SECTION 2

SUBSECTION 2.1

GUIDANCE AND CONTROL

2.1.1 GUIDANCE AND CONTROL SYSTEMS INTERFACE

The Apollo guidance and control functions are performed by the primary guidance, navigation, and control system (PGNCS), and stabilization and control system (SCS). The PGNCS and SCS systems contain rotational and translational attitude and rate sensors which provide discrete input information to control electronics which, in turn, integrate and condition the information into control commands to the spacecraft propulsion systems. Spacecraft attitude control is provided by commands to the reaction control system (RCS). Major velocity changes are provided by commands to the service propulsion system (SPS). Guidance and control provides the following basic functions:

- Attitude reference
- Attitude control
- Thrust and thrust vector control

The basic guidance and control functions may be performed automatically, with primary control furnished by the command module computer (CMC), or manually, with primary control furnished by the flight crew.

2.1.2 ATTITUDE REFERENCE

The attitude reference function (figure 2.1-1) provides display of the spacecraft attitude with respect to an established inertial reference on the two flight director attitude indicators (FDAI) located on the main display console (MDC), panels 1 and 2. The displayed information consists of:

- Total attitude displayed by the FDAI ball.

- Attitude errors by three needles across scales on the top, right, and bottom of the apparent periphery of the ball.

- Angular rates by needles on the top, right, and bottom of the FDAI face.

Total attitude information is derived from the inertial measurement unit (IMU) or the gyro display coupler (GDC). The total attitude provided by the IMU is the gimbal angles from the gyro-stabilized platform aligned to an inertial reference (spacecraft attitude with respect to inertial reference). Angular rates from the gyro assemblies are transformed and converted to inertial angles in the GDC for total attitude display.

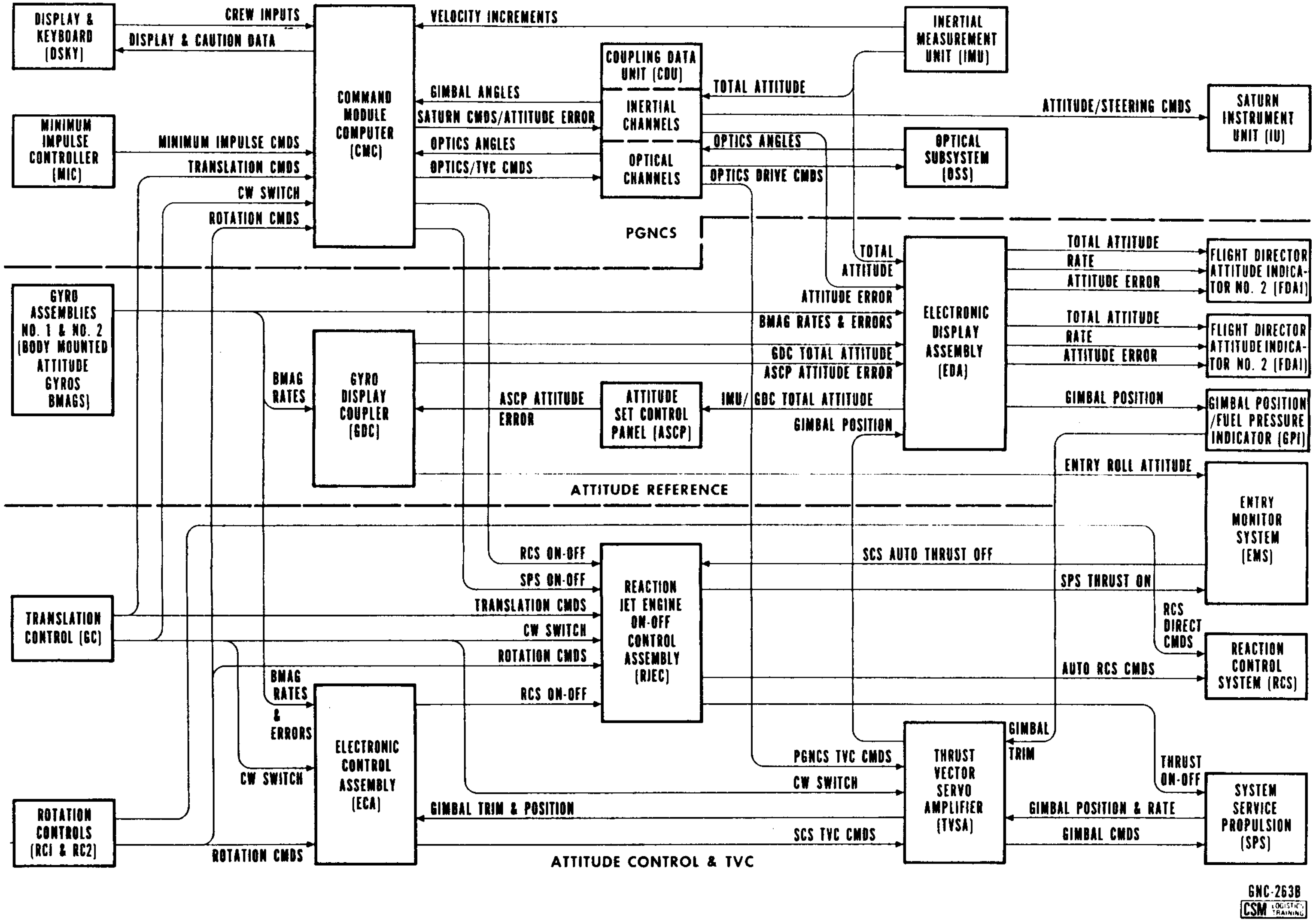

Figure 2.1-1. G&C Block Diagram

Attitude error is derived from the following three sources:

- PGNCS coupling data unit (CDU) inertial channels.
- Gyro assembly No. 1 body-mounted attitude gyros (BMAGs).
- GDC produced attitude set control panel (ASCP) attitude errors.

The attitude errors from the PGNCS are computed in the CMC as angular differences between the desired attitude (gimbal angles) and present IMU gimbal angles. The coupling data unit converts the digital output of the CMC to analog signals for the FDAI. The body-mounted attitude gyros (one for each of the X, Y, and Z axes) are single degree-of-freedom attitude gyros. Any spacecraft rotation about an axis will offset the case of the gyro from the float. This rotation is sensed as a displacement off null, and a signal is produced representative of the magnitude and direction. The GDC produces attitude errors by comparing the transformed and converted angular rates with the stored attitude from the attitude set control panel. The attitude error signals from PGNCS, gyro assembly No. 1, and the GDC are processed in the electronic display assembly (EDA) and applied to the FDAI attitude error needles.

Rate information from the roll and yaw gyros is transformed and converted in the GDC to provide an entry roll attitude signal to the entry monitor system (EMS). This entry roll attitude is an indication of the spacecraft lift vector orientation about the stability axis.

Angular rates are derived from either gyro assembly No. 1 or No. 2. Normally, the No. 2 assembly is used; however, gyro assembly No. 1 may be switched to a backup rate mode if desired. The output signal from the caged gyro assembly is applied to the GDC for updating of spacecraft attitude and to the EDA for processing. The processed rate information from the EDA is applied to both FDAIs for rate display.

2.1.3 ATTITUDE CONTROL

The attitude control as illustrated in figure 2.1-1 is used to maintain a specific orientation or to command small rotations or translations. Attitude control consists of:

- Automatic maneuvers.
- Maintaining a specific orientation (attitude hold).
- Manual maneuvers.
- Direct commands.

Automatic maneuvers are controlled by the PGNCS. During phases of the mission automatic maneuvers are initiated by computer programs or the crew to align the attitude of the spacecraft. The command module computer (CMC) will supply a discrete RCS on-off signal to the reaction jet engine on-off control assembly (RJEC). The RJEC conditions the CMC input and applies an auto RCS command to the reaction control system (RCS) to fire the appropriate engines to perform the desired maneuver.

Attitude hold is controlled by the PGNCS or SCS. The attitude is maintained within a specified deadband (attitude and rate limits) limit. The crew specifies the deadband by switch settings for SCS control or by use of the display and keyboard (DSKY) to the CMC.

The CMC has the present orientation of the spacecraft stored, and with the deadband specified by the crew, any spacecraft drift is sensed by the IMU which transmits the gimbal angle changes to the CMC through the coupling data unit (CDU). When the spacecraft exceeds the limits specified by the crew, the CMC will issue discrete RCS on-off commands to the RJEC to turn on the appropriate engine to return the spacecraft within the specified deadband. To maintain attitude hold in the SCS, the attitude error signals from gyro assembly No. 1 and rate signals from assembly 1 or 2 as described in the attitude reference section are applied to the electronic control assembly (ECA). The crew specifies the deadband in the SCS by switch settings on MDC panel 1. If the spacecraft exceeds the limits specified, the ECA provides RCS on-off commands to the RJEC to turn on the appropriate engine to return the spacecraft within the specified deadband.

Manual maneuvers are provided by the PGNCS or SCS by use of the rotation controls (RC 1 and RC 2), translation control (TC) or minimum impulse controller (MIC). Movement of the rotation or translation controllers from the detent position closes switches (breakout) and applies a discrete to the CMC and RJEC. If the PGNCS is providing attitude control, the CMC will issue commands for rate maneuvering (rotation control input) about the selected axes or acceleration commands (translation control input) along an axes to the RJEC.

The RJEC will condition the PGNCS rate (rotation) and acceleration (translation) inputs and accept the discrete acceleration (rotation and translation) inputs during SCS attitude control to provide the auto RCS commands to the RCS system to turn on the appropriate engine. The rotation commands to the ECA are analog signals which change in amplitude proportional to the amount of rotation control deflection from detent. The analog signal is summed with the gyro assembly 1 or 2 rate feedback signal to provide a proportional rate output (RCS on-off) to the RJEC. The RJEC accepts the proportional rate command and discrete (breakout) command during SCS attitude control to provide the auto RCS commands to the RCS system. The minimum impulse controller (MIC) provides discrete inputs to the CMC, which supplies a 14 millisecond RCS on-off command to the RJEC each time the MIC is moved from the detent position. RCS direct commands to turn on the appropriate engine are provided from the rotation controls when the controller is deflected beyond the hard stop. The RCS direct commands bypass all electronics in the G&C system and are used in emergency conditions.

2.1.4 THRUST VECTOR CONTROL

The guidance and control system provides control of the following thrust functions:

- Guidance (thrust measurement and control)
- Thrust vector control (steering)

Primary control of the guidance function is performed by the PGNCS. Prior to a thrust maneuver, the CMC computes, or is supplied through up datalink or crew DSKY input, the thrust magnitude, direction, and time of thrust initiation. At time of thrust initiation and crew response to a display, the CMC will provide the SPS ON command to the RJEC. The RJEC conditions the command and supplies the thrust-on command to the service propulsion system (SPS) to ignite the engine and the SPS thrust-on signal to the EMS to illuminate the thrust-on lamp. The measurement of the thrust is performed by the three orthogonally mounted accelerometers on the stable platform of the inertial measurement unit (IMU). When the desired velocity change has been achieved, the CMC removes the SPS on command. Secondary control of the guidance function is performed by the SCS. Prior to a thrust maneuver, the thrust magnitude is set into the velocity counter of the EMS. Thrust initiation is performed by the crew by depressing the thrust-on switch located on MDC panel 1. The thrust-on command is conditioned by the RJEC which supplies the thrust-on command to the SPS and SPS thrust-on to the EMS to illuminate the thrust-on lamp. The velocity change is sensed by the +X axis accelerometer of the EMS which produces an output representative of the velocity change. These signals decrement the EMS velocity counter toward zero. When the velocity counter reaches zero the EMS issues the SCS auto thrust-off command to the RJEC.

Thrust vector control is required to steer the vehicle to maintain a fixed thrust line or fixed inertial orientation. In addition, the control system is used to maintain the thrust vector through the center of gravity of the vehicle for stability. Prior to a thrusting maneuver (whether PGNCS or SCS controlled), the SPS engine is trimmed (aligned) with the thrust vector through the center of gravity and the spacecraft is aligned (maneuvered) with the +X axis along the desired thrust line.

PGNCS thrust vector control is performed by the TVC digital autopilot (computer software) of the CMC which accepts steering commands from the thrusting program and maintains the thrust vector through the center of gravity. Attitude changes of the vehicle caused by center of gravity shift because of propellant usage, fuel slosh, bending moments, or trim misalignment are sensed by the IMU.

The gimbal angle changes are converted to vehicle body rates, differenced with thrusting program steering commands (vector rate), integrated to attitude errors and differenced with the present computed trim of the SPS engine. This error signal is applied to the CDU optical channels for conversion (digital to analog). The PGNCS TVC command is then applied to the thrust vector servo amplifier (TVSA).

SCS thrust vector control is provided automatically or manually. Attitude changes and vehicle body rates are sensed by gyro assembly No. 1 and No. 2 respectively. The attitude errors from GA 1 are differenced with the SPS gimbal position and trim, integrated and summed with rate from GA 2 to provide the SCS TVC command from the electronic control assembly (ECA) to the TVSA during the automatic mode. Manual thrust vector control utilizes the analog output of the rotation controls moved from detent. The analog signal is summed with rate feedback from GA 1 or GA 2 to provide the proportional rate command. This signal is integrated and applied to the TVSA as the SCS TVC command (manual thrust vector control - MTVC). The PGNCS and SCS TVC commands to the TVSA are summed with the gimbal position and rate commands from the SPS. The resultant signal is applied to the servo amplifier which supplies the extend or retract (gimbal commands) commands to the SPS.

SECTION 2

SUBSECTION 2.2

GUIDANCE AND NAVIGATION SYSTEM (G&N)

2.2.1 INTRODUCTION

The primary guidance, navigation and control system (PGNCS) provides the following functions:

- Inertial velocity and position (state vector) computation
- Optical and inertial navigation measurements
- Spacecraft attitude measurement and control
- Generation of guidance commands during CSM powered flight and CM atmospheric entry

The PGNCS system consists of three subsystems:

- Inertial subsystem (ISS)
- Optical subsystem (OSS)
- Computer subsystem (CSS)

They are located in the command module lower equipment bay (figure 2.2-1). System circuit breakers, caution and warning indicators and one of the display and keyboard panels (DSKY) are located on the main display console.

2.2.2 PGNCS DATA FLOW

2.2.2.1 Inertial Subsystem

The inertial subsystem (ISS) is composed of an inertial measurement unit (IMU), part of the power and servo assembly (PSA), part of the controls and displays, and three coupling data unit (CDU) channels. The IMU provides an inertial reference with a gimbaled, three-degree-of-freedom, gyro-stabilized platform. The alignment of the stable platform (figure 2.2-1A) is accomplished by the command module computer (CMC) providing a digital pulse train and control commands to the CDU. The CDU converts the pulse train to analog signals which drive the IMU to the desired orientation. Attitude change sensing is accomplished by monitoring the spacecraft attitude with reference to the stable platform. Resolvers are mounted at the gimbal axes to provide signals representative of the gimbal angles. The CDU converts these analog signals to digital pulses for the CMC. The CMC compares these angles with the CMC desired angles, and if the angles differ, error signals are generated. The error signals can be used as steering commands to the SIVB guidance system, attitude error display signals or RCS on-off commands to the stabilization and control system (SCS).

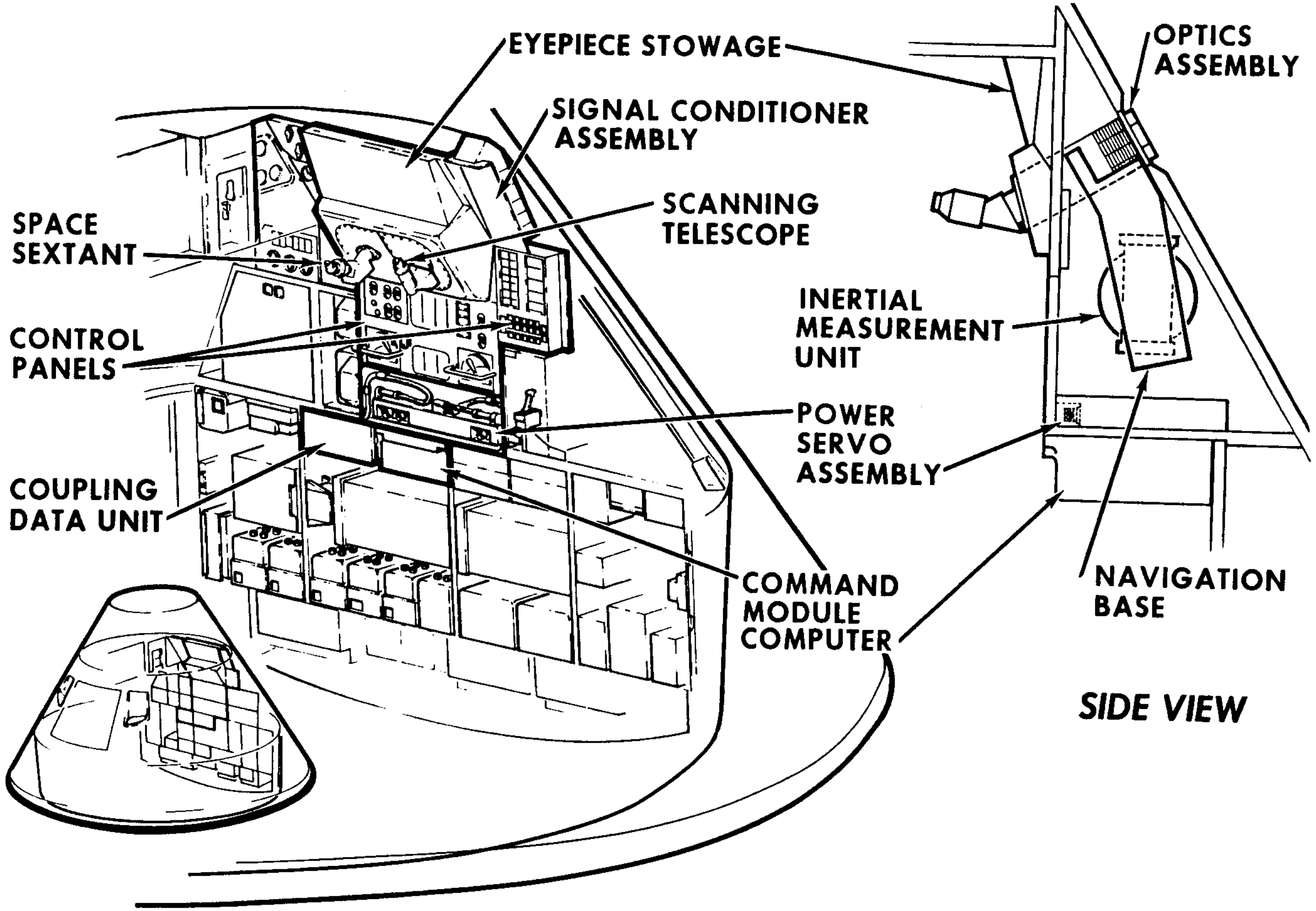

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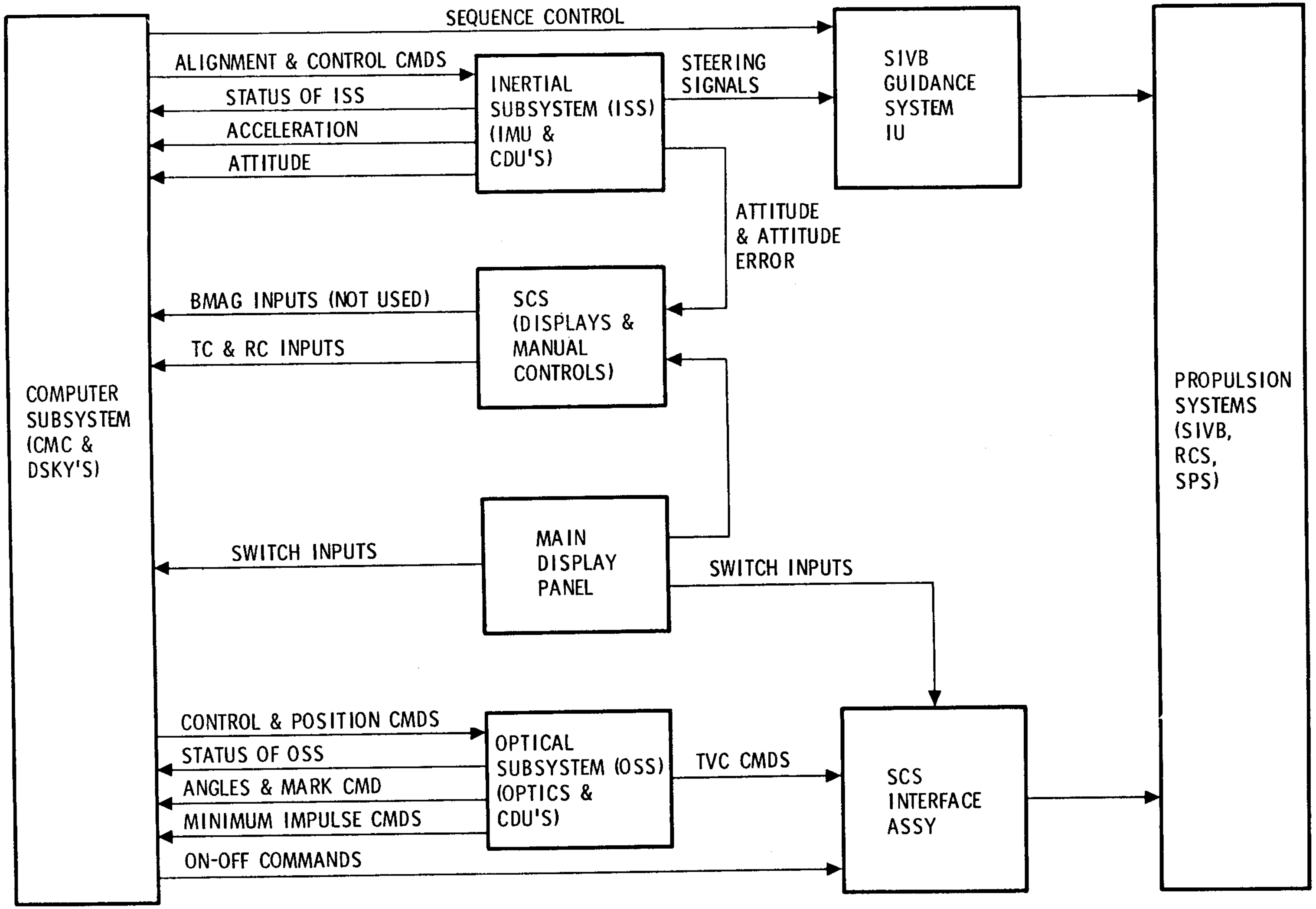
Figure 2.2-1. G&N Equipment Location



GNC-5G
CSM LOGISTICS TRAINING

Figure 2.2-1A. PGNCS Data Flow

Mounted on the stable platform are the pulsed integrating pendulous accelerometers (PIPAs) which sense changes in spacecraft velocity. An acceleration or deceleration results in output signals which are representative of the magnitude and direction of the velocity change. The output signals are applied to the CMC which uses the information to update spacecraft velocity data.

Also applied to the CMC are discrete signals reflecting the status (caution and warning information) of the IMU and CDU.

2.2.2.2 Optics Subsystem

The optics subsystem is composed of a scanning telescope (SCT), sextant (SXT), drive motors for positioning the SCT and SXT, parts of the PSA, part of the controls and displays, and two CDU channels. The SCT and SXT are used to determine the spacecraft position and attitude with relation to stars and landmarks or horizon.

The optics are positioned by drive motors commanded by the optics hand controller (located on the optics control panel, lower equipment bay) or by a digital pulse train from the CMC. The digital pulse train is converted to an analog drive signal in the CDU.

When the navigator is satisfied with the image position, he issues a mark command to the CMC. The position of the optics is provided by resolvers mounted on the optics. The CDU converts the analog resolver signal to digital pulses representative of the optics angles. The CMC reads these angles, IMU angles, and time of mark command. From this information the CMC computes the spacecraft position.

The minimum impulse commands from the minimum impulse controller (on the optics control panel in the lower equipment bay) are discrete inputs to the CMC. The CMC provides on-off commands to the SCS for firing of the RCS jets to maintain attitude during sightings with the optics.

The channels of the CDU used to position the optics are also used to convert the digital pulse train from the CMC to a d-c signal to the SCS as guidance commands (TVC) during CSM powered flight.

Also applied to the CMC are discrete signals reflecting the status (caution and warning information) of the CDU optics channels.

2.2.2.3 Computer Subsystem

The computer subsystem (CSS) consists of the command module computer (CMC) and two display and keyboard panels (DSKYs), which are part of the controls and displays.

The CMC provides automatic execution of computer programs, automatic control of ISS and OSS modes, and in conjunction with the DSKYs, manual control of ISS and OSS modes and computer displays. The CMC contains a two-part memory which consists of a large nonerasable (fixed) section and a smaller erasable section. Nonerasable memory contains mission and system programs, and other predetermined data which are wired in during assembly. Data readout from this section is nondestructive and cannot be changed during operation. The erasable section of memory provides for data storage, retrieval, and operations upon measured data and telemetered information. Data readout from this section is destructive, permitting changes in stored data to be made as desired. Information within the memory may be called up for display on the two DSKYs. The DSKYs enable the flight crew to enter data or instructions into the CMC, request display of data from CMC memory, and offer an interrupt control of CMC operation.

The CMC performs guidance functions by executing internal programs using predetermined trajectory parameters, attitude angles from the inertial channels of the CDU, velocity changes from the PIPAs, and commands from the DSKYs (crew) to generate control commands. The navigation function is performed by using stored star-landmark or star-horizon data, optics angles from the optics channels of the CDU, and velocity changes from the PIPAs in the execution of navigation programs.

2.2.3 MAJOR COMPONENT/SUBSYSTEM DESCRIPTION

2.2.3.1 Inertial Subsystem

The function of the inertial subsystem is to provide a space-stabilized inertial reference from which velocity changes and attitude changes can be sensed. It is composed of the navigation base (NB), the inertial measurement unit (IMU), parts of the power and servo assembly (PSA), parts of the control and display panels, and three coupling data units (CDUs).

2.2.3.1.1 Navigation Base

The navigation base (NB) is the rigid, supporting structure which mounts the IMU and optical instruments. The NB is manufactured and installed to close tolerances to provide accurate alignment of the equipment mounted on it. It also provides shock-mounting for the IMU and optics.

2.2.3.1.2 Inertial Measurement Unit

The inertial measurement unit (IMU) is the main unit of the inertial subsystem. It is a three-degree-of-freedom stabilized platform assembly, containing three inertial rate integrating gyros (IRIGs), and three pulsed-integrating pendulous accelerometers (PIPAs). The stable member itself is machined from a solid block of beryllium with holes bored for mounting the PIPAs and IRIGs.

The stable platform attitude is maintained by the IRIGs, stabilization loop electronics, and gimbal torque motors. Any displacement of the stable platform or gimbal angles is sensed by the IRIGs which generate error signals. IRIG error signals are resolved, amplified, and applied to stabilization loop electronics. The resultant signal is conditioned and applied to the gimbal torque motors, which restore the desired attitude.

The stable platform provides a space-referenced mount for three PIPAs, which sense velocity changes. The PIPAs are mounted orthogonally to sense the velocity changes along all three axes. Any translational force experienced by the spacecraft causes an acceleration or deceleration which is sensed by one or more PIPAs. Each PIPA generates an output signal proportional to the magnitude and direction of velocity change. This signal, in the form of a pulse train, is applied to the CMC. The CMC will use the signal to update the velocity information, and will also generate signals to enable the torquing of each PIPA ducosyn back to null.

The temperature control system is a thermostatic system that maintains the IRIG and PIPA temperatures within their required limits during both IMU standby and operate modes. Heat is applied by end-mount heaters on the inertial components, stable member heaters, and a temperature control anticipatory heater. Heat is removed by convection, conduction, and radiation. The natural convection used during IMU standby modes is changed to blower-controlled, forced convection during IMU operating modes. IMU internal pressure is normally between 3.5 and 15 psia enabling the required forced convection. To aid in removing heat, a water-glycol solution passes through coolant passages in the IMU support gimbal. Therefore, heat flow is from the stable member to the case and coolant. The temperature control system consists of the temperature control circuit, the blower control circuit, and the temperature alarm circuit. A separate external temperature control system is also provided for test configurations but will not be discussed in this manual.

2.2.3.1.3 Coupling Data Unit

The CDU, an all electronic device, is used as an interface element between the ISS and CSS, the OSS and CSS, and the CSS and various controls and displays. It functions primarily as an analog-to-digital (A/D) or digital-to-analog (D/A) converter. There are five, almost identical, loops, one each for the inner, middle, and outer IMU gimbals, and one each for the shaft and trunnion optical axes. The ISS portion of the CDU performs the following functions:

a. Converts IMU gimbal angles from analog-to-digital form, and supplies the CMC with this information.

b. Converts digital signals from the CMC to either 800-cps or d-c signals.

c. Controls the moding of the ISS through logical manipulation of computer discretes.

The analog signal from the 1X and 16X resolvers, located on the IMU gimbals, is transmitted to the CDU. This angular information, proportional to the sine and cosine of the gimbal angle, is converted to digital form with one pulse to the CMC equivalent to 40 arc-seconds of gimbal movement.

During coarse align, attitude error display, and Saturn takeover modes, the ISS channels of the CDU provide the digital to analog conversion of the CMC output to generate an a-c or d-c output. The a-c output is applied to the servo amplifiers of the PSA to drive the gimbals to the desired angle, and is also applied to the FDAI for deflection of the attitude error needles. The d-c signal is applied to the Saturn flight control computer which will gimbal the Saturn engine or provide commands to the Saturn attitude control system.

2.2.3.1.4 Power and Servo Assembly

The purpose of the power and servo assembly (PSA) is to provide a central mounting point for the majority of the G&N system power supplies, amplifiers, and other modular electronic components.

The PSA is located on the lower D&C panel rack directly below the IMU. It consists of 42 modules mounted to a header assembly. Connectors and harnessing are integral to the construction of the header assembly, and G&N harness branches are brought out from the PSA header. A thin cover plate is mounted on the PSA, providing a hermetic seal for the interior. During flight, this permits pressurization of the PSA to remain at 15 psi. Connectors are available at the PSA for measuring signals at various system test points.

2.2.3.2 Computer Subsystem

The computer subsystem (CSS) consists of the command module computer (CMC), and two display and keyboard panels (DSKYs). The CMC and one DSKY are located in the lower equipment bay. The other DSKY is located on the main display console.

2.2.3.2.1 Command Module Computer

The CMC is a core memory, digital computer with two types of memory, fixed and erasable. The fixed memory permanently stores navigation tables, trajectory parameters, programs, and constants. The erasable memory stores intermediate information.

The CMC processes data and issues discrete control signals, both for the PGNCS and the other spacecraft systems. It is a control computer with many of the features of a general purpose computer. As a control computer, the CMC aligns the stable platform of the inertial measurement unit (IMU) in the inertial subsystem, positions the optical unit in the optical subsystem, and issues control commands to the spacecraft. As a general purpose computer, the CMC solves guidance problems required for the spacecraft mission. In addition, the CMC monitors the operation of the PGNCS and other spacecraft systems.

The CMC stores data pertinent to the flight profile that the spacecraft must assume in order to complete its mission. This data, consisting of position, velocity, and trajectory information, is used by the CMC to solve the various flight equations. The results of various equations can be used to determine the required magnitude and direction of thrust required. Corrections to be made are established by the CMC. The spacecraft engines are turned on at the correct time, and steering signals are controlled by the CMC to reorient the spacecraft to a new trajectory, if required. The inertial subsystem senses acceleration and supplies velocity changes to the CMC for calculating the total velocity. Drive signals are supplied from the CMC to coupling data unit (CDU) and stabilization gyros in the inertial subsystem to align the gimbal angles in the IMU. Error signals are also supplied to the CDU to provide steering capabilities for the spacecraft. CDU position signals are fed to the CMC to indicate changes in gimbal angles, which are used by the CMC to keep cognizant of the gimbal positions. The

CMC receives mode indications and angular information from the optical subsystem during optical sightings. This information is used by the CMC to calculate present position and orientation, and is used to refine trajectory information. Optical subsystem components can also be positioned by drive signals supplied from the CMC.

CMC Organization. The CMC is functionally divided into seven blocks. (See figure 2.2-2.)

1. Timer
2. Sequence generator
3. Central processor
4. Memory
5. Priority control
6. Input-output
7. Power

Timer. The timer generates all the necessary synchronization pulses to ensure a logical data flow from one area to another within the CMC. It also generates timing waveforms which are used by (1) the CMC's alarm circuitry, and (2) other areas of the spacecraft for control and synchronization purposes.

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 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 used 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 subsequently word flow in the computer, can also be controlled by inputs from the computer test set (CTS) during preinstallation systems and subsystem tests.

Sequence Generator. The sequence generator directs the execution of machine instructions. It does this by generating control pulses which logically sequence data throughout the CMC. The control pulses are formed by combining the order code of an instruction word with synchronization pulses from the timer.

The sequence generator contains the order code processor, command generator, and control pulse generator. The sequence generator executes the instructions stored in memory by producing control pulses which regulate the data flow of the computer. The manner in which the data flow is regulated among the various functional areas of the computer and between the elements of the central processor causes the data to be processed according to the specifications of each machine instruction.

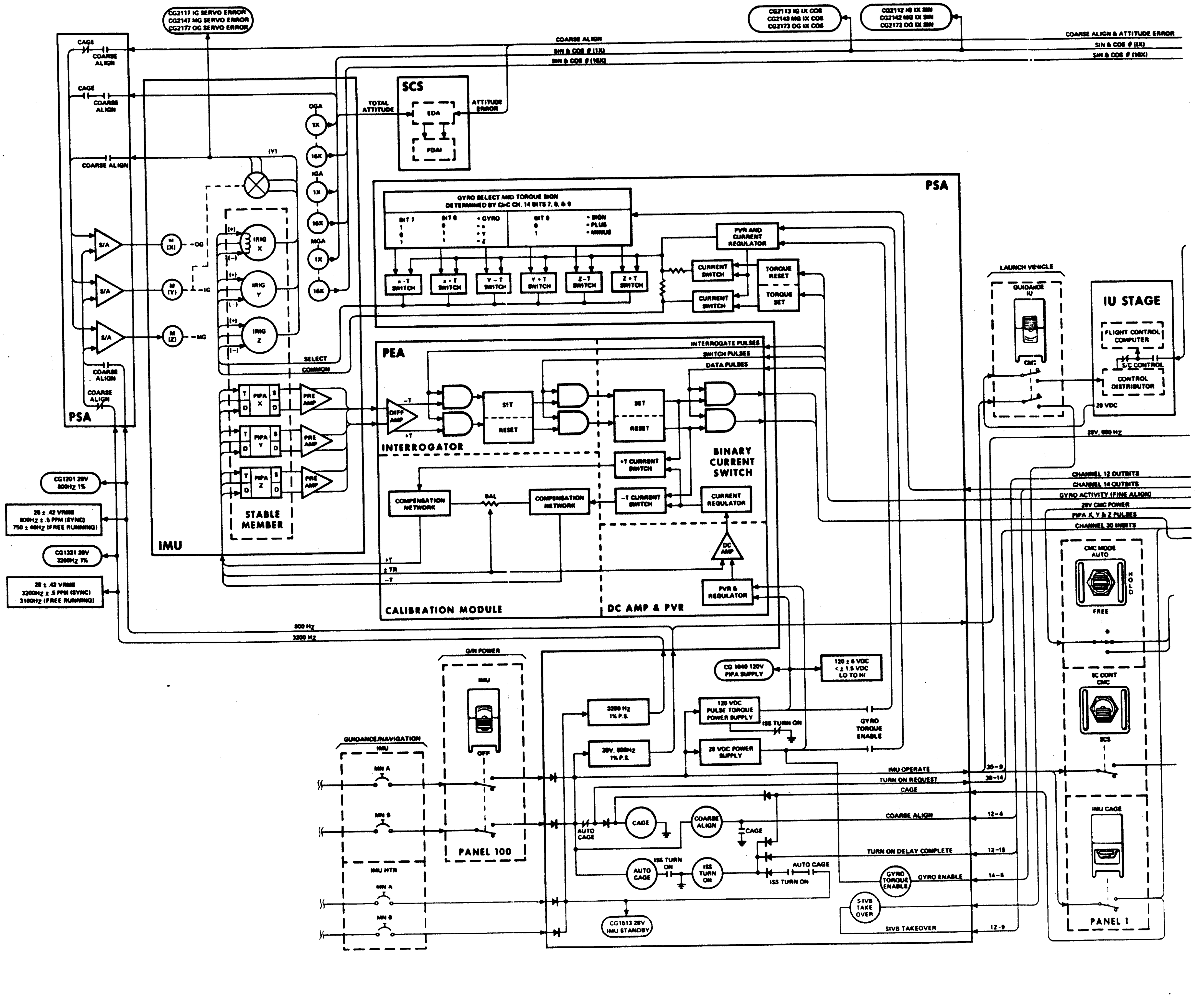


Figure 2.2-2. PGNCS Functional Diagram (Sheet 1 of 2)

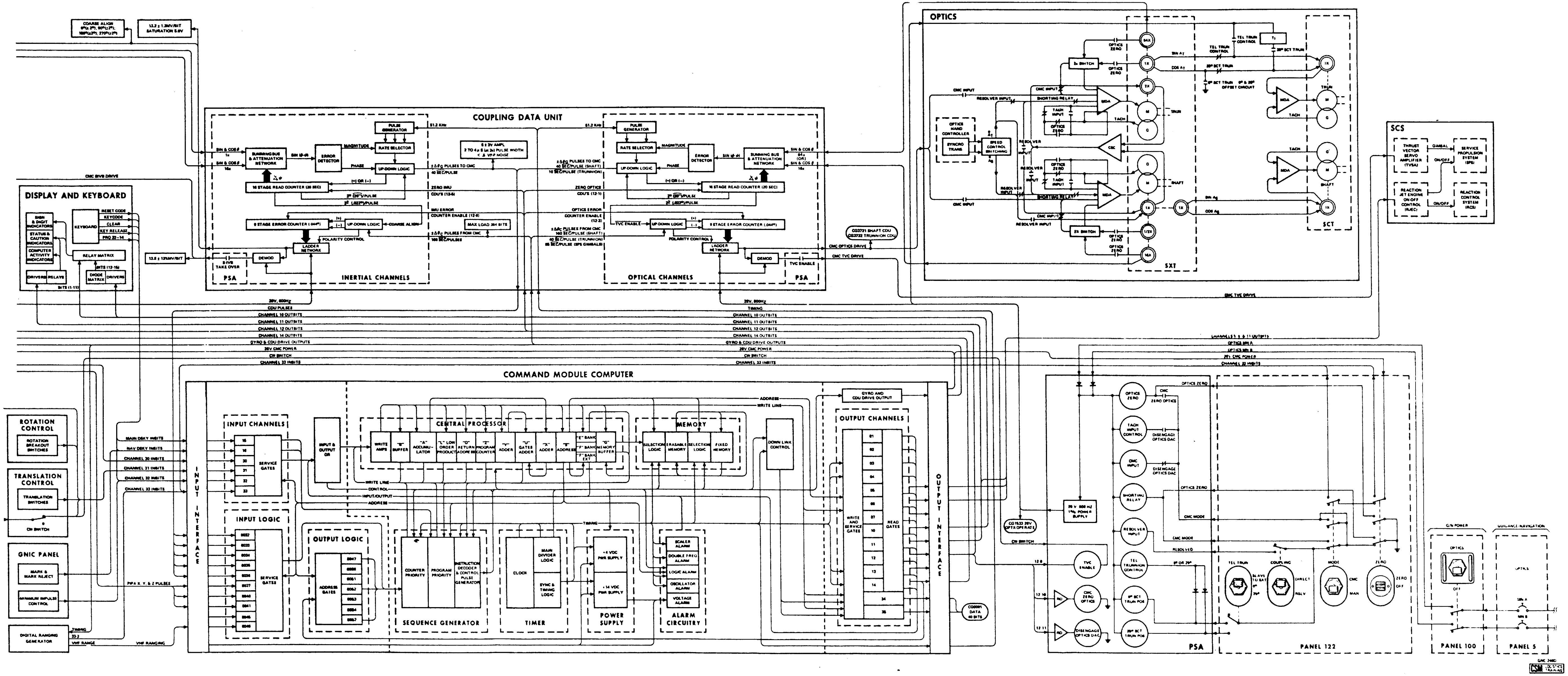


Figure 2.2-2. PGNCS Functional Diagram (Sheet 2 of 2)

The order code processor receives signals from the central processor, priority control, and peripheral equipment (test equipment). The order code signals are stored in the order code processor and converted to coded signals for the command generator. The command generator decodes these signals and produces instruction commands. The instruction commands are sent to the control pulse generator to produce a particular sequence of control pulses, depending on the instruction being executed. At the completion of each instruction, new order code signals are sent to the order code processor to continue the execution of the program.

Central Processor. The central processor performs all arithmetic operations required of the CMC, buffers all information coming from and going to memory, checks for correct parity on all words coming from memory, and generates a parity bit for all words written into memory.

The central processor 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 the 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 specific register, or to another functional area under control of the write, 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 read-out, 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 ary 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 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.

Registers. Registers A, L, Q, Z, and B consist of 16 bit positions each. These are numbered 16 through 1 reading from left to right. Register E BANK consists of three bit positions numbered 11 through 9. Register S consists of 12 bit positions numbered 12 through 1. Register SQ consists of seven bit positions, SQ, EXT, 16 and 14 through 10. Registers X and Y comprise the adder and each register consists of 16 bit positions. The 16 output gates of the adder are called register U; note, however, that U is not a register in the sense of the flip-flop registers comprising the central processor. Register U and the write amplifiers each consists of 16 bit positions numbered 16 through 1. All registers mentioned so far may contain addresses, a code, etc. They do not, however, contain a parity bit. Whenever a number is contained in these registers, the lowest order bit is stored in bit position 1 and the highest order bit is stored in bit position 14. The sign bit is stored in bit position 16. A zero in this bit position signifies a positive number and a one signifies a negative number. Bit position 15 is used for storing either the overflow or underflow bit.

Register G serves as a buffer between the central processor and memory. It consists of 16 bit positions numbered 16 through 1. Any parity bit received from memory is transferred to the parity block but not to the central processor register. The 16 inputs to the parity block are numbered 16 and 14 through 0. No provision is made for entering an overflow bit into the parity block.

Register A is called the "accumulator." It contains the results of arithmetic operations.

Register L is called the "lower order accumulator." It contains the least significant bits of the product or quotient after a multiplication or division process.

Register B is called the "buffer register." It also provides a means of complementing since its reset side can also be interrogated. The reset side is sometimes called "register C."

The Z register is the program counter. It contains the address of the next instruction word in the program. As each instruction is executed, this register is incremented by one because the instruction words usually are stored sequentially in memory.

The Q register is named the "return address register." When the CMC transfers control to another program or routine, the contents of the Z register are stored in register Q. When the CMC returns to the original program, register Q contains the address of the appropriate instruction.

The write amplifiers provide the current driving capabilities for the registers. These amplifiers in no way store information, they simply route information.

Register S contains the address of the word to be called out from memory. Register E BANK is also used when erasable memory is addressed. Register F BANK is used when fixed memory is addressed.

Memory. Memory provides the storage for the CMC and is divided into two sections: erasable memory and fixed memory. Erasable memory can be written into or read from; its readout is destructive. Fixed memory cannot be written into and its readout is nondestructive.

The CMC has erasable and fixed memories. The erasable memory can be written into and read out of; fixed memory can only be read out of. Erasable memory stores intermediate results of computations, auxiliary program information, and variable data supplied by external inputs from the PGNCS and other systems of the spacecraft. Fixed memory stores programs, constants, and tables. There is a total of 38,912, sixteen bit word storage locations in fixed and erasable memories. It should be noted that the majority of the memory capacity is in fixed memory (36,864 word locations). Both memories are magnetic core storage devices; however, the cores are used differently in each type of memory. It is assumed that the reader is familiar with the basic magnetic properties of a ferrite core as described by a square hysteresis curve. A core is a static storage device having two stable states. It can be magnetized in one or two directions by passing a sufficient current, I, through a wire which pierces the core. The direction of current determines the direction of magnetization. The core will retain its magnetization indefinitely until an opposing current switches the core in the opposite direction. Wires carrying current through the same core are algebraically additive. Sense wires which pierce a switched core will carry an induced pulse.

Priority Control. Priority control establishes a processing priority of operations which must be performed by the CMC. These operations are a result of conditions which occur both internally and externally to the CMC. Priority control consists of counter priority control and interrupt priority control. Counter priority control initiates actions which update counters in erasable memory. Interrupt priority control transfers control of the CMC to one of several interrupt subroutines stored in fixed memory.

The start instruction control restarts the computer following a hardware or program failure. The counter instruction control updates the various counters in erasable memory upon reception of certain incremental pulses. The counter instruction control is also used during test functions to implement the display and load requests provided by the computer test set. The interrupt instruction control forces the execution of the interrupt instruction (RUPTOR) to interrupt the current operation of the computer in favor of a programmed operation of a higher priority.

Input-Output. The input-output section routes and conditions signals between the CMC and other areas of the spacecraft. In addition to the counter interrupt and the program interrupts previously described, the CMC has a number of other inputs derived from its interfacing hardware. These inputs are a result of the functioning of the hardware or an action by the operator of the spacecraft. The counter interrupts in most cases, enable the CMC to process inputs representative of data parameters such as changes in velocity. The program interrupt inputs to the CMC are used to initiate processing of functions which must be processed a relatively short time after a particular function is present. The other inputs to the CMC, in general, enable the CMC to be cognizant of "conditions" which exist in its environment. These inputs are routed to CMC and are available to the CMCs programs through the input channels.

The outputs of the CMC fall in one of the following categories: data, control, or condition indications. Some of these outputs are controllable through the CMC program while others are present as a function of the CMC circuitry. All of the outputs which are controlled by the CMC programs are developed through the CMC output channels.

Channel 01 is the L register.
Channel 02 is the Q register.
Channel 03 the high-order scaler channel.
Channel 04 the low-order scaler channel.

Output channel 05 has eight bit positions and is associated with the reaction control system jets.

Output channel 06 has eight bit positions and is also associated with the reaction control system jets. A logic one in any of the bit positions will cause the appropriate reaction control jets to be fired. The outputs of this channel control the jets used for Z and Y translations, and the roll rotation. The logic is the same as for output channel 05. Assume that it was desired to perform a pure roll maneuver. One of the ways this could be implemented would be to have logic ones in bit positions 1 and 3 while all other bit positions contained a logic zero. There are other methods, of course, but these will not be detailed.

Channel 07 is the F EXT register. It is associated with the selection of word locations in fixed memory. This channel has three bit positions.

Output channel 10 routes information contained in this channel to the DSKYs. The different configurations light various displays on the DSKYs.

Output channel 11 routes information contained in bits 1 through 7 of this channel to the DSKYs. Bit 13 is routed to the SCS system.

Output channel 12 consists of 15 bit positions, 14 of which are presently used. The outbits are d-c signals sent to the spacecraft and PGNCS.

Output channel 13 associates the first four bits of this channel with the VHF ranging. Bit positions 12 through 14 have been covered under program interrupt priority control.

Output channel 14 associates bit positions 11 through 15 with the CDU drive control. This control generates the following pulse trains which are sent to the CDUs: CDUXDP (X CDU positive drive pulse), CDUXDM (X CDU negative drive pulse), CDUYDP, CDUYDM, CDUZDP, CDUZDM, TRNDP, TRNDM, SHAFTDP (shaft CDU positive drive pulse), and SHAFTDM. The CDU drive control also enters the following d-c signals into the counter priority control to request the execution of a DINC instruction: X IMU, CDU, Y IMU, CDU, Z IMU CDU, S OP CDU and T OP CDU.

Signal X IMU CDU is generated when bit position 15 contains a logic one. Signal Y IMU CDU is generated when bit position 14 contains a logic one, signal Z IMU CDU when bit position 13 contains a logic one, signal T OP CDU when bit position 12 contains a logic one, and signal S OP CDU when bit position 11 contains a logic one. More than one of these signals can be generated simultaneously.

Once a desired quantity, e.g., -432, has been entered into a CDU counter, e.g., erasable memory address 0050, and output channel 14 has been properly set (logic 1 in bit position 15), the CDU drive control generates signal X IMU CDU which sets a flip-flop in counter priority control and commands the sequence generator to execute a DINC instruction. As the instruction is executed, the counter control is diminished by one to -431. The CDU drive control then generates a CDUXDM pulse and routes it to the X CDU. Since the priority flip-flop is still set, another DINC instruction is requested. This is repeated until the counter content has diminished to zero. Once the counter contains zero and a DINC instruction is executed, a signal is generated which clears bit position 15 of output channel 14, resets the priority cell, and stops the transmission of pulses.

The gyro drive control selects a gyro to be torqued positively or negatively, and then applies a 3200-cps pulse train to the appropriate gyro to accomplish this function. There are six signals associated with selection of the gyro and the direction in which it will be torqued: GYXP (drive gyro x positive), GYXM (drive gyro x negative), GYYP, GYYM, GYZP, and GYZM. The appropriate signal is determined by the bit configuration of bits 7 through 9 of output channel 14. If bit positions 6 and 10 are a logic one, a 3200-cps pulse train is routed to the gyro electronics specified by bit positions 7 through 9, and a d-c signal is entered into the counter priority control which commands the sequence generator to perform a DINC instruction.

Assume that it is desired to torque the X-gyro in the negative direction by 123 pulses. The GYROS counter in counter priority control would be set to 123. Bit positions 7 through 9 would be 101 respectively, and bit positions 6 and 10 would be logic one. Each time a pulse is sent to the gyro, the GYROS counter is DINCed. The d-c signal to counter priority will remain until the GYROS counter goes to zero which will terminate the torquing.

Input Channel 15. This channel consists of five bit positions. When a key on the main panel DSKY is pressed, a unique five-bit code is entered into this channel. The RUPT 5 interrupt routine is also developed whenever a key on the main panel DSKY is pressed.

Input Channel 16. This channel consists of seven bit positions. If the MARK pushbutton has been pressed, a logic one is entered into bit position 6. This would cause a KEYRUPT 2 (RUPT 6) interrupt routine.

If the MARK REJECT pushbutton has been pressed, a logic one is entered into bit position 7 of this channel. This will also cause a KEYRUPT 2 interrupt routine to be performed. When a key on the navigation panel DSKY is pressed, a unique five-bit code is entered into bit positions 1 through 5. The insertion of this code into input channel 16 initiates a KEYRUPT 2 interrupt routine.

Input channels 17 through 27 are spares.

Input Channel 30. This channel consists of 15 bit positions. The inputs to these positions are inverted and utilized as follows:

a. Bit position 1 (ULLAGE THRUST PRESENT). This input is generated by the S-IVB instrumentation unit. If this input is a logic zero, it signifies that the action has occurred or has been commanded to occur.

b. Bit position 2 (SM SEPARATE). This input originates in the mission sequencer and is a logic 0 when the service module is separated from the command module.

c. Bit position 3 (SPS READY). A logic zero in this bit position indicates that the pilot has completed the SPS engine start checklist.

d. Bit position 4 and 5 (S-IVB SEPARATE - ABORT, LIFT OFF). These inputs are generated in the S-IVB instrumentation unit. They indicate that the appropriate actions have occurred or have been commanded to occur.

e. Bit position 7 (OCDU FAIL). This input is generated in the OSS and is a logic zero when a failure has occurred in one of the optical CDUs.

f. Bit position 9 (IMU OPERATE). A binary zero in this bit position indicates that the IMU is turned on and is operating with no malfunctions.

g. Bit position 10 (SC CONTROL OF SATURN). A logic zero in this bit position indicates that the SC has control over the SATURN stage.

h. Bit position 11 (IMU CAGE). A logic zero in this bit position indicates that the IMU gimbals are at their null position.

i. Bit position 12 (IMU CDU FAIL). A logic zero in this bit position indicates that a failure has occurred in one of the inertial CDUs.

j. Bit position 13 (IMU FAIL). A logic zero in this bit position indicates that a malfunction has occurred in the IMU stab loops.

k. Bit position 14 (ISS TURN ON REQUEST). A logic zero is inserted into this bit position when the ISS has been turned on, or commanded to be turned on.

l. Bit position 15 (TEMP IN LIMITS). A logic one is inserted into this bit position if the stable member temperature has not exceeded its design limits. If the limit has been exceeded, a logic zero will be stored.

Input channel 31, channel consists of 15 bit positions. Bit positions 1 through 6 receive their inputs from the rotational hand controller. A logic zero in any one of these bit positions is associated with roll, pitch, or yaw commands. Bit positions 7 through 12 receive their inputs from the translational hand controller. A logic zero in any one of these bit positions is associated with the X, Y, or Z translation commands.

A logic zero in bit position 13 indicates that the present SC attitude is being held and the hand controller is not being used. A logic zero in bit position 14 indicates that the SC is drifting freely, and that the CMC is not receiving inputs from the hand controller or minimum impulse controller. A logic zero in bit position 15 indicates that the CMC is controlling the present SC attitude and the hand controller is not commanding an attitude change. All inputs to this channel are inverted.

Input channel 32, the first six bit positions of this channel receive their inputs from the minimum impulse controller. A logic zero in any of these bit positions is associated with the pitch, yaw, or roll motion commanded by the minimum impulse controller. Bit position 11 contains a logic zero while the LM is attached to the CSM. All inputs to this channel are inverted.

Input channel 33, inputs to this channel are generated in the CMC and optics. A logic zero in bit position 2 indicates that the VHF digital ranging information is good. Bit positions 4 and 5 receive d-c signals from the optics control panel. The d-c signals are generated by switch and relay closures. A logic zero appears in bit position 10 if the BLOCK UPLINK switch is thrown to the BLOCK position. Bit positions 11 or 12 contain a logic zero if the uplink or downlink telemetry rates are too high. Bit position 13 contains a logic zero if a failure occurs in the accelerometer loops. All inputs to this channel are inverted.

Output channels 34 and 35 provide 16 bit words including a parity bit for downlink telemetry transmission.

Power. This section provides voltage levels necessary for the proper operation of the CMC.

CMC power is furnished by two switching-regulator power supplies: a +4-volt and a +14-volt power supply which are energized by fuel cells in the electrical power system.

Input voltage from the electrical power system is chopped at a variable duty cycle and then filtered to produce the required voltages. Chopping is accomplished by varying the pulse width of a signal having a fixed repetition rate and known amplitude.

Source voltage, +28 vdc, is supplied from the electrical power system through the power switch to the control module. The control module, essentially a pulse generator, detects the difference between the primary feedback output of the power supply and a reference voltage. (A secondary feedback path is connected to the CTS for marginal-voltage test operations.) A differential amplifier detects any change in the output voltage from the desired level. The output of the differential amplifier and a 51.2-kilocycle sync pulse from the timer drive a one-shot multivibrator in the control module. The differential amplifier output determines the multivibrator pulse width. The resultant +14-volt pulse is supplied to the power switch.

The power switch filters the control module output to produce the desired d-c voltage. Additional filtering action protects the electrical power system from the wide-load variations caused by the chopping action of the power supply. The power switch also contains a temperature sensing circuit. Because of load requirements, the +4-volt power supply requires two power switches.

The power supply outputs are monitored by a failure detector consisting of four differential amplifiers. There are two amplifiers for each power supply, one for overvoltage and one for undervoltage detection. If an overvoltage condition exists, a relay closure signal indicating a power failure is supplied to the spacecraft.

2.2.3.2.2 Display and Keyboard

The DSKYs facilitate intercommunication between the flight crew and the CMC. The DSKYs operate in parallel, with the main display console DSKY providing CMC display and control while the crew are in their couches. (See figure 2.2-3.)

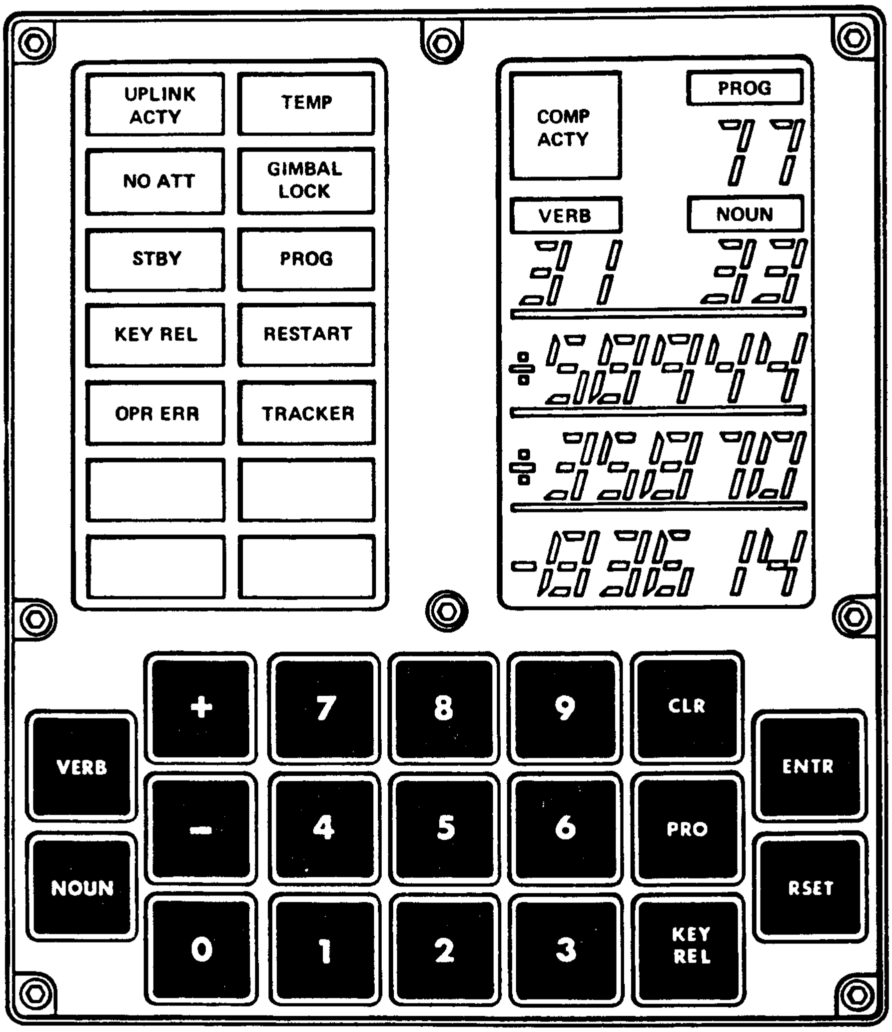


Figure 2.2-3. Display and Keyboard

The exchange of data between the flight crew and the CMC is usually initiated by crew action; however, it can also be initiated by internal computer programs. The exchanged information is processed by the DSKY program. This program allows the following five different modes of operation:

- Display of Internal Data. Both a one-shot display and a periodically updating display (called monitor) are provided.
- Loading External Data. As each numerical character is entered, it is displayed in the appropriate display panel location.
- Program Calling and Control. The DSKY is used to initiate a class of routines which are concerned with neither loading nor display. Certain routines require instructions from the operator to determine whether to stop or continue at a given point.

- Changing Major Mode. The initiation of large scale mission phases can be commanded by the operator.
- Display of PGNCS Caution and Status. The DSKY is used to display the status of the ISS, OSS, and CMC and to provide an indication of hardware and software cautions.

Displays. The displays consist of eleven status and caution indicators, three decimal displays and three decimal or octal registers. The function of the indicators and displays is as follows:

Indicator/Display	Function
UPLINK ACTY light	On when the CMC has received a complete 16 bit digital uplink message, or during the rendezvous navigation program, the gimbal angle changes are greater than 10 degrees to align the CSM to the desired tracking attitude and the astronaut has disabled the automatic tracking.
NO ATT light	Lighted when the ISS is in a coarse align mode.
STBY light	On when the CMC is in the standby mode.
KEY REL light	Lighted when an internal display desires the use of the DSKY and the astronaut is using the DSKY or the astronaut presses a key (exceptions: PRO, RSET and ENTR) when an internal flashing display is currently on the DSKY or the astronaut presses a key (exceptions: PRO, RSET and ENTR) on top of his Monitor Verb display.
OPR ERR light	On when the operator performs an improper sequence of key depressions.
TEMP light	Lighted when the CMC receives a signal from the IMU temperature control that the stable member is outside of the temperature range of 126.3 to 134.3°F.
GIMBAL LOCK light	On when the middle gimbal angle exceeds ±70° from its zero position.
PROG light	Lighted when the internal program detects computational difficulty.
RESTART light	On when the CMC detects a temporary hardware or software failure.

Indicator/Display	Function
TRACKER light	Lighted when the CMC receives a signal from the OCDU indicating a failure, or the rendezvous navigation program reads VHF range information but the Data Good discrete is missing.
COMP ACTY light	On when the CMC is occupied with an internal sequence.
PROG display	Provides a decimal display of the current mission program in sequence.
VERB display	Provides a decimal display of the verb (action) being performed.
NOUN display	Provides a decimal display of the noun (location or register) where the action (verb) is being performed.
REGISTER 1, 2 and 3	Provides a display of the contents of registers or memory locations.

The keyboard consists of ten numerical keys (pushbuttons) labeled 0 through 9, two sign keys (+ or -) and seven instruction keys: VERB, NOUN CLR (clear), PRO (proceed), KEY REL (key release), ENTR (enter), and RSET (reset).

Whenever a key is pressed, +14 vdc is applied to a diode encoder which generates a unique five-bit code associated with that key. There is, however, no five-bit code associated with the PRO key. If a key on the main panel DSKY is pressed, the five-bit code associated with that key is entered into bit positions 1 through 5 of input channel 15 of the CMC. Note that this input will cause a request for the KEYRUPT 1 program interrupt. If a key on the navigation panel DSKY is pressed, the five-bit code associated with that key is entered into bit position 1 through 5 of input channel 16 of the CMC. Note that this input will cause a request for the KEYRUPT 2 program interrupt. The function of the keys is as follows:

Pushbutton	Function
0 through 9 pushbuttons	Enters numerical data, noun codes, and verb codes into the CMC.
+ and - pushbuttons	Informs the CMC that the following numerical data is decimal and indicates the sign of the data.
NOUN pushbutton	Conditions the CMC to interpret the next two numerical characters as a noun code and causes the noun display to be blanked.

Pushbutton	Function
CLR pushbutton	Clears data contained in the data displays. Pressing this key clears the data display currently being used. Successive depressions clear the other two data displays.
PRO pushbutton	Commands the CMC to the standby mode if power down program has been run. An additional depression commands the CMC to resume regular operation. If power down program has not been run, a depression commands CMC to proceed without data.
KEY REL pushbutton	Releases the DSKY displays initiated by keyboard action so that information supplied by the CMC program may be displayed.
ENTR pushbutton	Informs the CMC that the assembled data is complete and the requested function is to be executed.
RSET pushbutton	Extinguishes the DSKY caution indicators. (OPR ERR, PROG, RESTART, STBY and UPLINK ACTY).
VERB pushbutton	Conditions the CMC to interpret the next two numerical characters as a verb code and causes the verb display to be blanked.

Verb-Noun Formats. A noun may refer to a device, a group of computer registers or a group of counter registers, or it may simply serve to convey information without referring to any particular computer register. The noun is made up of 1, 2, or 3 components, each component being entered separately as requested by the verb code. As each component is keyed, it is displayed on the display panel with component 1 displayed in REGISTER 1, component 2 in REGISTER 2, and component 3 in REGISTER 3. There are two classes of nouns: normal and mixed. Normal nouns (codes 01 through 39) are those whose component members refer to computer registers which have consecutive addresses and use the same scale factor when converted to decimal. Mixed nouns (codes 40 through 99) are those whose component members refer to non-consecutive addresses or whose component members require different scale factors when converted to decimal, or both.

A verb code indicates what action is to be taken. It also determines which component member of the noun group is to be acted upon. For example, there are five different load verbs. Verb 21 is required for loading the first component of the selected noun; verb 22 loads the second component; verb 23 loads the third component; verb 24 loads the first and second component; and verb 25 loads all three components. A similar component format is used in the display and monitor verbs. There are two general classes of verbs, regular and extended. The regular verbs (codes 01 through 39) deal mainly with loading, displaying, and monitoring data. The extended verbs (codes 40 through 99) are principally concerned with calling up internal programs whose function is system testing and operation.

Whenever data is to be loaded by the operator, the VERB and NOUN lights flash, the appropriate data display register is blanked, and the internal computer storage register is cleared in anticipation of data loading. As each numerical character is keyed in, it is displayed in the proper display register. Each data display register can handle only five numerical characters at a time (not including sign). If an attempt is made to key in more than five numerical characters at a time, the sixth and subsequent characters are simply rejected but they do appear in the display register.

The + and - keys are accepted prior to inserting the first numerical character of REGISTER 1, REGISTER 2, or REGISTER 3; if keyed in at any other time, the signs are rejected. If the 8 or 9 key is actuated at any time other than while loading a data word preceded by a + or - sign, it is rejected and the OPR ERR light goes on.

The normal use of the flash is with a load verb. However, there are two special cases when the flash is used with verbs other than load verbs.

- Machine Address to be Specified. There is a class of nouns available to allow any machine address to be used; these are called "machine address to be specified" nouns. When the "ENTR," which causes the verb-noun combination to be executed, senses a noun of this type the flash is immediately turned on. The verb code is left unchanged. The operator should load the complete machine address of interest (five-character octal). This is displayed in REGISTER 3 as it is keyed in. If an error is made in loading the address, the CLR key may be used to remove it. Pressing the ENTR key causes execution of the verb to continue.

- Change Major Mode. To change major mode, the sequence is VERB 37 ENTR. This causes the noun display register to be blanked and the verb code to be flashed. The two-character octal major mode code should then be loaded. For verification purposes, it is displayed as it is loaded in the noun display register. The entry causes the flash to be turned off, a request for the new major mode to be entered, and new major mode code to be displayed in the PROG display register.

The flash is turned off by any of the following events:

- Final entry of a load sequence.
- Entry of verb "proceed without data" (33) or depression of PRO pb.
- Entry of verb "terminate" (34).

It is important to conclude every load verb by one of the aforementioned three, especially if the load was initiated by program action within the computer. If an internally initiated load is not concluded validly, the program that initiated it may never be recalled. The "proceed without data" verb is used to indicate that the operator is unable to, or does not wish to, supply the data requested, but wants the initiating program to continue as best it can with old data. The "terminate" verb is used to indicate that the operator chooses not to load the requested data and also wants to terminate the requesting routine.

Keyboard Operation

The standard procedure for the execution of keyboard operations consists of a sequence of seven key depressions:

VERB V_2 V_1 NOUN N_2 N_1 ENTR

Pressing the VERB key blanks the two verb lights on the DSKY and clears the verb code register in the CMC. The next two numerical inputs are interpreted as the verb code. Each of these characters is displayed by the verb lights as it is inserted. The NOUN key operates similarly with the DSKY noun lights and CMC noun code register. Pressing the ENTR key initiates the program indicated by the verb-noun combination displayed on the DSKY. Thus, it is not necessary to follow a standard procedure in keying verb-noun codes into the DSKY. It can be done in reverse order, if desired, or a previously inserted verb or noun can be used without rekeying it. No action is taken by the CMC in initiating the verb-noun-defined program until the ENTR key is actuated. If an error is noticed in either the verb code or noun code, prior to actuation of the ENTR key, it can be corrected simply by pressing the corresponding VERB or NOUN key and inserting the proper code. The ENTR key should not be actuated until it has been verified that the correct verb and noun codes are displayed.

If the selected verb-noun combination requires data to be loaded by the operator, the VERB and NOUN lights start flashing on and off (about once per second) after the ENTR key is pressed. Data is loaded in five-character words and, as it is keyed in, it is displayed character-by-character in one of the five-position data display registers; REGISTER 1, REGISTER 2, or REGISTER 3. Numerical data is assumed to be octal unless the five-character data word is preceded by a plus or minus sign, in which case it is considered to be decimal. Decimal data must be loaded in full five-numeral character words (no zeros may be left out); octal data may be loaded with high-order zeros left out. If a decimal is used for any component of a multicomponent load verb, it must be used for all components of that verb. In other words, no mixing of octal and decimal data is permitted for different components of the same load verb. The ENTR key must be pressed after each data word. This tells the program that the numerical word being keyed in is complete. The on-off flashing of the VERB-NOUN lights terminates after the last ENTR key actuator of a loading sequence.

The CLR key is used to remove errors in loading data as it is displayed in REGISTER 1, REGISTER 2, or REGISTER 3. It does nothing to the PROG, NOUN or VERB lights. (The NOUN lights are blanked by the NOUN key, the VERB lights by the VERB key.) For single-component load verbs or "machine address to be specified" nouns, the CLR key depression performs the clearing function on the particular register being loaded, provided that the CLR key is depressed before the ENTR key. Once the ENTR key is depressed, the CLR key does nothing. The only way to correct an error after the data is entered for a single-component load verb is to begin the load verb again. For two-or three-component load verbs, there is a CLR backing-up feature. The first depression of the CLR key clears whichever register is being loaded. (The CLR key may be pressed after any character, but before its entry.) Consecutive CLR key actuations clear the data display register above the current one until REGISTER 1 is cleared. Any attempt to back up (clear) beyond REGISTER 1 is simply ignored. The CLR backing up function operates only on data pertinent to the load verb which initiated the loading sequence. For example, if the initiating load verb were a "write second component into" type only, no backing up action would be possible.

The numerical keys, the CLR key, and the sign keys are rejected if depressed after completion (final entry) of a data display or data load verb. At such time, only the VERB, NOUN, ENTR, RSET, or KEY REL inputs are accepted. Thus, the data keys are accepted only after the control keys have instructed the program to accept them. Similarly, the + and - keys are accepted only before the first numerical character of REGISTER 1, REGISTER 2, and REGISTER 3 is keyed in, and at no other time. The 8 or 9 key is accepted only while loading a data word which is preceded by a + or - sign.

The DSKY can also be used by internal computed programs for subroutines. However, any operator keyboard action (except RSET) inhibits DSKY use by internal routines. The operator retains control of the DSKY until he wishes to release it. Thus, he is assured that the data he wishes to observe will not be replaced by internally initiated data displays. In general, it is recommended that the operator release the DSKY for internal use when he has temporarily finished with it; this is done by pressing the KEY REL key.

2.2.3.3 Optical Subsystem

The optical subsystem is used for taking precise optical sightings on celestial bodies and for taking fixes on landmarks. These sightings are used for aligning the IMU and for determining the position of the spacecraft. The system includes the navigational base, two of the five CDUs, parts of the power and servo assembly, controls and displays, and the optics, which include the scanning telescope (SCT) and the sextant (SXT).

2.2.3.3.1 Optics

The optics consist of the SCT and the SXT mounted in two protruding tubular sections of the optical base assembly. The SCT and SXT shaft axes are aligned parallel to each other and afford a common line-of-sight (LOS) to selected targets. The trunnion axes may be parallel or the SCT axis may be offset, depending upon the mode of operation.

The sextant is a highly accurate optical instrument capable of measuring the included angle between two targets. Angular sightings of two targets are made through a fixed beam splitter and a movable mirror located in the sextant head. The sextant lens provides 1.8-degree true field-of-view with 28X magnification. The movable mirror is capable of sighting a target to 50 degrees LOS from the shaft axis. The mechanical accuracy of the trunnion axis is twice that of the LOS requirement because of mirror reflection which doubles any angular displacement in trunnion axis.

The scanning telescope is similar to a theodolite in its ability to accurately measure elevation and azimuth angles of a single target using an established reference. The lenses provide 60-degree true field-of-view at 1X magnification. The telescope allowable LOS errors are one minute of arc-rms in elevation with maximum repeatability of 15 arc-seconds and approximately 40 arc-seconds in shaft axis.

2.2.3.3.2 Coupling Data Unit

The identical coupling data unit (CDU) used in the ISS is also used as part of the OSS. Two channels of the CDU are used, one for the SXT shaft axis and one for the SXT trunnion axis. These CDU channels repeat the SXT shaft and trunnion angles and transmit angular change information to the CMC in digital form. The angular data transmission in the trunnion channel is mechanized to generate one pulse to the CMC for 5 arc-seconds of movement of the SXT trunnion which is equivalent to 10 arc-seconds of SLOS movement. The shaft CDU channel issues one pulse for each 40 arc-seconds of shaft movement. The location of the SXT shaft and trunnion axes are transmitted to the CDUs through 16X and 64X resolvers, located on the SXT shaft and trunnion axes, respectively. This angular information is transmitted to the CDUs in the form of electrical signals proportional to the sine and cosine of 16X shaft angle and 64X trunnion angle. During the computer mode of operation, the CDU provides digital-to-analog conversion of the CMC output to generate an a-c input to the SXT shaft and trunnion servos. This analog input to the SXT axes will drive the SLOS to some desired position. In addition, the OSS channels of the CDU perform a second function on a time-sharing basis. During a thrust vector control function, these channels provide digital-to-analog conversion between the CMC and the service propulsion system (SPS) gimbals.

2.2.4 OPERATIONAL MODES

The PGNCS has two systems, six inertial subsystem (ISS), and three optical subsystem (OSS) modes. The system modes are listed as follows:

- Saturn takeover
- Thrust vector control.

The ISS modes are listed as follows:

- IMU turn-on
- IMU cage
- Coarse align
- Fine align
- Attitude error
- Inertial reference.

The OSS modes are listed as follows:

- Zero optics
- Manual control
- Computer control.

The moding of the system and ISS is controlled by the CDU with the exception of one mode, a cage switch on the main display and control panel. All other modes must be commanded by the CMC through the issuance of discrete moding commands to the CDU.

The modes of operation for the OSS are selected by the astronaut using controls located on the indicator control panel.

2.2.4.1 S-IVB Takeover

The S-IVB takeover capability provides steering signals to the Saturn instrument unit autopilot. There are two modes of operation, automatic and manual. The automatic mode provides the backup capability of issuing steering commands to the IU during the boost phase. This mode is initiated by positioning the LAUNCH VEHICLE GUIDANCE switch on the main display and control panel to CMC during the boost monitor program only. This switch arms the S-IVB takeover relay with 28 vdc and issues a discrete to the CMC. The CMC, on recognition of this input discrete, switches to a control routine which generates an S-IVB takeover discrete. The S-IVB takeover discrete allows the relay in the mode module (CDU) to energize, closing the interface between the DAC and the S-IVB instrument unit.

Normally the boost monitor program monitors the CDUs, computes the difference between the desired attitude (determined by a stored polynominal) and the actual attitude, and displays the error on the FDAI. During the takeover mode the commands are computed by taking the error (difference between polynominal and actual attitude) at takeover and storing as a bias. This value is subtracted from the actual error computed on succeeding cycles and is used to issue steering commands that attempt to maintain a constant error equal to that existing at takeover.

The manual mode provides the capability of issuing rotation control commands, through the CMC, to the instrument unit. The manual mode is initiated by placing the LAUNCH VEHICLE GUIDANCE switch to the CMC position and enabling the Saturn digital autopilot with an extended verb. The switch arms the S-IVB takeover relay with 28 vdc and issues a discrete to the computer. The CMC, on recognition of this discrete and the Saturn digital autopilot enabled, generates the S-IVB takeover discrete.

If either rotation control is placed to a pitch, yaw, or roll breakout position, the CMC issues an error-counter-enable discrete to the CDU. The error-counter-enable discrete is buffered in the moding module, modified by the digital mode module finally allowing the error counters to be enabled. The CMC then generates a $\pm\theta_c$ pulse train to the appropriate error counter where it is accumulated and converted to a ±d-c output signal by the DAC. The ±d-c signal is applied to the S-IVB IU as a ±0.5°/sec roll, or ±0.3°/sec pitch or yaw rate command.

When the rotation control is returned to the null position, the CMC inhibits the error-counter-enable discrete to the CDU which causes the error counter to reset. This results in a 0-vdc output signal from the DAC which is applied to the S-IVB IU as a 0°/sec roll, pitch, or yaw rate command.

2.2.4.2 Thrust Vector Control

This system mode is initiated by CMC program control.

The CMC commands a TVC discrete which energizes the TVC relay closing the interface between the CDU DAC and the SPS gimbal servo amplifiers.

The computer also issues an OSS error-counter enable and an ISS error-counter enable. The computer, when all operating requirements are met, issues an SPS engine-on command.

The ISS read counters are repeating the gimbal angle changes indicating to the CMC the present spacecraft attitude. The accelerometers provide the program with ΔV inputs. These data are used to compute an attitude error and a SPS steering signal.

The attitude error is converted to a pulse train which is used to increment the CDU ISS error counters. The contents of these counters are converted to analog and displayed as they were in the attitude error display mode. The read counter input to the error counter is inhibited, allowing the error counter to be incremented or decremented only by CMC commands.

The OSS error counters are incremented by a $\Delta\theta$ command proportional to the steering signals required to steer the spacecraft on the proper trajectory. The error counter can operate completely independent of the read counter circuitry so the condition of the OSS is immaterial to this operation. The error counter contents are converted to analog 800 cps and then to a ±d-c voltage in the CDU OSS DAC. The pitch or yaw steering signal is routed through the TVC relay in the mode module to the SPS gimbal servo amplifiers. The TVC mode is complete when the spacecraft reaches the required velocity and the engine-off discrete is issued by the CMC. Each $\Delta\theta_C$ pulse from the CMC changes the SPS gimbals by 85 arc-seconds.

2.2.4.3 IMU Turn-On Mode

The purpose of the IMU turn-on mode is to initialize the ISS by driving the IMU gimbals to zero, and clearing and inhibiting the CDU read counters and error counters. The IMU turn-on mode is initiated by applying IMU operate power to the subsystem. The computer issues two CDU discretes required for this mode, CDU zero and coarse align. The computer also issues the turn-on delay complete discrete to the ISS after 90 seconds.

When IMU operate power is applied to the subsystem, the computer receives an ISS power-on discrete and a turn-on delay request. The computer responds to the turn-on delay request by issuing the CDU zero and coarse align discretes to the CDU. To prevent PIPA torquing for 90 seconds during the IMU turn-on mode, an inhibit is applied to the pulse torque power supply. This same inhibit is present when a computer warning has been issued. The CDU zero discrete clears and inhibits the read counters and error counters. The ISS operate power (+28 vdc) is routed through the de-energized contacts of the auto cage control relay to energize the cage relay. A 0-vdc signal, through the energized contacts of the cage relay, energizes the coarse-align relay. The energized contacts of the coarse-align relay switch the gimbal servo amplifier demodulator reference from 3200 cps to 800 cps, and close the IMU cage loop through the energized contacts of the cage relay. The coarse-align relay is held energized by the CDU coarse-align discretes and the energized contacts of the cage relay. The IMU gimbals will drive to the zero reference position using the sine output of the 1X gimbal resolvers ($\sin\theta$).

After 90 seconds, the computer issues the ISS turn-on delay complete discrete which energizes the ISS turn-on control relay. The auto cage control relay is energized by the ISS turn-on control relay. The ISS turn-on control relay then locks up through the energized contacts of the auto cage control relay. Energizing the auto cage control relay also removes the turn-on delay request and de-energizes the cage relay. This removes the $\sin\theta$ signal and applies the coarse-align output to the gimbal servo amplifier.

Energizing the ISS turn-on control relay removes the pulse torque power supply inhibit. The 90-second delay enables the gyro wheels time to reach their operating speed prior to closing the stabilization loops. The pulse torque power supply inhibit prevents accelerometer torquing during the 90 seconds.

2.2.4.4 IMU Cage Mode

The IMU cage mode is an emergency mode which (1) allows the astronaut to recover a tumbling IMU by setting the gimbals to zero, and (2) to establish an inertial reference. The IMU cage mode can also be used to establish an inertial reference when the CSS is not activated.

The IMU cage mode is manually initiated by closing the spring-loaded cage switch on the main display and control panel for sufficient time to allow the IMU gimbals to settle at the zero position (5 seconds maximum). The IMU gimbal zeroing can be observed on the FDAI.

If the mode is commanded to recover a tumbling IMU after the IMU turn-on mode is completed, closing the IMU cage switch will cause the IMU gimbals to drive to zero. When the switch is released, the ISS will enter the inertial reference mode.

If the IMU cage mode is commanded to establish an inertial reference with the CSS in standby or off, the closing of the IMU cage switch will cause the IMU gimbals to drive to zero. When the switch is released, the inertial reference mode will be established.

Closing the IMU cage switch energizes the cage and coarse-align relays, which apply the sin θ signals to the gimbal servo amplifier, and sends an IMU cage discrete to the computer. Releasing the switch causes the cage and coarse-align relays to de-energize. When the coarse-align relay is de-energized, the stabilization loops are closed. The computer, upon receiving the IMU cage signal, discontinues sending all of the following discretes and control signals:

- Error-counter enable (OSS)
- Error-counter enable (ISS)
- Coarse-align enable
- TVC enable
- SPS engine on (CSM only)
- Gyro-command enable (torquing)
- ±X and/or ±Y optics CDU - D/A
- ±X (outer), ±Y (inner), ±Z (middle) IMU CDU - D/A
- ±X, ±Y, ±Z gyro select
- Gyro set pulses.

The IMU cage mode should not be used indiscriminately. It is intended only as an emergency recovery function for a tumbling IMU. During the IMU cage mode, IMU gimbal rates are sufficient to cause the gyros to be driven into their rotational and radial stops because of no CDU rate limiting. This action causes both temporary and permanent (if gyro torquing was in process during cage) bias shifts on the order of several MERU (Milli Earth Rate Unit).

2.2.4.5 IMU Coarse Align

The coarse-align mode of operation is mechanized to allow the computer to rapidly align the IMU to a desired position with a limited degree of accuracy. The computer issues two discretes to the CDU in this mode, coarse-align and error-counter enable.

The coarse-align discrete is routed through the moding module where it is buffered. One buffered output provides a ground path to the coarse-align relay energizing the relay. The energized relay opens the gyro preamp output, replaces the normal 3200-cps demodulator reference with an 800-cps reference, and routes the 800-cps coarse-align output from the DAC into the gimbal servo amplifier demodulator, thereby allowing any 800-cps signal generated within the DAC to drive the gimbal until the DAC output is zero vrms.

The buffered coarse-align discrete and error-counter-enable discrete are routed from the moding module to the digital mode module for logical manipulations. The discretes at 0-vdc level are accepted by the error counter and logic module as moding commands enabling the error counter, and allowing the transfer of $\Delta\theta_g$ angles from the read counter to the error counter.

After the logic circuitry has been set up to accept commands from the computer, the CMC will begin transmitting $\pm\Delta\theta_c$ pulse trains at 3200 pps. These pulses, each equivalent to a change in gimbal angle of 160 arc-seconds, are accumulated in the error counter. The nine stages of the error counter are used solely to control ladder switches in the digital-to-analog converter module.

The $\Delta\theta_c$ pulse train is routed through a buffer stage in the DAC. The first $\Delta\theta_c$ pulse arriving at the EC&L logic will determine the direction the counter is to count, and will also provide a DAC-polarity control to the DAC. The polarity control provides an in-phase or an out-of-phase reference to the resistive ladder network through switches selected by the nine-bit error counter. An 800-cps analog signal will be generated at the ladder, the amplitude of which is dependent on the error counter content and the phase on the polarity of the input command $\Delta\theta_c$.

The ladder output is mixed with the coarse- and fine-resolver errors, after nulling, from the coarse module and the main summing amplifier module, respectively. These errors are out of phase with the ladder output and will act as a degenerative feedback providing rate limiting to the coarse-align loop drive rates.

The 800-cps mixing amplifier output of the DAC is routed through the coarse-align relay into the gimbal servo amplifier, causing the gimbal to drive in the direction commanded by the CMC.

The changing gimbal angles are recognized by the error-detection circuits in the coarse module and the main summing amplifier. These detected errors, recognized by the error counter logic circuitry, allow the $\phi 4$ pulse train at 6400 pps to increment the read counter. The incrementing read counter will close attenuation switches in the coarse, quadrant select, the main summing amplifier modules nulling the sine and cosine voltage inputs from 1X and 16X resolver into the error-detect circuits.

As the read counter is being incremented, the output of the first stage is routed through logic in the EC&L module, through a buffer in the DAC, and out to the CMC as an increase in gimbal angle of 40 arc-seconds. The output of the third stage of the counter, at 160 arc-seconds per pulse, is recognized in the EC&L logic as an incremental value to be entered into the error counter in the opposite direction to the commanded $\Delta\theta$. If $\Delta\theta$ is positive, the error counter is counted up and the $\Delta\theta_g$ from the read counter decrements the counter. For each read counter pulse into the error counter, the total content will decrease the DAC output and the rate of drive. When the number of digital feedback pulses equal the commanded pulse number, the error counter will be empty and the DAC output should be zero.

The limited read counter incrementing rate, and the fact that the fine error input to the DAC increases in proportion to $\theta - \psi$ as the drive rate exceeds the range controlled by the fine system, limits the gimbals rate of drive to a maximum of 35 degrees per second.

2.2.4.6 IMU Fine Align

The fine-align mode of operation allows the computer to accurately align the IMU to a predetermined gimbal angle within seconds of arc. The computer does not command any CDU discretes during this mode of operation; therefore, the read counter circuitry will repeat the changing gimbal angles exactly as was done in the coarse-align mode. The computer will keep track of the gimbal angle to within 40 arc-seconds.

The commanding signals for the fine-align mode are generated in the time-shared, fine-align electronics. The computer first issues a torque-enable discrete which applies 28 vdc and 120 vdc to the binary current switch and the differential amplifier precision voltage reference circuit, allowing the circuit to become operative. The circuit switch is reset to allow a dummy current, which is equal to the torquing current, to flow. This allows the current to settle to a constant value prior to its being used for gyro torquing. A gyro is then selected for either plus or minus torquing. After the preceding discretes have been issued, the computer then sends set commands or fine-align commands to the set side of the current switch. The pulse turns on the selected plus or minus torque current to the gyro, causing the float to move. The resulting signal generator output causes the platform to be driven through an angle equal to the commanded angle. The CMC will receive inputs from the CDU read counter indicating the change in gimbal angle.

The number of torquing pulses sent from the CMC to the torquing electronics is computed, based on the angle of the gimbal at an instant of time and a desired alignment angle. The difference is converted into the number of pulses necessary to drive the gimbal through the difference angle. Each pulse sent is equivalent to 0.615 arc-second of gimbal displacement. The required number of fine-align pulses is computed only once and is not recomputed based on the gimbal angle after the desired number of pulses have been sent. The fine-align loop operation is open-loop as far as the computer is concerned.

The fine-align pulses generated by the CMC are issued in bursts at a bit rate of 3200 pulses per second. The fine-align electronics will allow the torquing current to be on in the direction chosen by computer logic for the duration of the pulse burst.

2.2.4.7 Attitude Error Display Mode

The attitude error display mode of the inertial subsystem allows the computer to display to the operator, in analog fashion, an attitude error. In this mode of operation, only the CDU error-counter-enable discrete is generated by the computer. In this mode of operation, the computer is again informed of the gimbal angle and any changes to it through the read counter and the analog-to-digital conversion associated with it. The read counter 20 arc-second output is routed through logic in the EC&L module through the DAC buffer to the CMC.

The computer is then aware of the present attitude of the spacecraft. The digital autopilot program has a computed desired attitude associated with the present time and position of the spacecraft. Any difference between the desired and actual is an attitude error. The attitude error is converted to $\Delta\theta_C$ pulses, each pulse being equivalent to 160 arc-seconds of error, which are sent to the error counter at a rate of 3200 pps. The error counter is incremented to contain the number of pulses commanded. The contents of the error counter are converted to an 800-cps error signal by the DAC. The phase of the DAC output is determined by logic in the EC&L module, based on whether the input command was a plus or minus $\Delta\theta$. The 800 cps with a maximum amplitude of 5 vrms zero or pi-phase is displayed on the attitude error needles of the FDAI as an attitude error. The digital feedback from the read counter to the error counter is disabled during this mode of operation allowing only the CMC-generated $\Delta\theta$ commands to increment or decrement the error counter.

The spacecraft attitude can also be displayed on the FDAI. This information is taken from the 1X gimbal angle resolver sine and cosine windings. Pitch, yaw, and roll can be displayed from the inner, middle, and outer gimbals, respectively.

2.2.4.8 Inertial Reference Mode

The inertial reference mode of operation is a mode of operation in which no computer discretes are being issued by the computer to any part of the ISS. This mode is used as a means of obtaining an inertial reference only. This reference is taken from the 1X gimbal angle resolver sine and cosine windings. The reference can be displayed on the FDAI or used as an input to the attitude set relays of the SCS.

In this mode of operation, the 25 IRIGs hold the stable platform inertially referenced. The CDU read counter will continuously monitor the changing gimbal angles because of spacecraft motion and indicate to the CMC the changing angles. The error counter and the DAC are not used in this mode of operation.

2.2.4.9 Zero Optics Mode

During the zero optics mode, the shaft and trunnion axes of the SXT are driven to their zero positions by taking the outputs of the transmitting resolvers (1X and 64X in trunnion and 1/2X and 16X in shaft) and feeding them through the two-speed (2X) switches to the motor drive amplifier (MDA).

The MDA in turn drives loops to null positions as indicated by zero output from the resolvers. The SCT shaft and trunnion axes follow to a zero position. After 15 seconds, the computer will issue a CDU zero discrete, and will initialize the shaft and trunnion counters in preparation for receiving new data from the CDU.

The zero optics mode is selected by the flight crew. Placing the ZERO switch to ZERO position will energize a relay in the PSA via a relay driver, which, in turn, will energize the two-speed switch. The computer is notified of the zero optics mode by a signal from the zero switch when the change from off to zero position occurs.

2.2.4.10 Manual Mode Operation

The manual mode can be selected to operate under either direct hand control or resolved hand control. Independent control of the SCT trunnion is possible in both of these mode variations.

2.2.4.10.1 Manual Direct Operation

When in this mode, the hand controller outputs are applied directly to the SXT shaft and trunnion motor drive amplifiers. Forward and back motion of the hand controller commands increasing and decreasing trunnion angles, and right and left motion of the hand controller commands increasing and decreasing shaft angles, respectively. The target image motion is in the R-M coordinate system, the position of which is dependent upon the position of the SXT shaft.

The apparent speed of the image motion can be regulated by the flight crew by selecting either low, medium, or high controller speed on the indicator control panel. This regulates the voltage applied to the motor drive amplifier, $A_{\dot{s}}$ and $A_{\dot{t}}$; therefore, the shaft and trunnion drive rates. The maximum rates are approximately 20 degrees per second for the shaft and 10 degrees per second for the trunnion.

2.2.4.10.2 Slave Telescope Modes

The slave telescope modes provide for alternate operation of the telescope trunnion while the SXT is being operated manually. The alternate modes are selected by the TELTRUN switch on the mode control panel. There are three possible selections, SLAVE to SXT, 0°, and 25°. With this switch in the SLAVE to SXT position, the SCT trunnion axis is slaved to the SXT trunnion; this is the normal operating position for the SCT. With the switch in the 0° position, the SCT trunnion is locked in a zero position by the application of a fixed voltage to the SCT trunnion 1X receiving resolver. This will cause this position loop to null in a zero orientation. Therefore, the centerline of the SCT 60-degree field-of-view is held parallel to the LLOS of the SXT.

With the switch in the 25° position, an external voltage is applied to the same 1X receiving resolver which will cause the SCT trunnion position loop to null out so that the centerline of the 60-degree field-of-view is offset 25 degrees (A_t of SCT at 12.5 degrees) from the LLOS of the SXT. This position of the SCT trunnion will allow the landmark to remain in the 60-degree field-of-view while still providing a total possible field-of-view of 110 degrees if the SCT shaft is swept through 360 degrees.

2.2.4.10.3 Manual Resolved Operation

When in this mode, the hand controller outputs are put through a matrix transformation prior to being directed to the shaft and trunnion motor drive amplifiers. The matrix transformation makes the image motion correspond directly to the hand controller motion. This is up, down, right, and left motions of the hand controller command; the target image moves up, down, right, and left respectively, in the field of view. In other words, the image motion is in the X-Y spacecraft coordinate system. The matrix transformation takes place in two steps. The outputs of the hand controller are routed to the 1X resolver on the SXT shaft. Here the drive signals, $A_{\dot{s}}$ and $A_{\dot{t}}$, are transformed by the sine and cosine functions of the shaft angle (A_s). One of the two outputs of the 1X resolver is sent to the SXT trunnion motor drive amplifier. The second output is then resolved through the SLOS angle (A_{LOS}) so that the target image motion will be independent of SLOS angle. This is accomplished by the cosecant computing amplifier (CSC) and the 2X computing resolver located on the SXT trunnion axis. The net result is that the shaft drive rate, $A_{\dot{s}}$, is inversely proportional to the sine of the SLOS angle. The speed controller is also operational in this mode.

2.2.4.10.4 Optics-Computer Mark Logic

The MARK and MARK REJECT buttons on the indicator control panel are utilized to instruct the computer that a navigational fix has taken place, and that SXT shaft and trunnion position and the time should either be recorded or rejected. The mark command is generated manually by the flight crew which energizes the mark relay. The mark relay transmits a mark command to the computer. If an erroneous mark is made, the mark reject button is depressed; this will generate a "mark reject" command to the computer.

2.2.4.10.5 Computer Mode Operation

The computer-controlled operation is selected by placing the moding switch in computer position. The mechanization of this loop is chosen by the computer program that has been selected by the flight crew. The operation of the SXT under computer control is accomplished by completing the circuit from the CDU digital-to-analog converters (DAC) to the shaft and trunnion motor drive amplifier. The computer can then provide inputs to these amplifiers via a digital input to the CDU, which are converted in the DAC to an 800-cycle signal that can be used by the MDA. This mode is used when it is desired to look at a specific star for which the computer has the corresponding star coordinates. The computer will also know the attitude of the spacecraft from the position of the IMU gimbals and will, therefore, be able to calculate the position of the SXT axes required to acquire the star. The computer can then drive the shaft and trunnion of the SXT to the desired position via the DAC.

2.2.5 POWER DISTRIBUTION

The guidance and navigation circuit breakers (panel 5) supply a-c and d-c power to switches on panels 5 and 100 and directly to the PSA and CMC. The panel 5 switch (G/N POWER) supplies AC1 or AC2 power to the PSA (figure 2.2-4) where it is routed to the dimmer power supply. The output of the dimmer power supply is provided to the following:

- Caution and warning lamp on LEB panel 122
- Star acquired lamp on LEB panel 122
- TPAC readout on LEB panel 122
- Optics (SCT and SXT) reticles

The panel 100 switches (G/N POWER - IMU and OPTICS) supply the d-c power to the PSA for power to the ISS, OPTICS and CDU power supplies. The IMU HTR and COMPUTER circuit breakers supply power to the ISS temperature control circuits and the CMC power supplies.

Circuit breakers on panel 226 supply a-c power to dimmer controls on panels 8 and 100 for lighting on the DSKYs, EMS, SCS displays and controls (FDAI 1 and 2, ASCP and GP/FPI), and LEB panel 122. The circuit breakers (LMDC-AC1 and LEB AC2) supply the a-c power to variable transformers in panels 8 and 100 and to isolation transformers (figure 2.2-5) for control of intensity of the status and key integral lamps on the DSKYs and integral lamps on the EMS, SCS displays and controls, and LEB panel 122. The intensity of the electro-luminescent displays on the DSKYs are controlled by rheostats on panels 8 and 100.

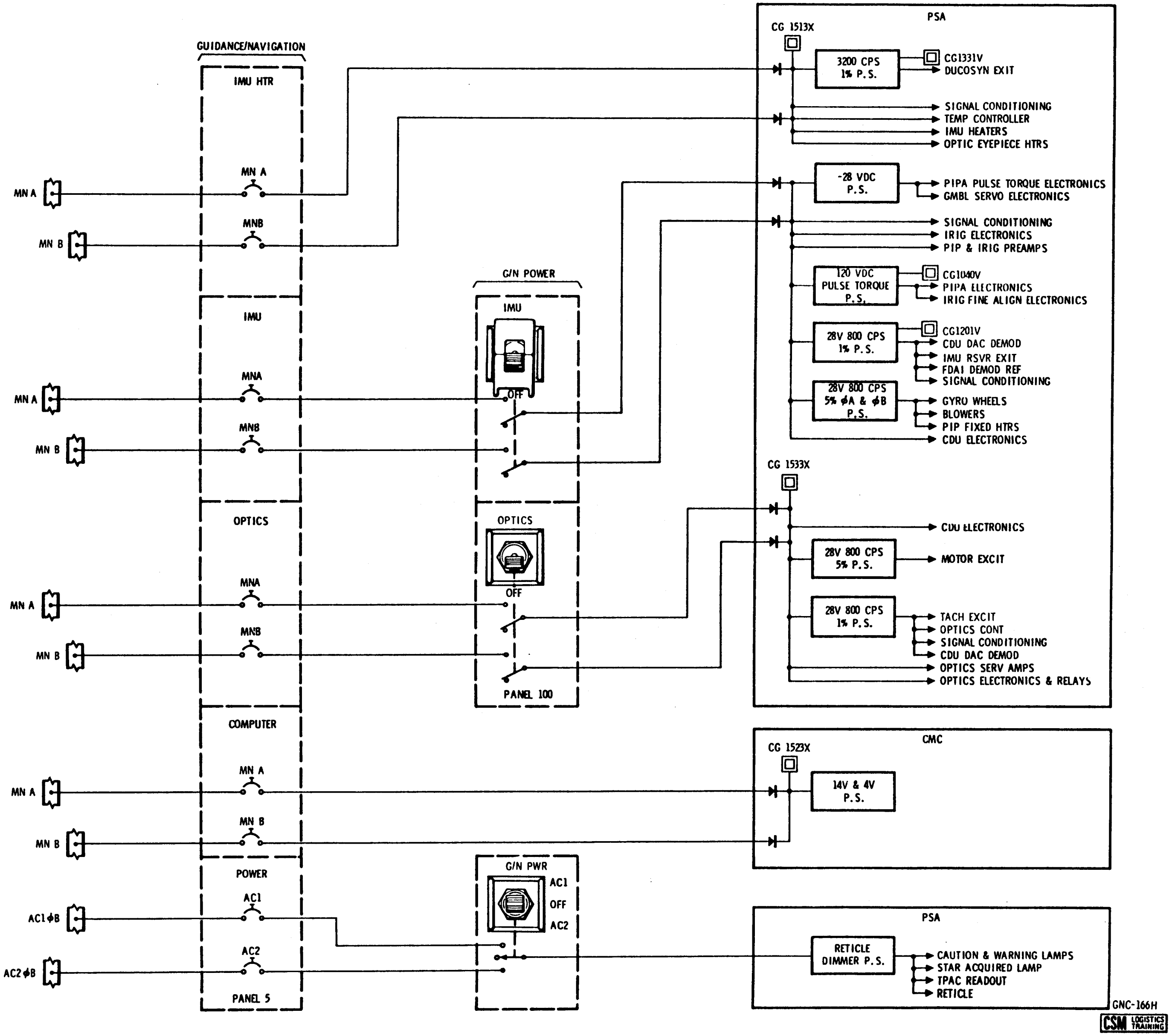


Figure 2.2-4. PGNCS Power Distribution

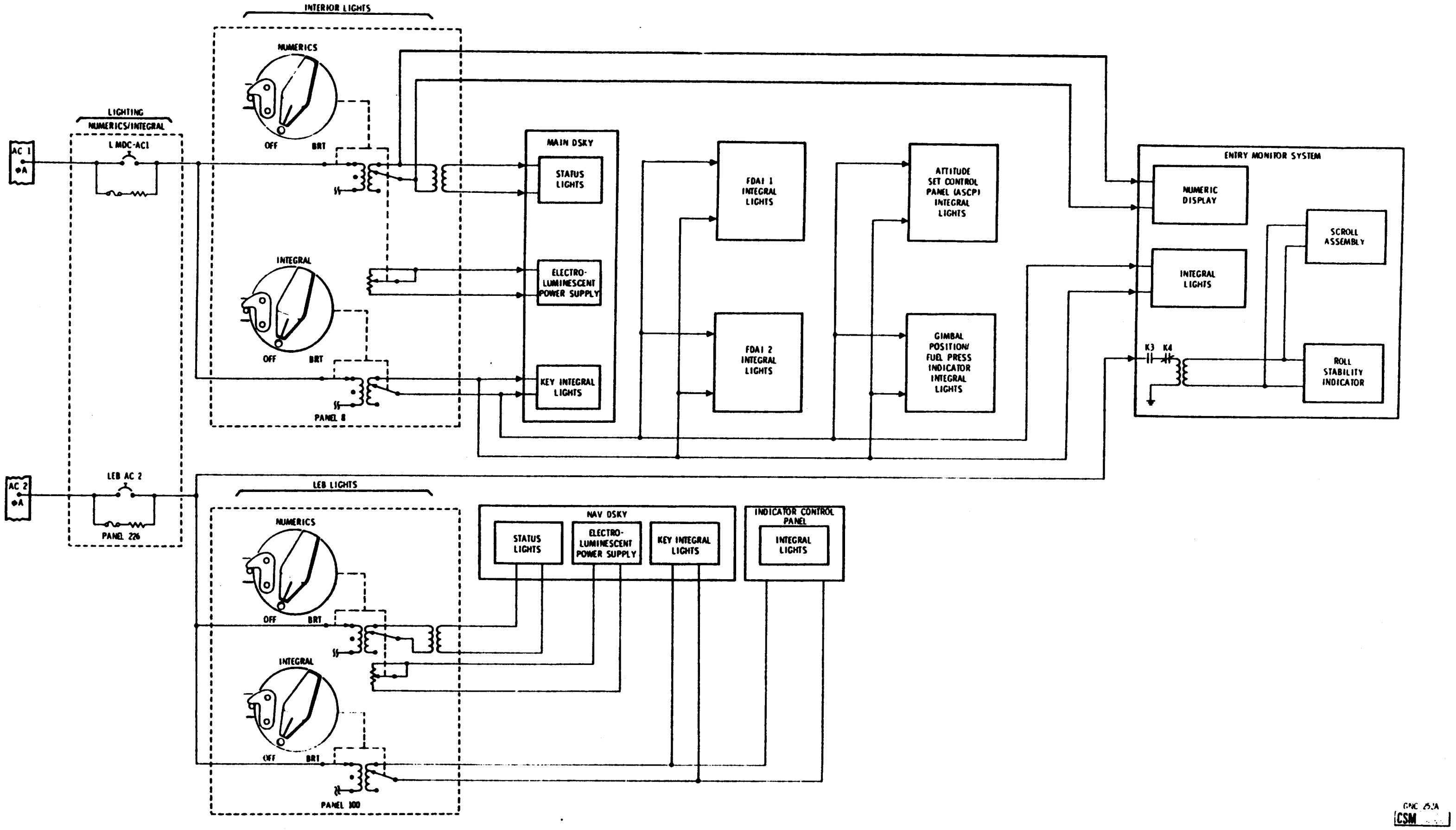


Figure 2.2-5. PGNCS Lighting