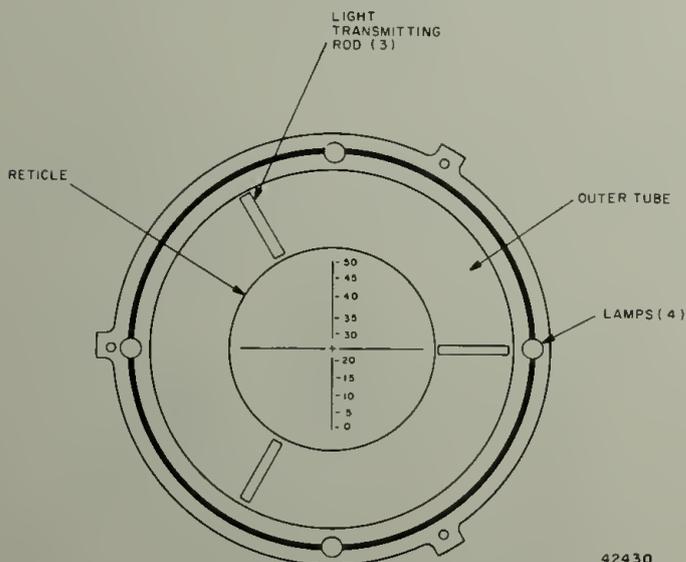
The pechan prism (figure 4-28) (located in the inner telescope tube assembly at the end facing the reticle assembly) erects the inverted images. The prism is in the optical path between the reticle and the relay lens assembly. The pechan prism consists of two sections separated by an air space. This design achieves the erecting of the images and increases the axial length of the optical path and decreases the physical length of the SCT.

The relay lens assembly consists of a group of relay lenses fastened to the end of the inner telescope tube assembly opposite the end holding the pechan prism. The relay lenses receive the erected image from the pechan prism and transfer it without distortion to the relay lenses of the plus 4.6-power telescope.



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Figure 4-26. SCT Reticle



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Figure 4-27. SCT Reticle Housing and Lamp Assembly

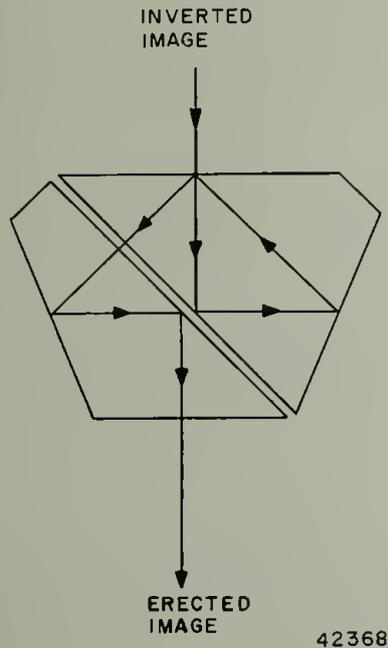


Figure 4-28. Pechan Prism

4-6.1.1.3 Plus 4.6-Power Telescope. The plus 4.6-power telescope consists of part of the relay lens assembly mounted in the inner telescope tube assembly, an eyepiece window, an eyepiece prism housing assembly, and an eyepiece housing assembly.

The relay lenses receive the images transmitted by the minus 4.6-power telescope relay lenses and transfers them through the eyepiece window to the eyepiece prism housing assembly.

The eyepiece window is mounted in the SCT panel assembly. The eyepiece window acts as a seal between the eyepiece prism housing assembly and SCT components exposed to environmental conditions outside the command module. The eyepiece window has no optical effect and transmits the image directly from the relay lens assembly to the SCT eyepiece prism housing assembly.

The eyepiece prism housing assembly is fastened to the front of the SCT panel assembly. It transfers the image from the relay lens assembly to the eye of the observer. The eyepiece prism housing assembly contains two right-angle prisms, one small and one large. The small prism is mounted in-line with the shaft axis and receives the images from the relay lens assembly and reflects the images 90 degrees

into the large prism. The large prism is mounted in such a manner as to correct for the 90 degree image orientation by reflecting the images 90 degrees into the eyepiece housing assembly parallel to the SCT shaft axis. The prism mountings enable the eyepiece housing assembly to be mounted in a position that provides the astronaut with the most viewing comfort.

The eyepiece housing assembly is fastened to the end of the eyepiece prism housing assembly. This assembly contains three telescope objective lens assemblies. The objective lenses are optically identical to the minus 4.6-power telescope objective lenses.

The SCT eyeguard assembly is fastened to the end of the eyepiece housing assembly. It is made of non-toxic, synthetic rubber and is adjustable in an axial direction. The adjustment allows for differences in facial contours of the astronauts.

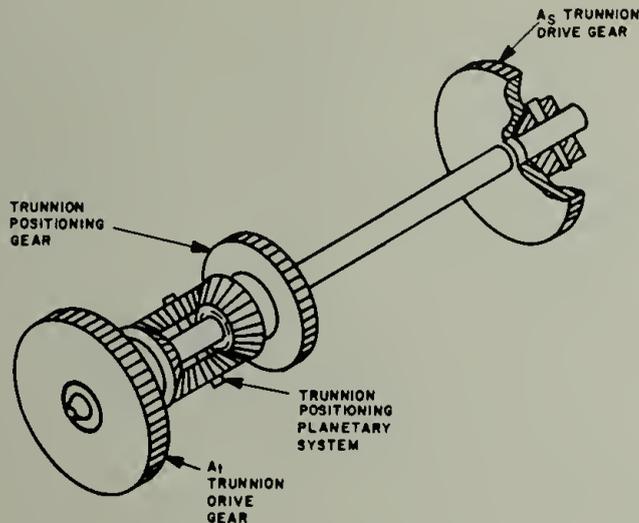
The SCT long relief eyepiece assembly is provided as optional equipment as a replacement for the SCT eyepiece assembly. It contains a lens assembly and a positive lens mounted into a SCT eyepiece housing. Unlike the contoured eyeguard assembly of the SCT eyepiece assembly, a flat rubber guard is cemented against the end of the SCT eyepiece housing assembly.

4-6.1.2 SCT Optics Light Transmission. The optical efficiency of the SCT allows approximately 40 percent of the light impinging on the double dove prism to be transmitted to the eyepiece. Light losses in the SCT are held to a minimum by the use of multiple anti-reflection coatings which increase the efficiency of all transmitting surfaces.

4-6.1.3 SCT Drive Assemblies. The single speed SCT obtains rotational drive about shaft and trunnion axes through two motor generators, one for each axis. Reduction gearing, motor generators, resolvers, and angle counters for shaft and trunnion axes are assembled in two separate gearboxes located in the optical base. The following paragraphs contain details of SCT gearbox components and their operation.

4-6.1.3.1 Gear Reduction Ratios. Figure 4-29 contains an operational diagram of the SCT reduction gearing. In trunnion axis, the gear reduction ratio between motor generator shaft and double dove prism is 5952:1. Worm mesh lead accuracy is maintained within 30 arc seconds. In shaft axis, the gear reduction ratio between motor generator shaft and double dove prism is 2976:1.

4-6.1.3.2 SCT Differential. SCT shaft and trunnion axis drives are linked by a differential gear assembly. The differential gear assembly permits trunnion axis positioning independent of shaft axis, and shaft axis rotation without introducing errors in the trunnion axis. The differential gear assembly is shown in detail in figure 4-30. The A_s trunnion drive gear and the trunnion positioning planetary gearing system are pinned to the differential drive shaft, while the A_t trunnion drive gear and the trunnion positioning gear can rotate about the differential drive shaft. However, the use of the planetary gearing system and the result of friction in the A_t trunnion drive gear train, a rotation of the differential drive shaft will cause the trunnion positioning gear to rotate.



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Figure 4-30. SCT Differential Gear Assembly

Shaft Axis Positioning - Positioning the SCT in shaft results in the A_s trunnion drive gear rotating and driving the differential drive shaft. Because the trunnion positioning planetary system gears are pinned to the differential drive shaft and the A_t trunnion drive gear is held stationary by the gear train friction, the planetary gears rotate about the A_t trunnion drive bevel gear. The planetary gears are thus forced to rotate about their own axes (parallel to the planetary gear pin) and force the trunnion positioning gear to rotate. The trunnion positioning gear will rotate in the same direction as the differential drive shaft and drive the trunnion assembly in the same direction and at the same speed as the SCT shaft. Since the rotation of the trunnion assembly is coincident with the rotation of the SCT shaft, rotation about the SCT shaft axis is possible without introducing errors in the trunnion axis.

Trunnion Axis Positioning - Positioning the SCT in trunnion results in the A_t trunnion drive gear rotating about the differential drive shaft and driving the trunnion positioning gear. When the A_t trunnion drive gear is rotated, the trunnion positioning planetary gears are forced to rotate about their own axes and force the trunnion positioning gear to rotate. The trunnion positioning gear rotates and positions the SCT double dove prism about the trunnion axis. Since the A_t trunnion drive gear and the trunnion positioning gear are free to rotate about the differential drive shaft and the A_s trunnion drive gear is held stationary by the gear train friction, rotation of the A_t trunnion drive gear does not result in a rotation of the differential drive shaft. The SCT can thus be positioned about the trunnion axis without introducing errors in the SCT shaft.

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4-6.1.3.3 SCT Angle Counter. Two identical counters (figure 4-31) displaying SCT shaft and trunnion axis angles are located in the optical base. The counters are viewed through lighted bezel windows in the SCT panel. Each counter contains three drums interconnected through geneva gearing. A flip-up counter shade is geared to the drums to permit continuous numerical display. The counter is calibrated to display readouts from 0 to 359.98 degrees with graduations in 0.02 degree increments. Counter rotation is continuous in either direction. One revolution of the counter input shaft results in a one degree change in counter indication.

4-6.2 SEXTANT. The SXT structure is shown in figure 4-32. For purposes of description, the SXT is divided into the index head assembly and the base section. The SXT index head assembly contains the indexing mirror and mount assembly, SXT right angle mirrors, beam splitter, and trunnion drive electromechanical components.

The SXT portion of the optical base contains the shaft axis assembly, shaft drive electromechanical components (motor-generator, shaft drive gearbox, and resolvers), and SXT eyepiece. Rotating components, mounted on the shaft axis assembly include the SXT telescope tube assembly (with objective and intermediate lens), the SXT reticle assembly, and the shaft resolver rotors. The SXT panel assembly covers the underside (face) of the optical base. This assembly contains the eyepiece window and has provision for mounting the SXT eyepiece assembly. The detailed theory of operation for the SXT is divided into two general areas of discussion: optical complex and eyepiece assembly.

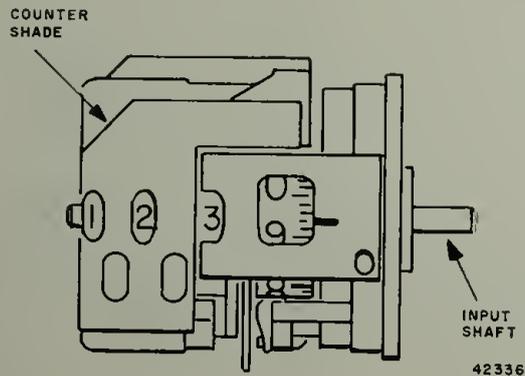
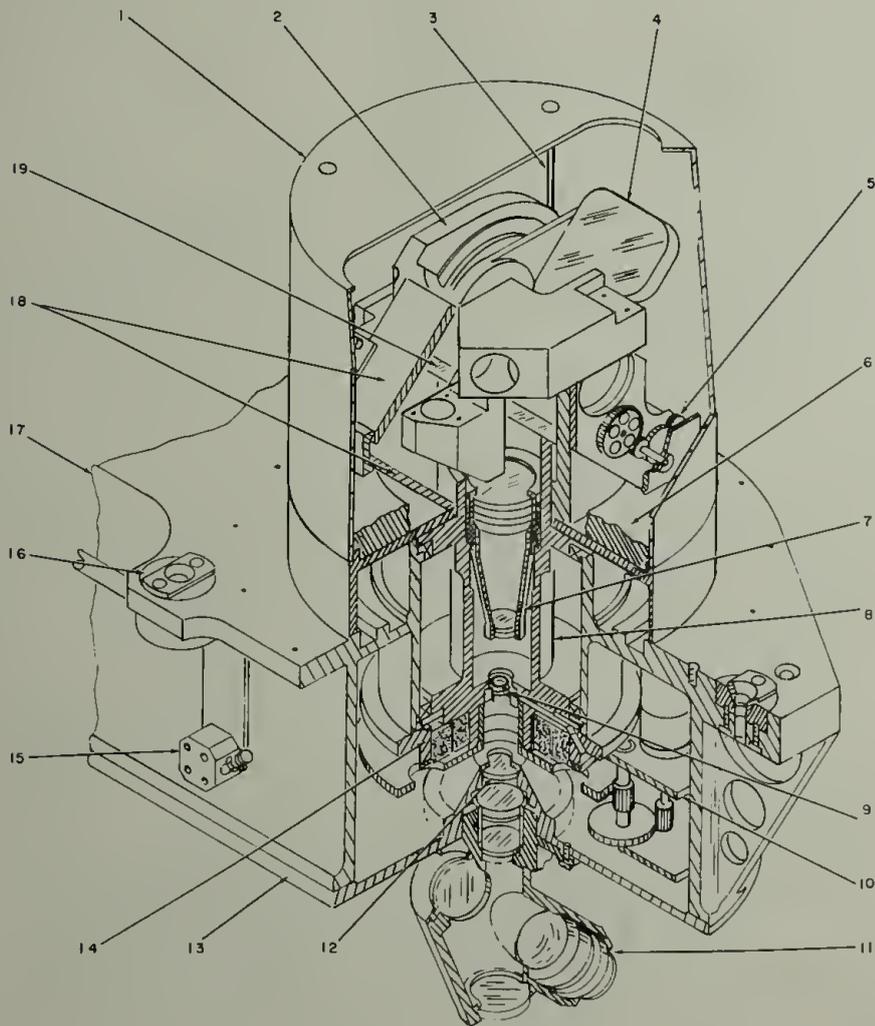


Figure 4-31. SCT Angle Counter



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Figure 4-32. SXT, Cutaway View (Sheet 1 of 2)

1. SXT head assembly cover
2. Trunnion pancake resolvers
3. Threaded rod (cover support) (2)
4. Trunnion indexing mirrors and mount assembly
5. Trunnion servo gear box
6. Dummy weight
7. Objective lens assembly
8. Shaft axis assembly
9. Reticule assembly
10. Shaft servo gear box
11. SXT eyepiece assembly
12. Eyepiece window
13. SXT panel assembly
14. Shaft resolvers
15. Coolant passages (not used)
16. Ball mount (3)
17. Optical base
18. Right-angle mirrors
19. Beam splitter

Figure 4-32. SXT, Cutaway View (Sheet 2 of 2)

4-6.2.1 SXT Optical Complex. The SXT optical complex (see figure 4-33) consists of SXT indexing mirror and mount assembly, right angle mirrors, beam splitter, SXT telescope lenses, and eyepiece assembly.

4-6.2.1.1 SXT Indexing Mirror and Mount Assembly. The SXT indexing mirror is constructed of heat-treated beryllium with a reflective coating and is used to pickup and direct a target star image onto the right angle mirrors. The indexing mirror is mounted in the mirror mount assembly of the sextant head. The assembly rotates on precision ball bearings in the trunnion axis and is provided with counterweights to maintain balance in any position. For every one degree of indexing mirror movement, the S_tLOS moves two degrees.

4-6.2.1.2 SXT Head Right Angle Mirrors. Two mirrors are fixed at right angles to each other and reflect the star image onto the reflecting surface on the underside of the beam splitter.

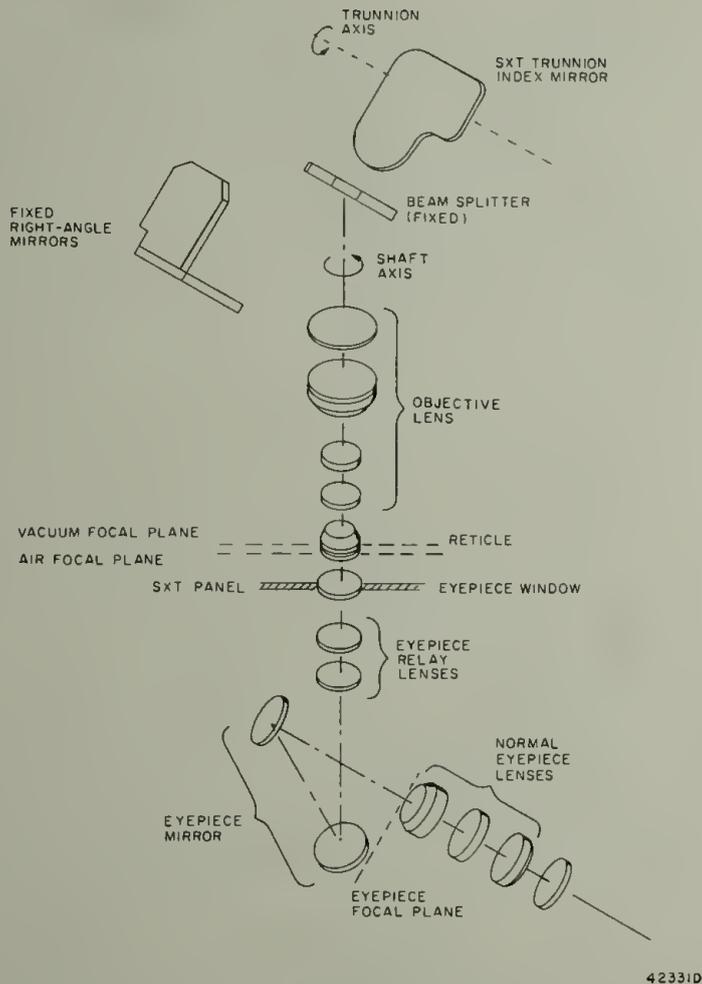
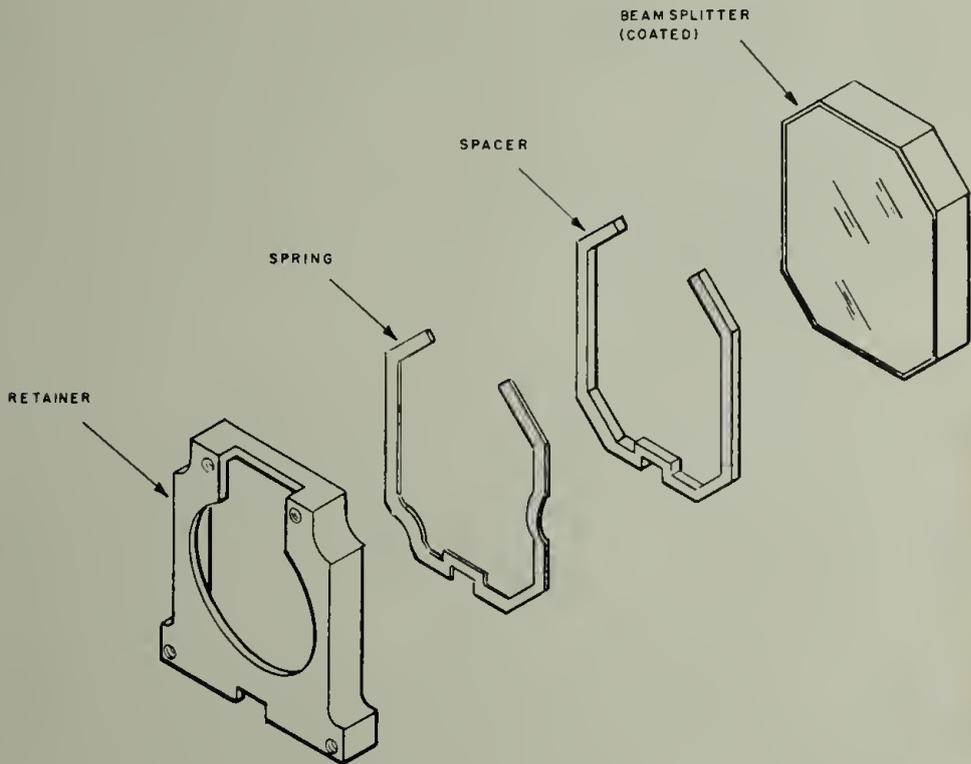


Figure 4-33. SXT Optics

4-6.2.1.3 Beam Splitter. The SXT optics provides two distinct lines of sight with different degrees of light transmission for two simultaneously viewed images. These capabilities are derived by incorporation of the beam splitter. (See figure 4-34.) The beam splitter is more properly termed a beam combiner since it functions by reflecting the S_tLOS into the same path as the transmitted LLOS.



42330A

Figure 4-34. Beam Splitter Construction

The landmark image is brighter than the star image, therefore it is necessary to transmit the image intensities at different levels to keep the landmark image from obscuring the star image. The beam splitter provides the required variations in transmission due to its surface reflectivity characteristics.

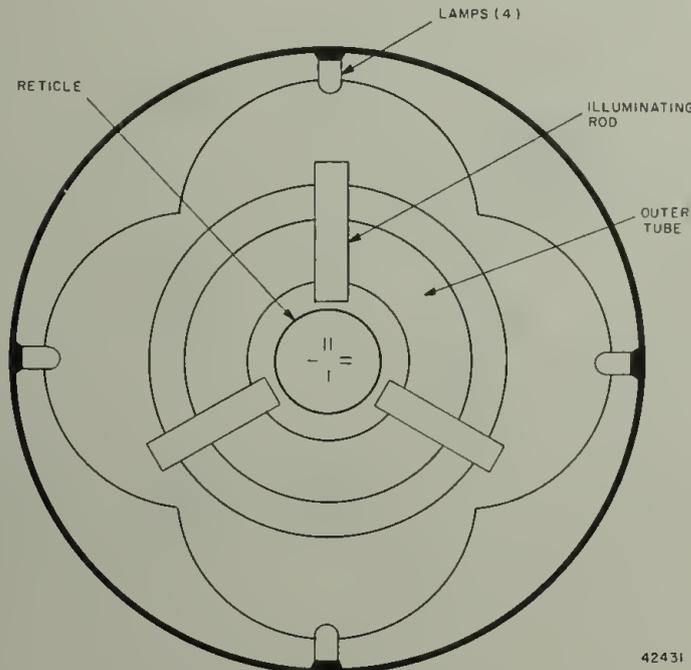
4-6.2.1.4 SXT Telescope Optical Complex. The SXT telescope optical complex, mounted in the SXT shaft axis assembly, consists of an objective lens, the intermediate lens, and reticle assemblies. A triplet and a single lens form part of the telescope objective lens assembly at the upper end of the lens holder which tapers due to the smaller diameter of the intermediate lenses. A set of these intermediate lenses is mounted at the lower end of the lens holder assembly. The objective and intermediate lens assemblies form a telephoto type lens system. The reticle is positioned in the forward vacuum focal plane of the SXT optics. This position provides optimum focus of

the reticle vacuum pattern etched on the forward face of the reticle assembly (figure 4-35). When operating in the earth atmosphere, the reticle vacuum pattern becomes indistinct due to a shift in the focal plane of the SXT optics. An air pattern is etched on the rear face of the reticle and an air focusing shim is inserted between the SXT plate and eyepiece assemblies to compensate for the shift. The air focusing shim is removed prior to launch for vacuum (outer space) operation of the SXT. The edge illumination of the SXT reticle is provided by four lamps which light three transmitting rods spaced evenly around the reticle. (See figure 4-36.) The eyepiece window serves as a seal in the SXT panel. The SXT eyepiece window is similar in function to the SCT eyepiece window.



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Figure 4-35. SXT Reticle



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Figure 4-36. SXT Reticle Housing and Lamp Assembly

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4-6.2.1.5 SXT Eyepiece Assembly. The SXT eyepiece assembly consists of the relay lens assembly, two mirrors, and the ocular eyepiece assembly. The relay assembly contains two doublets which relay the image to the primary of two mirrors. The mirrors reduce the length of the system and transfer the image into the eyepiece ocular assembly. The eyepiece ocular assembly contains two doublets, a single lens, and a polaroid filter. The adjustable filter provides landmark (LLOS) image brightness adjustment without affecting star image (S_t LOS).

In effect, the SXT eyepiece assembly represents a telemicroscope of 0.34 inch focal length and contributes to the SXT 28 power magnification by providing 3.4 power magnification from the relay assembly. Focal length of the eyepiece assembly equals one inch, which results in a total magnification of 28 power.

4-6.2.1.6 SXT Optics Light Transmittance. When a beam of light passes through a different medium, the intensity will decrease. This loss of intensity is mainly due to absorption. With respect to the SXT S_t LOS (see figure 4-37), incident light impinging on and emerging from the trunnion mirror is reduced by a factor of approximately 4 percent. The resulting 96 percent is passed on to the first fixed mirror, which causes a further reduction of 4 percent passing on 92 percent of the light to the second fixed mirror. The second fixed mirror further reduces transmitted light by 4 percent, leaving approximately 88 percent to be reflected by the beam splitter. The beam splitter will reflect approximately 82 percent of the light principally in the shorter wavelength of the visible spectrum. Light loss in the objective lens assembly and through the eyepiece results in total light transmissions of approximately 25 percent for the S_t LOS.

The total light losses in the LLOS (see figure 4-37) amount to approximately 97 percent, with 89 percent occurring at the beam splitter. The remaining 11 percent emerging from the beam splitter is further attenuated through the objective and eyepiece assemblies. This results in an overall transmittance of 3.2 percent.

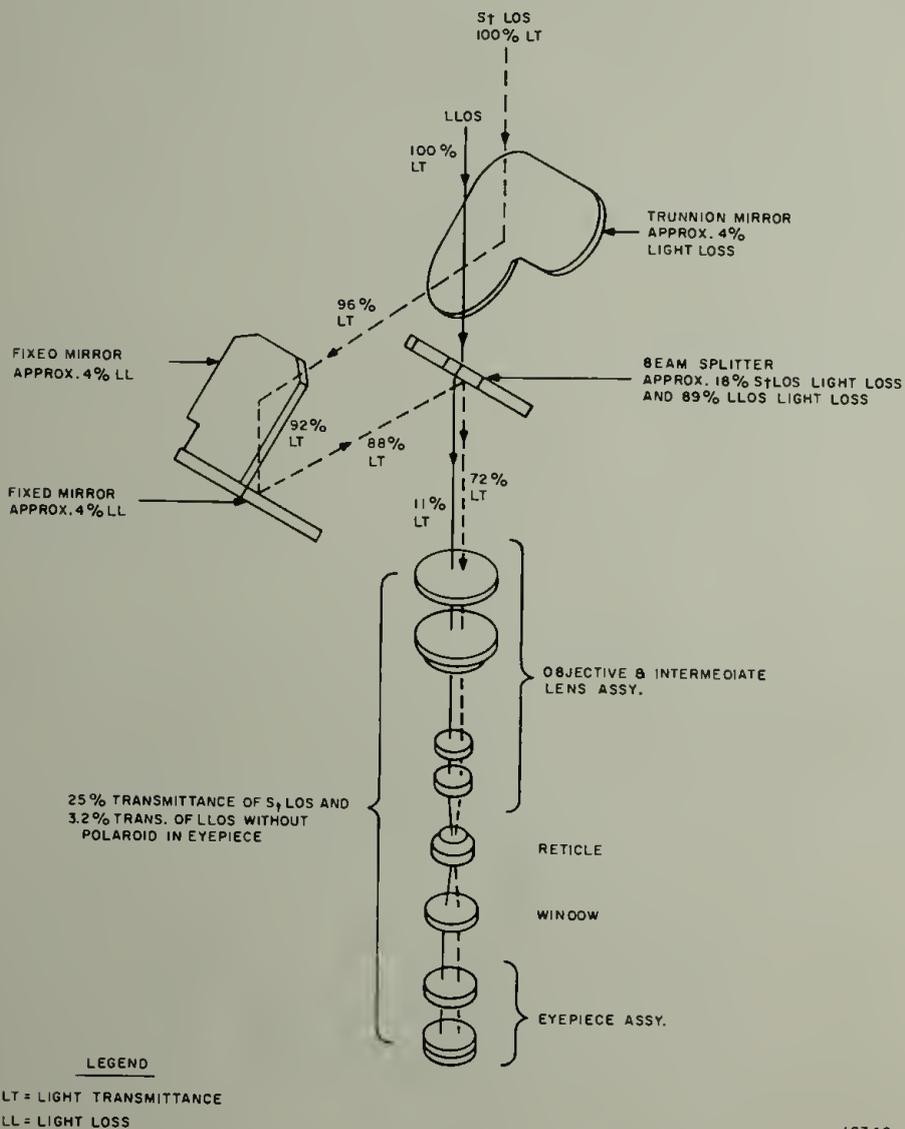
4-6.2.2 SXT Drive Assemblies. The SXT obtains rotational movement about shaft and trunnion axes through two motor generators. Reduction gearing, motor generators, and resolvers are contained in two separate gearboxes. One is located in the optical base; the other is located in the index head assembly (see figure 4-38).

In trunnion axis, positioning of the indexing mirror is restricted mechanically to a range of -5 to +50 degrees through the use of a limit stop. A command torsion spring assembly is provided in the drive assembly to minimize positioning error.

In trunnion axis, the gear reduction ratio between motor generator shaft and indexing mirror is 11780:1. The gear reduction ratio in shaft axis drive between motor generator shaft and indexing mirror is 3010:1.

4-7. COMMAND MODULE COMPUTER

See LEM Primary Guidance, Navigation, and Control System Manual, ND 1021042, paragraph 4-5 for computer theory of operation.



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Figure 4-37. SXT Optics Light Transmittance



Chapter 5

PRELAUNCH AND IN-FLIGHT OPERATIONS

5-1 SCOPE

This chapter describes operation of the Block II PGNCS during prelaunch and in-flight phases of the Apollo mission. PGNCS operation and crew procedures have been correlated for the following major phases of the flight profile: IMU alignment, guidance monitor, optical measurements, thrust vector control, attitude control, S-4B takeover, and entry.

5-2 PREPARATION FOR LAUNCH AND PRELAUNCH IMU ALIGNMENT

Preparation for launch begins when the backup crew enters the spacecraft and begins the checkout before liftoff. After control circuits linking the spacecraft to the launch pad have been verified as operational, the PGNCS subsystems are energized and the PGNCS operational test is performed. Data on trajectory and launch coordinates is entered into the computer in preparation for prelaunch alignment of the IMU.

During prelaunch IMU alignment, the IMU stable member is aligned to and held earth referenced at a predetermined orientation with respect to an earth referenced coordinate system. Stable member prelaunch alignment is required since the PGNCS monitors Saturn guidance during earth ascent and must be able to assume control of Saturn booster steering during earth orbit insertion and translunar trajectory injection. Prelaunch stable member alignment is maintained until just prior to lift-off when the stable member is released to an inertially referenced coordinate system. This procedure establishes an inertial starting point from which the PGNCS can determine spacecraft velocity, position, and attitude.

Stable member alignment (figure 5-1) is accomplished by vertical erection and azimuth alignment. During vertical erection, the X accelerometer input axis is positioned to sense local gravity and the Y and Z accelerometer input axes are maintained in the horizontal plane. If the stable member drifts from this orientation, so that the outputs of the Y and Z accelerometers indicate a portion of local gravity, the CMC repositions the stable member through the stabilization loop.

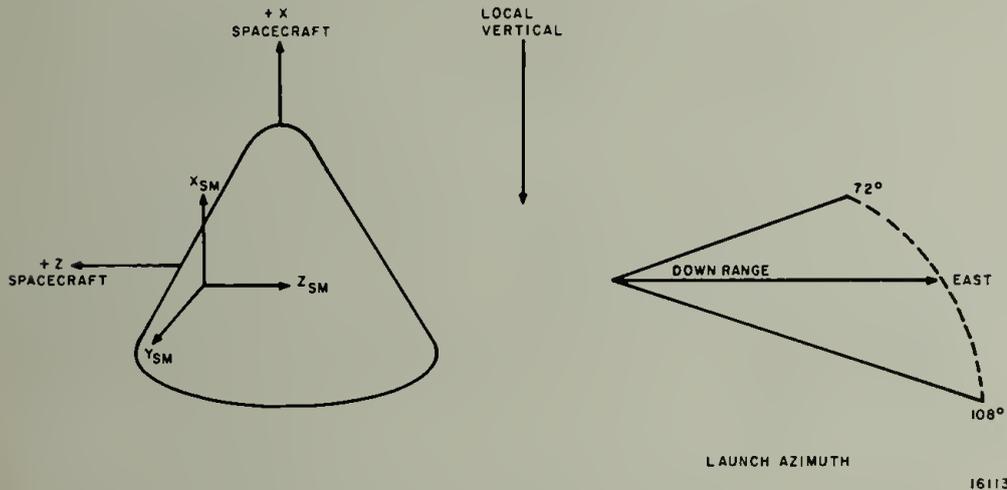


Figure 5-1. Prelaunch Alignment Axes Orientation

A computer controlled gyro compassing program aligns the stable member to and maintains the stable member at the desired azimuth. The desired azimuth of the down range accelerometer (dependent on the launch constraints) will vary from 72 to 108 degrees from true North. Gyro compassing is a self-alignment process: each gyro will sense a calculable portion of earth rate when the stable member is aligned to some particular orientation with respect to an earth referenced coordinate system. The computer compensates for earth rate torquing of the stable member gyros by sending a predetermined number of torquing pulses per unit of time to each IRIG torque ducosyn. If the stable member is not aligned to the desired azimuth, the gyro torquing pulses per unit time will not compensate for the earth rate torquing of the gyros. Consequently, the accelerometers originally located in the horizontal plane will be located in a different plane and will sense components of acceleration due to gravity. The computer interprets the acceleration data from the accelerometer loops as error signals. The error signals are used by the computer to calculate the necessary additional gyro torquing pulses per unit time to drive the stable member to the desired azimuth alignment.

After the desired azimuth of the stable member has been obtained, it is also maintained by the gyro compassing program. The east 25 IRIG will sense a component of earth rotation when the stable member is misaligned in azimuth. The resultant signal is used by the computer to reposition the stable member, thus compensating for earth rate and bias drift until launch.

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To accomplish the task of prelaunch IMU alignment, (figure 5-2) the inertial subsystem is cycled through the IMU turn-on mode, coarse align mode and into the fine align mode. The inertial subsystem remains in the fine align mode during vertical erection and gyro compassing of the IMU. Accelerometer outputs and IMU gimbal angles are provided to the computer. The computer uses the accelerometer and gimbal angle information to control ISSmoding and to generate the commands to initiate the positioning of the IMU stable member.

The backup crew leaves the spacecraft after disconnecting the GSE and securing the navigation station by folding up the work table, installing the hand controller on the center couch, and checking PGNCS indicator lamps and controls.

The flight crew enters the spacecraft about 2-3/4 hours before liftoff. The navigator selects the required computer program. The status of IMU alignment is monitored by the navigator on the DSKY and by the ground station telemetry and post installation ground support equipment.

5-3 GUIDANCE MONITOR

The PGNCS performs the function of guidance monitor during the earth ascent phase and the translunar injection phase of the Apollo mission. During these phases, the PGNCS monitors flight profile and mission sequencing.

During guidance monitor, the CMC computes the difference between the desired spacecraft attitude and the actual spacecraft attitude. The astronaut can send attitude error signals from the PGNCS to Saturn instrumentation for use as steering signals by setting a switch on the main D and C panel. The CMC also computes and updates an abort re-entry program which can be initiated during the earth ascent phase at the command of the astronaut.

The inertial and computer subsystems (figure 5-3) are used for the guidance monitor functions. The inertial subsystem is operated in the attitude control mode. Changes in velocity due to engine thrust and gravitational fields are supplied to the computer by accelerometer loops. Spacecraft attitude, as determined from the gimbal angle resolvers, is used as total attitude inputs to the FDAI. The CMC computes the difference between the actual IMU gimbal angles (spacecraft attitude), as indicated by the CDU, and the desired gimbal angles (desired spacecraft attitude), as specified by the pitch program. The computed differences are converted to analog values in the CDU and displayed as attitude error signals on the FDAI. Discretes, such as guidance release and liftoff, generated by the boost guidance equipment are received by the CMC. Trajectory information, such as velocity, position, attitude, and time are available to the ground tracking stations through downlink.

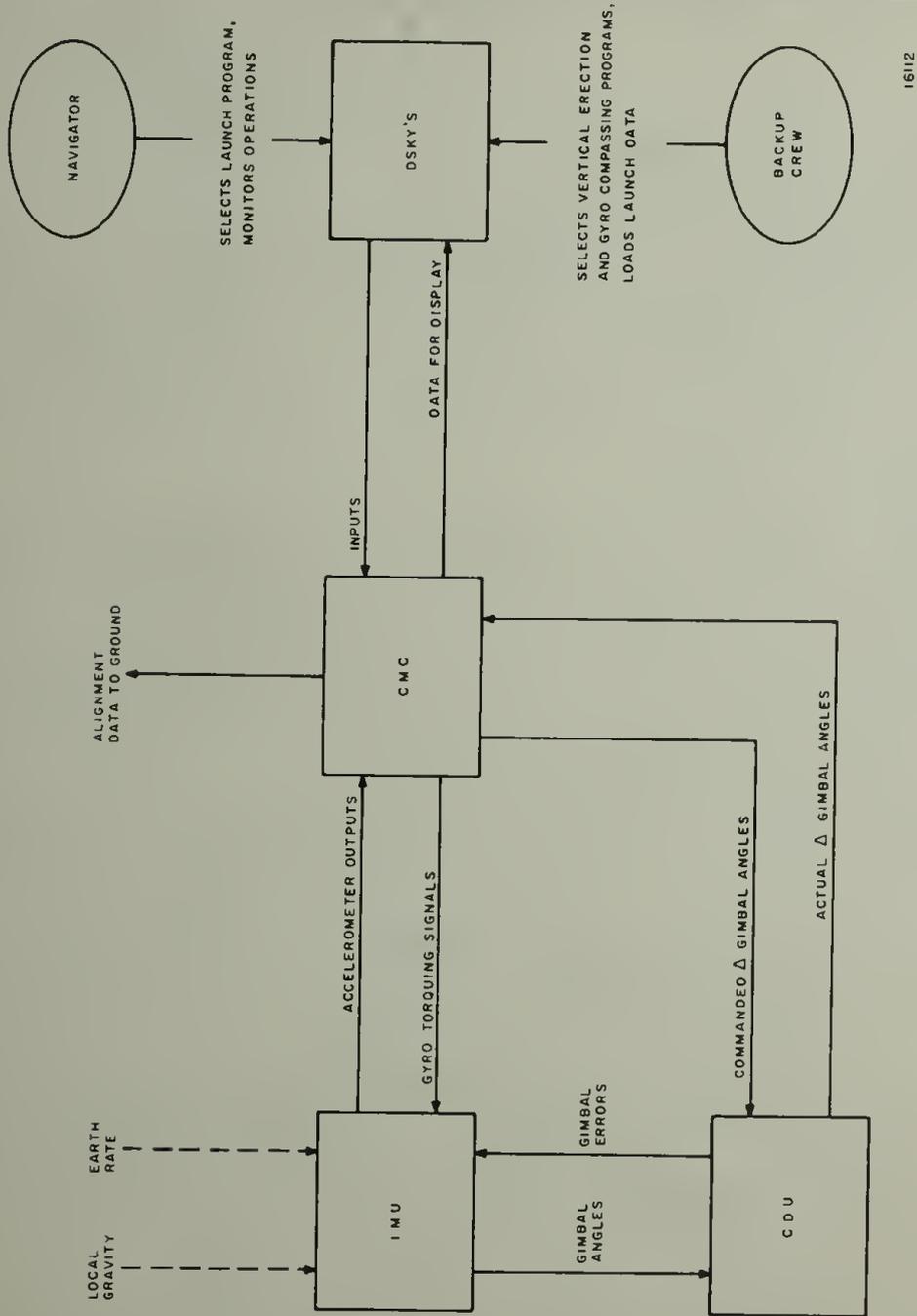
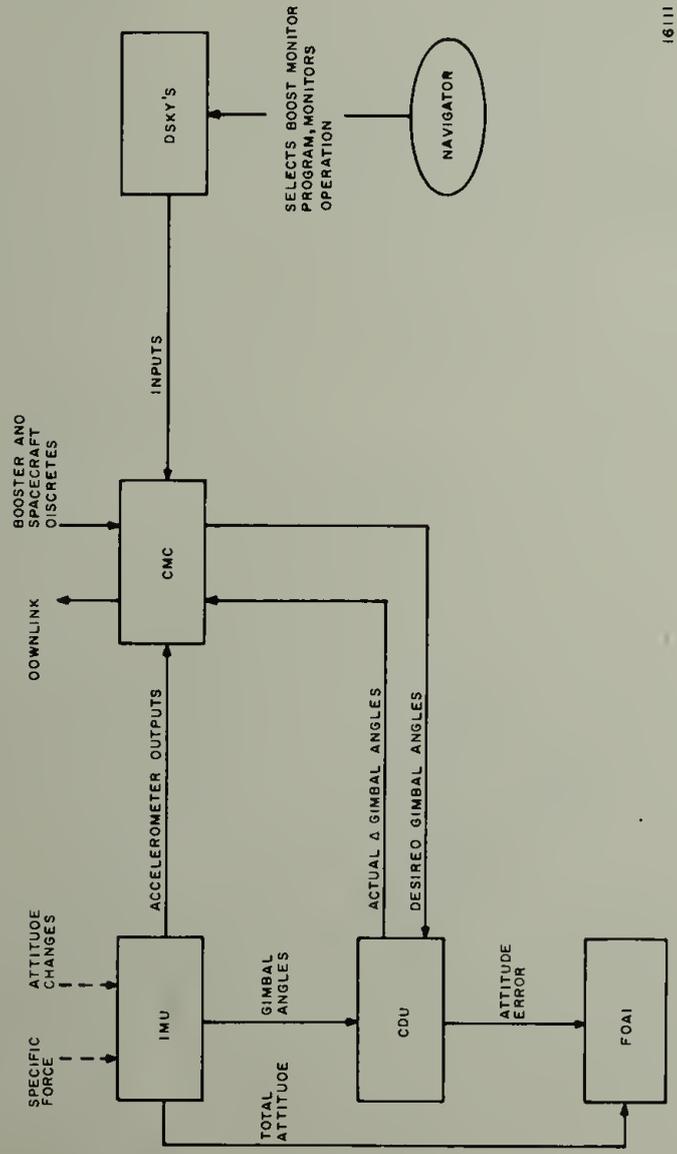


Figure 5-2. Prelaunch IMU Alignment

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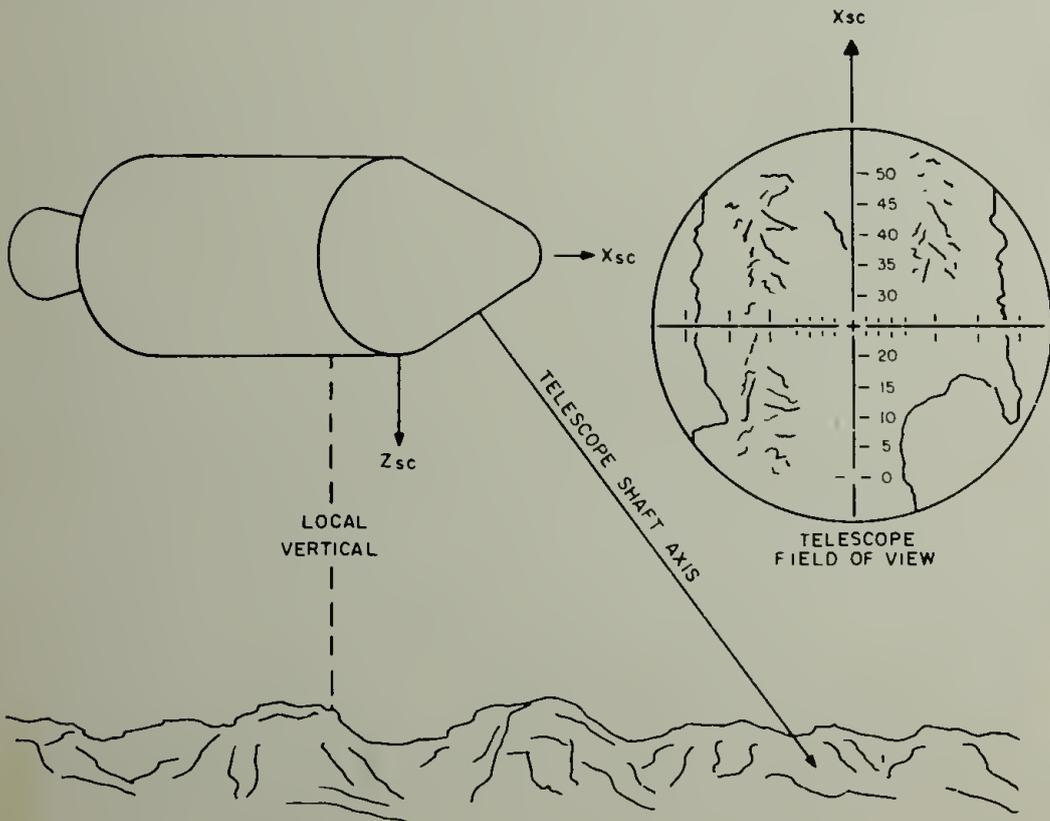
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Figure 5-3. Guidance Monitor

5-4 ORBITAL NAVIGATION

During earth or lunar orbits, velocity and position data is updated by taking navigational measurements. Earth and lunar orbit sightings are taken using well defined landmarks or using landmarks or the horizon and a prominent star as reference targets.

During orbital navigation, the spacecraft is orientated with the Z axis approximately down and the X axis in the direction of motion. (See figure 5-4.) This orientation points the optical axes toward the earth or lunar surface. The spacecraft is referenced to local vertical through computer control.



15167

Figure 5-4. Orbital Navigation Sighting

In preparation for orbital navigation measurements, the navigator mounts the optical eyepieces and adjusts instrument panel and interior spacecraft lighting. To assure maximum accuracy of orbital navigation measurements, the navigator verifies that the IMU has been fine aligned within the past 15 minutes. During the orbital navigation measurements, the IMU is operated in the inertial reference mode.

5-4.1 LANDMARK NAVIGATIONAL MEASUREMENT. Because of the high angular rate of landmark targets with respect to the spacecraft, the SCT, with its large field of view, is used for tracking and taking optical measurements. The chosen landmark targets are close to the orbital ground path so that a target image acquired near the horizon is tracked along a path which passes beneath the spacecraft.

The navigator applies power to the optical subsystem, selects the zero optics mode, verifies that the optics has zeroed, refers to the procedures checklist to obtain the code number for orbital navigation and enters that number into the computer DSKY. (See figure 5-5.) The OPTICS MODE switch is set to MANUAL and the TELESCOPE TRUNNION switch is set to SLAVE TO SXT. When the landmark latitude, longitude and attitude is set into the computer, the optics shaft and trunnion angles are driven to the required angles. The navigator places the optics in manual resolved mode, centers the landmark in the telescope using the optics hand controller, and presses the mark pushbutton. Three equally spaced marks are taken on each target. The computer subsystem records the optical and inertial angles and the time when the mark pushbutton is pressed. The specific code number for the landmark sighted is then entered into the computer and the optics shaft and trunnion portions of the CDU are driven to the required values.

With the inertial subsystem in the attitude control mode, the CDU provides gimbal angle changes to the computer. The computer uses the angular information to calculate the spacecraft orientation with respect to the stable member. The CDU also provides changes in the optical angles defining landmark direction with respect to the spacecraft. The computer uses the CDU inputs to calculate the landmark direction relative to the stable member.

Resultant position and velocity data is sent to MSFN by downlink telemetry and is checked for accuracy by comparison with ground calculations.

5-4.2 STAR HORIZON NAVIGATIONAL MEASUREMENT. The SXT is used to measure the angle between an earth landmark or horizon and a target star.

To perform a star horizon navigational measurement, the navigator selects the computer program, zeros the optics and optics channels of the CDU, and selects a target star. The target must be a rising star on a bright horizon with less than 57° azimuth relative to the orbital plane of the spacecraft. After the SLAVE TO SXT mode is entered and the star acquired in the SCT, the navigator verifies that the target star is in the SXT field of view by observing the star image on the calibrated shaft axis crosshair.

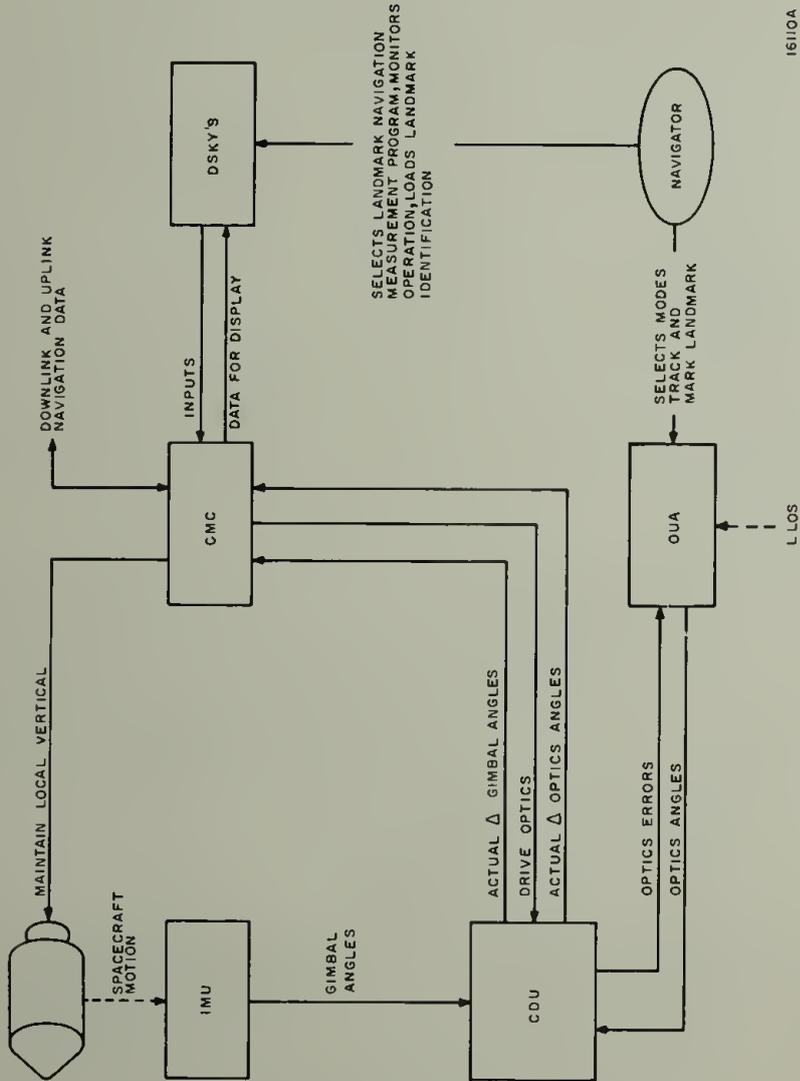


Figure 5-5. Orbital Navigation

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

The command module rolls approximately 75° to point the LLOS toward a bright portion of the earth's horizon. After the astronaut has acquired the horizon in the SXT, and has centered the star and horizon in the SXT field of view, the mark pushbutton is pressed to send the optics angles to the computer.

The inertial subsystem operates in the attitude control mode with the CDU providing gimbal angles to the computer. The optical subsystem is operated in the zero optics, manual, and computer modes with the optical portion of the CDU providing shaft and trunnion angles to the computer. The MARK commands are provided to the computer. The computer uses the CDU inputs to calculate the landmark direction relative to the stable member. MSFN receives the positional data at the time the MARK occurs through the downlink telemetry. The values are verified by ground computers and relayed back to the navigator.

5-5 IN-FLIGHT IMU ALIGNMENT

In-flight IMU alignment consists of using optical sightings to align the stable member to an inertial frame of reference. The CMC has geocentric coordinates of 28 stars stored in its fixed memory. The catalog of stars is used as the primary reference for alignment and navigational measurements. The IMU requires alignment each time the inertial subsystem is energized or after prolonged operation. As a general rule, the IMU will be aligned just prior to applying thrust to the spacecraft, prior to making orbital navigation sightings, and when the PGNCS is used for spacecraft attitude control. During the alignment process, the navigator is at the navigation station (lower D and C panel).

Basically the alignment procedure consists of two steps, coarse and fine alignment. In the coarse align mode, the stable member is approximately positioned to the desired orientation. In the fine align mode, the stable member is precisely aligned with respect to the inertial frame. Either an in-flight initial alignment or an update alignment may be required. If the inertial subsystem is in the standby mode, an initial alignment is performed and the subsystem is cycled through the IMU turn on, coarse align, and fine align modes. If the IMU has been aligned but has not been recently realigned, an update alignment may be required. The update alignment requires only the precise orientation of the fine align mode.

To accomplish alignment of the IMU, the navigator selects the required computer program (initial or update IMU alignment) and the target stars. (See figure 5-6.) With the initial alignment program selected, the IMU gimbal angles are set to zero and the spacecraft is maneuvered for coarse align sightings on two target stars. The navigator centers each star on the SCT optical field of view, operating the optics in the zero optics and manual modes, and initiates a MARK command. After each sighting, a star code number is entered into the computer. The CMC records the optics angles and the time and uses the recorded data to calculate the coarse align stable member orientation. After the computer has coarse aligned the stable member through the CDU, it maneuvers the spacecraft to obtain the fine align stars. With the optical subsystem in the computer mode, the optical portion of the CDU receives shaft and trunnion angle commands from the computer to point the SXT S_iLLOS toward the target star for the

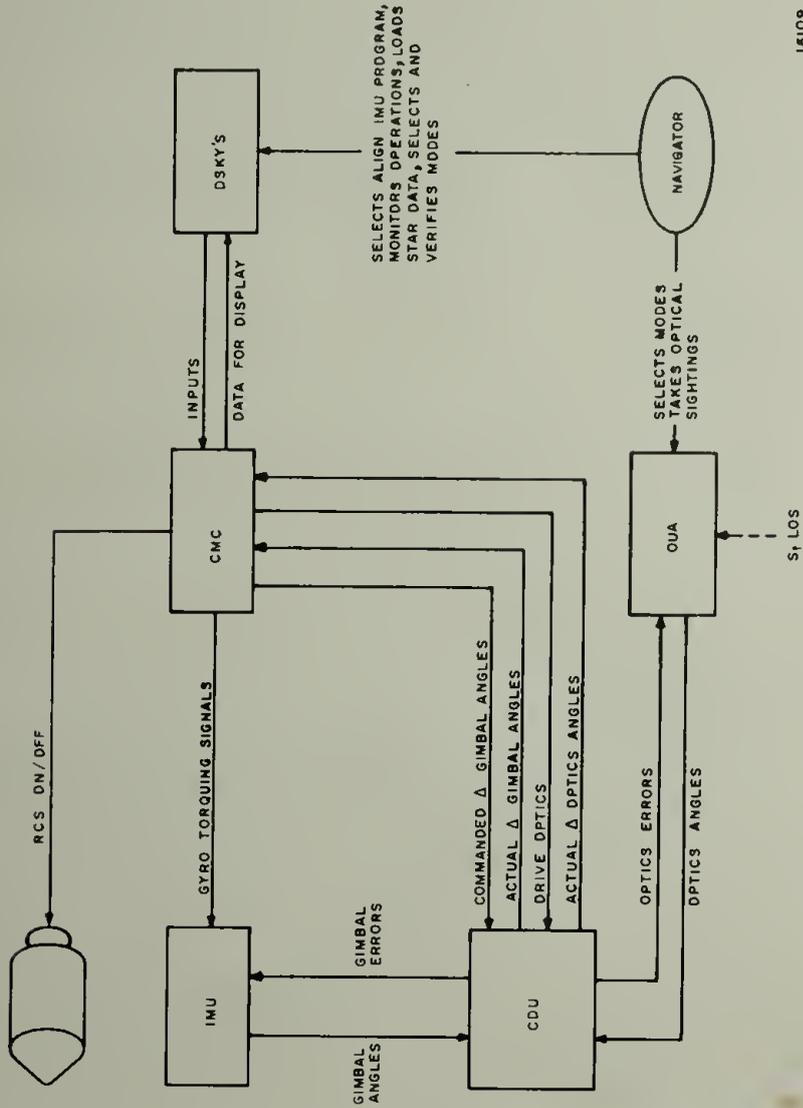


Figure 5-6. In-Flight IMU Alignment

fine alignment measurements. The two fine align stars are separately acquired in the center of the SXT field of view and a MARK command is initiated after each star is centered. Using the measured optical angles, the fine align star components are transformed into stable member axes by CMC programs. The existing stable member orientation is compared to the desired stable member orientation to determine the alignment requirements and the stable member is then torqued into position. A final check of the alignment can be performed by sighting on two additional stars.

If an update alignment is performed, the required computer program is selected and the spacecraft maneuvered into position for taking fine align sightings. Upon completion of sightings, the stable member is torqued into position.

5-6 MIDCOURSE NAVIGATION

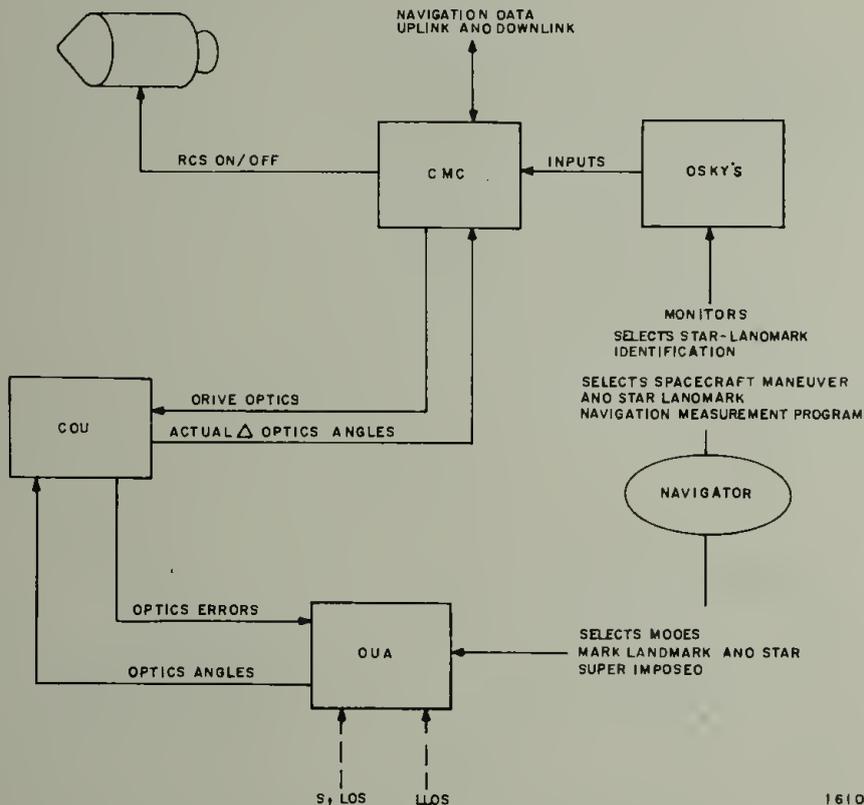
A midcourse navigation measurement is accomplished by using the SCT for coarse acquisition and the SXT for final measurement of an angle between a star and a well defined landmark.

The catalog of 28 star coordinates stored in the CMC fixed memory is used as the primary reference for navigational measurements. The stars are selected for uniform distribution on the celestial sphere so that for a random optical shaft axis direction a reference star is not more than 31 degrees away. Brightness and compatibility with midcourse navigation are also factors in star selection.

The landmarks are outstanding geographic locations on the surface of the earth or moon. The earth landmarks used are selected points of demarkation between land and water that are clear of cloud cover during the mission. When the optical angle is obtained a MARK command is sent to the computer by the navigator.

The MARK command sends the angle between the S_t LOS and LLOS and time of measurement to the CMC. (See figure 5-7.) The recorded data defines a cone in space with the apex at the landmark. (See figure 5-8.) The size of the cone is dependent on the measured angle which is equal to one-half the cone angle. The cone axis is parallel to the S_t LOS. For any arbitrary point on the surface of the cone, the angle between the landmark and star is the same. Therefore, one sighting defines the spacecraft position somewhere on the surface of the cone. The point on the cone surface nearest the present estimated position becomes an improved estimate of position at the time of the sighting.

Since the spacecraft moves in accordance with dynamic laws, departure from a computed trajectory is sufficiently small to permit linear reduction of the navigation problem by a running fix technique. This technique avoids dependence on a preprogrammed trajectory. It consists of improving or updating the velocity and position



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Figure 5-7. Midcourse Navigation

information with each succeeding optical measurement. At the time of translunar injection, the CMC contains an indication of velocity and position, which has been calculated from the inertial subsystem velocity measurements, and data on gravitational fields. Solving the equations of motion, the projected position data is obtained by extrapolation and an estimated trajectory is established. Whenever a navigational measurement is taken, the velocity and position information is used in conjunction with the landmark and star coordinates to predict or estimate the angle that should be measured. If the current estimates of position and velocity are correct and there is no instrument error, the measured angle is equal to the predicted angle. If the measured and predicted angles are not equal, the difference is used to update the estimated velocity and position. The CMC calculates the new estimate and verifies its calculation with MSFN.

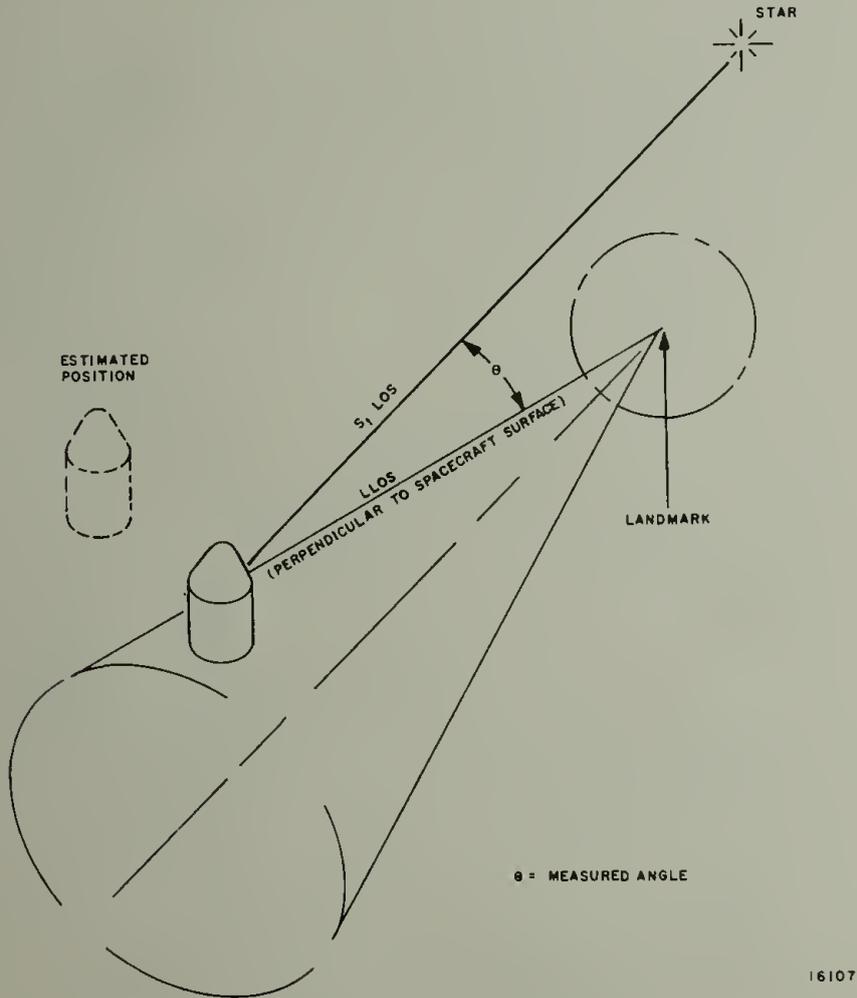


Figure 5-8. Midcourse Position Determination

The process of taking navigation measurements and converting to linear terms around the present best estimate is performed throughout the midcourse flight. The velocity and position data determines whether a velocity correction is required to maintain a satisfactory trajectory.

5-7 MIDCOURSE CORRECTION AND THRUST VECTOR CONTROL

During the Apollo flight thrust maneuvers such as translunar injection, lunar orbit injection, transearth injection and midcourse corrections are performed. All the maneuvers performed during these phases result in plane and/or orbital changes.

The purpose of midcourse correction is to change spacecraft velocity during the transearth and translunar portions of the flight and to monitor the thrusting to determine the resultant trajectory parameters. Midcourse corrections are accomplished after midcourse navigation has determined that velocity corrections are needed.

The purpose of a thrust maneuver is to change the velocity and position of the spacecraft, such that, the free-fall trajectory will carry the spacecraft to a required aim point. The thrust is provided by the SPS engine.

Prior to a midcourse correction or thrust vector control maneuver, the IMU will be aligned with respect to an inertial frame with the X PIPA input axis along the desired thrust vector. (See figure 5-9.) The spacecraft center of gravity is determined. The computer positions the SPS engine through error signals developed in the optics portion of the CDU. After an ullage maneuver, the computer issues on-off discretes to the SPS engine. (For small midcourse corrections, the astronaut makes translation maneuvers using the RCS.)

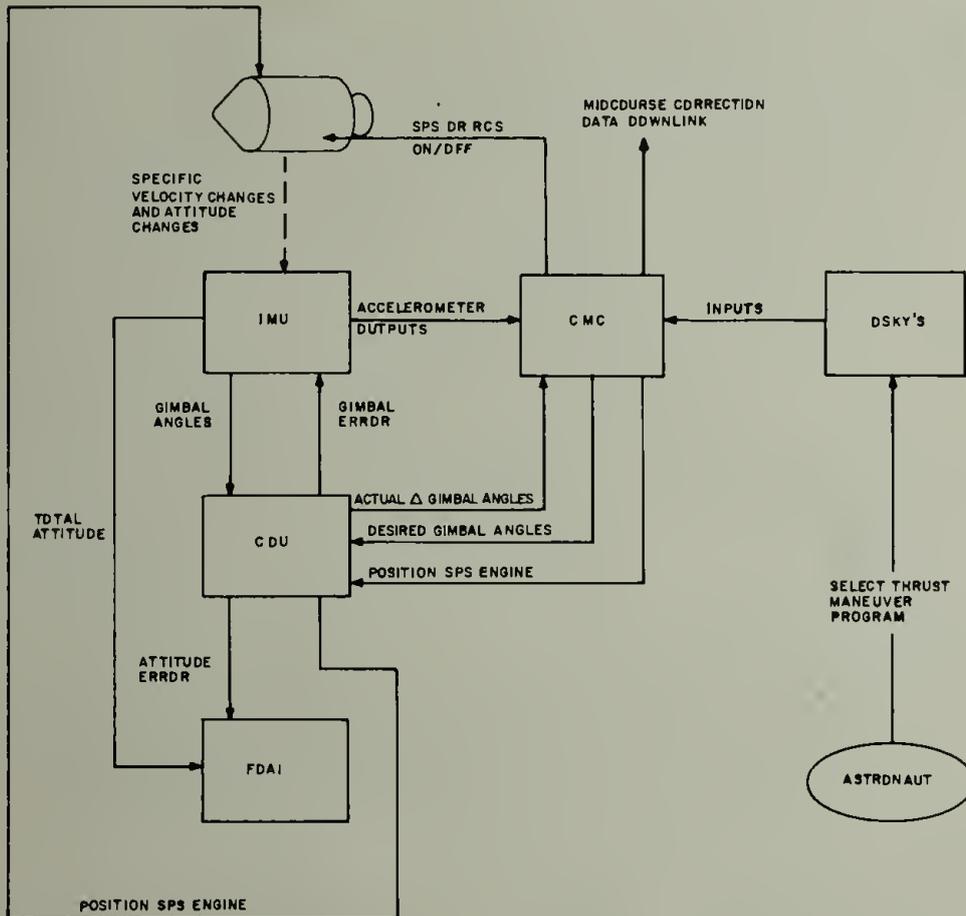
A thrust is applied to the spacecraft, the accelerometer loops provide changes in velocity and the CDU provides attitude change data to the computer. The computer uses this data to determine the spacecraft's changing position, velocity, and attitude.

Velocity to be gained is displayed on the computer DSKY. Attitude error signals and total attitude is displayed by the FDAI. Upon completion of the maneuver, velocity and positional data is displayed and checked with MSFN.

5-8 ATTITUDE CONTROL

The attitude of the spacecraft is changed frequently during the flight for the following reasons:

- (1) To direct antennas for communications.
- (2) To change orientation with respect to the sun for thermal controls.
- (3) To observe celestial bodies.
- (4) To align the spacecraft in preparation for a velocity correction.



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Figure 5-9. Midcourse Correction and Thrust Vector Control

The PGNCS can generate spacecraft attitude control signals by three methods:

- (1) Automatic computer control.
- (2) Rotation control (computer aided manual control).
- (3) Minimum impulse controller (computer aided manual control).

Computer control (see figure 5-10) is used in orienting the spacecraft to a given star field or alignment for thrusting. The astronaut uses the SC CONT switch along with the rotation control to position the spacecraft. The three position switch selects the means of controlling spacecraft attitude after the rotation control is released. The attitude can be either held at a position selected by the astronaut, allowed to drift or be controlled by the computer. The minimum impulse is used when taking optical sightings to make small changes in the spacecraft rotational rate.

The inertial and computer subsystems are used in the attitude control function. The CDU is pulsed by the computer to change the gimbal angles. Attitude error and IMU gimbal angles are displayed on the FDAI. The CMC uses the attitude error signals to determine the need for commanding RCS on-off discretetes.

5-9 ENTRY

The entry attitude of the command module has certain aerodynamic characteristics associated with it as it enters and travels in the earth's atmosphere. These aerodynamic characteristics develop lift and drag vectors that oppose the acceleration vector and affect the trajectory of the command module. (See figure 5-11.) The PGNCS attitude control mode is used during the entry function to control the lift to drag ratio.

Prior to entry, the CMC entry program is selected, the service module is jettisoned and the command module is oriented to the entry attitude. The computer receives pre-calculated lift and drag ratios from ground control and provides a signal representing desired roll angles to the outer gimbal CDU. This signal is compared with the actual roll angle signal from the IMU, and the difference error signal is applied to the RCS roll jets on the command module. The module rolls about the entry roll axis, varying the lift-drag ratio and thereby maintaining the module on the proper trajectory. The stabilization loop senses spacecraft rotation and cancels the difference error signal when the proper angle is reached.

To keep the command module in the entry "corridor" (difference between under-shoot or g-limit condition and overshoot or skip-out condition), the CMC uses velocity increments from the accelerometers and attitude inputs from the CDU to compute steering commands. The steering commands are used to fire roll reaction control jets on the command module.

Upon entry into the atmosphere (.05 g indication on main D and C panel), the astronaut starts the elapsed time event time clock. During the entry phase, the astronaut monitors the attitude indicator, entry monitor display, and DSKY to assure proper attitude, velocity, and roll control. This procedure is followed until the Earth Landing System parachutes are deployed.

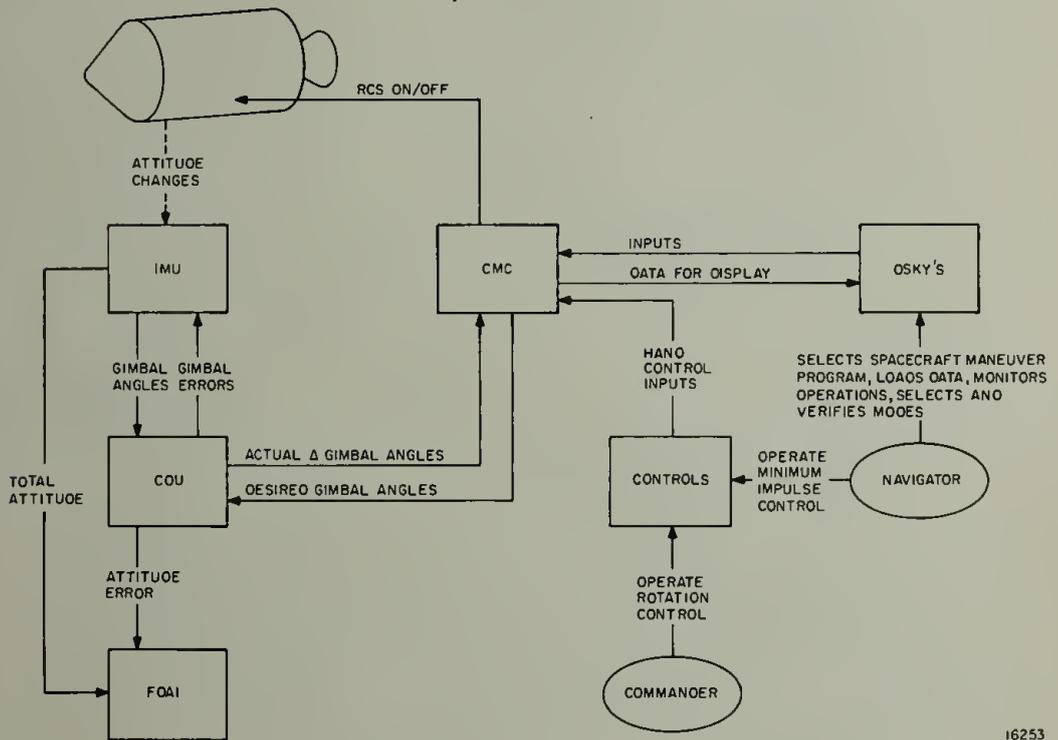
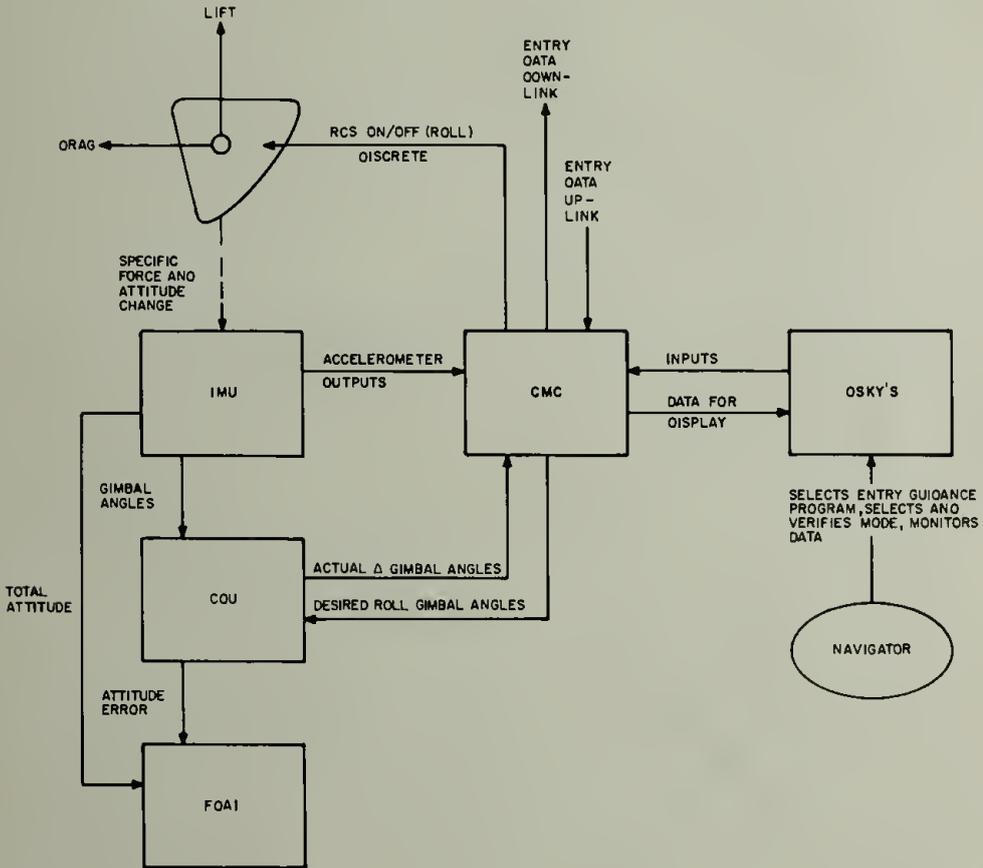


Figure 5-10. Attitude Control

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Figure 5-11. Entry

Chapter 6

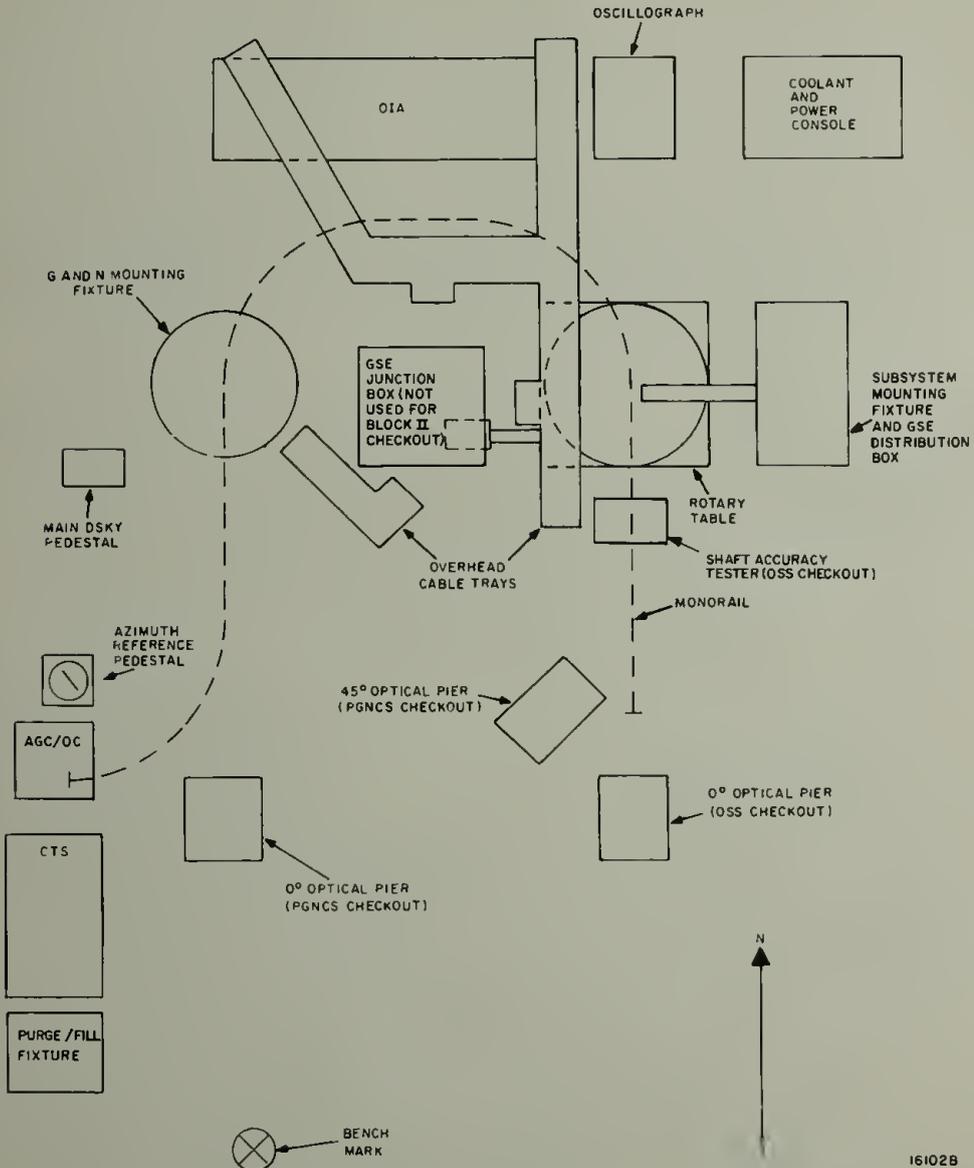
CHECKOUT AND MAINTENANCE EQUIPMENT

6-1 SCOPE

This chapter contains a list of test equipment and tools necessary to complete checkout of the Block II PGNCSS and the PGNCSS subsystems. The test equipment is listed in alphabetical order in table 6-I. The tools are listed in alphabetical order in table 6-II. Table 6-III lists the job description cards (JDC's) which contain operation and front-panel calibration procedures for the ground support equipment (GSE). The layout of equipment in test stations at Kennedy Space Center (KSC), the Manned Spacecraft Center (MSC), and North American Aviation (NAA) is shown in figures 6-1, 6-2, and 6-3, respectively. The test stations are environmentally controlled and provide precision checkout of the PGNCSS and the PGNCSS subsystems. Each test station contains the test equipment required to check out the PGNCSS and the PGNCSS subsystems except for the following test equipment.

- a. AGC/CTS operations console*
- b. Azimuth reference prism*
- c. Degausser assembly*
- d. Purge/fill fixture*

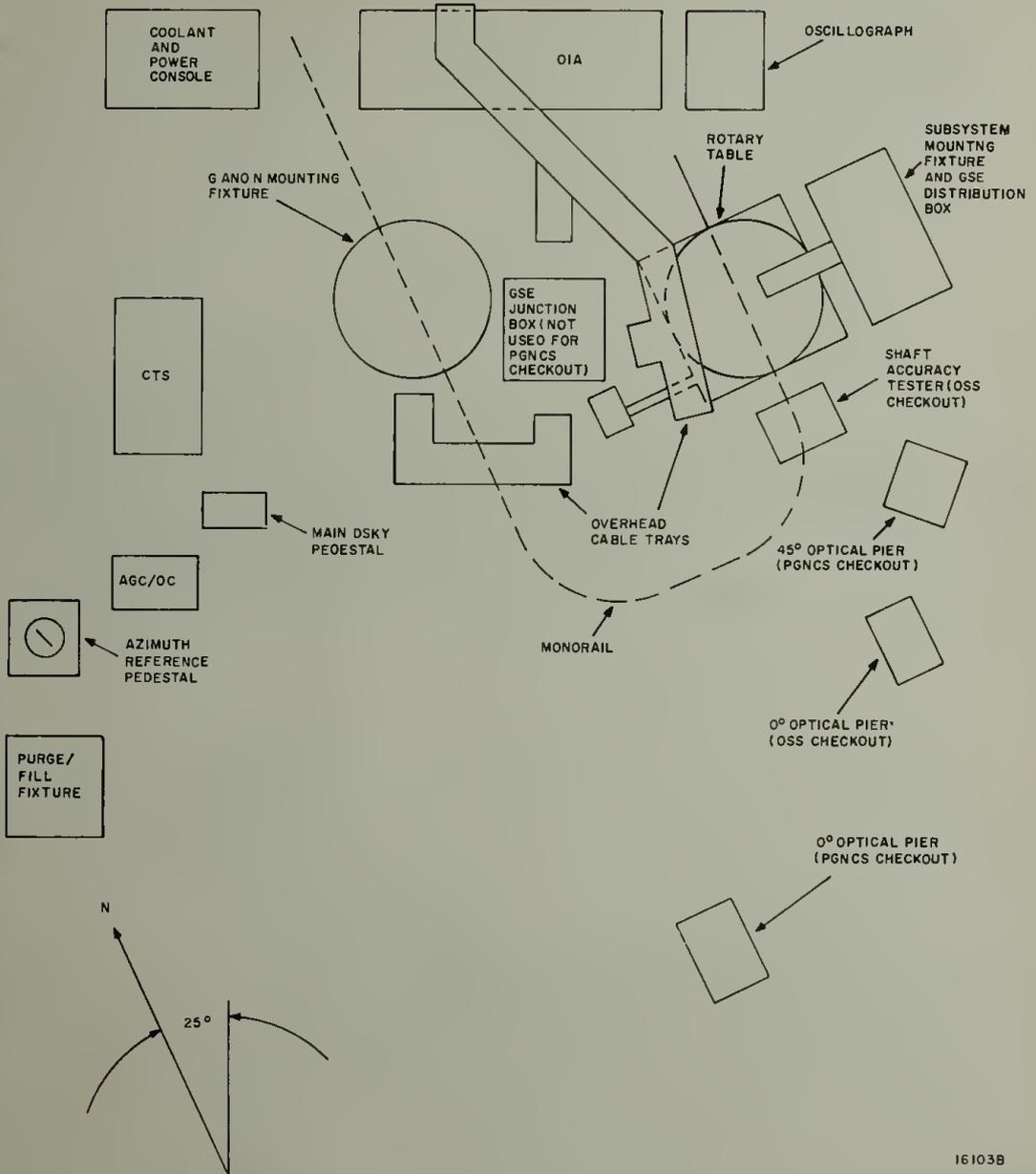
* One provided for each field site.



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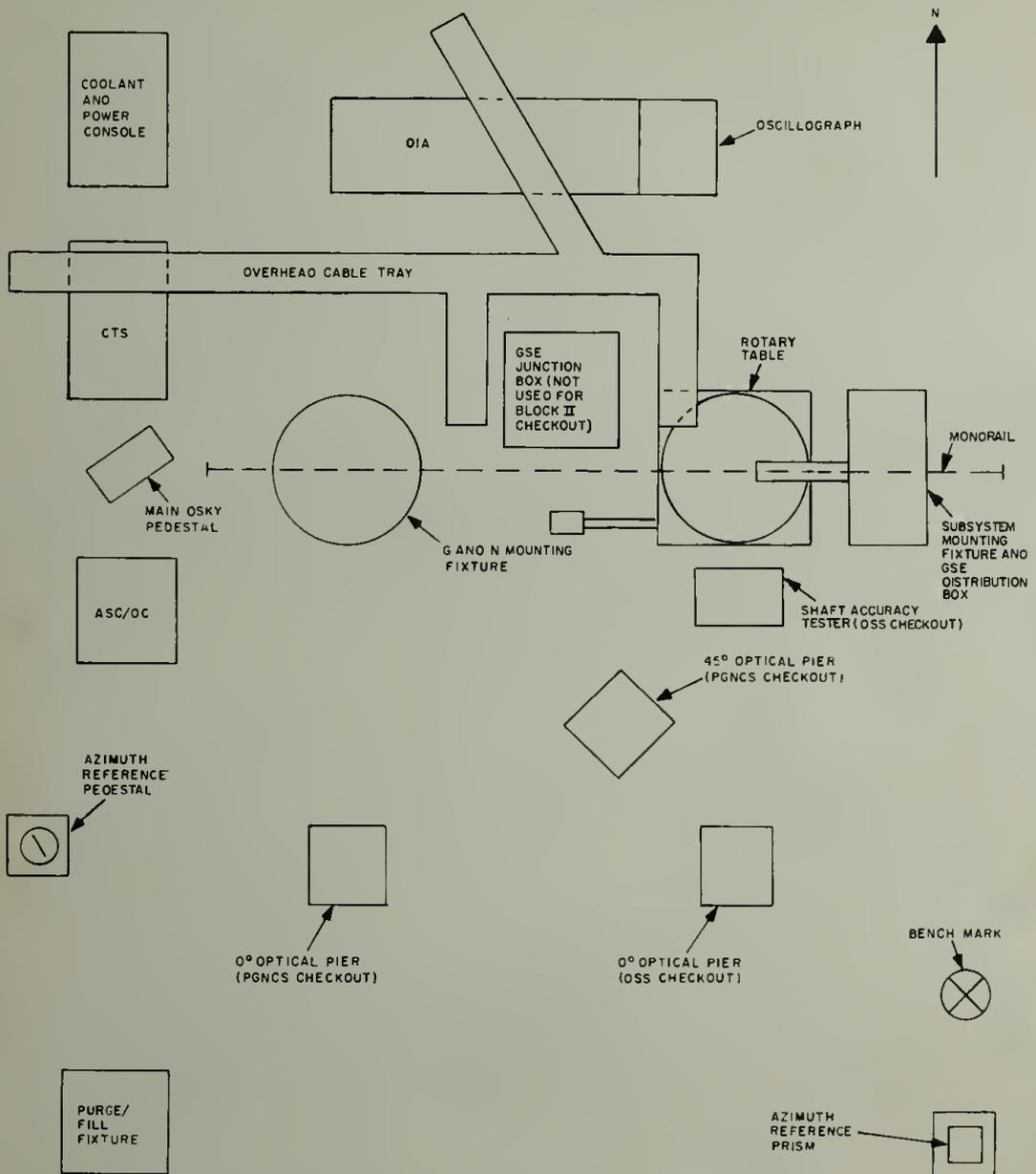
Figure 6-1. Universal Test Station Layout (KSC)

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Figure 6-2. Universal Test Station Layout (MSC)



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Figure 6-3. Universal Test Station Layout (NAA)

Table 6-I. Checkout and Maintenance Test Equipment

Equipment and Part Number	Short Nomenclature	Description and Use
Adjustable Mirror and Pedestal Assembly, 1019759	adjustable mirror	Serves as alignment reference device when aligning autocollimator assemblies during PGNCS checkout
AGC/CTS Operation Console, 2014024	AGC/OC	Provides mounting, power, test connections, and cooling for CSS
AGC GSE Interconnect Kit, G and N, 2014255-011	interconnect kit, CMC-GSE-PGNCS	Provides cables and buffer circuit assembly for interconnecting CMC to GSE and PGNCS
AGC GSE Interconnect Kit, Subsystem, 2014268-011	interconnect kit, CMC-GSE-CSS	Provides cables and mounting bracket for interconnecting CMC to GSE and CTS
AGC Handling Fixture, 2014282-011	CMC handling fixture	Provides mounting and protection for CMC prior to installation and during handling
AGC Test Set, 2014042	CTS	Checks operation of CSS
AGC Universal DSKY Handling Fixture, 2014013-011	DSKY handling fixture	Provides mounting and protection for DSKY during handling and transit. Provides mounting for DSKY in AGC/OC
Auxiliary Calibration System Console, 2014059	auxiliary calibration console	Checks calibration of the CMC clock oscillator
Cable Breakout Adapter Set, 2901011-011	cable breakout adapter	Provides capability for continuity checks and signal monitoring PGNCS interconnect harness group
CMC Connector Covers	CMC connector covers	Provides protection for CMC and DSKY electrical connectors during transit or storage

(Sheet 1 of 6)

Table 6-I. Checkout and Maintenance Test Equipment

Equipment and Part Number	Short Nomenclature	Description and Use
Component Mounting Plate, 2900677-011	component mounting plate	Used with subsystem mounting fixture; provides mounting for selected PGNCS component during PGNCS, ISS, and OSS checkout
Computer Calibration System Console, 2014049	computer calibration console	Checks calibration of the CMC clock oscillator and provides frequency reference to auxiliary calibration system
Computer Simulator, 2014048	computer simulator	Simulates CMC signals, loads, and outputs for ISS and CSS checkout
Degausser Assembly, 1900299-021	degausser	Demagnetizes ducosyns of the 16 PIP's and 25 IRIG's during ISS and PGNCS checkout
DSKY Mounting Stand, 2014014-011	DSKY mounting stand	Provides mounting for main panel DSKY during PGNCS checkout
Electronic Level, 1901328	electronic level	Used to align adjustable mirror and shaft accuracy tester rotary table
G and N Coolant and Power Console, 1902134-021	coolant and power console	Part of OITS. Provides cooling, power, and precision voltage monitoring during PGNCS, ISS, or OSS checkout
G and N Mounting Fixture, 2900067-011	G and N mounting fixture	Serves as mounting fixture for selected PGNCS components for PGNCS, ISS, and OSS checkout
G and N Transportation Cart Assembly, 1900009-031	G and N transportation cart	Used for local transportation of PGNCS components

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BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

Table 6-I. Checkout and Maintenance Test Equipment

Equipment and Part Number	Short Nomenclature	Description and Use
GSE Coolant Interconnect Hose Set, 2900405	GSE coolant hoses	Connects PGNCs components to coolant and power console
GSE Distribution Box, 2900024-011	GSE distribution box	Part of OITS. Provides test interconnection for use during PGNCs, ISS, and OSS checkout
GSE P&M Cable Kit, 2014064-011	P&M cables	Interconnects CTS to buffer circuit assembly
IMU Mounting Fixture Assembly, 2900000-011	IMU mounting fixture	Mounts IMU to rotary table for ISS checkout
IMU Pressure Seal Tester Assembly, 1900804-011	IMU pressure seal tester	Checks for leakage of pressure seals in IMU case during PGNCs checkout
IMU Snap-on Bellows Assembly, 1900802-011	IMU snap-on bellows	Allows for expansion of coolant in IMU during storage
Interconnect Cable Set, 2900025-011	interconnect cables	Part of OITS. Interconnects GSE and PGNCs components during PGNCs, ISS, and OSS checkout
Interconnect Cable Set, 2900712-011	interconnect cables	Interconnects GSE and PGNCs components during PGNCs, ISS, and OSS checkout.
ISS Connector Covers, 2900065-011	ISS connector covers	Provides protection for indicator control panel, PEA, signal conditioner, and PGNCs interconnect cables electrical connectors during transit or storage
Optics Connector Covers, 1022970-011	optics connector covers	Provides protection for OUA electrical connectors during transit or storage

(Sheet 3 of 6)

Table 6-I. Checkout and Maintenance Test Equipment

Equipment and Part Number	Short Nomenclature	Description and Use
Optics Covers, 1022880	optics covers	Provides protection for SXT and SCT during transit and storage
Optics Inertial Analyzer, 2900023-011	OIA	Part of OITS. Provides control signals and monitoring and measurement facilities for use during PGNCS, ISS, and OSS checkout
Optics Inertial Test Set, 2900022-011	OITS	Provides control signals and monitoring and measurement facilities for use during PGNCS, ISS, and OSS checkout
Optics/Nav Base Mounting Fixture, 2900072-011	optics/nav base mounting fixture	Provides mounting for optical unit on rotary table during OSS checkout
Oscillograph Console Assembly, 1900000-021	oscillograph	Part of OITS. Monitors and records signals from OIA
Portable Light Assembly, 1019837	portable light assembly	Illuminates SXT and SCT reticle during OSS checkout
Portable Temperature Controller, 2900060-011	PTC	Provides IMU temperature control during local transportation and storage
PSA Test Point Adapter, 2900037-011	PSA test point adapter	Part of OITS. Provides test interconnections for use with OIA
PTA/PEA Mounting Fixture, 2900066-011	PEA mounting fixture	Provides mounting for PEA on rotary table during ISS checkout and on G and N mounting fixture during PGNCS checkout
PTA/PEA Test Point Adapter, 2900145-011	PEA test point adapter	Provides test interconnections for use with OIA

(Sheet 4 of 6)

Table 6-I. Checkout and Maintenance Test Equipment

Equipment and Part Number	Short Nomenclature	Description and Use
Purge/Fill Fixture, 1902371-011	purge/fill fixture	Purges and fills all components requiring coolant
Remote Optics Controller Assembly, 1902046-021	remote optics controller	Positions optical unit during OSS checkout
Resolver Circuit Tester, 2900708	resolver circuit tester	Provides simulated loads for IMU and OUA resolvers during PGNCSS, OSS, and ISS checkout
Retroreflecting Prism Assembly, 1019840	retroreflecting prism	Used in aligning OSS targets and checking SCT shaft accuracy
Rotary Table Calibration Set, 1900810-011	rotary table calibration set	Contains all equipment necessary to perform rotary table calibration
Shaft Accuracy Tester, 1019769	shaft accuracy tester	Checks accuracy of SXT shaft during OSS checkout
Subsystem Mounting Fixture, 2900070-011	subsystem mounting fixture	Provides mounting for selected PGNCSS components during PGNCSS, ISS, and OSS checkout
Theodolite and Support Assembly, 1017447	theodolite	Aligns 0° autocollimator assembly and 45° autocollimator assembly
Ultra Precision Rotary Table Assembly, 1900926-021	rotary table	Serves as mounting and test platform for selected PGNCSS components during ISS and OSS checkout
Variable Deviation Wedge, 1017376	variable deviation wedge	Checks optical alignment and accuracy during PGNCSS checkout

(Sheet 5 of 6)

Table 6-I. Checkout and Maintenance Test Equipment

Equipment and Part Number	Short Nomenclature	Description and Use
Vertical Leveling Mirror, 1017445	vertical leveling mirror	Checks optical target alignment during PGNCs and OSS checkout
0° Autocollimator Plate Assembly, 1017380	0° autocollimator assembly	Checks optical alignment and accuracy during PGNCs and OSS checkout
45° Autocollimator Plate Assembly, 1017381	45° autocollimator assembly	Checks optical alignment and accuracy during PGNCs checkout

(Sheet 6 of 6)

Table 6-II. Checkout and Maintenance Tools

Equipment	Short Nomenclature	Description and Use
AGC sling; MY-4, Abbot Jordan Hoist Co., Brighton, Mass.	computer sling	Connects lifting hoists to CMC when transporting the CMC outside the CMC shipping container
Allen adapter; 5/32 inch, JO Line, or equivalent	allen adapter	Adapts the torque wrench to the CMC module inserts
Torque wrench; 17 inch-pound, JO Line, or equivalent	torque wrench	Torques CMC modules onto CMC trays
IMU lift and handling fixture, part number 1015462-011	IMU lift and handling fixture	Connects lifting hoist to the IMU or the IMU mounting fixture to position and remove IMU or the IMU mounting fixture from rotary table during ISS or PGNCs checkout
Tool kit	tool kit	Contains general usage tools required to support maintenance activities in G and N laboratory and stockroom

Table 6-III. List of Operating Procedure JDC's for GSE

Equipment	JDC Number	JDC Description
Auxiliary input panel	18204	Operating the primary signal selector panel, auxiliary input panel, PSA test point adapter, and PTA/PEA test point adapter to apply auxiliary signals to the dual beam oscilloscope.
Counter (OIA)	18017	Operating the counter as a forward or reverse counter.
Counter (OIA)	18018	Operating the counter to count the number of input events that occur during any preselected time interval.
Counter (OIA)	18019	Operating the counter to count the number of input events that occur during interval determined by "D" input events.
Counter (OIA)	18020	Operating the counter to count the clock frequency pulses that occur during interval determined by "D" input events.
Counter (OIA)	18021	Test operation of N_1 switches, time base circuitry, and count-chain circuitry (counter operation).
Counter (OIA)	18022	Test operation of N_2 switch (counter operation).
Counter-timer (CTS)	05401	Operating the counter-timer to measure frequency.
Counter-timer (CTS)	05402	Operating the counter-timer to count the number of pulses during a time interval.
Counter-timer (CTS)	05403	Operating the counter-timer to measure the period between leading edges of pulses.
Counter-timer (CTS)	05404	Operating the counter-timer to measure the time between pulses using the internal frequency standard.
Digital recorder	18043	Operating and interpreting the digital recorder.

Table 6-III. List of Operating Procedure JDC's for GSE

Equipment	JDC Number	JDC Description
Digital voltmeter	18035	Operating the digital voltmeter to measure a dc voltage.
Digital voltmeter	18036	Operating the digital voltmeter to measure an ac voltage.
Digital voltmeter	18037	Operating the digital voltmeter to automatically measure an ac or dc voltage.
Dual beam oscilloscope	18005	Operating the dual beam oscilloscope, scope A, upper beam differential amplifier, and primary signal selector panel to measure voltages.
Dual beam oscilloscope	18006	Operating the dual beam oscilloscope upper beam differential amplifier to measure phase shift.
Dual beam oscilloscope	18007	Operating the dual beam oscilloscope to make time measurements.
Dual beam oscilloscope	18008	Operating the dual beam oscilloscope to make frequency measurements.
Dual beam oscilloscope	18009	Operating the dual beam oscilloscope, scope B, channel 1, to monitor pulses.
Dual beam oscilloscope	18010	Application of two signals simultaneously to the dual beam oscilloscope, scope B.
Dual beam oscilloscope	18011	Application of an oscillograph signal to the dual beam oscilloscope, scope B, channel 2.
Electronic counter (auxiliary calibration console)	05400	Operating the counter to measure frequency.
Galvanometer and current source monitor panel	18216	Operating the galvanometer and current source monitor panel to measure voltages.

(Sheet 2 of 4)

Table 6-III. List of Operating Procedure JDC's for GSE

Equipment	JDC Number	JDC Description
G and N coolant and power console	18046	Operating and interconnecting the G and N coolant and power console for PGNCS, ISS, and OSS testing.
Gimbal position control panel	18244	Operating the gimbal position control panel.
Oscillograph console	18023	Operating the oscillograph (electric writing).
Oscillograph console	18024	Operating the oscillograph (ink writing).
Oscillograph console	18025	Adjustment of oscillograph console dc amplifiers.
Oscillograph console	18026	Operating the oscillograph console dc amplifiers.
Oscillograph console	18027	Adjustment of oscillograph console phase sensitive demodulators (800 cps reference).
Oscillograph console	18028	Adjustment of oscillograph console phase sensitive demodulators (3200 cps reference).
Oscillograph console	18031	Operating the oscillograph console phase sensitive demodulators.
Oscillograph console	18032	Installation of new ink cartridge in oscillograph console.
Oscillograph console	18033	Installation of new ink pen in oscillograph console.
Oscillograph console	18034	Installation of new paper in oscillograph console.
Oscilloscope (CTS)	05405	Operating the oscilloscope to measure pulse characteristics.

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Table 6-III. List of Operating Procedure JDC's for GSE

Equipment	JDC Number	JDC Description
Phase angle voltmeter	18038	Operating the phase angle voltmeter to measure total rms voltage.
Phase angle voltmeter	18039	Operating the phase angle voltmeter to measure a fundamental rms voltage.
Phase angle voltmeter	18040	Operating the phase angle voltmeter to measure a phase angle.
Phase angle voltmeter	18041	Operating the phase angle voltmeter to measure in-phase and quadrature components.
Phase angle voltmeter	18042	Operating the phase angle voltmeter to indicate a phase sensitive null.
Portable temperature controller	18249	Operating the PTC to provide heat to the IMU.
Primary signal selector panel	18000	Operating the primary signal selector panel to apply internal signals to the digital voltmeter, phase angle voltmeter, and dual beam oscilloscope.
Primary signal selector panel	18001	Operating the primary signal selector panel to apply reference signals to the dual beam oscilloscope.
Primary signal selector panel	18002	Operating the primary signal selector panel to apply PSA test point adapter test point signals to the digital voltmeter, phase angle voltmeter, and dual beam oscilloscope.
Primary signal selector panel	18202	Operating the primary signal selector panel to apply PTA/PEA test point adapter test point signals to the digital voltmeter, phase angle voltmeter, and dual beam oscilloscope.
Primary signal selector panel	18003	Operating the primary signal selector panel to apply auxiliary signals to the digital voltmeter, phase angle voltmeter, dual beam oscilloscope, and counter via the auxiliary input panel.
Purge/fill fixture	18045	Operating the purge/fill fixture to purge and fill PGNCS components.

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Chapter 7

CHECKOUT

7-1 SCOPE

This chapter contains flowgrams which outline checkout procedures for the PGNCS and the PGNCS subsystems. Checkout is performed in the G and N laboratories of KSC, MSC, and NAA. A master flowgram for the PGNCS and one for each of the PGNCS subsystems precedes more detailed preparation and checkout flowgrams. Each master flowgram references the detailed flowgrams which in turn reference the JDC's required to fulfill the checkout function.

Information regarding packing, shipping, and handling of any component of the PGNCS will be found in Packing, Shipping, and Handling Manual, ND-1021038.

7-2 PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

7-2.1 PREPARATION. The PGNCS master flowgram (figure 7-1) specifies the conditions leading to a PGNCS checkout and specifies the mandatory sequence to be followed. Prepare the PGNCS for checkout in accordance with figure 7-2 which gives the sequential listing of JDC's to be performed. Table 7-I lists PGNCS components and the GSE required for a PGNCS checkout. Tables 7-II, 7-III, and 7-IV list the interconnect cabling required for a PGNCS checkout.

7-2.2 CHECKOUT. Check out the PGNCS in accordance with figure 7-3 which gives the sequential listing of JDC's to be performed. Upon completion of checkout and necessary maintenance, prepare the PGNCS for storage, shipment, or subsystem checkout in accordance with figure 7-1.

7-2.3 TEST DESCRIPTIONS. This paragraph will provide a description of tests performed during PGNCS checkout. Information will be provided when available.

7-3 INERTIAL SUBSYSTEM

7-3.1 PREPARATION. The ISS master flowgram (figure 7-4) specifies the conditions leading to an ISS checkout and specifies the mandatory sequence to be followed. Prepare the ISS for checkout in accordance with figure 7-5 which gives the sequential listing of JDC's to be performed. Table 7-I lists PGNCS components and the GSE required for an ISS checkout. Table 7-V lists the interconnect cabling required for an ISS checkout.

7-3.2 CHECKOUT. Check out the ISS in accordance with figure 7-6 which gives the sequential listing of JDC's to be performed. Upon completion of checkout and necessary maintenance, prepare the ISS for shipment or PGNCS checkout in accordance with figure 7-4.

7-4 OPTICAL SUBSYSTEM

7-4.1 PREPARATION. The OSS master flowgram (figure 7-7) specifies the conditions leading to an OSS checkout and specifies the mandatory sequence to be followed. Prepare the OSS for checkout in accordance with figure 7-8 which gives the sequential listing of JDC's to be performed. Table 7-I lists PGNCS components and the GSE required for an OSS checkout. Table 7-VI lists the interconnect cabling required for an OSS checkout.

7-4.2 CHECKOUT. Check out the OSS in accordance with figure 7-9 which gives the sequential listing of JDC's to be performed. Upon completion of checkout and necessary maintenance, prepare the OSS for shipment or PGNCS checkout in accordance with figure 7-7.

7-5 COMPUTER SUBSYSTEM

7-5.1 PREPARATION. The CSS master flowgram (figure 7-10) specifies the conditions leading to a CSS checkout and specifies the mandatory sequence to be followed. A flowgram will be provided which will give the sequential listing of JDC's to be performed to prepare the CSS for checkout. Table 7-I lists PGNCS components and the GSE required for a CSS checkout. Table 7-VII lists the interconnect cabling required for a CSS checkout.

7-5.2 CHECKOUT. A flowgram will be provided which will give the sequential listing of JDC's to be performed for a CSS checkout. Upon completion of CSS checkout and necessary maintenance, prepare the CSS for shipment or PGNCS checkout in accordance with figure 7-10.

Table 7-I. Equipment Required for Checkout

Equipment	Part Number	Used In			
		PGNCS	ISS	OSS	CSS
<u>PGNCS COMPONENTS</u>					
CDU	2007222-011	X	X	X	
CMC	2003100-021	X			X
Indicator control panel	2014578-011	X		X	
IMU	2018601-011 or 2018601-021	X	X		
Main panel DSKY	2003985-051	X			X
Nav base	2899982-011	X			
Navigation panel DSKY	2003985-051	X			X
OUA	2011000-031	X		X	
PEA	2007201-011	X	X		
PGNCS interconnect harness group	2014567-011	X			
PSA	2007200-021	X	X	X	
Signal conditioner		X			
<u>GSE</u>					
Adjustable mirror	1019759	X			
AGC/OC	2014024-011				X
Alignment mirror	1016951-011				
Auxiliary calibration console	2014059-011				X

(Sheet 1 of 4)

Table 7-I. Equipment Required for Checkout

Equipment	Part Number	Used In			
		PGNCS	ISS	OSS	CSS
CMC handling fixture	2014282-011	X			X
Component mounting plate	2900677-011		X	X	
Computer calibration console	2014049-011				X
Computer simulator	2014048		X	X	
Coolant and power console	1902134-021	X	X	X	
CTS	2014042	X			X
Degausser	1900299-021	X	X		
DSKY handling fixture	2014013-011	X			X
DSKY mounting stand	2014014-011	X			
Electronic level	1901328			X	
G and N mounting fixture	2900067-011	X		X	
GSE coolant hoses	2900405	X	X	X	
GSE distribution box	2900024-011	X	X	X	
IMU mounting fixture	2900000-011		X		
IMU pressure seal tester	1900804-011	X	X		
Interconnect cables	2900025-011	X	X	X	
Interconnect cables	2900712-011	X	X	X	
Interconnect kit, CMC-GSE-CSS	2014268-011				X

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Table 7-I. Equipment Required for Checkout

Equipment	Part Number	Used In			
		PGNCS	ISS	OSS	CSS
Interconnect kit, CMC-GSE-PGNCS	2014255-011	X			
OIA	2900023-011	X	X	X	
Optics/nav base mounting fixture	2900072-011			X	
Oscilloscope	1900000-021	X	X	X	
P&M cables	2014064-011	X			X
PEA mounting fixture	2900066-011	X	X		
PEA test point adapter	2900145-011	X	X		
Portable light assembly	1019837			X	
PSA test point adapter	2900037-011	X	X	X	
PTC	2900060-011	X	X		
Purge/fill fixture	1902371-011	X	X	X	
Remote optics controller	1902046-021			X	
Resolver circuit tester	2900708	X	X	X	
Retroreflecting prism	1019840			X	
Rotary table	1900926-021		X	X	
Rotary table calibration set	1900810-011		X	X	
Shaft accuracy tester	1019769			X	
Subsystem mounting fixture	2900070-011		X	X	

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Table 7-I. Equipment Required for Checkout

Equipment	Part Number	Used In			
		PGNCS	ISS	OSS	CSS
Theodolite	1017447	X		X	
Variable deviation wedge	1017376	X			
Vertical leveling mirror	1017445	X		X	
0° autocollimator assembly	1017380	X		X	
45° autocollimator assembly	1017381	X			

(Sheet 4 of 4)

Table 7-II. PGNCS Interconnect Harness Group Connections (PGNCS Checkout)

PGNCS Interconnect Harness			Connects to	
Designation	Part Number	Plug	Jack	Equipment
A	2014641	P1	J1	PGNCS interconnect harness D
		P2	J2	PGNCS interconnect harness D
		P3	J3	PGNCS interconnect harness D
		P4	J4	PGNCS interconnect harness D
		P5	J5	PGNCS interconnect harness H
		P6	J9	G and N mounting fixture harness E
		P7	P3	Cable W155
		P8	P1	Cable W160
		P9		CDU
		P10		CMC
B	2014642	P13	J2	SXT
		P14	J1	SXT
		P18	J5	PSA
C	2014643	P12	J14	PEA
		P15	J2	IMU
		P16	J1	IMU
		P19	J6	PSA
D	2014644	J1	P1	PGNCS interconnect harness A
		J2	P2	PGNCS interconnect harness A
		J3	P3	PGNCS interconnect harness A
		J4	P4	PGNCS interconnect harness A
		P17	J2	G and N mounting fixture harness B
E	2014645	P24	J1	Indicator control panel
		P26	J7	PSA
F	2014646	P23	J1	SCT
		P28	J9	PSA
G	2014647	J6		Not used
		J7		Not used
		P20	J5	G and N mounting fixture harness C
		P21	J4	G and N mounting fixture harness C
		P22	J6	G and N mounting fixture harness D
		P29	J10	PSA
P32	P2	Cable W163		
H	2014648	J5	P5	PGNCS interconnect harness A
		P25	J9	Navigation panel DSKY
		P27	J8	PSA
		P30	P2	Cable W164
		P31	P3	Cable W164

Table 7-III. G and N Mounting Fixture Harness Connections (PGNCS Checkout)

G and N Mounting Fixture Harness			Connects to	
Designation	Part Number	Plug	Jack	Equipment
A	2900753	J1 P1 P2 P3 P4 P5	A1J3 J1 J1 J1 J1 J2	GSE distribution box CDU coldplate CMC coldplate IMU coolant inlet line PSA coldplate PEA coldplate
B	2900915	J2 P6	P17 J4	PGNCS interconnect harness D PSA
C	2900924	J3 J4 J5 P7 P8	P2 P21 P20 J1 J2	Cable W165 PGNCS interconnect harness G PGNCS interconnect harness G Signal conditioning module Signal conditioning module
D	2900925	J6 P9	P22 J3	PGNCS interconnect harness G Signal conditioning module
E	2900666	J7 J8 J9	P1 P1 P6	Cable W232 Cable W233 PGNCS interconnect harness A

Table 7-IV. GSE Interconnect Cable Connections (PGNCS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W1	1900886	P1 P2	J1 J1	OIA Oscillograph
W2	1900669	P1 P2	J2 J2	OIA Oscillograph
W3	1900670	P1 P2	J3 J3	OIA Oscillograph

(Sheet 1 of 6)

Table 7-IV. GSE Interconnect Cable Connections (PGNCS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W4	1900671	P1 P2	J4 J4	OIA Oscillograph
W19	1900873	P1 P2	J20 J3	OIA Coolant and power console
W22	1900959	P1 P2	J23 J5	OIA CTS
W26	1900921	P1 P2	A30J1 Facility	OIA Wall power
W27	1900871	P2 P2	A30J2 J1	OIA Coolant and power console
W28	1900872	P1 P2	J2 Facility	Coolant and power console Wall power
W33	1901404	P1 P2	E1 E4	OIA Oscillograph
W37	1901662	P1 P2	Facility E300	Facility ground Rotary table
W64	1901676	P1 P2	E1 E300	G and N mounting fixture base Rotary table
W65	1900739	P1 P2	J4 J15	Current source monitor panel PSA test point adapter
W85	1901960	P1 P2	A30J5 Facility	OIA Auxiliary wall power
W120	2900456	P1 P2	J19 J2	OIA PSA

Table 7-IV. GSE Interconnect Cable Connections (PGNCS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W121	2900257	P1	J8	OIA
		P2	J9	OIA
		P3	J13	OIA
		P4	J14	OIA
		P5	J15	OIA
		P6	J57	GSE distribution box
W122	2900378	P1	J18	OIA
		P2	J17	OIA
		P3	J16	OIA
		P4	J22	OIA
		P5	J55	GSE distribution box
		P6	J59	GSE distribution box
		P7	J62	GSE distribution box
		P8	J58	GSE distribution box
W123	2900379	P1	J21	OIA
		P2	J24	OIA
		P3	J25	OIA
		P4	J26	OIA
		P5	J60	GSE distribution box
		P6	J63	GSE distribution box
		P7	J66	GSE distribution box
		P8	J67	GSE distribution box
W124	2900380	P1	J5	OIA
		P2	J6	OIA
		P3	J7	OIA
		P4	J64	GSE distribution box
		P5	J61	GSE distribution box
		P6	J65	GSE distribution box
W125	2900186	P1	J28	OIA
		P2	J29	OIA
		P3	J30	OIA
		P4	J50	GSE distribution box
		P5	J51	GSE distribution box
		P6	J54	GSE distribution box

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BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

Table 7-IV. GSE Interconnect Cable Connections (PGNCS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W126	2900381	P1	J10	OIA
		P2	J11	OIA
		P3	J12	OIA
		P4	J52	GSE distribution box
		P5	J53	GSE distribution box
		P6	J56	GSE distribution box
W127	2900327 (2 required)		E1	OIA
			E300	Rotary table
			E1 E80	GSE distribution box OIA
W128	2900458 (2 required)		E2	GSE distribution box
			E300	Rotary table
			E1 E300	Subsystem mounting fixture Rotary table
W129	2900459		E1 E3	Subsystem mounting fixture GSE distribution box
W130	2900460		E1 E300	Coolant and power console Rotary table
W140	2900457	P1	J4	Coolant and power console
		P2	J34	GSE distribution box
W145	2900589	P1	A1J3	Temperature indicator assembly (GSE distribution box)
		P2	P1	W171
W150	2900529	P1	J2	PSA test point adapter
		P2	J3	PSA
W155	2900662	P1	J14	GSE distribution box
		P2	J19	GSE distribution box
		P3	56P7	PGNCS interconnect harness A
		P4	P5	W166

(Sheet 4 of 6)

Table 7-IV. GSE Interconnect Cable Connections (PGNCS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W159	2900675	P1 P2	J1 J15	PEA test point adapter PEA
W160	2900665	P1 P2 P3	56P8 J29 J9	PGNCS interconnect harness A GSE distribution box Main panel DSKY
W162	2900667	P1 P2	J18 J2	GSE distribution box PEA test point adapter
W163	2900668	P1 P2	J13 56P32	GSE distribution box PGNCS interconnect harness G
W164	2900669	P1 P2 P3	J33 56P30 56P31	GSE distribution box PGNCS interconnect harness H PGNCS interconnect harness H
W165	2900670	P1 P2	J26 J3	GSE distribution box G and N mounting fixture harness C
W166	2900671	P1 P2 P3 P4 P5	J24 J28 J3 J4 P4	GSE distribution box GSE distribution box PSA test point adapter PSA test point adapter W155
W167	2900672	P1 P2	J1 J1	PSA test point adapter PSA
W226	2014137-011	P1 P2 P3 P4	J4 J5 J6	AGC test connector Buffer circuit assembly Buffer circuit assembly Buffer circuit assembly
W232	2014484-011	P1 P2 P3 P4	J7 J2 J7 P6	G and N mounting fixture harness E CTS CTS W259

(Sheet 5 of 6)

Table 7-IV. GSE Interconnect Cable Connections (PGNCS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W233	2014483-011	P1	J8	G and N mounting fixture harness E CTS CTS CTS
		P2	J16	
		P3	J10	
		P4	J4	
W236	2014463-011	P1	J1	Buffer circuit assembly CTS
		P2	J5	
W237	2014462-011	P1	J2	Buffer circuit assembly CTS
		P2	J11	
W238	2014462-021	P1	J3	Buffer circuit assembly CTS
		P2	J17	
W239	2014462-031	P1	J9	Buffer circuit assembly CTS
		P2	J18	
W259	2014470-011	P1	CP1	AGC calibration system Digital ohmmeter Digital ohmmeter
		P2		
		P3		
		P4	J7	Buffer circuit assembly
		P5	J8	Buffer circuit assembly
		P6	J4	W232
		P7		Digital ohmmeter
		P8		Digital ohmmeter

Table 7-V. GSE Interconnect Cable Connections (ISS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W1	1900886	P1	J1	OIA
		P2	J1	Oscillograph
W2	1900669	P1	J2	OIA
		P2	J2	Oscillograph
W3	1900670	P1	J3	OIA
		P2	J3	Oscillograph
W4	1900671	P1	J4	OIA
		P2	J4	Oscillograph
W19	1900873	P1	J20	OIA
		P2	J3	Coolant and power console
W26	1900921	P1	A30J1	OIA
		P2	Facility	Wall power
W27	1900871	P1	A30J2	OIA
		P2	J1	Coolant and power console
W28	1900872	P1	J2	Coolant and power console
		P2	Facility	Wall power
W33	1901404	P1	E1	OIA
		P2	E4	Oscillograph
W37	1901662	P1	Facility	Facility ground
		P2	E300	Rotary table
W64	1901676	P1	E1	G and N mounting fixture base
		P2	E300	Rotary table
W65	1900739	P1	J4	Current source monitor panel
		P2	J15	PSA test point adapter

(Sheet 1 of 5)

Table 7-V. GSE Interconnect Cable Connections (ISS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W68	1902284	P1	E300	Rotary table
		P2	E1	PEA coldplate
W85	1901960	P1	A30J5	OIA
		P2	Facility	Auxiliary wall power
W120	2900456	P1	J19	OIA
		P2	J2	PSA
W121	2900257	P1	J8	OIA
		P2	J9	OIA
		P3	J13	OIA
		P4	J14	OIA
		P5	J15	OIA
		P6	J57	GSE distribution box
W122	2900378	P1	J18	OIA
		P2	J17	OIA
		P3	J16	OIA
		P4	J22	OIA
		P5	J55	GSE distribution box
		P6	J59	GSE distribution box
		P7	J62	GSE distribution box
		P8	J58	GSE distribution box
W123	2900379	P1	J21	OIA
		P2	J24	OIA
		P3	J25	OIA
		P4	J26	OIA
		P5	J60	GSE distribution box
		P6	J63	GSE distribution box
		P7	J66	GSE distribution box
		P8	J67	GSE distribution box
W124	2900380	P1	J5	OIA
		P2	J6	OIA
		P3	J7	OIA
		P4	J64	GSE distribution box
		P5	J61	GSE distribution box
		P6	J65	GSE distribution box

Table 7-V. GSE Interconnect Cable Connections (ISS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W125	2900186	P1	J28	OIA
		P2	J29	OIA
		P3	J30	OIA
		P4	J50	GSE distribution box
		P5	J51	GSE distribution box
		P6	J54	GSE distribution box
W126	29000381	P1	J10	OIA
		P2	J11	OIA
		P3	J12	OIA
		P4	J52	GSE distribution box
		P5	J53	GSE distribution box
		P6	J56	GSE distribution box
W127	2900327 (2 required)		E1	GSE distribution box
			E80	OIA
			E1 E300	OIA Rotary table
W128	2900458 (2 required)		E2	GSE distribution box
			E300	Rotary table
			E1 E300	Subsystem mounting fixture Rotary table
W129	2900459 (2 required)		E1	Subsystem mounting fixture
			E2	Subsystem mounting fixture
			E1 E3	Subsystem mounting fixture GSE distribution box
W130	2900460		E1	Coolant and power console
			E300	Rotary table

(Sheet 3 of 5)

Table 7-V. GSE Interconnect Cable Connections (ISS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack.	Equipment
W132	2900497	P1	P15	W146
		P2	P16	W146
		P3	P17	W146
		P4		Not used
		P5	J2	PEA test point adapter
		P6	J14	GSE distribution box
		P7	J10	GSE distribution box
		P8	J17	GSE distribution box
		P9		Not used
		P10	J18	GSE distribution box
W134	2900588	P1	P18	W146
		P2	J23	GSE distribution box
W136	2900461	P1	J24	GSE distribution box
		P2	J28	GSE distribution box
		P3	J3	PSA test point adapter
		P4	J4	PSA test point adapter
W140	2900457	P1	J4	Coolant and power console
		P2	J34	GSE distribution box
W141	2900591	P1	A1J3	Temperature indicator assembly (GSE distribution box)
		P2	J1	IMU coolant inlet line
		P3	J2	PEA coldplate
		P4		Not used
		P5	J1	CDU coldplate
		P6	J1	PSA coldplate
W146	2900351	P15	P1	W132
		P16	P2	W132
		P17	P3	W132
		P18	P1	W134
		P19	P1	W158
		P20	J2	IMU
		P21	J1	IMU
		J1		Not used

(Sheet 4 of 5)

Table 7-V. GSE Interconnect Cable Connections (ISS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W148	2900652	P1 P2	J33 J8	GSE distribution box PSA
W149	2900658	P1 P2	J26 J10	GSE distribution box PSA
W150	2900529	P1 P2	J2 J3	PSA test point adapter PSA
W154	2900661	P1 P2 P3 P4	J19 J20 J4	GSE distribution box GSE distribution box PSA CDU
W156	2900663	P1 P2 P3	J11 J12 J6	GSE distribution box GSE distribution box PSA
W158	2900664	P1 P2	P19 J14	W146 PEA
W159	2900675	P1 P2	J1 J15	PEA test point adapter PEA
W167	2900672	P1 P2	J1 J1	PSA test point adapter PSA

(Sheet 5 of 5)

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

Table 7-VI. GSE Interconnect Cable Connections (OSS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W1	1900886	P1	J1	OIA
		P2	J1	Oscillograph
W2	1900669	P1	J2	OIA
		P2	J2	Oscillograph
W3	1900670	P1	J3	OIA
		P2	J3	Oscillograph
W4	1900671	P1	J4	OIA
		P2	J4	Oscillograph
W19	1900873	P1	J20	OIA
		P2	J3	Coolant and power console
W26	1900921	P1	A30J1	OIA
		P2	Facility	Wall power
W27	1900871	P1	A30J2	OIA
		P2	J1	Coolant and power console
W28	1900872	P1	J2	Coolant and power console
		P2	Facility	Wall power
W33	1901404	P1	E1	OIA
		P2	E4	Oscillograph
W37	1901662	P1	Facility	Facility ground
		P2	E300	Rotary table
W64	1901676	P1	E1	G and N mounting fixture base
		P2	E300	Rotary table
W65	1900739	P1	J4	Current source monitor panel
		P2	J15	PSA test point adapter
W85	1901960	P1	A30J5	OIA
		P2	Facility	Auxiliary wall power

(Sheet 1 of 4)

Table 7-VI. GSE Interconnect Cable Connections (OSS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W93	1902349	P1	P3	W152 Remote optics controller
		P2	J2	
W121	2900257	P1	J8	OIA
		P2	J9	OIA
		P3	J13	OIA
		P4	J14	OIA
		P5	J15	OIA
		P6	J57	GSE distribution box
W122	2900378	P1	J18	OIA
		P2	J17	OIA
		P3	J16	OIA
		P4	J22	OIA
		P5	J55	GSE distribution box
		P6	J59	GSE distribution box
		P7	J62	GSE distribution box
		P8	J58	GSE distribution box
W123	2900379	P1	J21	OIA
		P2	J24	OIA
		P3	J25	OIA
		P4	J26	OIA
		P5	J60	GSE distribution box
		P6	J63	GSE distribution box
		P7	J66	GSE distribution box
		P8	J68	GSE distribution box
W124	2900380	P1	J5	OIA
		P2	J6	OIA
		P3	J7	OIA
		P4	J64	GSE distribution box
		P5	J61	GSE distribution box
		P6	J65	GSE distribution box
W125	2900186	P1	J28	OIA
		P2	J29	OIA
		P3	J30	OIA
		P4	J50	GSE distribution box
		P5	J51	GSE distribution box
		P6	J54	GSE distribution box

(Sheet 2 of 4)

Table 7-VI. GSE Interconnect Cable Connections (OSS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W126	2900381	P1	J10	OIA
		P2	J11	OIA
		P3	J12	OIA
		P4	J52	GSE distribution box
		P5	J53	GSE distribution box
		P6	J56	GSE distribution box
W127	2900327 (2 required)		E1	OIA
			E300	Rotary table
			E80	OIA
		E1	GSE distribution box	
W128	2900458 (2 required)		E2	GSE distribution box
			E300	Rotary table
			E1	Subsystem mounting fixture
		E300	Rotary table	
W129	2900459 (2 required)		E1	Subsystem mounting fixture
			E2	Subsystem mounting fixture
			E1	Subsystem mounting fixture
		E3	GSE distribution box	
W130	2900460		E1	Coolant and power console
			E300	Rotary table
W136	2900461	P1	J24	GSE distribution box
		P2	J28	GSE distribution box
		P3	J3	PSA test point adapter
		P4	J4	PSA test point adapter
W140	2900457	P1	J4	Coolant and power console
		P2	J34	GSE distribution box

(Sheet 3 of 4)

Table 7-VI. GSE Interconnect Cable Connections (OSS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W141	2900591	P1	A1J3	Temperature indicator assembly (GSE distribution box)
		P2		Not used
		P3		Not used
		P4		Not used
		P5	J1	CDU coldplate
		P6	J1	PSA coldplate
W148	2900652	P1	J33	GSE distribution box
		P2	J8	PSA
W149	2900658	P1	J26	GSE distribution box
		P2	J10	PSA
W150	2900529	P1	J2	PSA test point adapter
		P2	J3	PSA
W152	2900659	P1		Not used
		P2		Not used
		P3	P2	W153 (indicator control panel)
		or		
		P3	P2	W93 (remote optics controller)
		P4	J5	PSA
W153	2900660	P5	J9	PSA
		P6	J7	PSA
		P1	J1	Indicator control panel
		P2	P3	W152
W154	2900661	P1	J19	GSE distribution box
		P2	J20	GSE distribution box
		P3	J4	PSA
		P4		CDU
W167	2900672	P1	J1	PSA test point adapter
		P2	J1	PSA

(Sheet 4 of 4)

Table 7-VII. GSE Interconnect Cable Connections (CSS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W212	1006482-001	P1 P2	J7 J1	AGC/OC CTS
W213	1006482-002	P1 P2	J8 J7	AGC/OC CTS
W214	1006482-003	P1 P2	J9 J13	AGC/OC CTS
W215	1006482-004	P1 P2	J4 J2	AGC/OC CTS
W216	1006482-005	P1 P2	J5 J8	AGC/OC CTS
W217	1006482-006	P1 P2	J6 J14	AGC/OC CTS
W218	1006482-007	P1 P2	J11 J3	AGC/OC CTS
W219	1006482-008	P1 P2	J12 J9	AGC/OC CTS
W220	1006482-009	P1 P2	J10 J15	AGC/OC CTS
W221	1006482-010	P1 P2	J1 J10	AGC/OC CTS
W222	1006482-011	P1 P2	J2 J16	AGC/OC CTS
W223	1006482-012	P1 P2	J3 J4	AGC/OC CTS

(Sheet 1 of 2)

Table 7-VII. GSE Interconnect Cable Connections (CSS Checkout)

Cable			Connects to	
Designation	Part Number	Plug	Jack	Equipment
W224	2014493-011	P1	J9	Main panel DSKY AGC/OC
		P2	J1	
W225	2014486-011	P1	J9	Navigation panel DSKY AGC/OC
		P2	J3	
W226	2014137-011	P1		AGC test connector
		P2	J4	Buffer circuit assembly
		P3	J5	Buffer circuit assembly
		P4	J6	Buffer circuit assembly
W227	2014199-011	P1	SC conn.	AGC
		P2	J2	AGC/OC junction panel assembly
		P3	J3	AGC/OC junction panel assembly
		P4	J4	AGC/OC junction panel assembly
		P5	J5	AGC/OC junction panel assembly
		P6	J1	AGC/OC junction panel assembly
W236	2014463-011	P1	J1	Buffer circuit assembly
		P2	J5	CTS
W237	2014462-011	P1	J2	Buffer circuit assembly
		P2	J11	CTS
W238	2014462-021	P1	J3	Buffer circuit assembly
		P2	J17	CTS
W239	2014462-031	P1	J9	Buffer circuit assembly
		P2	J18	CTS
W259	2014470-011	P1	CP1	AGC calibration system
		P2		Digital ohmmeter
		P3		Digital ohmmeter
		P4	J7	Buffer circuit assembly
		P5	J8	Buffer circuit assembly
		P6	J6	AGC/OC junction panel assembly
		P7		Digital ohmmeter
		P8		Digital ohmmeter

(Sheet 2 of 2)

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

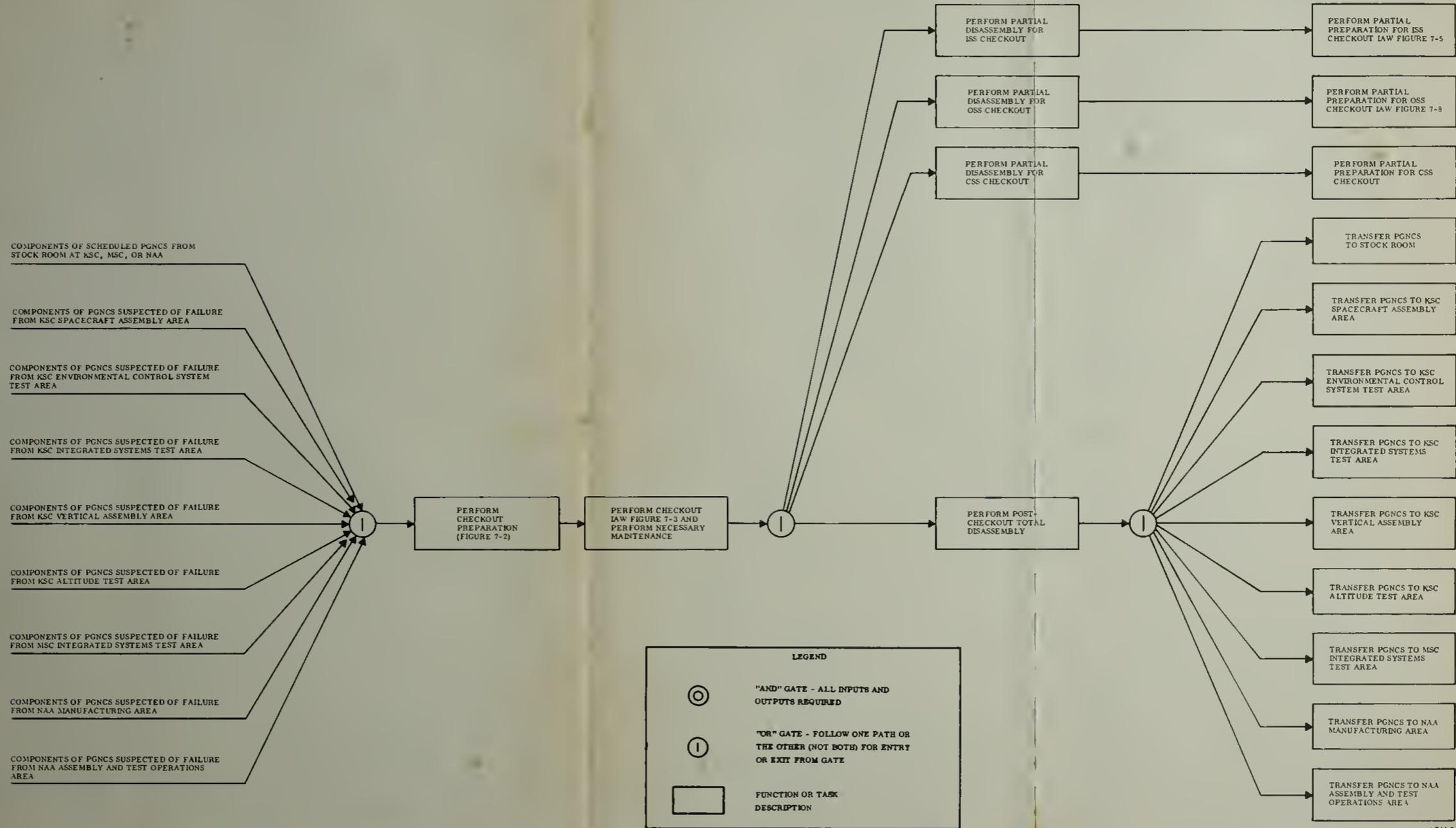
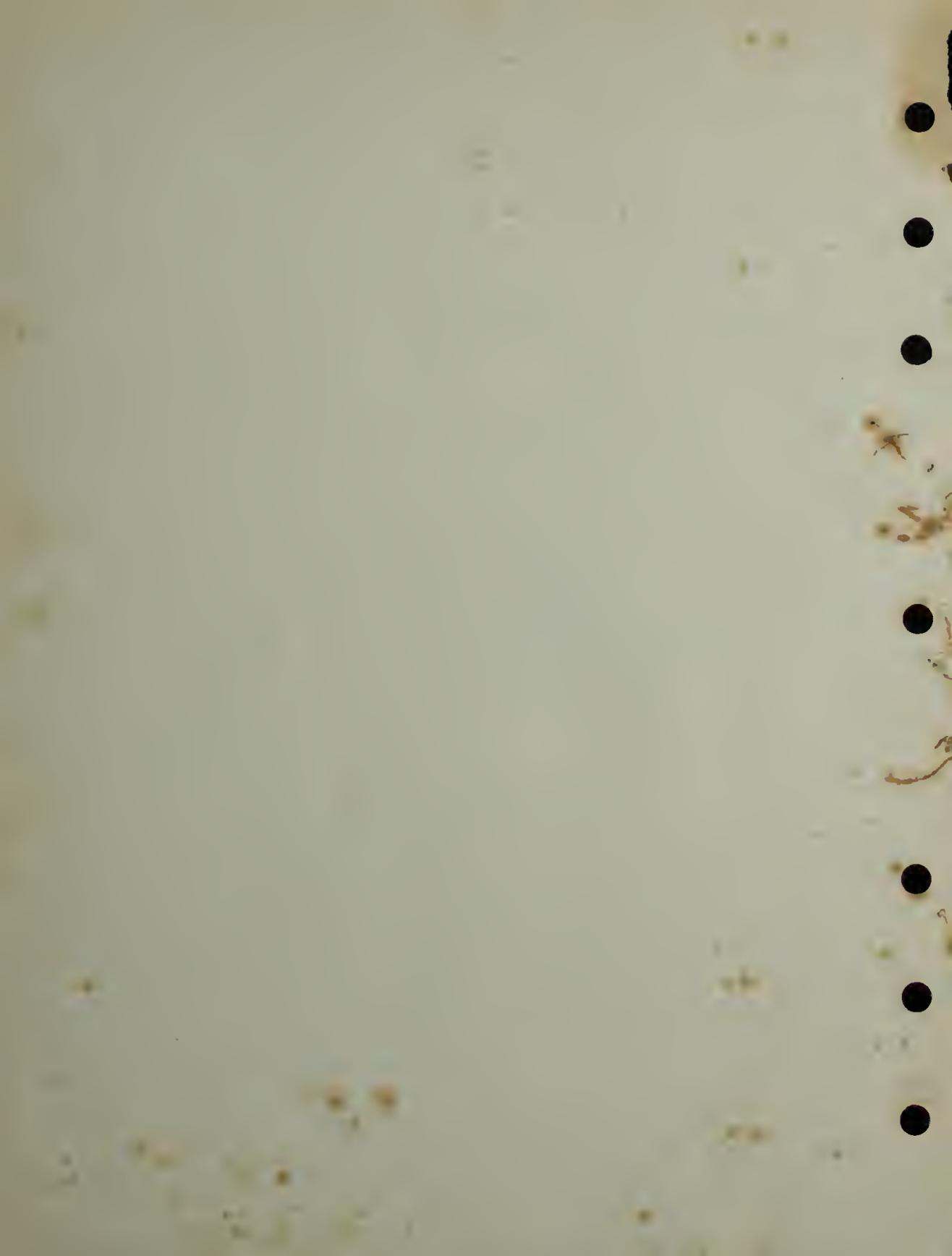


Figure 7-1. PGNCS Master Checkout Flowgram

16114

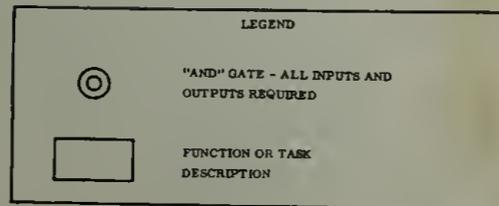
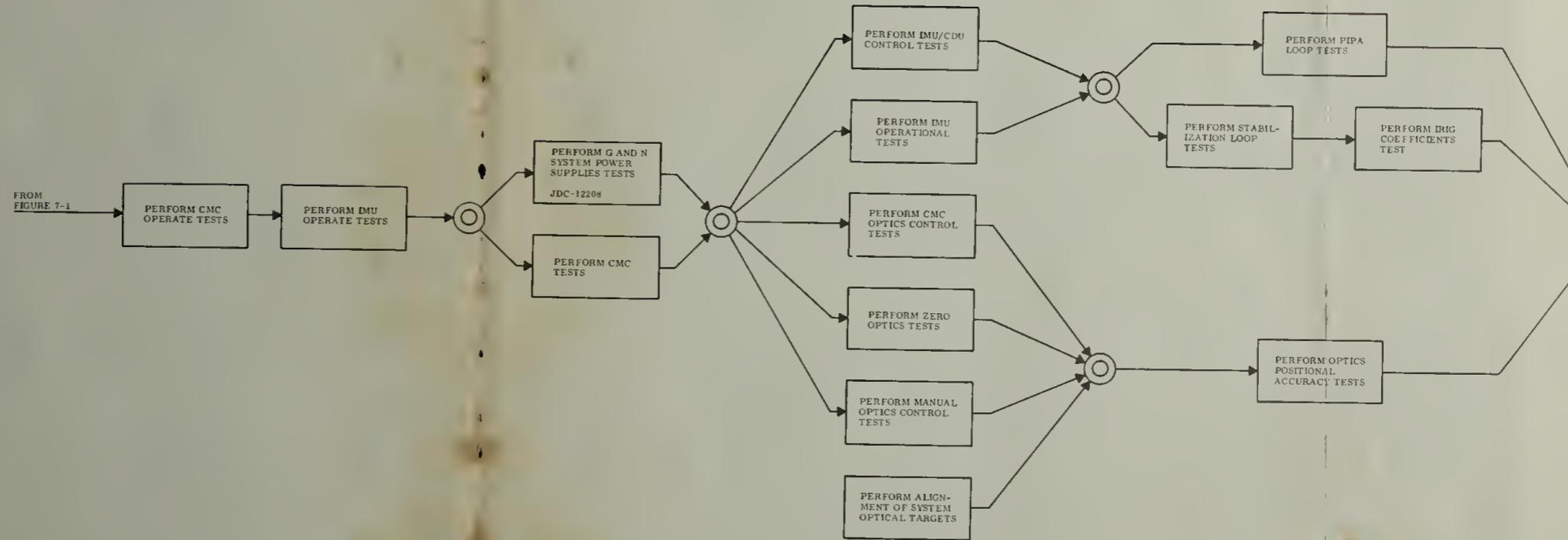


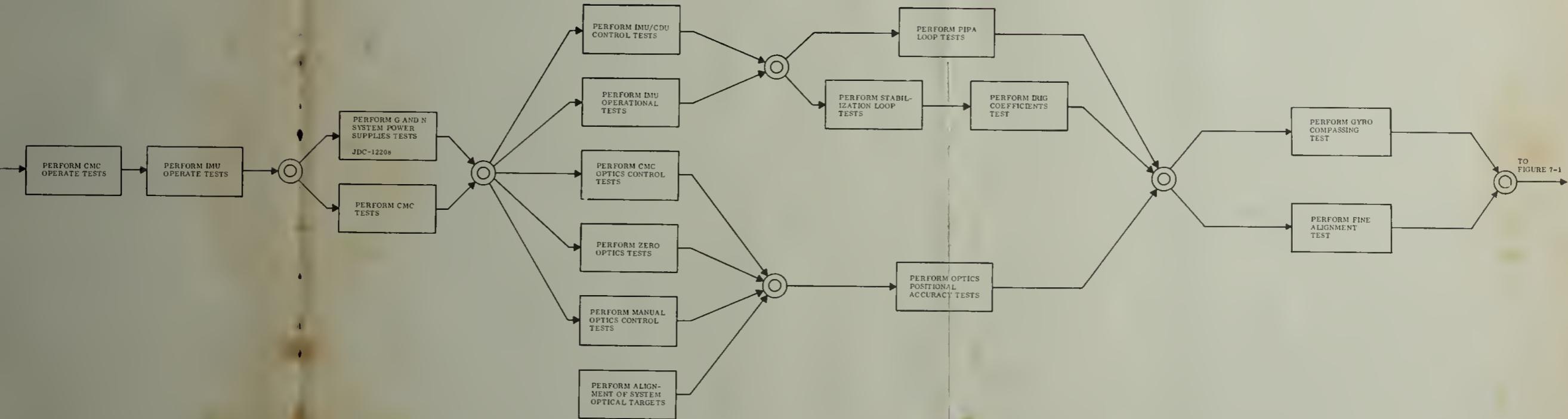


16115A

Figure 7-2. PGNCs Checkout Preparation Flowgram







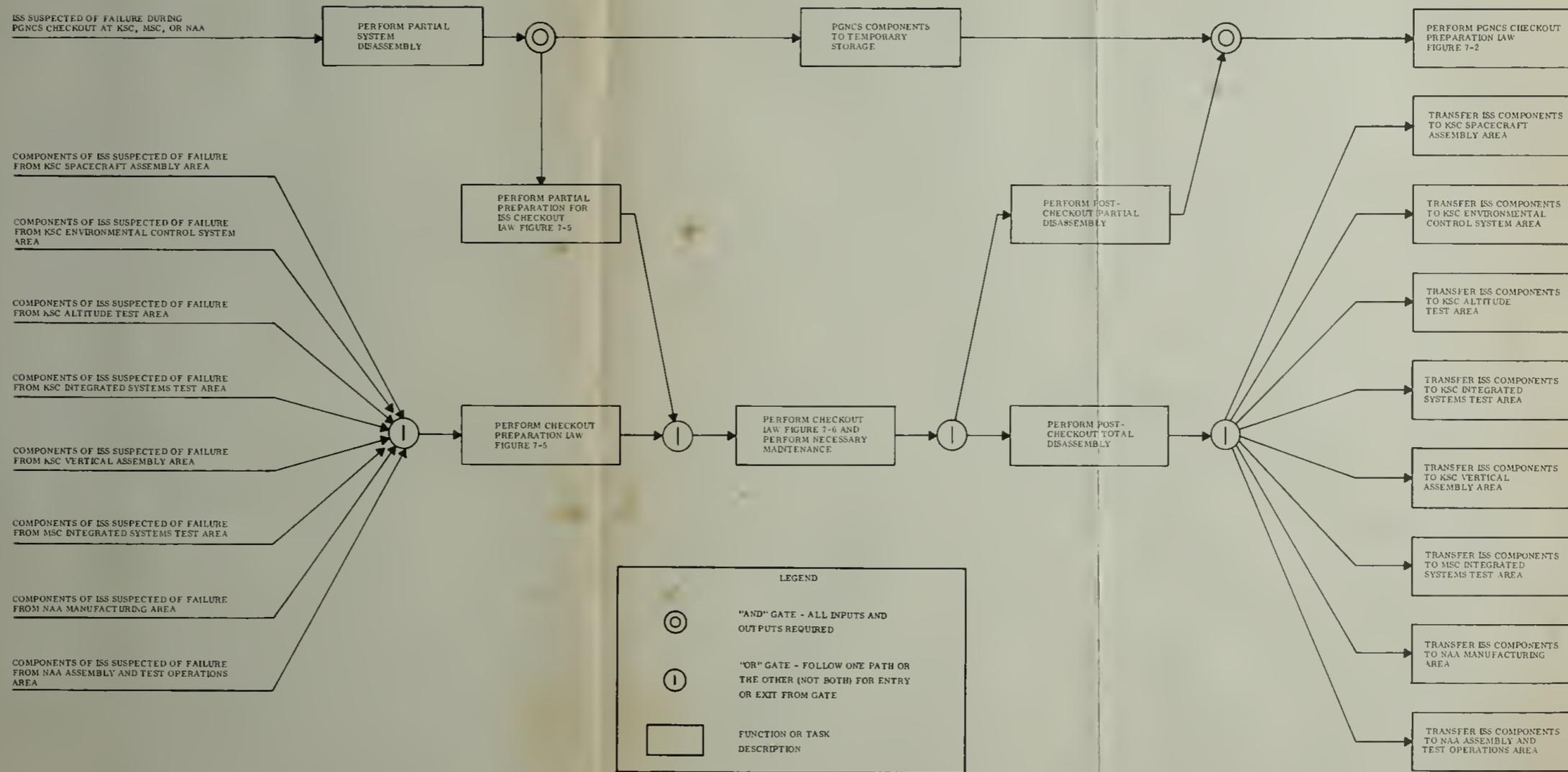
LEGEND

"AND" GATE - ALL INPUTS AND OUTPUTS REQUIRED

FUNCTION OR TASK DESCRIPTION

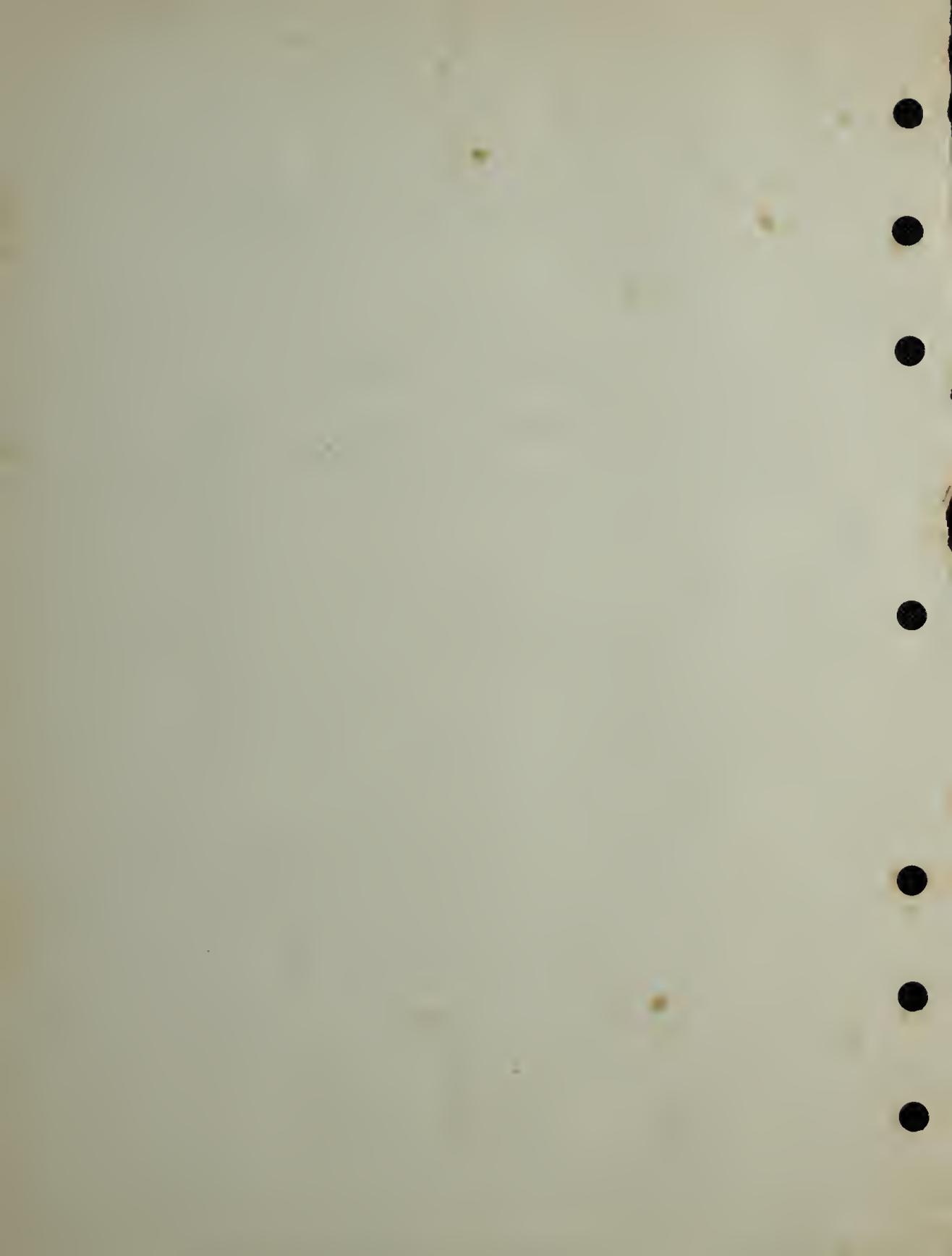
Figure 7-3. PGNCS Checkout Flowgram

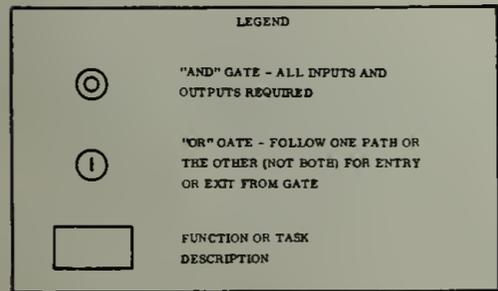
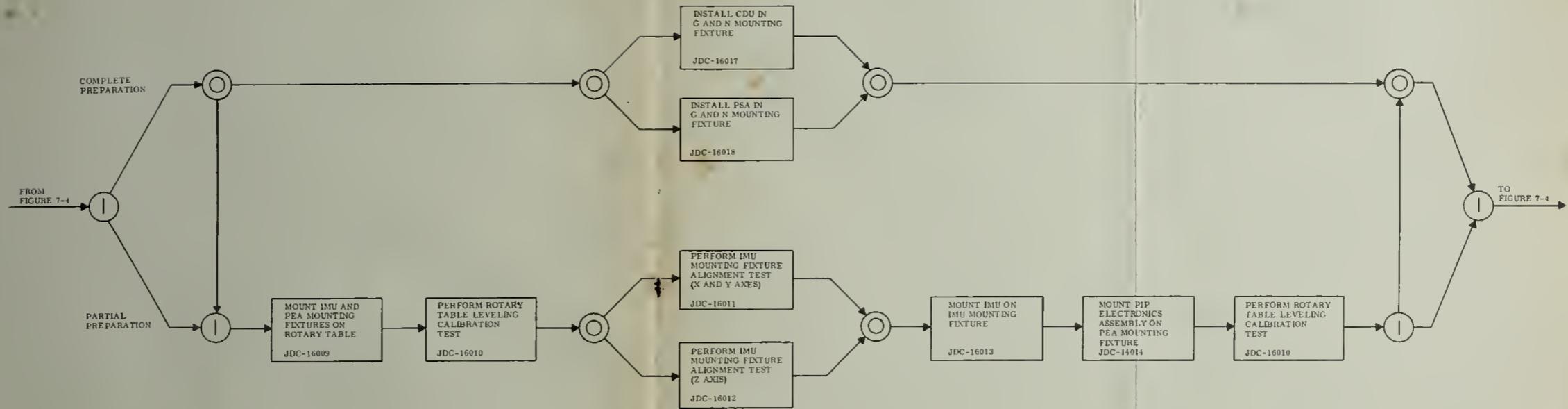




16117

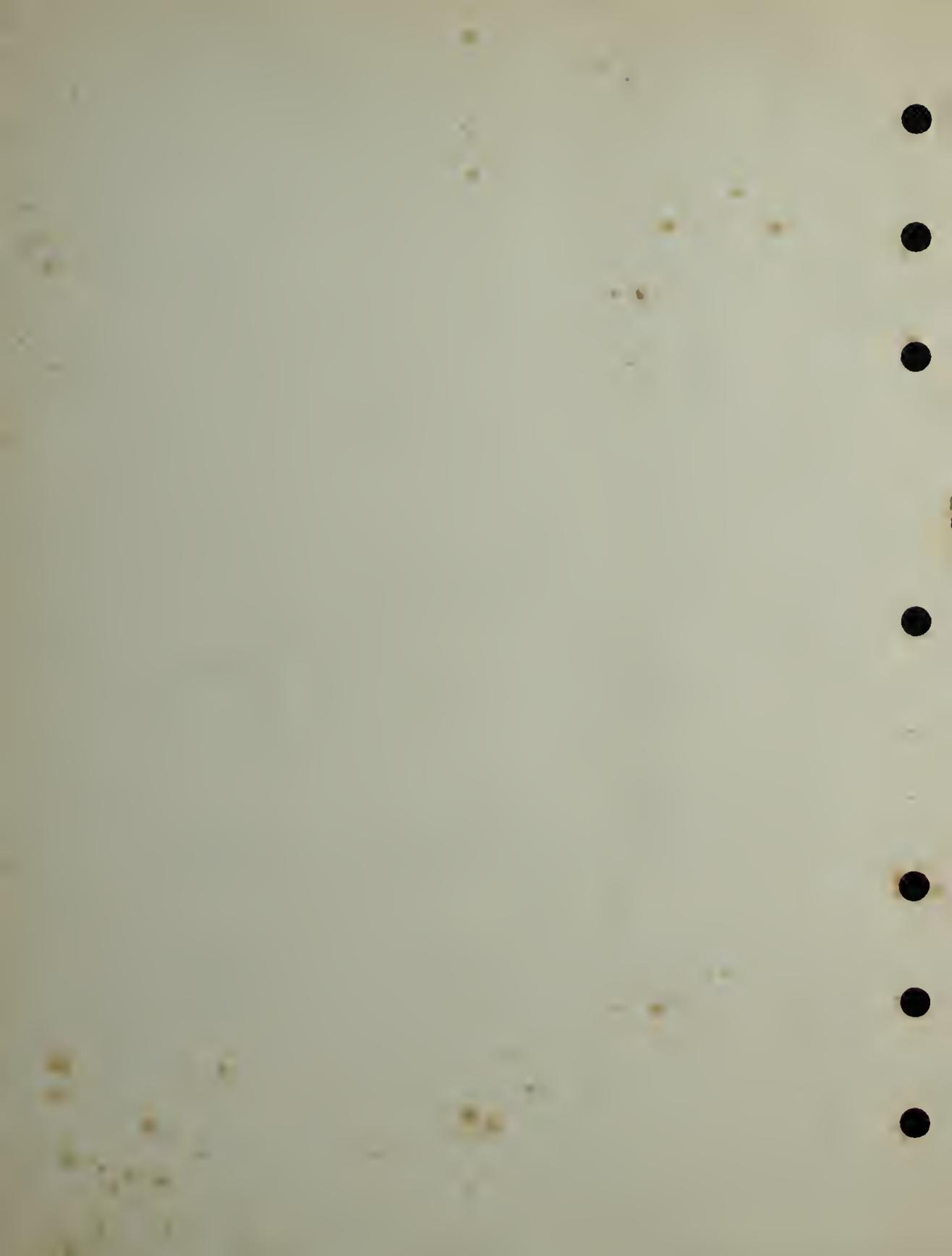
Figure 7-4. ISS Master Checkout Flowgram

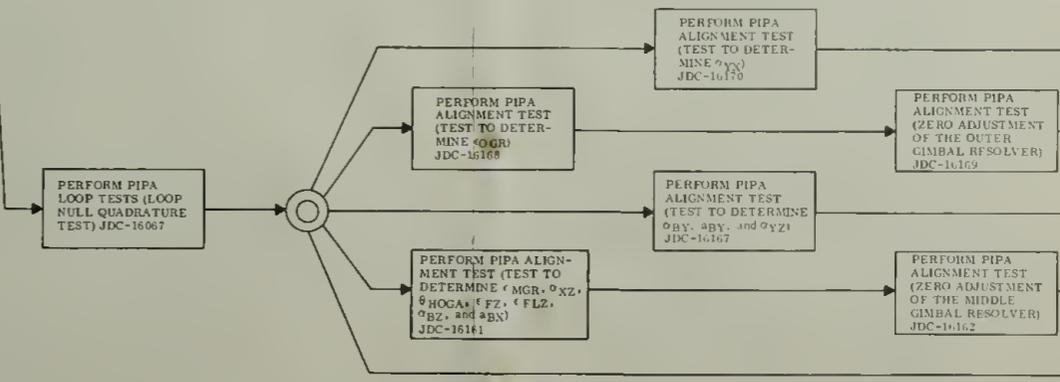
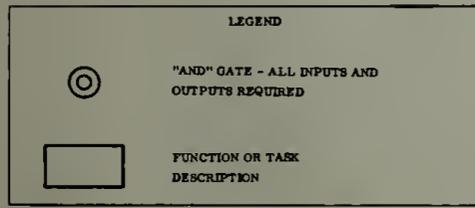
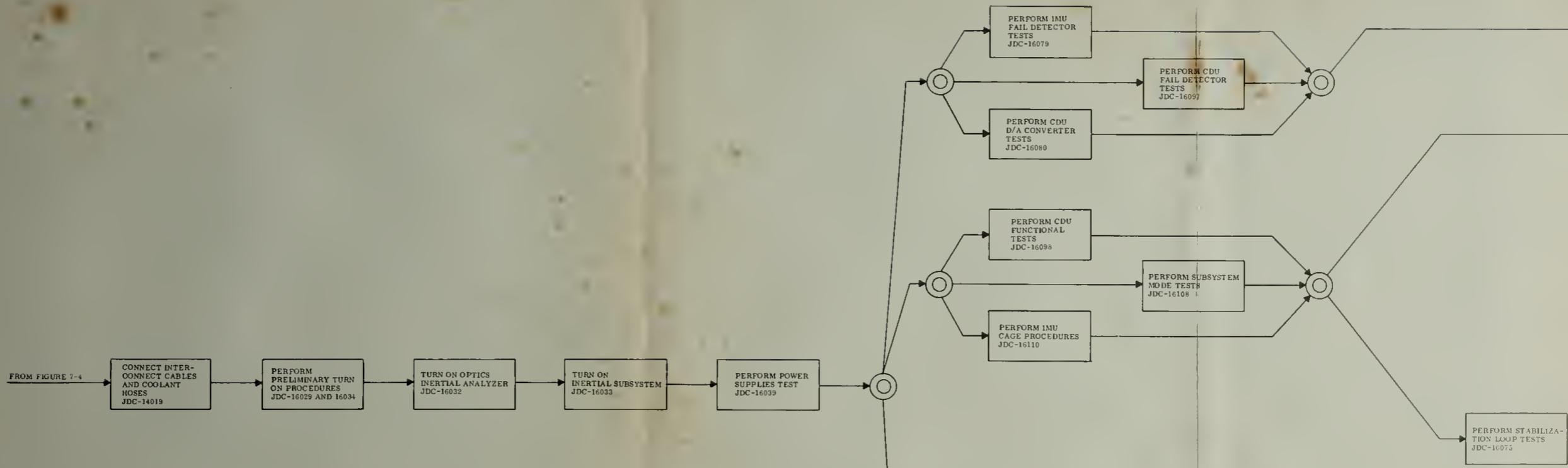




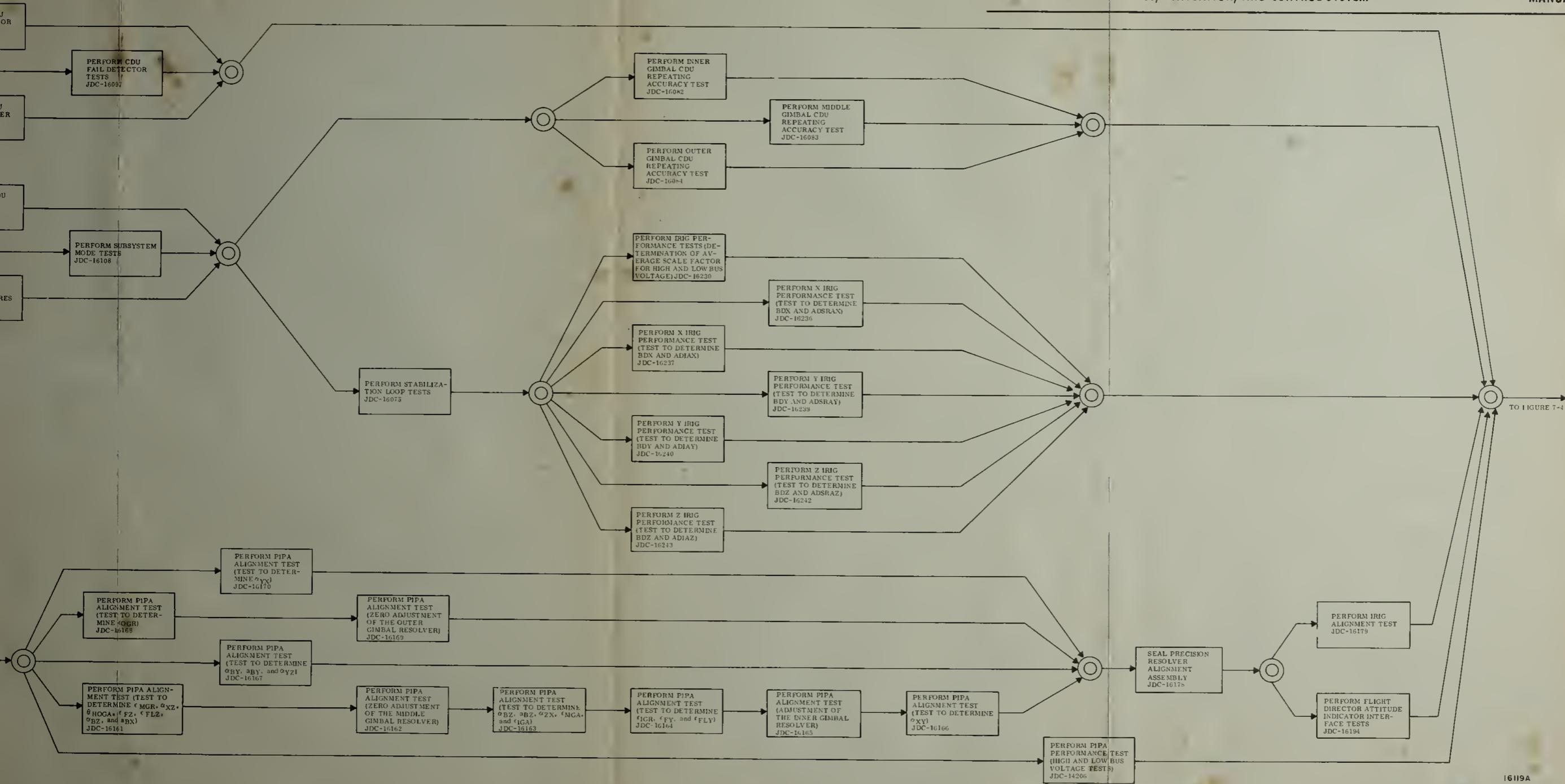
16118A

Figure 7-5. ISS Checkout Preparation Flowgram



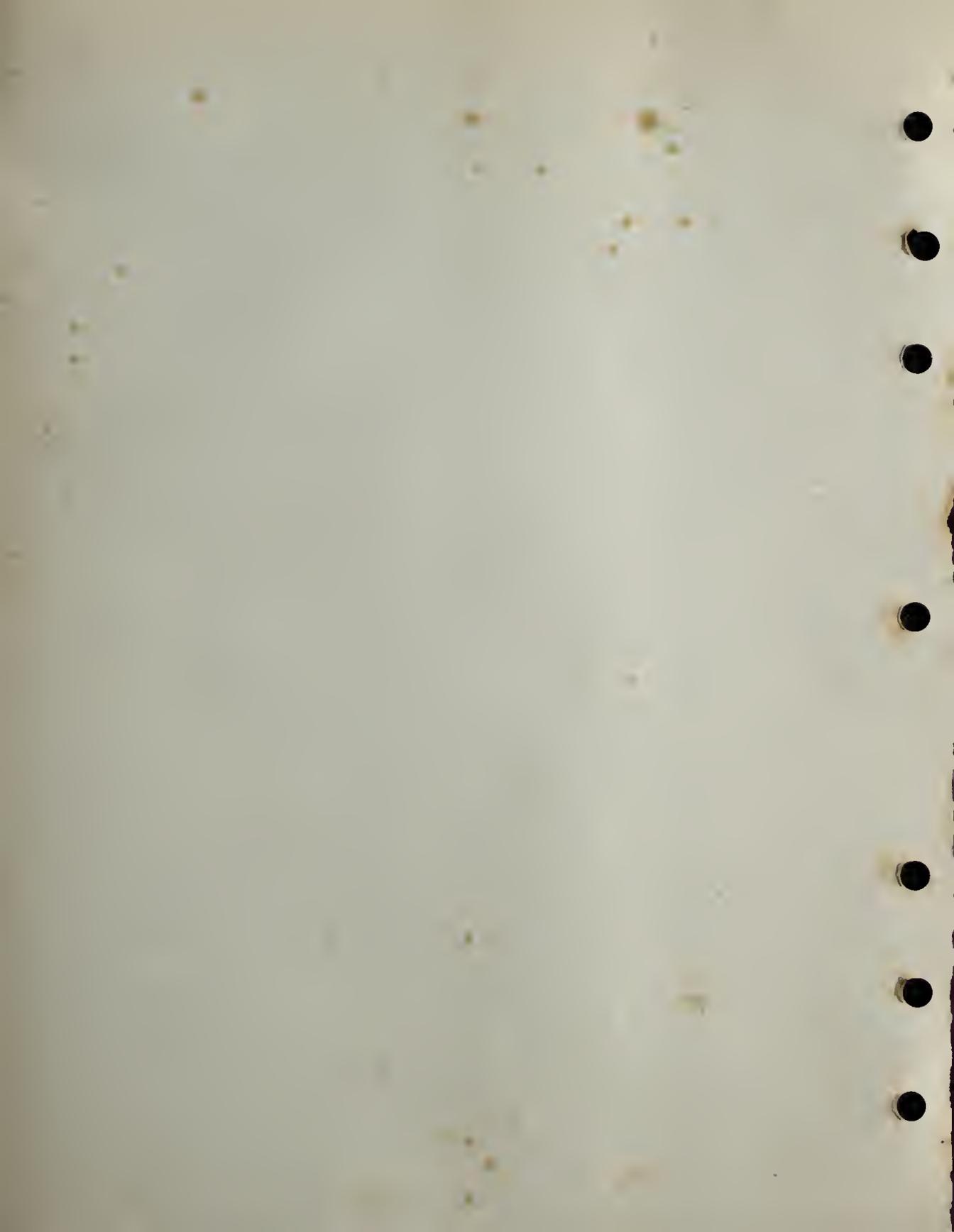


BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

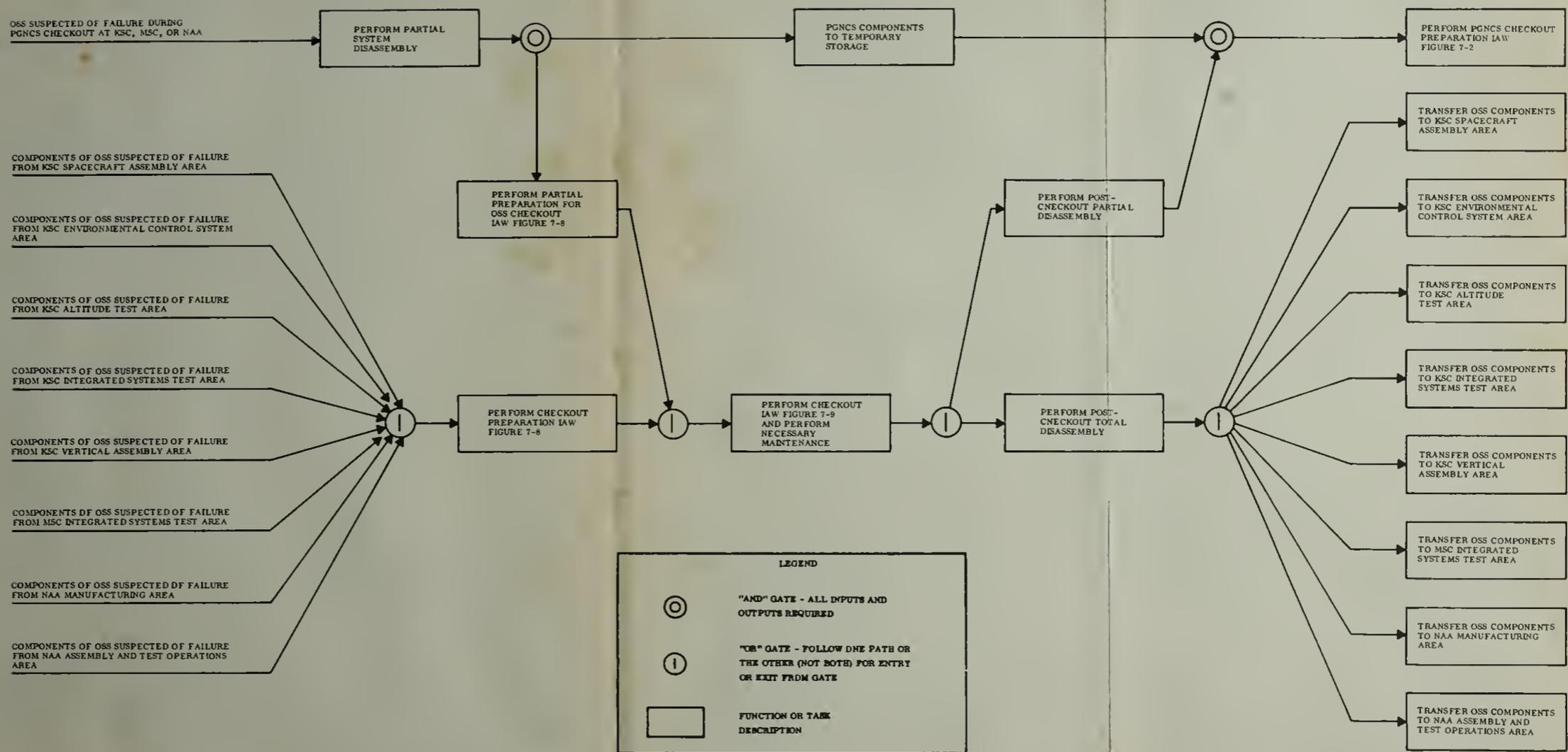


16119A

Figure 7-6. ISS Checkout Flowgram

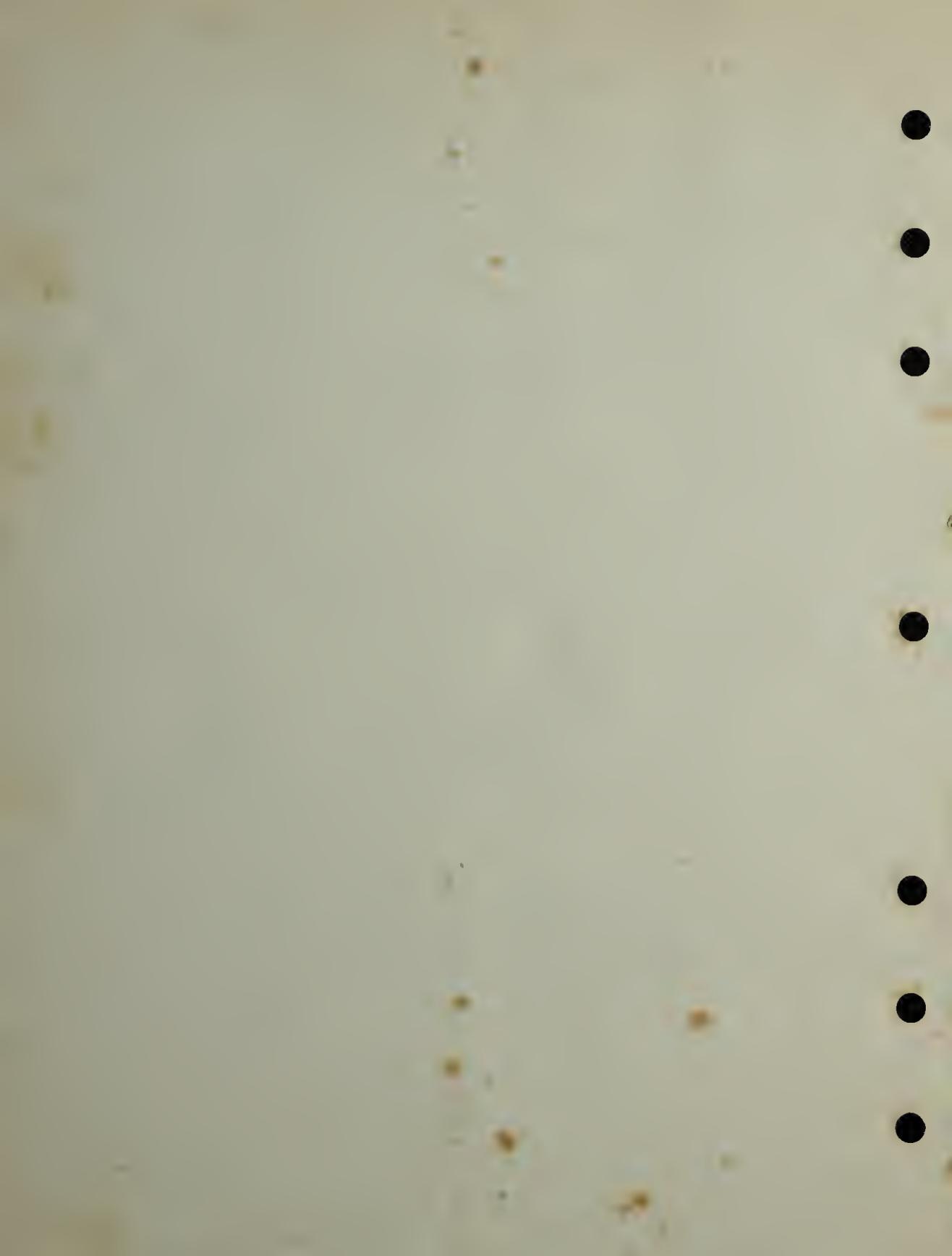


BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM



16120

Figure 7-7. OSS Master Checkout Flowgram



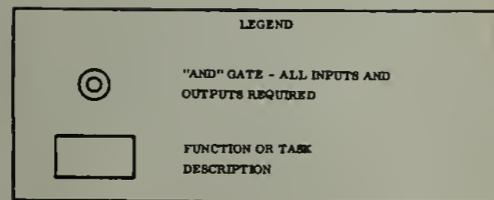
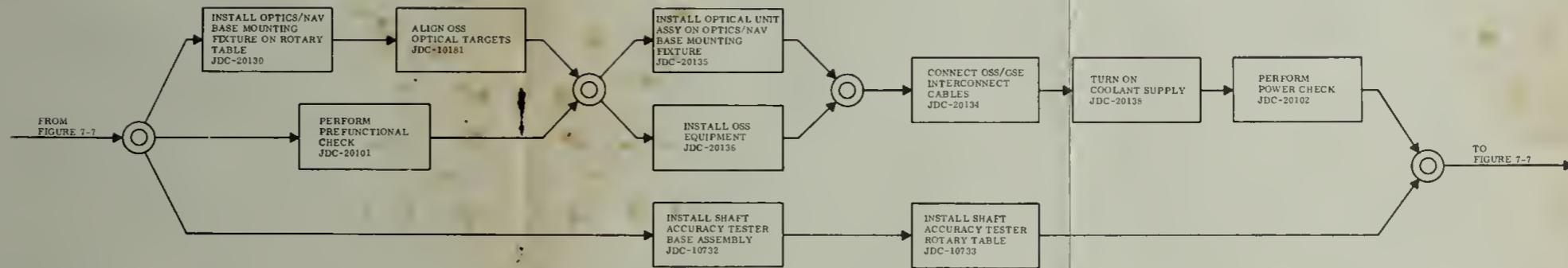
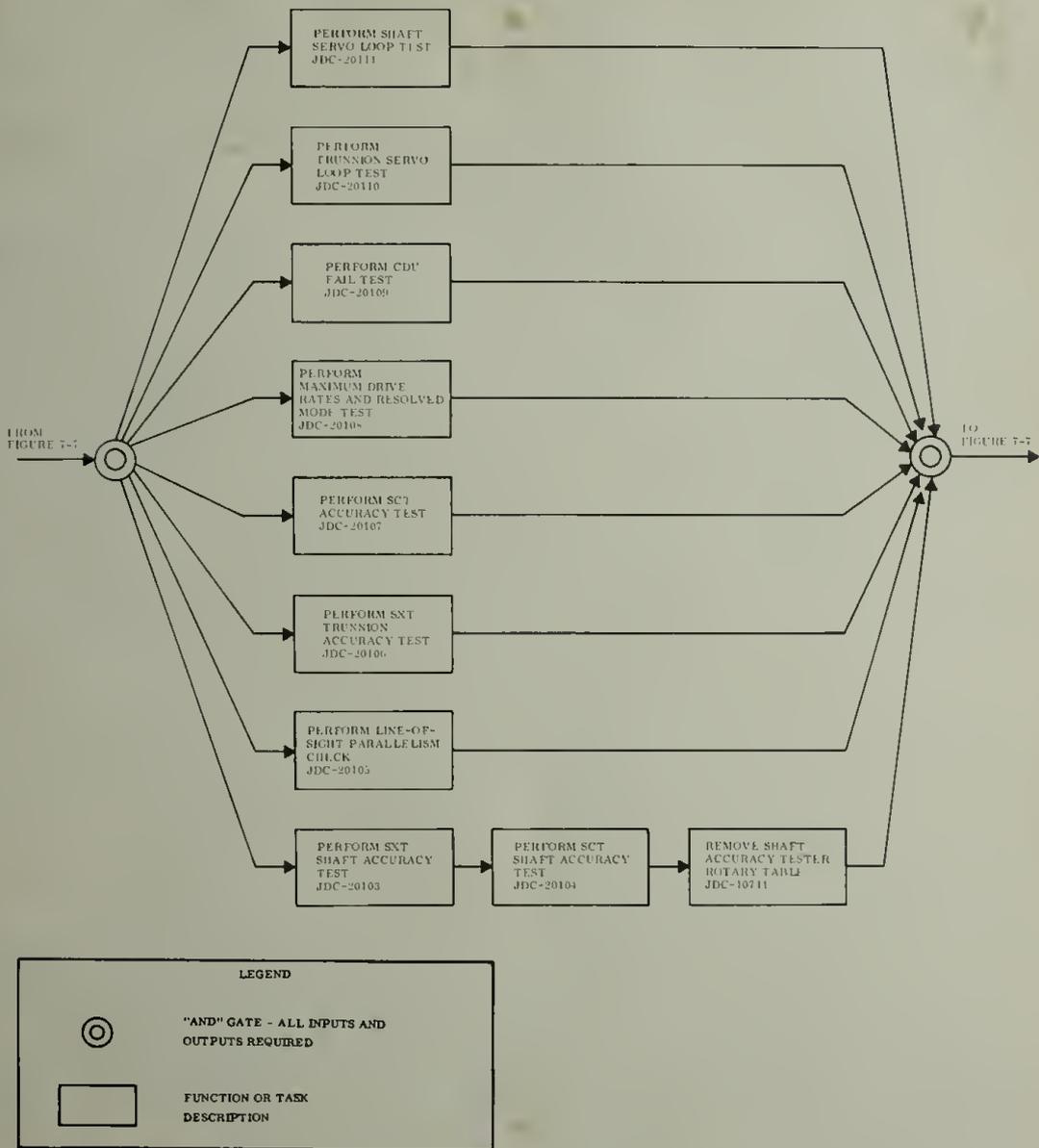


Figure 7-8. OSS Checkout Preparation Flowgram



BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM



16122A

Figure 7-9. OSS Checkout Flowgram

BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

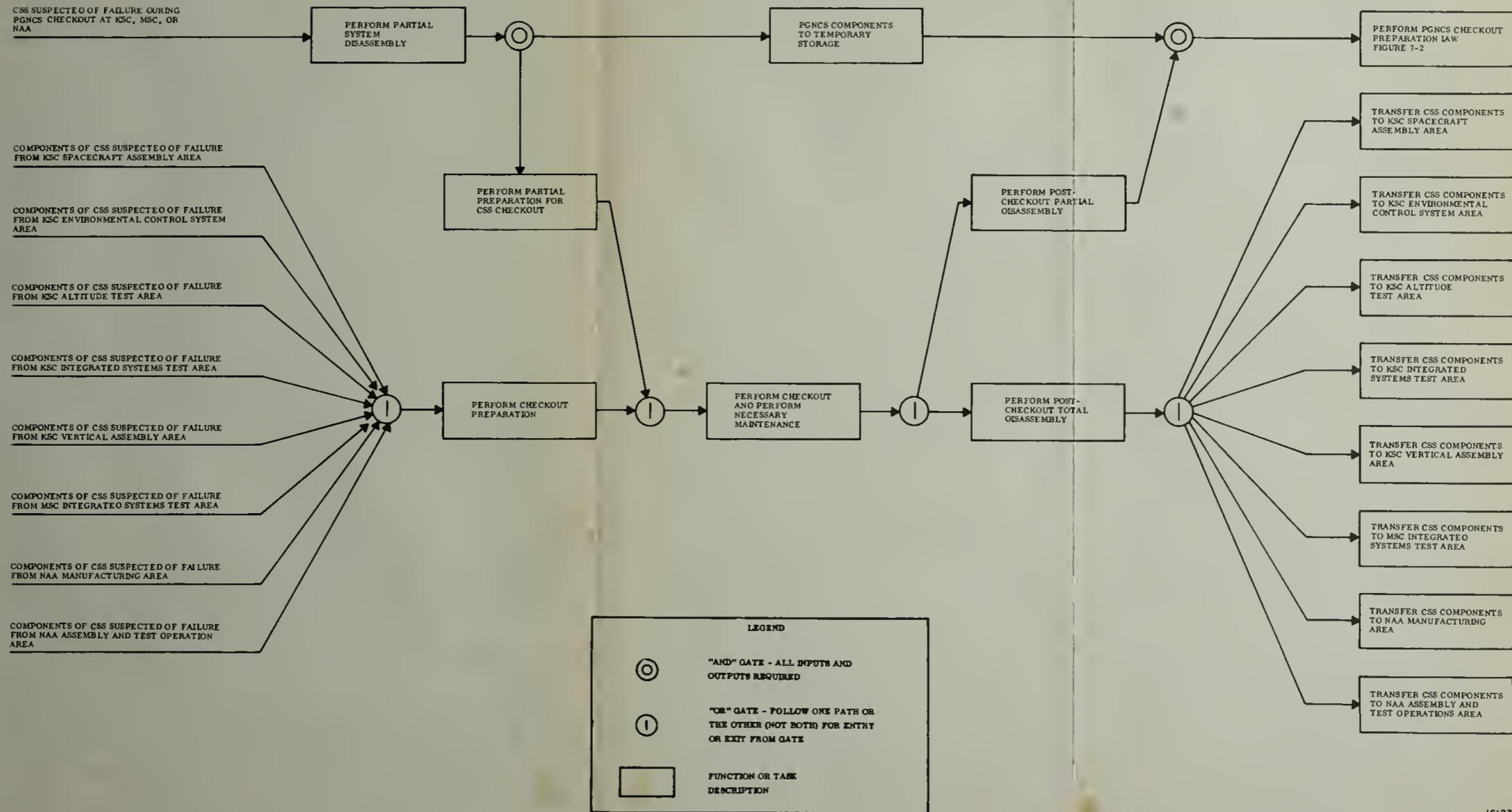
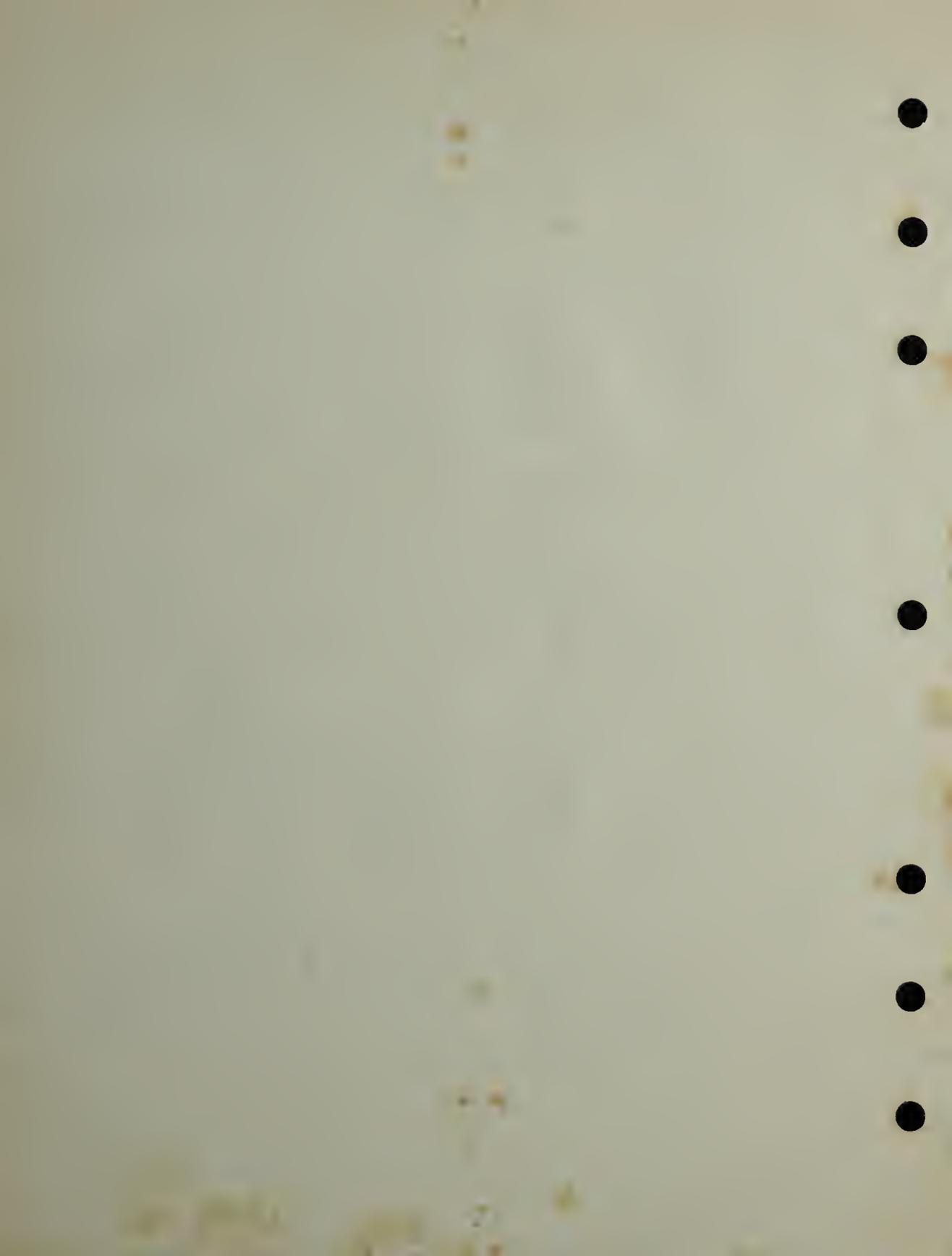


Figure 7-10. CSS Master Checkout Flowgram



Chapter 8

MAINTENANCE

8-1 SCOPE

This chapter describes maintenance for the Block II PGNCS at KSC, MSC, and NAA. JDC's are referenced as necessary to provide detailed instructions for checkout, removal, and replacement. Loop diagrams and schematics are referenced to aid malfunction isolation at system or subsystem level. In addition, chapter 8 contains a maintenance schedule and cleaning requirements for the PGNCS.

8-2 MAINTENANCE CONCEPT

The PGNCS is maintained at KSC, MSC, and NAA by the black box replacement method. (Black boxes represent only major components or assemblies.) Equipment is received at field locations as a complete PGNCS or as spare black boxes. If the PGNCS fails during checkout, the malfunction must be isolated to one of the following replaceable black boxes:

- (1) Coupling data unit.
- (2) Inertial measuring unit and matched PIP electronics assembly.
- (3) Power and servo assembly.
- (4) Command module computer and display and keyboard.
- (5) Flight ropes.
- (6) Test ropes.
- (7) Optical unit assembly.
- (8) Navigation base assembly.
- (9) Signal conditioner.

- (10) Indicator control panel.
- (11) PGNCS interconnect harness assembly.

Figure 8-1 presents, in flow diagram format, the maintenance concept for the PGNCS. If a malfunction occurs, the following maintenance activities are performed:

- (1) The PGNCS malfunction is isolated to a black box.
- (2) The black box is tested sufficiently to verify that a malfunction exists.
- (3) The malfunction is analyzed to determine if other PGNCS malfunctions are present.
- (4) A spare black box is tested to insure that it is serviceable.
- (5) The spare black box is installed in the PGNCS.
- (6) The PGNCS is tested sufficiently to verify that repair is satisfactory.
- (7) PGNCS checkout is resumed at the JDC which originally failed.

8-3 MALFUNCTION ISOLATION

Malfunction isolation is isolating a malfunction to a black box with the aid of GSE indications, PGNCS indications, loop diagrams, and schematics.

The PGNCS subsystem loop diagrams and schematics required to perform malfunction isolation are referenced in table 8-I. The CSS logic diagrams and schematics required to perform malfunction isolation are listed in table 8-II. The system and subsystem functional analysis in chapter 2 and the component theory of operation in chapter 4 is useful in analyzing malfunctions. If a malfunction cannot be isolated to a black box during PGNCS testing, ISS, OSS, or CSS subsystem testing is required. Flowgrams in chapter 7 list the JDC's required to perform subsystem checkout.

After malfunction isolation is completed, malfunction verification testing and preinstallation acceptance (PIA) testing are performed.

8-4 MALFUNCTION VERIFICATION

After a malfunction is isolated to a black box, additional tests are performed to verify that a malfunction exists in the black box. JDC's providing procedures for bench testing and partial subsystem testing of each black box will be listed in a table when information is available.

The malfunction verification JDC's are provided as an aid to malfunction verification, and are used at the discretion of the engineer. However, specified prepower assurance (PPA) tests of some black boxes are required prior to further subsystem testing to prevent a black box malfunction from causing possible damage to the subsystem.

Table 8-I. PGNCS, ISS, and OSS Loop Diagrams and Schematics

Title	Drawing Number
IMU-CDU one line mech - Block II	2015568
Optics trunnion and shaft CDU block diagram - Block II (2 line mech)	2015567
Two wire mechanization of Apollo PIPA loops	2015563
Two wire mechanization of Apollo stabilization loops	2015564
Apollo IMU temperature control system - Block II two wire mechanization	2001452
CSM 5 axis moding (2 line mech)	2015562
IMU temperature control system schematic diagram - Block II	2001463
Functional diagram optics subsystem - Block II	2015500

Table 8-II. CSS Logic Diagrams and Schematics

Title	Drawing Number
Tray A Subassembly	
Module A1	2005059
Module A2	2005060
Module A3	2005051
Module A4	2005062
Module A5	2005061

Table 8-II. CSS Logic Diagrams and Schematics

Title	Drawing Number
Tray A Subassembly (cont)	
Module A6 Module A7 Module A8 Module A9 Module A10 Module A11 Module A12 Module A13 Module A14 Module A15 Module A16 Module A17 Module A18 Module A19 Module A20 Module A21 Module A22 Module A23 Module A24 Interface module A25, A26 Interface module A27 to A29 Power supply module A30, A31	2005063 2005052 2005055 2005056 2005057 2005058 2005053 2005069 2005064 2005065 2005066 2005067 2005068 2005070 2005054 2005050 2005071 2005072 2005073 2005021 2005020 2005010
Tray B Subassembly	
Rope memory module B1 to B6 Oscillator module B7 Alarm module B8 Erasable driver module B9, B10 Current switch module B11 Erasable memory module B12 Sense amplifier module B13, B14 Strand select module B15 Rope driver module B16, B17	2005012 2005003 2005008 2005004 2005005 2005006 2005002 2005009 2005000
DSKY	
DSKY assembly Indicator driver module D1 to D6 Keyboard module D8 Power supply module D7	2005900 2005902 2005903 2005904

(Sheet 2 of 2)

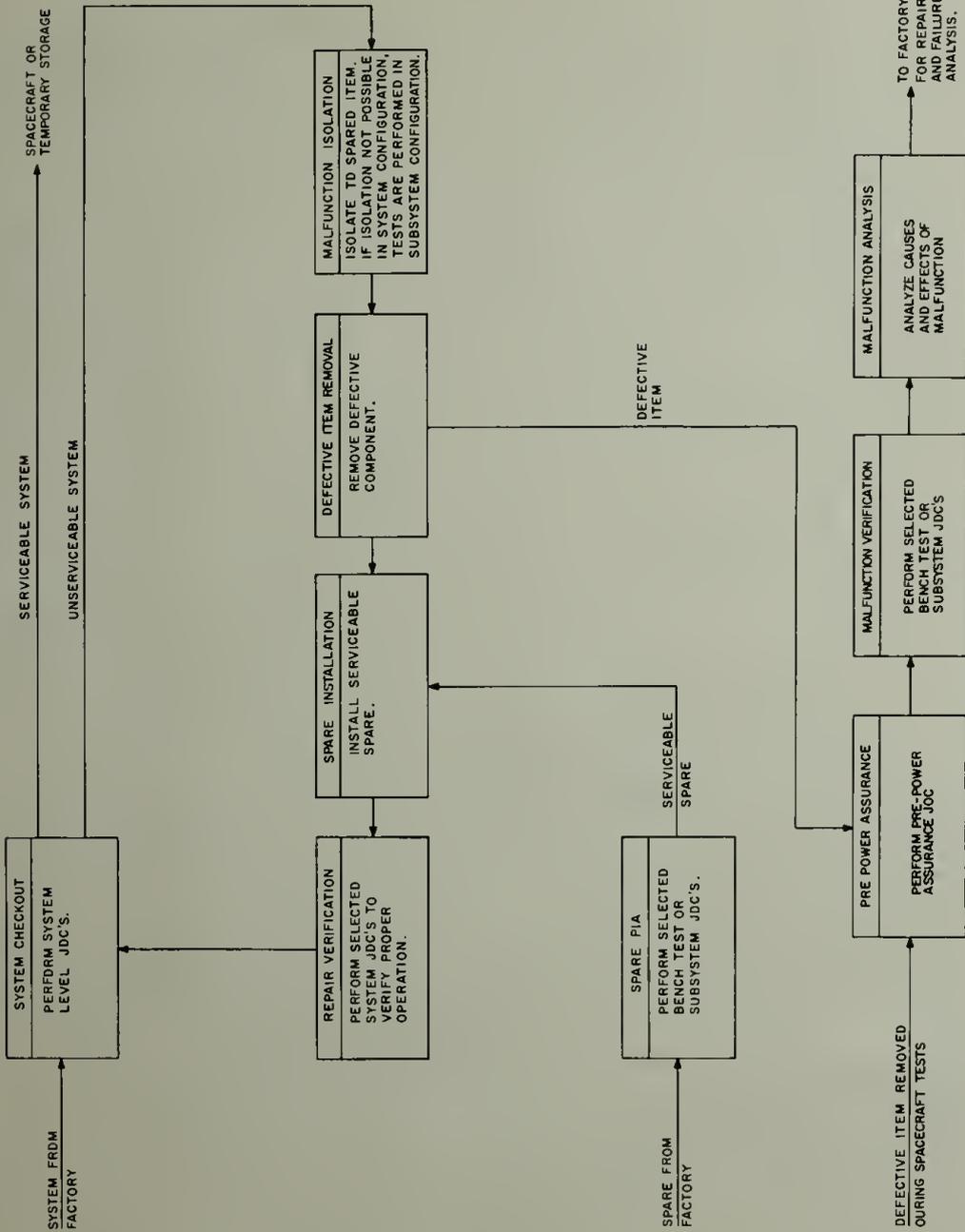


Figure 8-1. Maintenance Flowgram

15765C

If a malfunction in the black box can be verified, a spare black box, after passing a PIA test, is installed in the PGNCS. If no malfunction occurs during malfunction verification testing, a malfunction still exists in the PGNCS and further malfunction isolation is required.

8-5 MALFUNCTION ANALYSIS

After a malfunction has been verified, an analysis is performed to determine if the malfunction was caused by another PGNCS failure, or if the malfunction could have caused other damage in the PGNCS. If the analysis indicates other PGNCS malfunctions may exist, further malfunction isolation and malfunction verification testing are required.

The results of the malfunction analysis are returned to the factory, along with the failed black box, to aid factory analysis of the malfunction.

8-6 PRE-INSTALLATION ACCEPTANCE TEST

A spare black box must pass a PIA test prior to installation in the PGNCS in the spacecraft, but a PIA is not necessary prior to installation in the PGNCS at the laboratory. A PIA test is a partial subsystem checkout or a bench test of the spare black box.

The standard test equipment and JDC's required to perform PIA for each black box will be referenced in a table when information is available. If no malfunction occurs during the specified procedures, the spare black box is acceptable for installation in the spacecraft. If a malfunction occurs during PIA testing, the black box is unsatisfactory and must be returned to the factory.

8-7 REMOVAL AND REPLACEMENT

JDC's providing detailed instructions for removing and replacing black boxes in the PGNCS, ISS, OSS, and CSS will be referenced in a table when information is available.

8-8 REPAIR VERIFICATION

After the malfunction is verified, a malfunction analysis performed, and a spare black box installed in the laboratory PGNCS, a partial system checkout is performed to verify that the PGNCS is repaired.

The JDC's required to perform repair verification after installation of a spare black box will be listed in a table when information is available. If no malfunction occurs during the specified tests, the PGNCS is repaired and system checkout may be resumed at the JDC which originally failed. If a malfunction occurs during repair verification testing, it is probable that a new malfunction exists or that more than one system malfunction existed originally.

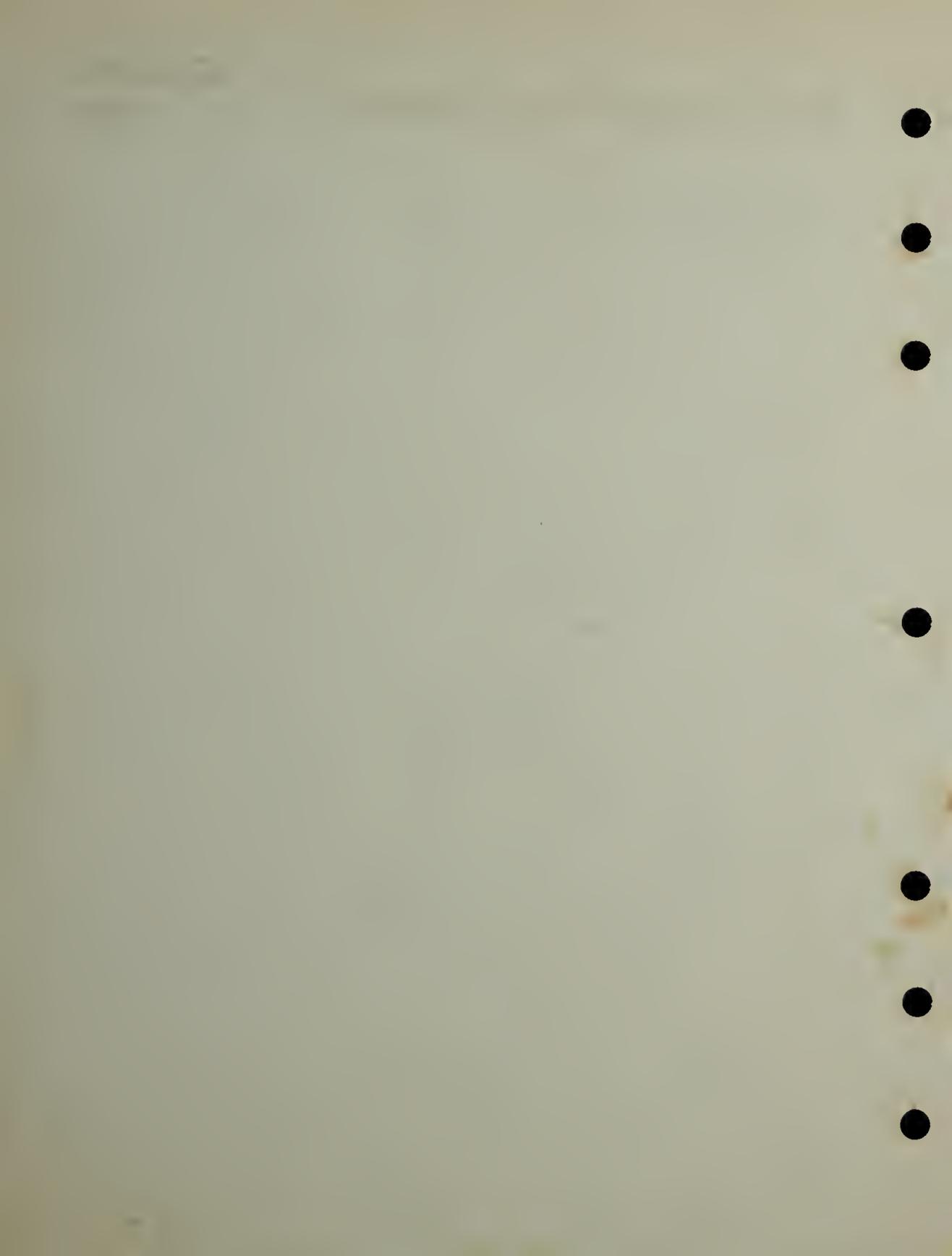
BLOCK II PRIMARY GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

8-9 MAINTENANCE SCHEDULE

The maintenance schedule will be provided when information is available.

8-10 OPTICAL CLEANING

Cleaning of the optics shall be performed only when necessary, and with the approval of the responsible engineer. A JDC giving detailed cleaning instructions will be referenced when information is available.



Appendix A

List of Technical Terms and Abbreviations

<u>Term</u>	<u>Definition</u>
A _{IG}	Inner gimbal angle
A _{MG}	Middle gimbal angle
A _{OG}	Outer gimbal angle
A _S	Shaft angle
A _t	Trunnion angle
a	Accelerometer
AAC	Automatic amplitude control
ABP	Auxiliary battery pack
ACA	Attitude controller assembly
ACC	Accepted
ACCL or ACCEL	Accelerometer
ACE	Automatic checkout equipment
ACTREQ	Action request
ACTY	Activity
AD	Add

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
A/D	Analog to digital
ADA	Angular differentiating accelerometer
ADC	Analog to digital converter
ADIA	Gyro drift due to acceleration along the input axis caused by an unbalance on the spin reference axis
ADSRA	Gyro drift due to acceleration along the spin reference axis caused by an unbalance on the input axis
AGC	Apollo guidance computer
AGC/CS	AGC calibration system
AGC/OC	Apollo guidance computer test set operation console
AGCU	Attitude gyro coupling unit
A-GSE	Auxiliary ground support equipment
AICR	Apollo Integrated Inventory and Consumption Report
αB	Hypothetical rotation of the PIP case about its output axis equivalent to bias. Subscripts (X, Y, or Z) may be added to denote a specific PIP case rotation.
αX , αY , or αZ	Misalignment of PIP case about stable member axis. Subscripts (X, Y, or Z) may be added to denote a specific PIP case alignment.
ATP	Assembly test procedure
ATT	Attitude
BAL	Bank alarm
BD	Bias drift of IRIG. Subscripts (X, Y, or Z) may be added to denote a specific IRIG bias drift.
BKTF	Block transfer

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
BLKUPL	Block uplink
BM-GSE	Bench maintenance ground support equipment
BMAG	Body mounted attitude gyro
BNK	Bank
BPP	Battery power pack
CAGEN	Counter address generate
CCB	Change control board
CCS	Count, compare and skip
CDU	Coupling data unit
CES	Control electronics section
CIS	Communications and instrumentation
CG	Center of gravity
CLR	Clear
CM or C/M	Command module
CMC	Command module computer
COMP	Computer
COMP FAIL	Computer fail
CONT	Control
CS	Clear and subtract
C/S	Computer simulator
CSM	Command and Service Module
CSS	Computer subsystem

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
CTRAL	Counter fail alarm
CTROR	Request to increment counter
CTS	AGC test set
CYL	Cycle left
CYR	Cycle right
D/A	Digital to analog
D and C	Display and control
DAC	Digital to analog converter
DEC	Decrease
DEM0D	Demodulator
DKEND	Downlink end
DLKHN	Downlink inhibit
DLNK	Downlink
DRB	Design review board
DSKY	Display and keyboard
DV	Divide
DVM	Digital voltmeter
ECP	Engineering change proposal
ECS	Environmental control system
E _{ig}	Inner gimbal error signal
E memory	Erasable memory
ENC	Encoder

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
$E\phi_{NB}$	Roll body offset error signal
$E\phi_{sc}$	Roll body error signal
EPS	Electrical power system
$E\Psi_{NB}$	Yaw body offset error signal
$E\Psi_{sc}$	Yaw body error signal
E_{θ}	Pitch body offset error signal
ϵ_{in}	In-phase component of voltage
ϵ_q	Quadrature component voltage
ϵ_t	Total voltage
ϵ_{Fy}	Misalignment between rotary table fixed axes and gimbal case fixed axes
ϵ_{IGA}	Inner gimbal axis error
ϵ_{IGR}	Inner gimbal resolver error
ϵ_{MGA}	Middle gimbal axis error
ϵ_{MGR}	Middle gimbal resolver error
ENOFF	Engine off
ENON	Engine on
ENRST	Engine reset
ϵ_{OGR}	Outer gimbal resolver error
EPS	Electrical power system
ERR	Error

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
EXC or EXCIT	Excitation
$E(X_g)$	X gyro error signal
$E(Y_g)$	Y gyro error signal
$E(Z_g)$	Z gyro error signal
FDAI	Flight director attitude indicator
FINDVAC	Find vector accumulated data
F memory	Fixed memory
FF	Flip-flop or fixed-fixed
FS	Fixed-switchable
g	Gyro
GAEC	Grumman Aircraft Engineering Corporation
$\gamma X, \gamma Y,$ or γZ	Misalignment of IRIG case about stable member corresponding axis. (First subscript denotes a specific gyro, second subscript is added to denote a specific stable member axis about which the gyro input axis is misaligned.)
G and N	Guidance and navigation
GDC	Gyro display coupler
GSE	Ground support equipment
GYRST	Gyro reset
HICOSLAM	High cosine of lambda
HISINLAM	High sine of lambda
HND PPS	Hundred pulses per second
HLOS	Horizon line of sight

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
IA	Input axis
LAW	In accordance with
ICTC	Inertial components temperature controller
IG	Inner gimbal
IIP	Interrupt in progress
ILP	Parity inhibit
IMU	Inertial measuring unit
INC	Increase
INHINT	Inhibit interrupt
INKL	Counter increment request
IP	Interrogate pulse
IRIG	Inertial reference integrating gyro
ISS	Inertial subsystem
IU	Instrumentation unit
JDC	Job description card
JDC-DS	Job description card data sheet
K	Address or location
KEY RLSE	Key release
KRST	Key reset
KSC	Kennedy Space Center
LEM	Lunar excursion module
LINC	Load location

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
LLOS	Landmark line of sight
LOCOSLAM	Low consine of lambda
LOS	Line of sight
LOSINLAM	Low sine of lambda
LSD	Least significant digit
LTRST	Light reset
MC	Memory cycle or memory control
MCT	Memory cycle time
MD	Malfunction diagram
MDA	Motor drive amplifier
Meru	Milliearth rate unit(s)
MG	Middle gimbal
MILA	Merritt Island Launch Area
MINC	Minus increment
MIT/IL	Massachusetts Institute of Technology Instrumentation Laboratory
MKTRP	Mark trap
MNHRPT	Monitor inhibit interrupt
MP	Multiply
MSA	Main summing amplifier
MSA&QR	Main summing amplifier and quadrature rejection
MSC	Manned Spacecraft Center
MSD	Most significant digit

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
MSFN	Manned Space Flight Network
MSK	Mask
MSK K	Mask with data from K
MSTRT	Monitor start
N	Negative velocity pulse
N	Noun
N ₁	Sample time
N ₂	Display time
NAA	North American Aviation
Nav base	Navigation base assembly
NBD	Normal bias drift
ND	NASA document
NDX	Index
NHSYNC	Inhibit upsync
NISQ	Next instruction sequence
NLT	Not less than
NMT	Not more than
NOOP	No operation
NOVAC	No vector accumulated data
NRPTAL	Interrupt has not occurred during an 80 millisecond period
OA	Output axis
OG	Outer gimbal

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
OIA	Optics-inertial analyzer
OINC	Display location
OITS	Optics-inertial test set
OJB	GSE junction box
OPR	Operator
OSS	Optical subsystem
OUA	Optical unit assembly
OUTCR	Out counter
OVCTR	Overflow counter
OVF	Overflow
P	Positive velocity pulse
P _I	Incrementing pulse
P&M	Program & monitor
PA	Pendulum axis
PA	Preamplifier
PAC	Program Analyzer console
PAL	Parity fail alarm
PAVM	Phase angle voltmeter
PCM	Pulse code modulated
PEA	PIPA electronics assembly
PGNCS	Primary guidance, navigation, and control system

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
ΦH_{MGA}	Corrected reading taken from the tilt axis optigon screen with rotary axis at θH_{OGA} , outer gimbal at precision zero, and middle gimbal axis in horizontal plane
ΦH_{RA}	Corrected reading taken from the tilt axis optigon screen with rotary axis in horizontal plane
PIA	Pre-installation acceptance
PINC	Plus increment
PIP	Pulsed integrating pendulum
PIPA	Pulsed integrating pendulum accelerometer
PPA	Pre power assurance
PROG ALM	Program alarm
PSA	Power and servo assembly
PTC	Portable temperature controller
PTE	Pulse torque electronics
PTPS	Pulse torque power supply
PVR	Precision voltage reference
RCS	Reaction control system
RDA	Resolver drive amplifier
RDRST	Radar reset
REJ	Rejected
REL	Release
RELINT	Release inhibit interrupt
RIB	Retrofit instruction bulletin
RL	Read line
RLSE	Release

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
RLYBIT	Relay bit
RLYWD	Relay word
RPTAL	Interrupt lock alarm
RPTLDS	Interrupt in progress longer than 10 milliseconds
RSM	Resume
RSTRT	Read start
RUPT	Interrupt
S	Total gain from rotation about an IRIG input axis to voltage output of the preamplifier, (millivolts per milliradians). Subscripts (X, Y, or Z) may be added to denote a specific IRIG total gain voltage.
SA	Servo amplifier
SAT	System assembly and test
S/C or SC	Spacecraft
SCAFAL	Scaler fail alarm
SCS	Stabilization and control system
SCT	Scanning telescope
SC _x	Spacecraft roll axis
SDA	Shaft drive axis
SETEK	Set strobe
SF(A)	Scale factor of PIP. Subscripts (X, Y, or Z) may be added to denote a specific PIP scale factor.
SFTG	Scale factor of torque generator, (milliradians per pulse). Subscripts (X, Y, or Z) may be added to denote a specific IRIG torque generator scale factor.

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
SG	Signal generator
SHANC	Shift and add increment
SHINC	Shift increment
SIDL	System Identification Data List
SJB	GSE-PSA junction box assembly
SL	Shift left
SM	Stable member or service module
SP	Switch pulse
SPS	Service propulsion system
SQG	Sequence generator
SR	Shift right
SRA	Spin reference axis
ST	State
STBY	Standby
STD2	Standard subinstruction two
S _t LOS	Star line of sight
STMIC	Standard memory inquiry cycle
SU	Subtract
SXT	Sextant
TC	Transfer control
TCAL	Transfer control trap alarm

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
TCSA	Start at specified address
TDA	Torque drive amplifier or trunnion drive axis
TDCR	Technical data change request
TDCR-RB	Technical data change request review board
TDRR	Technical data release or revision
TG	Tachometer-generator
THRCOM	Thrust command
θH_{IGA}	Corrected reading taken from the rotary axis optigon screen with outer and middle gimbals at precision zero, and inner gimbal axis at local vertical
θH_{OGA}	Corrected reading taken from the rotary axis optigon screen with rotary axis horizontal and outer gimbal axis horizontal and east
$\theta + lg$	True table rotary axis angle which places PIP input axis opposite local vertical vector. Subscripts (X, Y, or Z) may be added to denote a specific PIP input axis.
$\theta - lg$	True table rotary axis angle which places PIP input axis along local vertical vector. Subscripts (X, Y, or Z) may be added to denote a specific PIP input axis.
TLEND	Telemetry end
TLOS	Tracker line of sight
TLSTRT	Telemetry start
TM	Torque command pulse
TP	Test point or test parity
TPA	Test point adapter

Appendix A (cont)

<u>Term</u>	<u>Definition</u>
TS	Transfer to storage
ULNK	Uplink
UNF	Underflow
UPTLM	Up telemetry
V	Velocity
V	Verb
VDW	Variable deviation wedge
VTVOM	Vacuum tube voltohmmeter
WA	Write amplifier
WL	Write line
wrt	With respect to
XCH	Exchange
XFMR	Transformer
X_{sc}	Spacecraft roll axis
Y_{sc}	Spacecraft pitch axis
Z_{sc}	Spacecraft yaw axis
ZID	Inhibit strobe

Appendix B

RELATED DOCUMENTATION

This appendix explains the function and relationship of the System Identification Data List (SIDL), the Apollo Integrated Inventory and Consumption Report (AIICR), and the aperture card system to the manual.

SIDL is an official release record for documents issued to implement NASA contracts. SIDL identifies drawings, specifications, manuals and job description cards (JDC's), and other documents released to support the Block II Primary Guidance, Navigation, and Control System (PGNCS).

Manuals and JDC's are based upon the latest information available as of the publication freeze date. Manuals and JDC's are distributed after formal CCB approval. SIDL shall be consulted to determine which is the currently effective information. AC Electronics, Field Service Publications Department, will periodically revise the manuals and JDC's to the latest technical information releases.

The AIICR is a listing of all approved spare parts for the PGNCS and its associated ground support equipment (GSE).

The aperture card system is a compilation of documents in the Apollo program. Each aperture card consists of a mounted 35 MM microfilm copy of a complete document, with the exception that for manuals, only the title page, signature page, record of revisions page, and list of effective pages are included to identify the revision letter, change pages, and TDRR number.

Aperture card sets are maintained at all field sites and are used with the PGNCS manual to refer to schematics, wiring diagrams, and other drawings which are not included in the manual.

