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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

INSTRUMENTATION LABORATORY

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FROM: J. C. Dunbar

DATE: 27 August 1963

SUBJECT: DG Memo No. 20, Description of Command Module G&N Displays and Controls

The attached preliminary document is currently being circulated in-house for review by cognizant groups before general distribution.

Any comments regarding recommended chang[illegible] to this document should be forwarded as early as possible to the undersigned.

TO

John C. Dunbar

J. C. Dunbar

W7-210, 30-367

The alarm lights defined in here have been change. See the latest class A drawings of display panel for correct definitions

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MIT Instrumentation Lab

DG MEMO #20

DESCRIPTION OF COMMAND MODULE G & N DISPLAYS AND CONTROLS

15 August 1963

PRELIMINARY

Approved_______________

J. L. Nevins
Group Leader

PRELIMINARY

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INTRODUCTION

The purpose of this document is to provide a description of the displays and controls (D & C) associated with the Apollo Guidance and Navigation (G & N) system in the Command Module.

The G & N system uses three major subsystems: 1) an inertial measurement unit (IMU) to provide measurement of vehicle attitude and acceleration, 2) an optical subsystem for angle measurements to stars and landmarks, and 3) a digital computer (AGC) which serves as the central data processor. These subsystems and other supplementary equipment are integrated with the G & N displays and controls for system status monitoring and operation by the astronaut navigator.

The primary location of the G & N displays and controls is at the navigation station where they are arranged in functional groups about a navigation base which incorporates the optics and the IMU (see Fig. 1). Spacecraft attitude controls, functionally related to the G & N system, are also located at the navigation station for use by the navigator in the performance of the navigation tasks. A computer display and control panel and G & N system power controls requiring primary control by the pilot are located on the main instrument panel.

The subsystems and their associated displays and controls are described in functional groups in the following order:

1. Inertial Measurement Unit
2. Optics
3. Apollo Guidance Computer
4. Map and Data Viewer
5. IMU Condition Lights
6. Illumination Controls
7. Clocks
8. Power and Servo Assembly
9. Attitude Controls

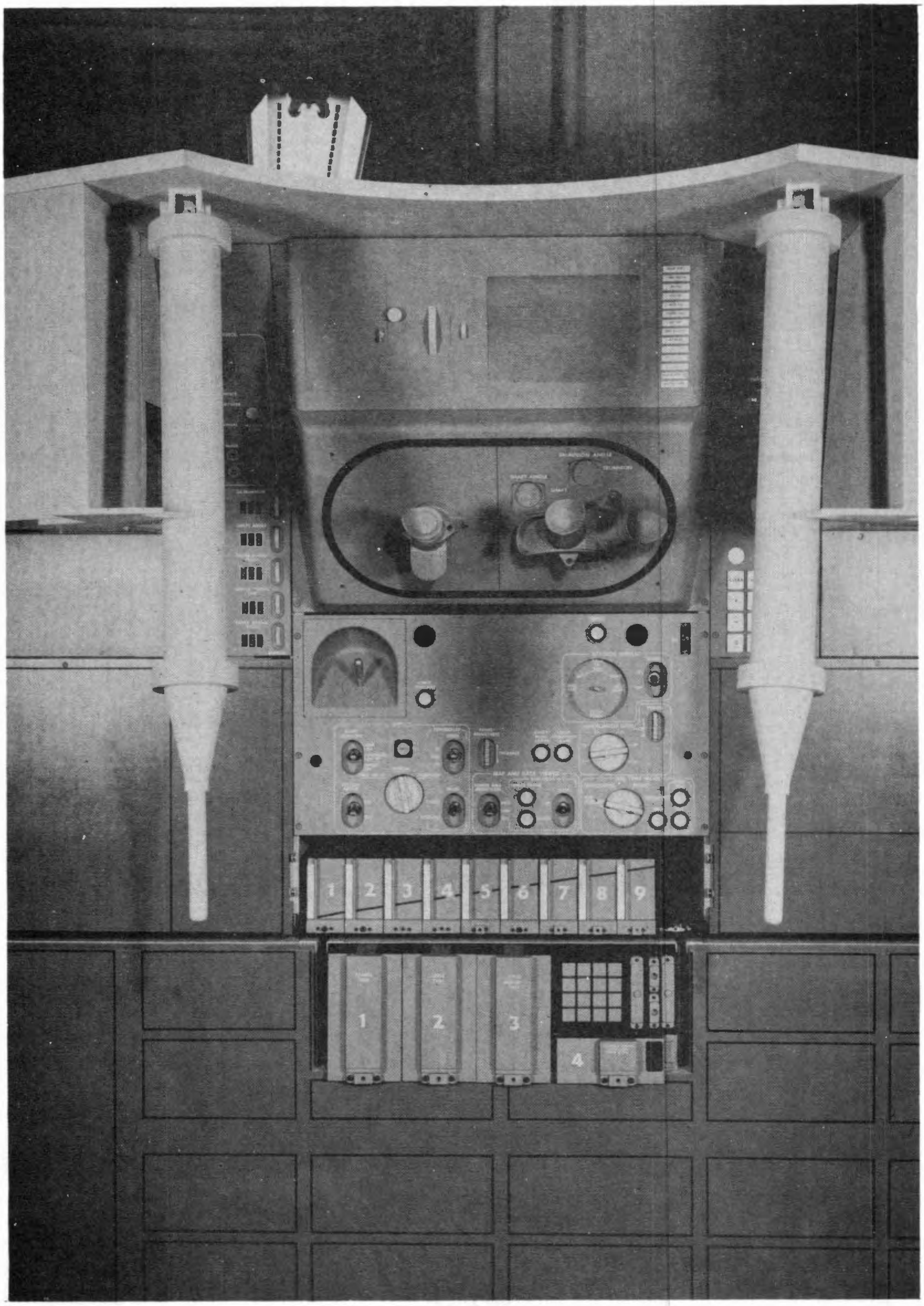


Fig. 1   Navigation station panel.

COMMAND MODULE G & N DISPLAYS AND CONTROLS

1.0 Inertial Measurement Unit

The inertial measurement unit is the primary inertial sensing device of the G & N system. The IMU consists of a three-degree-of-freedom gimbal system containing three pulsed integrating pendulum accelerometers (PIPA) and three inertial reference integrating gyroscopes (IRIG). The inertial components are mounted on the innermost gimbal, or stabilized member, which is held nonrotating with respect to inertial space by the action of error signals from the three gyroscopes. The outer axis of gimbal freedom is mounted parallel to the reentry control wind axis so that the high angular rates, during reentry roll control of lift, are "unwound" by the outer gimbal. This places the outer gimbal axis 33 degrees from the spacecraft symmetry axis. To avoid danger of gimbal lock, the inner gimbal axis is positioned normal to the plane of any planned trajectory or attitude turning maneuver.

The IMU produces two major outputs: 1) vehicle orientation signals from the gimbal angle transducers (or resolvers) mounted on each gimbal axis, and 2) velocity increments from the accelerometers which measure the specific forces applied to the vehicle by aerodynamic forces and thrust. A functional and schematic diagram of the IMU is shown in Fig. 2. The controls and displays associated with the IMU are described below (see Fig. 3).

1.1 IMU Coupling Display Units (CDU)

There are five CDU's, three of which are associated with the IMU. The IMU CDUs, one for each gimbal angle of the IMU, are used to transfer angular information between the IMU, the computer (AGC), the stabilization and control system (SCS) and the astronaut. The CDUs are located on the IMU control panel. They are identical and interchangeable. Each CDU contains a gearbox, motor, resolvers, incremental digital encoders, a drum type angle display, slew switch and thumbwheel. The incremental digital encoders provide a pulse to the computer for each increment of angular change of the CDU.

CDU angles may be set either automatically by the AGC or manually by use of the slew switch and the thumbwheel. Figure 4 shows a typical CDU. A single axis schematic of IMU-CDU-AGC operation is shown in Fig. 5.

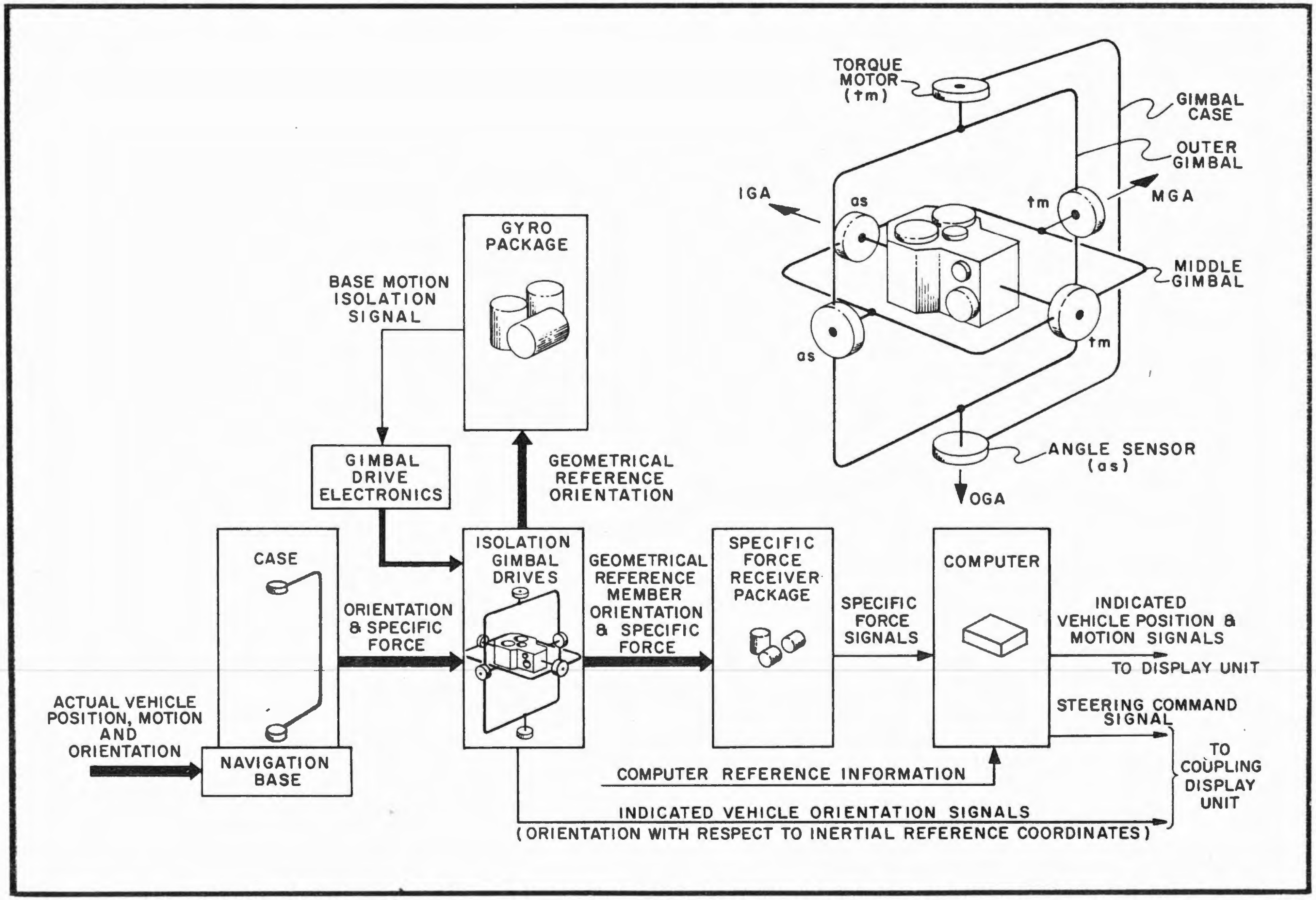


Fig. 2 IMU functional and schematic diagram.

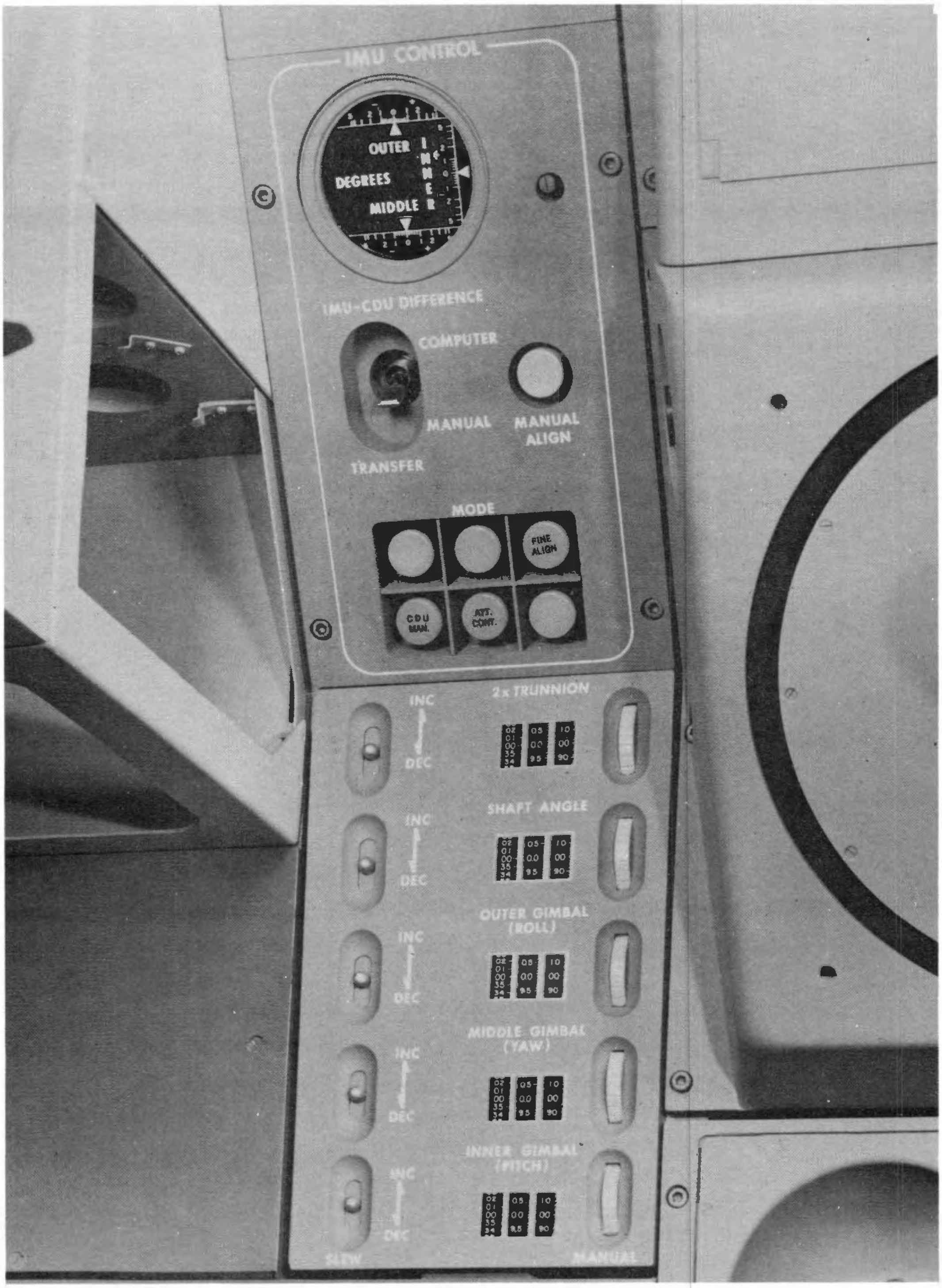


Fig. 3 IMU control panel.

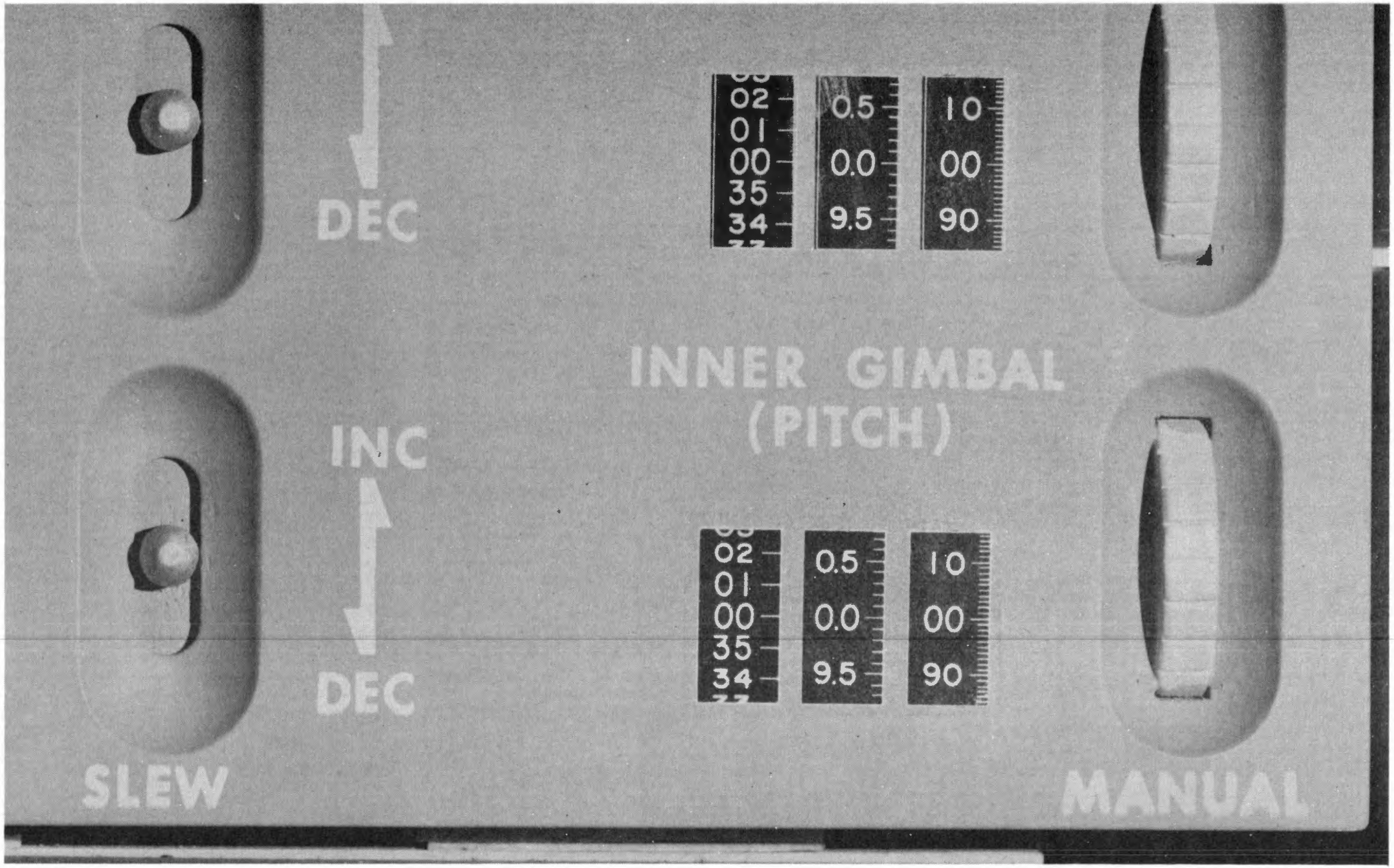


Fig. 4 Typical CDU.

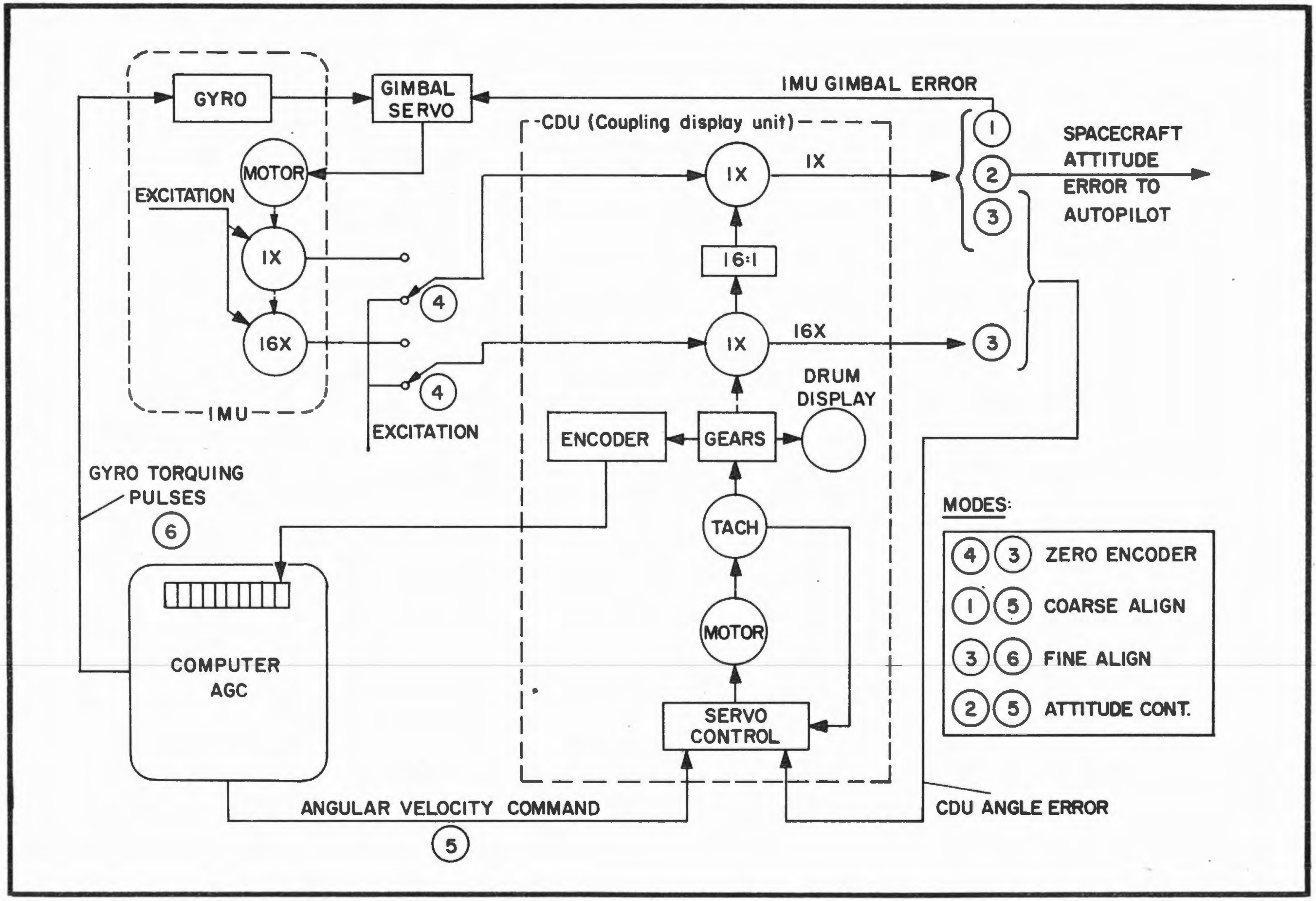


Fig. 5 IMU, CDU, AGC single axis schematic.

1.2 Transfer Switch

A two position (COMPUTER-MANUAL) transfer switch is provided for selecting either manual or computer control of the six IMU modes. In the COMPUTER position, mode selection is accomplished by the AGC using relay logic. In the MANUAL position, the astronaut selects the operating mode by means of the IMU mode control buttons.

1.3 IMU Mode Control Buttons

The IMU MODE control buttons is a 6 button matrix which provides manual selection of the six operational IMU modes. The mode buttons will function after the IMU is turned to OPERATE. A time delay is provided to permit the gyros to come up to operating speed. The mode buttons can function following the time delay and only when the TRANSFER switch is in the MANUAL position. In either MANUAL or COMPUTER operation, the appropriate button will illuminate to indicate the current operating mode. The functions of the mode buttons are as follows (See Fig. 6).

1.3.1 Zero Encoder Button

Actuating the ZERO ENCODER button activates a relay to place 800 cps /0° reference voltage on the CDU resolvers which drives the CDUs to their mechanical zeros. Simultaneously a second relay is closed sending a discrete signal to the computer indicating zero encode and fine align. The computer clears the registers for 30 seconds and the CDU angles stored in the computer go to zero.

1.3.2 Coarse Align Button

Actuating the COARSE ALIGN button activates the coarse align relay which causes error signals, representing the difference between IMU gimbal angles and CDU angles, to drive the IMU gimbals into alignment with the CDUs. In this mode the computer can position the CDUs to any desired angle.

1.3.3 Fine Align Button

Actuating the FINE ALIGN button causes error signals, representing the difference between IMU gimbal angles and CDU angles, to drive the CDU's to follow and repeat the IMU gimbal angles. The incremental digital encoders attached to the CDU motor shafts transmit IMU gimbal angular changes to the AGC.

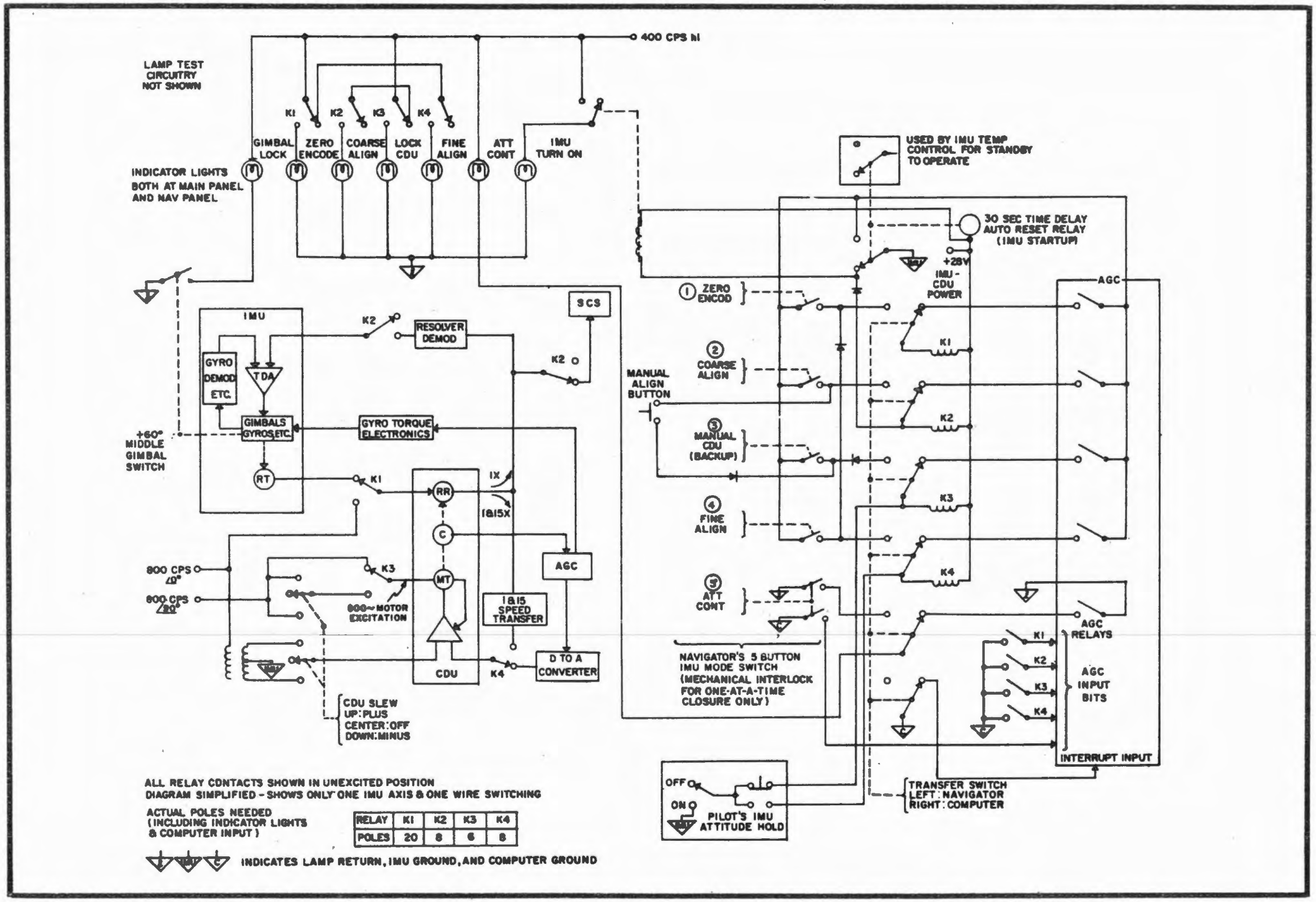


Fig. 6 IMU mode switching schematic.

In this mode, the IMU can be oriented with respect to star directions. This requires a simultaneous reading of star direction by means of the optics, and the IMU gimbal angles by means of the CDU's. This data is then processed by the AGC and the necessary angular corrections are derived. The corrections, if any, are accomplished by torquing the IMU gyros until the required IMU orientation is obtained.

1.3.4 Attitude Control Button

Actuating the ATTITUDE CONTROL button causes steering signals from the G & N system to be transmitted to the SCS system to control spacecraft orientation.

This is accomplished as follows: 1) navigator selects appropriate program on AGC, 2) the AGC drives the CDU's to the required angles with respect to the IMU, 3) error signals, representing the difference between IMU gimbal angles and CDU angles, are sent to the SCS system, and 4) the error signals operate on the SCS system as steering signals to drive the spacecraft to the desired orientation.

If the AGC is inoperative, CDU angles may be set in by means of the CDU MANUAL button and the slew switches.

1.3.5 Entry Button

The ENTRY button permits steering signals to be transmitted to the SCS system for control of spacecraft attitude during entry into the earth's atmosphere. In this mode, the gain of the roll control loop is increased by a factor of 16 to provide increased roll rate capability during entry.

1.3.6 CDU Manual Button

The CDU manual mode provides a backup capability for manual alignment of the IMU without use of the AGC. Actuating the CDU MANUAL button disables the AGC drive signals to the CDU drive motors and activates the CDU SLEW switches. The CDU angles may then be set to any desired value by using the slew switches and thumbwheels provided on the front of the CDU's. The IMU gimbals can then be coarse aligned to the CDU angles by holding the MANUAL ALIGN button in until the IMU-CDU DIFFERENCE indicator is zeroed. Simultaneously, caging loops are activated which supply torquing signals to cage the gyros to their null position.

1.4 Manual Align

In the CDU manual mode, holding in the MANUAL ALIGN button causes the IMU gimbals to be driven into alignment with the CDUs.

1.5 IMU-CDU Difference Indicator

The IMU-CDU DIFFERENCE indicator provides a 3-axis display of the angular difference between the IMU gimbal angles and the CDU angles. The maximum angular difference displayed is ± 5 degrees.

1.6 Slew Switch

The CDU slew switch provides a ground connection to the fixed field winding on the CDU motor and supplies in-phase or out-of-phase 800 cps voltage to the CDU servo amplifier to drive the CDU shaft to the desired angle.

1.7 Thumb Wheel

The CDU thumb wheel provides a mechanical drive to the CDU shaft for fine positioning of the CDU shaft.

1.8 CDU Angle Display

The CDU angle display is a drum type display mechanically connected to the CDU shaft drive. It is calibrated in degrees and decimal parts of a degree on three drums. The first drum displays 360° per revolution in 10° increments; the second drum displays 10° per revolution in 0.1° increments; the third drum displays 0.2 degrees per revolution in 0.001 degree increments. This display provides the only continuous visual indication of IMU gimbal angles.

1.9 IMU Temperature Control

The IRIG's and PIPA's within the IMU are maintained at their normal operating temperatures (135° ± 1°F and 130° ± 1°F respectively) by the IMU temperature control system (see Fig. 7). Basically, this system comprises a temperature control circuit, a temperature indicating circuit and associated heaters and blowers. Normally, the temperature control circuit controls the temperature by means of heaters and blowers while the temperature indicating circuit monitors IMU temperature. The indicating circuit has the additional capability of controlling the heaters and blowers in the event of malfunction of the normal temperature control circuit.

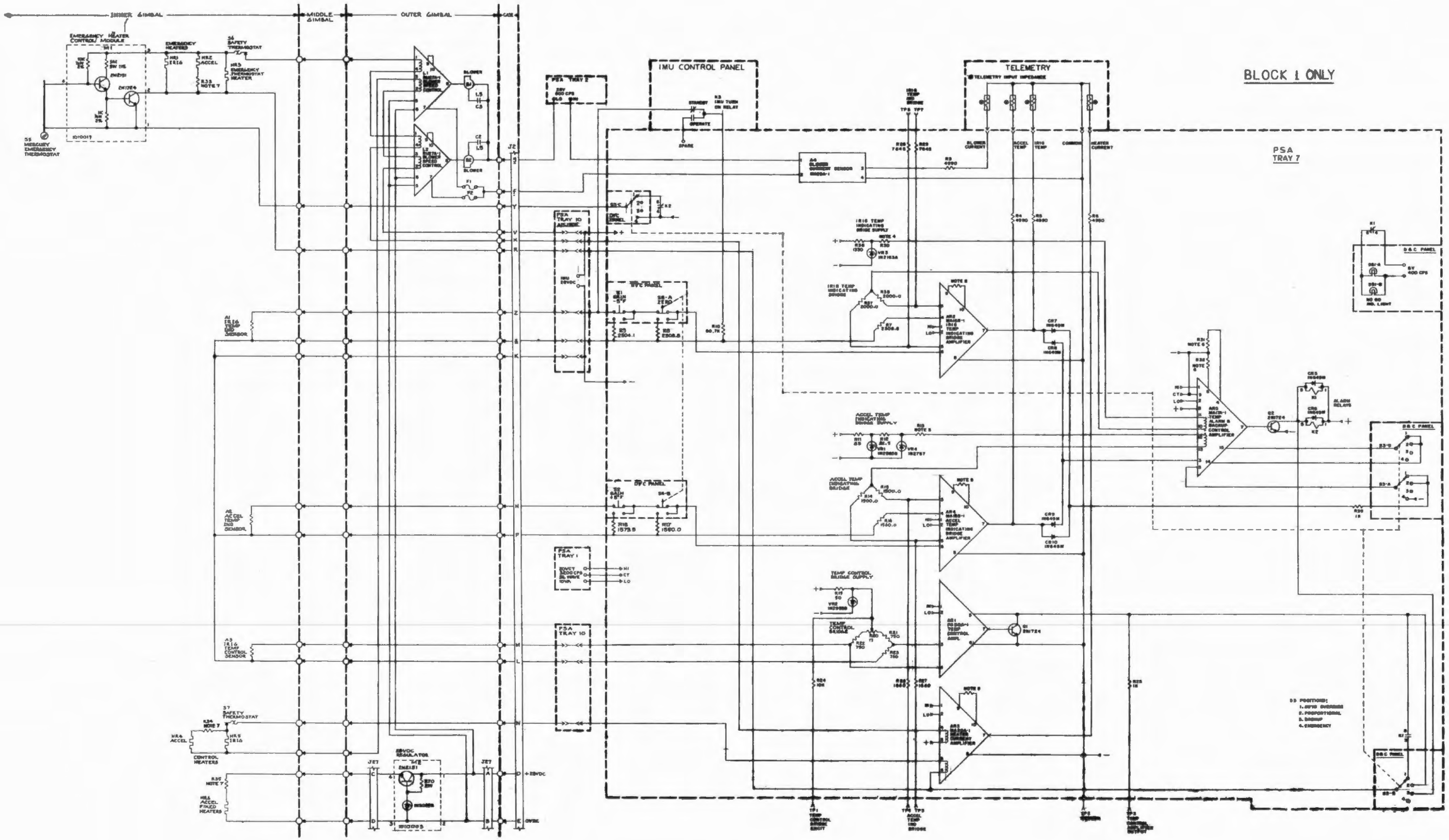


Fig. 7 IMU temperature control system schematic.

The temperature control circuit includes the following elements:

1. Two control sensors mounted on each IRIG.
2. A temperature control bridge which incorporates all the series connected sensors in one leg of the bridge.
3. A temperature control amplifier.

The temperature indicating circuit includes:

1. Two temperature sensors mounted in each IRIG and one in each PIPA.
2. PIPA and IRIG temperature indicating bridges.
3. PIPA and IRIG temperature indicating bridge amplifiers.
4. A temperature alarm and backup control amplifier.
5. Temperature alarm relays.
6. IMU TEMP warning light (in IMU condition light group).

The system includes the following heaters and blowers:

1. Two control heaters and two emergency heaters mounted on each IRIG.
2. An emergency heater, a control heater and a fixed heater mounted on each PIPA. The fixed heaters are on whenever the IMU power switch on the main instrument panel is in the OPERATE position.
3. Two cooling blowers mounted on the outer gimbal. Blower speed is inversely proportional to control heater and emergency heater current.
4. Safety thermostats in the emergency heater circuit and in the heater circuit. These thermostats are set to open at 256°F and close at 144°F.

Tests points have been provided on tray No. 7 of the power and servo assembly to allow trouble shooting of the IMU temperature control system with the in-flight test set.

To provide maximum reliability, temperature control can be accomplished in four different modes using combinations of the above circuitry. The controls and indicators provided in the temperature control system are: a 4-position rotary mode selector, a ZERO button, and IRIG GAIN button, a PIPA GAIN button, and an IMU TEMPERATURE condition light.

1.9.1 Temperature Control Mode Selector

The IMU TEMP MODE selector is a 4-position rotary switch. The four positions and their functions are as follows: (see Fig. 8)

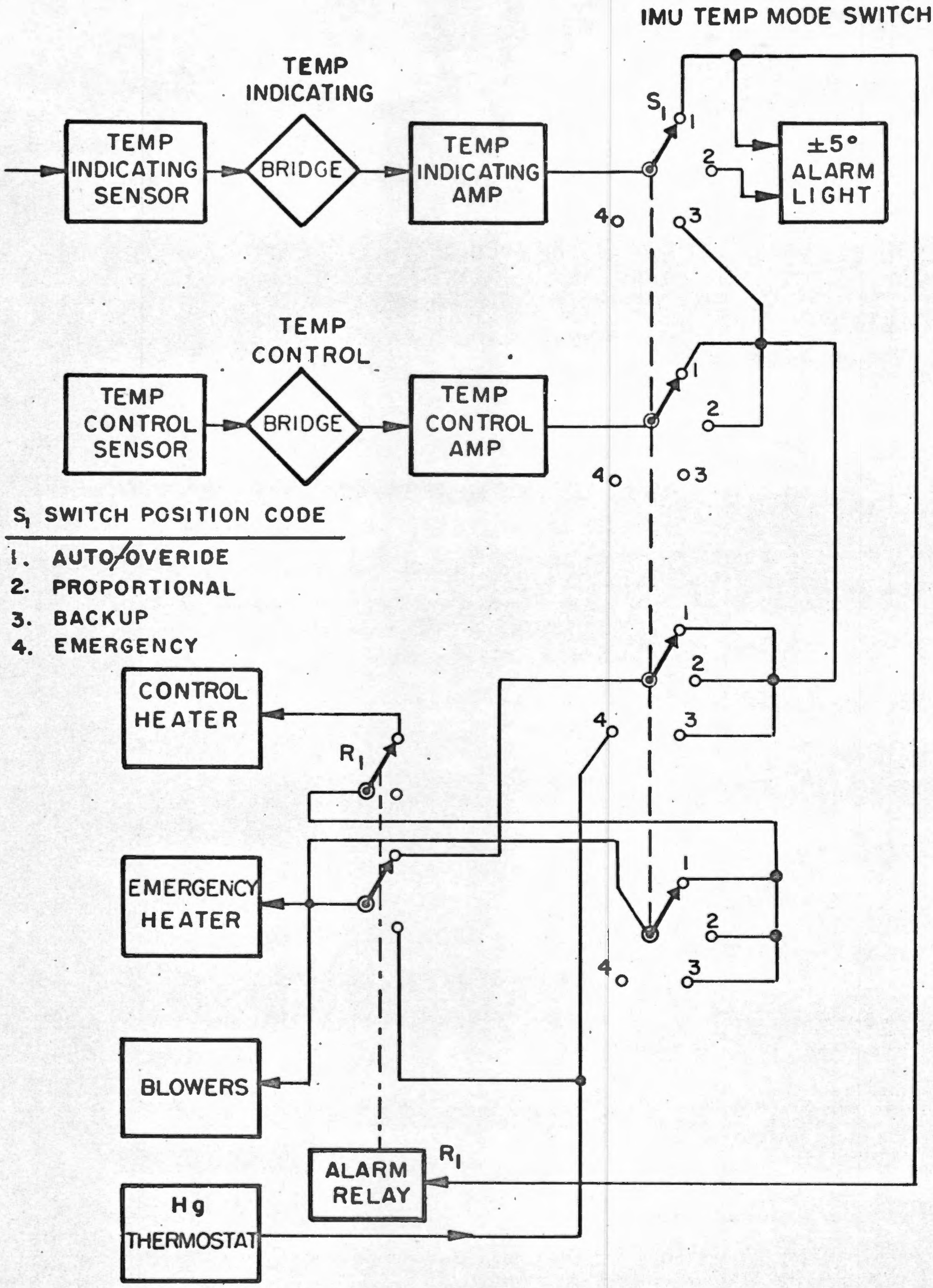
1.9.1.1 Auto/Override

The AUTO/OVERRIDE switch position is the normal operating position. In this mode, both the temperature control circuit and temperature indicating circuit are utilized. Temperature control is furnished by the temperature control amplifier using the IRIG temperature control sensors. Temperature indication, utilizing the IRIG and PIPA temperature indicating sensors, may be obtained from the temperature indicating bridge (test point) or the temperature indicating bridge amplifier (telemetry).

Normally, heating is accomplished by the control heaters and emergency heaters operating in parallel. If the IMU exceeds normal temperature tolerances (± 5°F), the system will automatically switch to the emergency mode and the IMU TEMP light will illuminate. When this occurs, the temperature alarm relays turn off the control heaters. The emergency heaters continue to operate under the control of an emergency mercury thermostat. When the temperature returns to within ± 1° F of normal, the IMU TEMP temperature light will be extinguished and the system will switch back to the normal control mode. The system will continue to cycle between auto override and emergency modes with an attendent cycling of the IMU TEMP light as long as the malfunction exists and the selector switch remains in the AUTO/OVERRIDE position. In this event, the navigator should select another mode. The mode selected will depend on whether the malfunction exists in the control circuit or indicating circuit as determined with the in-flight test system.

1.9.1.2 Proportional

The PROPORTIONAL mode is used if a malfunction occurs in the temperature indicating circuit causing undesirable cycling to the EMERGENCY mode. In the proportional mode, temperature control is furnished by the same heater control circuitry used in the auto/override mode. The temperature indicating circuitry is not used. Abnormal temperature will cause the IMU TEMP light to illuminate, but will not switch the system to the emergency mode.



IMU TEMPERATURE CONTROL FUNCTIONAL DIAGRAM
FIG. 8

1.9.1.3 Backup

The BACKUP mode is used if a malfunction occurs in the normal control circuit. Temperature control is then furnished by the temperature indicating circuits. In this mode, the IMU TEMP light will illuminate when the heaters are off and will extinguish when the heaters are on. The navigator must monitor the IMU temperature with the in-flight test set and manually switch to the emergency mode if the temperature becomes excessive.

1.9.1.4 Emergency

In the EMERGENCY switch position, IRIG temperature is controlled to approximately 135° ± 3°F by means of an emergency mercury thermostat and the emergency heaters. A safety thermostat provides overheat protection for the IMU by opening the emergency heater circuit when the stable member temperature exceeds 156°F. When this temperature drops below 144°F the thermostat closes the circuit to reactivate the heaters.

1.9.2 Zero Button

The ZERO pushbutton is a momentary contact pushbutton used for checking the calibration of the temperature monitoring devices. Depressing this button replaces the IRIG and PIPA temperature indicating sensors in the bridge with standard resistances equal to the resistance of the indicating sensors at their normal operating temperature, thus providing a calibration point for the condition of normal temperature.

1.9.3 IRIG Gain Button

The IRIG GAIN pushbutton is similar in function to the ZERO button. Depressing the IRIG button replaces the IRIG temperature indicating sensor in the bridge with a standard resistance equal to the resistance of the temperature indication sensor when it is operating at 5°F below normal. Depressing the IRIG button also tests the temperature alarm circuit and will light the IMU TEMP light.

1.9.4 PIPA Gain Button

The PIPA GAIN pushbutton performs the same function as the IRIG GAIN button with the exception that the resistance used is equivalent to PIPA indicating sensors operating at 5°F above normal.

2.0 Optics

The G & N system uses two optical instruments: a scanning telescope which is used for general viewing and orbital measurements and a sextant which is used for mid-course navigation measurements and IMU alignment. See Figure 9. The optical instruments and the IMU are mounted on a common navigation base so that angle data measured by them can be referenced to one rigid structure. Figure 10 shows simplified optical schematics of the two sighting instruments with a summary of their optical characteristics.

Two of the five CDU's are associated with the optics. The two optics CDU's, one for the sextant trunnion axis and one for the sextant shaft axis, are used to transfer angle information between the sextant and the other major G & N subsystems. The optics CDU's are mechanically identical to, and interchangeable with, the IMU CDU's. (paragraph 1.1)

At the navigators discretion a protective cover is fastened to the optics shroud to protect the alignment between the optics assembly and the navigation base.

2.1 Scanning Telescope

The scanning telescope is a single-line-of-sight, low power, wide field of view instrument used for making navigation measurements in earth or lunar orbit, or for general use such as acquisition of landmarks and stars for sextant sightings. Manual flip-flop selection of two eyepieces provides either a 1 power, 60 degree field of view or a 3 power, 20 degree field of view.

The telescope has two degrees of mechanical freedom to deflect the line-of-sight with respect to the navigation base: 1) a shaft axis, normal to the local conical surface of the spacecraft, permitting unlimited rotation of the optics assembly, and 2) a trunnion axis perpendicular to the shaft axis permitting unlimited rotation of the line of sight away from the shaft axis. Due to interference between the line of sight and the optics well the useful rotation about the trunnion axis is limited to less than 70°. The telescope shaft axis is electrically coupled to the sextant shaft axis. Figure 11 shows the relation of the optics axes system to the spacecraft axes system. The telescope line of sight may be directed as follows: 1) fixed along the shaft axis, 2) fixed at 25° trunnion angle with shaft axis slaved to the sextant, or 3) slaved

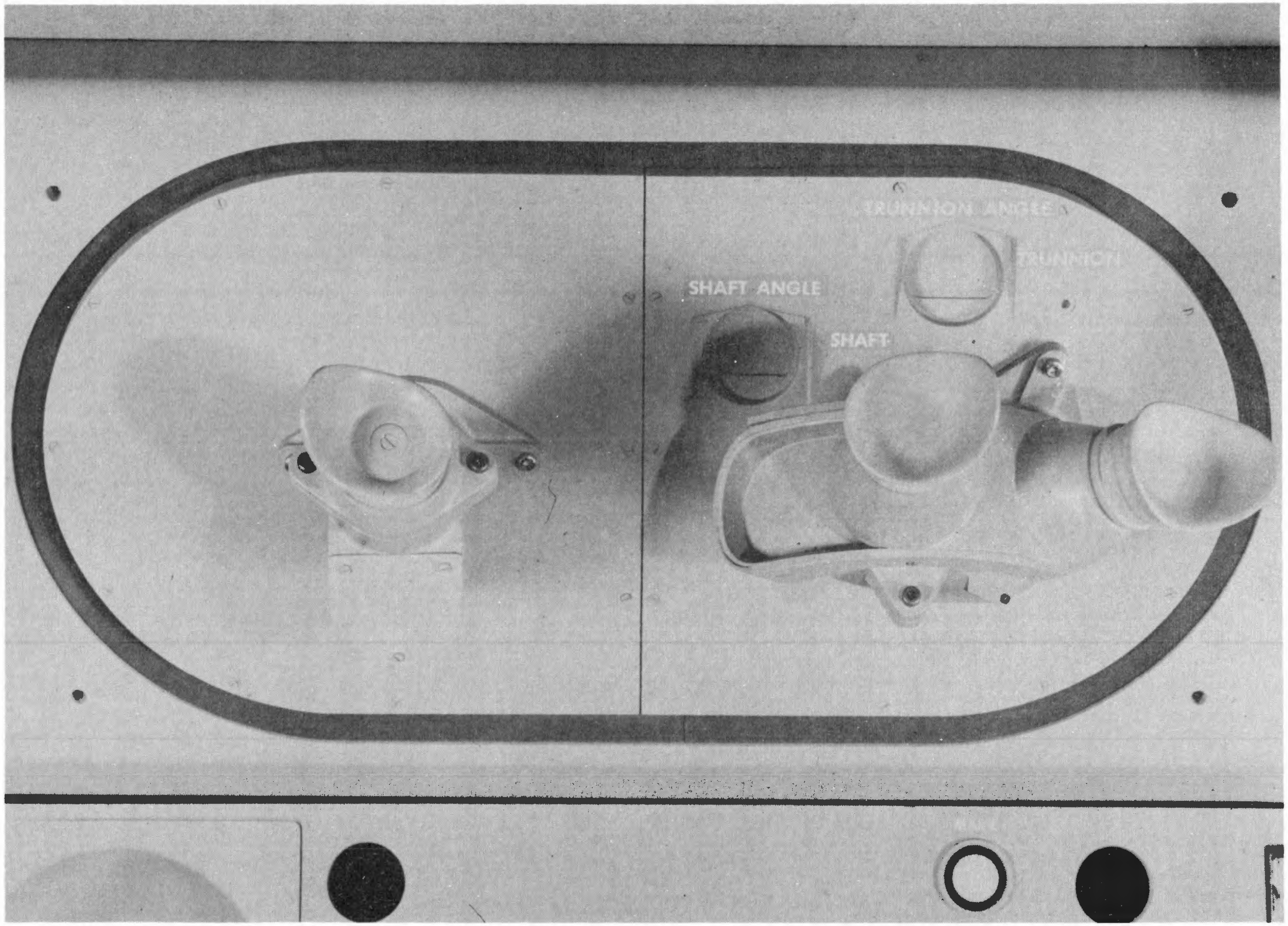


Fig. 9 Sextant and telescope.

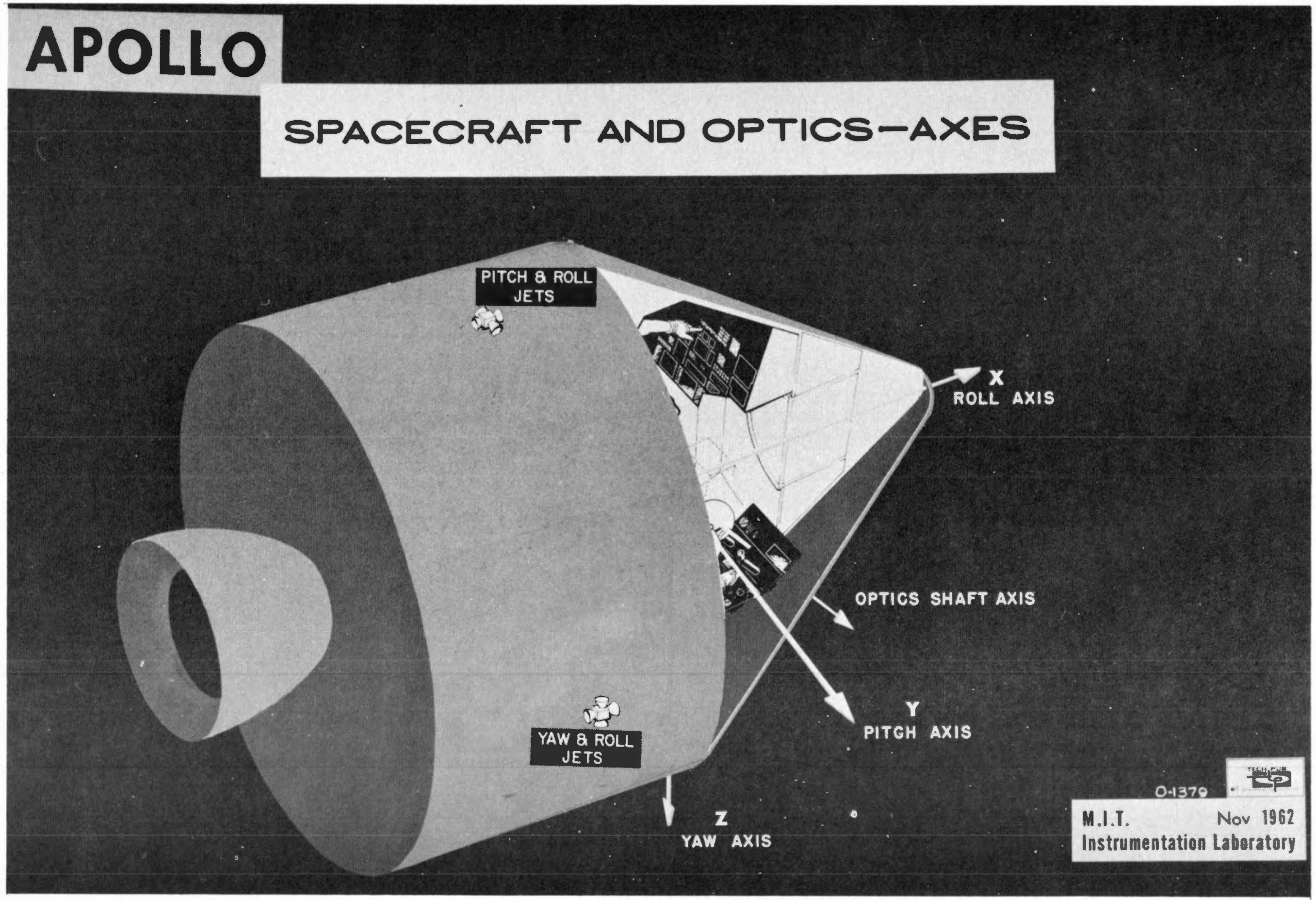

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Fig. 11

to the sextant star line of sight, in which case it is controlled by the hand controller, the AGC, or the tracker.

A back-up mechanical control for each axis is provided by means of a gear box which is driven by the universal tool. The telescope eyepieces must be removed to gain access to the universal tool sockets located on the base of the instrument.

Telescope line-of-sight angles with respect to the navigation base are read on mechanical counters through viewing windows on the telescope base. The telescope shaft angle is normally repeated on the sextant shaft axis CDU. When the telescope is slaved to the sextant star line of sight the telescope trunnion angle may also be read on the sextant trunnion axis CDU.

2.2 Sextant

The sextant is a precision, two-line-of-sight, high power instrument used to make star-to-planet angle measurements for navigation purposes and to make star direction measurements for orienting the IMU and the spacecraft in inertial space.

This instrument is a 28 power, 1.8 degree field of view telescope containing a beamsplitter, redirection mirror elements, and an articulating mirror all outboard of the objective element of the telescope. The beamsplitter divides the entering light to the telescope and directs approximately 20 percent along the focal axis of the instrument and 80 percent of the light is reflected by the articulating mirror. These two light paths constitute the landmark and star lines of sight respectively. Measurement of the angle the reflecting mirror element makes with respect to the head of the instrument and navigation base when the star is coincident with the landmark in the field of view constitutes the navigational sighting desired.

The sextant, like the telescope, has two degrees of mechanical freedom to deflect the line of sight with respect to the navigation base: 1) a shaft axis which permits ± 270° rotation of the optics assembly and 2) a trunnion axis perpendicular to the shaft axis which permits rotation of the line of sight from − 10° to + 70° of useful rotation. However, actual navigational sightings are limited to 58° between landmark and star as vignetting of the star line of sight occurs beyond this angle.

The sextant star line of sight may be controlled by the AGC or manually controlled by use of the optics hand controller. Star line of sight angles with respect to the navigation base can be read on the sextant CDUs. The sextant shaft angle is also displayed on the telescope mechanical counter since the shaft axes are electrically coupled. The star line of sight trunnion angle is also displayed on the telescope counter if the telescope is slaved to the star line of sight. In normal operation the CDU should be read in lieu of the mechanical counter due to greater accuracy of the CDU.

A tracker-photometer instrument may be attached to the sextant in place of the normal eyepiece for use in automatic tracking of a point light source, such as a star, or for use in determining the true horizon in navigation measurements. In the latter use, two applications are: 1) measurement of the angle between a star and the true horizon on the bright side of the earth during earth orbit and during the first 100,000 miles of the cislunar trajectory, and 2) measurement of the true horizon on the dark side of the earth during the first 40,000 miles of the cislunar trajectory.

The description of displays and controls associated with the optics follow (see Figure 12).

2.3 Optics Coupling Display Units

The optics CDU's provide control and display of the sextant shaft and trunnion angles. Their operation is similar to the IMU CDU's in that the thumbwheels provide backup control over the sextant which is normally controlled by the optics hand controller.

All CDU's have a 16 speed and a 64 speed resolver capability. However, the trunnion CDU is the only one using the 64 speed resolver system due to greater accuracy requirements. As a result of the interrelationship between the 64 speed resolver system and mirror movement, the trunnion angle displayed is twice the actual optical trunnion angle and is labelled accordingly on the display panel.

2.4 Optics Power Switch

A master optics power switch is located on the main instrument panel.

2.5 Sextant Power Switch

The SEXTANT POWER switch is an ON-OFF toggle switch which enables

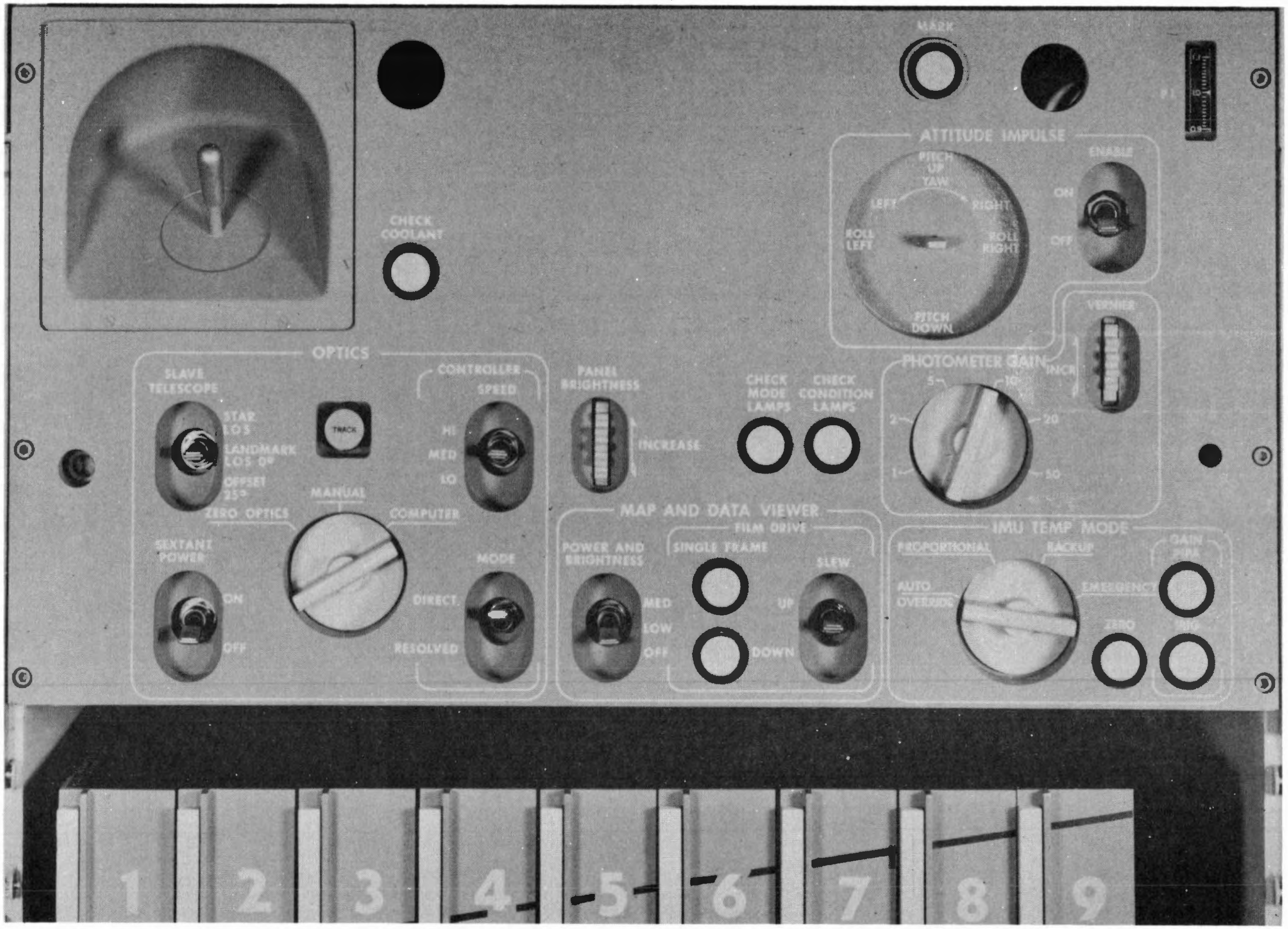

Fig. 12 Optics control panel.

power to be removed from the sextant independent of the rest of the optics subsystem. Operation of the sextant power switch also provides a sextant on-off signal to the AGC.

2.6 Focus Control

Focus control is provided for the sextant only. Focusing of the reticle is accomplished by rotating the knurled portion of the sextant eyepiece until the desired focus is obtained.

2.7 Attenuation Control

Variable attenuation of the landmark line of sight is accomplished by means of a polarizer which may be installed at the discretion of the navigator. The polarizer is inserted in a slot provided in the sextant eyepiece and is rotated to obtain the light balance desired. When not in use, the polarizer is stored in a slot provided on the side of the eyepiece housing.

2.8 Optics Door Control

The optics door cover, which protects the optics on the outside of the command module,is operated manually with the universal tool. The engagement socket is located to the left of the optics control panel.

2.9 Optics Hand Controller

The optics hand controller is a two-degree-of-freedom control stick which is used to control the sextant shaft and trunnion angles. The angular rate of travel of the line-of-sight is proportional to the stick displacement. A dead zone is provided to prevent the servos from creeping when the stick is in the neutral (center) position.

2.10 Optics Mode Control Selector

The optics mode control selector is a three position rotary switch which provides the following modes of operations: (If sextant power is off, only the telescope will be affected by the mode control selector).

2.10.1 Zero Optics

In the ZERO OPTICS mode, excitation is applied to the CDU resolvers to close the CDU resolver feedback loop and drive the CDU resolvers and optics to zero.

2.10.2 Manual

The MANUAL mode is the normal operating position in which the sextant and telescope are controlled by the optics hand controller.

2.10.3 Computer

In the COMPUTER mode the sextant and telescope are positioned by signals from the AGC.

2.11 Telescope Backup Mechanical Drive

If necessary, the telescope can be mechanically driven by means of the universal tool and two drive sockets. The sockets are located adjacent to the telescope mechanical counters and are labeled SHAFT and TRUNNION. See Figure 13.

Before mechanically operating the telescope, the optics power switch on the main instrument panel must be turned off.

2.12 Telescope Backup Mechanical Counters

Two mechanical counters on the base of the telescope (see Figure 13) display the telescope shaft and trunnion angles with respect to the navigation base. Normally, the SHAFT ANGLE displayed is the same as that displayed on the sextant shaft angle CDU (paragraph 2.3) due to the electrical coupling of the telescope and sextant shaft axes.

The TRUNNION ANGLE displayed is the telescope trunnion angle only, except when the telescope is slaved to the sextant star line of sight. In this condition, the telescope and sextant trunnion angles are identical. However, the telescope trunnion angle displayed is the actual trunnion angle and will therefore read one-half of the angle displayed on the sextant 2 x TRUNNION CDU.

The mechanical counters are drum-type indicators which present a digital display in four windows. The first three windows indicate degrees of arc; the fourth window indicates tenths of a degree in 0.02 degree increments.

2.13 Tracker Button

When a star or other light source has been acquired by means of the telescope, pressing the tracker pushbutton initiates automatic tracking.

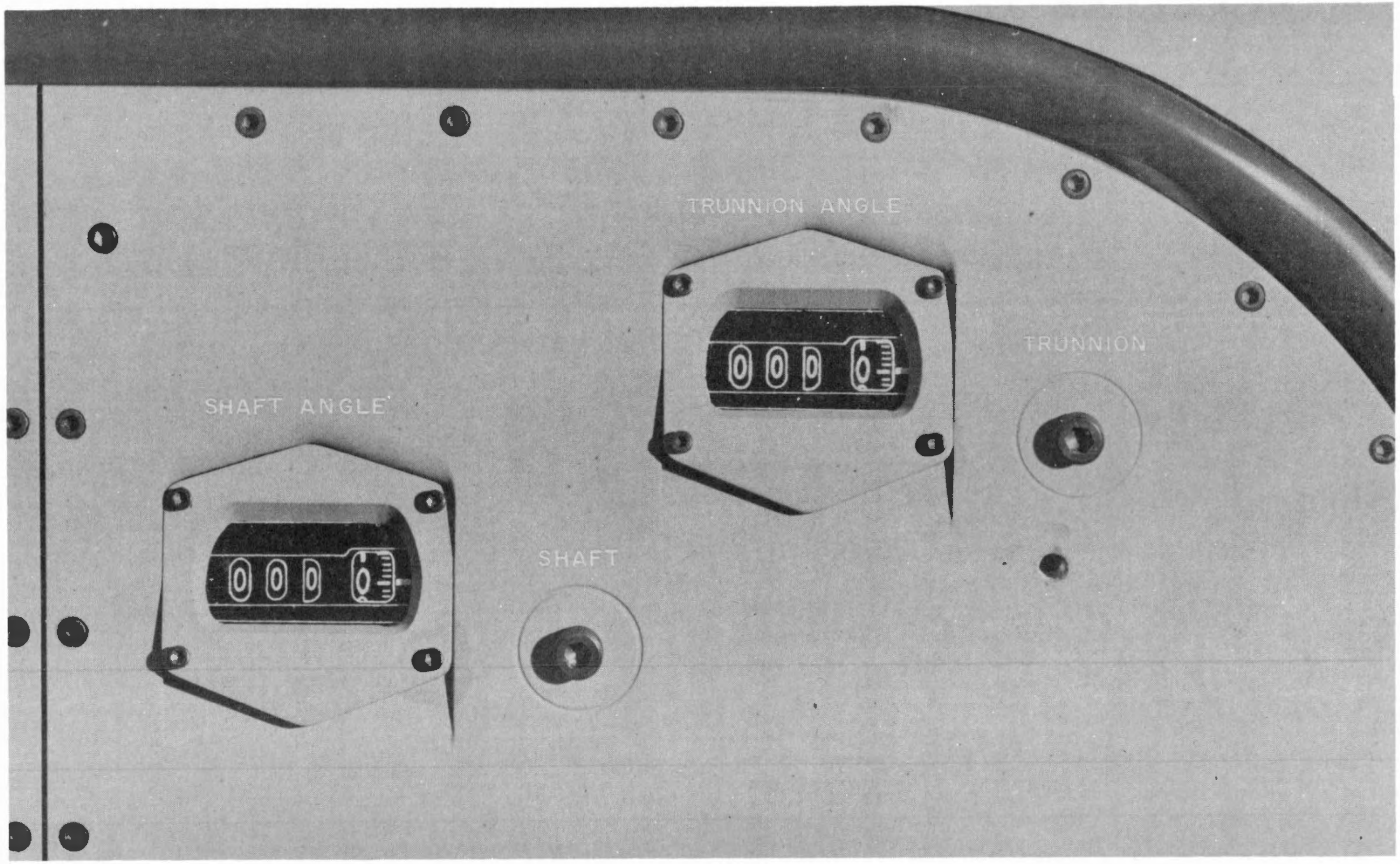

Fig. 13 Telescope backup mechanical counters.

2.14 Direct-Resolved Switch

The DIRECT-RESOLVED switch is a two-position toggle switch which provides the following functions:

2.14.1 Direct

In this position, the shaft and trunnion axis servos are commanded directly by the control stick motion. Right-left stick motion commands clockwise-counterclockwise shaft rotation respectively and fore-aft stick motion commands decrease-increase of trunnion angle respectively.

2.14.2 Resolved

In this position, the rate inputs to the command servos are resolved such that right-left/fore-aft stick motion results in left-right/down-up motion of the reticle.

2.15 Slave Telescope Switch

The SLAVE TELESCOPE switch is a three position toggle switch which affects the telescope trunnion angle control. It provides the following functions:

2.15.1 Landmark LOS 0°

In the LANDMARK LOS 0° switch position the telescope trunnion is positioned at zero and the line of sight is along the shaft axis. A landmark is acquired by sighting through the telescope while controlling spacecraft attitude with the rotational hand controller. When the landmark has been positioned in the center of the telescope field of view, the switch should be placed in the OFFSET 25° position.

2.15.2 Offset 25°

In this position the telescope trunnion drive is offset 25 degrees from the shaft axis. A 360° rotation of the shaft axis will then permit acquisition of all targets within a 110° cone. In this mode the landmark is held in the 1.8° reticle circle by the 1/2° deadband control of the SCS or by the navigator using the impulse controller. The shaft axis is rotated until the target star appears on the reticle line. The STAR LOS position is then selected.

2.15.3 Star LOS

In this position, the telescope trunnion axis is slaved to the sextant star line of sight. In this mode, the navigator sights through the telescope and uses the optics hand controller to center the star in the field of view. He then sights through the sextant and uses the optics hand controller to superimpose the star on the landmark or position both images parallel to an M line.

2.16 Optics Speed Switch

The optics SPEED switch is a three position toggle switch which selects three different ranges of speed control (LOW, MED, HI) for the optics hand controller. The maximum control rate for each speed is 0.1, 1.0, and 8.6 deg/sec respectively.

2.17 Mark Button

The MARK button is a momentary contact pushbutton switch which supplies an interrupt signal to the AGC to note optics angles, time of measurement, and, if the IMU is operating, the IMU gimbal angles. It is actuated, for example, when star-landmark superimposition is achieved.

2.18 Photometer-Tracker Controls

The photometer gain selector, vernier control and photometer level indicator are used when the photometer tracker is used for a navigation measurement, as follows:

2.18.1 Navigation Measurement Using Bright Horizon

1) Install the photometer-tracker on the sextant

2) Slave the telescope to the sextant star LOS

3) Use the telescope to acquire a target star

4) After centering star in reticle, push tracker button for automatic tracking

5) Return telescope to LANDMARK LOS 0° and orient vehicle to point the telescope (and therefore the sextant landmark LOS) at brightest level on horizon. This is accomplished by maneuvering the spacecraft perpendicular to the horizon until a maximum photometer reading is obtained.

6) Set photometer gain selector to position that results in a photometer level indication close to 1.0

7) Make final adjustment to 1.0 with vernier thumbwheel

8) Rotate vehicle to slowly raise sextant landmark LOS above the horizon. An automatic MARK signal and navigation measurement occur when the brightness decreases approximately 50 percent.

2.18.2 Navigation Measurement Using Star Occultation

In this operation, the navigator uses the photometer-tracker as previously described to acquire and track a target star which will soon set on the dark horizon. The photometer gain is set in the same manner as described above. No vehicle rotation is necessary other than to maintain automatic tracking of the setting star. An automatic MARK signal and navigation measurement is accomplished when the star brightness decreases to a calibrated value.

3.0 Apollo Guidance Computer (AGC)

The Apollo guidance computer is the central data processing system. The AGC is a core memory, variable speed 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 AGC receives inputs from the inertial and optical subsystems and the navigator, processes the information, and furnishes an output in the form of command signals and/or a data display on a computer control panel at the navigators station. The computer also supplies timing signals to synchronize and control the operation of components in the inertial and optical subsystems. The computer control panel provides the interface between the navigator and the AGC and contains the displays and controls necessary for selecting programs and inserting or calling-up data. A slightly abridged version operating in parallel with this panel is located on the main instrument panel between the center and left astronauts. The individual controls and displays are described below. (A preliminary layout of the AGC D & C is shown in Fig. 14.)

3.1 Computer Keyboard

The computer keyboard is used to manually insert or call up data from the computer. The keyboard consists of 10 digital pushbuttons, 2 algebraic sign pushbuttons, and 4 instruction pushbuttons. Code numbers for inserting or calling up data are stored in the map and data viewer or on a placard.

3.2 Numerical Display

A numerical display is associated with the computer keyboard for display of called-up data and verification of inserted data. Three 2-digit decimal readouts identify the current program (PROGRAM) being processed by the computer and variables (NOUN-VERB) being displayed or entered into the computer. Three rows of data, each with five digits and an algebraic sign, are displayed.

3.3 Computer Activity and Uplink Indicator

Two ACTIVITY lights on the computer control panel illuminate to indicate either COMPUTER activity or UPLINK activity. The computer activity light would be used for long subroutines to indicate to the operator that the subroutine selected by the operator is still being processed. The uplink activity

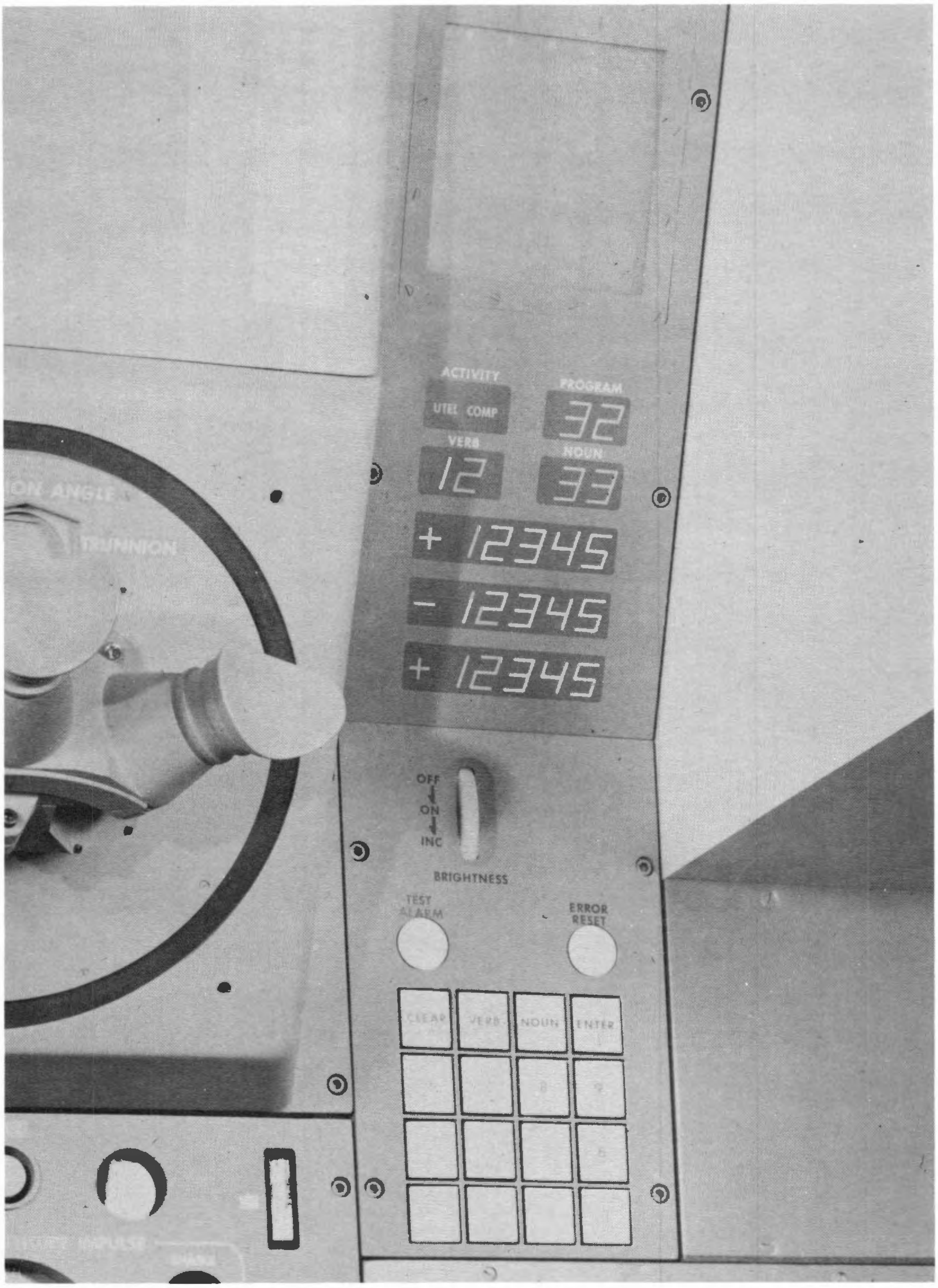

Fig. 14 AGC control panel.

light indicates to the operator when computer data is being transmitted to the AGC by the telemetry uplink.

3.4 Computer Condition Lights

Computer condition lights located at the top of the navigation station computer control panel indicate abnormal conditions of computer operation. Each light is labeled with the condition it represents and will illuminate if that condition occurs. On the main instrument panel computer control panel a CAUTION/ WARNING light indicates an abnormal operating condition. The condition lights and their functions are as follows:

3.4.1 Rupt Lock

This alarm light is triggered if AGC is in the interrupted state for longer than 20 milliseconds, or if there is a malfunction in the interrupt priority circuits. It also detects failure to interrupt within 40 microseconds.

3.4.2 TC Trap

This alarm light (Transfer Control) is triggered if the counter is "hung up" on certain kinds of endless loops of instructions.

3.4.3 Cross Point Fail

This alarm indicates that no cross-point is active at any one time.

3.4.4 Scaler Fail

This alarm is triggered when the lowest frequency (about 0.039 cps) pulse has not occurred within the last second during scaler check.

3.4.5 Inactivity

This alarm function detects such malfunctions as oscillator failure, or 512 KC reference frequency failure.

3.4.6 Illegal Order

This alarm indicates an incompatible request.

3.4.7 Parity Alarm

The purpose of the parity circuit is to ensure that the numbers stored in erasable and fixed memory are read out correctly.

3.4.8 AGC Power Supply Fail

This alarm detects the absence of proper voltage in any of the three AGC power supplies (-13 vdc and two -3 vdc).

3.5 Test Alarm

A TEST ALARM pushbutton is provided on the navigation station computer control panel to test the computer alarm circuitry and the lamps in the computer condition lights.

3.6 Error Reset Button

The ERROR RESET button is provided to recycle the computer when an abnormal indication is indicated.

3.7 Display Brightness Control

A DISPLAY BRIGHTNESS thumbwheel is provided to turn on power to the numerical display lights and for adjusting their intensity.

3.8 UTLM Switch

A two position (ACCEPT-BLOCK) switch is provided on the main panel computer control panel to enable the pilot to accept or block uplink telemetry data to the AGC.

4.0 Map and Data Viewer

The map and data viewer is a projection device used to display data prepared on 16 mm color film on a rear-viewing screen. See Figure 15. The viewer utilizes interchangeable cartridges pre-loaded with 50 feet (ie. 2000 frames) of film. Filmed data will include lunar and earth terrestrial maps, star charts, procedure check lists, maintenance information and other useful data. An access door is provided on the viewer for changing the film cartridge and for replacement of the projection lamp.

Viewer controls provide three modes of film positioning (step, slew, and manual) adjustment of the screen reticle, and three levels of screen luminence for viewing under different ambient light conditions.

4.1 Viewer Screen

The map and data viewer screen is a 5.4 in. by 7.4 in. opaque plastic projection surface. It is adjustable ± 3/16 inch horizontally. Horizontal and vertical indices are scribed on the screen to permit measurement of relative coordinate positions on the projected maps. Also, a series of marks on the top portion of the screen will, in conjunction with indices on the film, indicate the approximate location in the total film strip of the particular frame being viewed. This will enable rapid slewing to a particular section of the strip.

4.2 Focus Control

A focus control knob on the front of the viewer is used for mechanical focusing of the displayed data.

4.3 Horizontal Vernier Control

The horizontal vernier control, located on the front of the viewer, is a thumb-wheel used for horizontal positioning of the viewer screen (ie. positioning of the horizontal indice).

4.4 Vertical Vernier Control

The vertical vernier control, a large thumb-wheel provided on the front of the viewer, is used for: 1) vertical positioning of the displayed maps with respect to the vertical indice, and 2) manual film drive to back up the motor drive system.

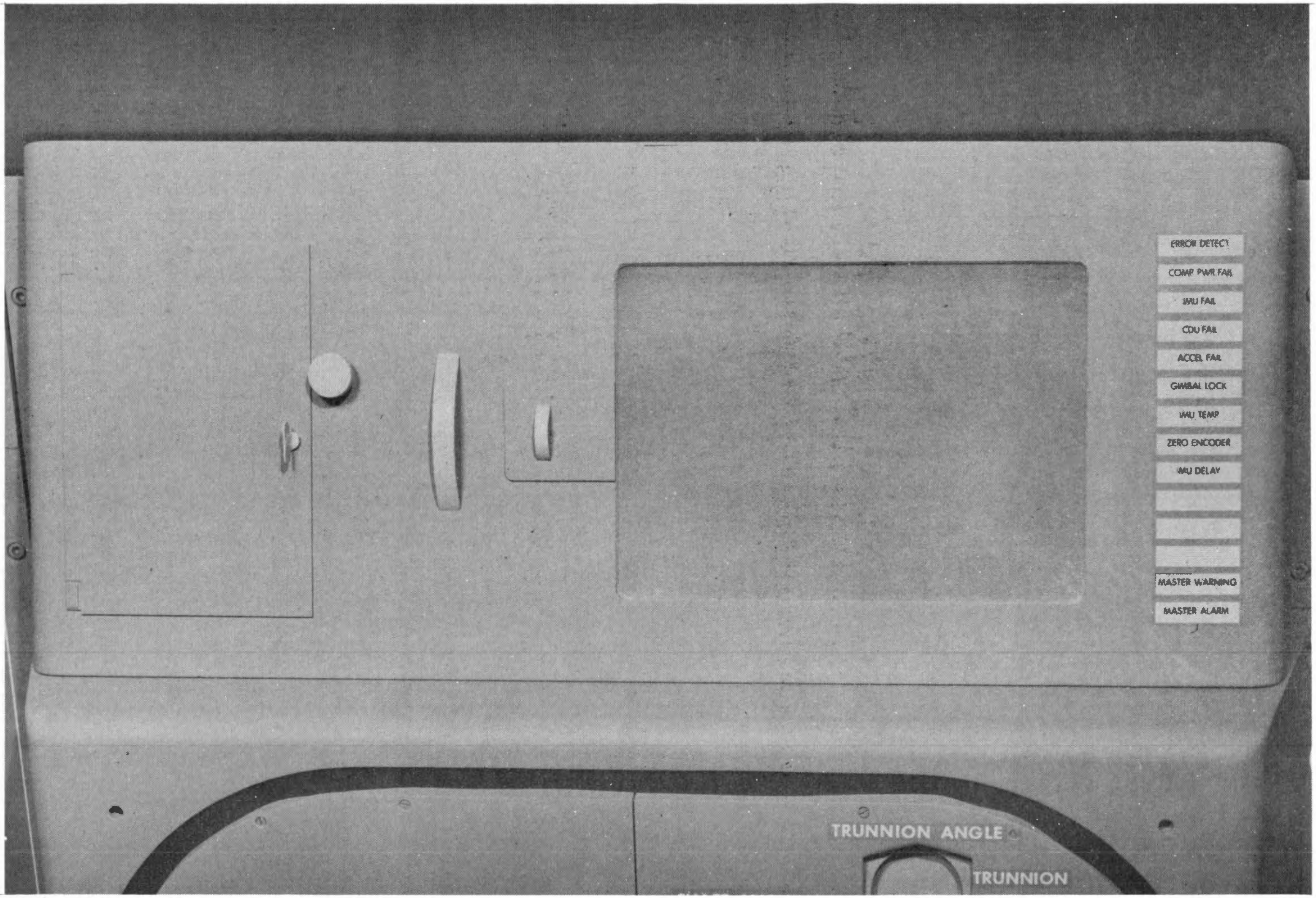

Fig. 15 Map and data viewer.

4.5 Power and Brightness Control

The POWER AND BRIGHTNESS switch is a three position (OFF-LOW-HIGH) toggle switch which supplies power to the map and data viewer drive electronics and projection bulb. The two projection bulb intensities available are 5 W (LOW) and 7 W (HIGH). A toggle switch, located behind the bulb access door provides more illumination if required,by placing the 5 and 7 watt filaments in parallel.

4.6 Slew Switch

The film drive SLEW switch is a three position toggle switch which permits slewing the film at approximately 20 frames/sec.

4.7 Single Frame Pushbuttons

The single frame drive pushbuttons (UP-DOWN) are momentary contact switches which permit step-film feed in single frame increments.

5.0 Condition Lights

G & N condition lights, located at the right of the map and data viewer, (see Figure 15) are provided to inform the navigator of detected subsystem errors. Error detectors at critical points throughout the equipment monitor error signals which are combined by logical "or" into groups of master error detection signals. (See Figure 16) The detectors which sense emergency conditions send discrete bits to the computer which light the appropriate light. The navigator can then take the necessary emergency action. The monitor points can be sampled individually with the spacecraft in-flight test system in order to localize the failure.

The G & N condition lights include three amber colored warning lights which indicate a condition of operation requiring caution, five red colored alarm lights which indicate an equipment malfunction requiring immediate attention, and a green light indicating a normal time delay period.

Also located with the G & N condition light group are a master caution and a master warning light which are associated with the spacecraft Master Caution and Warning Subsystem. All of the above lights are duplicated on the main instrument panel.

5.1 Error Detect Alarm Light

The ERROR DETECT lamp will light if an error is detected anywhere by the G & N error monitors.

5.2 Computer Power Failure Alarm Light

The COMP PWR FAIL lamp will light if there is a failure in the -10V, -13V or 28V power supply within the computer.

5.3 IMU Failure Alarm Light

The IMU FAIL lamp will light if there is an IMU gimbal servo error, microsyn power supply loss, gyro wheel power supply loss, resolver and tachometer excitation power supply loss, or a -28 vdc loss within the IMU.

5.4 CDU Failure Alarm Light

The CDU FAIL lamp will light if there is a digital encoder excitation power supply loss, CDU motor power supply excitation loss, or a CDU servo error.

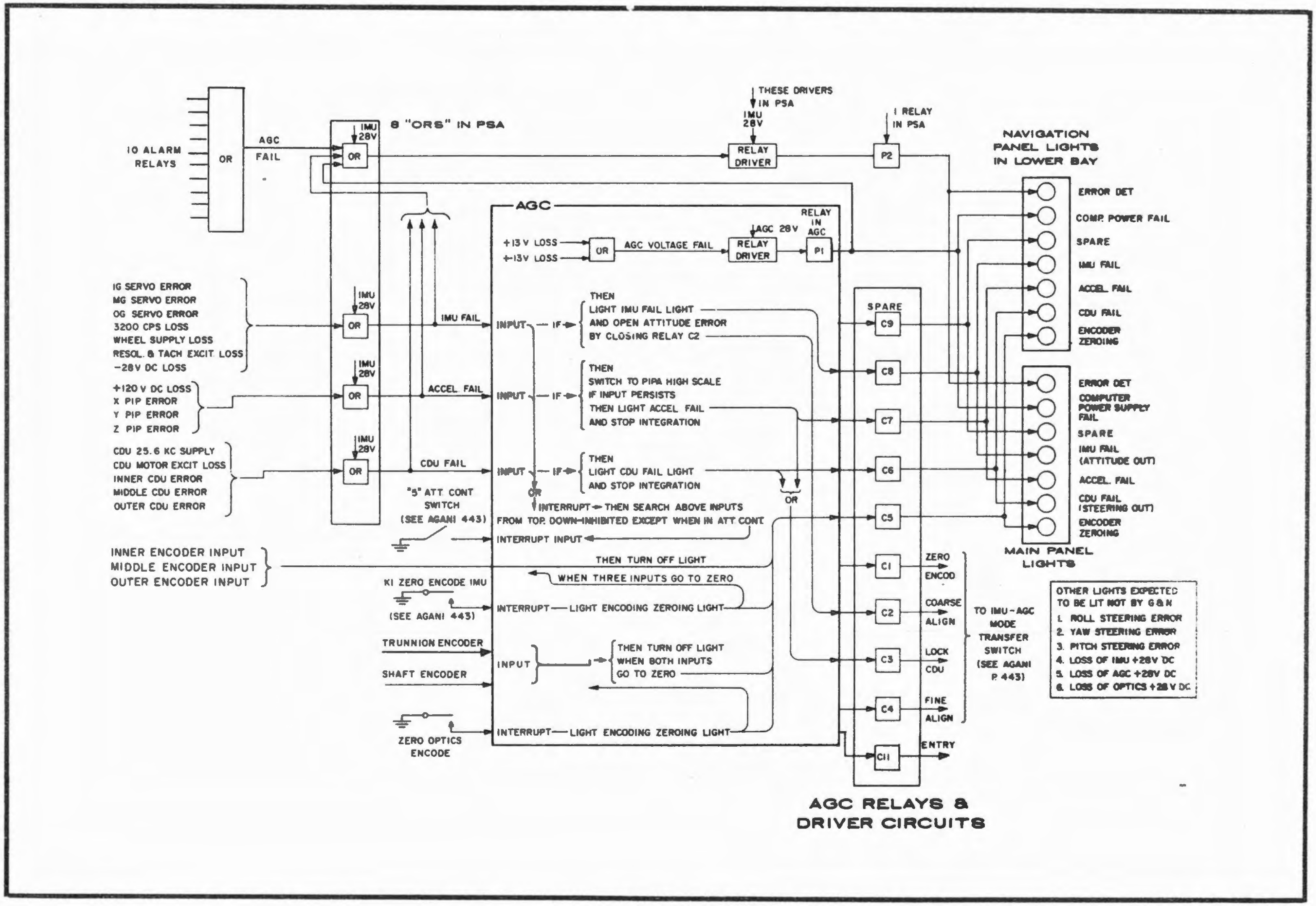

Fig. 16 Condition lights schematic.

5.5 Accelerometer Failure Alarm Light

The ACCEL FAIL lamp will light if there is a 120 vdc power supply loss, an IMU 28 vdc power supply loss, or an accelerometer error.

5.6 Gimbal Lock Caution Light

The GIMBAL LOCK lamp will light when the middle gimbal angle becomes greater than ± 60° with respect to the outer gimbal thus indicating a potential gimbal lock. Note: The gimbal angle at which gimbal lock warning occurs is a design variable. On Block 2 Systems, it is expected that the warning will be given at ± 75°.

5.7 IMU Tmperature Caution Light

The IMU TEMP lamp will light when the IMU Temperature deviates greater than ± 5 F° from normal.

5.8 Zero Encoder Caution Light

The ZERO ENCODER lamp will light when the IMU CDU's are in the process of zeroing. They are extinguished when all CDU's are at zero.

5.9 IMU Delay Light

The IMU DELAY lamp is the only green light in the condition light group. This light illuminates for 40 seconds following IMU turn-on. During this time delay, the gimbals are caged to the CDU's to allow the IMU gyros to attain operating speed. During this time the IMU cannot be commanded manually or by the computer since 28 vdc power is not supplied to the TRANSFER switch until the time-delay relay closes. If necessary, the time-delay relay can be by-passed by depressing the MANUAL ALIGN button.

5.10 Master Caution and Warning Lights

The MASTER CAUTION and MASTER WARNING lights are associated with the spacecraft error detection subsystem. These lights are duplicated on the main instrument panel. A tone generator activated in conjunction with these lights, provides an audible alert over tne intercom system.

6.0 Illumination Controls

Illumination controls are provided at the navigation station for control of display illumination and testing of condition lamps for the G & N equipment. See Figure 12.

6.1 Panel Brightness

A PANEL BRIGHTNESS thumbwheel controls the intensity of the following:

Optical reticles

IMU-CDU Difference indicator

Six CDU mode buttons

Five CDU displays

Tracker button

Telescope angle readouts

6.2 Check Mode Lamps Button

A CHECK MODE LAMPS button is provided to test the lamps in the six CDU MODE buttons and the tracker button.

6.3 Check Coolant Button

The CHECK COOLANT button is a momentary contact pushbutton which applies power to the flood lamps located behind the panel to illuminate the IMU quick disconnect couplings. The couplings are viewed through two windows provided in the panel covering the IMU.

6.4 Check Condition Lamps

A CHECK Condition LAMPS button is provided to test the IMU condition lights on the Map and Data Viewer panel.

6.5 Panel Floodlight Control

A panel floodlight rheostat, located above the IMU control panel, is used to control the intensity of one of the two floodlights which illuminate the navigation station displays. This rheostat also controls illumination of the clocks.

7.0 Clock Group

The clock group comprises three mechanical clocks: A Greenwich Meridian Time clock, a Time-To-Event clock, and a Time-From-Event clock.

7.1 Greenwich Meridian Time (GMT) Clock

The GMT clock is an eight-day mechanical clock with a conventional round dial and an hour, minute, and sweep second hand. This clock displays time-of-day on a 24 hour face.

7.2 Time-To-Event (TTE) Clock

The TTE clock displays the time to an event which has been manually set into the clock by the navigator. The clock counts down to zero. It can display up to 10 hours in one second increments.

7.3 Time-From-Event (TFE) Clock

The TFE clock is identical to the TTE clock except that it displays total elapsed time from a major event up to 100 hours.

8.0 Power and Servo Assembly

The power supplies required to operate the G & N subsystems are contained in the power and servo assembly (PSA) located at the base of the navigation station. See Figure 17. The PSA provides various types of DC and AC power to the rest of the G & N system and also serves as the location of various other support electronics such as the servo control amplifiers for the IMU and optics drives. The PSA consists of eight slide-in blocks of electronics which are numbered and mounted on a cold plate and interconnected by a junction box. Each block is identified by a number.

G & N system power controls, not previously described, are located on the main instrument panel. They include the following circuit breaker switches which supply power, protection, and isolation to the G & N equipment.

8.1 IMU Power Switches

Two two-position (STANDBY-OPERATE) IMU power switches are located on the right-hand side console of the main instrument panel.

8.2 AGC Power Switch

The AGC power switch is a two position ON-OFF switch.

8.3 Rendezvous Radar Power Switch

The rendezvous radar power switch is a two position ON-OFF switch which supplies power for search and tracking modes of operation.

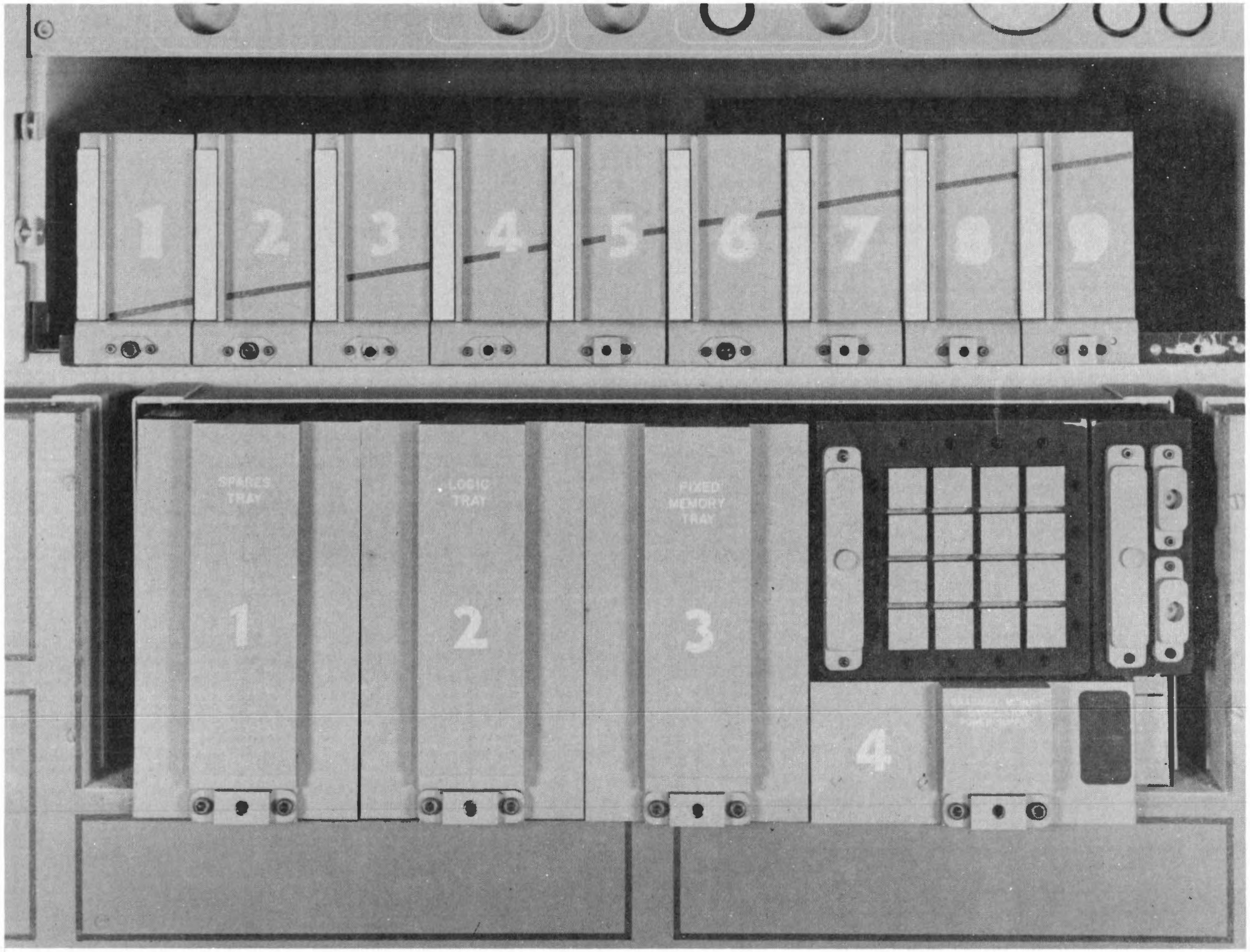

Fig. 17 Power and servo assembly (and AGC trays).

9.0 Attitude Controls

The spacecraft attitude controls, located at the navigation station, include a spacecraft rotational hand controller, an attitude impulse controller and an attitude impulse enable switch. Other controls, used for coupling the G & N system to the SCS system for spacecraft attitude control, are located on the SCS control panel on the main instrument panel. The G & N system may be selected to control vehicle attitude during nonaccelerated phases of the mission as well as to control thrust magnitude and direction (or lift forces during re-entry) to achieve a desired trajectory.

9.1 Rotational Hand Controller

The rotational hand controller is a 3 degree-of-freedom controller normally mounted on the right arm rest of all three couches. For use at the navigation station it is removed from the center couch and fastened to a panel on the right side of the navigation station. The controller is operational for manual attitude maneuvers when the hand controller DIRECT-ENABLE switch is switched ON by the pilot.

If the controller is to be used to maneuver to and hold a new attitude when in the G & N attitude control mode, the pilot must also place the G & N SYNC switch in the ON position. A detent switch in series with the SYNC switch is incorporated in the rotational hand controller and is closed when the controller is operated. The SYNC switch is used to cause the CDU's to follow manually commanded spacecraft attitude changes and then to establish the attitude hold condition on termination of the manual commands. The controller inputs are sent to the SCS system to provide spacecraft attitude rates proportional to stick displacement. Maximum control rates are $\pm 0.5°/sec$ except in the entry mode when maximum roll rate is increased to $\pm 17°/sec$ and maximum pitch and yaw rate increased to $\pm 5°/sec$.

9.2 Attitude Impulse Control

The attitude impulse control is a 3 degree-of-freedom stick controller used to apply small impulses to the spacecraft by means of the service module (SM) reaction jets. This controller has the same sensing as the rotational hand controller. It can be used to apply individual or any combination of roll, yaw or pitch impulses to given spacecraft attitude rates of 1.2 minutes of arc per second or less. Impulse control gives the navigator a manual vernier control of spacecraft attitude and aids him in reducing drift rates to a minimum while making precision optical measurements.

9.3 Attitude Impulse Enable Switch

The attitude impulse ENABLE switch is a two-position (ON-OFF) switch. In the On position, it disables the SCS and G & N attitude control and activates the attitude impulse controller. The enable switch is spring loaded to the OFF position but, when turned on, is held in the ON position by a solenoid. The switch turns off automatically when any SCS CONTROL MODE button other than G & N ATT CONT or SCS ATT CONT is selected, or it may be turned off manually.

9.4 SCS Panel Controls

The SCS panel controls include SCS attitude set controls, a 0.05 g backup selector switch, a two position deadband switch and eight SCS mode buttons. The mode buttons enable the pilot to select automatic attitude control either by means of G & N system commands to the SCS system or by means of the SCS system alone utilizing the body mounted attitude gyros (BMAG's) for attitude information.

9.4.1 Backup Rate Switches

Three BACKUP RATE switches, one for each BMAG, are provided to place a selected BMAG into a rate mode and have it operate as a rate gyro in place of the rate gyro in that axis. If a BMAG is used in this manner the attitude error display for that axis does not indicate attitude error in SCS modes.

9.4.2 Channel Disable Switches

The CHANNEL DISABLE switches are used to disable any channel which malfunctions or when channel disabling is operationally desirable.

9.4.3 Deadband Select Switch

The DEADBAND select switch is used by the pilot to select either a ± 5.0° limit cycle or a ± 0.5° limit cycle.

9.4.4 0.05 g Backup Switch

The 0.05 g BACKUP switch is used in SCS entry mode or G & N entry mode to normally backup the 0.05 g entry switching signal. When the 0.1 g lamp on the Entry Monitoring Display illuminates, the astronaut will initiate the entry switching signal with the 0.05 g Backup Switch.

9.4.5 SCS Control Mode Switches

Eight SCS CONTROL MODE SELECT switches are provided for pilot selection of control mode. The switches are momentary contact, internally lighted push-buttons.

9.5 Control Modes

The function of the guidance and navigation system in the spacecraft control system is described in the following paragraphs:

9.5.1 Monitor Mode

The monitor mode will be used primarily to monitor the boost phases of the mission. The SCS system will automatically return to this mode in event of power shutoff. In this mode the FDAI (flight director attitude indicator) attitude error needles (range ± 5°) and the FDAI ball display are positioned by outputs from the G & N system.

9.5.2 G & N Attitude Control Mode

In the G & N attitude control mode the G & N system is coupled to the SCS system for spacecraft attitude control. In this mode attitude command signals from the G & N system may: 1) hold the spacecraft orientation in space within the deadband selected by the pilot (±5.0° or ±0.5°) or 2) maneuver the spacecraft to an orientation commanded by setting the CDUs (manually or by computer control) to the desired angles. In either case the navigator must use the ATTITUDE CONTROL CDU mode. The FDAI attitude error needles (range ± 5°) and ball display are positioned by outputs from the G & N system.

9.5.3 G & N ΔV mode

The G & N ΔV mode is essentially a G & N attitude hold mode with computer controlled SPS (spacecraft propulsion system) engine thrusting capability. During thrusting, the attitude command signals are supplied to the TVC (thrust vector control) system by the G & N system. Prior to thrusting, the G & N system holds the spacecraft attitude within the manually selected deadband.

The FDAI attitude error needles (range ± 5°) and ball display are positioned by the G & N system.

9.5.4 G & N Entry Mode

The G & N entry mode, prior to the 0.05 g entry switching signal, is a

G & N attitude hold mode, with attitude maneuvering capability. After receipt of the 0.05 g switching signal, the G & N system controls roll attitude only and the pitch and yaw channels go into a rate damping mode. This mode permits a fully automatic entry.

The FDAI attitude error needles (range ± 25° in roll and ± 5° in pitch and yaw) and ball display are positioned by the G & N system.

9.5.5 SCS Control Modes

The SCS control modes function similarly to the G & N control modes with the following exceptions:

1) SCS BMAG's supply spacecraft attitude reference.

2) SCS electronics supply ΔV control functions.

3) FDAI attitude error needles are positioned by BMAG signals or dialed attitude and the ball display is positioned by the AGCU (attitude gyro coupling unit) or FDAI align signal.

4) Manual roll control is used for entry.

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