MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

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GUIDANCE, NAVIGATION, AND CONTROL
LUNAR MODULE FUNCTIONAL DESCRIPTION
AND OPERATION USING
FLIGHT PROGRAM SUNDANCE

VOL. I

DECEMBER 1968

MIT INSTRUMENTATION LABORATORY
CAMBRIDGE 39, MASSACHUSETTS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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GUIDANCE, NAVIGATION AND CONTROL

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PREFACE

The purpose of this document is twofold. The first is to provide a functional description (operationally oriented) of the LM PGNCS hardware and software and its interfaces with other SC systems. The level of detail is that required to identify and define the telemetry outputs. Also included are functional flow diagrams of the SUNDANCE 306 programs and routines together with the lists of verbs, nouns, option codes, and checklist codes for this flow.

The second purpose is to provide the operational procedures for this hardware and software including malfunction procedures, and program notes. The expanded and condensed checklist for program SUNDANCE appear in Volume II of this document.

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SECTION 1

GENERAL DESCRIPTION OF THE LM PGNCS

1.1 FUNCTIONAL DESCRIPTION

The primary guidance, navigation and control system (PGNCS) consists of the sensing, data processing, computational, control, and display devices necessary to accomplish spacecraft navigation and guidance. The system's primary task is to obtain LM orientation, position, and velocity data; and thereby, calculate any steering and thrust commands necessary to fulfill the LM flight objectives.

The system's navigation function consists of determining the location of the LM and calculating pertinent trajectory information related to the present location and predicted locations so that the guidance function can be performed. Using a computerized dead reckoning process, the last known position of the spacecraft is updated to present position by keeping track of incremental changes in velocity and time. The predicted present position is revised whenever fix information from communications or radar is entered into the computation loop. The fix information is used to derive deviations of position and velocity which are added to the vehicle position and velocity estimates to form a new orbit estimate. This procedure is repeated for each navigation measurement until orbital uncertainties are reduced to an acceptable level.

The guidance function interrelates the navigation function to the flight control function. Navigation information is employed to determine what commands should be issued to maintain desired flight control. A velocity to be gained concept results from a comparison of the actual velocity and the velocity required. Steering equations are used which force the difference between the actual velocity and the velocity to be gained to zero by issuing the appropriate commands to the flight control subsystems. Thus, the PGNCS is capable of performing an autopilot task or an augmentation task. In addition, a fully manual piloting task is available by the crew's use of navigational displays.

The functional subsystems contained within the PGNCS are the inertial subsystem, optical subsystem, computer subsystem, rendezvous radar subsystem, and the landing radar subsystem.

1.1.1 Inertial Subsystem Functions

The inertial subsystem (ISS) senses LM acceleration and changes in attitude and provides incremental velocity and attitude data to the computer subsystem. The ISS sensor is the inertial measurement unit (IMU) which consists of a stable member mounted in a three-degree-of-freedom gimbal system. Three gyroscopes and three accelerometers are mounted on the stable member. Each gyroscope has a stabilization loop associated with it for maintaining the stable member nonrotating with respect to inertial space. Thus, each stabilization loop maintains one axis of an orthogonal reference system; whereby, the spacecraft yaw, pitch, and roll orientation is definable. The LM orientation is measured by the stabilization loops producing signals proportional to the changing orientation of the gimbals relative to the stable member. The three accelerometers are pendulous mass unbalanced devices with each maintaining one axis of another orthogonal system parallel to the gyro orthogonal system. Hence, each accelerometer and its associated accelerometer loop permits measurement of changes in velocity along its axis relative to the inertial reference frame.

1.1.2 Optical Subsystem Functions

The optical subsystem (OSS) provides directional data of a selected target to the LGC. Consisting of the alignment optical telescope (AOT), its primary function is to provide star sighting data for insertion into the computer system to establish an accurate reference frame for IMU alignment. The computer control and reticle dimmer assembly is the inflight device by which optical data is entered into the computer subsystem.

1.1.3 Rendezvous Radar Subsystem Functions

The rendezvous radar subsystem (RRS) is designed to operate with a transponder located on the CSM. The rendezvous radar (RR) provides to the computer subsystem range, range rate, and line-of-sight angles to the CSM. This information is used in the guidance and navigation computations to obtain an effective rendezvous.

After separation from the CSM, the RR permits the first independent check of the PGNCS by comparing the RR range and range rate displays to LGC computations. It can also be used to check the operation of the PGNCS or AGS (Abort Guidance Section) at other times. However, its prime function is to provide data to the computer so that the CSM orbit can be accurately determined. If the PGNCS computer or AGS malfunction, manual backup mid-course correction can be derived using only the radar data.

1.1.4 Computer Subsystem Functions

The computer subsystem (CSS) performs data processing, storing and monitoring; maintains a time standard; performs computational programs; provides central control ability; and performs limited malfunction diagnosis.

The subsystem consists of the LM guidance computer (LGC) and the display and keyboard (DSKY).

The DSKY is the interface device between the astronaut and the LGC. It permits the astronaut to enter data into the LGC and to receive data from the LGC.

The LGC processes data from the astronaut and the other LM subsystems to solve navigation and guidance equations. The computer performs a control function by issuing command pulses to the ISS, radar subsystems, and flight control subsystems. Malfunction diagnosis is performed by monitoring certain operational discretes and issuing appropriate discretes to the caution/warning subsystem when an irregularity occurs. The computer also supplies timing signals to synchronize and control PGNCS operations.

1.1.5 Landing Radar Subsystem Functions

The purpose of the landing radar subsystem (LRS) is to sense the velocity and range of the LM relative to the lunar surface. (Hence, the LRS will not be used functionally during earth orbit missions, but it will be energized and tested during the flights.) It provides LM velocity (components $\dot{h}$, $\dot{x}$, and $\dot{y}$) in antenna coordinates and LM slant altitude. In addition, velocity data is made available to displays in spacecraft coordinates.

The velocity and range data is used by the LGC during a lunar flight to update flight parameters; thereby achieving a controlled rate of descent; a hover at low altitude to permit selection of landing site; and a soft landing. To accomplish these objectives, the LGC and/or astronaut must know the distance from the LM to the lunar surface and the velocity of the LM relative to the lunar surface.

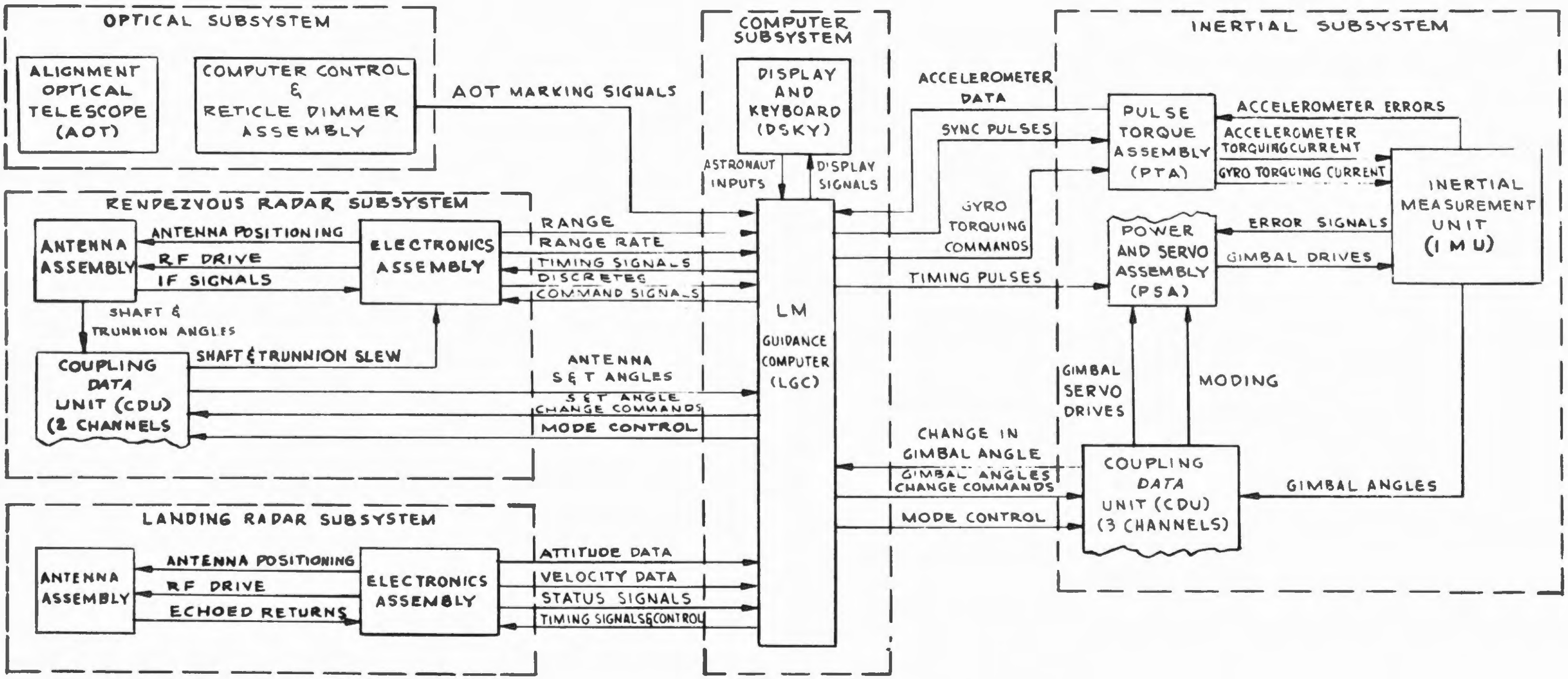


Fig. 1-1. PGNCS components and subsystem interfaces.

1.2 PGNCS COMPONENTS

The components of the PGNCS and their major functional interfaces are illustrated in Fig. 1-1. The sensors of the system are the IMU, AOT, and the radars. The LGC is the interface component between the subsystems. The communication link between the astronaut and the LGC is the DSKY which permits loading of data by a keyboard into the LGC and provides information to the astronaut from the LGC by its displays.

The AOT is manually operated by the astronaut. During inflight IMU alignment, star directional data is entered into the LGC using the computer control and reticle dimmer assembly (CCRD).

The coupling data unit (CDU) is an interface device between the LGC and the ISS and between the LGC and rendezvous radar. Its primary function is to convert analog data to digital data and digital data to analog data. Three channels of the CDU are used to communicate with the ISS and two channels for the rendezvous radar subsystem.

Support electronics are contained in the pulse torque assembly (PTA) and power and servo assembly (PSA). The PTA supplies inputs to and processes outputs of the IMU. The majority of ISS power supplies are contained in the PSA which also contains such support items as the moding relays and the stabilization loop servo amplifiers.

SECTION 2

DETAILED DESCRIPTION OF THE LM PGNCS

2.1 INERTIAL SUBSYSTEM

During LM thrusting phases the inertial subsystem (ISS) provides attitude references, processes steering commands from the LGC to the flight control system, and provides the velocity increment signals which are counted by the LGC and used for thrust termination. During nonthrust phases the ISS is used to hold or control changes in spacecraft attitude at the direction of the astronaut or the LGC. To accomplish these tasks, the IMU stable member must maintain a predetermined inertial referenced coordinate system. Thus, each time the ISS is energized the stable member must be aligned. Since use of the ISS during nonthrusting phases is optional within the limitations of available electrical power, the system may be re-energized several times during a flight and require realignment.

Before LM separation from the Command Service Module (CSM), a coarse alignment of the LM IMU gimbals is made to the CSM IMU gimbals by coarse aligning the LM IMU to zero angles and then keying into the DSKY the difference angles. The LM established inertial reference system is then accurately aligned after separation by sightings of the alignment optical telescope (AOT) on celestial objects. This fine alignment procedure by use of the AOT is the prime method used throughout the flight for establishment of the inertial reference system. Once the IMU is aligned, the stable member remains essentially in a fixed spatial orientation and rotational motion of the LM is sensed by resolvers mounted on the gimbal axes.

2.1.1 ISS Theory of Operation

Operational tasks of the ISS are implemented by the three accelerometers and three inertial reference integrating gyro (IRIG) mounted on the stable member (see Fig. 2-1). The three stabilization loops hold the stable platform at a fixed orientation which permits acceleration measurement by the three associated acceleration loops. In addition, each gimbal movement about the stable member changes the phase and amplitude of the associated resolver output to convey attitude information.

2.1.1.1 Stabilization Loops

The stabilization loops associated with the IRIG's maintain the IMU stable member at the spatial orientation to which it was aligned; and thereby, isolate the stable member from roll, pitch, and yaw motions of the LM vehicle (see Fig. 2-2). The LGC retains in memory a record of the reference coordinate system established by the stable member. Hence, when movement of the LM structure produces IMU gimbal movement about the stable member, representative electrical signals of this movement are transmitted from the 1X and 16 X gimbal resolvers.

Motion of the LM structure produces a torque on the stable member tending to move it from its inertially fixed orientation. Each IRIG or gyro senses a component of this torque about is input axis and produces an error signal. Since the Y-gyro is mounted with its axis parallel to the inner gimbal axis, it detects the full component of torque about the inner gimbal axis represented by signal $E(Y_g)$. However, movement of the stable member about the inner gimbal axis changes the relationship of the X and Y gyro input axes to the middle and outer gimbal axes. Hence, the detected $E(X_g)$ and $E(Z_g)$ values must be first

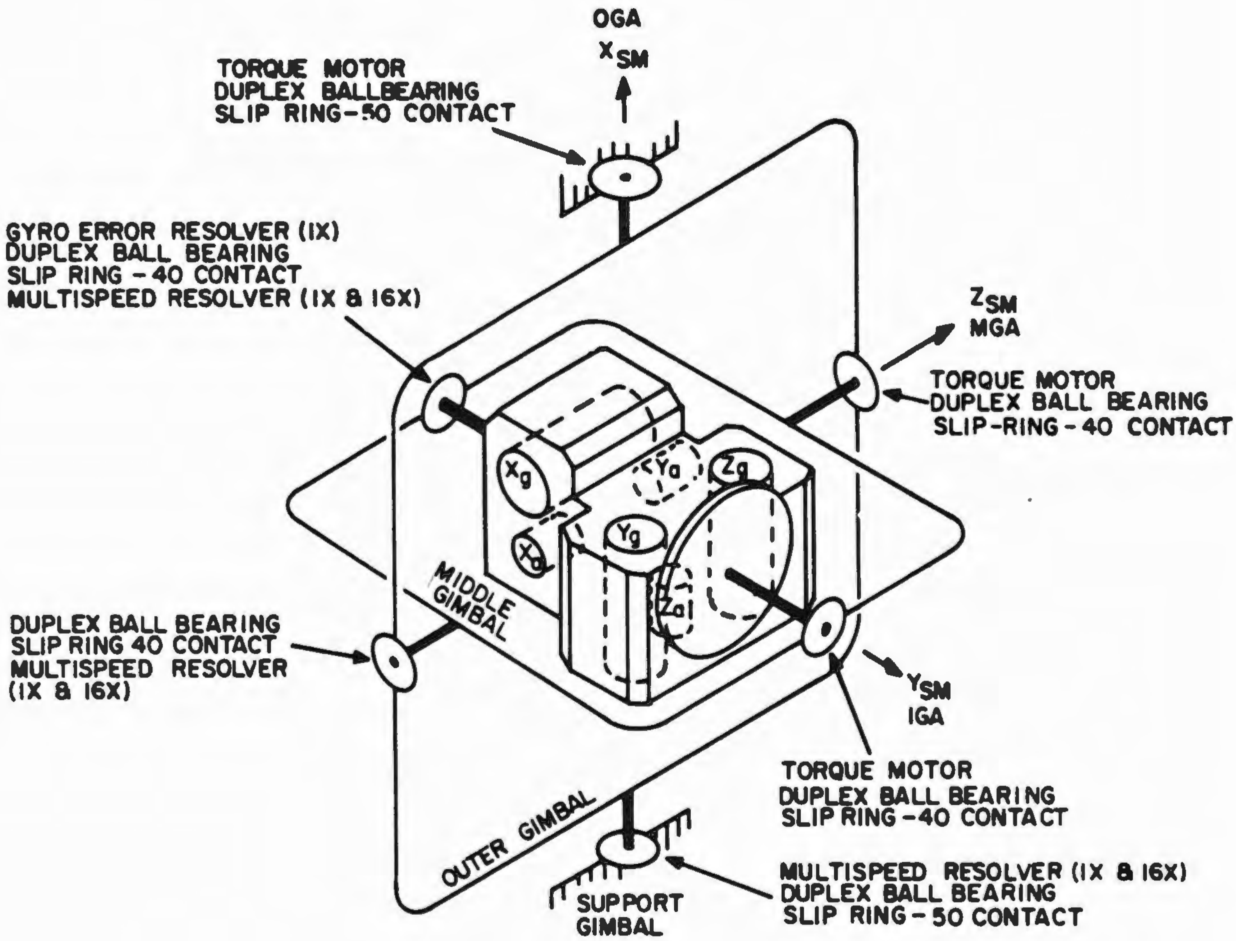


Fig. 2-1. IMU gimbal assembly and gimbal axes.

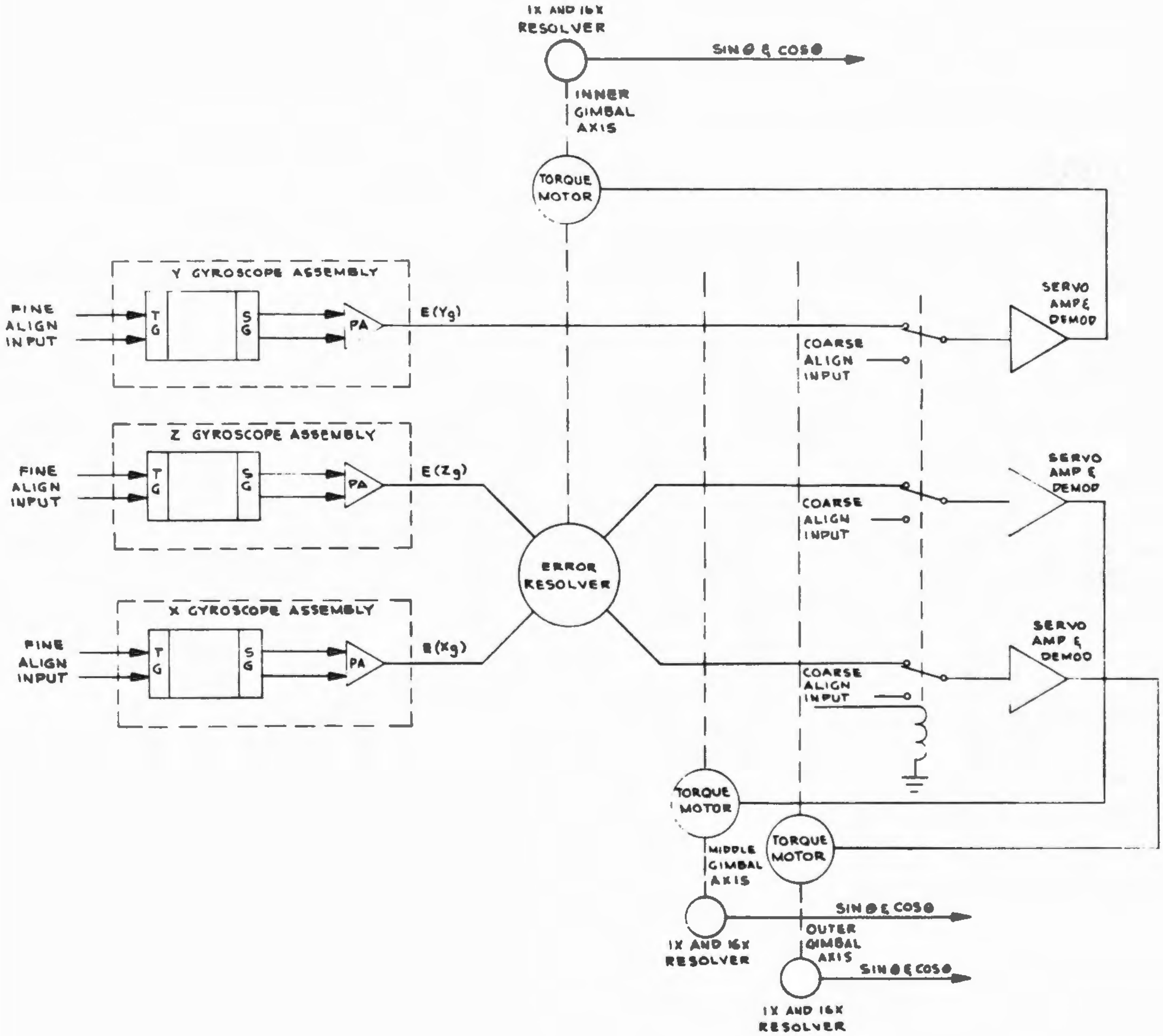


Fig. 2-2. Stabilization loops functional block diagram.

resolved into their correct representative value of gimbal axes displacement. The three resultant signals $E(Y_g)$, resolved $E(X_g)$, and resolved $E(Z_g)$ are amplified and provide drive to the torque motors for counteracting the components of torque and maintaining the stable member at its inertially fixed orientation.

The 1X and 16X resolver outputs are transmitted to the gimbal angle sequence transformation assembly (GASTA) and to the CDU (see Fig. 2-3). Each resolver has a sine and cosine output via an 800 cps suppressed carrier voltage analog. The coordinate conversion of the GASTA provides a total attitude display to the flight director's attitude indicator (FDAI). It transforms the three axis attitude information from the IMU into three axis attitude information in a sequence usable by the FDAI. The outputs to the CDU are converted to digital representations that are sent incrementally to the LGC so that it is continuously aware of the present gimbal angle displacements and by comparison to stable member alignment is also aware of spacecraft attitude.

2.1.1.2 Analog-to-Digital Conversion

Analog-to-digital (A/D) conversion is accomplished by resolving an unknown gimbal angle θ about a preselected angle ψ by the expression

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

When the equation goes to zero, $\theta = \psi$ and as a consequence ψ is a representative value of θ. The value ψ is sequentially selected in incremental steps within a binary counter. A value for θ is obtained by the LGC accumulating the number of binary steps required to null $\sin(\theta - \psi)$.

An analog-to-digital circuit is associated with each of the three gimbals (two A/D circuits are also associated with the rendezvous radar subsystem). Figure 2-4 illustrates a functional block diagram of one of these circuits. The CDU

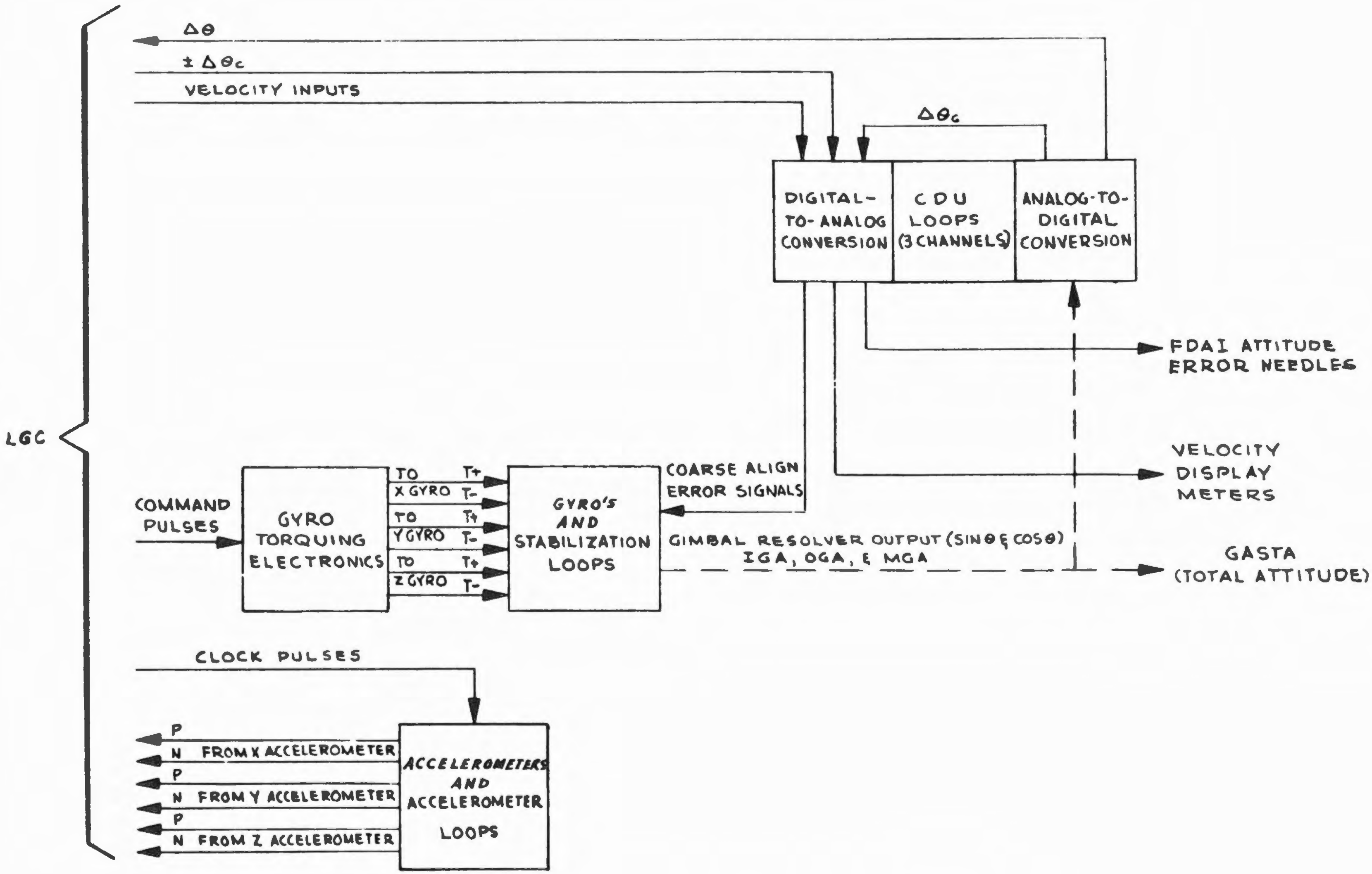


Fig. 2-3. Inertial subsystem functional block diagram.

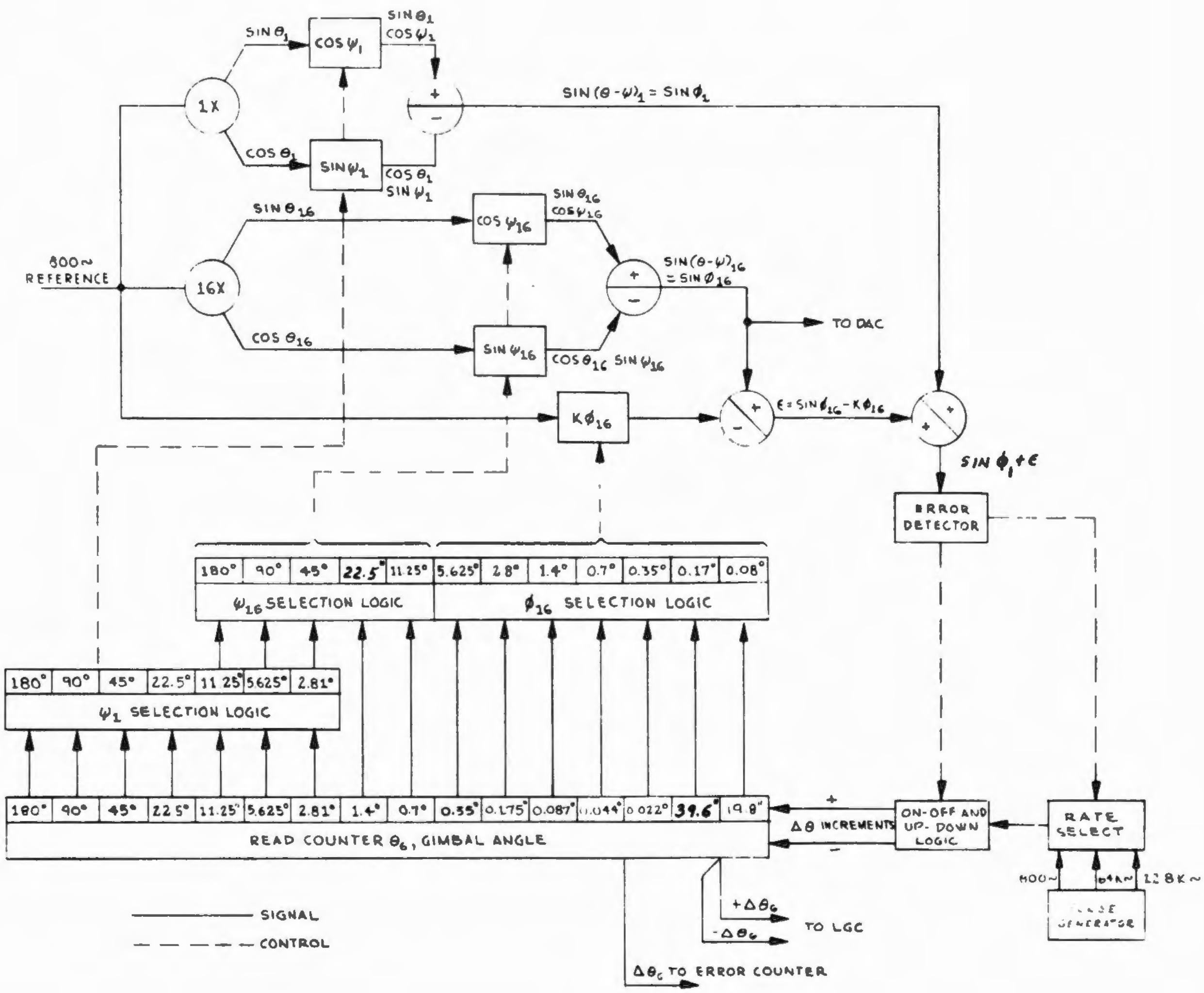


Fig. 2-4. Analog-to-digital conversion functional block diagram.

receives sin θ and cos θ signals from the 1X and 16X resolvers. The θ_G information is contained in the amplitude of the sin θ and cos θ signals and their phase with respect to the 800 cycle reference. The value of ψ is accumulated in a 16-stage counter called the read counter. A binary one value contained in a stage of the counter energizes transistor switches that accumulatively by means of ladder networks (voltage dividers) and summing networks form analog attenuation values for nulling the input resolver voltages and the 800 cycle reference. As long as the equation is not nulled, the phase and amplitude of the difference signal out of the error detector circuit produces a count up or count down signal for incrementing the read counter. The amplitude of the error signal (sin $\theta_1 + \epsilon$) determines the rate (either 800 pps, 6.4 kpps, or 12.8 kpps) at which the digital pulses, equivalent to 19.8 arc seconds of gimbal displacement, are generated. The phase of the error signal determines a count-up or count-down condition. By counting the number of steps until a null takes place, the LGC obtains a digital representation of the gimbal angle. The $\Delta\theta_G$ counts to the LGC gimbal angle register are the output of the least significant stage of the read counter and are each equivalent to 39.6 arc seconds of gimbal angle change.

The functional nulling takes place in two loops, coarse and fine nulling. When ψ is within 22.5° of θ, a nulling ladder from 0 to 22.5° in steps of 2.81° is used to provide a coarse null for sin ϕ_1. The fine null is utilized to repeat the gimbal angle within approximately 1 bit (19.8 arc seconds). An overlapping between the coarse and fine nulling circuitry provides a smooth transition. Thus, the ψ selection logic for both loops is selected simultaneously with 180 electrical degrees of the 16X resolver rotation being equal to 11.25 degrees of the 1X resolver angle. The ψ_{16} selection logic develops a linear approximation of the gimbal angle within ±11.25° of the fine null. The phase and amplitude of the sin $\theta_1 + \epsilon$ signal develops a complete count-down or count-up for a value $K\phi_{16}$ to obtain a null. Subsequent changes in gimbal angle continue the process and produce incremental pulses to the LGC so that the computer is continuously aware of the gimbal angle.

2.1.1.3 Digital-to-Analog Conversion

Digital-to-analog conversion (DAC) is used to provide attitude error information to the FDAI, coarse align error information to the gimbal servo amplifiers, and forward-lateral velocity information to the velocity display meters. Five DAC loops exist and their function is dependent upon the ISS mode of operation. Three of these loops are associated with the IMU gimbal angles and the other two are considered part of the rendezvous radar subsystem.

A block diagram of a typical DAC loop is shown in Fig. 2-5. Assuming that the loop is one of the three associated with gimbal angles, the pulses entered into the error counter from the LGC provide a binary-coded representation of a desired gimbal angle change ($\Delta\theta_c$). Each pulse is equivalent to 160 arc seconds of gimbal angle displacement. The binary stages of the counter activate transistor switches in the voltage ladder decoder. The switches set a voltage divider into a configuration which provides a voltage output with an amplitude proportional to the binary count of the error counter. This output voltage is an 800 cps signal with its phase determined by whether a positive or negative value has been entered into the error counter. It serves as an input into the servo amplifier demodulator (see Fig. 2-3) or an attitude error display signal.

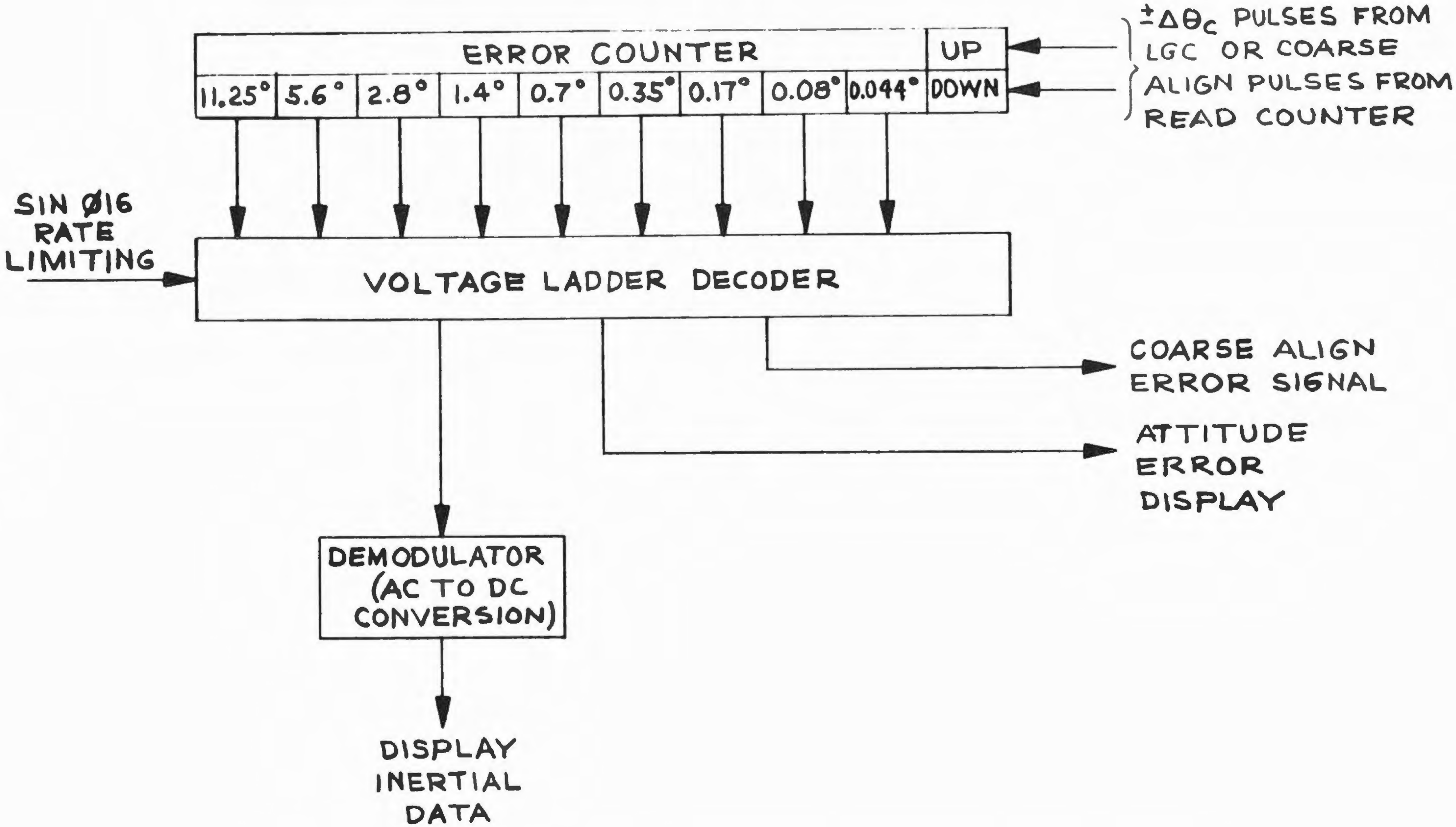


Fig. 2-5. Digital-to-Analog conversion functional block diagram.

During coarse alignment, the read counter provides count-down pulses into the error counter as the value within the read counter accumulates changing gimbal angle ($\Delta\theta_G$) due to coarse repositioning of the gimbal. These pulses are accepted from the third stage of the read counter for decrementing the error counter. The error counter tends to null as θ_G approaches θ_c. Rate limiting pulses are also received from the analog-to-digital conversion circuit to be summed with the voltage ladder decoder output and limit gimbal driving rate. A signal out of phase with the ladder voltage and with an amplitude proportional to the difference between the gimbal angle and the angle in the read counter provides gimbal rate limiting.

If attitude error is to be displayed, the error counter accumulates the $\Delta\theta$ pulses from the LGC and maintains this accumulative value until the LGC counts the binary-value down. Thus, three separate signals from the three digital-to-analog conversion circuits are available to the FDAI attitude error needles. Each signal is a ±5.06 volt rms, 800 cps suppressed carrier voltage analog of each axis at a scaling of 3.3 degrees per volt. If the error counter contents are representative of LGC calculated forward or lateral velocity, the ac output of the voltage ladder decoder is demodulated to a dc display signal.

2.1.1.4 Gyro Torquing Electronics

The gyro torquing electronics is used only during the fine alignment mode (Fig. 2-11). It permits the stable member to be aligned within seconds of arc to a coordinate frame determined by optical measurements. Control is maintained by the LGC which computes the difference between the angle of the gimbals at an instant of time and the desired gimbal angles. This difference is transposed into a number of pulses, each equivalent to 0.618 arc seconds necessary to drive the gimbal through this difference angle.

Figure 2-6 illustrates a block diagram of the gyro torquing electronics. The gyros are torqued on a time shared basis. The LGC sends to the fine align electronics four types of pulses: torque enable pulses, gyro select pulses, torque set pulses, and torque reset pulses. The torque enable pulse train is first sent to a relay driver to activate the circuit. The LGC then sends gyro select pulses ($+\Delta\theta x$ or $-\Delta\theta x$ or $+\Delta\theta y$ or $-\Delta\theta y$, and $+\Delta\theta z$ or $-\Delta\theta z$) which select a particular gyro and the direction it is to be torqued by means of a transistor switch network that closes the current path through the proper torque ducosyn coil. The third and fourth types of pulse trains are the torque set and torque reset commands which control a binary current switch to start and stop the current flow through the selected coil. The amount of current flow (T+ or T-) through the torque ducosyn coils is precisely controlled at a fixed value by the precision power supply and regulating differential amplifier. The duration of application is controlled by the length of time that set pulses are applied. The ducosyn winding appears to the circuit as a pure resistive load due to the effect of the load compensation network.

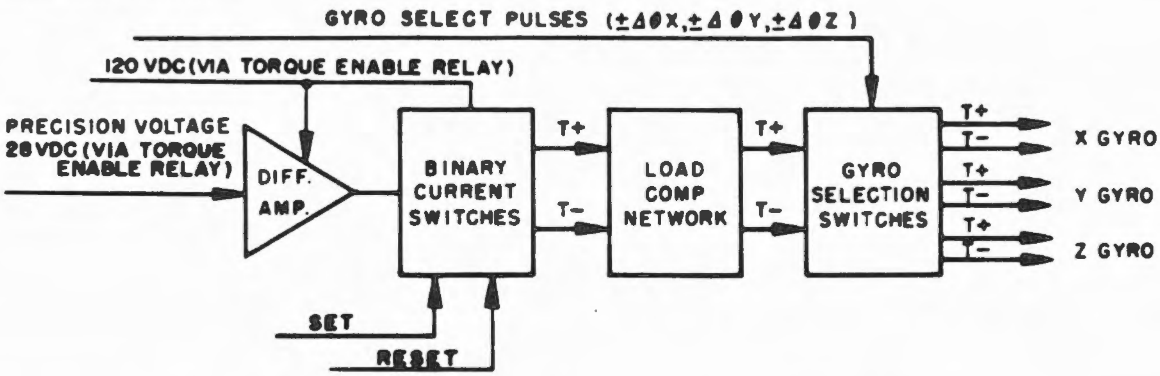


Fig. 2-6. Gyro torquing loop functional block diagram.

2.1.1.5 Accelerometer Loops

The accelerometer loops block of Fig. 2-11 consists of three loops. Each loop measures a component of linear acceleration felt by the stable member along the axis of the accelerometer within the loop. Since the axes of the three accelerometers or PIP (pulsed integrating pendulum) are mutually perpendicular and parallel to the gyro axes, the three measured components of acceleration are representative of the acceleration on the stable member (Fig. 2-7).

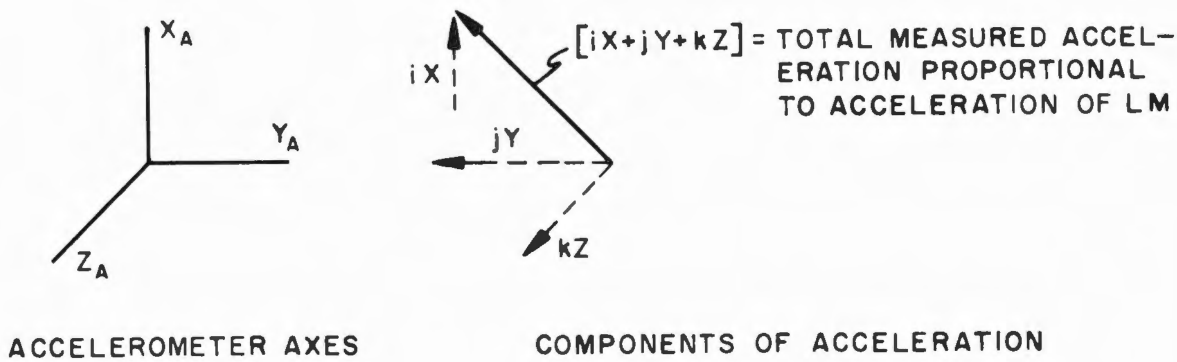


Fig. 2-7. Acceleration detected on stable member.

A block diagram of a typical acceleration loop is shown in Fig. 2-8. The accelerometer pendulum is maintained in oscillatory motion about its null point. That is, with no LM thrusting a constant input to the torque ducosyn (TD) will hold the pendulum cycle constant. The signal ducosyn (SD) output phase changes as the pendulum passes through its null and the clock pulses from the LGC interrogate the ac differential amplifier output to determine the phasing. The frequency of the clock pulses is 3200 pps and with no acceleration acting on the stable member, the frequency of the accelerometer pendulum is 533-1/3 pps, which approaches its natural frequency. Hence, a complete pendulum cycle occurs during six clock pulses. The binary current switches use the TM+ and TM- set pulse outputs to generate accelerometer torquing current. The TM+ set pulse occurring for three clock pulses and the TM- set pulse for the next three clock pulses. A TM+ set condition

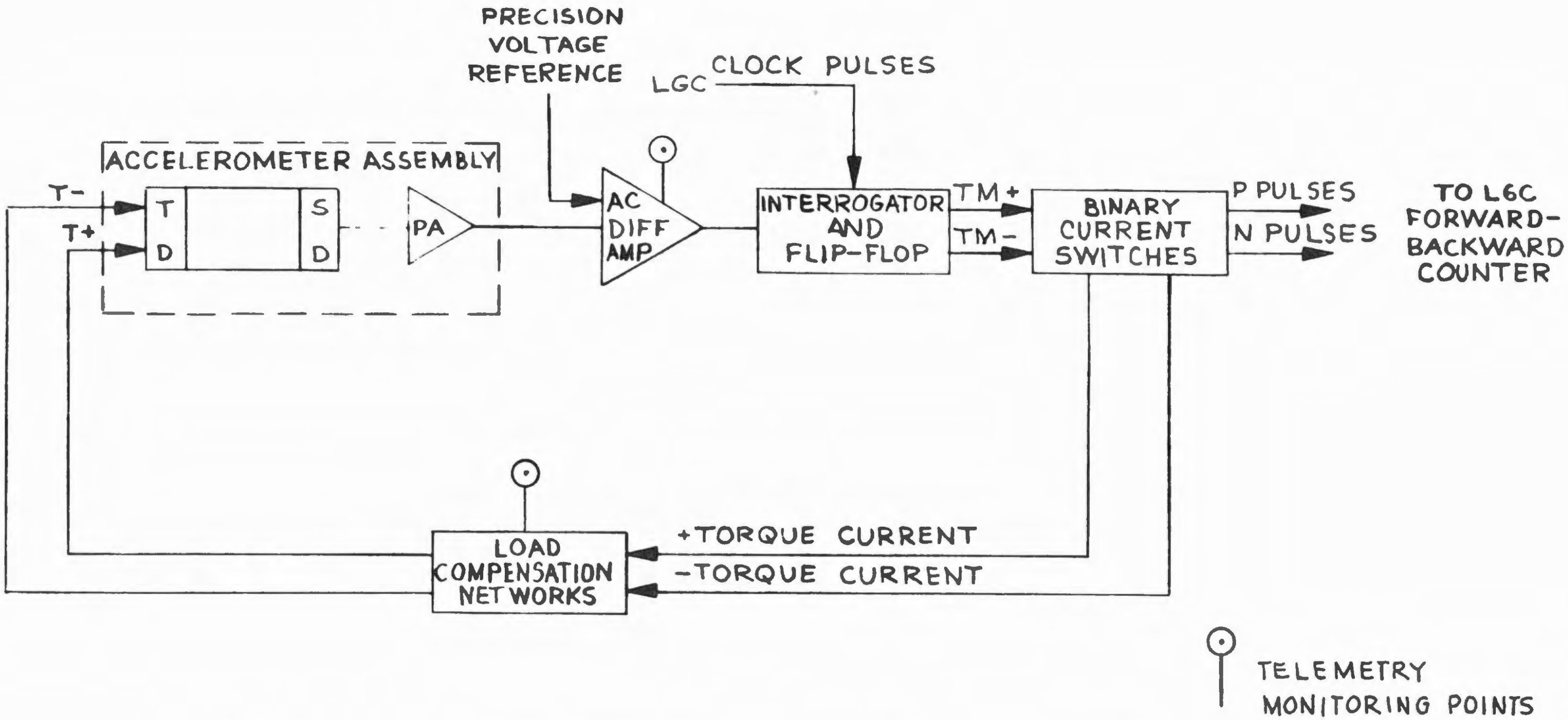


Fig. 2-8. Typical accelerometer loop functional block diagram.

produces a plus torque condition and a TM- set condition produces a minus torque condition to the accelerometer TD maintaining the pendulum at 533-1/3 pps.

To regulate the balance of the plus and minus torques, the load compensation networks compensate for the inductive load of the accelerometer generator ducosyns. Thus, the generator coils appear as pure resistive load to the binary current switches. Therefore, as long as no acceleration acts on the loop, three P pulses and three N pulses are generated to the LGC forward-backward counter causing a count up of three and then a count down of three. The computer, in effect, is then recognizing a condition of no acceleration.

When an acceleration acts on the stable member, the equilibrium of the loop is interrupted. Each accelerometer feels a linear component of this acceleration as an additional torque that aids and opposes the torque generator forces. Because the torque current from the binary current switches is constant, a longer application of plus or minus current application is necessary to keep the pendulum in its oscillatory motion. The change in time required for the float to be torqued back through null, results in an unequal number of P and N pulses sent to the computer. The computer synchronizes its sampling of each of the three forward-backward counters to once every $1/533\frac{1}{3}$ seconds which is equivalent to a pendulum period. Thus, the difference of the accumulative count of P and N pulses $[\Sigma(P) - \Sigma(N)]$, is proportional by a constant (K) to the magnitude of a component of acceleration. Since the computer performs its calculations with discrete values, the formula $a = (dv/dt)$ becomes $a = (\Delta V/\Delta t)$ [that is, $\Delta V = a\Delta t$]. Hence, the computer's calculations for solution of a change in velocity (ΔV) can be summarized as follows:

$$\Delta V = K[\Sigma(P) - \Sigma(N)]\ \Delta t$$

2.1.2 ISS Modes of Operation

The ISS modes of operation are normally initiated automatically by the LGC or by the astronaut selecting an LGC program through the DSKY. Mode control is regulated by the issuance of LGC discretes to the CDU.

The ISS is in a standby state when the IMU STBY circuit breaker is closed and the IMU OPR circuit break is open on the circuit breaker panel. During the standby state, + 27.5 dc prime power is supplied only to the IMU heater circuit. The remaining portions of the ISS are deenergized.

2.1.2.1 IMU Turn On

The IMU turn on mode is entered only when the IMU OPR circuit breaker is closed. This mode drives the IMU gimbals to their zero position and holds them there. It also clears the LGC gimbal angle registers and the CDU read counters. By establishing this zero reference, the LGC is prepared to obtain incremental changes in gimbal orientation from the read counters into its registers in any subsequent mode and is thereby aware of gimbal angle orientations.

Figure 2-9 illustrates the circuit configuration for one of the three gimbals during the turn on mode. Application of ISS operating power energizes the IMU cage relays which in turn energizes the coarse align relays. In addition, the initial application of power routes to the computer an ISS turn on delay request discrete which provides a 90-second period for mode completion; and thereby, permitting the gyro wheels to run up to full speed. Upon reception

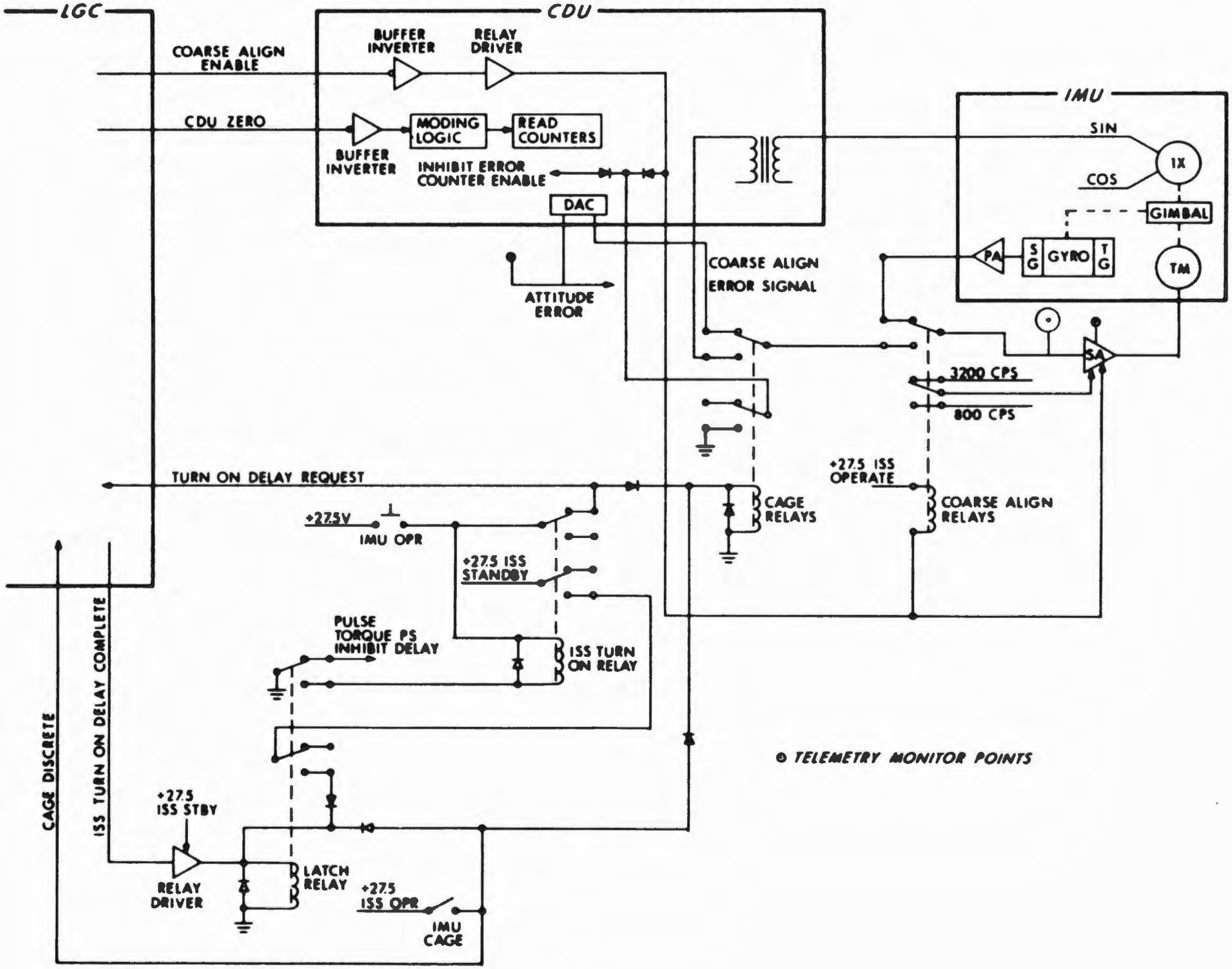


Fig. 2-9. IMU turn on mode.

of this delay request, the LGC issues the coarse align enable and CDU zero discretes. The coarse align enable discrete provides a redundant means of energizing the coarse align relays. The CDU zero discrete clears the three read counters, clears the LGC gimbal angle registers, and inhibits any incrementing pulses to the read counter.

The relay configuration is such that an 800 cps reference is applied to the gimbal servo amplifier enabling the 800 cps sin θ signal from the 1X resolver to be converted to a dc drive signal. The gimbal torque motor drives the gimbal to its zero position where the sin θ value is now zero.

A set of contacts of the latch relay route ground to the time delay circuit of the pulse torque power supply. This inhibits the operation of the power supply to prevent accelerometer pulse torquing during the 90-second period. Thereby, permitting time for the accelerometer to be centered and the gyro wheels to run up prior to torquing.

After the 90-second delay is completed, the LGC issues the delay complete discrete. This discrete causes the latch relay to be energized to remove the turn-on delay discrete to the LGC and to deenergize the cage relay. The LGC then removes both the CDU zero discrete and the coarse align discrete allowing the ISS to go into the inertial reference mode or it can remove the CDU zero discrete and issue an error counter enable discrete (while maintaining the coarse align discrete) allowing the ISS to go into the coarse align mode.

2.1.2.2. IMU Cage

The IMU cage mode is an emergency mode used to stop a tumbling gimbal and drive the gimbals to a known reference with respect to the spacecraft axes. Functionally the mode operates the same as the IMU turn on mode. When the momentary IMU CAGE switch on the primary guidance and navigation panel is positioned to ON, the IMU cage relay and coarse align relay are energized to feed the sinθ signal from the 1X resolver into the gimbal servo amplifier (see Fig. 2-9). The switch is held until the gimbals settle at the zero position (five seconds maximum). The gimbal position is observed on the FDAI. Upon release of the IMU CAGE switch, the LGC allows the read counters to zero and then places the ISS in an attitude control mode. During the read counter settling period, the IMU cage discrete is present and the NO ATT lamp on the DSKY is lighted. Release of the switch releases the IMU to inertially stabilize at an attitude within 1 degree of that at the time of switch release.

The IMU cage mode may also be used to establish an inertial reference with the LGC deenergized or in a standby state. However, the IMU cage mode is an emergency back up mode and should not be employed at any time unnecessarily due to lack of CDU rate limiting which could cause gimbal rates sufficient to drive the gyros into their rotational and radial stops. Such action could cause gyro bias shift.

2.1.2.3 Coarse Align

The coarse align mode is entered when the LGC has issued the ISS error counter enable and coarse align discretes. The purpose of this mode is to allow the LGC to rapidly align the IMU to a desired orientation with a limited degree of accuracy.

When the mode is entered by issuance of the discretes, the CDU read counters are in the process of repeating gimbal angles and supplying this information as $\Delta\theta_G$ pulses to the computer (see Fig. 2-10). By incremental storing up-and-down counts in the gimbal angle registers, the computer is aware of total gimbal angles and calculates the necessary changes in angles to bring the gimbals to the desired orientation. Hence, the LGC computes the number of pulses that must be entered into each error counter to produce the desired analog drive signal.

The coarse align enable discrete has energized the coarse align relays

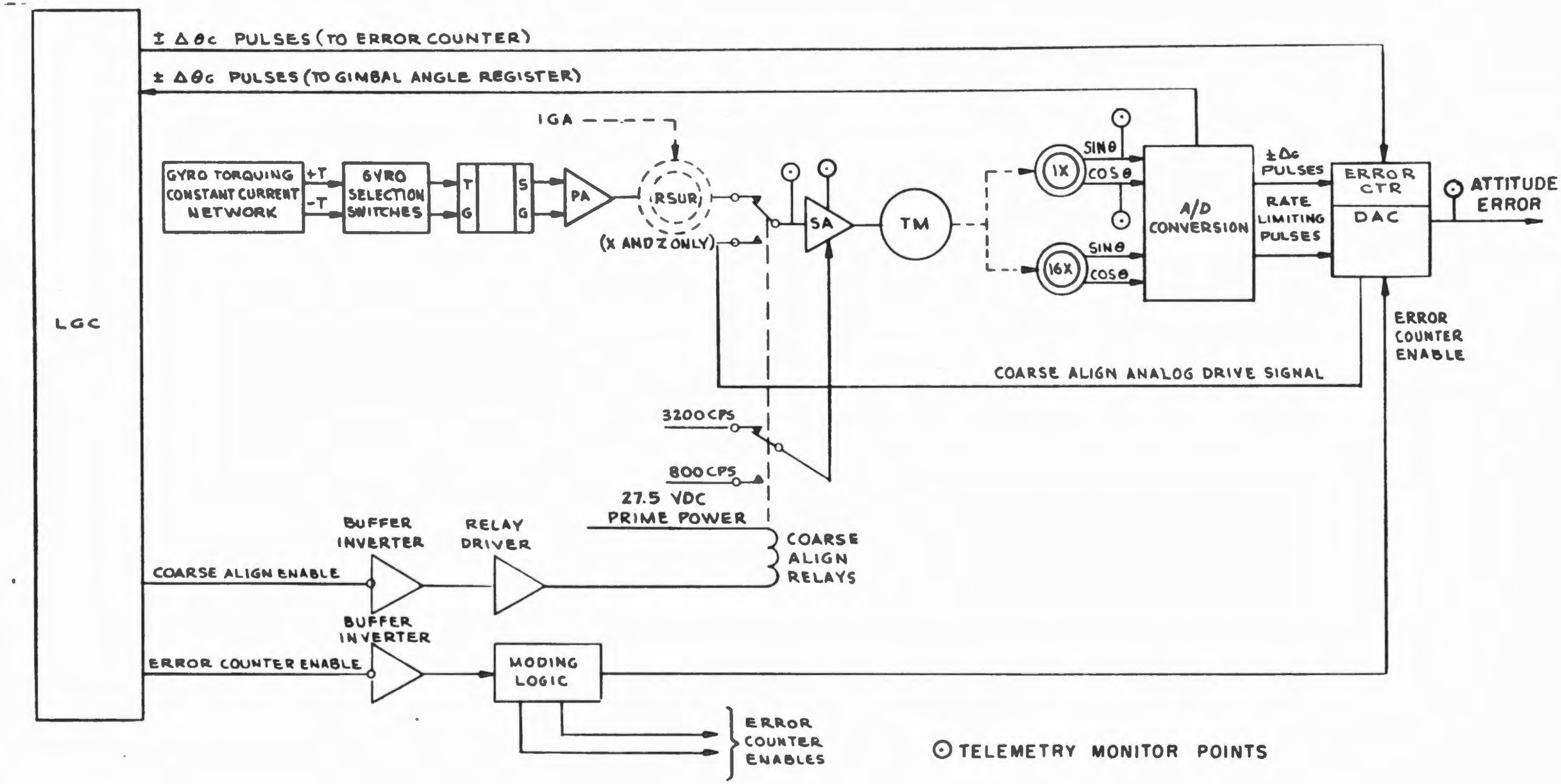


Fig. 2-10. Coarse align mode.

to disengage the fine align electronics and produce an input into the servo amplifier from the digital-to-analog conversion circuit where the error counter has been enabled by the error counter enable discrete. The LGC sends bursts of pulses ($\pm\Delta\theta_c$) at 3200 pps to the CDU with each pulse equivalent to a desired angle change of 158.2 arc seconds on the IMU 1X resolver. Suppose for example, the LGC desires an 11.25 degree change in a gimbal angle with respect to the spacecraft. Since 11.25 degrees is equivalent to 40,500 arc seconds, the LGC sends a burst of $40,500 \div 158.2 = 256$ pulses to the CDU. The value in the CDU error counter is converted to an analog value for servo amplifier input. The resulting torque motor drive moves the gimbal to produce a new resolver angle in the read counter which transmits the incremental change to the computer and to the error counter. The pulses sent to the error counter subtract from the original binary value so that the error counter ultimately contains a zero value when the gimbal has moved to the commanded position.

To prevent damage to the gyros and to assure that the read counter tracks the gimbal angle accurately, the rate of gimbal drive is limited. A fine error signal performs rate limiting by being mixed with the decoded error counter output. This error signal is out of phase with the output of the ladder decoder and has an amplitude proportional to the difference between the actual gimbal angle and the angle in the read counter. During the coarse align mode, the read counter is limited to a high counting speed of 6.4 kpps and a low counting speed of 800 pps. If the gimbals are moving at a faster rate than that which the read counter is counting, the fine error signal increases, causing a retarding torque to be developed by the gimbal servo amplifier. If the gimbals are moving at a rate slower than the rate at which the read counter is counting, the fine error signal decreases, causing the gimbal servo amplifier to apply an accelerating torque to the gimbals. The gimbal drive rate is limited to either 35.5°/second (at the 6.4 kpps counting rate) or 4.5°/second (at the 800 cps counting rate).

2.1.2.4 Inertial Reference

The ISS is in the inertial reference mode during any operating period in which the LGC does not issue moding commands. The inertial reference mode provides a fixed coordinate reference system for attitude and velocity measurements.

During this mode, the stable member is held at a fixed orientation by the stabilization loops (see Fig. 2-11). The read counters provide the LGC with changes in gimbal angles with respect to the stable member and the accelerometer loops provide the LGC with changes in acceleration. The coordinate conversion of the gimbal angle sequence transformation assembly (GASTA) converts the six signals from the 1X gimbal resolvers (sine and cosine windings) to the total attitude FDAI display. Hence, the IMU coordinate transformation to the indicator coordinates permits display of vehicle attitude on the FDAI ball (when ATTITUDE MON selector is in PGNS position).

2.1.2.5 Fine Align

The fine align mode precisely repositions the stable member to a coordinate frame determined by optical measurements. It is essentially a gyro torquing submode of the inertial reference mode. Command discretes are not issued, but this submode is entered by the LGC activation of the fine align electronics during the inertial reference mode. Upon deactivation, the ISS returns to the inertial reference mode.

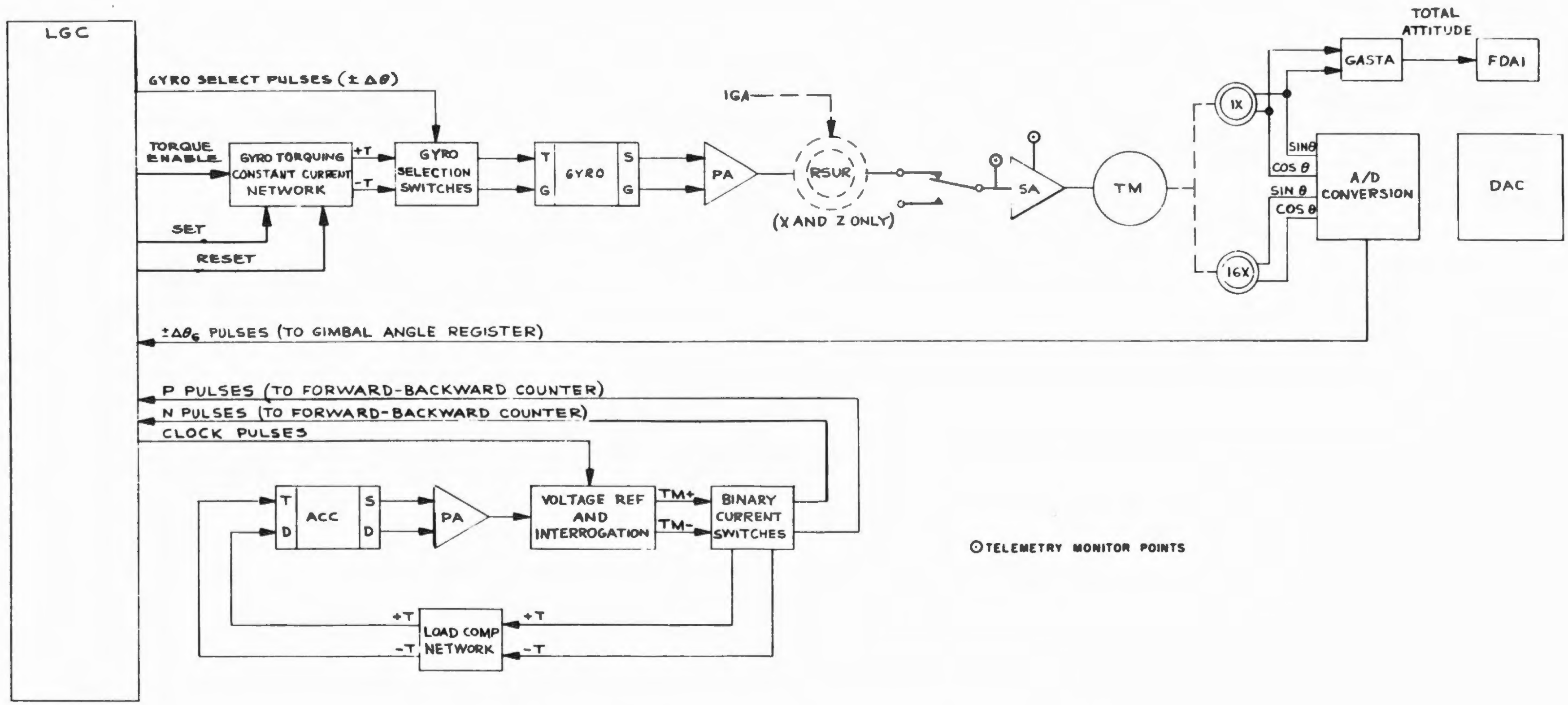


Figure 2-11. Intertial reference mode

Figure 2-11 illustrates the operating configuration of the fine align mode. The error counter is cleared and inhibited. The read counter continues to supply gimbal angle data to the computer. Line-of-sight data from the OSS is transformed by the LGC into stable member coordinates. From the difference between the actual gimbal angle and the desired gimbal angle, the LGC computes the angular rotation about each stable member axis necessary to change the stable member to the desired coordinate frame. Thus, the difference (θ_G - θ_c) determines the number of set pulses necessary to be sent from the LGC to the torquing electronics. The pulses are generated by the LGC in bursts at a bit rate of 3200 pps. Each pulse is equivalent to 0.618 arc seconds of gimbal displacement. The LGC simultaneously supplies a torque enable command to the PTA, selects the gyro to be torqued, and gates the required number of pulses through the fine align electronics to each gyro. The number of set pulses to each gyro determine the duration of a constant current applied to the torque generator coil which results in a repositioning of the gimbal to the desired angle. Upon completion of torquing, stable member orientation can be checked with another set of star sightings.

2.1.2.6 Display Attitude Error

The ISS is in the display attitude error mode during the LGC autopilot program. The mode permits attitude error display on the FDAI error needles. The ISS enters this mode of operation whenever the error counter enable discrete is the only mode command discrete issued by the LGC. (See Fig. 2-12.)

The LGC through its autopilot program controls maneuvering and thrusting of the LM by issuing commands to the reaction control jets and to the trim gimbal. During the display attitude error mode, the error counter is enabled

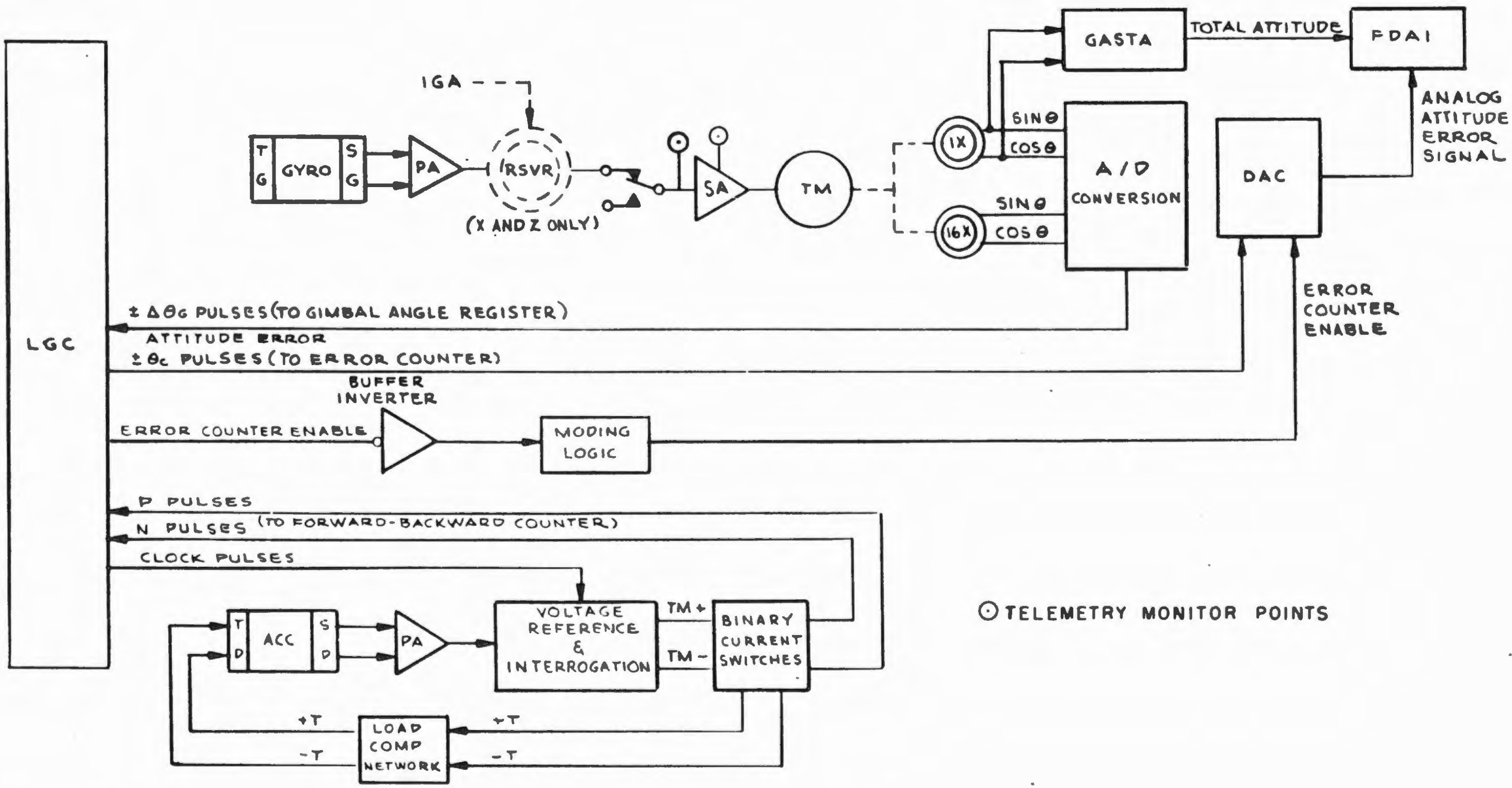


Fig. 2-12. Display attitude error mode.

and the read counter continues to supply actual attitude information to the computer. The difference between actual attitude and desired attitude (in each reference axis) is an attitude error. The LGC transmits $\Delta\theta_c$ pulses that are representative of attitude errors into each error counter. These pulses are generated at a bit rate of 3200 pps with each pulse equivalent to $\approx$ 160 arc seconds of error. The output of each error counter is developed into an analog error signal and fed to the FDAI error needles (when the ATTITUDE MON selector is in PGNS position and the RATE/ERR MON selector is in LDG RDR/CMPTR position). The error counter is incremented or decremented only from the LGC as the digital feedback from the read counter to the error counter is disabled.

Changes in LM orientation are sensed by the IMU stabilization loops which results in gimbal angle resolver output being transmitted to the FDAI eight ball for total attitude display and to analog-to-digital converter. The LGC uses the resulting read counter information for the LGC autopilot control loop.

2.1.2.7 Display Inertial Data

The display inertial data mode is used only during the last phase of a lunar descent. During this period the LGC provides inertially derived forward and lateral velocity signals for meter display by utilizing the rendezvous radar CDU channels. With the MODE SEL selector on the commander's center panel set to PGNS, a discrete is sent to the LGC to initialize the mode. During the mode, the ISS CDU error counters are enabled and attitude errors are displayed on the FDAI error needles. The rendezvous radar error counters are enabled and display inertial data discretes are issued by the LGC. The LGC provides forward and lateral velocity to the rendezvous radar CDU channels which then supply this velocity data to the forward velocity/lateral velocity indicator on the astronaut's center panel (when RATE/ERR MON selector is in LDG RDR/CMPTR position).

2.1.3 IMU Temperature Control

The IMU temperature control circuitry maintains the temperature of the stabilization gyros and accelerometers within their required temperature limits during both standby and operating modes of the IMU (see Fig. 2-13). Heat is supplied and removed to maintain the IMU heat balance with minimum power consumption. Heat is removed by convection, conduction, and radiation. The IMU internal pressure is maintained between 3.5 and 15 psia to enable the required forced convection. To aid in removing heat, a water-glycol solution at approximately 45.0 degrees Fahrenheit from the spacecraft coolant system passes through the coolant passages of the IMU support gimbal.

2.1.3.1 Temperature Control Circuit

The temperature control circuit maintains the gyro and accelerometer temperature. The temperature control circuit consists of a temperature control thermostat and heater assembly, a temperature control module, three gyro end mount heaters, three gyro tapered mount heaters, two stable member heaters, and three accelerometer heaters, and four anticipatory heaters (see Fig. 2-13). The thermostat and heater assembly is located on the stable member and contains a mercury-thallium thermostat, a bias heater, and an anticipatory heater. Except for the bias heater, all heaters (a total of 15) are connected in parallel and are energized by 28 vdc through the switching action of Q1 and Q2.

When the temperature falls below 130 (±0.2) degrees Fahrenheit, the thermostat opens and transistors Q1 and Q2 conduct and current flows through the

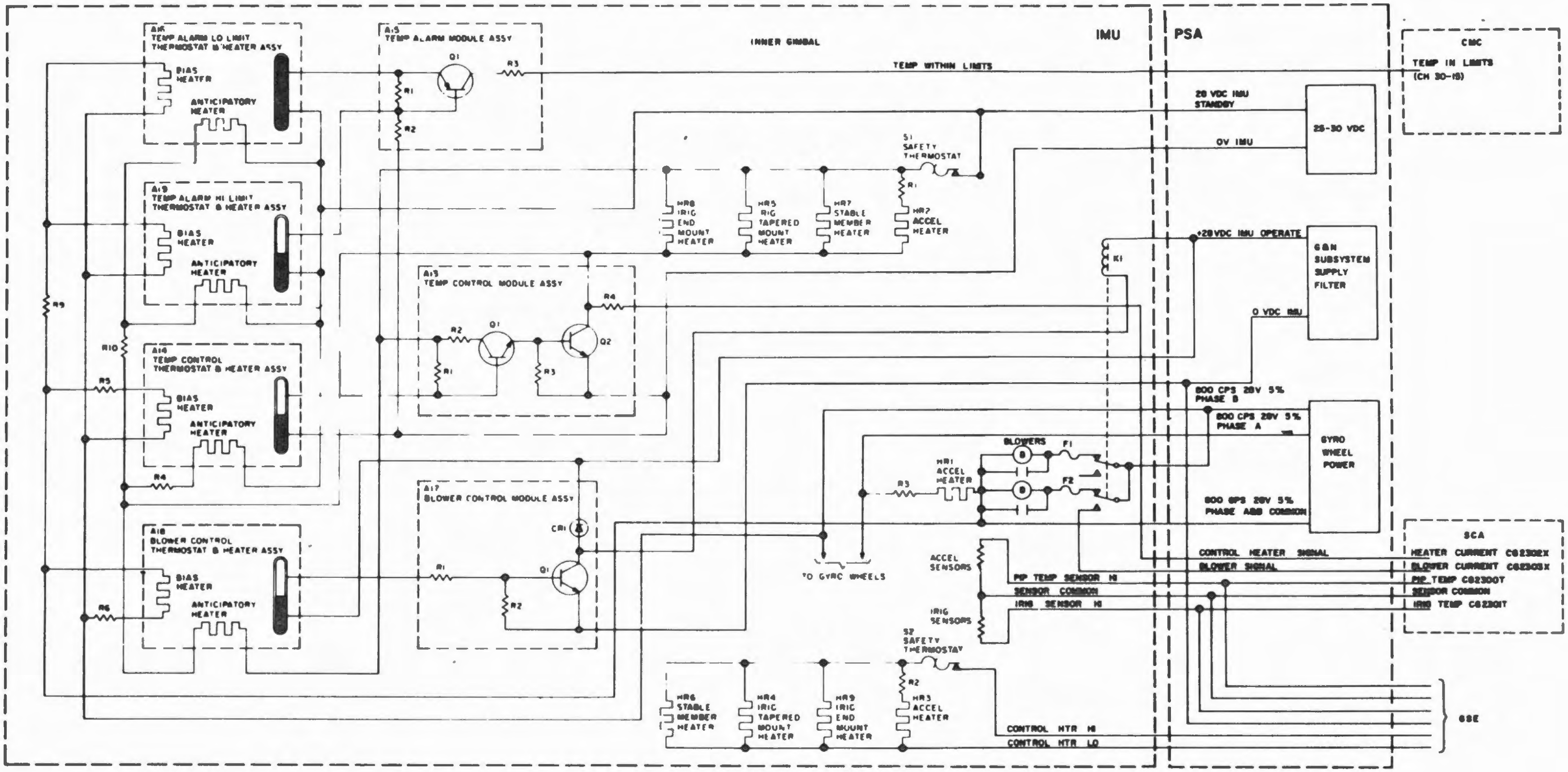


Figure 2-13. IMU temperature control system.

heaters. Because of the large mass of the stable member, its temperature increases at a relatively slow rate as compared to the gyros. The anticipatory heater improves the response of the thermostat to insure that the magnitude of the temperature cycling of the gyros and accelerometers is as small as possible. When the temperature rises above 130 (± 0. 2) degrees, the thermostat closes and the base of Q1 is shorted to ground, cutting off Q1 and Q2. The temperature control circuit maintains the average gyro temperatures at 135 (± 1. 0) degrees and the average accelerometer temperatures at 130 (± 1. 0) degrees under normal ambient conditions.

The 28 vdc heater power is applied to the heaters through the contacts of a safety thermostat which provides protection against an extreme overheat condition in case a malfunction occurs in the temperature control circuit. The safety thermostat contacts open at 139. 5 (± 3. 0) degrees and close at 137 (± 3. 0) degrees.

2. 1. 3. 2 Blower Control Circuit

The blowers maintain IMU heat balance by removing heat. The blowers operate continuously during IMU operate modes. They are supplied 28 vdc, 800 cps power which is also supplied to the gyro wheels (see Fig. 2-13). Fused phase shift networks are associated with each blower so that excitation and control current can be supplied from the same source.

The blower control circuit consists of a blower control thermostat and heater assembly, a blower control module assembly, two axial blowers, and a relay. The contacts of the thermostat contained in the blower control thermostat and heater assembly close at 139 (± 0. 2) degrees Fahrenheit and remain closed at higher temperatures. Resistor R6 is provided to limit the current through the bias heater in the blower control thermostat and heater assembly. The amount of heat supplied by the bias heater is a constant. If the duty cycle of the temperature control circuit exceeds 50 percent, enough additional heat will be provided by the anticipatory heater to increase the temperature of the blower control thermostat and heater assembly to 139 degrees Fahrenheit. When the thermostat contacts close, transistor Q1 conducts and relay K1 is energized to remove the power from the blowers. The normal duty cycle of the temperature control circuit, with the IMU in a 75 degree Fahrenheit ambient temperature, is approximately 15 to 20 percent. Under this condition the blowers will operate continuously. Only a very low ambient temperature will cause a blower off condition.

2.1.3.3 Temperature Alarm Circuit

The temperature alarm circuit monitors the temperature control (see Fig. 2-13). If a high or low temperature is sensed by the temperature alarm thermostat located on the stable member a discrete is sent to the LGC and the PSA. When the temperature is within the normal range of 126.3 to 134.3 degrees Fahrenheit, 28 vdc is applied through the temperature alarm transistor which conducts through a ground in the LGC. When the temperature falls below 126.3 degrees Fahrenheit, 28 vdc is removed from the temperature alarm transistor, causing it to stop conducting and thus signaling the LGC of an alarm condition. When the temperature rises above 134.3 degrees Fahrenheit, 28 vdc is applied directly to the base of the transistor as well as to the emitter. Thus, the base-emitter junction is no longer forward biased and the transistor stops conducting which signals the LGC of an alarm condition. No differentiation is made by the computer between a high or low temperature alarm. When the LGC senses a temperature alarm, it causes the TEMP lamp on the DSKY to light. When the PSA receives a temperature alarm, it sends the information to telemetry.

2.1.4 ISS Power Supplies

Four power supplies convert the +27.5 vdc prime power into the various voltages required by the ISS. The power supplies employed in the ISS are:

a. Pulse torque power supply

b. 800 cps power supply

c. -28 volt power supply

d. 3200 cps power supply

The pulse torque power supply is located in the PTA and the remaining power supplies are located in the PSA. Closing of IMU OPR circuit breaker supplies the prime +28 vdc to these power supplies. Prime power is redundantly supplied to the 3200 cps power supply through the LGC/DSKY circuit breaker.

In addition to prime power, the ISS power supplies require clock pulses from the LGC for synchronization. The dc power supplies utilize multivibrators as ac sources for synchronization. If LGC clock pulses are lost, the multivibrators free run at a lower frequency.

2.1.4.1 Pulse Torque Power Supply

The pulse torque power supply provides 120 vdc to the three binary current switches and three dc differential amplifiers in the accelerometer loops and the binary current switch and dc differential amplifier in the stabilization loop fine align electronics. It also supplies three 28 vdc outputs to the accelerometer loop precision voltage reference, and 20 vdc and -20 vdc to the differential amplifiers, integrators, and binary current switches in the accelerometer loops.

The -20 vdc output is derived from the -28 vdc power supply by using a zener diode as a voltage divider and regulator. (See Fig. 2-14.) The output is regulated at -20 (± 0. 8) vdc. The 20 vdc is derived from +27. 5 vdc prime power by the use of a transistor series regulator which maintains the output at 20 (± 0. 55) vdc.

A synchronizing frequency of 12. 8 kpps originates from the LGC and after being amplified and inverted is applied to the multivibrator-chopper causing it to be synchronized at 6,400 cps. A transistorized time delay circuit is incorporated into the emitter circuits of the multivibrator to provide a turn on delay of approximately 350 milliseconds. During the 90-second IMU turn on mode, 0 vdc is applied through the turn on circuits to the time delay circuit which inhibits the 120 vdc and +28 vdc outputs.

The multivibrator output is applied to the primary of a transformer which has prime power applied to its center tap. The secondary of the transformer is coupled to a two stage push-pull power amplifier which operates from prime power. Each of the rectifier regulators obtains full wave rectification. The precision voltage reference time delay circuit inhibits the operation of the regulators to provide a 6 to 8 second delay in the 28 vdc outputs.

2. 1. 4. 2 800 cps Power Supply

The 800 cps power supply provides 800 cps, 0 phase power for IMU gimbal resolver excitation, gimbal servo amplifier demodulator reference, and FDAI

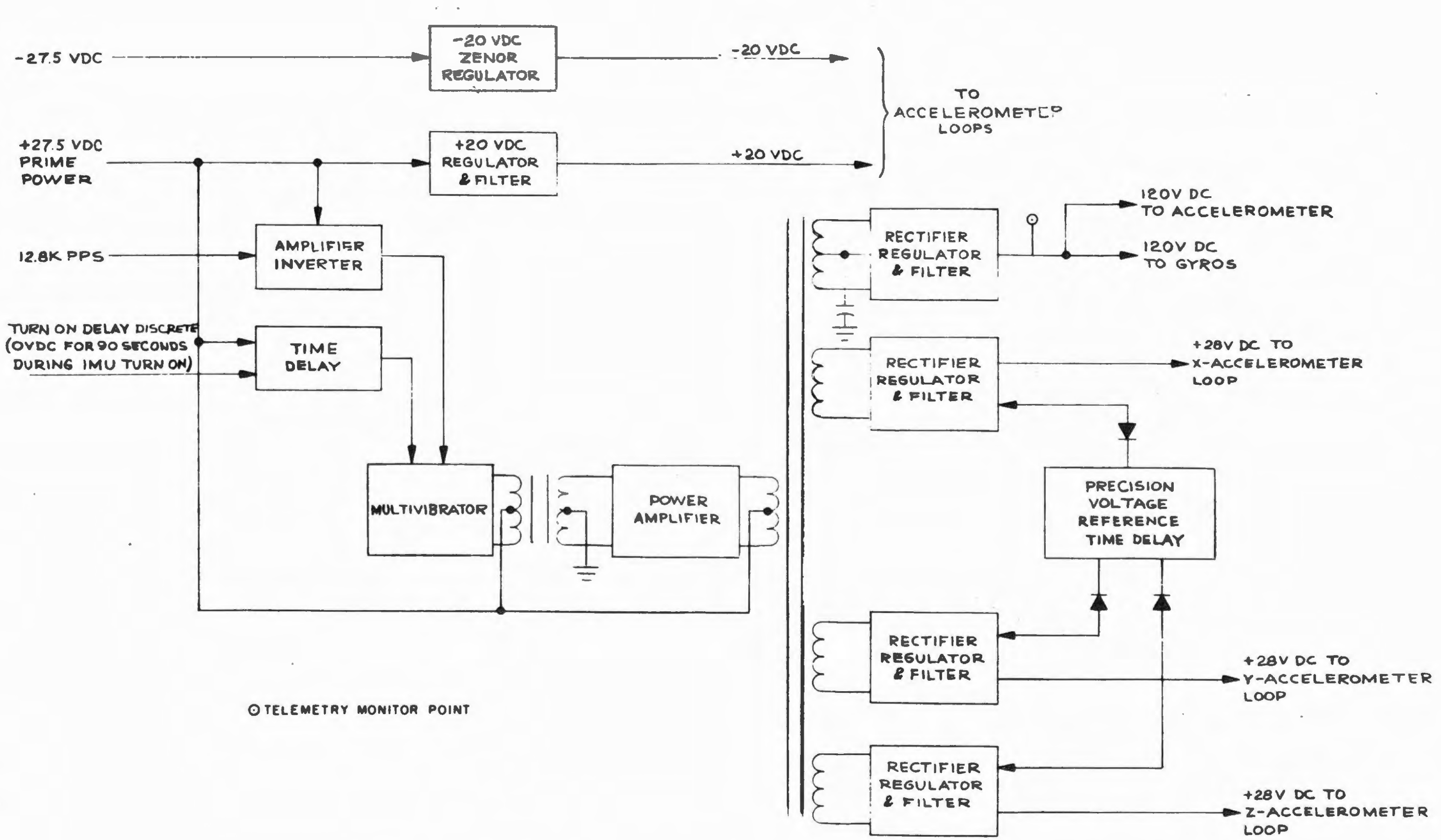


Figure 2-14. Pulse torque power supply.

and autopilot reference. The two, 5 percent outputs provide gyro wheel excitation, IMU blower excitation, and accelerometer fixed heat power.

Zero and pi phase, 800 cps pulse trains from the LGC synchronize the multivibrator at 800 cps. (See Fig. 2-15.) In absence of the LGC pulses, the multivibrator free runs between 720 and 800 cps. The multivibrator output controls the operation of the chopper and filter circuit. A feedback from the 1 percent amplifier is detected and added to a dc reference signal. The positive sum is filtered and provides a dc bias to the multivibrator driven chopper for amplitude control. Each of the 5 percent amplifiers perform a -90 degree phase shift to achieve the output voltage phasing. A power factor correction is maintained by the IMU load compensation network for regulating the three output voltages.

2.1.4.3 -28 vdc Power Supply

The -28 vdc power supply provides input power to the three gimbal servo amplifiers in the stabilization loops and to the pulse torque power supply to generate -20 vdc for use in the accelerometer loops. (See Fig. 2-16). The 25.6 kpps synchronization pulse input is amplified and inverted for use in synchronizing the multivibrator-chopper at 12.8 kcps. The output of the power amplifier is transformer coupled to a full wave rectifier and filter whose positive side is referenced to ground to provide a -27.0 (± 1.0) vdc output.

2.1.4.4 3200 cps Power Supply

The 3200 cps power supply provides excitation voltage for the signal generator and the magnetic suspension portions of the gyro and accelerometer ducosyns. The 3200 cps output is also used as a reference for the demodulator in the gimbal servo amplifiers.

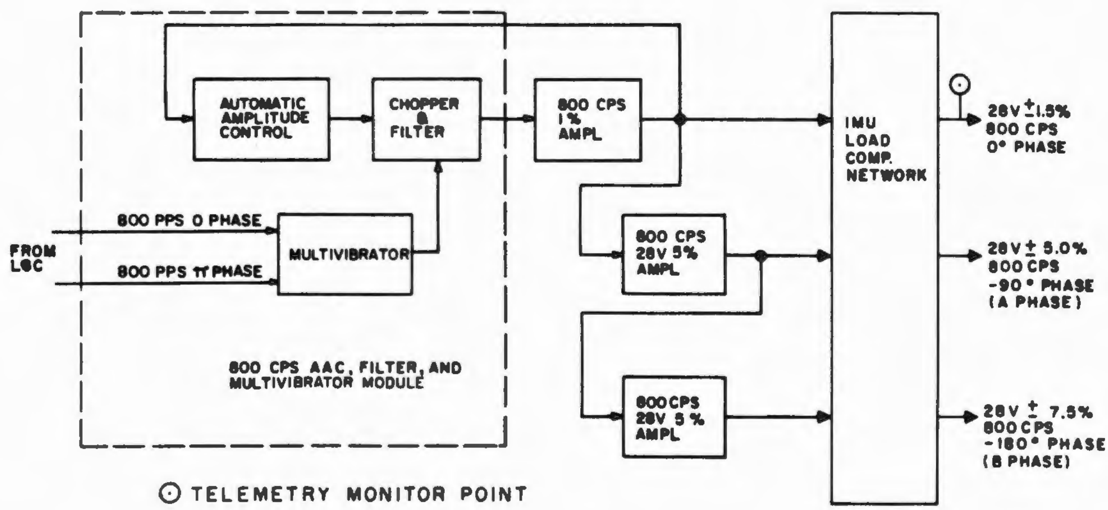


Fig. 2-15. 800 cps power supply.

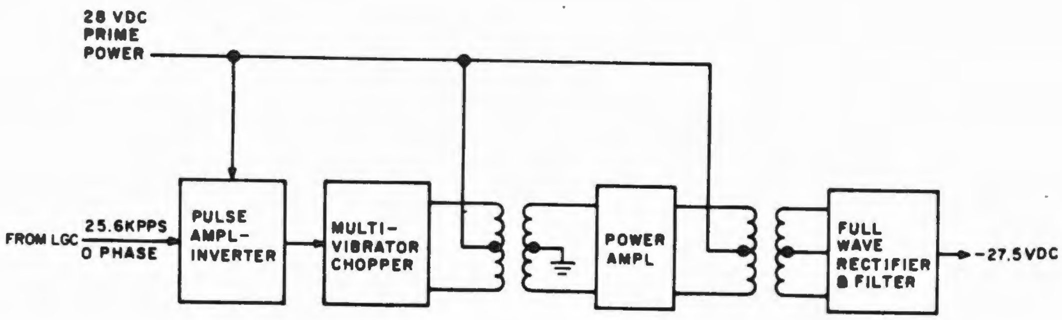


Fig. 2-16. -28 vdc power supply.

The excitation voltage to the signal generators requires both voltage stability and phase stability. (See Fig. 2-17.) To accomplish this stability, the excitation voltage power transmission to the stable member is through a step down transformer on the stable member which reduces the slip ring current and, therefore, voltage drop effects due to slip ring, cable, and connector resistance. In addition, each wire connecting the output of the transformer to the input terminal of each accelerometer is cut to exactly the same length. The voltage level at the primary of the transformer is fed back to the power supply and is compared to a voltage reference.

The 3200 pps pulse train inputs synchronize the multivibrator which controls the operation of the chopper circuit. The 28 volt rms output of the amplifier is transmitted through the slip rings to the transformer on the stable member where the voltage is stepped down to 2 volts for the accelerometer ducosyns and 4 volts for the gyro ducosyns. A sample of the 28 volt level at the primary of the transformer is fed back through the slip rings to the automatic amplitude control circuit. The positive peaks of the feedback signal are detected and added to a dc reference signal. The sum is filtered and provides a dc bias to the chopper circuit. The dc bias controls the amplitude of the chopper output to the filter.

2.2 OPTICAL SUBSYSTEM

The optical subsystem (OSS) consists of the alignment optical telescope (AOT) and computer control and reticle dimmer assembly (computer control). The AOT provides star sighting data for manual insertion into the LGC to accurately establish the inertial reference. The inflight means of data insertion into the LGC is by the computer control.

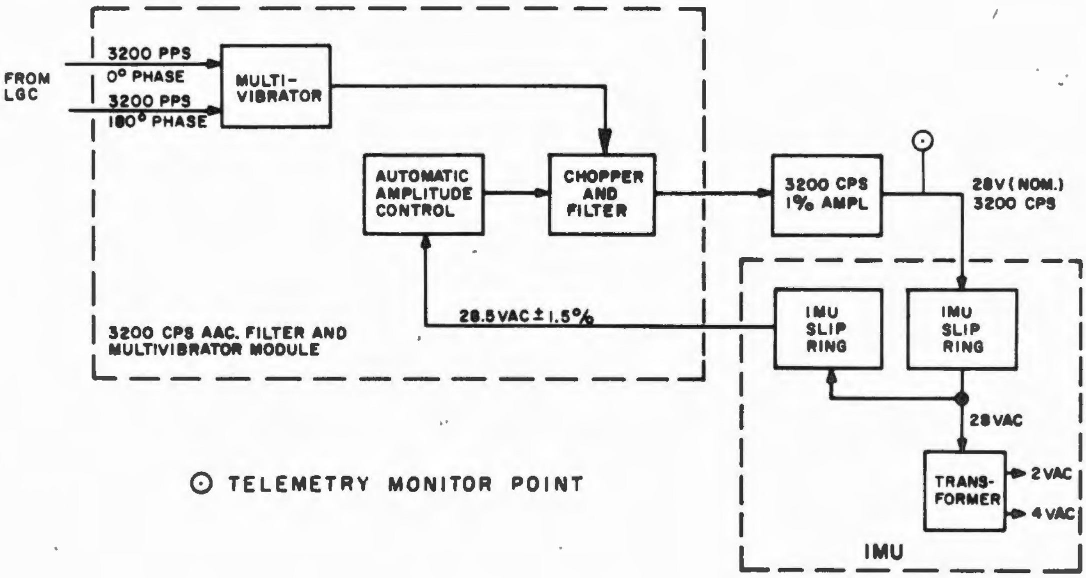


Fig. 2-17. 3200 cps power supply.

The AOT is a unity power telescope with a 60 degree, conical field of view. It is mounted on the navigation base with its telescope shaft drive axis parallel to the LEM X-axis; thereby, establishing an accurate reference to a selected star and a criterion for fine alignment of the IMU.

2.2.1 OSS Theory of Operation

The AOT is illustrated in a cutaway view in Fig. 2-18. It consists entirely of a mechanical and optical constructure operated by manual control. The positioning mechanism is operated by the detent control which rotates the prism about the shaft axis to any of three viewing positions and three storage positions. The function of the worm and gear housing is to locate the reticle and provide the means for its manual positioning by the control knob mounted on the right side of the eyepiece. The counter located on the left side displays a visual readout of the angle to which the reticle has been located. The purpose of the lens and housing and eyeguard is to project the star image in the plane of the exit pupil where it is viewed by the astronaut.

2.2.1.1 Mechanical Positioning

The AOT is fixed in elevation and movable in azimuth to six detent positions. The three operating positions (L, F, and R) detent the periscope telescope at -60, 0, and +60 degrees. Each of these positions maintain the telescope field of view (FOV) 45 degrees from the LEM X-axis. The 0 detent position centers the FOV 45 degrees down from the X-axis in the LEM X, Z plane. The -60 and +60 degree detent positions offset the center of the FOV 60 degrees in each direction from the X, Z plane. Hence, the bottom of the FOV is 15 degrees above the LM Y, Z plane to insure that sunlit terrain does not interfere with star sightings when the LM is on the lunar surface. The remaining three

1. Prism
2. Prism Mount
3. Hood
4. Objective Housing
5. Bearings (Duplex)
6. Objective Lenses
7. Aspheric Field Lens
8. IMU Mounting Surfaces (2)
9. AOT Mounting Surfaces (2)
10. Baffles (7)
11. Outer Tube
12. Inner Tube
13. Pressure Seal
14. Relay Lenses
15. Aperture
16. Relay Housing (Relay Half)
17. Baffles (4)
18. Detent Control
19. Ring Gear
20. Window
21. Mirror
22. Reticle & Cover
23. Bearings (Duplex)
24. Worm & Gear Hsg.
25. Focus Control
26. Reticle Control
27. Worm Gear
28. Lamps (10)
29. Reticle Gear
30. Angle Counter
31. Eyeguard
32. Eyepiece Lenses

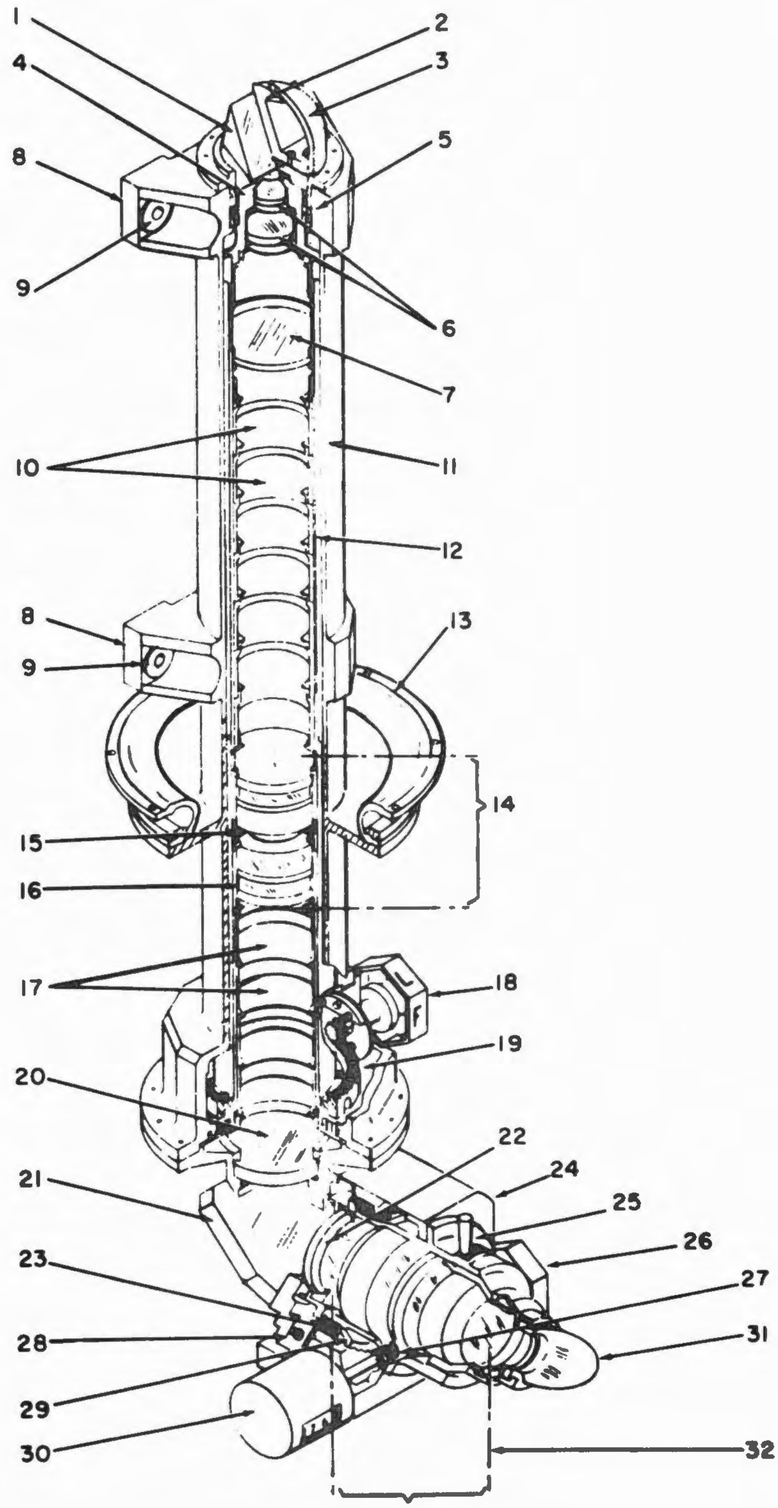


Fig. 2-18. Alignment optical telescope cutaway view.

detent positions (R_R, CL, and L_R) are intended for reversing the telescope prism so its frontal plane is protected by a shield. (In an emergency on the lunar surface, manual removal of the shield would allow these positions to be used for viewing.)

Positioning is obtained by rotating the detent hand knob. The lettered hex knob is turned until the desired detent position is obtained. By means of a bevel pinion the bevel shaft is rotated until the detent ball contacts the gear hub. The gear hub contains detent grooves on its periphery to hold the position.

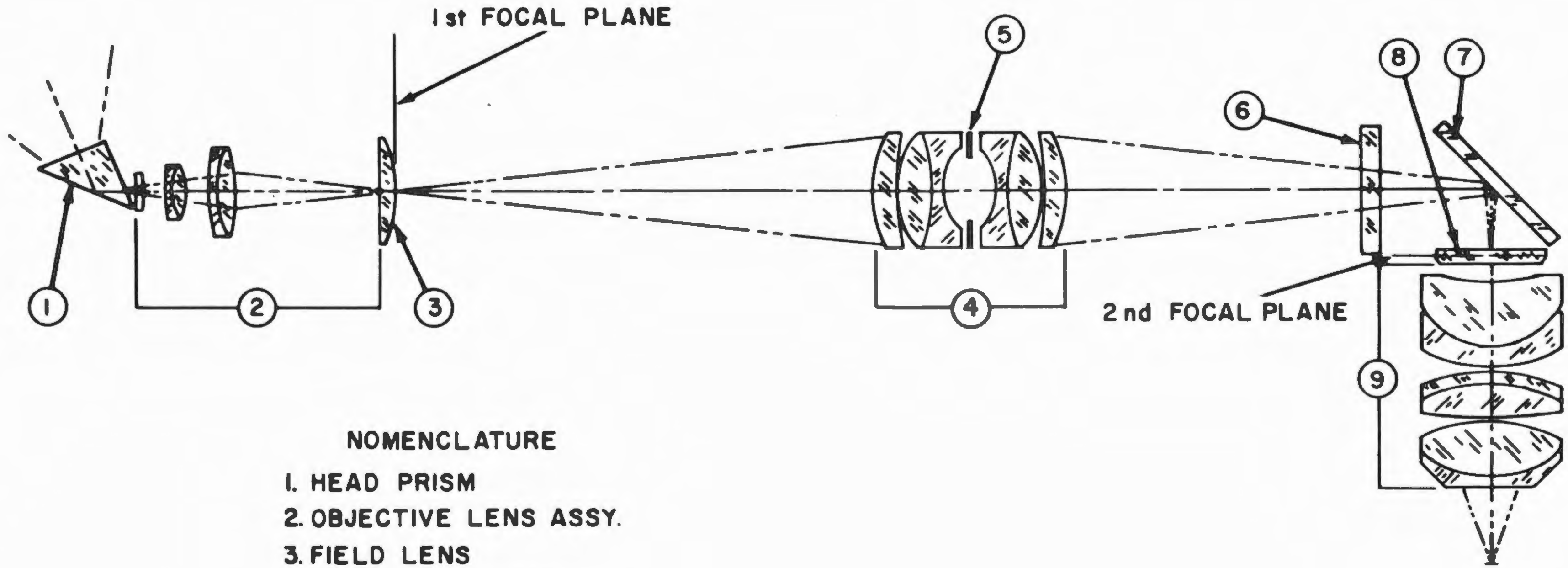
2.2.1.2 Optics

A schematic of the AOT optics is presented in Fig. 2-19. The main components are the head prism, objective lens assembly, relay lens assembly, and the eyepiece assembly.

The head prism is fixed in elevation and in conjunction with the inner tube is movable in azimuth to any of the six detent positions. Acting as a mirror, the prism through its internal reflections diverts the star image into the telescope inner tube. In the 180° detent position, the viewing surface of the prism is covered by the prism shield to protect its surface from micrometeorite impingement.

The objective lens assembly provides for focusing of the target image at the eyepiece side of the field lens. Image diameter at the first focal plane is approximately 0.0006 inch. The objective lenses are coated black on their periphery for elimination of scattered light in the optical path.

The relay lens assembly transfers and focuses the image at the second focal plane located at the reticle. A glass window is mounted between the relay lens and the eyepiece to provide a seal between assemblies. Also



NOMENCLATURE

1. HEAD PRISM
2. OBJECTIVE LENS ASSY.
3. FIELD LENS
4. RELAY LENS ASSY.
5. APERTURE
6. TELESCOPE WINDOW
7. BERYLLIUM MIRROR
8. RETICLE
9. EYEPIECE LENS ASSY.

Fig. 2-19. AOT optics schematic.

located between the relay lens and eyepiece is a specially coated beryllium mirror fixed at an angle of 45°. This mirror reflects the image from the relay lens into the eyepiece.

The eyepiece assembly magnifies the reticle and star image for viewing at the exit pupil 1.5 inches behind the last lens element. The image at this point is erect and noninverted.

2.2.1.3 Computer Control and Reticle Dimmer Circuitry

The computer control and reticle dimmer assembly (computer control) routes heater power to the AOT, supplies reticle lamp power to the AOT, and supplies the mark discretes for inflight star sightings to the LGC (see Fig. 2-20). The 115v, 400~ power is stepped down to 6 volts and full-wave rectified. The INCR RETICLE BRIGHTNESS control permits adjustment of the voltage supplied to the reticle lamps from 0 volts (fully counterclockwise) to 5 volts (fully clockwise). Transistor protection is provided by the limit switch which closes at the fully clockwise position to prevent too high a voltage being applied to the base.

2.2.2 OSS Modes of Operation

The two IMU alignment modes of operation are inflight and lunar surface. Though the lunar surface mode is impractical to employ on an earth orbit mission even for simulated testing, the mode is described to provide an understanding of the AOT displays and controls.

2.2.2.1 Inflight IMU Alignment

For inflight fine alignment of the IMU, AOT sightings must be taken on two stars. (See Fig. 2-21 for the inflight IMU alignment data flow.) The following preparations are made for these sightings:

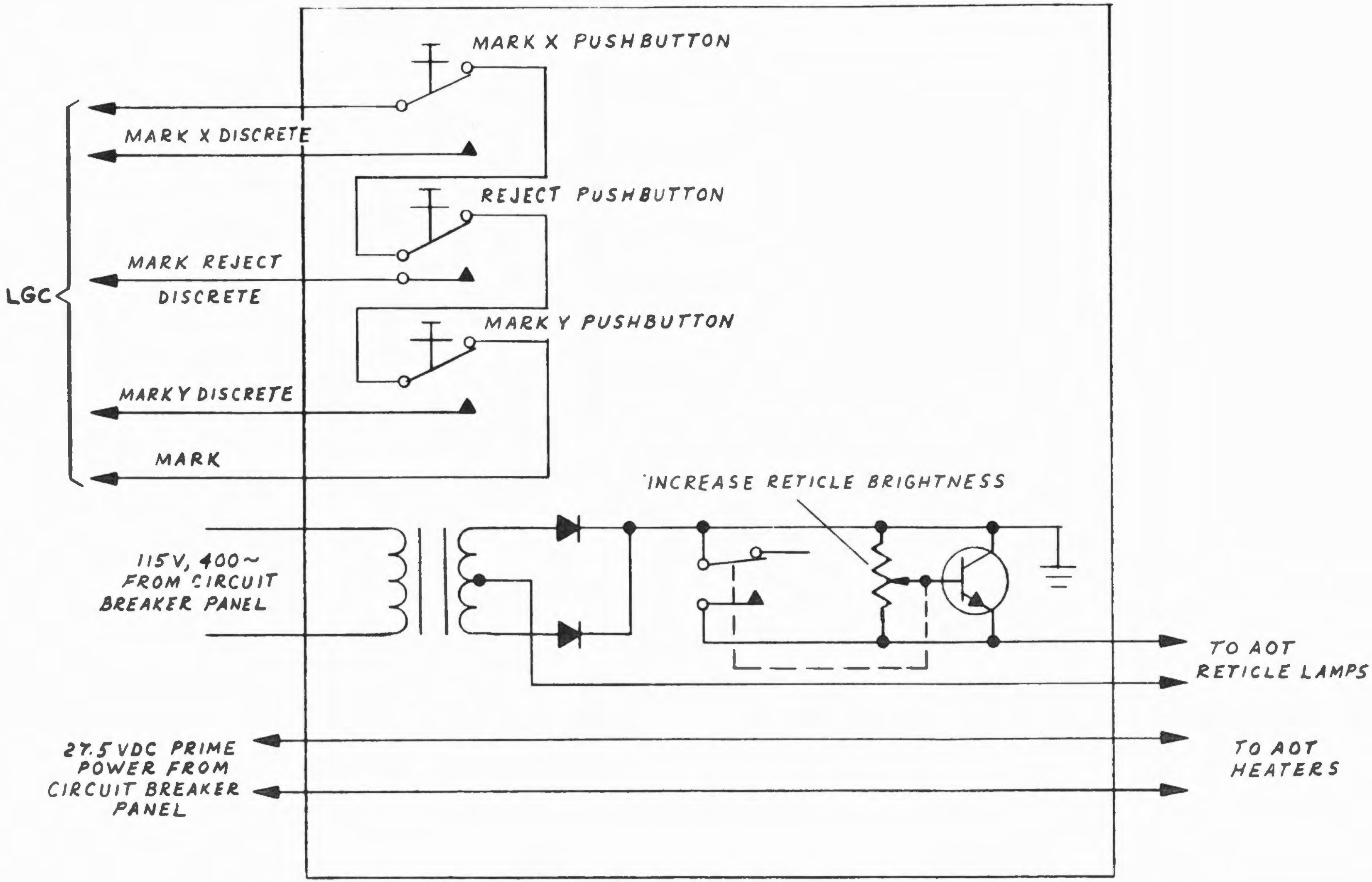


Fig. 2-20. Computer control and reticle dimmer assembly schematic.

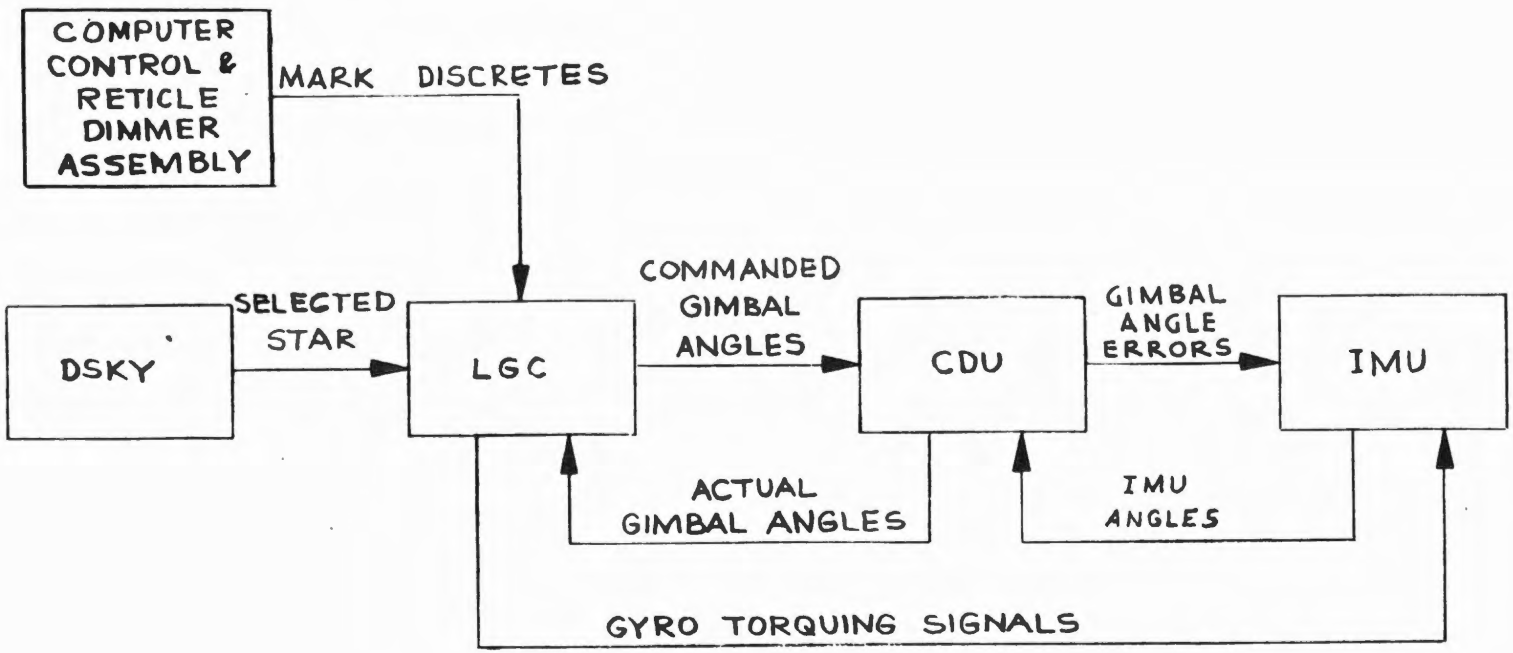


Fig. 2-21. Inflight IMU alignment data flow diagram.

a. CB AOT LAMP is closed

b. The telescope is set to a sighting detent position

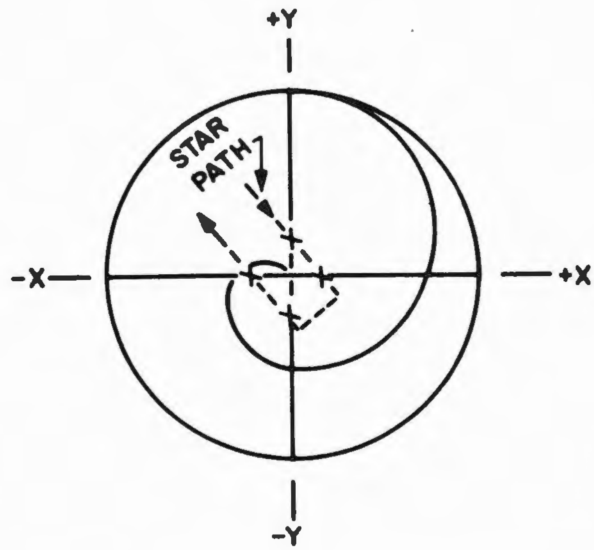
c. The AOT optics reticle light brightness is adjusted by the INCR RETICLE BRIGHTNESS control

d. The reticle counter is set to zero

e. The star code and detent position code are keyed into the DSKY.

Optical sightings are then made by maneuvering the LM in attitude until a selected star is approximately centered in the FOV. (If necessary, the focus control is adjusted.) The LM is then maneuvered so that the star image crosses the reticle crosshairs (see Fig. 2-22) near the center of the FOV. When the star image is coincident with a reticle X-line, the astronaut presses the MARK-X pushbutton and when the star image is coincident with a reticle Y-line, he presses the MARK-Y pushbutton. If a mistake is made, the REJECT button is pressed to eliminate the last mark.

When a mark button is pressed, a discrete is transferred from the computer control and reticle dimmer assembly to the LGC. The computer records the time, the type of mark, and the IMU gimbal angles at the instant of mark. The star code number was entered into the DSKY at the beginning of the sighting mark routine (R53). Hence, crossing of a reticle line by the star image defines a plane containing the target star. Crossing of the other reticle line defines another plane containing the target star. The intersection of these planes form a line defining the direction of the target star.



1. ATTITUDE LIMIT CYCLE OPERATION

2. PILOT MARKS STAR CROSSING ON EACH AXIS

Fig. 2-22. AOT reticle pattern during inflight alignment.

2.2.2.2 Lunar Surface IMU Alignment

During lunar surface IMU alignment, the target star can be selected in either the AOT left, right, or forward viewing positions. The astronaut using the manual drive knob, adjusts the reticle to superimpose the orientation line or Y line on the target star (see Fig. 2-23). This reticle angle displayed on the AOT counter is then inserted into the LGC via the DSKY. This provides the computer with the star orientation angle (shaft angle). The astronaut then continues to rotate the reticle until a point on the spiral is superimposed on the target star and enters this angular readout into the computer via the DSKY. The AOT detent position and star code number are also inserted into the LGC via the DSKY. The computer can now calculate the angular displacement of the star from the center of the field of view by computing the difference between the two counter readings. At least two star sightings are required for IMU fine alignment.

2.3 RENDEZVOUS RADAR SUBSYSTEM

The rendezvous radar subsystem (RRS) consists of the rendezvous radar (RR) and two channels of the CDU. An 800 cps reference voltage is provided from the PSA. The radar consists of an antenna assembly and an electronics assembly. The antenna assembly is a two degree of freedom device which contains the two-foot, four-horn cassegrain antenna. The antenna has a narrow 4° beam. The electronics assembly contains most of the radar circuitry, but the microwave radiating and receiving circuits are in the antenna assembly. Hence, the use of microwave rotary joints has been avoided. Flexible low frequency coaxial cables connect the outboard antenna components to the inboard electronics assembly. A flexible cable wrap-up system is used at each of the rotary bearing points.

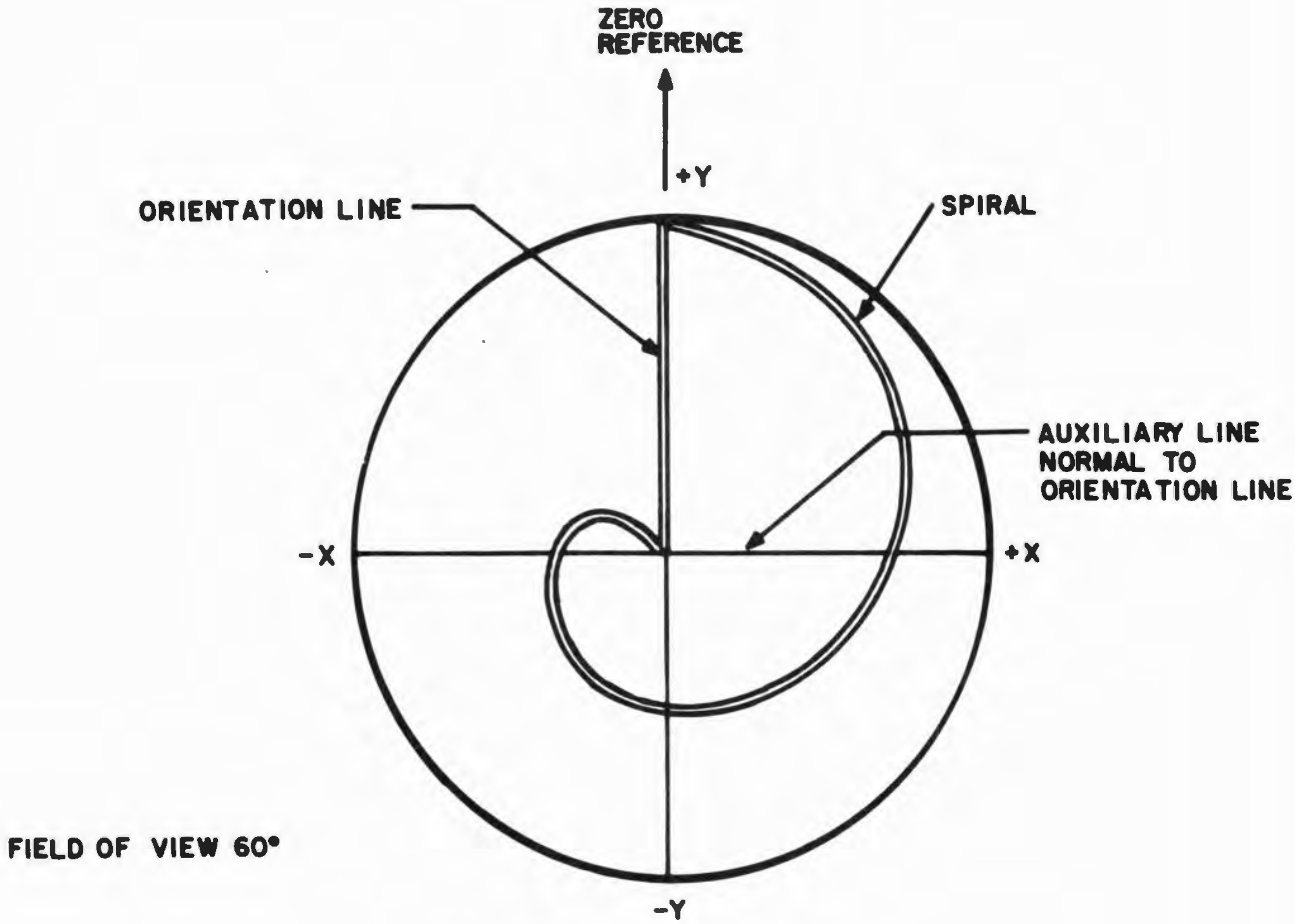


Fig. 2-23. Alignment optical telescope reticle pattern.

The accuracy requirements for RR are governed by the allowable fuel expenditures for main propulsion and attitude jets to execute the trajectory corrections required for rendezvous. The long range, accurate system permits corrections in rendezvous trajectory to be made early, thus requiring less fuel.

2.3.1 RRS Theory of Operation

The RRS is an amplitude comparison, monopulse tracking system. When tracking or locked on to the CSM transponder, the RR is a continuous wave, coherent system that uses phase lock techniques. Range is measured by comparing the received modulation phase with the transmitted modulation phase.

A block diagram of the subsystem is illustrated in Fig. 2-24. A frequency synthesizer develops the reference frequency for the transmitter. This frequency is multiplied to X band. During the transponder tracking, the transmitter frequency is phase modulated by three frequencies (200 cps, 6.4 kc, and 204.8 kc) generated from a reference counter in the range tracker. The phase modulated signal is applied to the antenna for radiation. The radiated energy incident upon the CSM transponder activates the transponder such that the tones are removed, the radio frequency is side-stepped, the tones are replaced, and the energy is returned to the RR antenna. The return signal, when combined with the transmitted frequency, results in a difference frequency. Resulting IF signals to the IF receiver produce a sum signal (with tones) to the range tracker. The range tracker compares sequentially the phase of the 200 cps, 6.4 kc, and 204.8 kc return modulation with the phase of the reference signal from the reference counter to provide range information to the computer interface. Phase comparison between the return and reference signals provide unambiguous ranging from approximately 80 feet to 390 nautical miles.

The received frequency is not constant, but varies with changing range. This difference in frequency caused by the changing range is called the doppler frequency. The doppler frequency is a function of the rate of range change. Thus, by measuring the doppler frequency the range rate may be determined. The frequency tracker detects the doppler frequency by continually comparing the received frequency, after it has been converted to IF, with a reference frequency. A voltage controlled oscillator (VCO) in the frequency tracker is maintained at the reference frequency plus the doppler frequency by means of an automatic phase lock loop. Any change in doppler frequency results in a corresponding change in VCO frequency. The instantaneous frequency of the VCO then indicates range rate.

The doppler frequency component has to be eliminated from the ranging and antenna positioning circuits for it would result in inaccurate information. Therefore, the loop controlling the VCO frequency encompasses part of the receiving circuits. In that way, this loop removes (washes out) the doppler frequency from the ranging and antenna positioning circuits but still is effective in maintaining the VCO at the doppler frequency plus the reference frequency.

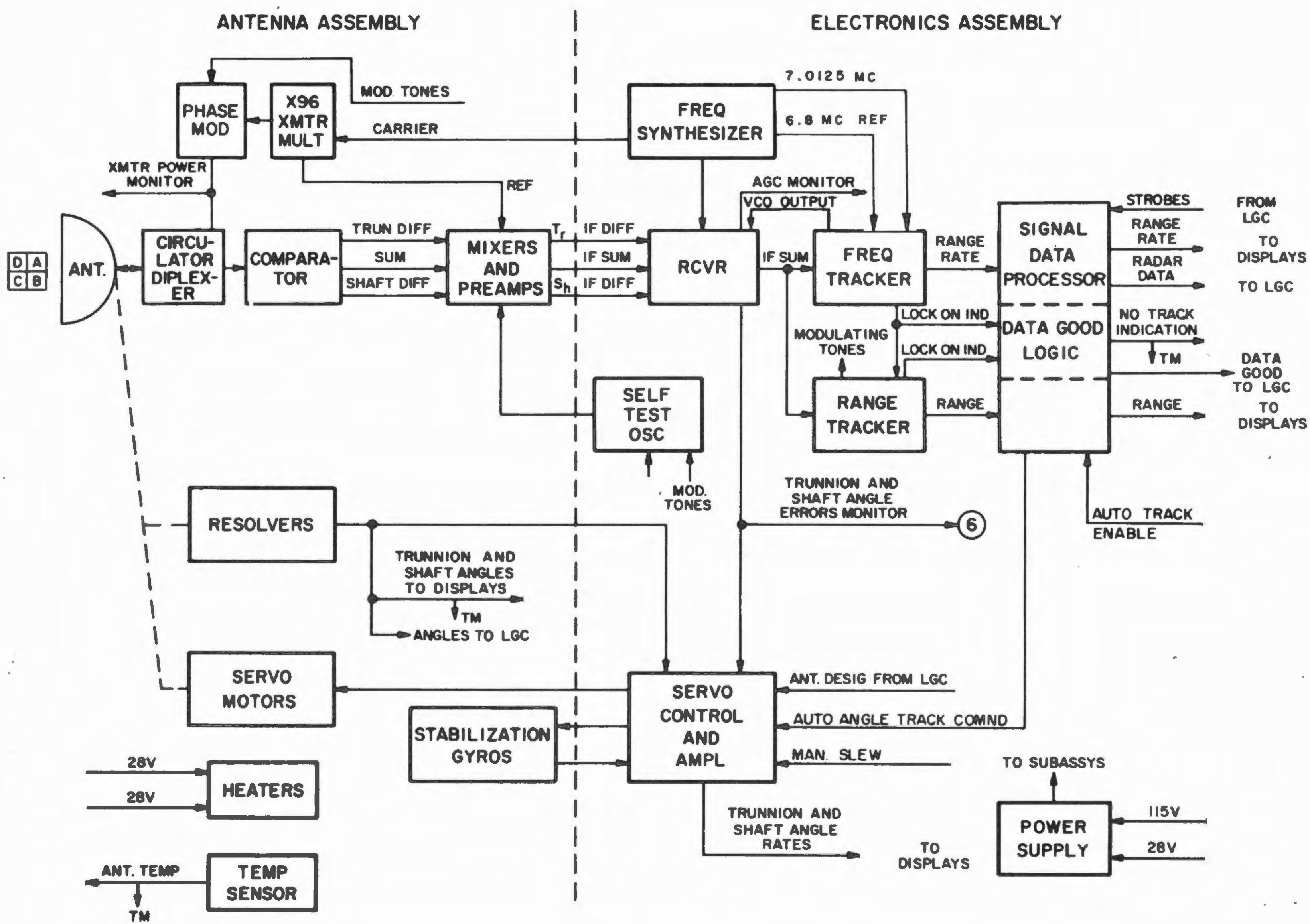


Figure 2-24. Rendezvous RADAR subsystem functional block diagram

The returned energy is received by four feed horns arranged in a simultaneous lobing configuration. If the transponder is directly in line with the RR antenna line-of-sight, the return energy is equally received by each of the four feed horns. If the transponder is not directly in line, the amount of energy received by each feed horn is not equal.

The position of the transponder with respect to the RR line-of-sight determines the type of antenna pointing error generated. With the RR line-of-sight directly below the transponder, an X coordinate pointing error is generated. The receiving circuits contain three similar channels: the X channel, the Y channel, and the sum channel. The X channel input is the difference in received energy between the vertically adjacent feed horns. The Y channel input is the difference in received energy between the horizontally adjacent feedhorns. The sum channel input is the sum of the received energy of all four feedhorns.

After triple conversion, the sum channel output is compared with the X and Y channel outputs to obtain drive signals for the antenna (shaft LOS error and trunnion LOS error). The effect of these drive signals is to eliminate the antenna pointing error. This automatic antenna positioning loop then keeps the RR antenna line-of-sight directed at the transponder. Vehicle motion is compensated for in the antenna positioning loop by use of a gyro stabilization loop. The position of the antenna, as a result of the antenna positioning and stabilization loops, indicates the direction of the transponder with respect to the LM vehicle. Resolver outputs (1X and 16X) indicating antenna position are provided to the LGC by way of the CDU. Hence, the LGC can use the directional data for rendezvous maneuver computations and automatic tracking. The shaft and trunnion resolvers are the same type as in the IMU.

In addition to tracking, the antenna may be positioned for acquisition purposes either by manual commands from the radar panel or automatically by the LGC. The maximum antenna angular slew rates are 3° per second, although higher rates can be commanded. The antenna can be slewed manually by a commanded rate of 9° per second or 1.3 per second by an open loop servo, with the astronaut observing the antenna angles on the FDAI. The LGC can command up to 9° per second. However, for a precision angle readout, the maximum antenna angular tracking rates are limited to 1° per second.

Analog displays for range, range rate, antenna angles, and antenna angular rates are provided to the astronauts for manual control interfaces. Self check circuitry within the radar includes a built in test for simulating returned energy.

2.3.1.1 Frequency Synthesizer

The frequency synthesizer generates all of the fixed frequencies required for coherent signal transmission and reception. A single 1.7 megacycle stable crystal oscillator (Colpitts common base) and a system of multiplication, division, and mixing are used to produce the required frequencies (see Fig. 2-25). A CW output signal of 102.425 megacycles is generated for excitation of the transmitter multiplier chain. The synthesizer also generates various local oscillator, clock, and reference frequencies used by the receiver, the computer interface, and the trackers.

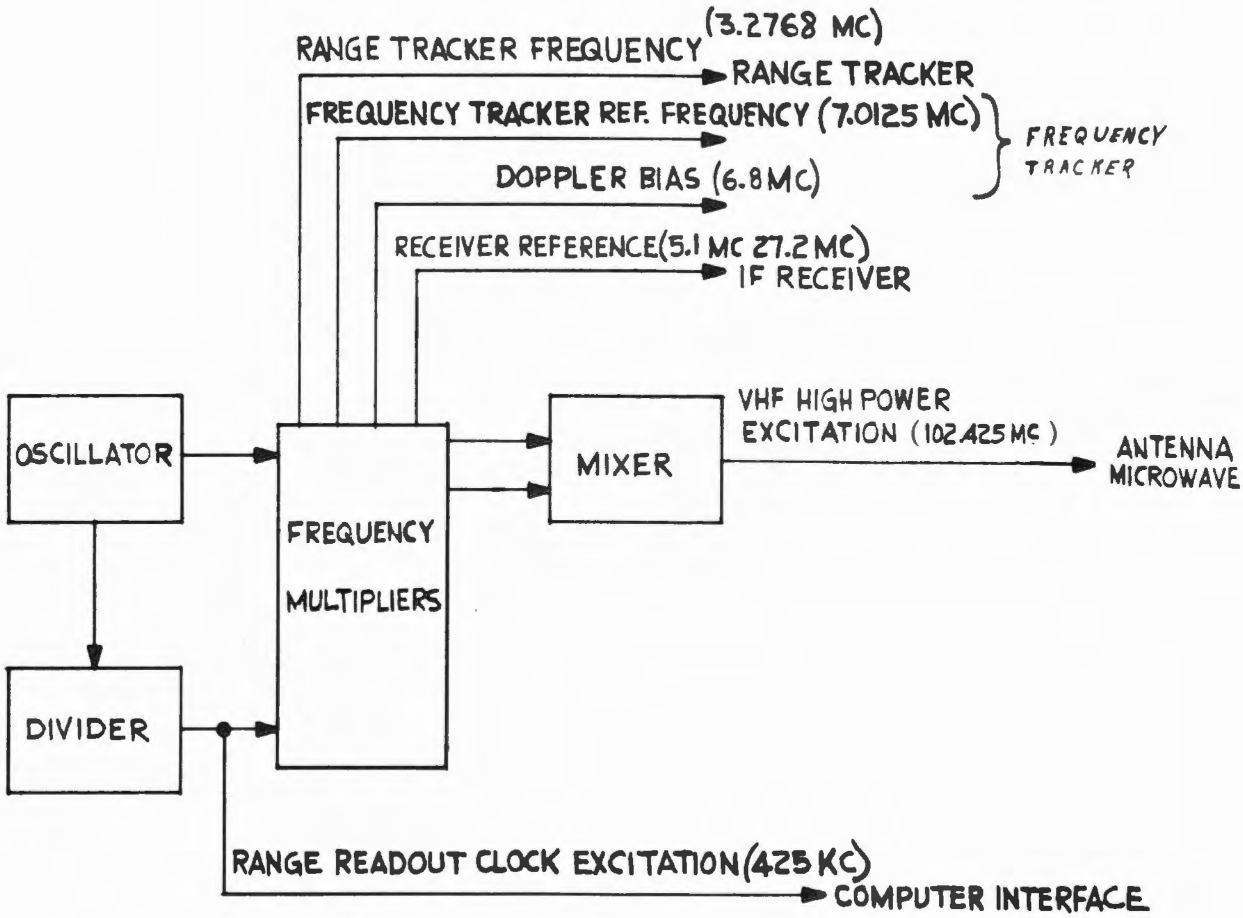


Fig. 2-25. Frequency synthesizer functional block diagram.

2.3.1.2 Antenna Microwave Electronics

The antenna microwave electronics consists of the transmitter, the (PHASE) modulator, the receiver RF section, and the duplexer (see Fig. 2-26). The antenna transmits and receives circularly polarized radiation so as to minimize the signal variations resulting from attitude changes of the linearly polarized transponder antenna. Components are distributed inside the antenna to achieve balance around each axis.

The multiplier chain supplies X-band power for radiation and local oscillator excitation. This is feasible, since the transponder replies with a frequency side-step equal to the radar first IF frequency (40.8 megacycles). The multiplier chain, frequency multiplies the inputs from the synthesizer 96 times to obtain the X band frequencies. The heat dissipated by the multiplier chain is radiated back into space by the antenna dish. The phase-modulator utilizes a ferrite rod inside a waveguide and a solenoid for varying the magnetic field inside the rod. Ranging tone signals are applied to the solenoid, varying the length of the rod, and providing phase modulation of the X-band carrier.

The polarization duplexer is a switching device between the receiver and transmitter. It permits energy to enter the receiver if the energy is a low level and is approximately 9792.0 megacycles. Hence, only the side-stepped returns enter the receiver. This is accomplished by magnetic biasing so that permeability characteristics provide mutual interaction of the magnetic field from electromagnetic energy of a specified frequency range.

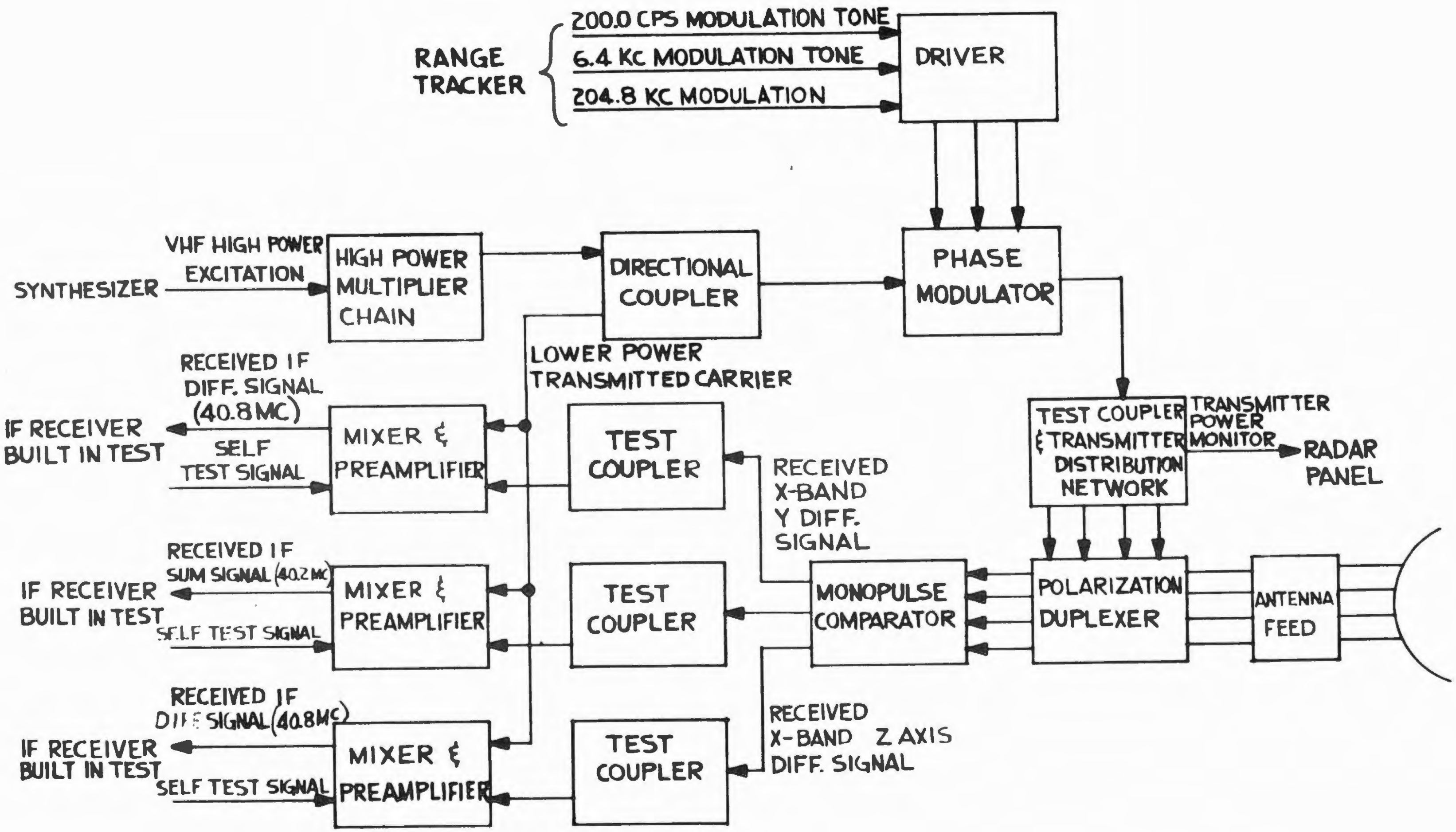


Fig. 2-26. Antenna microwave electronics functional block diagram.

Since each of the antenna feed horns receive some of the returned energy, the RF signal is passed through the circulator to the nonopulse comparator which processes the signal to develop the required sum and difference signals. the Y difference signal produced from the energy difference between horizontally adjacent feedhorns is an indication of shaft LOS error and the Z-axis difference signal produced from the energy difference between vertically adjacent feedhorns in an indication of trunnion LOS error. The sum frequencies from the four feedhorns is used as a signal strength and phase reference.

The preamplifiers are tuned to a difference frequency of 40.8 megacycles. This difference frequency is developed by the difference between the transmitted and received frequencies.

The self test signals simulate received energy for testing purposes. In addition, when the TEST/MONITOR selector on the radar panel is in RNDZ RADAR XMTR PWR position the transmitter output power from the test coupler and transmitter distribution network can be monitored on the radar panel SIGNAL STRENGTH meter.

2.3.1.3 <u>IF Receiver</u>

The receiver is a highly stable three-channel, triple-conversion superheterodyne. It has intermediate frequencies of 40.8 mc, 6.8 mc, and 1.7 mc (see Fig. 2-27). The bandwidth of the first and second IF amplifiers is approximately 3 megacycles and the bandwidth of the third IF amplifier is approximately 1 kilocycle. Two channels are provided for amplifying the shaft and trunnion axis error signals and one channel is provided to amplify the sum or reference signal. The receiver also includes phase sensitive detectors for generating angle error signals, an AGC circuit for controlling the gain of the three receiver channels, an IF distribution amplifier unit for supplying reference channel signal to range and frequency trackers, and a gated local oscillator mixer for generating the local oscillator signal.

The second local oscillator frequency is obtained by beating the frequency tracker VCO output with a reference frequency to produce a sum frequency exactly 6.8 megacycles lower than the incoming 40.8 megacycle doppler shifted frequency (± fd). That is, the doppler shifted frequency is removed and all subsequent signal processing is accomplished at fixed carrier frequencies, but an indication of the doppler frequency is maintained by the frequency tracker VCO frequency. The VCO is maintained at 6.8 mc ± fd and varies in frequency only according to the changes in doppler frequency. Thereby, maintaining the IF receiver outputs to the antenna servo electronics free from doppler errors in maintaining the monopulse.

The sum channel is used for AGC development, for development of the ranging and range rate signals, and for comparison reference to the X and Y channels. Comparison of the sum channel output with the X and Y channel outputs provides drive signals for the antenna to eliminate the antenna pointing error. The phase sensitive detectors convert the outputs of the shaft and trunnion channels to two bipolar-video angle error signals. A 6.8 megacycle signal is routed from the sum channel to the range tracker where processing begins for range and range rate definition.

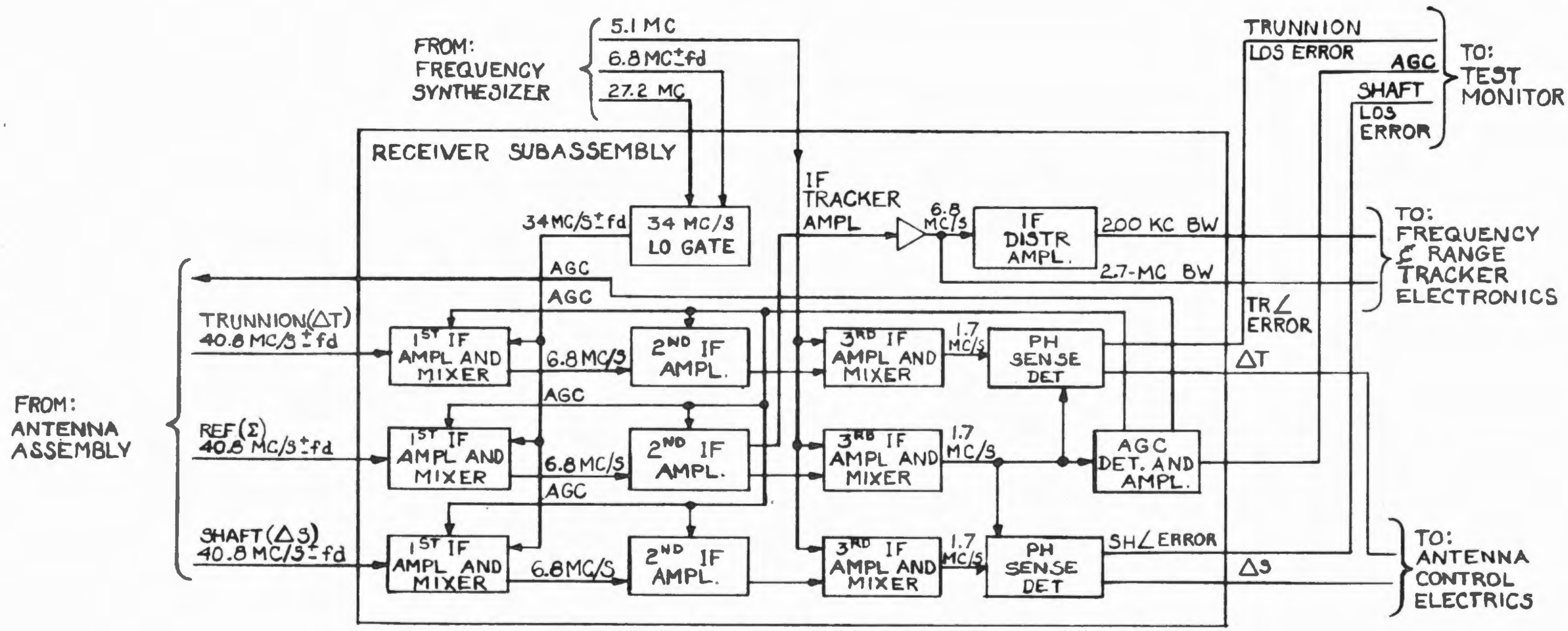


Fig. 2-27. IF Receiver Functional Block Diagram.

The most stringent requirement on the receiver is that the three channels must gain-track within ± 2. 5 db and phase track within 27 degrees over a dynamic range greater than 110 db, and a temperature range of greater than 70°C.

Positioning of the TEST/MONITOR selector to AGC position permits display of the incoming signal strength, to SHAFT ERR position permits the SIGNAL STRENGTH meter to show movement of antenna shaft, and to TRUN ERR position permits the SIGNAL STRENGTH meter to show movement of antenna trunnion.

2. 3. 1. 4 Range Tracker

The range tracker is used to determine the range to the transponder by measuring the phase angle between the transmitted tones and the received tones. The received sum signal (at 6. 8 mc) is demodulated in a coherent product detector which uses a 6. 8 megacycle quadrature reference (see Fig. 2-28). The individual sinewave tones are extracted from the receiver noise using bandpass filters to the tone frequencies. Range phase-delay is measured independently on each of the three tones in a closed tracking loop. Three reference square waves are locally generated each having variable phase with respect to the transmitted tones. This phase delay is adjusted until the reference sqaure waves have matching phase with respect to each of the received tones. (The 200 cps, 6,4 kc, and 204. 8 kc signals are nulled in order.) These reference square waves are produced digitally by comparison between a running high-speed counter and a low-speed forward-backward range counter. The low-speed range counter is driven forward or backward until phase null is achieved in each of three phase detectors. The range counter is driven forward or backward by incremental range pulses

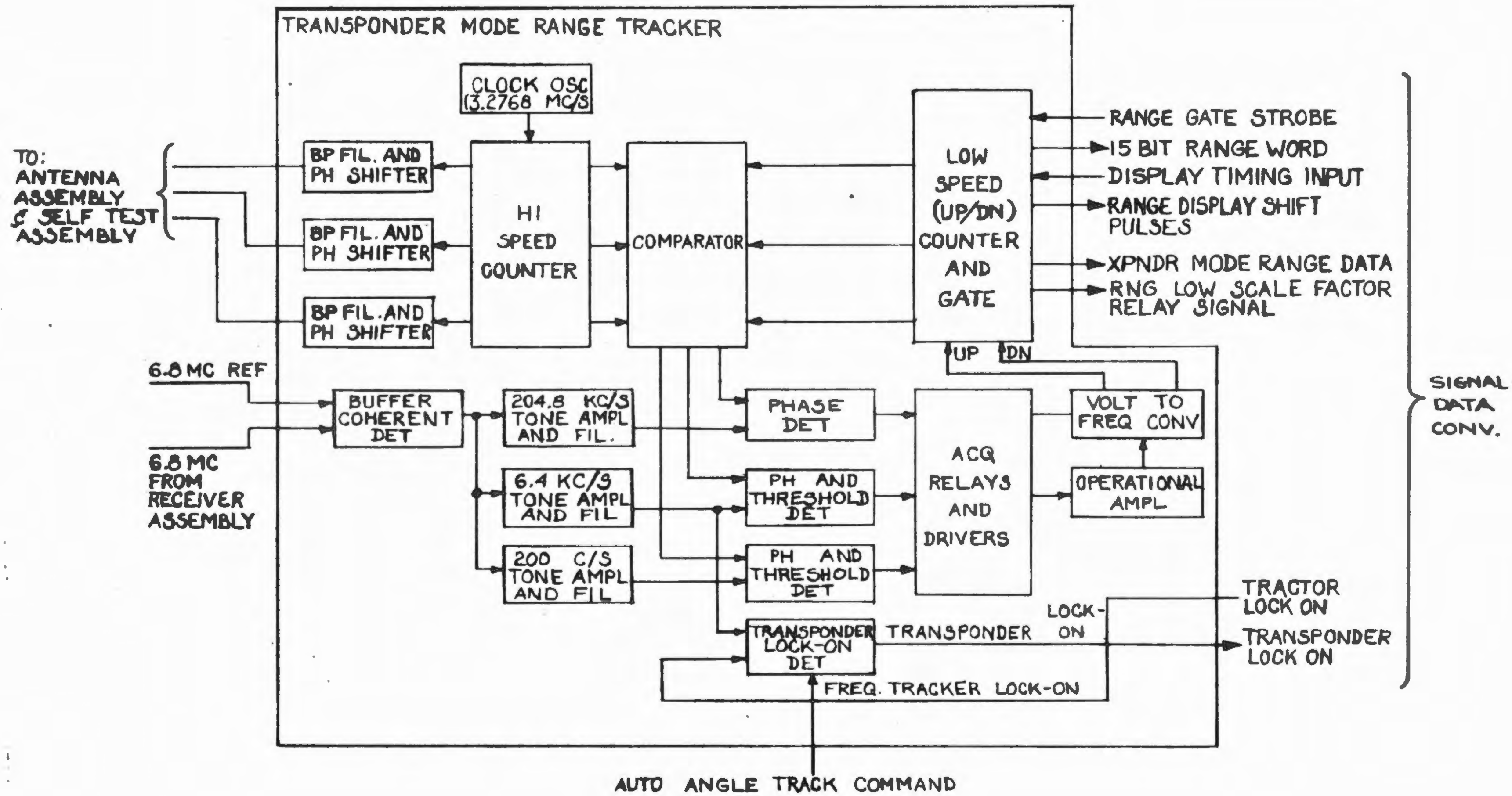


Fig. 2-28. Range Tracker Functional Block Diagram.

obtained from a dc to PRF converter controlled by weighted integration of the three phase detector error signals. When acquisition is obtained, the lock-on indication is sent to the computer interface which sends the data good discrete to the LGC.

The digital count is transferred from the low speed counter to an 18-bit shift register which supplies the count to the computer interface, transponder mode display processor. In addition, when the transfer signals are received from the LGC, 15-bit range data is entered into the LGC range register via a transfer register in the computer interface.

The 15-bit range data routed through the computer interface to the LGC has two different scalings. As a result, the LGC must be aware of what scaling is being used for the transferred range data. Range low scale factor switching is implemented automatically by the scale logic at a range of approximately 50.8 nautical miles. That is, 15 of 18 bits are gated to a counter in the computer interface and range scaling is a factor in determining whether the 15 least significant or 15 most significant bits are gated out. At ranges greater than 50.8 nautical miles, the most significant bits are transferred and at ranges of less than 50.8 nautical miles, the least significant bits are transferred. A discrete is initiated from the scale logic to inform the LGC that low scale factor is in effect when such a change takes place.

As a result of this most or least significant bit transfer, an 8 to 1 ratio exists between high and low scale factors. The low scaling is approximately 9.38 feet/bit and the high scale factor is approximately 75.04 feet/bit. The range scale factor switching does not occur during range data transfer.

2.3.1.5 Frequency Tracker

The frequency tracker tracks the coherent narrow-line spectra received from the transponder. The tracker is switched to phase-lock the VCO with this narrow-line spectrum. This switching is initiated by the bandwidth control signal (see Fig. 2-29).

The phase detector for the phase lock loop uses a 6.8 megacycle signal from the frequency synthesizer as a reference. Balanced modulators perform a phase detection function, giving an output proportional to phase difference between input and synthesizer reference. The notch filtering removes the audio tones which would otherwise introduce large errors. The resultant error signal drives the VCO to such a frequency that when it is used as the local oscillator signal for the second IF mixer after being mixed with a 27.2 megacycle synthesizer signal, it removes the doppler frequency shift from all signals in succeeding IF stages and assures passage of the signal through the 1.7 megacycle filters.

The tracker utilizes a frequency sweep circuit for sweeping the VCO frequency across the doppler frequency range (± 100 kc), searching for the received signal. A threshold circuit senses the presence of carrier signal by comparing the narrow band frequency with the wide band ambient noise level. Upon detection of a preset value, it stops the sweep, and permits the VCO to phase lock. When lock on is obtained, an indication of this condition is forwarded to the computer interface.

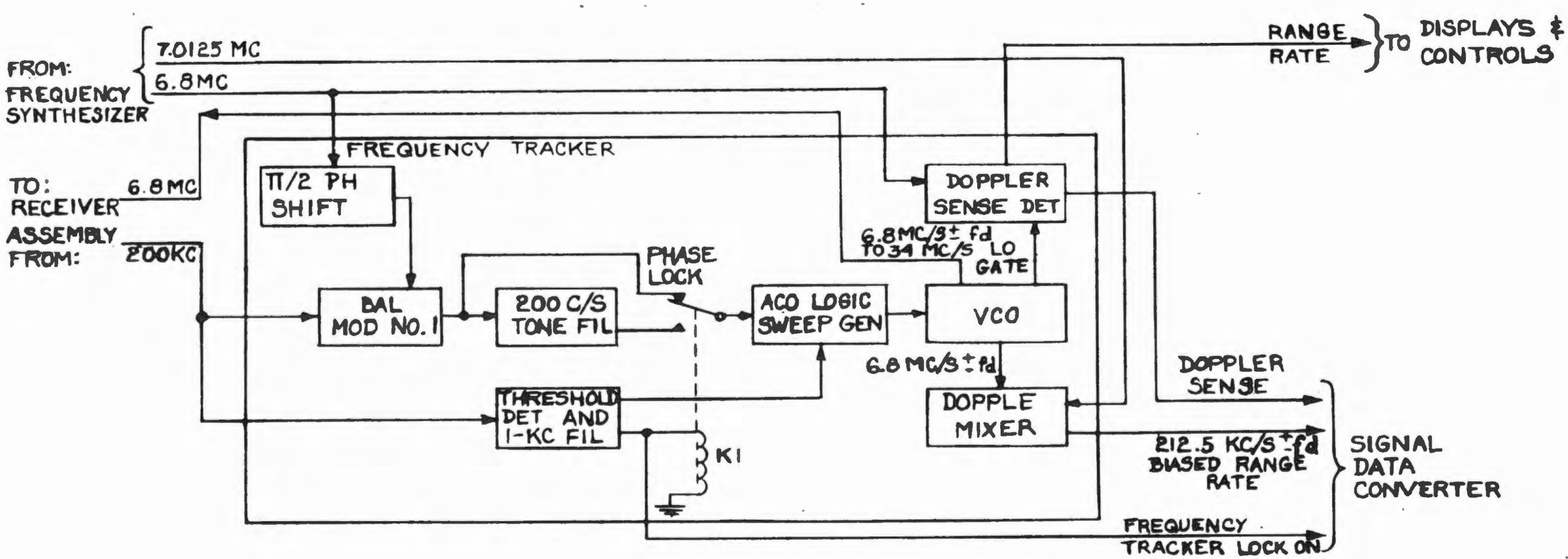


Fig. 2-29. Frequency Tracker Functional Block Diagram.

Changes in range are indicated by the difference frequency (fd). The VCO maintains an indication of range rate by being held to 6.8 mc ± fd which is sent to the receiver for doppler frequency washout. This 6.8 mc ± fd signal is also mixed with a reference frequency to obtain the range rate frequency which is decoded to a digital format in the computer interface.

The display mixer provides a difference frequency signal to the quantizer which processes the signal and routes it to the computer interface for display drive.

2.3.1.6 Antenna Control Assembly

The antenna control assembly contain amplifiers for driving the antenna shaft and trunnion axis servo motors, amplifiers for driving the gyro torquer coils, and voting logic for selecting the correct gyro pair (see Fig. 2-30). The control assembly, in connection with the antenna components and radar receiver, form an inner and outer closed loop for each axis. The inner or stabilization loop maintains the antenna boresight axis fixed in inertial space in the presence of body motions. The outer or tracking loop maintains the antenna boresight on the target based upon tracking error signals from the monopulse receiver.

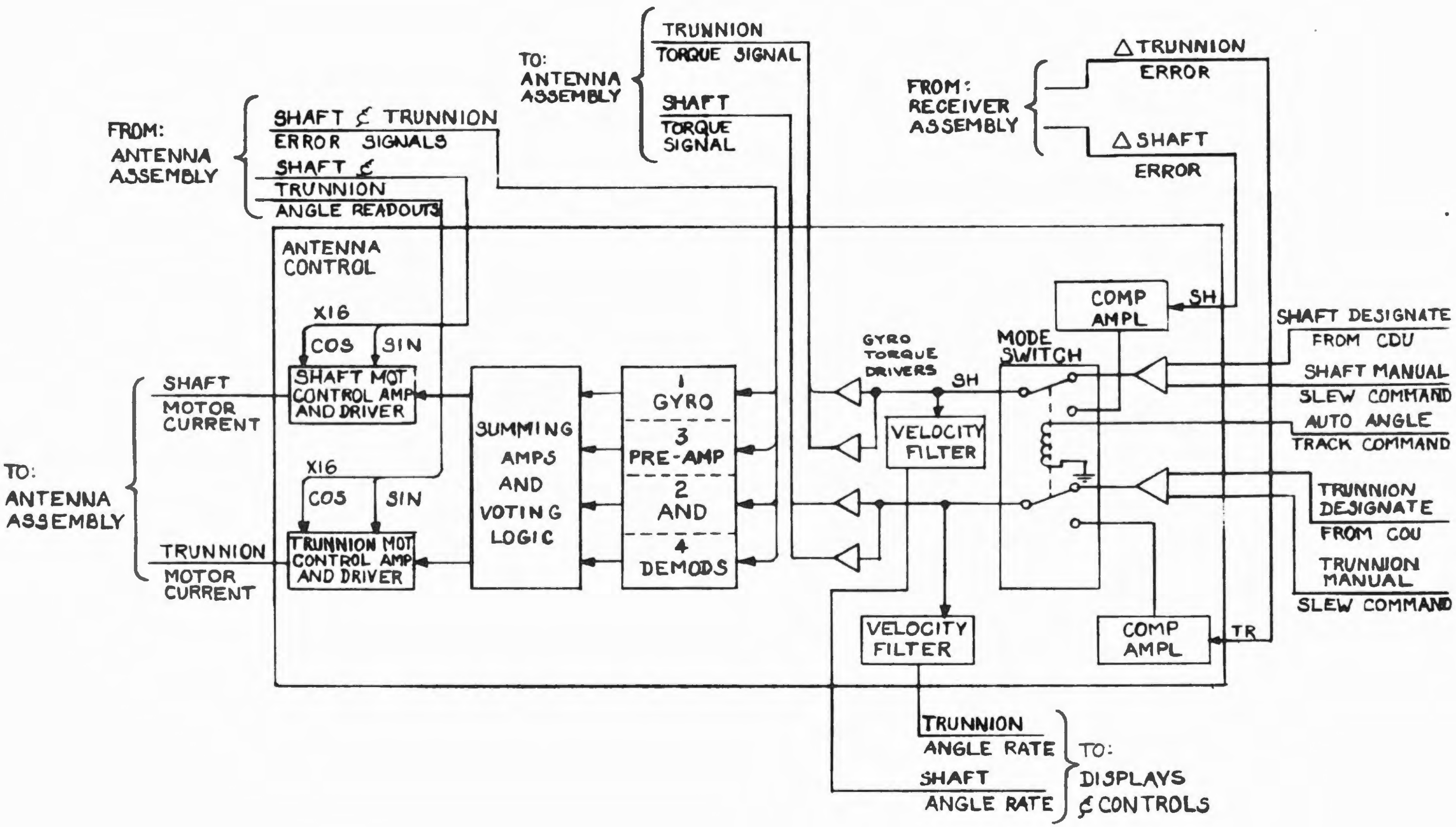


Fig. 2-30. Antenna Control Assembly Functional Block Diagram.

The antenna is designated to the target by commands from the LGC (via the CDU) or the astronaut. In the LGC mode, the LGC designates the antenna boresight to the target, supplying an automatic track enable discrete to the RR when the boresight is within 1/2° of the computed line of sight. This together with frequency lock on causes the loop to close. The antenna then continuously tracks the target by maintaining the monopulse receiver angle error signals at null.

By the command and error signals received, the gyro voting logic selects the gyro torquing signals to be generated. Gyro monitoring is performed to check the performance of the gyros. If an abnormal performance is obtained, the gyro voting logic automatically transfers control to a backup gyro.

For LGC operation, the CDU monitors the 1X resolvers in the antenna servo mechanism directly. The 16X resolvers are monitored via buffers in the antenna control assembly which also provide the shaft and trunnion drive limiting signals. In order for the astronaut to view the shaft and trunnion angle rates, he must set the RATE/ERR MON selector on the system engineer's center panel to the RNDZ RADAR position.

2.3.1.7 Antenna Assembly

Four rate-integrating gyros are used for line-of-sight space stabilization and line-of-sight angle rate measurement (see Fig. 2-31). They are located in the lower section of the trunnion axis to act as a counter weight. Only two of the gyros are used at any one time and a voting logic is utilized to transfer control to the other two gyros in the event of a failute in either of the two gyros being used. The voting logic system compares the two active and one of the redundant gyro outputs.

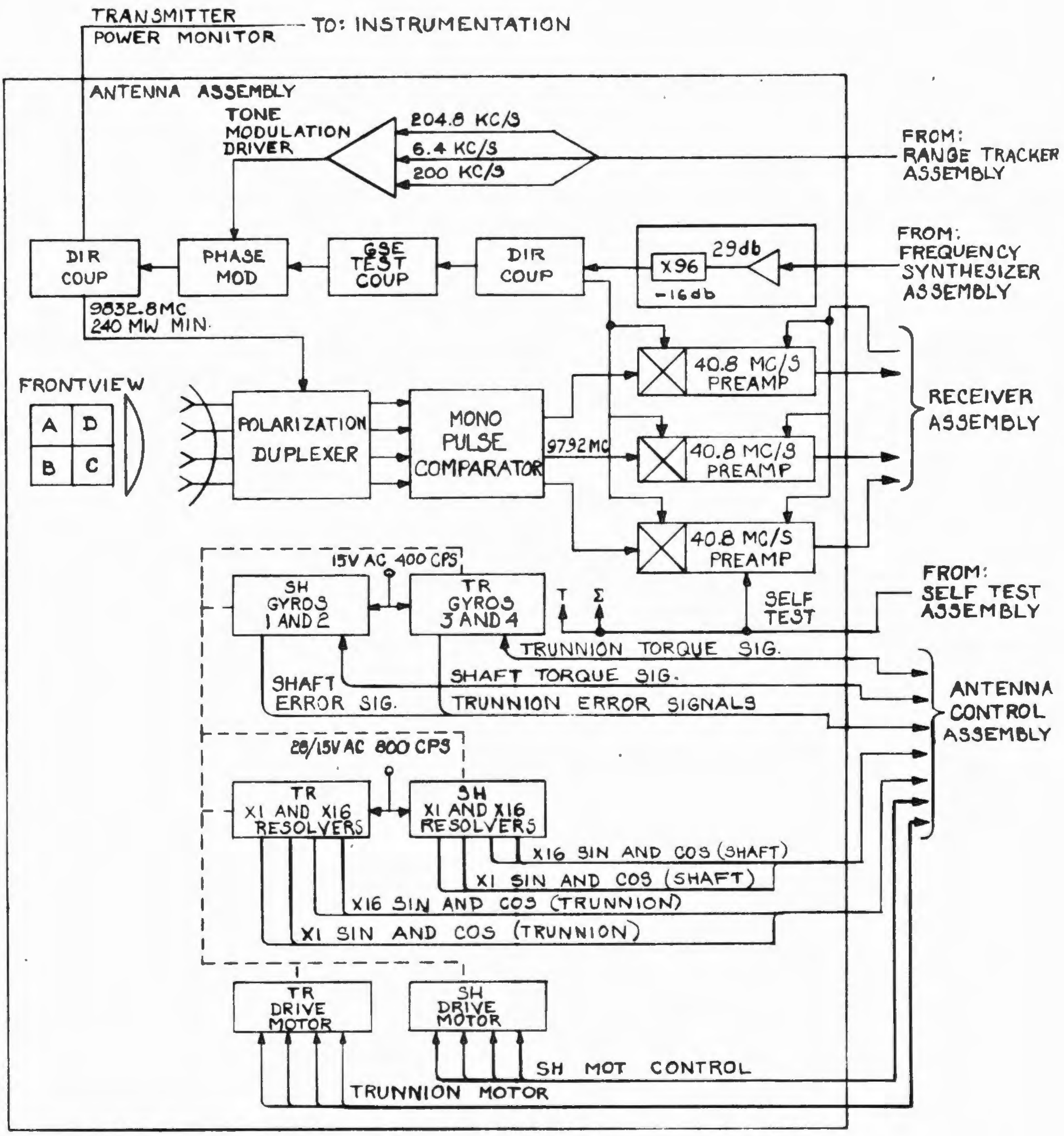


Fig. 2-31. Antenna Assembly Functional Block Diagram.

The antenna shaft and trunnion motors are 32-pole, brushless, permanent-magnet rotor types driven by pulse-width modulated drive signals applied to sine and cosine windings of each motor. Reversal of the direction of rotation is accomplished by reversing the motor windings across the pulse-width modulated drive voltage obtained by on/off switching of the 28 volt dc power at 1.8 kc rate.

A two-speed resolver is mounted on each axis for high accuracy angle-data pickoff for the LGC and for display.

2.3.1.8 Coupling Data Unit Channels

Positioning of the RR antenna can be accomplished by the LGC via the CDU. Shaft and trunnion angle errors are supplied by the LGC and the antenna resolvers provide antenna angle information to the LGC.

The LGC initializes the RR CDU channels by sending an RR CDU zero discrete to the CDU which simultaneously clears the two read counters and inhibits the transmission of incrementing pulses to the read counters. After the removal of the RR CDU zero discrete, which enables the read counter, a rendezvous radar error counter enable is issued by the LGC which simultaneously enables both error counters. The error counters are normally inhibited and zeroed. The LGC (via the CDU digital-to-analog converters) positions the radar antenna.

The digital-to-analog converter outputs provide 800 cps torquing signals to the rate gyros. The maximum value of these torquing signals is 5.06 vac, which corresponds to a rate command of 9° per second. The signal is derived from the digital-to-analog converter in 384 positive and equal amounts of negative steps. Each step equals 0.0132 vac. The polarity is contained in the phase of the 800 cps signal. Since the read counters are enabled during the operation, the change in position of the antenna is sent to the LGC. (Detailed operation of these two channels of the CDU is similar to that described in paragraphs 2.1.1.2 and 2.1.1.3.)

2.3.1.9 Built in Test

Radar self-test circuits are located in the frequency tracker subassembly. These circuits permit testing of the radar without the presence of a cooperating transponder (see Fig. 2-32). The self-test circuit permits a check of transmitter power, phase-lock at minimum signal level, angle error detection, AGC action, range and range rate measurement. Insertion of single values of range and range-rate permit quantitative checking via the displays.

The self-test circuit is disabled when the radar is in the automatic mode. When the RADAR TEST selector on the radar panel is set to the RNDZ position, a discrete is sent to the RR. This discrete is ANDed with another derived from the RENDEZVOUS RADAR mode selector in either the AUTO TRACK or SLEW positions. This ANDing produces the self-test enable which activates the oscillator. Modulation tones are superimposed on the oscillator output. The carrier is frequency multiplied and the tones are phase shifted to simulate returned energy. Range-rate information is contained in fixed IF offset of 10 kmc, corresponding to a velocity of 500 ft/sec.

2.3.1.10 Computer Interface

The computer interface is primarily a signal data converter. It accepts range and range-rate data from the range and frequency trackers for conversion to the 15-bit serial format required by the guidance computer. Data is shifted out to the computer on range or range-rate output lines as requested by the computer. It also sends various discrete radar status indications to

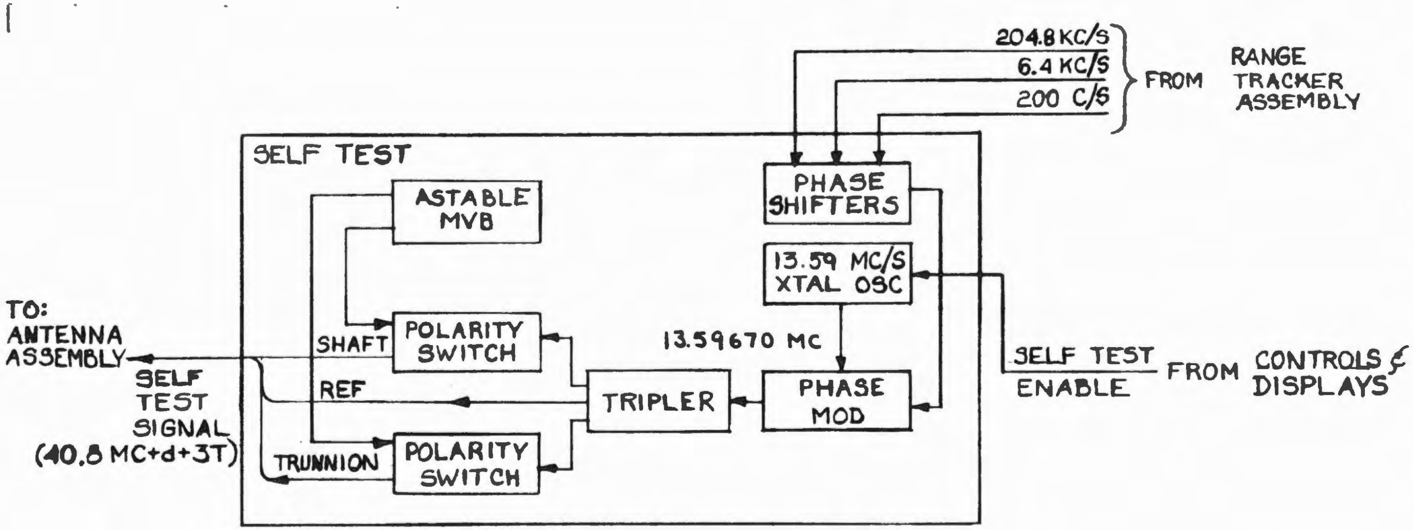


Fig. 2-32. Self Test Assembly Functional Block Diagram.

the computer, selects radar modes, and processes display data for activation of the astronaut display panels.

As shown in Fig. 2-33, the LGC furnishes timing pulses in the form of range and range rate strobe pulses and reset pulses. The range and range rate strobe pulses enable the respective transfer gate so that the range and range rate data can be gated to the high speed counter. The LGC initiates the counter readout command and the 15 bit range data is transferred via the 15 bit shift register to the LGC registers over two separate lines. The range or velocity data is transferred serially to the LGC with the most significant bit being transferred first.

The range or range rate transfer gate that is enabled is determined by the bit configuration of LGC output bits 1, 2, and 3 of channel 13. When in a 001 configuration, range is transferred and when in a 010 configuration range rate is transferred.

The pulse generator and display driver processes the signals for the range and range rate indicator displays. In order for RR range and range rate to be displayed, the ALT/RNG MON selector on the commander's center panel must be in the RNG/RNG RT position.

When the target is acquired by the RR positioning the antenna, a data good discrete is routed to the LGC. The data good discrete is defined as being the ANDing of range, range rate, signal-to-noise ratio, and gimbal angles within a permissible range. The LGC will not accept range, range rate or angular information for computation purposes unless the data good discrete is present. While this discrete is not present, the no track indication discrete will light the NO TRACK indicator on panel III. If the RR is in LGC controlled status with data

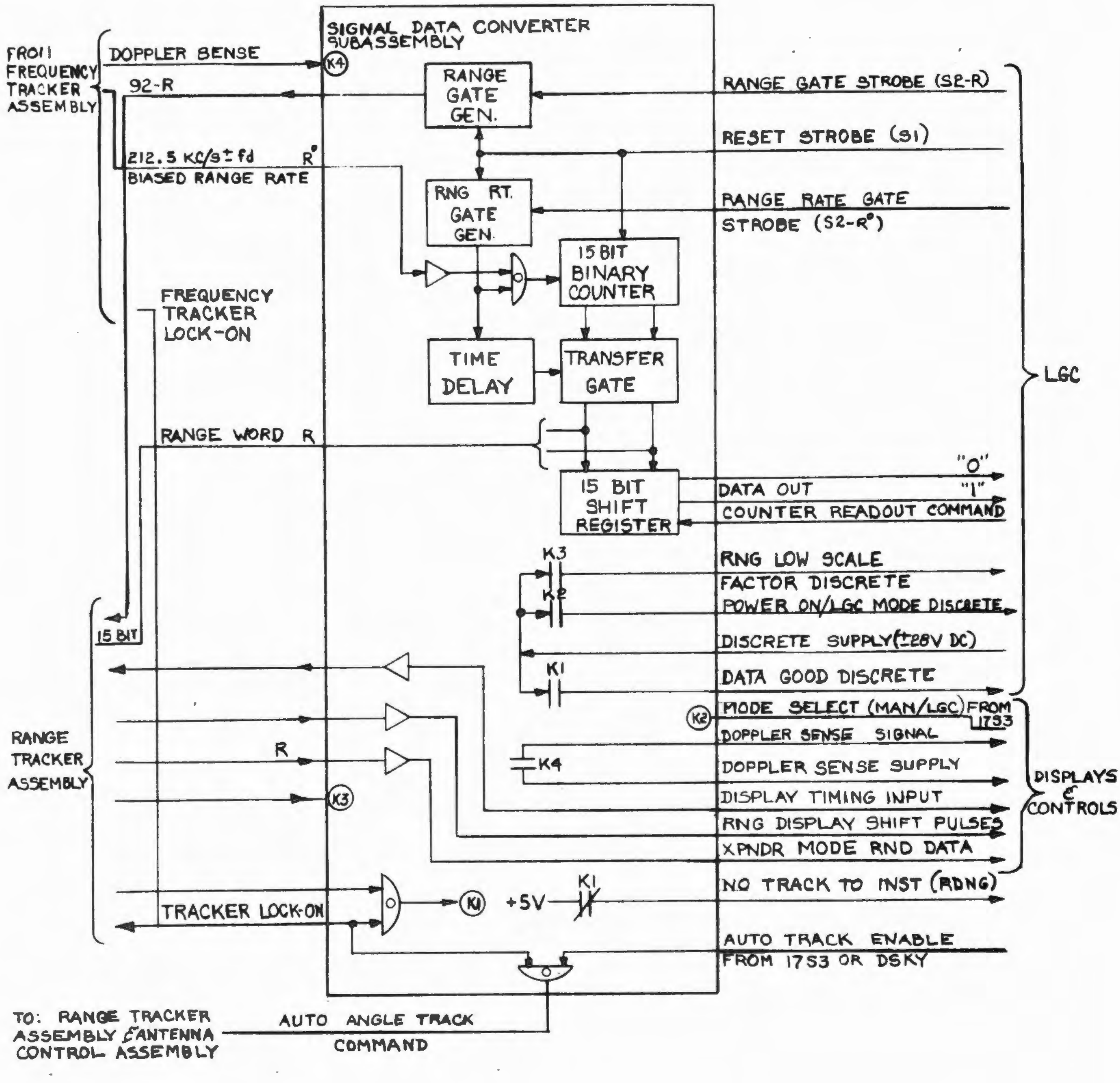


Fig. 2-33. Signal Data Converter Assembly Functional Block Diagram.

read but the CSM is not acquired, the data good discrete is absent and lights the TRACKER indicator on the DSKY.

2.3.2 RRS Modes of Operation

The RRS modes of operation are manual, LGC, reposition, designate, search, and auto track. Associated with these modes is the position of the antenna mode selector: SLEW, LGC, and AUTO TRACK. (See Fig. 2-34.)

For the antenna manual mode, antenna positioning commands originate from the radar panel controls. The mode is selected by setting the antenna mode selector to the SLEW position. The SLEW RATE selector is in either the HI or LO position; permitting manual slewing at 9° per second in the HI position or 1.3° per second in the LO position. The direction of manual slewing is determined by the SLEW switch by the UP, DOWN, LEFT or RIGHT positions. The SIGNAL STRENGTH meter is used to aid in acquisition by obtaining a near peaked AGC indication. The shaft or trunnion error is displayed when the TEST MONITOR switch is set to the SHAFT ERR or TRUN ERR position. Thus, the meter displays a diminishing error signal as lock is approached (that is, as manual positioning approaches the LGC calculated LOS).

Upon manual acquisition, the NO TRACK light is extinguished and the RR automatically maintains tracking. If switching is proper, the range and range rate are displayed by the RANGE and RANGE RATE meters.

Setting the antenna mode selector to the LGC position enables the LGC to control antenna positioning via the CDU. The LGC is notified that the antenna is in this mode and that RR power is on by a discrete to the LGC. The LGC issues the RR CDU zero discrete to zero the appropriate counters. The

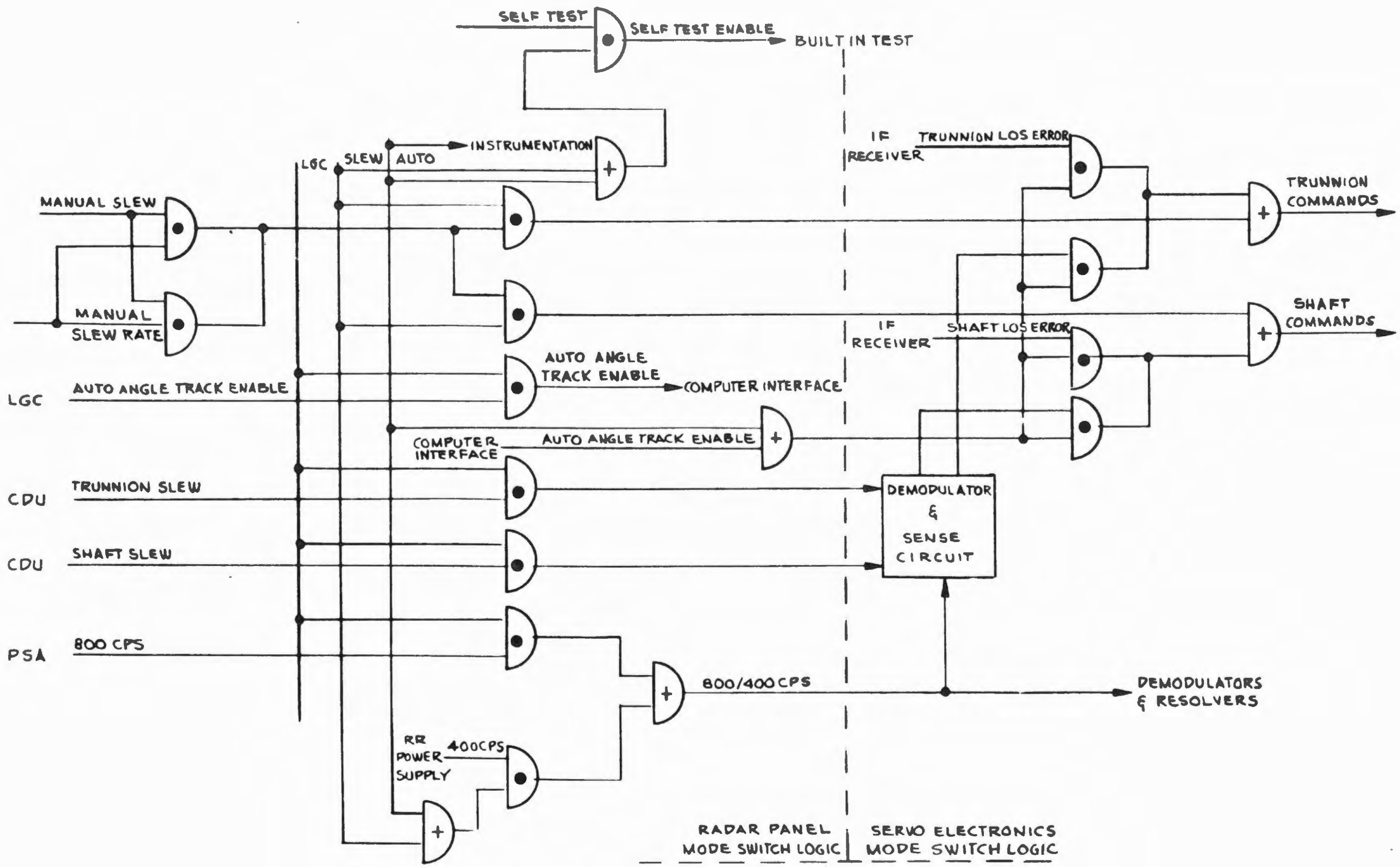


Fig. 2-34. Antenna modes switching logic.

CDU zero discrete is then removed allowing the read counters to count up to the shaft and trunnion angles. The LGC uses the read counter information to determine if the antenna is within the limits of mode1 or mode 2.

The reposition mode automatically follows with a check of operational limits of the antenna. (See fig. 2-34 A.). For mode 1, the operational limits are ± 55° trunnion angle and +59° to -70 shaft angle. For mode 2 (the lunar site mode), the operational limits are +41° to +155° shaft angle and +125° to +235° trunnion angle. If the antenna is within one or the other of these sets of operational limits, the LGC automatically leaves this mode and proceeds to the designate mode. If the antenna position is outside the operational limits, the reposition mode drives the antenna to the zero reference position: for mode 1 zero reference is shaft = 0°, trunnion = 0° and for mode 2 zero position is shaft = 270° trunnion = 180°. During this positioning process, the PROG indicator is lighted and the DSKY displays V05N09 with 00501 code in R1. Upon completion of repositioning, the designate mode is entered.

The designate mode consists of automatically positioning the radar antenna to acquire the transponder by LGC commands. The computer LM and CSM state vectors and RR antenna shaft and trunnion angles to compute the necessary commands to send to the CDU to position the antenna to the LOS. When the LGC determines that the antenna is within 0.5° of the reference shaft and trunnion angles, it issues the auto track enable discrete. Within the computer interface logic (Fig. 2-33) this discrete is ANDed with the frequency tracker lock on discrete to cause entry into auto track mode (NO TRACK indicator is extinguished). The LGC then removes the RR enable error counter discrete.

If the data good discrete is not received by the LGC within 45 seconds of entry into the designate mode, the PROG indicator is lighted and the DSKY displays V05N09 and error code 00503 in R1. The astronaut can then enter the manual mode or search mode. The search mode is then initiated by DSKY entry V33E. In the search mode, the LGC continuously generates a 5.6° by 5.6° hexagonol search pattern about the LOS. The time to complete one search is about 45 seconds. During the search mode, the RR track enable discrete is issued so that the RR may acquire the target.

The auto track mode can be entered upon target acquisition from either the manual or LGC designate modes. Control of antenna positioning is then obtained within the RR by means of the shaft and trunnion error signals. The error signals from the IF receiver are amplified and provide drive to the shaft and trunnion torque motors.

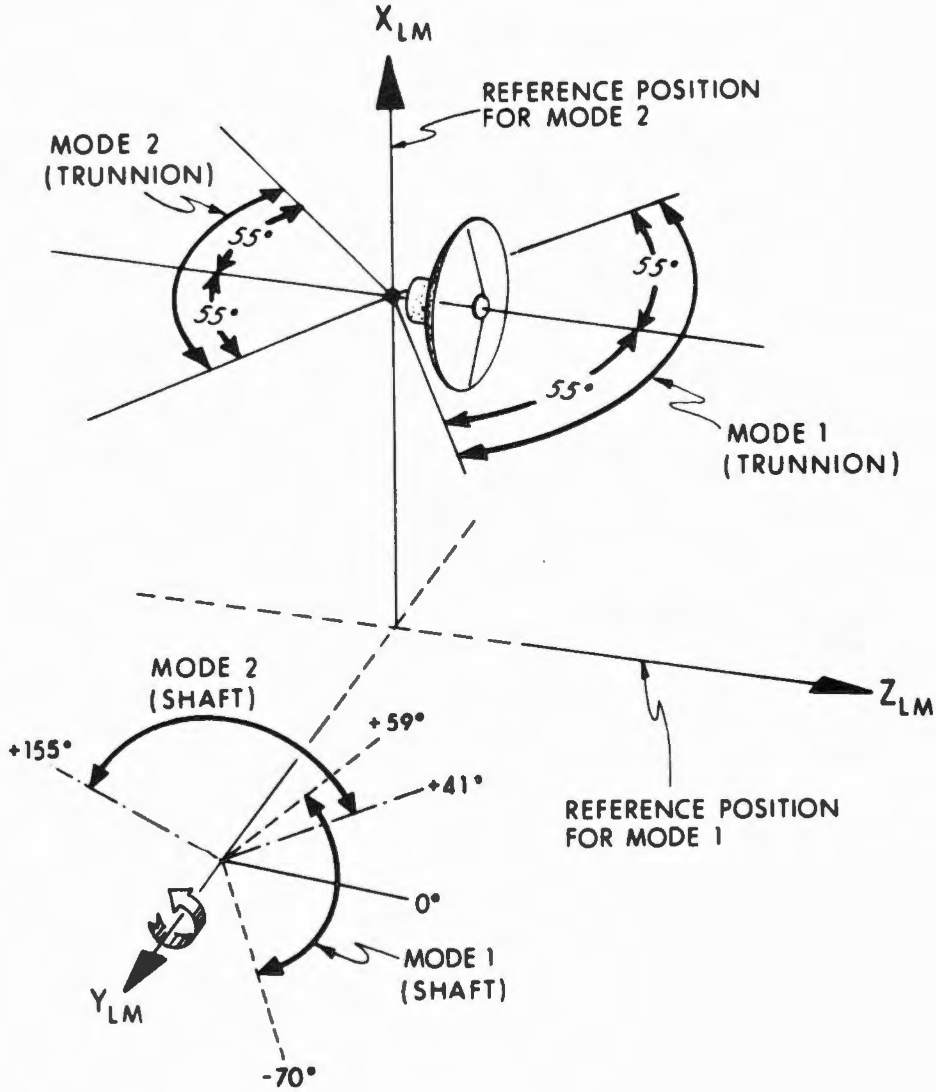


Fig. 2-34A RR antenna shaft and trunnion operating regions.

2.3.3 RRS Power Supply

The RR power supply is basically, a highly efficient dc-dc converter which provides six regulated dc output voltages (+25 vdc No. 1, +25 vdc No. 2, +12 vdc, + 12 vdc, +6 vdc, and +4 vdc). The unit utilizes the method of switching tap modulation for input regulation. After chopping, rectification and filtering, series regulators are used at each output. A chopping frequency of 20 kilocycles is used to minimize the weight of transformer and ripple filter components. Short circuit protection circuitry senses overload current conditions on any of the output lines and deactivates the 20 kc chopping oscillator for a preset period of time. If the overload has been removed after this time, normal operation is resumed. If it has not, the deactivation cycle continues until the overload is removed.

2.4 COMPUTER SUBSYSTEM

The computer subsystem (CSS) is the control and computational center of the PGNCS. It consists of the LGC and the DSKY. The LGC is a core memory, parallel digital control computer with two types of memory, fixed and erasable. The main task of the LGC is to execute the programs stored in the memory. Programs are written in a digital machine language called basic instructions. A basic instruction contains an operation (order) code and a relevant address. The computer logic decodes the order code to obtain the data flow within the LGC and uses the address code to select the data that is to be used for computations. With the DSKY keyboard the astronaut can load information into the LGC, initiate any program stored in memory, and retrieve and display information contained in the LGC.

The LGC stores data pertinent to the flight profiles that the spacecraft must assume in order to complete its mission. This data includes position, velocity, and trajectory information and is used by the LGC to solve the various flight equations. (LM position and velocity is maintained within the LGC in the form of a six-dimensional vector called the state vector.) The results of these equations can be used to determine the required magnitude and direction of thrust required. Corrections to be made are established by the LGC. The spacecraft engines are turned on at the correct time, and when required, steering signals are controlled by the LGC to reorient the spacecraft to a new trajectory. The ISS senses acceleration and supplied velocity changes to the LGC for calculating the total velocity. Drive signals are supplied from the LGC to the ISS for alignment of the IMU and to the RR for the antenna tracking profile. Error signals are fed to the CDU to provide steering capabilities of the spacecraft. CDU position signals are fed to the LGC to indicate changes in gimbal angles, which are used to keep cognizant of the gimbal positions. The LGC receives angular information from the OSS to calculate present position, orientation, and refine trajectory information.

2.4.1 LGC Language

The LGC uses the binary ones complement number system. In this system, a negative binary number is the complement of the corresponding positive binary number. Functional operations occur through the processing of words. All words are 16 bits long in the LGC and are of two basic types: data words and instruction words. The format of the words depends on where the words are located. Figure 2-35 shows the word formats in memory and in the central processor. In memory, data words contain a parity bit, fourteen magnitude bits, and a sign bit. A binary one in the sign bit indicates a negative number and a binary zero in the sign bit indicates a positive number. When located in the central processor, bits 1 through 14 are the magnitude bits, bit 15 is the uncorrected sign bit, and bit 16 is the sign bit as before. The uncorrected sign bit is used to enable an overflow detection without destroying the sign bit when two numbers are manipulated. Parity bits are only included in words that are stored in memory.

2.4.1.1 Instructions

An instruction word in memory contains a 12 bit address code and a 3 bit order code. Bits 10 through 12 are sometimes used to extend the order code when transferring to the SQ register. The address code normally calls out a word location in memory or in the central processor. The order code represents an operation which is to be performed on the data whose location is defined by the address code.

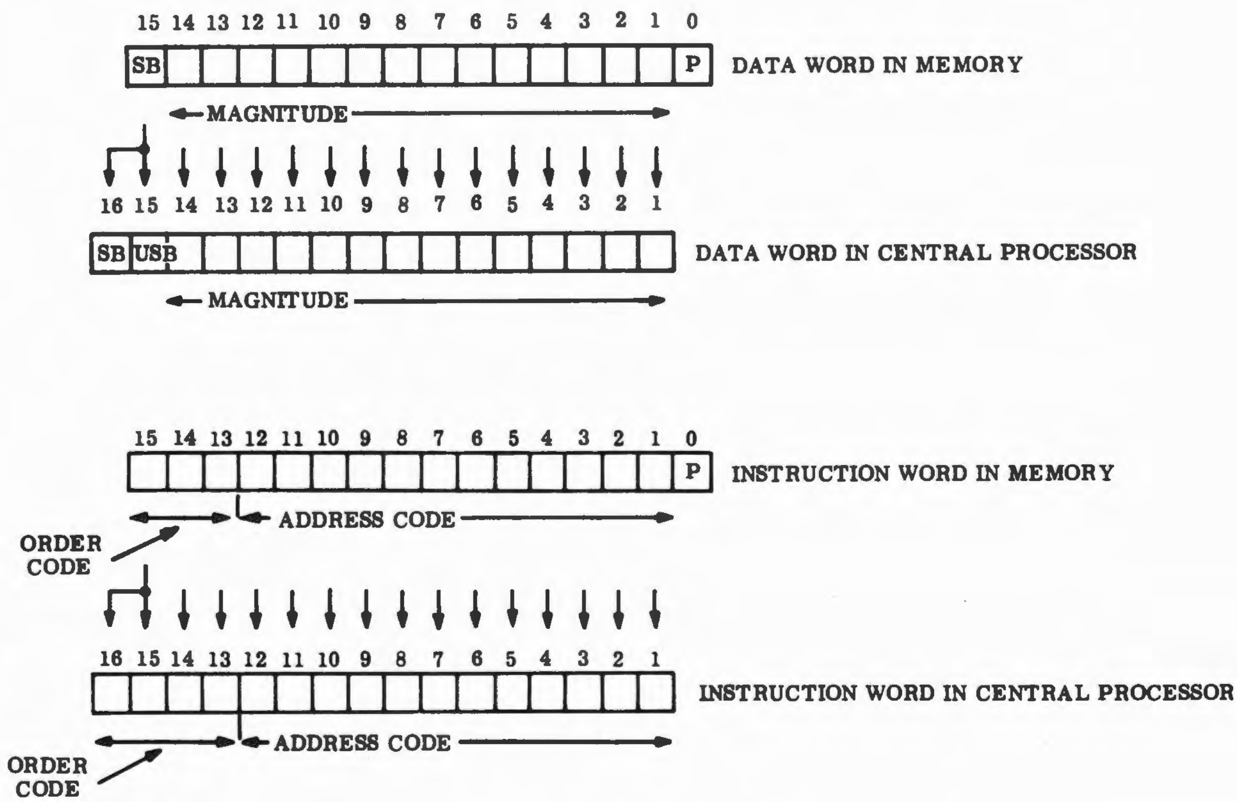


Fig. 2-35. Word formats in memory and central processor.

The LGC has three classes of instructions: regular, involuntary, and peripheral. Regular instructions are programmed and are executed in whatever sequence they are stored in memory. Involuntary instructions, are not programmable, with the exception of one instruction which may be programmed to test computer operations. Involuntary instructions have priority over regular instructions and are executed at the occurrence of certain events during normal operation. The peripheral instructions are used when the LGC is conected to ground test equipment and are therefore not used during a flight.

2.4.1.1.1 Regular Instructions. Four types of instructions comprise the regular instruction class. They are the basic, channel, extracode, and special instructions. Basic instructions are the most frequently used instructions. The instruction words stored in memory are called basic instruction words. As shown in Fig. 2-36, these words contain a three bit order code field and a twelve bit address field. The content of the order code field defines the instruction and is represented by a single-digit octal number with the octal point at the right. The content of the address field defines a location and is represented by a four-digit octal number with the octal point at the left. An instruction word in memory therefore may be written as a five digit octal number (e.g., 2.0314). The order code field is extended an additional bit when the basic instruction is transferred from memory to the central processor. Therefore, the instruction word used in the example changes to 02.0314 in the central processor. This additional high order bit is always zero for basic instructions. When the LGC is switched to the extend mode, the high order bit is one, indicating that an extracode or channel instruction will be executed next.

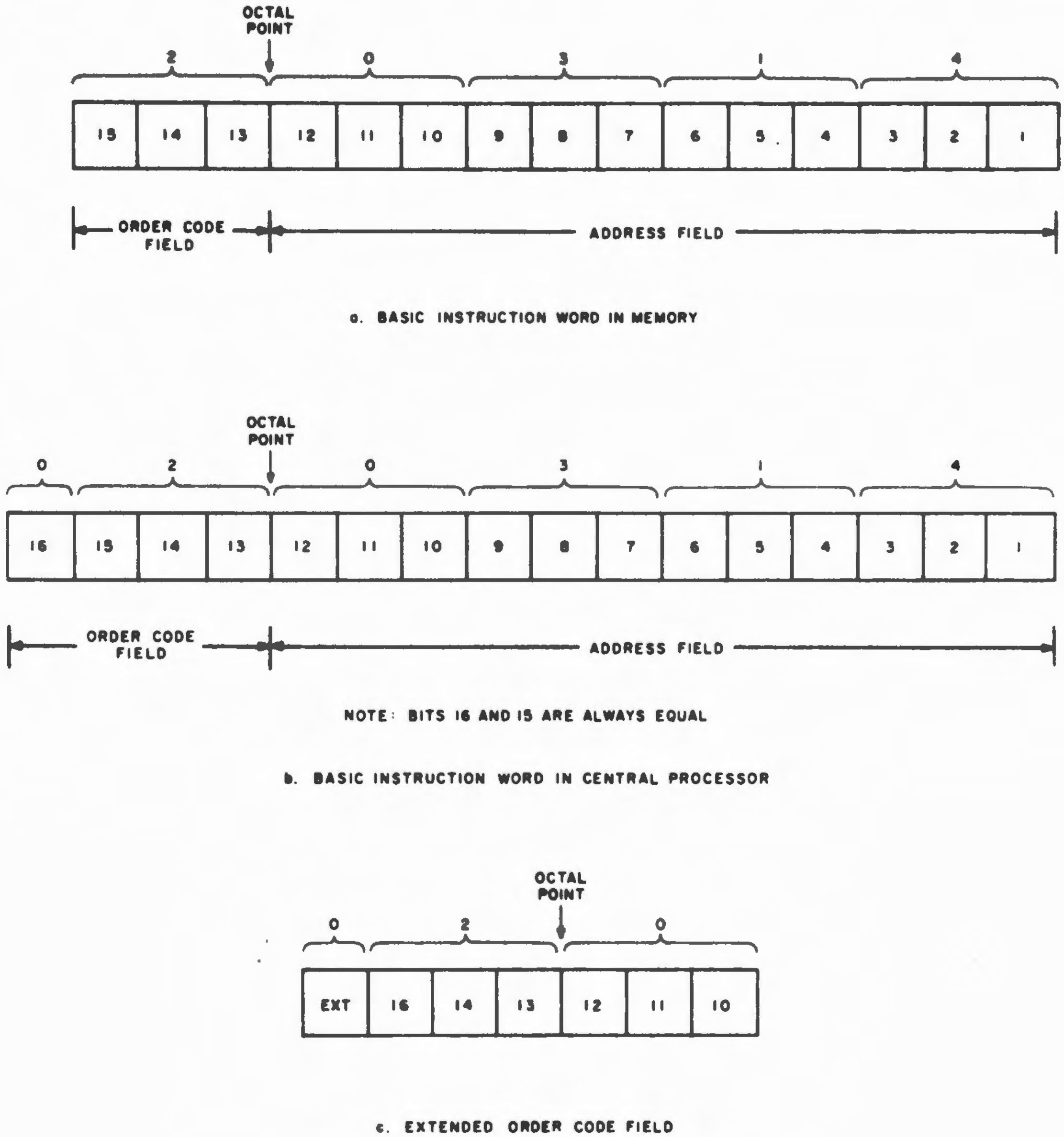


Fig. 2-36. Instruction word.

Computer logic permits the use of the three high order bits (one octal digit) of the address field to further lengthen the order code field. A typical instruction can then be represented as 02. 0 numerically. This encroachment on the address field limits the use of some instructions to a certain portion of memory. The high order bits of the address field may be used this way because of the differences between fixed and erasable memory. The instructions which apply only to erasable memory do not copy the two high order bits of the address field into the address register. However, the address register receives the entire address field for those instructions which apply to fixed memory.

The editing or special instructions are address-dependent basic instructions which have predefined addresses and order codes where as basic instructions have only predefined order codes. The order codes are represented as 00. 0006 numerically. Those address-dependent instructions which may be combined with any order code are represented, for example, as 0. 0021 which is the entire content of the address field.

The special instructions are used to control certain operations in the computer. For example, one special instruction, as mentioned previously, is used to switch the computer to the extend mode of operation. This mode extends the length of the order code field and converts basic instruction words to channel or extra code instruction words. Channel instructions can only be used with input/output channel addresses. Extra code instructions perform the more complex and less frequently used arithmetic operations.

2. 4. 1. 1. 2 Involuntary Instructions. The involuntary instruction class contains two types of instructions – interrupt and counter. The interrupt

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

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

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

2.4.1.2 <u>Programs</u>

The LGC performs such tasks as solving guidance and navigation problems by means of a set of instructions called a program. A program consists of a group of program sections that are classified according to the functions they perform. These functions are defined as mission functions, auxiliary functions, and utility functions. (See Fig. 2-37.)

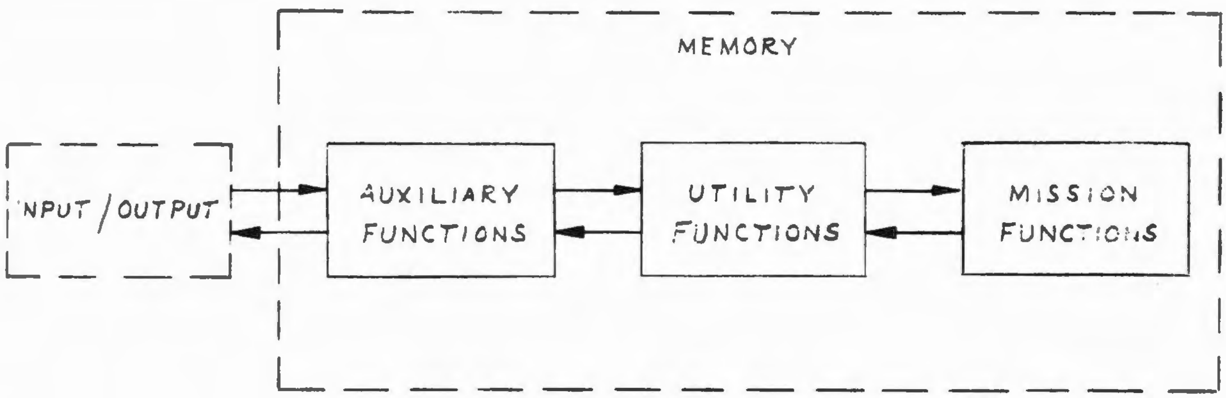


Fig. 2-37. Program functions diagram.

Mission functions are performed by program sections that implement operations concerned with the major objectives of the mission. These operations include aligning the IMU stable member and computation of spacecraft position and velocity during coasting periods of the flight by solution of second-order differential equations which describe the motions of a body subject to the forces of gravity.

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

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

2.4.2 CSS Theory of Operation

The LGC consists of nine functional sections as illustrates in Fig. 2-38. The sequence generator controls data flow. The order code of each instruction is entered into the sequence generator, and the sequence generator produces a different sequence of control pulses for each instruction. The execution of each instruction sets the conditions for the execution of the next instruction. In order to specify the sequence in which instructions are to be executed, the instructions are normally stored in successive memory locations. By adding the quantity one to the address of an instruction being executed, the location of the instruction to be executed next is derived. Execution of an instruction is complete when the order code of the next instruction is transferred to the sequence generator and the relevant address is in the central processor.

The central processor consists of several flip-flop registers. It performs arithmetic operations and data manipulations on information accepted from memory, the input registers, and priority control. Arithmetic operations are performed using the ONE's complement number system values up to 14 bits (excluding sign) can be processed with an additional bit produced for overflow or underflow. All operations within the central processor are performed under control of pulses generated by the sequence generator (indicated by dashed lines in Fig. 2-38). In addition, all words read out of memory are checked for correct parity, and a parity bit is generated for all words written into memory within the central processor. Odd parity is used; therefore, all words stored in memory including the parity bit contain an odd number of ONE's. The central processor also supplies data and

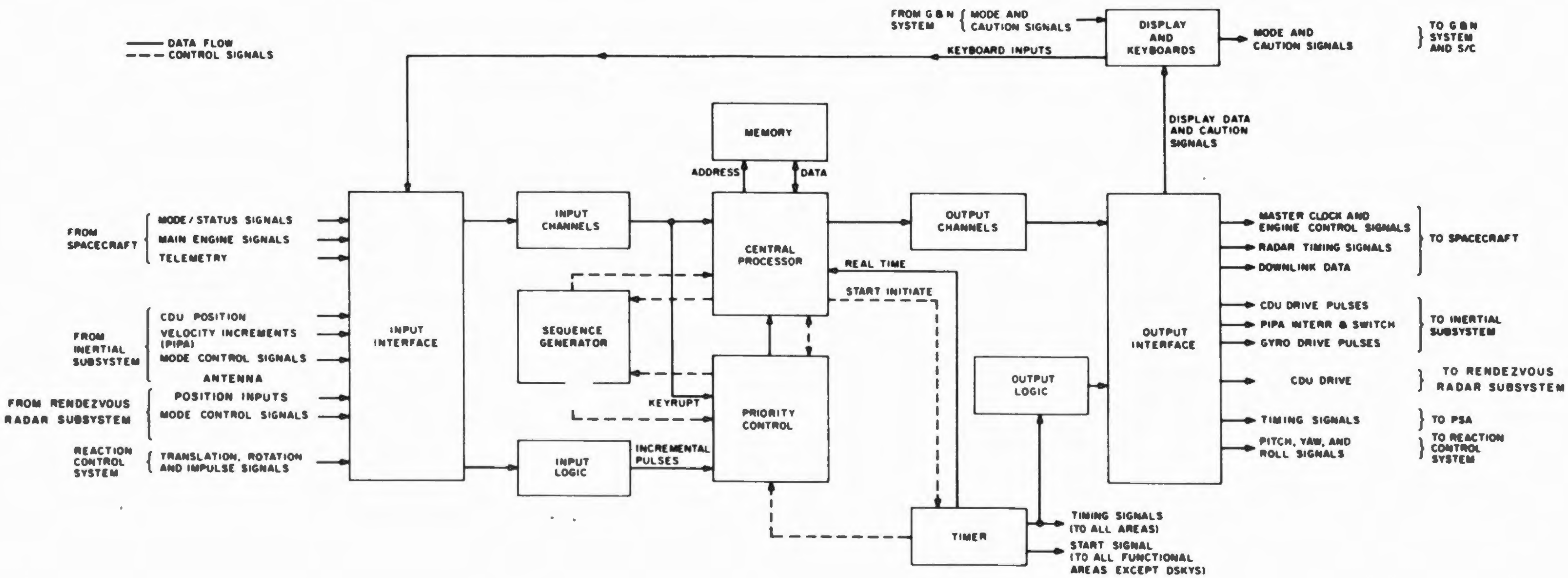


Figure 2-38. Computer subsystems functional block diagram.

program counter and intermediate results from their storage locations in memory back to the central processor.

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

Real time plays a major role in solving guidance and navigation problems. Real time is maintained within the LGC in the main time counter of memory. The main time counter provides a 745.65 hour (approximately 31 days) clock. Incremental pulses are produced in the timer and sent to priority control for incrementing the main time counter. The Apollo mission requires that the LGC clock be synchronized with the Eastern Test Range (ETR) clock. The LGC time is compared with ETR time once every two seconds by downlink telemetry.

Continuous drive pulses originate in the timer as fixed-frequency timing and strobe signals. The timing signals strobe the outputs from the output registers and the resulting continuous drive pulses are sent to the spacecraft. Rate signals, which are bursts of drive pulses, originate in the output section and are sent to the gyros and the ISS portion of the CDU, and to the RR portion of the CDU. Rate signals are also used for controlling the attitude of the spacecraft. The number of pulses in each burst and occurance of each burst are controlled by a program. The program is dependent on incremental pulse feedback to priority control from the IMU. The destination of the various rate signals, as well as the type of rate signals (incrementing or decrementing), are also selected by this program.

The downlink operation of the LGC is asynchronous to the spacecraft telemetry system. The telemetry system supplies all the timing signals necessary for the downlink operation. These signals include start, end, and bit sync pulses. The end pulse is sent also to priority control.

A key code is assigned to each DSKY keyboard operation. When a keyboard pushbutton is pressed, the keycode is produced and sent to an input register. The same keycode is sent also to priority control, where it produces both the address of a priority program stored in memory and a priority request signal, which is sent to the sequence generator. An interrupt request functions as an order code and initiates an instruction for interrupting the program in progress and executing the priority program stored in memory. A function of this program is to transfer the keycode, temporarily stored in the input register, to the central processor, where it is decoded and processed. A number of keycodes are required to specify an address or a data word. The program initiated by a keyboard also converts the information from the DSKY keyboard to a coded display format. The coded display information is transferred by another program to an output register and sent to the display portion of the DSKY. The display notifies the astronaut that the keycode was received, decoded, and processed properly by the LGC.

2.4.2.1 Timer

The timer portion of the LGC generates all of the timing signals required for operation of the computer and also supplies timing signals to other spacecraft subsystems. The timer is divided into the functional areas indicated in Fig. 2-39. The oscillator is a crystal controlled modified Pierce oscillator design that generates a source frequency of 2.048 mc for the clock divider logic. Temperature compensated components in the oscillator circuit maintain a high degree of stability and assure an extremely accurate output frequency to the divider logic.

The 2.048 mc input from the oscillator is applied to the main divider logic. This circuit divides the input frequency by two and generates the following outputs: clear, write, and read control pulses which are applied to the central processor to produce the signals necessary to clear, write into, and read out the flip-flop registers; 1.024 mc gating pulses which are used throughout the LGC; the master clock signal which is used to synchronize other spacecraft systems; and a signal which is applied to the oscillator alarm circuit in the power supply to indicate oscillator activity. In addition, the main divider by further frequency division supplies 512 kc signals to drive the ring counter, and signals to the time pulse generator.

The ring counter generates pulses of 5 microseconds at a 102.4 kc rate which are used for gating and for derifing other timing functions in the LGC.

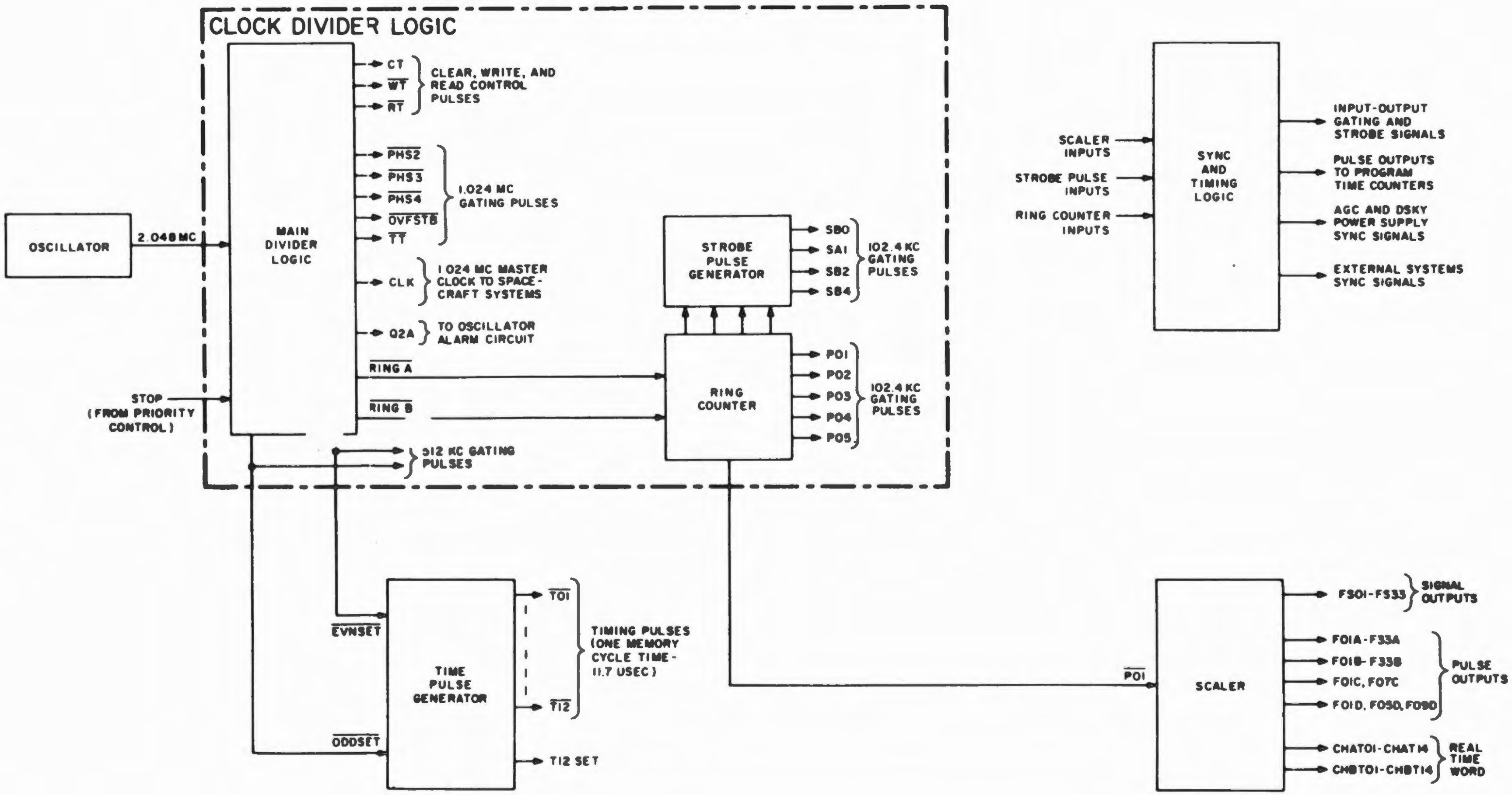


Figure 2-39. Timer functional block diagram

Ring counter outputs also derive the strobe pulses of 2 and 3 microseconds at a 102.4 kc rate.

The scaler consists of 33 identical divider stages (flip-flops) which are cascaded so that frequency division is successive. The outputs include timing and gating pulses, and the real time word which indicates time intervals up to 23.3 hours.

The time pulse generator consists of 12 flip-flops which generate a sequence of 12 timing pulses ($\overline{T01}$ through $\overline{T12}$). This sequence of timing pulses defines one memory cycle within the LGC or a period of 11.7 microseconds in which word flow takes place. The STOP signal is used during preinstallation testing to inhibit the time pulses from being generated, and thereby preventing LGC word flow.

The ring counter, strobe pulse generator, and the scaler supply inputs to the sync and timing logic. These inputs are used to derive gating and strobe signals for the input and output channels, pulse outputs for the program time counters in memory, and synchronization signals.

During standby operation, the oscillator, clock divider logic, and the scaler are operative. The only outputs, however, that have functional significance at this time are the real time word from the scaler and the synchronization signals to other LEM systems.

2.4.2.2 Sequence Generator

The sequence generator contains the order code processor, command generator, and control pulse generator (see Fig. 2-40). The sequence generator executes the instructions stored in memory by producing control pulses which regulate the data flow of the computer. The order code

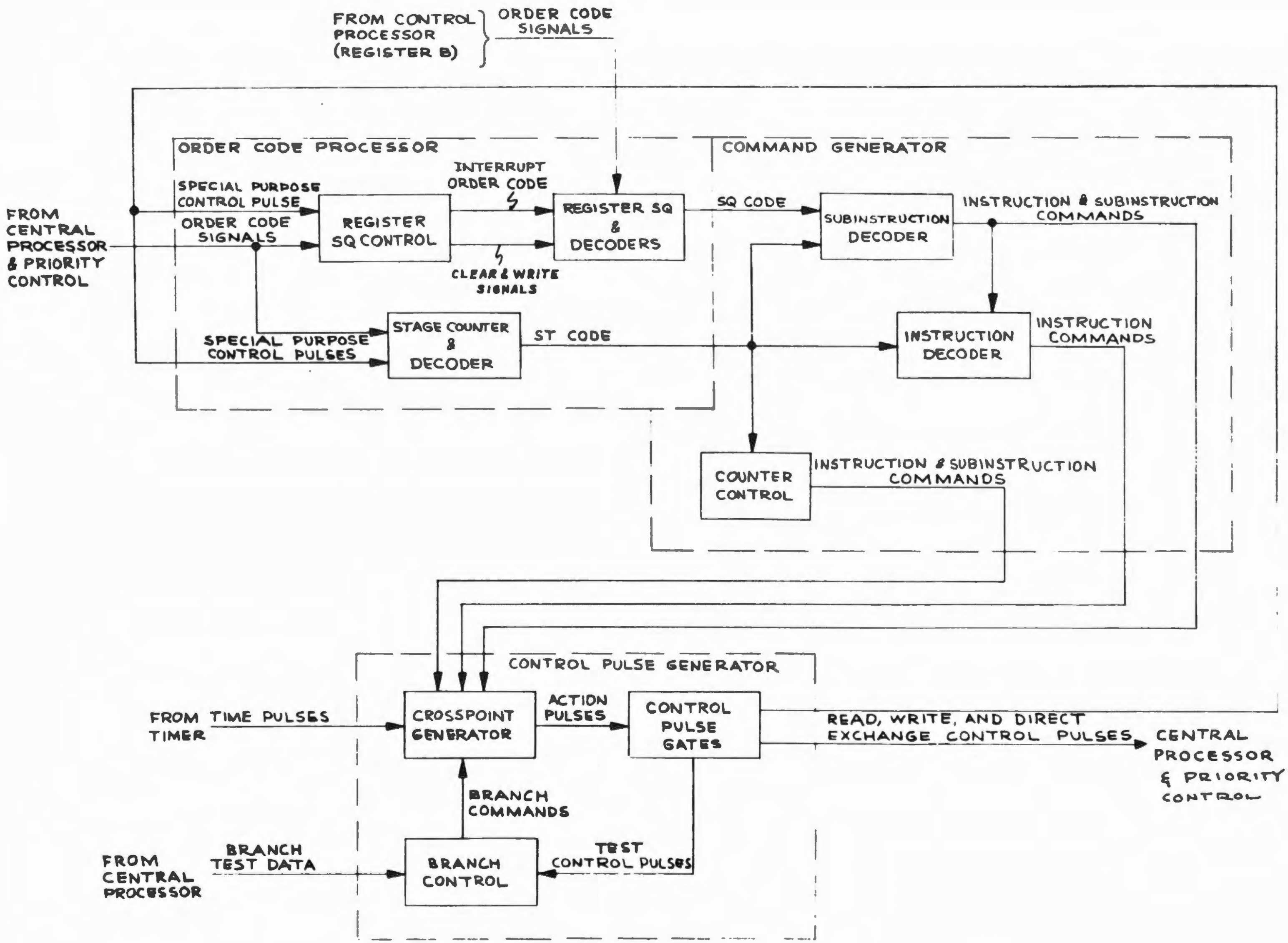


Fig. 2-40. Sequence generator functional block diagram.

processor receives signals from the central processor and priority control. The order code signals are stored in the order code processor and converted to coded signals for the command generator. 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.

2.4.2.2.1 Order Code Processor. The register SQ control portion of the order code processor is regulated by special purpose control pulses from the control pulse generator. These control pulses produce clear and write signals for register SQ and initiate a read signal for register B. The clear, read, and write signals place the order code content of register B onto the write lines and into register SQ. The order code signals from the priority control portion to instructions start, interrupt, and transfer control to specified address. These order code signals cause the register SQ control to produce the clear signals. If the order code signal is start or transfer control to specified address, no further action occurs because the order code for each of these instructions is binary 0 000 000. If the order code is interrupt, register SQ is set to 1 000 111.

Register SQ is a seven-bit register with only six of its bit positions (16 and 14 through 10) connected to the central processor write lines. The seventh (high order) bit position is the extend bit which is a zero for basic instructions and is a one for other instructions.

The stage counter is a three-state Gray counter. Most instructions are several memory cycle times (MCT's) long. The stage counter controls the length of each instruction. Most instructions use the two low-order bits of the stage counter. The stage counter always starts an instruction with count 000. Then it may be advanced to 001, 010, or 011 by special purpose control pulses ST1 and ST2 from the control pulse generator. The Gray code count is used for the divide instruction. Control pulse DVST advances the counter through the states 000, 001, 011, 111, 110, and 100. The control pulse ST2 sets the stage counter to 010 to complete the divide instruction. The content of the stage counter is decoded into the ST code signals. Some of the ST code signals reflect the standard binary count from octal 0 through 3, and others reflect the Gray code count of octal 0, 1, 3, 7, 6, and 4. The order code signals from the priority control sets the stage counter to a particular state in a manner similar to that in which the SQ register is set. The interrupt order code signal sets the stage counter to 000, the start order code signal sets it 001, and the transfer control to specified address signal sets it to 011. The outputs of the SQ and stage decoders are sent to the command generator where they are used to produce subinstructions and instruction commands.

2.4.2.2.2 Command Generator. The subinstruction coder receives SQ and ST code signals from the order code processor. These signals represent the order codes of all machine instructions and are decoded into subinstruction and instruction commands.

The instruction decoder receives the coded signals from the order code processor in addition to certain subinstruction commands. It produces signals called instruction commands. An instruction command is used for two or more subinstructions as compared to a subinstruction command which is used only for one subinstruction.

The counter control receives instruction signals from the priority control. These signals are applied to separate circuits which control the individual counter instructions. The instruction signals from the priority control pertain to counter locations and the instruction(s) associated with location.

2.4.2.2.3 Control Pulse Generator. Subinstruction and instruction command outputs of the command generator are used by the control pulse generator in conjunction with time pulses T01 through T12 to produce action pulses. The crosspoint generator produces an action pulse when a command signal and a time pulse are ANDed. This is called the crosspoint operation. The branch commands are used to change the action pulse that normally is produced at a given time.

The control pulse gates perform the Boolean NOR function. There is one gate for each control pulse. These gates split the action pulses into as many control pulses as are required for a particular operation. Some of the control pulses produced by the control pulse gates are used by the sequence generator. These include the special purpose control pulses which control the operation of the order code processor and the test control pulses which are applied to the branch control. The other control pulse groups, namely the read, write, and direct exchange control pulses are used in the central processor and the priority control.

The branch control is connected to the write lines of the central processor. Data which is placed onto the write lines by read control pulses is tested in the branch control. The branch control contains two stages. Branch 1 normally tests for sign and branch 2 tests for full quantities such as plus or minus zero. Both branches test for positive and negative overflow and have the overflow bits written directly into the branch register. Positive overflow is 01 where branch 1 is the high order bit. Negative overflow is 10. The branch commands sent to the crosspoint generator affect the action pulses at given times.

2.4.2.3 Central Processor

All data and arithmetic manipulations within the LGC take place in the central processor (see Fig. 2-41). It primarily performs operations indicated by the basic instructions of programs stored in memory. Communication within the central processor is accomplished through the write amplifiers. Data flows from memory to the flip-flop registers or vice-versa, between individual flip-flop registers, or into the central processor from external sources. In all instances, data is placed on the write lines and routed to a specific register or to another functional area under control of the write, 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 LGC. 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 LGC.

The memory buffer register buffers all information read out or written into memory. During readout, parity is checked by the parity logic and an alarm is generated in case of incorrect parity. During write-in, the parity

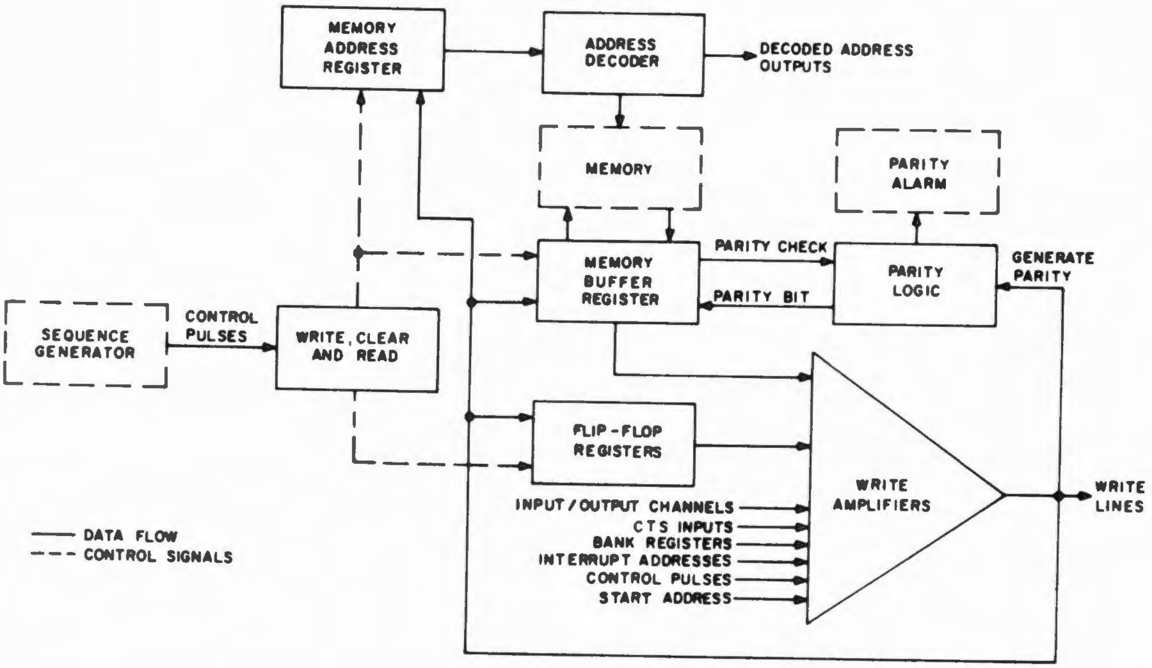


Fig. 2-41. Central processor functional block diagram.

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

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

2.4.2.4 Memory

Memory consists of an erasable memory with a storage capacity of 2,048 words, and a fixed core rope memory with a storage capacity of 36,864 words. (See Fig. 2-42). Erasable memory is a random-access, destructive-readout storage device. Data stored in erasable memory can be altered or updated. Fixed memory is a nondestructive storage device. Data stored in fixed memory is unalterable since the data is wired in and readout is nondestructive.

Both memories contain magnetic-core storage elements. In erasable memory the storage elements form a core array; in fixed memory the storage elements form three core ropes. Erasable memory has a density of one word per 16 cores; fixed memory has a density of 12 words per core. Each word is located by an address.

In fixed memory, addresses are assigned to instruction words to specify the sequence in which they are to be executed, and blocks of addresses are

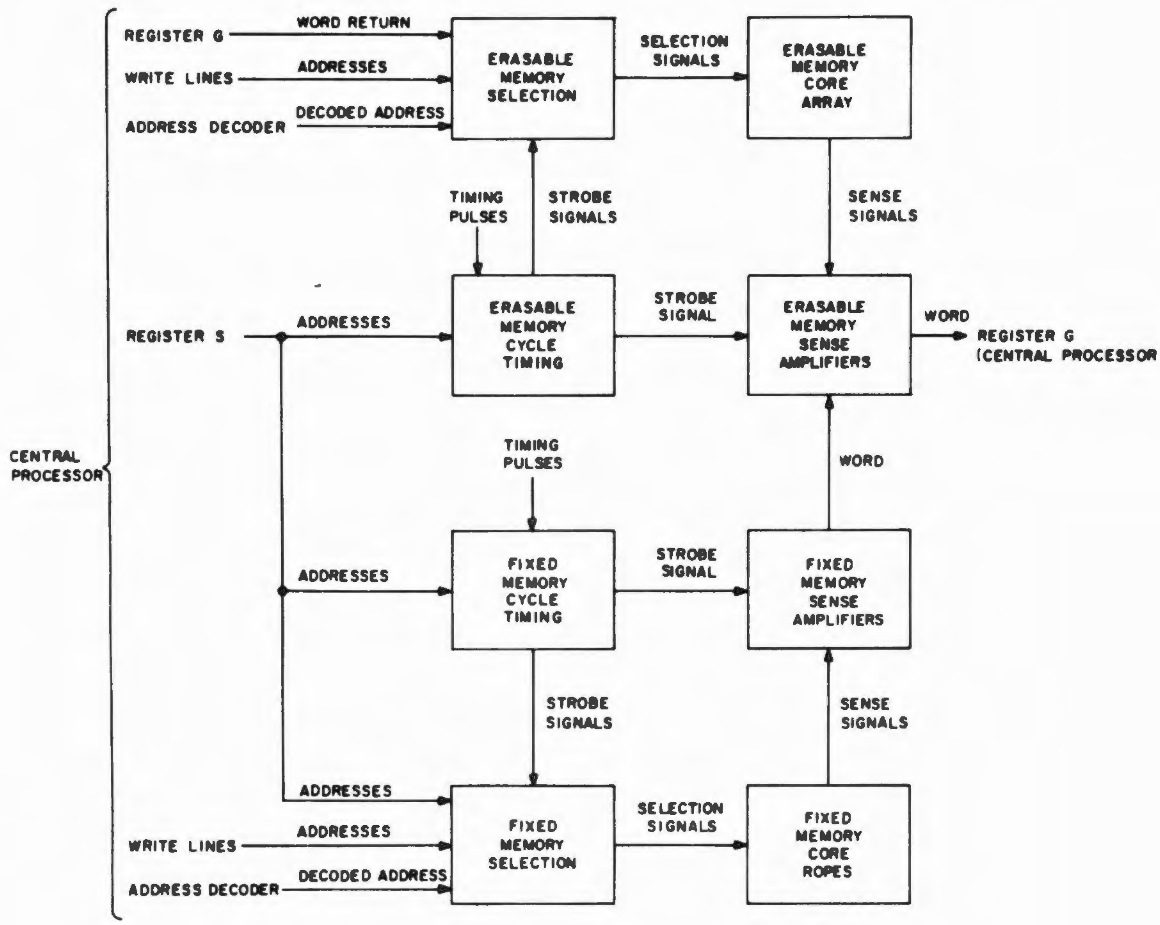


Fig. 2-42. Memory functional block diagram.

reserved for data, such as constants and tables. Information is placed into fixed memory permanently by weaving patterns through the magnetic cores. The information is written into assigned locations in erasable memory with the DSKY's, uplink, or program operation.

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

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

2.4.2.5 Priority Control

Priority control is related to the sequence generator in that it controls all involuntary or priority instructions. Priority control processes input-output information and issues order code and instruction signals to the sequence generator and twelve-bit addresses to the central processor. (See Fig. 2-43.)

Priority control consists of the start, interrupt, and counter instruction control circuits. The start instruction control initializes the computer if the program works itself into a trap, if a transient power failure occurs, or if the interrupt instruction control is not functioning properly. The computer is initialized with the start order code signal, which not only forces the sequence generator to execute the start instruction, but also resets many other computer circuits. When the start order code signal is being issued, the T12 stop signal is sent to the timer. This signal stops the time pulse generator until all essential circuits have been reset and the start instruction has been forced by the sequence generator.

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

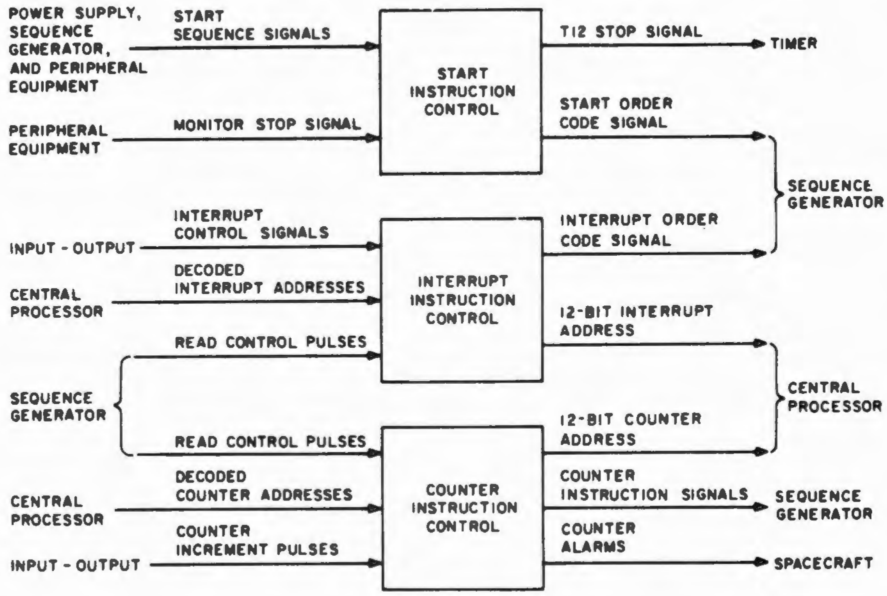


Fig. 2-43. Priority control functional block diagram.

allows sequential control of the ten interrupt addresses. The decoded interrupt addresses from the central processor are used to control the priority operation.

The counter instruction control is similar to the interrupt instruction control in that it links input-output functions to the program. It also supplies twelve-bit addresses to the central processor and instruction signals to the sequence generator. The instruction signals cause a delay (not an interruption) in the program by forcing the sequence generator to execute a counter instruction. The addresses are transferred to the central processor by read control pulses. The counter instruction control also has a built-in priority of the 29 addresses it can supply to the central processor. This priority is also controlled by decoded counter address signals from the central processor. The counter instruction control contains an alarm detector which produces an alarm if an incremental pulse is not processed properly.

2.4.2.6 Input-Output

The input-output section accepts all inputs to, and routes to other subsystems all outputs from the computer. Most of the input channels and the output channels are flip-flop registers similar to the flip-flop registers in the central processor. (See Fig. 2-44.) Certain discrete inputs are applied to individual gating circuits which are part of the input channel structure. Typical inputs to the channels include keycodes from the DSKY, from other PGNCS subsystems, and other spacecraft systems as shown. Input data is applied directly to the input channels; there is no write process as in the central processor. However, the data is read out to the central processor under program control. The input logic circuits accept inputs which cause interrupt sequences within the computer. These incremental inputs (such as,

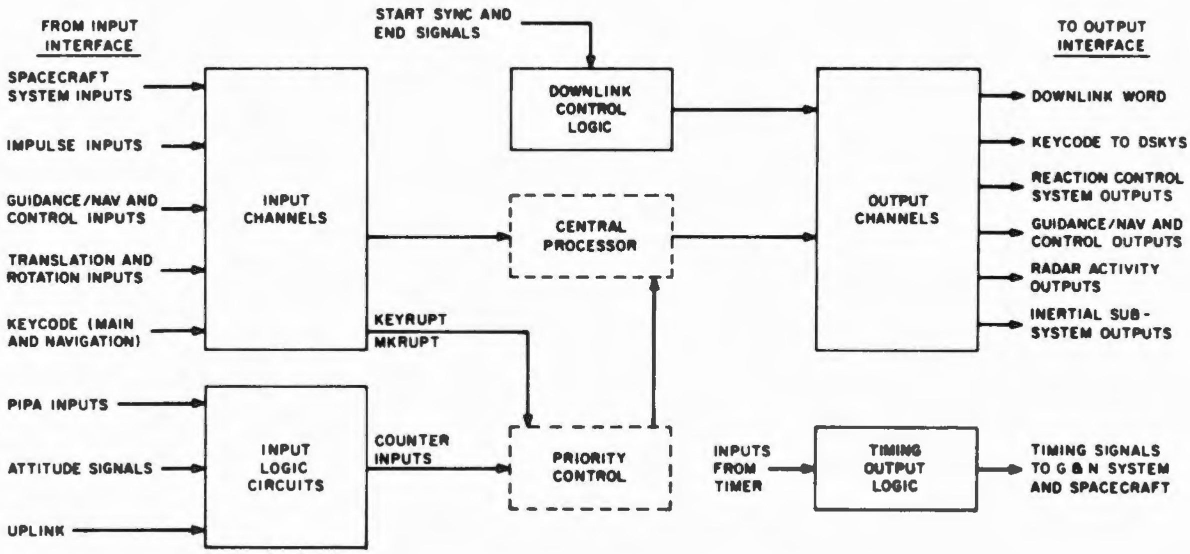


Fig. 2-44. Input-output functional block diagram.

acceleration data and RR antenna shaft and trunnion) are applied to the priority control circuits and subsequently to associated counters in erasable memory.

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

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

2.4.2.7 Display and Keyboard

The display and keyboard (DSKY) allows the astronaut to exercise control of the LGC. The DSKY consists of a keyboard, power supply, decoder, relay matrix, status and caution circuits, and displays (see Fig. 2-45).

The keyboard contains the key controls with which the astronaut operates the DSKY. Each of the key controls is lighted by 115 vac, 400 cps. Inputs to the LGC initiated from the keyboard are processed by the program. The results are supplied to either the decoder and relay matrix or to the status and caution circuits for display. Each key when depressed, will produce a 5-bit code. The keycode enters into the LGC and initiates an interrupt to allow the data to be accepted. The key reset signal (+28 vdc) is generated each time a key is released, and conditions the LGC to accept another keycode.

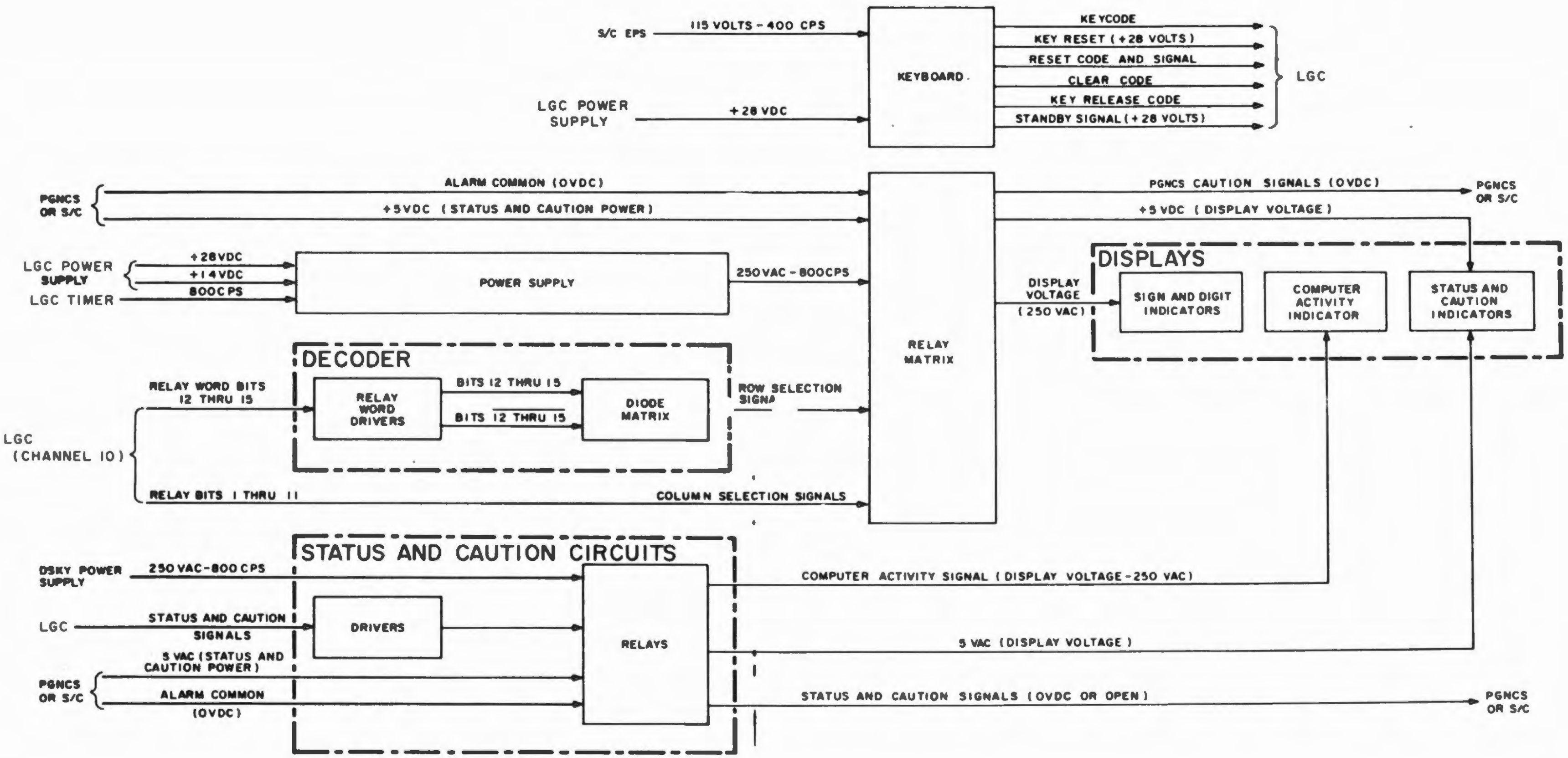


Figure 2-45. DSKY functional block diagram.

The reset code and signal (+28 vdc) is used when the astronaut wishes certain display indicators to go out. It also checks on whether a particular indicator is transient or permanent. The clear code is used when the astronaut wishes to clear displayed sign and digit information. Key release turns the control of displaying information on the DSKY over to the LGC. The standby signal (+28vdc) initiates putting the LGC into the standby mode. It also initiates putting the LGC into operate mode when pressed a second time. The STBY pushbutton also initiates the proceed with or without data signal (this is explained more fully in Section V).

The power supply utilizes +28 vdc and +14 vdc from the LGC power supply and an 800 cps sync signal from the timer to generate a 250 volt, 800 cps display voltage. The display voltage is applied to the displays through the relay matrix and status and caution circuits.

The decoder receives a four bit relay word (bits 12 through 15) from channel 10 in the LGC. The decoded relay word, in conjunction with relay bits 1 through 11 from channel 10, energizes specific relays in the matrix. The relays are energized by the coincidence of a selection signal from the diode matrix in the decoder which produces a row selection, signal, and relay bits which produce column selection signals. Relay selection allows the display voltage (250 vac) from the power supply to be routed to the proper sign and digit indicators. Relay selection also allows the alarm common (0 vdc) or +5 vdc from the PGNCS, or from the LM to be routed through the relay to the PGNCS or to the LM (caution signals) or to the proper status and caution indicators respectively. All relays associated with the relay matrix are the latching type.

The status and caution circuits receive all LGC status and caution signals. Each signal is applied to a driver circuit and to an associated relay. When a relay is energized, it allows the voltage from the DSKY power supply (250 vac) or +5 vdc or 0 vdc from the PGNCS or LM to be routed to the proper display indicators or equipment. The voltage from the power supply is routed through a relay to the computer activity indicator (COMP ACTY). The +5 vdc is routed through relays to the following status and caution indicators: UPLINK ACTY, RESTART, OPR ERR, KEY REL, and TEMP.

The displays consist of sign and digital (operational and data display) and status and caution indicators. The sign and digital indicators allow the astronaut to observe the data entered or requested from the keyboard. The status and caution indicators present an indication of any variance from certain normal operations.

2.4.3 LGC Power Supplies

The LGC power is furnished by the switching regulator power supplies, +4 volt and + 14 volt. (See Fig. 2-46.) Primary + 28 vdc power is applied to the power input circuit of the + 4 vdc power supply, filtered, and applied to the power output circuit. A second filter supplies output + 28 COM to both the LGC and the DSKY. A zenor diode regulator in the power input circuit supplies + 9.2 vdc to the voltage regulator. The voltage regulator is a parallel regulator which operates on a 50 kc sync signal from the timer. The 50 kc signal triggers a multivibrator circuit in the voltage regulator, the output of which is of sufficient duration to provide 4 vdc to the power output circuit. The 4 vdc output is regulated by feedback from the power output circuit.

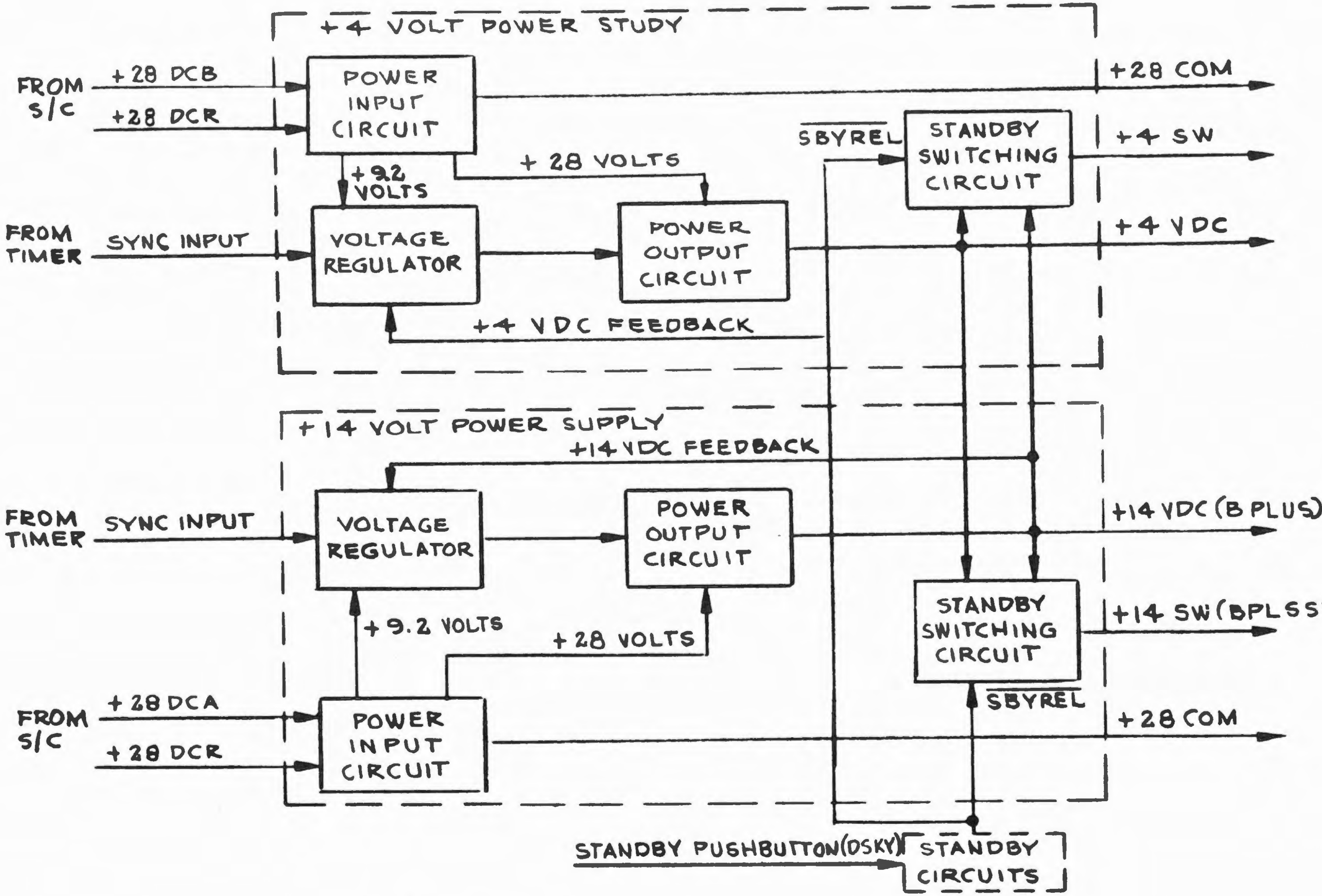


Fig. 2-46. LGC power supplies functional block diagram.

Operation of the +14 volt power supply is identical to the +4 volt power supply with the exception that a 100 kc sync signal is used instead of 50 kc.

Standby operation, which is initiated by the STBY button on the DSKY, allows the LGC to conserve power by operating in a low power mode. (Retention of stored data is maintained during the standby state.) Signal SBYREL disables the +4 SW and BPLSSW outputs during the standby mode.

2.4.4 CSS Modes of Operation

The LM mission is divided into LGC programs. The currently active program is displayed as a two-digit, decimal number in the DSKY program display. Most of the programs are automatically sequenced on the basis of the elapse of a specific interval of time as measured by the counter structure. When the counter overflows, it causes an interrupt that activates the next program. Other major programs are initiated by the crew. A crew start, stop, and change the program capability is provided through the DSKY.

Subprograms which consist of routines or a component of a routine are normally performed in succession automatically or semiautomatically. Some subroutines may be specifically called for by the crew by selecting the specific keyboard combinations and upon completion of any subroutine, the entire routine may be halted by DSKY entry.

A LGC standby state is entered by pressing the STBY pushbutton on the DSKY (see paragraph 2.4.3). During this state, the maximum average LGC power dissipation drops from 100 watts to 10 watts.

2.4.5 LGC Monitoring

2.4.5.1 LGC Alarm Detection Circuits

The alarm detection circuits perform monitoring and conditioning of some key LGC signals. These circuits do not particularly belong to any of the functional areas described in paragraph 2.4.2, but monitor and provide alarm signals to many of these circuits (see Fig. 2-47).

The voltage alarm circuit monitors (by means of differential amplifiers) the +28 COM, +14 vdc and +4 vdc outputs from the LGC power supplies and generates a signal VFAIL for an out-of-limits condition or complete failure of any one of these power supplies. Signal VFAIL, conditioned by timing signals, will generate signal STRT1 from the logic circuits, provided it is not inhibited by interface signal NHVFAL. Signal STRT1, when applied to priority control, prevents counter instructions from being executed. Simultaneously, if the computer is in the standby mode, an input (FILTIN) is issued to the warning integrator. This input is controlled by signal STNDBY.

The oscillator alarm circuit generates signal STRT2 if the LGC 2.048 megacycle oscillator should fail or if the LGC is in the low power mode (standby). A delay circuit in the oscillator alarm assures signal STRT2 is applied to priority control to prevent the counter instructions from being executed. This condition remains until the oscillator starts running. Signal STRT2 also causes the generation of signal OSCALM from the logic circuits to input channel 33, but position 15.

There are two scaler alarm circuits in the LGC: scaler alarm and double frequency scaler alarm. The scaler alarm provides a check on the

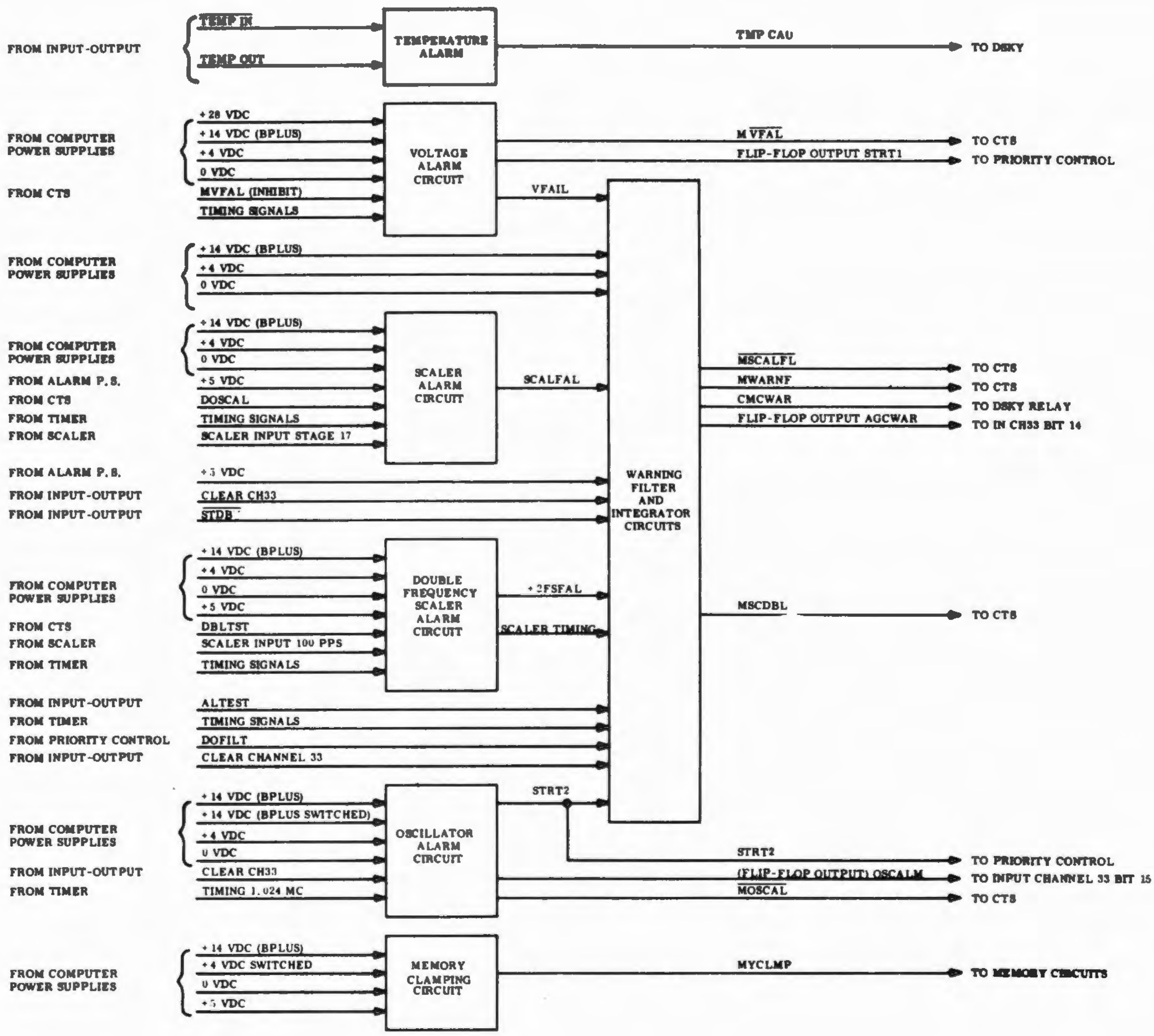


Fig. 2-47. LGC Alarm Detection Circuits Functional Block Diagram

timer, scaler stage 17 and generates signal SCAFAL when stage 17 fails to produce pulses. Signal SCAFAL generates signals AGCWAR and LGCWAR directly from the logic circuits to the input-output channels that interface relays in the DSKY. Double frequency scaler alarm generates signal 2FSFAL if the 100 pps scaler signal (signal SCASIO from the logic circuits conditioned by timer signals) should fail. Signal 2FSFAL provides an input to signal FILTIN which causes signals AGCWAR and LGCWAR to be generated.

The warning integrator initiates the generation of warning signals AGCWAR and LGCWAR simultaneously from the logic cir uits. Input signal FILTIN, conditioned by timing signals, represents restart or counter fail signal (DOFILT), voltage fail in the standby mode, alarm test signal (ALTEST) or double frequency scaler alarm.

If either LGC power supply is out of limits or fails completely, or if in the standby mode, the MYCLAMP circuit output inhibits access to memory. Operation of the MYCLAMP circuit is identical to that of the voltage alarm circuit. It employs a differential amplifier that has a threshold voltage applied to it. If the +4 volt input voltage falls below this threshold signal, MYCLAMP goes high indicating an alarm condition.

The incorporation of a +5 vdc source within the alarm detection circuits eliminates the need for more semiconductors, and components normally used where a reference voltage is required.

The IMU stable member temperature is also monitored by the alarm circuits. Signal TEMPIN, an indication that the stable member temperature is outside its design limits, causes signal TMPCAU to be generated and routed to the DSKY for display (TEMP).

2.4.5.2 Caution and Warning Indications

The caution and warning indicators associated with the CSS are the PGNS caution on the system engineer's center panel (lights yellow); the LGC warning and ISS warning on the commander's center panel (light red); and RESTART, TEMP, GIMBAL LOCK, PROGRAM, and TRACKER on the DSKY. Whenever a failure is sensed, one or more of these lights come on, the MASTER ALARM light illuminates, and an audible tone is introduced into the headsets of both crew members. The tone may be stopped and the MASTER ALARM light extinguished by depressing the MASTER ALARM pushbutton, but the appropriate warning light remains on until the trouble is cleared up.

Each of the caution and warning indicators are actuated by relays contained in the DSKY. A generalized logic diagram of LGC and DSKY circuits is contained in Fig. 2-48. Each OR gate immediately preceding an indicator is a representation of DSKY relay logic. (Table 2-1 describes some of the caution and warning signals.)

An LGC warning alarm is generated in the event of LGC power failure, scaler failure, restart or counter fail during LGC operate, or in response to an alarm test program. A scaler fail or prime power fail result in an immediate alarm indication whereas other inputs are buffered by a filter so as to prevent momentary transient disturbances which recover from causing an alarm.

An ISS warning signal is under LGC program control. It is ignored by the LGC program when the PGNCS is in the coarse align mode and for 5 seconds after. During coarse align the servo errors normally exceed the alarm criteria.

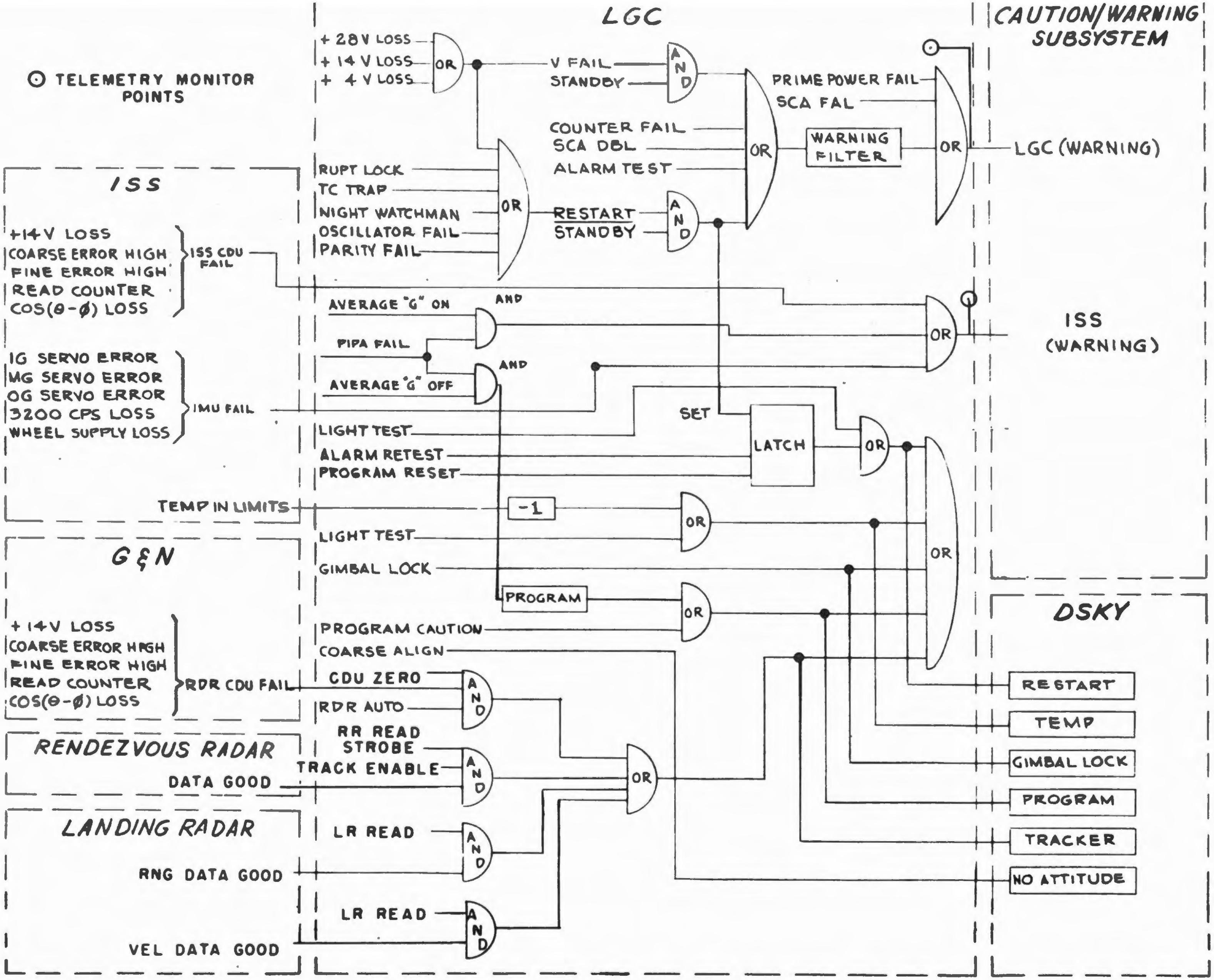


Fig. 2-48. Caution and warning indicator logic diagram.

When a restart or program alarm are illuminated on the DSKY, either V05N09 will automatically appear on the DSKY with a code in R1 that specifies the source of trouble or by astronaut calling up the code by keying in V05N09E.

Table 2-1. Description of caution and warning activation signals.

Signal	Description
Rupt Lock	Occurs if interrupt is too long or too infrequent. The criterion for "too long" is phase dependent varying from 140 ms to 300 ms. Likewise, the criterion for "too infrequent" varies from 140 ms to 300 ms.
TC Trap	Occurs if too many TC or TCF (transfer control) instructions are run or are too infrequent. The criterion for "too many" varies from 5 ms to 15 ms duration and for "too infrequent" it varies from 5 ms to 15 ms absence.
Night Watchman	Occurs if the computer should fail to access address 67 within a period whose duration varies from 0.64 seconds to 1.92 seconds.
Oscillator Fail	Occurs if LGC 2.048 mc oscillator stops. A 250-millisecond delay keeps the fail signal present after the oscillator starts.
Standby	Turns off the switchable +4 and +14 vdc, thus putting the LGC into a low power mode where only the scaler, timing signals, and a few auxiliary signals are operative. Standby is initiated by first setting the enable standby outbit (Channel 13, bit 11), and then pressing the STBY button on the DSKY for a time, which can varies from 0.64 seconds to 1.92 seconds. All LGC alarms are inhibited during the standby mode with the exception of LGC warning, which can be caused by a prime voltage failure or scaler fail; and TEMP caution, which can be caused by temperature alarm (TMPCAU).
Scafal	Occurs if scaler stage 17 (1.28 sec. period) fails to produce pulses. This provides a check on the timing for all logic alarms.
Counter Fail	Occurs if counter increments happen too frequently or else fail to happen following an increment request. "Too frequently" means continuous counter request and/or incrementing for from 0.625 ms to 1.875 ms.
Scadbl	Occurs if the 100 pps scaler stage operates at a pulse rate of 200 pps or more.

Table 2-1. Description of caution and warning activation signals. (Cont.)

Signal	Description
PIPA Fail	Occurs if no pulses arrive from an accelerometer during a 312.5 microsecond period, or if both plus and minus pulses occur, or if a long duration (1.28s to 3.84s) without at least one plus pulse and one minus pulse arriving.
Light Test	Tests RESTART, STBY, and PGNS lights.
Alarm Reset	Furnishes a reset for PGNCS, RESTART, and OPR ERR indicators.
V Fail	Occurs if the LGC voltages (28, 14, 4) are out of limits. The following criteria apply for V fail: 4V supply > 4.4V; 14V supply > 16V 4V supply < 3.65V; 14V supply < 12.5V 28V supply < 22.6V
IMU Fail	Occurs under the following conditions (but not during coarse align or the 5 second interval following coarse align): 1) IG Servo Error - Greater than 2.9 milliradians for 2s 2) MG Servo Error - Greater than 2.9 milliradians for 2s 3) OG Servo Error - Greater than 2.9 milliradians for 2s 4) 3200 cps decrease to 50% of nominal level 5) 800 wheel supply decrease to 50% of nominal level
ISS CDU Fail	Occurs under the following conditions (but not during CDU zero moding): 1) CDU fine error in excess of 1.0 vrms 2) CDU coarse error in excess of 2.5 vrms

Table 2-1. Description of caution and warning activation signals (Cont.)

Signal	Description
	3) Read counter limit cycle in excess of 160 cps 4) Cos $(\theta - \phi)$ below 2.0 volts 5) +14 volt supply ecrease to 50% of nominal level
Temp out of Limits	Occurs when stable member temperature is outside the range 126.3°F to 134.3°F.
Gimbal Lock	Occurs when the IMU middle gimbal angle (MGA) excesses 70°. (When the MGA exceeds 85°, the ISS is downmoded to coarse align and the NO ATT indicator on the DSKY is activated.) Gimbal lock is defined as a condition in which the IMU middle gimbal has moved to a position such as to make the outer and inner gimbal axes colinear.
RDR CDU Fail	Occurs under the following conditions (but not during CDU zero moding): 1) CDU fine error in excess of 1.0 vrms 2) CDU coarse error in excess of 2.5 vrms 3) Read counter limit cycle in excess of 160 cps 4) Cos $(\theta - \phi)$ below 2.0 volts 5) +14 volt supply decrease to 50% of nominal level
RR Data Fail	Occurs when LGC is unable to obtain coherent data from the RR or when the LGC receives the data "no good" discrete from the RR.
LR Data Fail	Occurs when the LGC is unable to obtain data from an enabled landing radar.

2.4.5.3 Program Alarms

The program alarm is a program-controlled alarm that is issued when some program check has failed. The program alarm lights the PROG alarm indicator on the DSKY.

Upon issuance of the program alarm, the LGC also issues a five-digit error code. This error code indicates the specific condition that caused the alarm, and thereby, provides diagnostic data to an information level at which the crew can make effective decisions. The alarm codes are listed in Table 2-2. Main alarms (indicated by an asterisk in Table 2-2) display the error codes on the DSKY when the alarm occurs; side alarm codes are displayed only by keying V05 N09E.

If only one alarm has occurred since the last reset, its code appears in DSKY register one. If two alarms have occurred since the last reset, the first alarm code appears in register one and the second in register two. If more than two alarms have occurred since the last reset, the first and second alarm codes are displayed in registers one and two, respectively, and the last alarm code is displayed in register three.

Some computer alarms also initiate a computer restart. These alarms are called aborts and are mostly intended for program debugging and ground checkout.

Table 2-2. Program Alarms

Alarm Code	Description	Corrective Action
00105	AOT mark system in use.	Key RSET. Continue normal operation.
00107	More than 5 mark pairs entered. There is room for only 5 pairs of X, Y marks.	Key RSET. Continue normal operation.
00111	Mark missing. If subroutine finds only one mark, either X or Y, it cannot process a pair.	LGC flashes V50 N25 R1 = 00017 Reset program caution. Perform additional sightings.
00112	Marks not being accepted. Indicates that either an X or Y mark or a mark reject did not get accepted.	Key RSET. Wait for LGC to flash "Please Mark" code.
00113	No inbits in channel 16. This alarm is generated when the MARKRUPT program is entered with no input bits in channel 16 set. Bit 3 = X MARK, Bit 4 = Y MARK, Bit 5 = MARK REJECT, Bits 6 and 7 are descent bits.	Key RSET. Reattempt the entry into MARK-RUPT program which failed. (MARK, MARK REJECT or Rate of Descent switch.)
00114	Mark made but not desired. Occurs as a result of a "Mark X" when the LGC is requesting a "Mark Y" or vice versa.	Key RSET. Continue normal operation.
00115	No marks in last pair to reject. Occurs as a result of performing more than two mark rejects.	Key RSET. Continue normal operation.
00206	Zero encode not allowed during coarse align with gimbal lock. In this condition, zero encoding can only be done by first commanding coarse alignment to zero by V41.	Key RSET. Key V41 N20E and load 00000E 00000E 00000E Key V40N 20E.
00207	ISS turn-on not present for 90 sec.	Wait for NO ATT light to go out then key RSET. If alarm is still present, re-initiate turn on sequence.

Table 2-2. Program Alarms (Cont.)

Alarm Code	Description	Corrective Action
00210	IMU not operating. Occurs when programs or routines using IMU inputs are requested with IMU not operating.	Perform IMU turn on procedure. Reset. Continue normal operation.
00211	Coarse align error. Occurs when gimbal angles are not within two degrees of commanded position at completion of coarse alignment.	To determine the magnitude of error, Key V06N20E for display of gimbal angles. The operator may reattempt coarse align, continue with fine align or terminate use of ISS.
00212	PIPA failure while PIPA's are not in use.	Key RSET. Perform PIPA bias check (see Section 6).
00213	IMU not operating with IMU turn on request.	Key RSET. Perform ISS turn-on procedure.
00214	ISS turned off while in use.	Key RSET. Perform ISS turn-on procedure.
00215*	IMU orientation not specified and preferred orientation has been selected.	Key RSET. Perform either a or b: a) Key V32E and select nominal orientation or REFSMMAT option b) If preferred orientation is still desired select a new program to define the orientation.
00217	Bad return from STALL routines.	Key RSET. Reinitiate current program; if alarm recurs, terminate use of ISS.
00220	Bad REFSMMAT. If the IMU is operating but the REFSMMAT is not known, this program alarm will occur.	Key RSET. Perform IMU orientation determination (P51).

*Displayed automatically without keying V05 N09E.

Table 2-2. Program Alarms (Cont.)

Alarm Code	Description	Corrective Action
00401	Desired gimbal angles yield gimbal lock.	Key RSET. Either select new gimbal angles or maneuver spacecraft to avoid gimbal lock.
00405*	Two useable stars not available in AOT center detent position.	Perform a or b: a) Maneuver spacecraft until two useable stars are manually acquired, then key PRO. b) Maneuver spacecraft until two useable stars may be automatically acquired, then key V32E.
00421	W matrix overflow. Indicates that W matrix has been integrated forward without new navigation updates for so long a time that terms in the matrix exceed their scale factors.	Key RSET. Get state vector update from ground (P27). Perform rendezvous navigation P20.
00501*	Radar antenna out of limits. Occurs if RR CDU antenna angles exceed mode limits.	Perform a or b: a) Key RSET V37E 00E b) Key RSET V37E 20E and reacquire CSM by manual or automatic search.
00502	Bad radar gimbal input. Occurs if designated position for RR antenna is not possible for either mode.	Key RSET. LGC will perform preferred tracking attitude routine (R60 and R61).
00503*	Radar antenna designate failed. Occurs when the LGC fails to receive the DATA GOOD discrete from the RR within ≈ 45 sec of initiation of a designate sequence. Indicates the RR is unable to acquire the CSM.	Key RSET. Perform a, b, or c. a) If automatic search is desired: Key PRO (exit to RR search routine R24) b) Designate RR again: V32E c) Terminate V34E

Table 2-2. Program Alarms (Cont.)

Alarm Code	Description	Corrective Action
00510	Radar auto discrete not present. Occurs if the LGC attempts to zero encode the RR without the auto discrete present.	Key RSET. Continue normal operation. (insure RR mode control switch is in LGC position)
00514	Radar goes out of auto mode while in use. Will occur in P20 only.	Key RSET. Continue normal operation. (insure RR mode control switch is in LGC position)
00515	RR CDU fail discrete present. Indicates a RR CDU failure has occurred.	Perform one of the following: a) If not in P20: Press KEY REL and RSET (RR not operative under LGC control and not available for vector update.) b) If in P20: Press KEY REL and RSET (Evaluate CDU performance (see Section 6) if OK, continue in P20 otherwise terminate)
00520	RADARUPT not expected at this time.	Key RSET. Continue normal operation.
00521	Could not read radar. Occurs when DATA GOOD discrete lapses during data read routine. Likely to be accompanied by a tracker fail alarm.	Key RSET. Continue normal operation.
00522	LR position change.	Not applicable to earth orbit mission.
00523	LR did not achieve Position 2.	Not applicable to earth orbit mission.

Table 2-2. Program Alarms (Cont.)

Alarm Code	Description	Corrective Action
00525*	Delta theta greater than 3 deg. Occurs if RR LOS is not within 3 degrees of present state vector indicated LOS. Occurs only in R22 (data read routine).	Key PRO. Key RSET. FL V06 N05 XXX. XX Delta theta Operator options: a) Key PRO (accept data as is) b) Key V32E (recycle)
00526*	Range greater than 400 miles. Occurs if LOS vector from LM to CSM shows range greater than 400 n. m. Occurs in beginning of P20 only.	Perform one of the following as desired: a) Wait as desired Key RSET Key V32E b) Key RSET V37E 00E Key V83E (monitor range) c) Terminate P20 Key V56E Key RSET
00527*	RR out of limits in R23. Occurs if CSM is outside the limits of present RR antenna mode.	Perform one of the following: a) Key RSET Key V32E (performs preferred tracking attitude routine R61 again) b) Key RSET Key V34E (terminates R23 and P20)
00600*	Occurs if on first iteration there is no intersection of the desired LOS at TPI with the fictitious circular orbit.	Key RSET Key V32E (return to start of program and adjust input parameters)
00601*	Occurs if pericent or ALT (POST CSI) is less than the 35000 ft (lunar orbit) or 85 nm (earth orbit)	Key RSET Key V32E (return to start of program and adjust input parameters)

Table 2-2. Program Alarms (Cont.)

Alarm Code	Description	Corrective Action
00602*	Occurs if pericenter ALT (POST CDH) is less than 35000 ft (lunar orbit) or 85 nm (earth orbit)	Key RSET Key V32E (return to start of program and adjust input parameters)
00603*	Occurs if GETI(CDH) or GETI(CSI) is less than 10 min.	Key RSET Key V32E (return to start of program and adjust input parameters)
00604*	Occurs if GETI(TPI) or GETI(CDH) is less than 10 min or computed CDH time is greater than input TPI time.	Key RSET Key V32E (return to start of program and adjust input parameters)
00605*	Number of iterations exceeds loop maximum. Occurs if the iteration counter exceeds 15 without arriving at a problem solution.	Key RSET Key V32E (return to start of program and adjust input parameters)
00606*	DV exceeds maximum. Occurs if on any two consecutive iterations the magnitude of Delta V (CSI) is greater than 1000 fps.	Key RSET Key V32E (return to start of program and adjust input parameters)
00611*	Not GETI for given elevation angle. Occurs if no solution for GETI(TPI) can be reached.	Key PRO Key RSET (program returns to start to adjust input parameters)
00777	PIPA fail caused the ISS warning.	Key RSET Perform PIPA bias check (see Section 6)
01102	LGC self test error.	Reinitiate self test. If failure recurs LGC may not be usable (see Section 6).
01103	Unused CCS branch executed. Intended for program debugging; will not occur in flight. Causes restart.	Terminate and reinitiate program Key RSET If alarm recurs perform LGC self check (see Section 6).
01104	Delay routine busy. Intended for CMC checkout; not likely to occur in flight. Causes restart.	See alarm 01103.

Table 2-2. Program Alarms (Cont.)

Alarm Code	Description	Corrective Action
01105	Down telemetry too fast. Occurs when end of word pulse rate of downlink exceeds 100 pps.	Key RSET Perform one of the following: a) Ignore this alarm: if it occurs at turn on, also ignore if it can be reset. b) Notify MSFN
01106	Uplink too fast	Key RSET Perform one of the following: a) Ignore if it can be reset Ignore if it occurs at turn on b) Notify MSFN
Note: Alarms 01107 through 01302 are intended for LGC debugging and testing. They are not likely to occur in flight.		
01107	Phase table failure. Assume erasable memory destroyed.	LGC does automatic fresh start. Erasable memory must be re-initialized or operator goes to AGS.
01201	No vacant areas available. Occurs when more than five jobs requiring vacant areas are requested at the same time. Causes restart. (See note preceding alarm 01107)	Terminate and reinitiate program. Key RSET If alarm recurs, perform LGC self check (see Section 6).
01202	No core sets available. Occurs when more than seven jobs are requested at one time. Causes restart. (See note preceding alarm 01107.)	See alarm 01201.
01203	Waitlist overflow – too many tasks. Occurs when more than seven tasks are requested at one time. Causes restart. (See note preceding alarm 01107.)	See alarm 01201.
01206	Second job attempts to go to sleep via keyboard and display program. Causes restart. (See note preceding alarm 01107.)	See alarm 01201.

Table 2-2. Program Alarms (Cont.)

Alarm Code	Description	Corrective Action
01207	No vacant areas available for marks. Occurs if a mark is received when all five mark areas are filled.	See alarm 01201.
01210	Two programs attempting to use the same device (ISS or OSS). Causes restart. (See note preceding alarm 01107.)	See alarm 01201.
01211	Illegal interrupt of extended verb. Occurs when an internal program requests marking while marking system is already in use or an extended verb is active. Causes restart. (See note preceding alarm 01107.)	See alarm 01201.
01301	Arcsine, arccosine input too large. Causes restart. (See note preceding alarm 01107.)	See alarm 01201.
01302	Square root routine called with a negative argument. Causes restart. (See note preceding alarm 01107.)	See alarm 01201.
01407	Velocity to be gained increasing.	Terminate thrusting. Check orbital parameters and reinitiate orbit change targeting and thrust as necessary.

Table 2-2. Program Alarms (Cont.)

Alarm Code	Description	Corrective Action
01501	Keyboard and display alarm during internal use. Intended for ground checkout; not likely to occur in flight. Causes restart.	Terminate and reinitiate program. Key RSET. If alarm recurs, perform CMC self check (see Section 6).
01502	Illegal use of flashing display. Intended for ground checkout; not likely to occur in flight. Causes restart.	See alarm 01501.
01520	Verb 37 not allowed at this time. Occurs when program change is attempted when it is not allowed.	Key RSET. Do not attempt to change programs until allowed.
01600	Overflow in drift test. For ground test only.	Cannot occur in flight.
01601	Bad IMU torque. For ground test only.	Cannot occur in flight.
01703*	Less than 45 seconds to ignition. The general purpose ignition routine, checks time to go to ignition, at a specific point in the routine.	Either slip GETI to 45 seconds from time PRO is keyed: Key PRO Key RSET Or terminate program: Key V34E Key RSET
01706	Stage verify discrete does not agree with Noun 46 (DAP configuration). Occurs in P42 (APS program) if stage verified discrete indicates DPS has not been staged.	Terminate program V34E Key RSET
01711*	State vector integration has overlapped average G turn on time.	Terminate program Key V34E Key RSET

Table 2-2. Program Alarms (Cont.)

<table>
<tr><th>Alarm Code</th><th>Description</th><th>Corrective Action</th></tr>
<tr><td>02000</td><td>DAP still in progress at next TIME5RUPT.</td><td>Key RSET
Perform LGC Self Test (see Section 6)</td></tr>
<tr><td>02001</td><td>Jet failures have disabled Y-Z translation.</td><td rowspan="4">Key RSET
Subsequent maneuvers will require utilizing remaining rotation and translation capabilities</td></tr>
<tr><td>02002</td><td>Jet failures have disabled X translation.</td></tr>
<tr><td>02003</td><td>Jet failures have disabled P rotation.</td></tr>
<tr><td>02004</td><td>Jet failures have disabled U-V rotations.</td></tr>
<tr><td>03777</td><td>ICDU caused the ISS warning.</td><td>Key RSET
Perform ISS malfunction procedure (see Section 6).</td></tr>
<tr><td>04777</td><td>ICDU PIPA fails caused the ISS warning.</td><td>Key RSET
Perform ISS malfunction procedure (see Section 6).</td></tr>
<tr><td>07777</td><td>IMU fail caused the ISS warning.</td><td>Key RSET
Perform ISS malfunction procedure (see Section 6).</td></tr>
<tr><td>10777</td><td>IMU, PIPA fails caused the ISS warning.</td><td>Key RSET
Perform ISS malfunction procedure (see Section 6).</td></tr>
<tr><td>13777</td><td>IMU, ICDU fails caused the ISS warning.</td><td>Key RSET
Perform ISS malfunction procedure (see Section 6).</td></tr>
<tr><td>14777</td><td>IMU, ICDU, PIPA fails caused the ISS warning.</td><td>Key RSET
Perform ISS malfunction procedure (see Section 6).</td></tr>
</table>

2.5 LANDING RADAR SUBSYSTEM

The LM-3 Landing Radar is specially modified for RF View Factor Test purposes. In the following description, this radar will first be described generally as it was designed to work on a lunar mission. This will then be followed by a listing of the special modifications performed on this radar for the RF View Factor Test program.

The Landing Radar senses the velocity and slant range of the Lunar Module relative to the lunar surface by means of a three beam doppler velocity sensor and a radar altimeter. The velocity and range information is processed and made available to the LM Guidance Computer in serial binary from and to the LM displays in the form of pulse trains and dc analog voltages.

The Landing Radar, located in the descent stage of the Lunar Module, is packaged in two replaceable assemblies. The Antenna Assembly (AA) serves to form, direct, transmit and receive four narrow microwave beams. To perform this function the AA is composed of two interlaced phase arrays for transmission, and four space-duplexed planar arrays for reception. The transmitting arrays form a platform on which are mounted four quadrature pair Balanced microwave mixers, four dual Audio Frequency preamplifiers, two solid-state microwave transmitters, an FM modulator, and an antenna pedestal tilt mechanism. The Electronic Assembly (EA) contains the circuitry required to track, process, convert and scale the Doppler and FM/CW returns which provide the velocity and slant range information to the LGC and to the astronaut displays.

This data obtained by direct microwave contact with the lunar surface is used by the computer and/or the astronauts to achieve a controlled rate of descent, a hover at low altitude to permit selection of a landing site, and a soft landing at the selected site. To accomplish these goals, the computer and/or astronauts must know the distance from the LM to the lunar surface and the velocity of the LM with respect to the lunar surface.

The cw microwave energy from the velocity sensor solid state transmitter is radiated toward the moon by the transmitting antenna. Reflected energy is received by three separate receiving antennas. The received doppler shifted energy, split in such a manner to form quadrature pairs, is mixed with a portion of the transmitted energy by microwave diodes, functioning as balanced mixers. The output of the balanced mixers is the difference frequency between the received and transmitted signals. The difference is the doppler shift which is directly proportional to velocity between the LM and the lunar surface along the detected microwave beam.

The altimeter transmitter is frequency modulated by the Frequency Modulator in a sawtooth manner. The repetition rate of the sawtooth is 130 cps. The altimeter microwave energy is applied to the altimeter transmitting antenna. The received energy from the receiving antenna is split to form a quadrature pair and is coupled to balanced microwave mixers along with a sample of the transmitted signal. The difference frequency at the output of the balanced mixers is proportional to the time difference of the transmitted and received modulated energy, plus the doppler shift. This doppler shift is undesired and must be compensated for in the range computer.

The quadrature outputs of the three velocity sensors and the altimeter balanced mixers are applied to the four Audio Frequency Amplifiers. Each of these amplifiers contains logic that switches the gain of the amplifier from 85 db to 55 db as the signal level increases to prevent distortion of the signal.

The broadband signals at the AF Amplifier outputs are applied to the inputs of frequency trackers which are located in the Electronics Assembly. The frequency trackers search for the signal over the expected frequency range with a narrow band tracking filter, and once acquired, track the signal with a high order of accuracy. The tracker output is an average frequency equal to the frequency corresponding to the center of power of the doppler or doppler and range signal spectrum plus a 614.4 kc reference. The tracker also provides a dc step voltage to indicate tracker lock.

The tracker outputs are applied to Velocity and Range Data Converters where beam velocity information indicated at the tracker outputs is resolved into velocity components. The coordinate system is referenced to the body coordinates of the antenna, or a line drawn at right angles to the face of the transmitting arrays (antenna X) which in turn is parallel to the beam group center line. The Velocity outputs to the LGC are denoted as V_{xa}, V_{ya}, and V_{za}.

The velocity outputs provided to the displays are called the "Primed Coordinate Velocity Outputs." These outputs, denoted as V_{xa}', V_{ya}' and V_{za}', are referenced to the altimeter beam which is displaced by approx. 20° from beam group center, in the XZ plane, towards -Z.

DC analog voltages are provided for V_{ya}' and V_{za}', and pulse train information is given for range and V_{xa}' (range rate) to drive the displays. A dc discrete signal is provided to indicate the sense of the V_{xa}' pulse train. In antenna position number two the velocity components yield true LM axes velocities, except for the errors introduced to V_{za} and V_{ya} due the antennas 6° CW rotation around the X axis.

The velocity data based on beam group center (to the LGC) are given in pulse train form, superimposed on a 153.6 kc reference frequency to facilitate indication of the sign of the velocity. These pulse trains, along with the range pulse train, are applied to the Signal Data Converter. The Signal Data Converter interfaces with the LM Guidance Computer by accepting strobe signals from the computer and using these to assemble and readout the range and velocity data in serial binary form. The serial binary radar output information is fed to the LGC.

Radar status signals which include Range Data Good, Velocity Data Good, Antenna Position Indication and Range Scale Factor are provided to the LGC in the form of discrete relay contact closures.

The power supply for the Landing Radar is located in the Electronic Assembly. The power supply provides regulated voltages of +25, -25, +4, and -2 volts at 1% regulation and with the low ripple over an input voltage range of 25 to 31.5 vdc.

2.5.1 Design Reference Mission Description

The Landing Radar Heater Circuit Breaker (4CB157 on Panel 11) is placed on at KSC launch pad and left on until lunar touchdown. The Landing Radar (LR) is first turned on and self-checked for five (5) minutes during LM checkout prior to the LM separation from the CSM. The self-check is accomplished by first manually activating the LR by closing the power circuit breaker 4CB105 on Panel 11, then after a 1 to 2 minute "warm-up" period, positioning the "Radar Self Test" switch (17S6) on Panel III to "LDG". This will provide a contact closure to the radar, which is used as a BIT activate command that permits the generation of internal self-test signals.

These self-test signals will represent simulated "known" doppler returns, which after processing through the radar are made available to the LGC, and presented to the Astronaut's displays, where they are represented as range and velocities and may be monitored for presence and accuracy. An additional self check is made by positioning the test monitor switch (17S8 on Panel 3) to the LR "ALT" or "VEL XMTR" position and monitoring the "signal strength meter" for a relative output power reading from each transmitter. A half scale reading will indicate the minimum power output level.

If the above self-check is successful, 4CB105 and 17S6 are returned to their "off" position.

The LR is again self tested, in the same manner as described above, prior to the start of LM powered descent, at an altitude of approximately 70,000 feet.

The Landing Radar is turned "ON" (4CB105) at start of Powered Descent (50,000 feet above the lunar surface), and is left "ON" until touch-down approximately 11 minutes later.

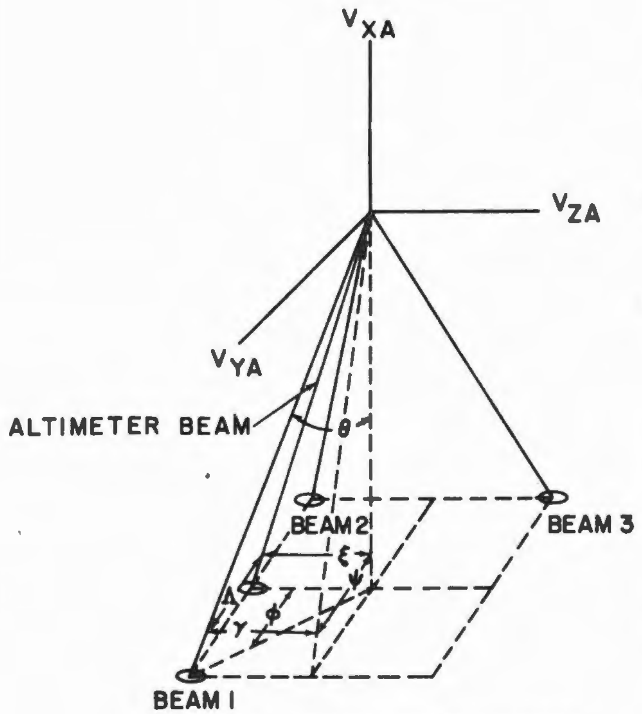
LR beams #1, 2; and 4 should "acquire" the lunar surface from an altitude of approximately 25,000 feet. When this occurs the astronaut will be presented slant range on his "range and range rate display" (meter 9M9). Range data will also be available to the LGC from this point thru touchdown. The display slant range data is corrected by a cos 15° multiplication to give the astronaut a better indication of his true altitude to the lunar surface.

Due to the vehicle altitude, relative beam angles, and presently assumed lunar back-scatter coefficient, beam #3 is not required to "acquire" the lunar surface until 18,000 feet. When beam #3 "acquires", velocity data is made available to the LGC, and velocities V_{za} and V_{ya} are displayed to the astronauts. At approximately 10-12Kft (Hi Gate) the LR antenna is tilted to the second of the two positions. (See Figure 2-49.) This serves the purpose of making the antenna group beam center parallel with the LM X axis. At this point the LGC will strobe for and accept the velocity data from the LR for updating its calculations. Velocity and range data will be strobed for sequentially.

The Control and Display Assembly, located in the cockpit of the LM Ascent Stage, is prominently visible to the astronauts during descent maneuvers. The purpose of the assembly is to present to the astronauts in readily understandable form the LR operational status, slant range, and velocity information. In addition, the assembly will permit the astronauts to turn the LR on and off, to self-check the velocity sensors and the altimeter, and to place the antenna in either one of two fixed positions. In antenna position one, beam group center is displaced in the XZ plane by 24° from vehicle -X towards -Z. In antenna position two, the beam group is parallel to the LM X axis and the computed velocities are therefore LM velocities. Range is always the range along the altimeter beam.

Antenna position No. 1 and beam angles are selected to optimize range accuracy at 15,000 ft. Antenna position No. 2 is selected to optimize range accuracy and velocity accuracy from 8600 feet thru touchdown.

When the spacecraft reaches 200 ft. altitude, a final pitch maneuver is made to orient the X axis perpendicular to the lunar surface. All velocity vectors should be near zero ft./sec. This is done to permit the astronauts to make final, visual selection of the most desirable landing site, and to manually control the soft let-down at the selected site. During this final and most critical phase of the landing part of the mission,



BEAM CONFIGURATION

VELOCITY EQUATIONS

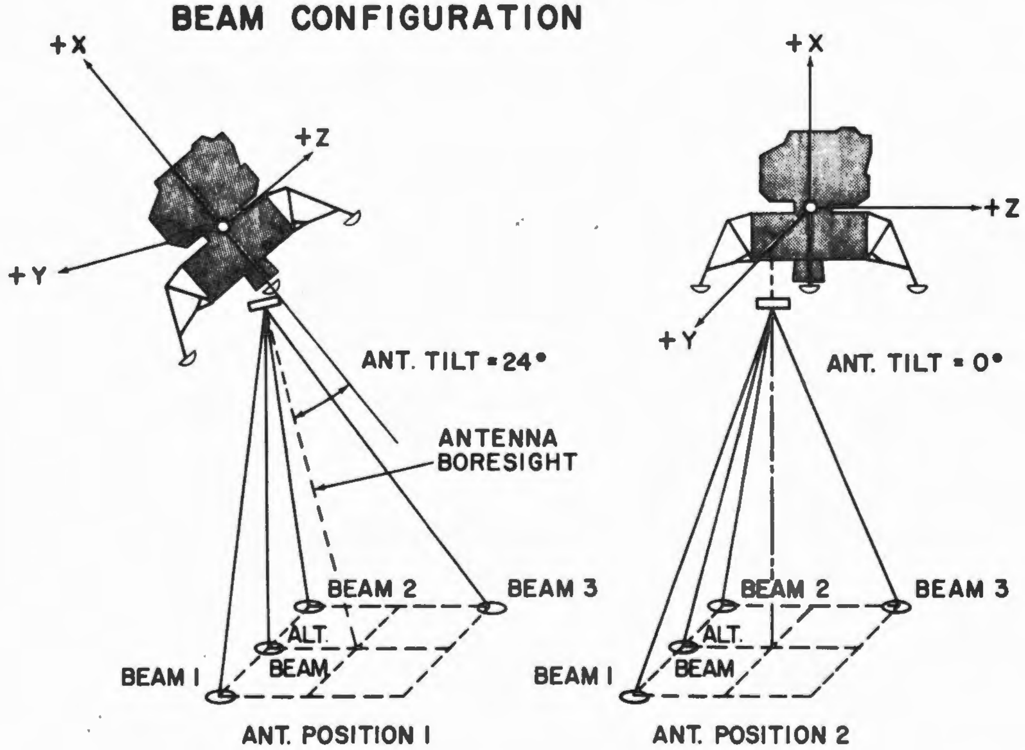
$$V_{xa} = \frac{\lambda}{2 \cos \Lambda \ \cos \xi} \ \frac{(D_1 + D_3)}{2}$$

$$V_{ya} = \frac{\lambda}{4 \sin \Lambda} \ (D_1 - D_2)$$

$$V_{za} = \frac{\lambda}{4 \cos \Lambda \ \sin \xi} \ (D_3 - D_2)$$

BEAM ANGLES

γ GAMMA	19°	45'	00"
θ THETA	24°	33'	00"
Λ LAMBDA	13°	59'	22"
ξ XI	20°	22'	48"
φ PHI	35°	34'	47"
ψ PSI	14°	53'	00"



ANTENNA TILT ANGLES

Fig. 2-49. LR Antenna Beam Configuration and Tilt Angles the astronauts obtain altitude and velocity data from the LR via the cockpit displays. The capability exists for a completely automatic landing or a manually controlled landing as selected by the astronaut.

The displays in addition to being capable of displaying raw LR data also have the capability of displaying LR corrected/modified PGNS data. The LGC "knows" the LR antenna position, and vehicle attitude. This enables the LGC to perform the necessary calculations for coordinate transformation i.e. changing the landing Radar's antenna based velocities and slant range to true altitude, altitude rate, forward and lateral velocity.

As this coordinate transformed information is much more directly useable to the astronaut, the normal procedure will be to have the PGNS information displayed on the cockpit instruments during powered descent, resorting only to display of LR raw data as a cross-check, if a problem occurs in the PGNS coordinate transformation.

When the let-down is accomplished, the LR mission is over. The LR is then deactivated (all LR circuit breakers off) and left on the lunar surface in the LM Descent Stage when the LM Ascent Stage takes off for rendezvous with the CSM.

2.5.2 LR Theory of Operation

As previously stated, the Landing Radar serves the two primary functions of radar velocity sensor and radar altimeter. This section provides a signal flow type description of each of these two functions, and a description of the circuits which support these primary functions.

2.5.2.1 Supporting Circuits

There are certain circuits in the Landing Radar that serve both the Velocity Sensor and Altimeter and therefore do not logically belong to either. These separate or supporting functions (circuits) include the following: (See figure 2-50)

a. Antenna Pedestal and tilt mechanism.

b. Antenna Heating Elements.

c. Low Voltage DC Power Supply.

d. Reference oscillator.

e. Signal Data Converter.

f. Built-In-Test Circuits.

g. Cabling Subassembly.

2.5.2.1.1 Antenna Pedestal

The Antenna Pedestal serves as both electrical and mechanical interface between the Antenna Assembly and the spacecraft. In addition it serves to position the antenna in either of its two operating positions, position 1 - Descent (from 50K feet to 10K feet), and Position 2 (Descent from 10K feet to touchdown). The antenna positioning is performed by a tilt actuator (reversible DC motor) controlled manually by positioning the LDG ANT switch 17S5 on the astronaut's control panel 3 to the desired position or automatically by an LGC command if 17S5 is placed in the Auto position. The Auto position, is the normal mission position and will allow the LGC to switch the antenna from POS 1 (Descent) to POS 2 (Hover) at approximately 10K feet. A position is selected by the application of +28 vdc on the appropriate control line. Power is removed from the actuator through the opening of a limit switch

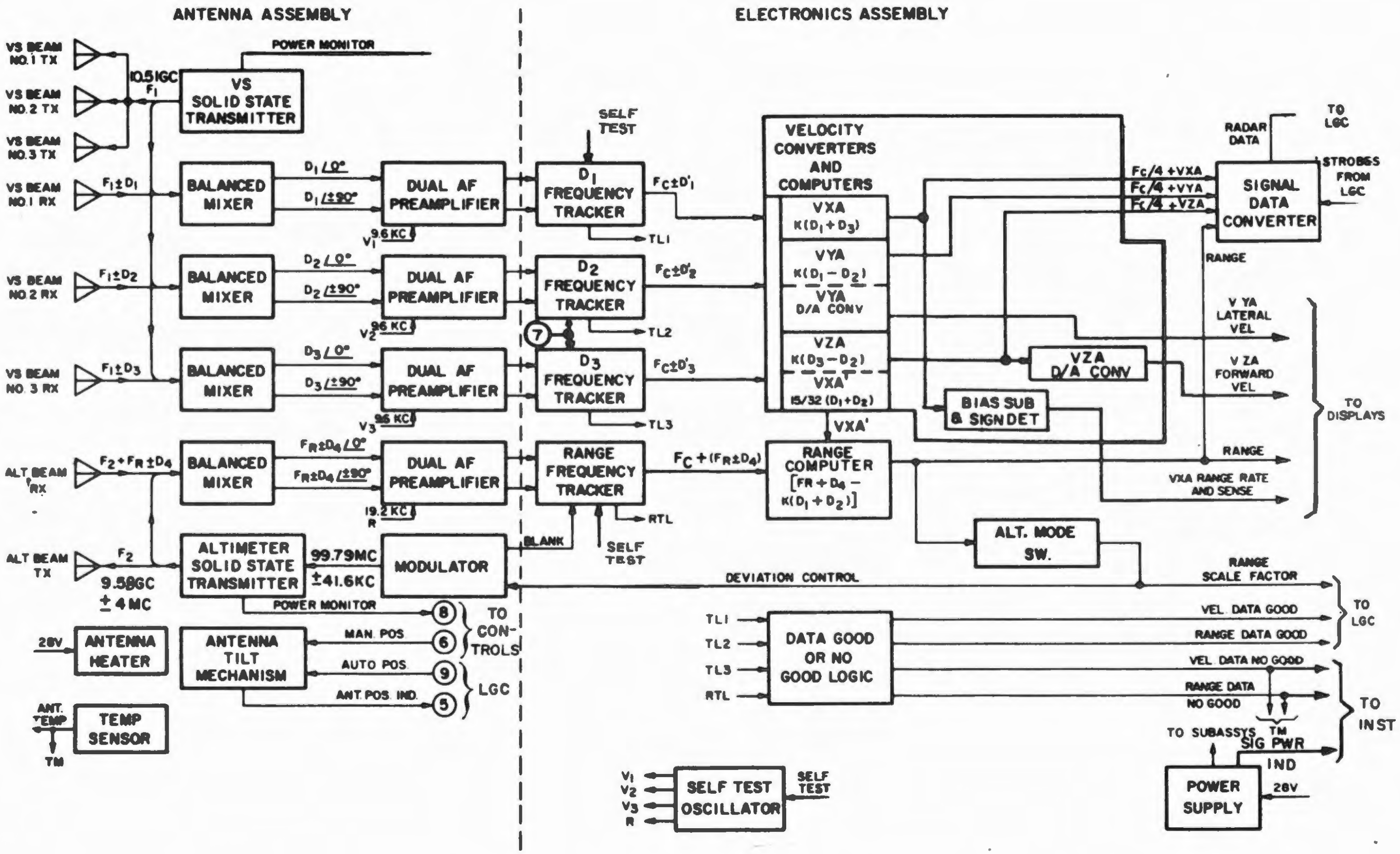


Figure 2-50. LR subsystem Block Diagram

when the antenna reaches the selected position. Travel time in either direction is approximately 10 seconds. It is not practical to make this time shorter because of the relatively high pre-load of 400 lb. used to prevent the antenna from vibrating off its stops. Nominal power drain during the 10 second travel time is 15 watts.

Antenna position indication is provided by a separate set of switch contacts which are located on the Antenna Pedestal. The discrete indication provided by the switch is used to generate Antenna Position 1 and Position 2 discrete indications to the LGC and Instrumentation.

2.5.2.1.2 Antenna Heater

The design temperature range of the Landing Radar is from 0°F to 185°F. The LM surface temperature (where the Antenna is mounted) may vary between -260°F and +260°F during the long trans-lunar and lunar orbital periods. The Antenna is partially protected from these extremes by thermal blankets and non-absorptive finishes. The low temperature extremes are however not adequately compensated for by these means when the radar is non-operating. To provide the additional protection needed during non-operate periods heating elements (cal-rods) have been imbedded in the transmitting array support structure. The heating elements control the antenna non-operating temperature between +55 and +70°F, and together with its control circuits represent a maximum power drain of 65 watts. Spacecraft power at +28 vdc is supplied to the control circuits and heating elements via contacts of a relay which is located in the cabling subassembly. This relay energizes and disables the heaters whenever power is applied to the LR Low Voltage DC Power Supply. The heater control circuit employs quadruple (X4) redundancy in switch drivers and thermistors to assure reliability. These switch driver circuits enable the power amplifier (which acts as a +28 vdc switch) when the internal antenna temperature reaches +55°F, and disables the power amplifier (Open the switch) when the antenna temperature reaches +70°F.

2.5.2.1.3 Low Voltage D.C. Power Supply

The Low Voltage DC Power Supply is mechanized in two subassemblies; the Inverter Subassembly and the Regulator Subassembly. Independent of packaging the power supply consists functionally of an input EMI filter, a pre-regulator used to boost input 28 voltage to 33.5 vdc, a 10 kc DC to AC converter, a power transformer, rectifiers, post-regulators and a 25V interlock used to insure removal of both the +25 vdc and the -25 vdc if one or the other should fail. This interlocking is required in order to prevent excessive back-biasing of transistor junctions and electrolytic capacitors.

Total unregulated input power to the supply is 132 watts, with approximately 86 watts of regulated power delivered to loads, and the remainder, 46 watts, dissipated as heat in the power supply. The regulated outputs are +25 vdc, -25 vdc, +4 vdc and -2 vdc.

2.5.2.1.4 Reference Oscillator

The reference oscillator located in the Velocity Converter provides all the sub-carriers used in the LR for signal processing, and mathematical constants used in velocity coordinate and range computation. These are derived by dividing and mixing the output of a 2.4576 mc oscillator. F_c is 614.4 kc and is the basic reference signal. Other signals are usually expressed as a function of F_c, for example, $F_c/4$, $F_c/32$, and $F_c/64$.

Landing Radar accuracy is largely dependent on Reference Oscillator accuracy. Therefore, the 2.4576 mc oscillator is a phase-lock oscillator that is synchronized with the 3.2 kc LGC clock reference.

2.5.2.1.5 Signal Data Converter

The basic function of the SDC is to convert the radar outputs into the 15 bit format used by the LGC. To accomplish this, the SDC uses a 15 bit counter, transfer gates, and a 15 bit shift register. The LGC provides the timing signals which sequentially select the PRF input to be counted, determine the counting time, and provide the Data Readout Command required to shift out the contents of the shift register. The resulting 15 bit range or velocity word is shifted out "most-significant-bit-first" (MSBF) on two lines (two twisted shielded pairs). This permits a parity check to be made by the LGC, on the transfer functions, since both lines can never simultaneously be high or low.

2.5.2.1.6 Built-In-Test Circuits

The BIT (built-in-test) or Self Test circuits generate fixed predetermined doppler and range signals which are fed to the signal processing channels of the Velocity Sensor and the Altimeter and produce known outputs on the display. A contact closure in the astronaut's Radar control Panel 3 ("Radar Test Switch" to LDG position) gates out $F_c/64$ (9.6 kc) to the Velocity Sensor, and $F_c/32$ (19.2 kc) to the Altimeter.

These signals go to phase splitters and scalers located in the V.S. and ALT Amp. Subassemblies of the Antenna Assembly. These circuits provide sine and cosine functions of the self test signals scaled to a level of 20 db above minimum acquisition level. The test signals are then applied to the 55 db pre-amplifiers and processed through the Velocity Sensor and Altimeter as if they were Lunar returns. The Alt/Alt. Rate Meter and the X-Pointers are driven to set pre-determined values.

2.5.2.1.7 Cabling Subassembly

The Cabling Subassembly contains all of the LR input/output wiring going to the operational connector. The subassembly also contains relays, relay drivers and pulse drivers. The relays are those required to obtain the "discretes" for LGC and instrumentation. The pulse drivers shape and drive the V_{xa} and Range PRF outputs over the 45 ft. cable between the LR EA and the Display/Control Assembly.

2.5.2.2 LR Velocity Sensor Functions

The CW Radar Velocity Sensor operates in the X-band (10.51Gc) using a single solid state transmitter in conjunction with a three-beam, electronically tilted transmitting array antenna. The reflected X-band energy in each beam is shifted in frequency in proportion to the relative velocities and beam angles of the LM and the reflecting surface.

$$F_d = \frac{2V \cdot F_t}{c} \text{Cos } \phi$$

Where:

F_d = The doppler shift

v = Relative velocity (total)

F_t = Transmitted Frequency

c = Velocity of Light

ϕ = Angle between velocity vector (total) and center of beam

A portion of the reflected energy is picked up by the three Velocity Sensor receiving arrays, one array for each of the three beams. The receiving antennas are broadside array antennas, tilted mechanically for maximum efficiency in the direction of the corresponding transmitter beam.

The received energy on each beam is routed through hybrids (signal splitting devices) to quadrature pair balanced mixers. In the balanced mixer, (Figure 2-51) the received energy is combined with energy directly from the solid state transmitter to accomplish a direct RF to AF conversion. Double balanced (Quadrature pair) mixers are used after the hybrids to permit retention of doppler signal sense. The signal in one channel of the balanced mixers leads or lags the signal in the other channel of the balanced mixers by 90° depending on the sense of doppler which results from an opening or a closing velocity. A closing velocity results in a positive doppler and a 90° lead signal.

The AF output of the balanced mixers is a doppler spectrum resulting from the finite width (approximately 4° in the fore-aft direction) of the transmitted and received beams. This doppler spectrum is amplified and processed in a Dual AF Preamplifier, (55 db and 33 db ampl.) then routed to a Frequency Tracker. The Preamplifiers employ a switched AGC. At high altitudes, where signal strengths are low, the Preamplifiers use two stages of amplification: 55 db and 33 db. The output of each Dual AF Preamplifier is sampled by a threshold detector. When the output signal level rises to approximately 300 mv (indicating a strong input signal to the preamplifiers) a solid state switch is enabled and a low gain indication is given the respective Frequency Tracker. When the solid state switch is thus enabled, the 33 db amplifier is bypassed, and the doppler signal gets only 55 db of amplification.

The Frequency Trackers acquire and track the center of each doppler spectrum. In this process the doppler return is averaged and smoothed to obtain the doppler frequency D' representative of the doppler shift corresponding to the center of the RF beams. (See Figure 2-52.) The smoothing tends to reduce

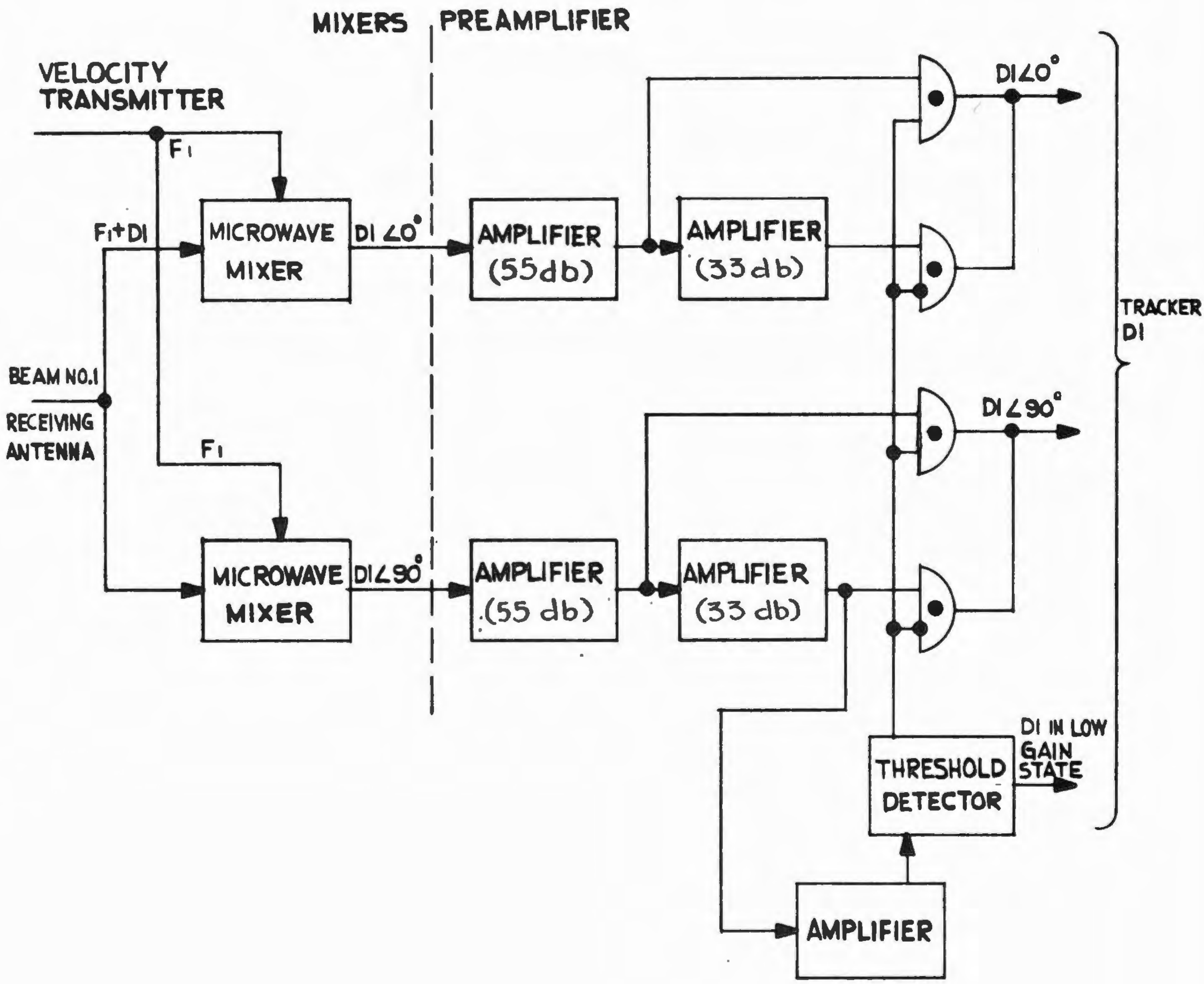


Fig. 2-51. Microwave mixers and preamplifier functional block diagram.

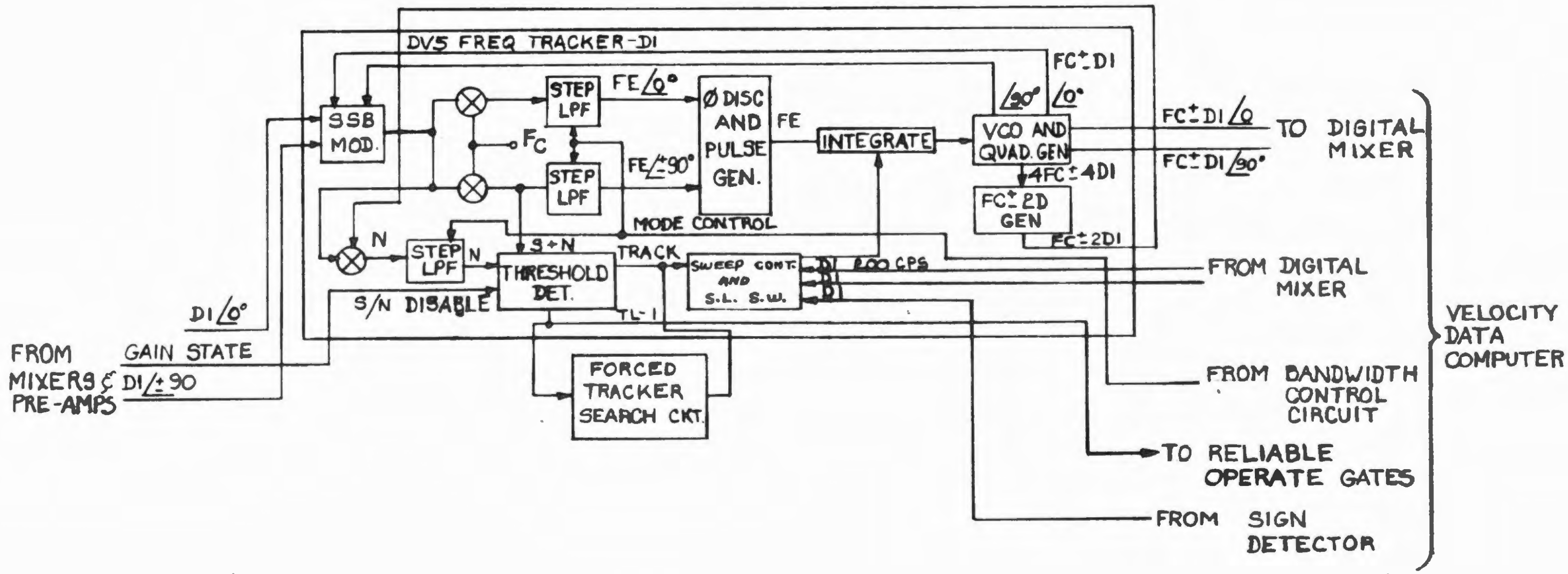


Fig. 2-52. Velocity Frequency Tracker Functional Block Diagram.

effects of random noise and flunctuations resulting from uneven or different quality of reflecting surfaces. In addition the AF doppler is mixed with a 614.4 kc subcarrier used in the further processing of the signal in the Velocity Data Converter.

The Doppler Velocity Sensor (DVS) Frequency Trackers consist of two functional loops: the Tracking Loop and the Acquisition Loop. The Tracking Loop is basically a narrow band AFC circuit. Its purpose is to smooth and track the center of the doppler spectrum. Doppler sense is retained. The output is a pure sinusoid at the frequency of $F_c + D'$.

The basic functions of the Acquisition Loop are to sweep the Tracking Loop to within its acquisition (pull-in) capability and to prevent the Tracking Loop from locking on and tracking a false return. In addition, the Acquisition Loop provides a tracker lock signal (TL) used to determine LR operational status.

Tracker lock, or acquisition, is determined based on a signal to noise power comparison in the Doppler Signal Threshold Detector. A S/N ratio of 3 db is required before the tracking loop is permitted to lock on, and start tracking the doppler return.

When all three frequency trackers are locked the Data Good Logic issues a Velocity Data Good (VDG) discrete to the LGC and to Instrumentation.

The Velocity Data Converter contains three identical doppler processing circuits, referred to here as the D1, D2 and D3 converter. These circuits extract the subcarrier F_c, synchronize and multiply the doppler frequency by four, indicate doppler sense, and based on doppler sense provide an output to the Velocity Data Computer (part of same block as Velocity Converter).

In addition to the three converters, the Velocity Data Converter contains the Velocity Sensor Bandwidth Control Circuit (VSBCC). This circuit is basically a frequency comparator used to switch each DVS Frequency Tracker to its Narrow Band-Pass Mode when (1) its output frequency becomes less than 1.47 kc ($D_1 < 1.47$ kc), and (2) to switch all of the DVS Frequency Trackers to the Narrow Band Pass Mode when altitude is less than 2500 ft. as indicated by the discrete signal from the Range Computer Altitude Mode Switch. (See figure 2-53.)

The Velocity Data Computer converts the beam doppler products, D_1, D_2 and D_3 into the antenna velocity coordinate outputs; V_{xa}, V_{ya}, V_{za}. The relationships computed are as follows:

Antenna Coordinate Outputs to LGC and Displays

$$V_{xa} = \left(\frac{D_1 + D_3}{2}\right) K_1$$

$$V_{za} = \left(D_3 - D_2\right) K_2$$

$$V_{ya} = \left(D_1 - D_2\right) K_3$$

The scale factors (K) used in interpreting the above velocity data specified as discrete numbers are derived from the appropriate trigonometric relationships of the beams associated with each velocity coordinate.

The three velocity data computers for obtaining LGC data each consists of an "adder, subtractor, divider", and a pulse shaper and driver. (See figure 2-54.) The "adder, subtractor, and dividers" form the velocity coordinate terms, and then combine this term with an $F_c/4$ subcarrier in order to retain velocity coordinate sense. The resulting PRF modulated pulse train is applied to a pulse shaper and driver.

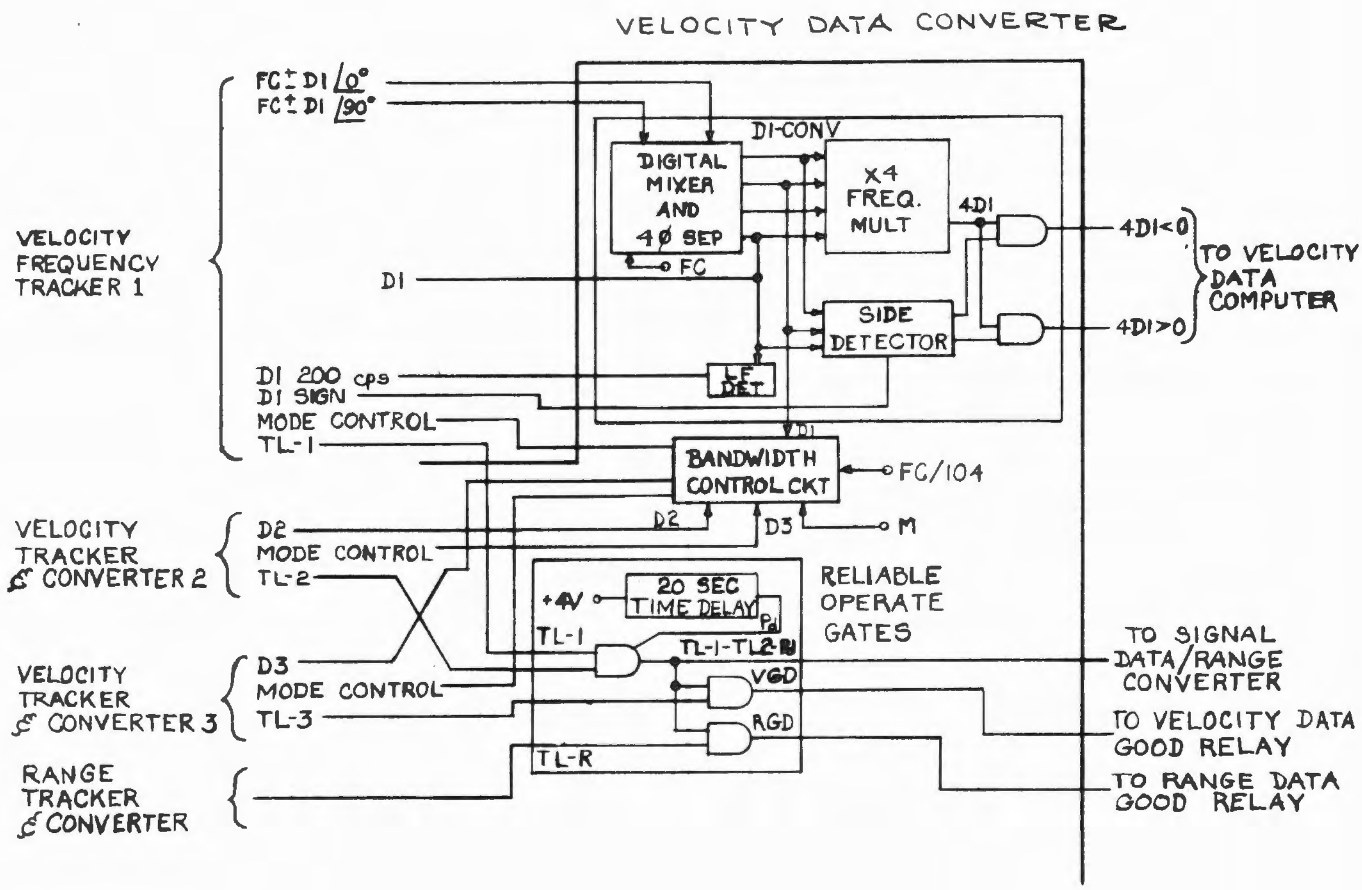


Fig. 2-53. Velocity Data Converters Functional Block Diagram.

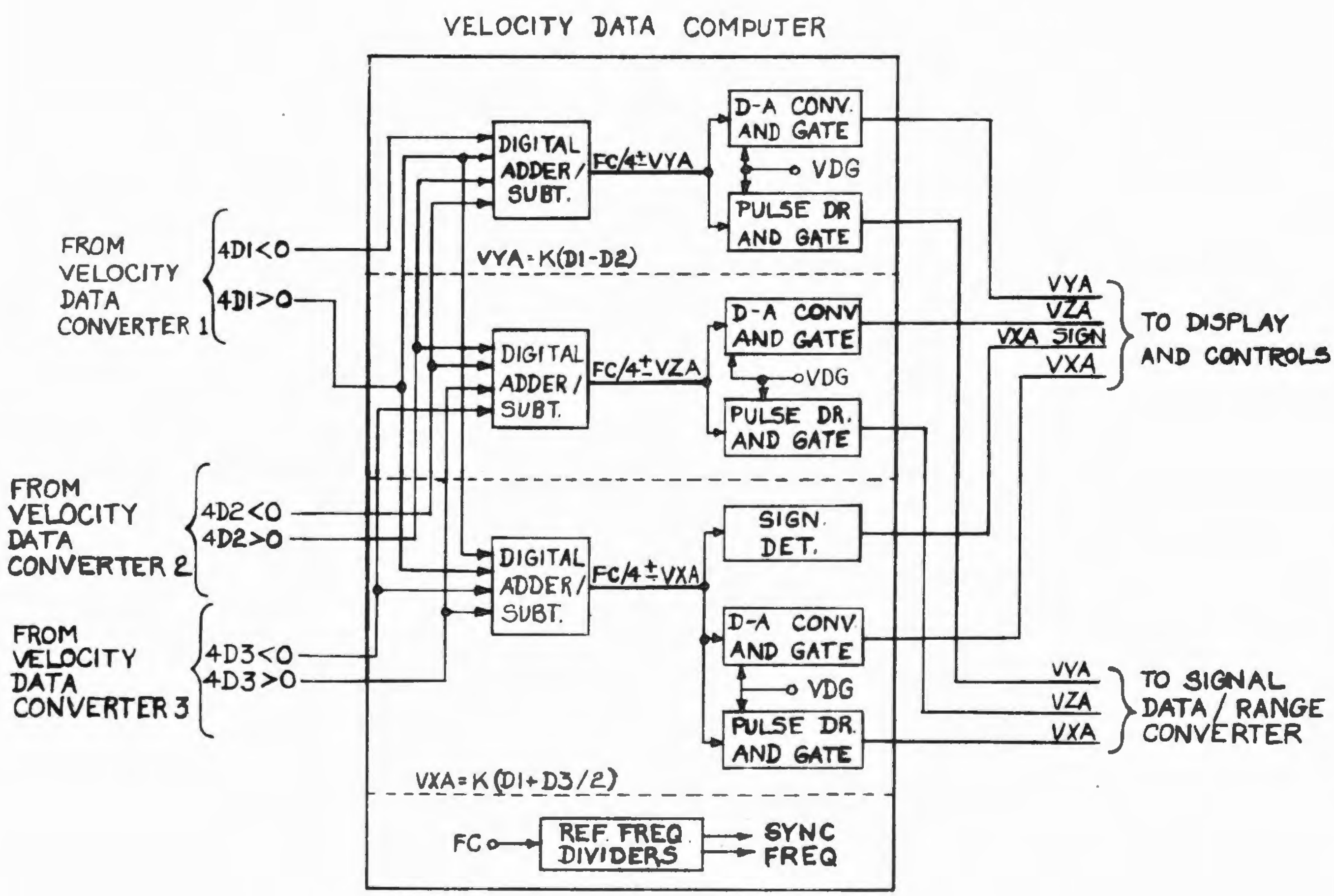


Fig. 2-54. Velocity Data Computers Functional Block Diagram.

There are also three display coordinate computers (Primed Velocity Computers) located in the Velocity Data Computer Sub-assembly. The outputs of two of these computers are dc voltages directly proportional to the measured velocity and are used to drive the X-pointer velocity displays. The pulse trains are applied to the "Gate and Averaging Circuit" (Digital to Analog Converter), where it is averaged to obtain the analog outputs for V_{ya}' and V_{za}'. The V_{xa}' pulse train is applied directly to the range rate meter with a sense signal (open relay contact for closing range rate).

2.5.2.3 LR Altimeter Functions

The FM/CW Radar Altimeter is very similar to the Doppler Velocity Sensor in circuitry and in operation. The Altimeter solid state transmitter is very similar to the DVS transmitter, however, it does not contain an internal oscillator. Instead it receives an input from the Modulator. This input is frequency modulated in a sawtooth manner, at a repetition rate of 130 cps. The Altimeter X-band (9.58 GC) microwave energy is applied to the altimeter transmitting antenna, a single-beam, electrically tilted array antenna.

A continuous sample is taken of the transmitted energy and mixed with the return energy. The resultant difference of the mixing process is called the range frequency and is proportional to the sawtooth frequency deviation rate, and two times the distance to the reflecting surface.

$$fr = \frac{2a \cdot dr}{c}$$

where

fr	=	Range Frequency	c	=	Velocity of Light
a	=	Distance to the reflecting surface			

$$dr = \text{Deviation rate} = \frac{40 \text{ mcps}}{7000 \text{ Msec}} \text{ (Hi)} = 59.429 \text{ Mc/sec}^2$$

$$\text{or} \quad \frac{8 \text{ mcps}}{7000 \text{ Msec}} \text{ (Lo)} = 11.886 \text{ Mc/sec}^2$$

In addition to this frequency difference, (fr), there will be an additional frequency component (doppler) due to any relative velocity along the altimeter beam.

This doppler component, (called D_4), is proportional to velocity along the altimeter beam, and adds to or subtracts from the range frequency (fr) depending on opening or closing velocity. A closing velocity results in a positive doppler signal. The signal processed by the Altimeter circuits can therefore be expressed as:

$$fr + D_4 = \left[\frac{2a \cdot dr}{c} \right] + \left[\frac{2v \cdot FT}{c} \text{ Cos } \phi \right]$$

Energy from the receiving antenna is split to form a quadrature pair of returns. These returns are coupled to microwave mixers along with a sample of the transmitted signal. The output is the difference frequency which is proportional to the time difference of the transmitted and received modulated energy, plus the doppler shift, as expressed above.

The quadrature pair output, ($fr + D_4$), is routed to and processed by a Dual AF Preamplifier in the same manner as was done in the Velocity Sensor. After Amplification, ($fr + D_4$) is routed to the Altimeter Frequency Tracker, where it is processed in a like manner as previously discussed for the doppler signals in the DVS Frequency Trackers. The main difference in operation is that the Altimeter Frequency Tracker contains a gate used to disable the tracking loop during flyback of the sawtooth modulation. This is accomplished with a 700 usec. blanking gate from the Oscillator/Modulator.

The Altimeter frequency tracker has two outputs; the tracker lock indication (RTL) routed to the Data Good Logic and $F_c + (fr + D_4)'$ which is routed to the Range Converter for processing and doppler compensation (removal of the term D_4).

In the Data Good Logic the term RTL is logically combined with the tracker lock indications TL1 and TL2 to provide the Range Data Good (RDG) signal used as a discrete indication of radar altimeter operation to the LGC and to Instrumentation.

Processing of the term $F_c + \left(f_r + D_4 \right)'$ consists of removing the term (F_c) and sending the signal to the Adder/Subtractor, where the term D_4 is removed through logical combination with $\frac{15}{32}(D_1 + D_2)$.

The velocity compensated range frequency (fr), a negative going pulse train, is routed to a frequency comparator, called the "Reference Signal Generator" and to a pulse shaper and gating circuit.

The Reference Signal Generator circuit functions as a frequency comparator, in that it compares (fr) against reference frequencies derived from the Reference Oscillator. The reference frequencies are selected so as to provide a change in the output logic states (M) and ($\overline{M}$) when slant range equals 2500 ft. on a descending trajectory, and 2600 ft. on an ascending trajectory. The logic state outputs are used as "mode control signals", and as "gating signals". As mode control signals, (M) (Altitude $<$ 2500 feet) is routed to the Velocity Sensor Bandwidth Control circuit, where it is used to simultaneously switch all DVS frequency trackers to the Narrow Bandwidth Mode whenever slant range is less than 2500 ft. (M) is also used to switch the ALT. Frequency Tracker to the Narrow Bandwidth Mode, and to accomplish the Oscillator/Modulator deviation rate change. Mode Control (M), is also called "Range Low Scale Factor", and as such it is routed to a driver and relay in the cabling subassembly, where it is converted to a range scale discrete signal for use by the LGC. When $\overline{M}$ is present, the altitude is greater than 2500 feet, a relay is energized to remove the low scale factor discrete from the LGC. At 2500 feet M is present and the relay contacts close for the discrete indication.

The range pulse train (fr) is routed to the displays and to the Signal Data Converter where it is processed by the 15 BIT counter and Shift Register in the same manner as previously described for V_{xa}, V_{za} and V_{ya}. (See figure 2-55.) The primary difference is that (fr) is not riding a bias frequency.

2.5.2.4 LM-3 LANDING RADAR RF VIEW FACTOR TEST MODIFICATIONS

Basically, the modifications performed on this radar for RF View Factor test purposes consist of those required to achieve the following three results:

1. Gating out of LR data regardless of Frequency Tracker Lock Status.
2. Monitoring of individual Frequency Tracker outputs by LGC rather than composite terms such as V_{xa}, V_{ya}, and V_{za}.
3. Defeating of any functions that would complicate the analysis of test performance, eg.; Altitude Mode Switching; Altimeter Frequency Deviation; and Fly-back Blanking of Altimeter Frequency Tracker.

A. Item number one was achieved by cutting the "wires" carrying the Frequency Tracker Lock-up indications from the individual frequency trackers to the "Data Good" Logic Circuits. The "Data Good" Logic Circuit inputs were then tied-up to +4V, resulting in simulated Velocity Data Good (VDG) and Range Data Good (RDG) conditions any time LR Signal Power is on.

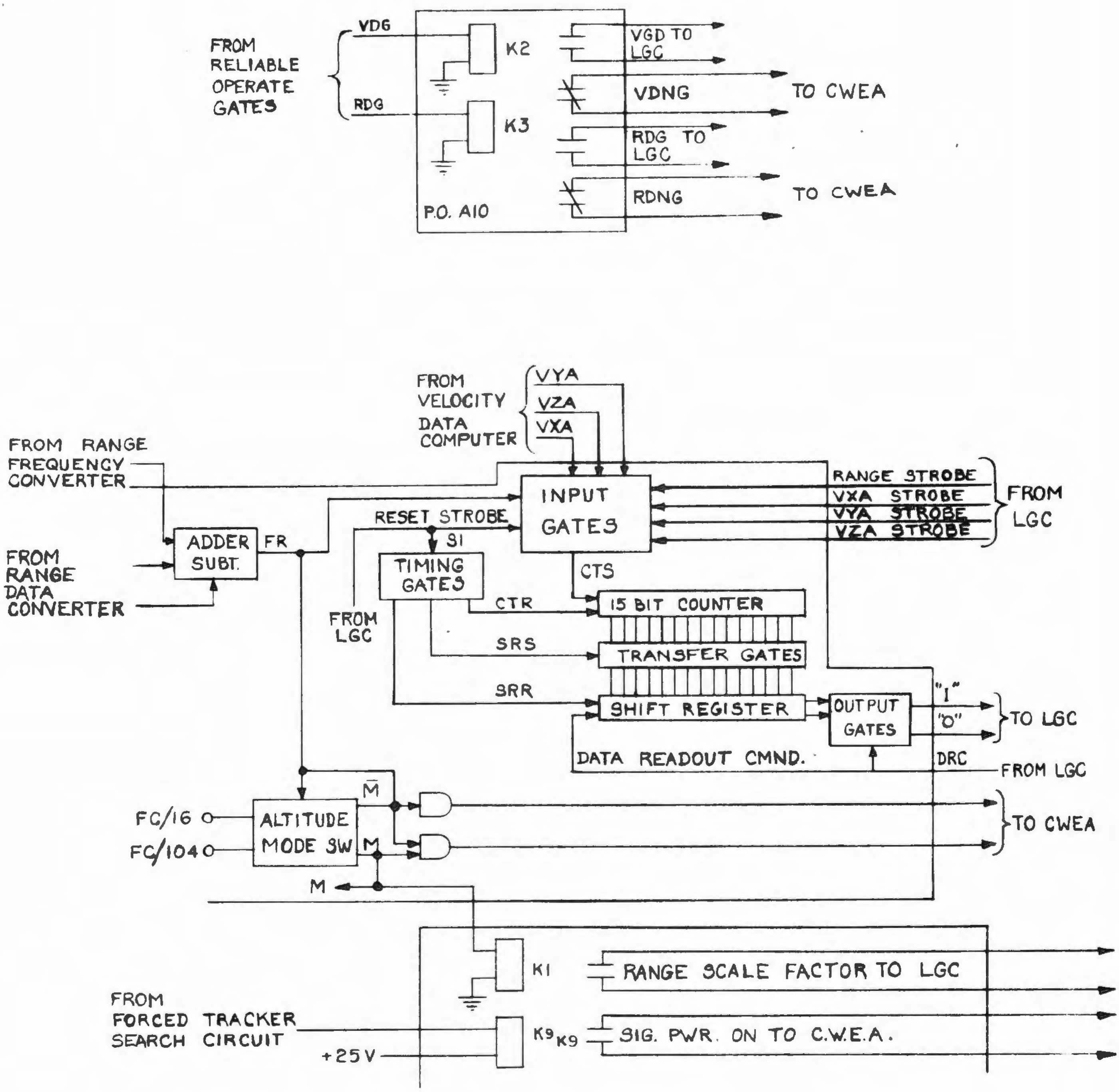


Fig. 2-55. Computer Interface Unit Functional Block Diagram.

B. Item number two has been achieved by modifying the inputs to the V_{xa}, V_{ya}, V_{za} Computers and the Range Computer. Where these computers normally combined two or more doppler components in specific proportions, their inputs now have been modified so that only one doppler term is processed by each computer.

The V_{xa} computer has been modified by removing the $4D_3 > 0$ and $4D_3 < 0$ inputs. The V_{xa} computer output then becomes $Fc/4 \pm D_1/2$.

The V_{ya} computer has been modified by removing the $4D_1 > 0$ and $4D_1 < 0$ inputs. The V_{ya} computer output then becomes $Fc/4 \pm D2$.

The V_{za} computer has been modified by removing the $4D_2 > 0$ and $4D_2 < 0$ inputs. The V_{za} computer output then becomes $Fc/4 \pm D3$.

The Range Computer has been modified by removing the doppler compensation term $V_{xa}' = 15/16 \frac{D_1 + D_2}{2}$, leaving $fr + D_4$ as the output. D_1, D_2, D_3 and the term fr and D_4 will now become the instantaneous value of frequency offset from Fc of the respective frequency trackers, as they are sweeping (at known rates) looking for an input signal, or tracking a spurious return.

C. Item number three has been achieved through the following modifications:

1) Defeating the switching action of the Altitude Mode Sw. (Range Mark Generator) by removing the fr input and tying up to +4VDC, thus assuring that the output will always command "high altitude mode", and therefore not affect the DVS Freq. Tracker Bandpass selections, or sweep rate selections.

2) Opening of Blanking Signal (700 micro sec) input to the Altimeter Frequency Tracker from the Altimeter Oscillator/Modulator. This

prevents "blinding" the Alt. Freq. Tracker to spurious returns for 1/10 of the time, as well as providing assurance against the possibility of permanent blanking when Alt. Osc./Mod. Deviation is inhibited.

3) In order to make the Altimeter Freq. Tracker more sensitive to spurious signals during this test flight, the Alt. Osc./Modulator has been modified to prevent its sweeping of the Alt. Transmitter excitation. This has been accomplished by, at the GSE connector, activating (grounding) the Alt. Osc./Mod. Deviation Inhibit input. This inhibits the 130 cps basic clock in the Alt. Osc./Mod., resulting in this subassembly generating a constant 99.79 Mc excitation for the Altimeter X96 Frequency Multiplier/Transmitter.

D. In addition to the above basic circuit modifications on the LM-3 Landing Radar, there are also certain added telemetry points and transducers for Developmental Flight Instrumentation.

This DFI includes the monitoring and downlinking of the D_1, D_3 and D_4 Dual AF Preampl. outputs, Both 0° and 90° spectrums; Antenna tilt position indications; two added antenna mounted temperature transducers; and one antenna mounted vibration transducer.

SECTION 3

INTERFACE OF THE PGNCS WITH OTHER LM SYSTEMS

3.1 STABILIZATION AND CONTROL SYSTEM

The stabilization and control system (SCS) contains two major functional sections: the control electronics section (CES) and the abort guidance section (AGS). The SCS maintains two independent loops for flight control of the LM by its interfaces with the PGNCS, the reaction control system (RCS), and the propulsion system (PS). The primary loop which performs all functions necessary to complete the LM mission consists of PGNCS, CES, RCS, and PS. If a major failure occurs in the PGNCS, the abort guidance loop is used. The abort loop is achieved when the AGS is substituted for the PGNCS, thereby providing backup guidance, navigation, and control functions for a safe rendezvous with the orbiting CSM. The rendezvous radar can then be operated independent of PGNCS operation to provide navigation and guidance data to the AGS or can be used independent of either guidance system to obtain an effective rendezvous with the CSM.

3.1.1 Digital Autopilot Flight Control

The digital autopilot (DAP) is that segment of the PGNCS (primarily LGC and DSKY) which interfaces with the flight control subsystems to perform an autopilot or augmentation task. The DAP works either in conjunction with the PGNCS guidance loop to provide an integrated guidance and control system, or in conjunction with the THRUST/TRANSLATION Controller Assy. (TTCA) and the Attitude Controller Assy. (ACA)

The major PGNCS functional interfaces for flight control are between the LGC and the CES (see Fig. 3-1). During autopilot operation, the LGC utilizes its navigation and guidance data to compute the necessary commands that must be issued to the CES to obtain proper flight control.

The LGC generates sixteen discrete (ON-OFF) commands for each of the 16 RCS jets to control LM translation, ullage, and rotation. The attitude and translation control assembly (ATCA) amplifies these commands to the level required by the RCS primary solenoids. A selectable deadband feature is associated with the ATCA jet selection logic to provide a wide or narrow deadband. The wide deadband is used during coasting phases of the mission to conserve fuel, while the narrow deadband is used when accurate attitude control is required.

For descent or ascent engine control, ON-OFF commands originate from either the LGC or the Abort Guidance Section (AGS). The two signals from the LGC are not issued until after receipt of the engine armed discrete and after the LGC has performed proper ullage. Engine off is signalled based upon computer guidance program.

The descent engine can be operated as a continuously-throttleable engine throttled from 10% to 60% of its maximum thrust either automatically or manually or it can be operated at fixed throttle setting of 92.5% of maximum thrust. Automatic throttle signals from the LGC are processed by the descent engine control assembly (DECA) and are directed to the descent engine. The two signals (increase or decrease throttle rate) from the LGC to the descent engine throttle servo are transformer coupled 3200 pps pulse trains which indicate increments of thrust.

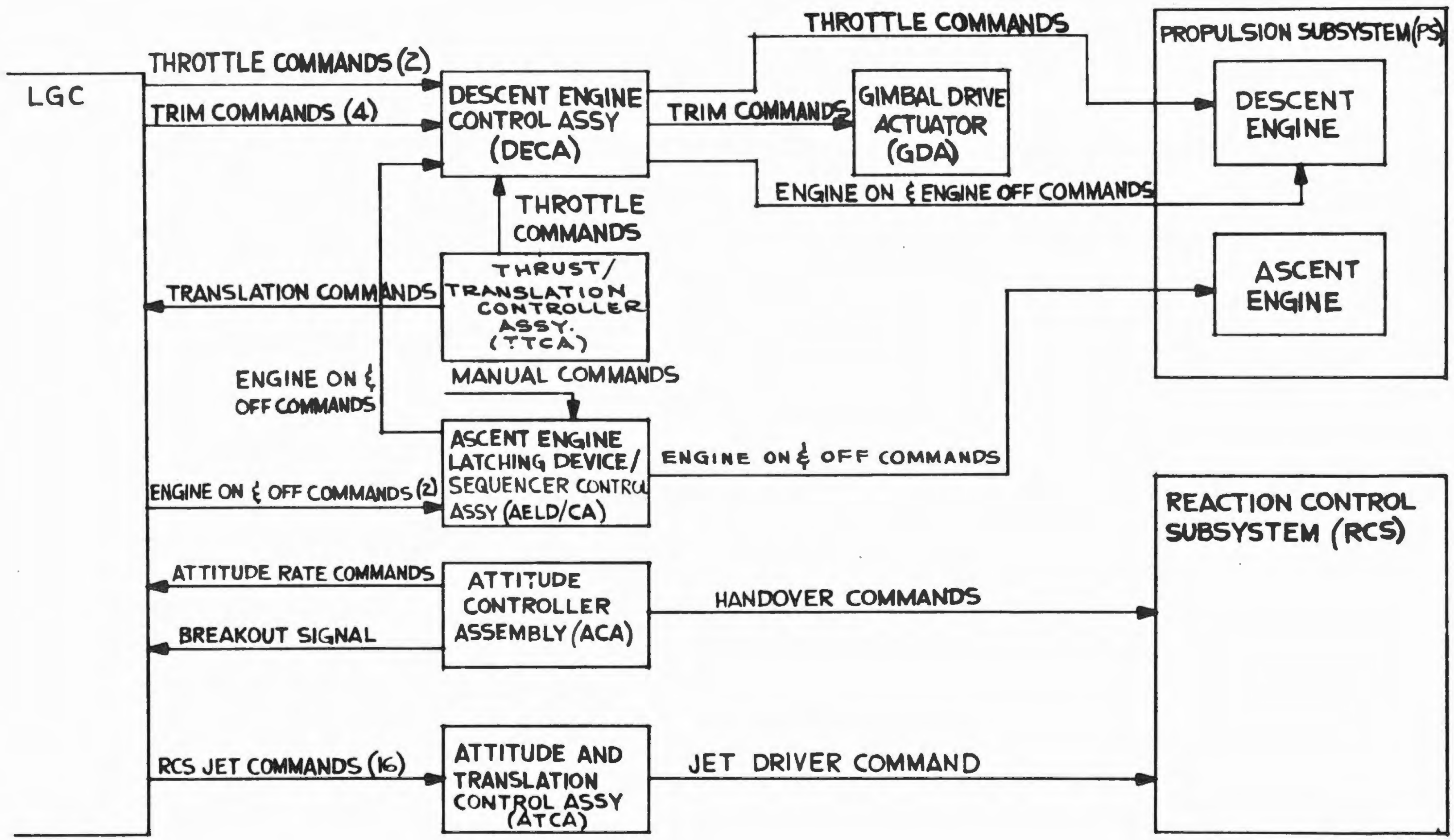


Fig. 3-1. LGC/flight control functional interfaces.

The automatic throttle can be manually overriden to increase engine throttle by advancing the TTCA. The crew can also select complete manual thrust control.

The DECA receives four discrete (ON-OFF) rotation commands from the LGC and mechanically gimbals the descent engine. The descent engine is rotated at a constant angular rate of 0.2 degrees/second about the pitch or roll axis in the direction commanded for the duration of the ON command. Limits of rotation are plus or minus 6 degrees from the center position.

During descent engine burning, the DAP tries to control the spacecraft attitude with the trim gimbal servo in order to save RCS propellants; but if the rather slow trim gimbal drive does not keep the attitude error within certain bounds, the RCS jets are used as the error is brought within the attitude deadband and then control is returned to the trim gimbal servo. The yaw control is always handled by RCS jets.

The LGC also monitors signals for modification of commands. Two dc signals from the automatic detection circuitry indicate the status of the descent engine from the gimbals to the LGC. With this information, the LGC modifies the descent engine gimbal commands appropriately. Monitoring is also done of the eight RCS thruster-off signals to choose the best set of jets to use under the combined conditions of rotational commands, translation commands, and failed jets. Eight dc signals from the THRUSTER PAIR switches indicate the status of RCS jet pairs to the LGC. With this information, the LGC modifies appropriately the jet select program in recognition of failed jets.

3.1.1.1 Attitude Controller

Astronaut manual control of vehicle attitude is commanded from either of the pistol-grip, right-hand controllers. Each attitude controller is mounted whereby the direction of LM rotations corresponds to the direction of the astronaut's hand motions. Hand movement to the left commands a left-roll and to the right commands a right-roll. Clockwise rotation of the controller commands a right-yaw and counterclockwise rotation commands a left-yaw. A forward hand movement on the controller commands a down-pitch and backward commands an up-pitch.

A functional diagram of an attitude controller is contained in Fig. 3-2. When the controller is displaced from the center detent position, a detent switch is closed to provide a discrete to the LGC indicating attitude rate commands are being generated. The LGC then issues attitude change commands to the jet drivers. These commands are proportional to the controller generated rate commands with polarity determined by the phase of the controller rate commands with respect to a PGNCS 800 cps reference. The limit switches at the hardover position are hardwired to the secondary RCS jet solenoids; thereby, enabling the astronaut to fire the reaction control jets directly, regardless of the flight control mode.

Guidance signals to the jet logic interrupted on an individual axis basis (direct, pulse signals to ATCA) is only utilized with the abort guidance loop.

3.1.1.2 Translation Controller

Astronaut manual control of LM translation and throttling of the descent engine is commanded from either of the tee-handle left-hand controllers.

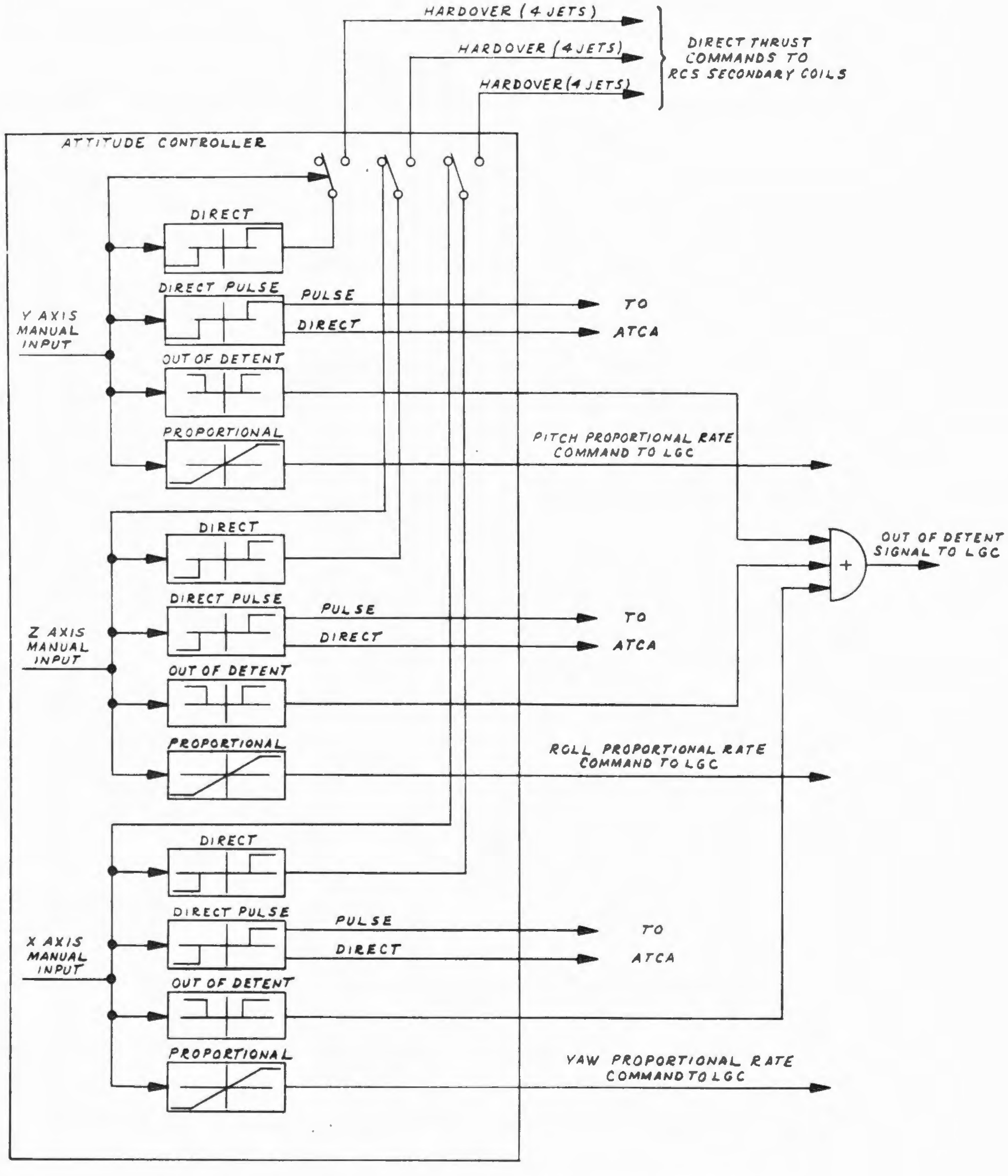


Fig. 3-2. Attitude controller functional diagram.

Both controllers always provide translation capability along the LM pitch axis (Y-axis) and LM yaw axis (Z-axis). Each of the translation controllers is installed with its longitudinal axis approximately 45° from a line parallel to the LM roll axis permitting the direction of LM translations to correspond to the direction of the astronaut's hand motion. Motion of the controller to the left or right commands translations along the LM pitch axis and movement forward or backward commands translations along the LM roll axis.

When the two-position selector on the controller is set to the JETS position, up and down motion of the hand controller commands translations along the LM yaw axis (X-axis). With the switch in the THROTTLE position, up and down motion results in varying the thrust magnitude of the descent engine. Only one of the two controllers has manual throttle capability at any one time, depending on the position of the MAN THROT switch which routes 800 cps excitation voltage to one of the controller throttle transducers (see paragraph 3.3).

Translation command signals generated by a controller are routed to the LGC (see Fig. 3-3). A pair of detent switches are located about each controller axis so that when the controller is displaced from its neutral position discretes are issued to indicate the direction and axis of displacement. Translation along the roll, pitch, and yaw axis can be commanded independently or in combination. Thus, the LGC issues translation commands in accordance with the controller motion and the resultant on-off jet commands originate from the LGC (a pair of limit switches about each controller axis provide the ability during abort guidance to manually issue translation commands directly to the jet logic and driver circuitry of the RCS.)

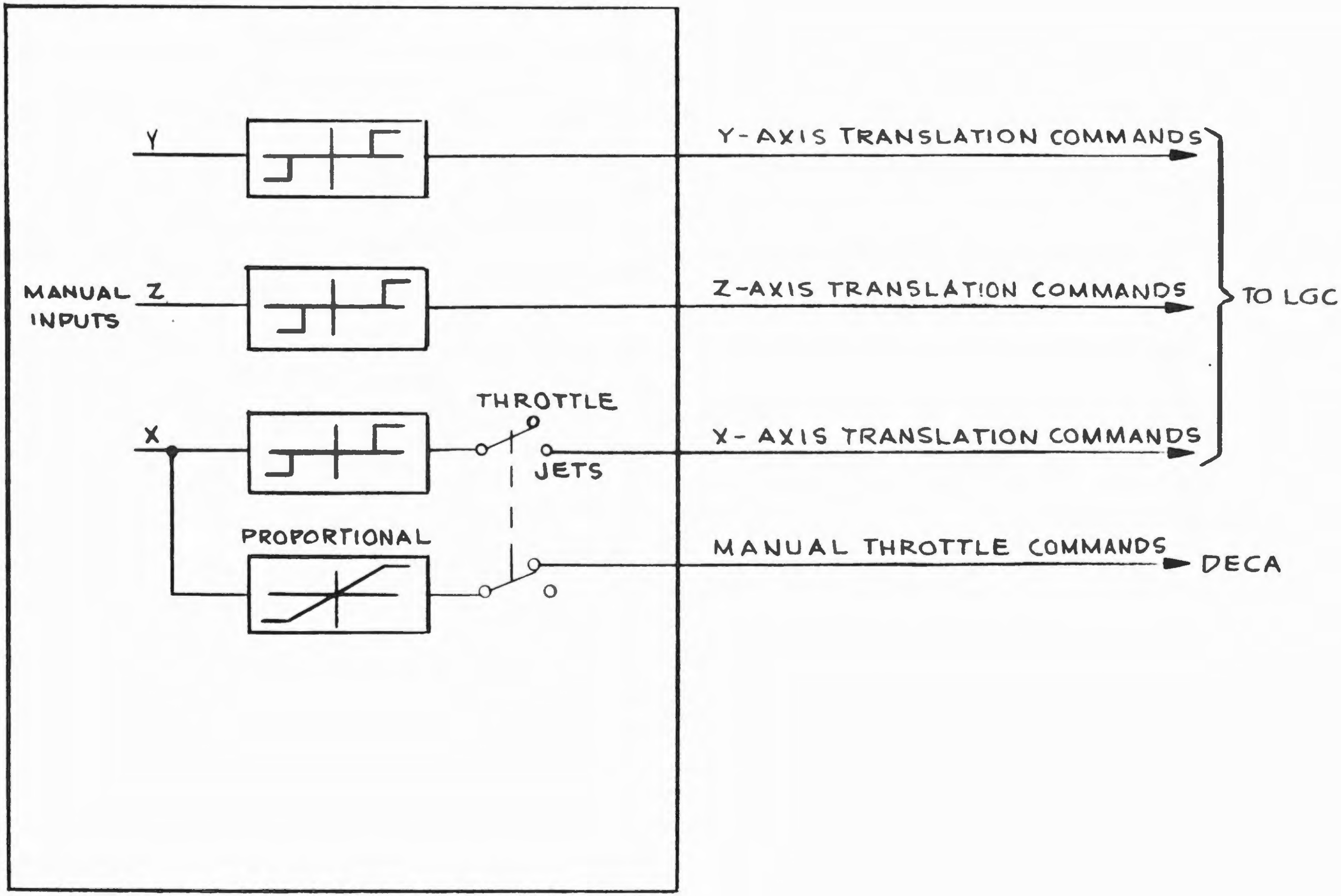


Fig. 3-3. Translation controller functional diagram.

3.1.1.3 Selectable Modes of the DAP

By means of the DSKY keyboard and the MODE CONTROL switch, the astronaut can select the DAP mode of operation. The DAP modes are as follows (for all of these modes, except the last, the GUID CONT switch must be in the PGNS position).

LM DAP Control Mode		Position of Mode Control Switch: AUTO	ATT HOLD	OFF
COASTING FLIGHT	Automatic Maneuvering	X		
	Attitude Hold	X	X	
	Manual Rate Control		X	
	X-axis override	X		
	Minimum Impulse Control		X	
	Off			X
POWERED FLIGHT	Automatic Steering	X	X	
	Attitude Hold		X	
	Manual Rate Control		X	
	X-axis override	X		
	Minimum Impulse Control		X	
	Off			X

TABLE 3-1. DAP Selectable Modes

Prior to the selection of DPS program (P40), RCS program (P41), or APS program (P42), keying in V48E selects the DAP data load routine (R03). This routine first flashes V01N46 which displays the DAP configuration code (ABCDE) in R1 (see Table 3-2). If the DAP configuration is not what is desired, V21E is keyed and the correct code is keyed into R1 display.

3.1.1.3.1 Automatic Mode

The automatic mode is used when the PGNCS rather than the astronaut is commanding the orientation of the spacecraft. The LGC guidance equations and steering law communicate with the DAP by periodically placing new numbers in the CDU desired registers and by specifying appropriate attitude deadbands. Hence, all attitude and translation commands necessary to perform a maneuver originate from the LGC. The LGC generates RCS jet

Code	Description
A = 0	LM Only
A = 1	LM and CSM
B = 0	2 Jet Translation (RCS System A)
B = 1	2Jet Translation (RCS System B)
B = 2	4 Jet Translation (RCS System A&B)
C = 0	Fine scaling ACA (0.125°/sec/bit)
C = 1	Normal scaling ACA (0.625°/sec/bit)
D = 0	Attitude deadband of 0.3 degrees
D = 1	Attitude deadband of 5.0 degrees
E = 0	Kalcmanu rate of 0.2 degrees/second
E = 1	Kalcmanu rate of 0.5 degrees/second
E = 2	Kalcmanu rate of 2 degrees/second
E = 3	Kalcmanu rate of 10 degrees/second

Table 3-2. DAP configuration codes.

commands, descent engine increase and decrease signals, ascent and/or descent engine on/off signals, and descent engine pitch and roll gimbal actuator on/off commands.

Associated with the automatic attitude maneuver is the V06N46 display, bit E, which selects the Kalcmanu rate of the maneuver. Low rates are chosen to conserve fuel, while high rates are chosen for expediency.

3.1.1.3.2 Minimum Impulse Command Mode

This mode of the DAP is sometimes used during the inflight star-sighting mark procedure. To enter the mode, V76E is keyed. To exit from this mode and use the ACA for the usual rate commands, the V77E is keyed. Fresh start initializes the ACA for rate commands. The autopilot stays in the selected mode (minimum impulse or rate command) until the contrary verb, 76 or 77, is entered.

The minimum impulse mode is used by the astronaut to control the spacecraft with very low rate maneuvers. Each discrete deflection of the ACA (2.5 degrees or more out of detent) will cause the DAP to issue commands to the appropriate jets for minimum impulse. In this mode, the astronaut must do his own rate damping, his own attitude steering, and his own anticipation. When the crew selects the minimum impulse mode, they can perform an economic low rate maneuver to a new orientation of the spacecraft.

During the minimum impulse command mode, the LGC commands one minimum impulse for each excursion of the hand controller beyond the limit switches (they are mounted 2.5 degrees to each and every side of the in-detent position). The ACA must be returned momentarily to the in-detent position between each pair of minimum impulses. Thus, no more than one pulse will be commanded by the LGC for each deflection of the hand controller. The maximum frequency at which minimum impulses can be commanded is about five per second. If the astronaut wants a moderate change in rate rather than a very small one, he should normally use the rate command mode.

It should be emphasized that no rate damping or attitude hold is exercised by the DAP during the minimum impulse command mode: the spacecraft drifts except for the minimum impulses commanded by the astronaut.

3.1.1.3.3 Rate Command Mode

The rate command mode is the normal means of astronaut control of the spacecraft. The DAP is ready to go, and the instant the astronaut enters verb 77, the CDU desired registers are initialized to the values of the CDU registers and the DAP begins attitude control.

The maximum maneuver rate about any axis of the spacecraft is 20°/second. The ACA acts as an analog device during rate command, producing a voltage proportional to stick deflection. The voltage represents the commanded rate; it is converted to a binary number and presented to the DAP. When the stick is out of detent the DAP tries to make the vehicle rate match the rate commanded by the ACA. When the rate error is less than the rate deadband (0.4 deg/sec during descent, 1.0 deg/sec during ascent), the jets are no longer commanded on. But if the rate error exceeds a certain bound (2.0 deg/sec in ascent, 1.4 deg/sec in descent), four jets are used to torque the spacecraft. When the ACA is returned to the in-detent position, the DAP computes the time of jet burning required to zero the rates of the vehicle. When the vehicle rate is brought inside a deadband about zero rate, the contents of the CDU registers are transferred to the CDU desired registers and attitude steering about the newly attained vehicle position is commenced. If the spacecraft has a sizable pitch and roll rate error, diagonal jets are used.

The Attitude Controller Ass'y scale factor per bit is selected via bit C register 1, display V01N46. A fine scale of 0.125°/second per bit permits fine analog rate commanding (when C = 0) and a normal scaling of 0.625 /second per bit (when C = 1).

3.1.1.3.4 Deadband Select Mode

The astronaut has his choice of two attitude deadbands during attitude hold. The wide deadband is used during coasting phases of the mission to conserve fuel, while the narrow deadband is used when accurate attitude control is required.

An attitude deadband of 0.3 degrees is obtained when bit D = 0 and of 5.0 degrees when bit D =1 of V01N46 R1 display.

3.1.1.3.5 Two or Four Jet X-Axis Translation Modes

A selection of two or four jet operation during attitude hold is attained via bit B of V01N46 R1 display.

If one of the four X-axis translation thrusters has failed, the jet selection routines in the DAP select the unfailed translation pair. Note that this policy allows the astronaut to exercise fuel management via his thruster isolation switches.

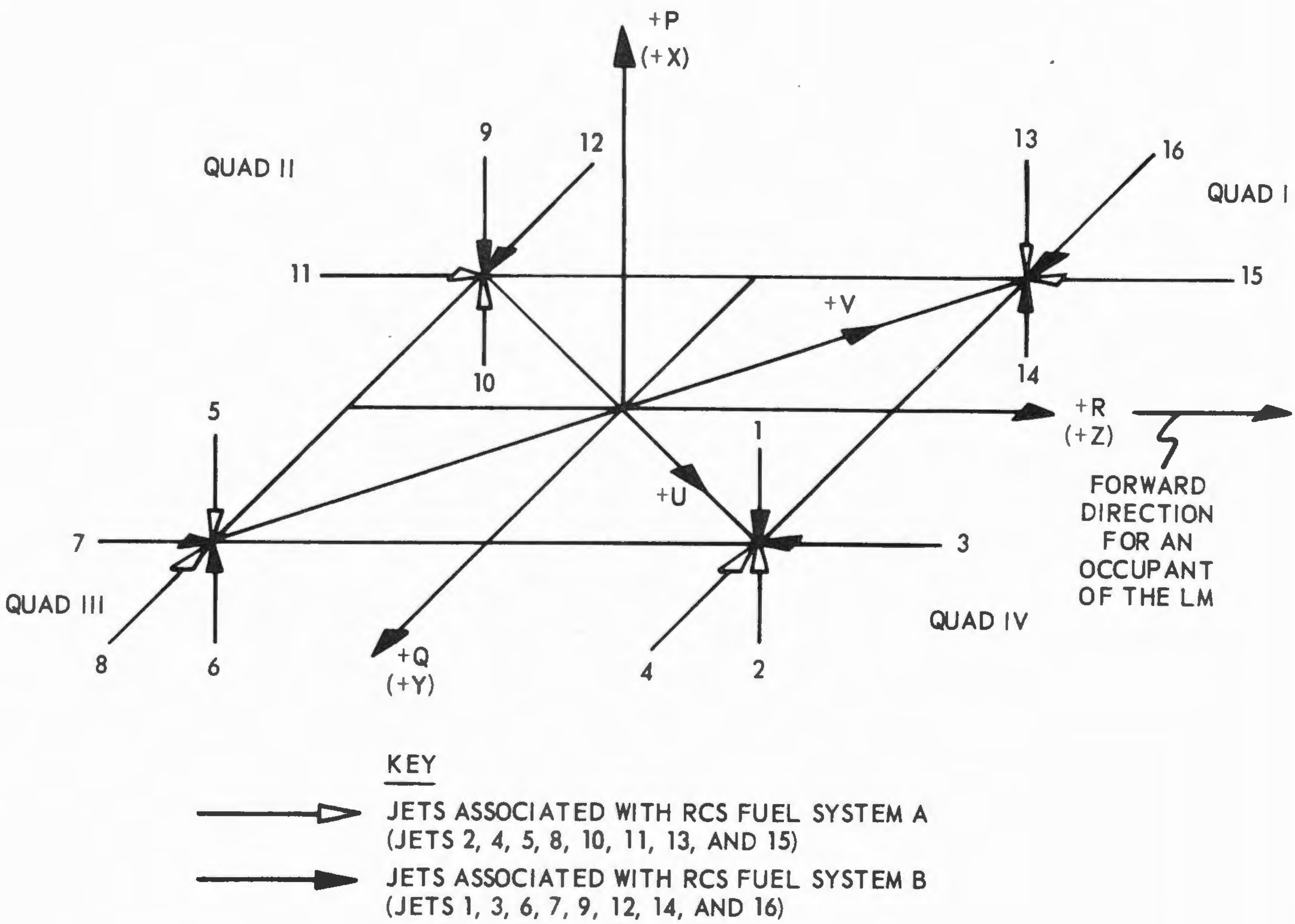
3.1.1.4 Manual Controller Capabilities

An override of the automatic attitude control is accomplished by moving the ACA to the hardover position, which commands on/off four jet operation in any or all axes through the secondary coils of the thruster solenoid values. This capability is available at all times. However, the minimum impulse command or proportional rate command capabilities are only available to the ACA during attitude hold (ATT HOLD position of the MODE CONTROL switch).

The TTCA is only actuated during the attitude hold modes. Manual translation control is accomplished by moving the translation controller out of detent. This causes on/off firing of the jets by LGC generated commands. Each thrust/translation controller provides the crew with the translation capability along the Y_{LM} and Z_{LM} axes. The X-axis translation capability is added to a controller when the arm-switch is set to the JETS position. Thrust control of the descent engine is available to one controller when its arm-switch is set to THROTTLE position and 800 cps is routed to it through the MAN THROT selector (by either CDR or SE position). In addition, for manual throttle to be present, the THR CONT switch must be in MAN position.

3.1.1.5 Jet Selection Policy

The RCS is composed of two parallel independent systems (system A and system B). Figure 3-4 illustrates the thrust directions of each system's jets. The DAP jet selection policy is listed in Table 3-3. The first entry is the optimal jet policy for the DAP to use when the specified maneuver is requested of the jet select policy by the attitude steering or rate command sections. Each of the subsequent entries defines the next most desirable jet policy to use when a detected jet failure precludes the use of the policy listed



NOTES:

1. THE ARROWS INDICATE THRUST DIRECTION, NOT EXHAUST VELOCITY.
2. IN CASE OF FAILED JETS, THE ASTRONAUT DISABLES JETS IN PAIRS AS FOLLOWS:

1,3	5,8	9,12	13,15
2,4	6,7	10,11	14,16

3. THE P, Q, AND R DESIGNATIONS FOR THE CONTROL AXES ARE USED IN CONNECTION WITH ROTATION, WHEREAS THE X, Y, AND Z DESIGNATIONS ARE USED IN CONNECTION WITH TRANSLATION.

Figure 3-4. RCS Jets and thrust direction

Type of Translation Commanded	Normal Policy	Alternative Disabled-Jet Policy
+Y translation	12,16	If 16 has been disabled, set up the tacking* policy of alternating between (12,3) and (12,11). If 12 has been disabled, set up the tacking policy of alternating between (16,15) and (16,7).
-Y translation	4,8	If 8 has been disabled, set up the tacking policy of alternating between (4, 3) and (4, 11). If 4 has been disabled, set up the tacking policy of alternating between (8,7) and (8,15).
+Z translation	7,11	If 11 has been disabled, set up the tacking policy of alternating between (7,8) and (7,16). If 7 has been disabled, set up the tacking policy of alternating between (11,12) and (11,4).
-Z translation	3,15	If 15 has been disabled, set up the tacking policy of alternating between (3,4) and (3,12). If 3 has been disabled, set up the tacking policy of alternating between (15,8) and (15,16).
(+Z, +Y) translation [+U translation]	7,11, 12,16	If either 11 or 12 has been disabled, use (7,16). If either 7 or 16 has been disabled, use (11,12).
(-Z, -Y) translation [-U translation]	3,4, 8,15	If either 8 or 15 has been disabled, use (3,4). If either 3 or 4 has been disabled, use (8,15).
(+Z, -Y) translation [+V translation]	4,7 8,11	If either 4 or 11 has been disabled, use (7,8). If either 7 or 8 has been disabled, use (4,11).

TABLE 3-3. Jet Selection Policy

Type of Translation Commanded	Normal Policy	Alternative Disabled-Jet Policy
(-Z, +Y) translation [-V translation]	3,12 15,16	If either 15 or 16 has been disabled, use (3,12). If either 3 or 12 has been disabled, use (15,16).
4-jet, +X translation	2,6,10, 14	If either 2 or 10 has been disabled, use (6,14). If either 6 or 14 has been disabled, use (2,10).
2-jet, +X translation with fuel system A	2,10	If either 2 or 10 has been disabled, use (6,14).
2-jet, +X translation with fuel system B	6,14	If either 6 or 14 has been disabled, use (2,10).
4-jet, -X translation	1,5,9,13	If either 5 or 13 has been disabled, use (1,9). If either 1 or 9 has been disabled, use (5,13).
2-jet, -X translation with fuel system A	5,13	If either 5 or 13 has been disabled, use (1,9).
2-jet, -X translation with fuel system B	1,9	If either 1 or 9 has been disabled, use (5,13).
2-jet, +U rotation	5,14	If 14 has been disabled, use 5 alone. If 5 has been disabled, use 14 alone.
1-jet, +U rotation (+X translational sense desired)	14	If 14 has been disabled, use 5.
1-jet, +U rotation (-X translational sense desired)	5	If 5 has been disabled, use 14.
2-jet, -U rotation	6,13	If 13 has been disabled, use 6 alone. If 6 has been disabled, use 13 alone.
1-jet, -U rotation (+X translational sense desired)	6	If 6 has been disabled, use 13.

TABLE 3-3 (Cont.) Jet Selection Policy

Type of Translation Commanded	Normal Policy	Alternative Disabled-Jet Policy
1-jet, -U rotation (-X translational sense desired)	13	If 13 has been disabled, use 6.
2-jet, +V rotation	1,10	If 10 has been disabled, use 1 alone. If 1 has been disabled, use 10 alone.
1-jet, +V rotation (+X translational sense desired)	10	If 10 has been disabled, use 1.
1-jet, +V rotation (-X translational sense desired)	1	If 1 has been disabled, use 10.
2-jet, -V rotation	2,9	If 9 has been disabled, use 2 alone. If 2 has been disabled, use 9 alone.
1-jet, -V rotation (+X translational sense desired)	2	If 2 has been disabled, use 9
1-jet, -V rotation (-X translational sense desired)	9	If 9 has been disabled, use 2.
4-jet, +P rotation	4,7,12,15	Normal Policy
	7,15 4,12 4,7 7,12 12,15 4,15	Alternate 2-jet policies
4-jet, -P rotation	3,8,11,16	Normal Policy
	8,16 3,11 8,11 11,16 3,16 3,8	Alternate 2-jet policies
2-jet, +P rotation	Alternate pulses between (4,12) and (7,15).	
2-jet, -P rotation	Alternate pulses between (3,11) and (8,16).	
Note: All rotations expressed are to be interpreted in terms of the right-hand rule.		

TABLE 3-3 (Cont.) Jet Selection Policy

above it. Use of these alternate jet policies naturally creates degraded performance of the DAP (which is to be expected after single or multiple jet failures). If all of the policies for a particular maneuver cannot be used, the program alarm light is lit and an alarm codes is stored which will indicate to the astronaut that a translation or rotation failure exists.

3.1.2 Abort Guidance Flight Control

The abort guidance section (AGS) is the backup for the PGNCS. Only in the event of a malfunction does the AGS actually take the place of the PGNCS. The AGS consists of the data entry and display assembly (DEDA), abort sensor assembly (ASA), and the abort electronics assembly (AEA); which represent, in effect, a backup loop for the DSKY, IMU, and the LGC.

The ASA uses a strap-down inertial technique instead of the inertial platform as used in the IMU. Where the inertial platform relies on a stabilized gimbal system to maintain fixed accelerometer orientation, the strap-down system measures the accelerometer rotation about a fixed reference frame and resolves the acceleration into the fixed reference frame. The ASA employs three accelerometers and three gyros. Angular velocity data from the gyros is processed to update vehicle attitude and resolve acceleration data.

The AGS is initially aligned to the PGNCS and operates in an open-loop fashion with the primary guidance system. Hence, the crew can sample the AGS constantly, calling up critical information and comparing it to the primary system.

3.1.2.1 AGS Initialization

Initialization of the AGS is obtained during the AGS initialization Routine (R-47). When the zero CDU discrete is issued from the LGC, it provides simultaneous zeroing of the angle counters in the AGS, CDU, and LGC. Hence, with removel of the discrete the CDU registers increment up to the present IMU gimbal angles while sending the same increments to the LGC and AGS counters. The six signals of plus and minus gimbal angles from the CDU are then continuously monitored by both the LGC and AGS, providing a common reference with which to define LM attitude.

In addition, R 47 establishes the ground elapsed time of AEA clock zero and provides the AEA with the LM and CSM state vectors (position, velocity, and time). At a desired GET, the astronaut simultaneously makes an ENTR in both DSKY and DEDA. The LGC stores the GET at this enter and subtracts this time from all state vector reference times used in the AGS initialization. (There is also the option of loading AGS initialization obtained from an external source.) The LGC program then divides the CSM and LM state vectors by a factor of four and puts these parameters with the modified time reference on a special telemetry down link list which is sent ten consecutive times, before the normal downlink format is resumed. During this initialization downlink, no interrupts take place and the AEA monitors the data. The

AEA accepts the first sixteen bits of each PGNCS 40-bit downlink word. The position, velocity, and time are transmitted within double precision words. The most significant part is transmitted prior to the least significant part. The bit weights are:

1. Position: Most significant bit = 2^{22} feet
2. Velocity: Most significant bit = 2^{12} feet/second
3. Time: Least significant bit = 10 milliseconds

Subsequent AGS initializations do not normally require a new time referencing operation involving the simultaneous LGC and AEA enter inputs. During AGS initializations following the first, the special initialization downlink list is prepared by modifying the state vector times by subtracting the initial GET reference time determined in the first initialization.

3.2 PGNCS/AGS SWITCHING

The controls and displays for flight control are functionally illustrated in Figs. 3-5 and 3-6.

3.3 GIMBAL ANGLE SEQUENCE TRANSFORMATION ASSEMBLY (GASTA)

The Gimbal Angle Sequence Transformation Assembly (GASTA) is used to transform the three axis attitude information from the LM inertial platform into three axis attitude information in a sequence usable by the LM attitude indicator. The GASTA must determine the necessary angular position of each gimbal in the ball indicator in order that the indicator sphere may assume the proper orientation.

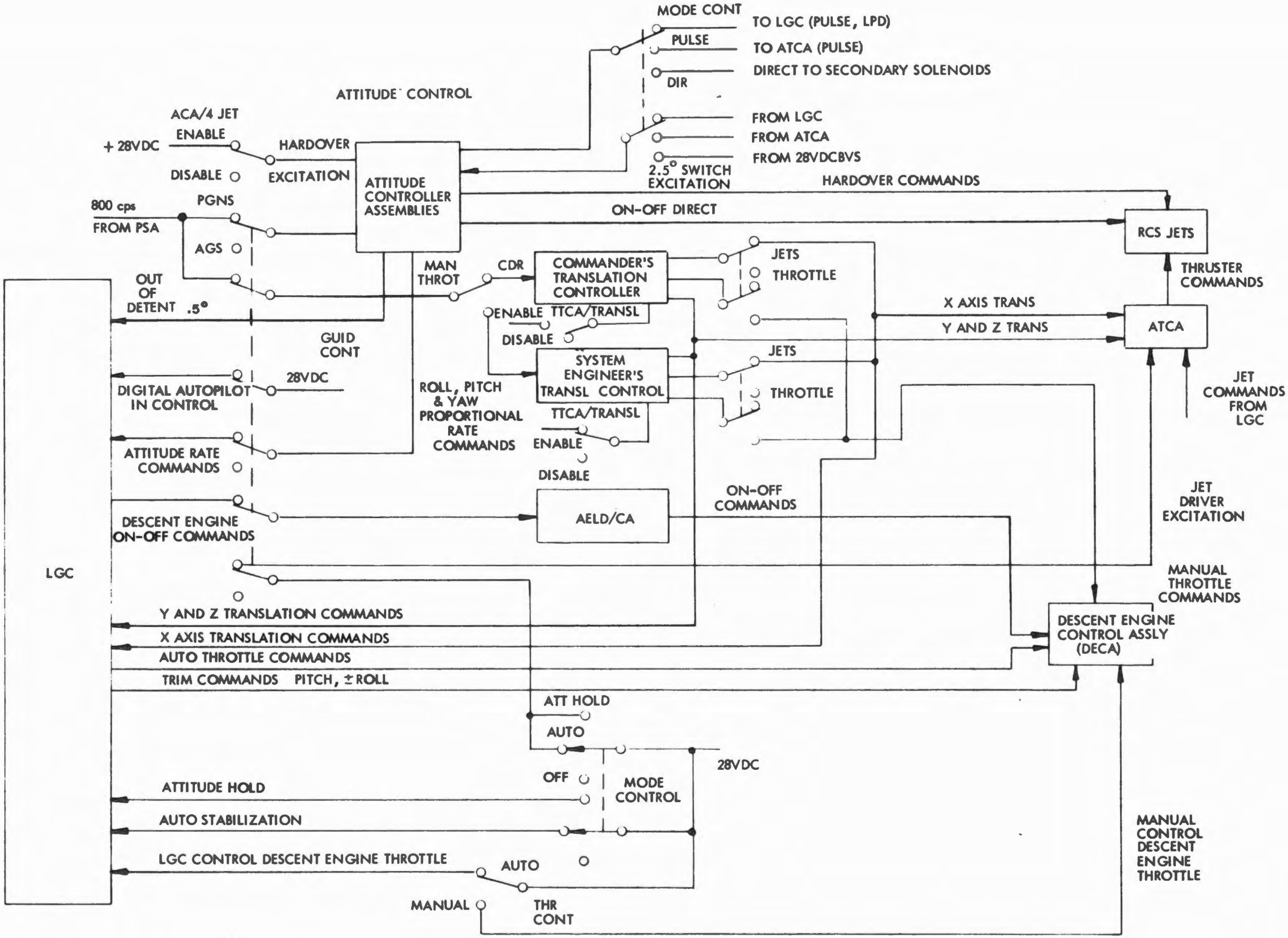


Fig. 3-5. PGNCS/flight control switching functional block diagram.

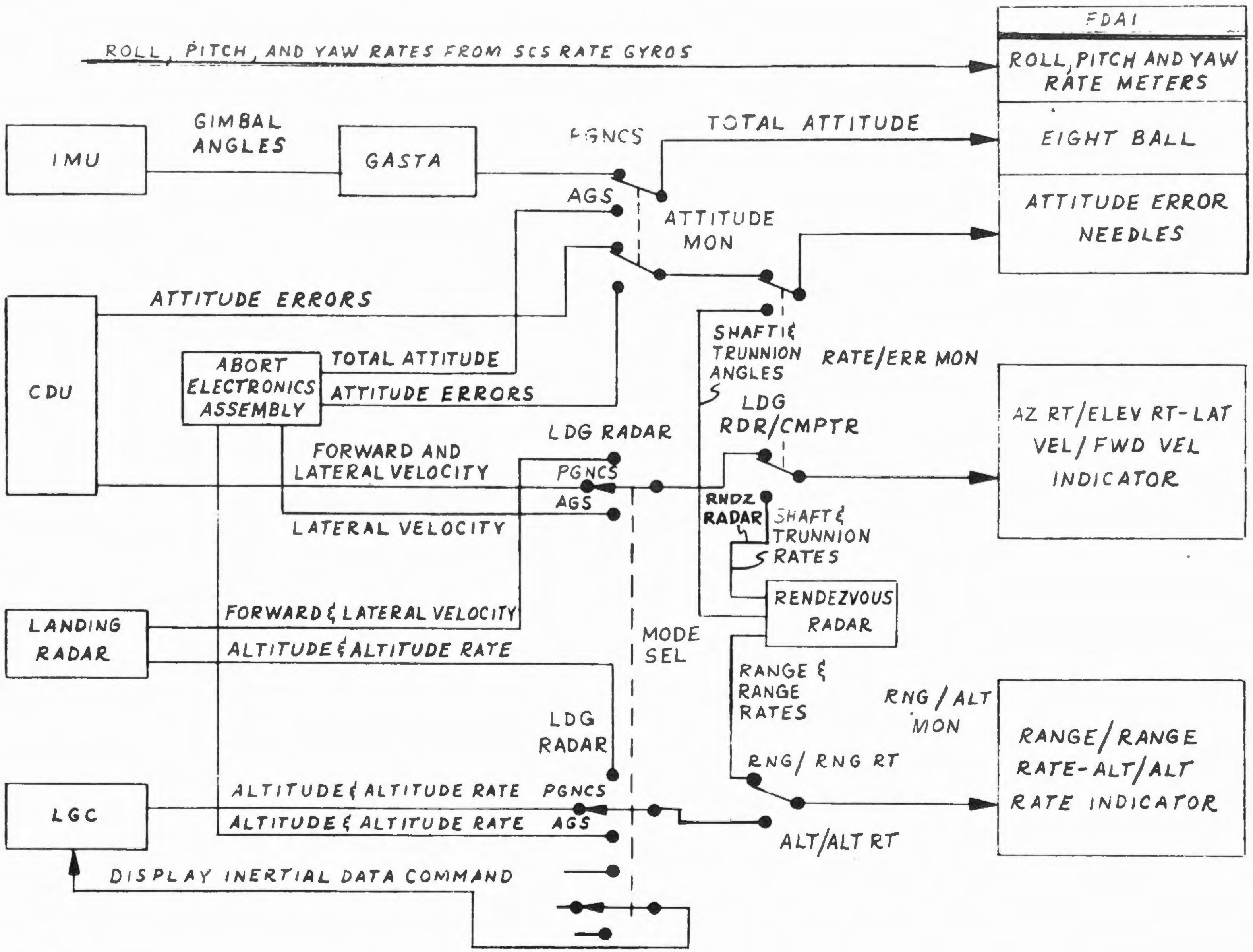


Fig. 3-6. Display switching functional block diagram.

The stable platform and its gimbal sequence is as shown in Figure 3-7. Note that the outer gimbal axis of the platform is parallel to the X axis of the lunar excursion module. The middle gimbal axis of the platform is perpendicular to the outer gimbal axis, and the inner gimbal axis is perpendicular to the middle gimbal axis. Rotation of each gimbal around its particular gimbal axis is measured by the output of a synchro resolver which is mounted on the respective gimbal. The output signal of each synchro resolver is given by two voltages; one proportional to the sine and one proportional to the cosine of the gimbal angle.

The sphere in the ball indicator and its gimbal sequence are as shown in Figure 3-7. Note that the outer gimbal axis of the sphere is parallel to the Z axis of the lunar excursion module. The middle gimbal axis is perpendicular to the outer gimbal axis, and the inner gimbal axis is perpendicular to the middle gimbal axis. The indicator sphere is positioned with respect to the LEM axes by position servo assemblies, which cause the indicator gimbals to rotate around their respective gimbal axes.

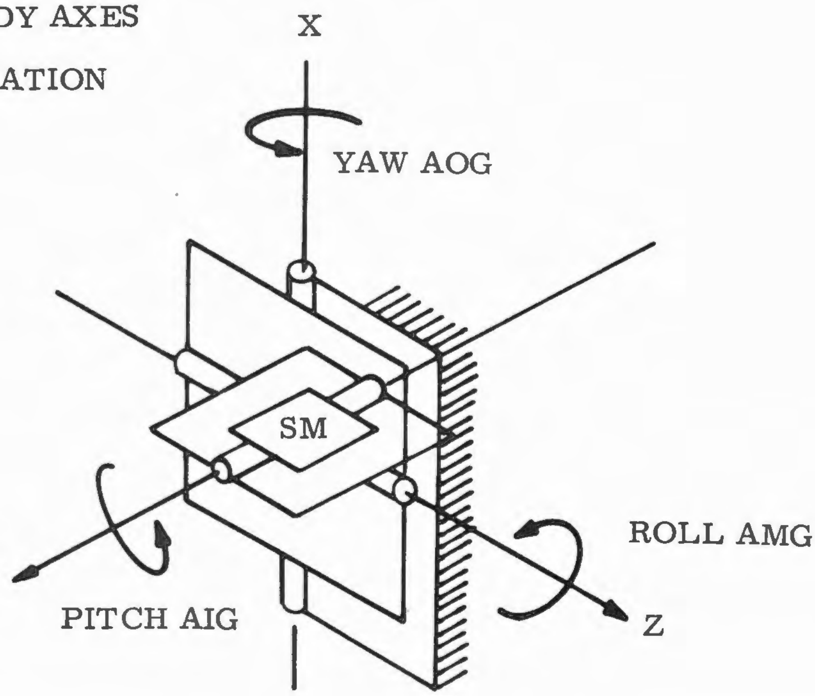
The GASTA output signals are voltages proportional to the sine and cosine of the required indicator gimbal angles. The roll, yaw, and pitch gimbal axis angles of the indicator are designated α, β, and γ respectively. The equations which define the conversion of the IMU gimbal angles to the FDAI gimbal angles are shown in Figure 3-7.

3.4 INSTRUMENTATION SUBSYSTEM

A primary function of the instrumentation subsystem is to monitor data pertaining to subsystems performance, and then condition this data to a format which can be assembled and digitalized for transmission to earth.

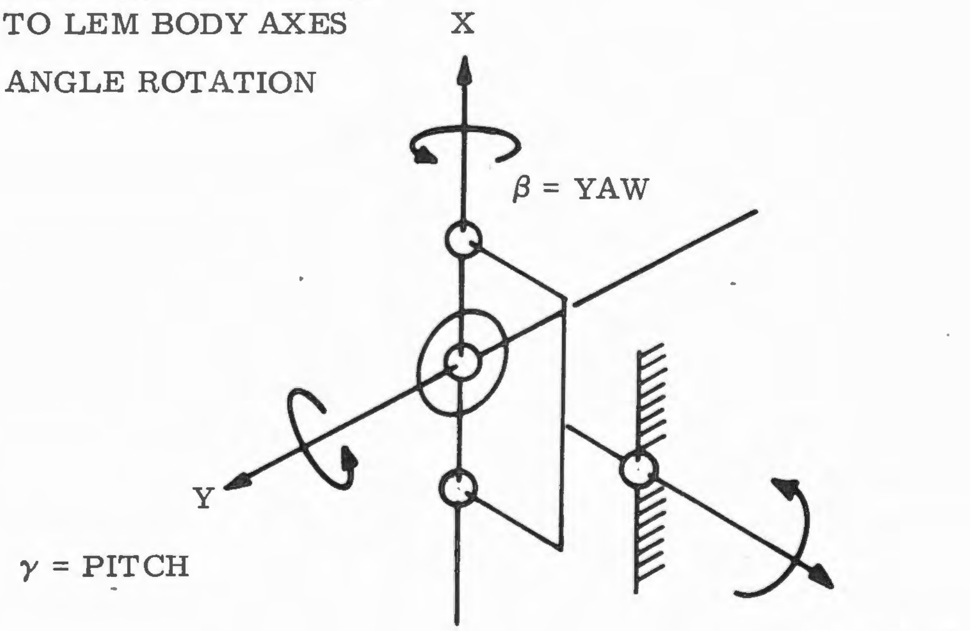
PLATFORM ORIENTATION WITH RESPECT TO LEM BODY AXES

POSITIVE ANGLE ROTATION SHOWN



INDICATOR ORIENTATION WITH RESPECT TO LEM BODY AXES

POSITIVE ANGLE ROTATION SHOWN



GASTA conversion:

$$\alpha = \tan^{-1}\left(\frac{-\sin AMG}{\cos AOG\ \cos AMG}\right)$$

$$\beta = \tan^{-1}\left(\frac{\text{Sin } AOG\ \cos AMG}{-\sin AMG\ \sin\alpha + \cos AOG\ \cos AMG\ \cos\alpha}\right)$$

$$\gamma = \tan^{-1}\left[\frac{-(\sin AOG \cos AIG + \cos AOG \sin AMG \sin AIG)\sin\alpha + (\sin AIG \cos AMG)\cos\alpha}{(\sin AIG \sin AOG - \cos AIG \cos AOG \sin AMG)\sin\alpha + (\cos AIG \cos AMG)\cos\alpha}\right]$$

Fig. 3-7. IMU and FDAI Axis Orientation & Angle Relationships

The manned space flight network (MSFN) converts this data into intelligible formats that permit participation in major decisions to abort or modify the missions, assistance in spacecraft management during crew high activity phases, and recording a detailed system status and performance history.

The instrumentation data consists of three types: discrete signals, LGC digital downlink data, and coded analog data. (See Fig. 3-8.) The PCM (pulse code modulator) encodes the analog data into digital form. The PCM output register receives both serial digital data from the LGC and parallel digital data from the PCM digital multiplexer upon PCM programmer commands. This data is then accurately timed and coded into NRZ (non-return-to-zero) serial format for transmission to earth. The PCM programmer also generates the commands which start, stop and synchronize the flow of LGC serial data to the instrumentation subsystem. A master clock signal (1024 kpps) is sent from the LGC to the central timing equipment to synchronize all spacecraft systems to a common frequency base.

All of the analog signals and some of the discretes must be converted to a common impedance and voltage range (0 to 5 vdc) to be acceptable to the PCM multiplexer. This is accomplished by the signal conditioning electronics assembly (SCEA) and the PGNCS signal conditioner. The PGNCS signal conditioner converts PGNCS signals to a compatible PCM form. (See Fig. 3-9.) The signal conditioner also provides isolation between the component or circuit

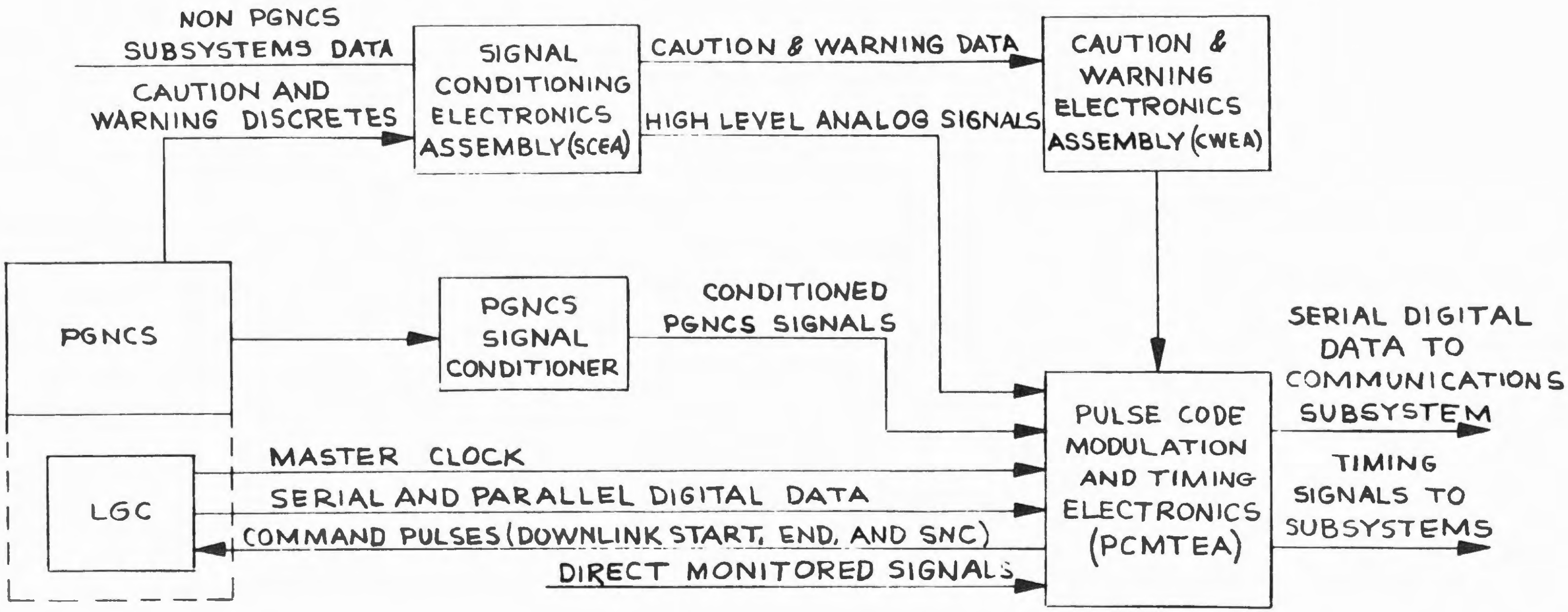


Fig. 3-8. Instrumentation subsystem functional block diagram.

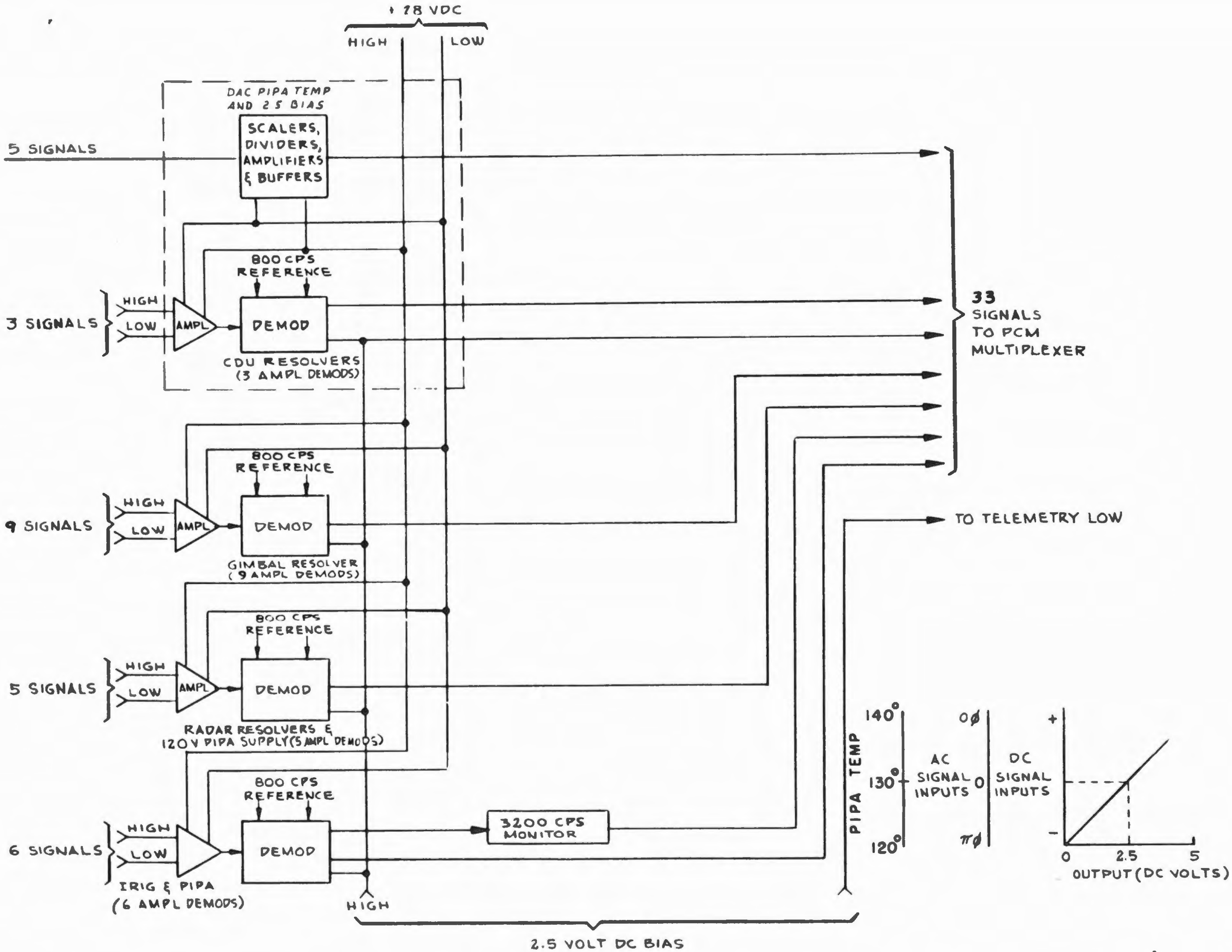


Fig. 3-9. Signal conditioner functional block diagram.

being monitored and the telemetry system. The PCM multiplexer transforms the conditioned signals into eight bit telemetry words suitable for the telemetry multiplexer and transmission. The PGNCS operational signal conditioner consists of four modules:

1. DAC PIPA temperature and 2.5 bias signal conditioner
2. IRIG and PIPA signal conditioner
3. Gimbal resolver signal conditioner
4. Radar resolver and 120 V PIPA supply signal conditioner

The signal conditioner receives a 28 volt dc, B+ supply voltage from the PSA, and a 2.5 volt DC bias voltage is generated in the signal conditioner. The 28 volt dc B+ is applied to each module. The 2.5 volt dc bias voltage is connected in series with the demodulated outputs of each module and is also monitored directly by the PCM multiplexer. The 2.5 volt dc bias high is connected to the signal low and becomes the reference point for the 0 to 5 volt signal outputs of the demodulators. In this manner, a zero-phase ac signal, after conditioning, is represented as a dc voltage value above the 2.5 volt reference. A piphase signal, after conditioning, is represented as a dc voltage value below the 2.5 volt reference. Bipolar dc signals from PGNCS which may be positive or negative and have a zero volt reference after conditioning are represented in a similar manner. Positive voltages are represented as a voltage value above the 2.5 volt reference and negative voltages are represented as a voltage value below the 2.5 volt reference.

Discrete signals are telemetered as single bits within eight bit words. The PGNCS, LGC, and ISS discretes are developed to their proper 5 vdc level by the SCEA.

Table 3-4 contains a complete listing of all PGNCS operational telemetry data that is monitored by flight controllers and ground support personnel. Also included in this table is reference to figures which will show the source of the telemetered signal.

3.4.1 LGC Digital Downlink

The downlink format is controlled by an LGC program. This program is entered on an interrupt caused by an "endpulse" from the telemetry system. The program loads the content of the next two 16-bit LGC registers that are to be transmitted into channels 34 and 35. The loading is accomplished according to the format described in the next paragraph.

Each downlist word consists of 33 significant bits plus seven repetition bits. The first bit is a "word order code bit". The next 16 bits comprise the contents of one 16-bit LGC register (15 bits of data followed by an odd parity bit). The final 16 bits are the content of another 16-bit LGC register. Since the spacecraft downlink is organized in 8-bit segments, seven "filler bits" are transmitted to follow the 33 bits outlined above in order to use all the downlink space available. These filler bits are repetitions of the first seven bits of the first LGC register transmitted.

The first word in any list contains the "ID" and synchronization registers and has a word order code bit of zero. (All other downlink words have word order code bit of one except word 51 on the nominal downlists which has a word order code bit of zero to indicate the mid-point of the nominal downlists.)

Measurement No.	Measurement Description	Data Limits	S/S	Reference Figures
GG0001	LGC digital data (40 bit)		50	Table 3-4
GG1040V	120 vdc PIPA supply DC level	85 - 135 vdc	1	2-14
GG1110V	2.5 vdc TM bias	nom 2.5 vdc	1	3-8
GG1201V	IMU 28v 0.8 kc 1% 0 deg, rms	0 - 31.1 vrms	1	2-15
GG1331V	3.2 kc 28v supply	0 - 31.1 vrms	1	2-17
GG1513X	+28v IMU standby	OFF-ON	10	3-10
GG1523X	+28v LGC operate	OFF-ON	10	3-10
GG2001V	X PIPA SG output in phase	-2.5 + 2.5 vrms	50	2-8
GG2021V	Y PIPA SG output in phase	-2.5 +2.5 vrms	50	2-8
GG2041V	Z PIPA SG output in phase	-2.5 +2.5 vrms	50	2-8
GG2107V	IG servo error in phase	-3 +3 vrms	100	2-9
GG2110C	IG torque motor current	-0.5 +0.5 amps	100	2-9
GG2112V	IG 1X resolver output sin	-20.25 +20.25 vrms	10	2-10
GG2113V	IG 1X resolver output cos	-20.25 +20.25 vrms	10	2-10
GG2121V	IG 1X resolver sin x	-5 +5 vrms	100	2-10
GG2137V	MG servo error in phase	-3 +3 vrms	100	2-9
GG2140C	MG torque motor current	-0.5 +0.5 amps	100	2-9
GG2142V	MG 1X resolver output sin	-21.5 +21.5 vrms	10	2-10
GG2143V	MG 1X resolver output cos	-21.5 +21.5 vrms	10	2-10
GG2151V	MG 1X resolver sin x	-5 +5 vrms	100	2-10
GG2167V	OG servo error in phase	-3 +3 vrms	100	2-9
GG2170C	OG torque motor current	-0.9 +0.9 amps	100	2-9
GG2172V	OG 1X resolver output sin	-20.5 +20.5 vrms	10	2-10

Table 3-4 . PGNCS Telemetry Operational Measurement List.

Measure-ment No.	Measurement Description	Data Limits	S/S	Reference Figures
GG2173V	OG 1X resolver output cos	-20.5 +20.5 vrms	10	2-10
GG2181V	OG 1X resolver sin x	-5 +5 vrms	100	2-10
GG2219V	Pitch attitude error	-5 +5 vrms	10	2-10
GG2249V	Yaw attitude error	-5 +5 vrms	10	2-10
GG2279V	Roll attitude error	-5 +5 vrms	10	2-10
GG2300T	PIPA temperature	120-140 deg F	1/1	2-13
GG3304V	RR shaft 1X rslvr out sin	-21.5 +21.5 vrms	10	2-31
GG3305V	RR shaft 1X rslvr out cos	-21.5 +21.5 vrms	10	2-31
GG3324V	RR trunnion 1X rslvr out sin	-21.5 +21.5 vrms	10	2-31
GG3325V	RR trunnion 1X rslvr out cos	-21.5 +21.5 vrms	10	2-31
GG6020T	PIPA cal temp.	0° +150°F	1	2-8
GG9001X	LGC warning	GAEC conditioned	1/1	2-48
GG9002X	ISS warning	GAEC conditioned	1/1	2-48

Table 3-4. PGNCS Telemetry Operational Measurement List (Cont.).

The ID register marks the beginning of a list and identifies the list being transmitted. All IDs are made negative so that word 1 of each list can always be distinguished from word 51 (TIME2/1 is always positive). The following IDs are used in SUNDANCE.

Powered List	77774_8
Coast and Align List	77777_8
Rendezvous and Prethrust List	77775_8
AGS Initialization/Update List	77776_8

The synchronization (sync) register always contains the same sixteen bits (111 111 011 100 000 0), which are used to synchronize remote site downlink processing equipment. Table 3-5 shows the general format of the downlink.

The nominal LGC downlink lists contain 100 downlink words (200 LGC registers) which are transmitted at a rate of 50 words per second.

The list switching is accomplished as follows: The DOWNLINK program, at the beginning of a pass, uses the ID word to trigger selection of the appropriate list for that pass. Whenever a new program is entered, it sets up a request for its list by placing the appropriate value in the register which the DOWNLINK will pick up as the ID. When, at the beginning of the next pass, the DOWNLINK reads this register, the appropriate list is then initiated (i. e., the list is not switched in the middle of a pass). This procedure is of course not true for the erasable memory dump downlist (see Section 2. 2. 1), which completes its required number of passes irrespective of other programs.

On each of the nominal downlists there are two time-homogeneous sets of data: words 2 through 13 and words 52 through 63. Since certain data on the downlink are only meaningful when considered in multiregister arrays

Word #	Word Order Code	Contents of 1st Register	Contents of 2nd Register
1	0	ID	Synch Bits
2 → 13	1 → 1	"Snapshot" data which will probably change with different lists	
14 → 34	1 → 1	Data which is likely to change with different lists	
35 → 39	1 → 1	CDU and PIPA counters	
40 → 44	1 → 1	Ten flagwords	
45 → 50	1 → 1	DSPTAB registers	
51	0	Time 2	Time 1
52 → 63	1 → 1	"Snapshot" of latest calculated LM state vectors	
64 → 84	1 → 1	Data which is likely to change with different lists	
85 → 94	1 → 1	Flagwords and input output channels	
95 → 100	1 → 1	DSPTABS	

Table 3-5. General LGC Downlink Format.

(i. e., state vectors) and since the programs which compute these arrays are not synchronized with the downlink program, a "snapshot" is taken of these registers so that changes in their values will not occur while these arrays are being transmitted to the ground. The "snapshot" of the 24 registers that make up words 2 through 13 is stored at the time that word 2 is transmitted and the next 11 words (22 registers) are read out of this "snapshot" buffer. The same is true for words 52 through 63, except that the "snapshot" is taken at the time that word 52 is transmitted. The other words in the downlist are read from the appropriate registers at the time of transmission, and therefore the only time homogeneity here is between the two registers making up a single word. Tables 3-5 A, B, C and D are lists of the various downlist register content.

3. 4. 2 Digital Uplink to the LGC

By means of the LGC uplink the ground can insert data or instruct the LGC in the same manner normally performed by the crew using the DSKY keyboard. No block uplink switch exists in the LM. The LGC update program (P27) is normally manually selected by the astronaut by DSKY entry. or by the ground by uplink transmission. Update is selected only from P00.

The LGC updates are of four categories:

1. To provide an octal increment for the LGC clock only (V73)
2. To provide an octal increment for the LGC clock and TEPHEM (V70)
3. To provide load capability for a block of sequential erasable locations (locations 1-18 inclusive, whose address is specified)(V71)
4. To provide load capability for specified erasable locations 1-9 (V72)

Word No.	First Register	Second Register	Word Order Code
1	Downlist I. D.	Sync bits (77340-octal)	0
2	Lat cal CM st vec X Pos MSB	Lat cal CM st vec X Pos LSB	1
3	Lat cal CM st vec Y Pos MSB	Lat cal CM st vec Y Pos LSB	1
4	Lat cal CM st vec Z Pos MSB	Lat cal CM st vec Z Pos LSB	1
5	Lat cal CM st vec X Vel MSB	Lat cal CM st vec X Vel LSB	1
6	Lat cal CM st vec Y Vel MSB	Lat cal CM st vec Y Vel LSB	1
7	Lat cal CM st vec Z Vel MSB	Lat cal CM st vec Z Vel LSB	1
8	State vector time MSB	State vector time LSB	1
9	Garbage	Desired CDUX	1
10	Desired CDUY	Desired CDUZ	1
11	Body rate (P)	Body rate (Q)	1
12	Body rate (R)	Garbage	1
13	RR trunnion error	RR shaft error	1
14	LR vel X (raw data)	LR vel Y (raw data)	1
15	LR vel Z (raw data)	LR range (raw data)	1
16	Time of event MSB	Time of event LSB	1
17	RR range (raw data)	RR range rate (raw data)	1
18	REFSMMAT Row 1 Col 1 MSB	REFSMMAT Row 1 Col 1 LSB	1
19	REFSMMAT Row 1 Col 2 MSB	REFSMMAT Row 1 Col 2 LSB	1
20	REFSMMAT Row 1 Col 3 MSB	REFSMMAT Row 1 Col 3 LSB	1
21	REFSMMAT Row 2 Col 1 MSB	REFSMMAT Row 2 Col 1 LSB	1
22	REFSMMAT Row 2 Col 2 MSB	REFSMMAT Row 2 Col 2 LSB	1
23	REFSMMAT Row 2 Col 3 MSB	REFSMMAT Row 2 Col 3 LSB	1
24	GDT/2 X MSB	GDT/2 X LSB	1
25	GDT/2 Y MSB	GDT/2 Y LSB	1
26	GDT/2 Z MSB	GDT/2 Z LSB	1
27	REDOCTR	THETA D	1
28	THETA D +1	THETA D +2	1
29	OMEGA DP	OMEGA DQ	1
30	OMEGA DR	Garbage	1
31	VRPREV X MSB	VRPREV X LSB	1
32	VRPREV Y MSB	VRPREV Y LSB	1
33	VRPREV Z MSB	VRPREV Z LSB	1

Table 3-5A. LM Powered Downlist.

Word No.	First Register	Second Register	Word Order Code
34	LM current weight MSB	LM current weight LSB	1
35	RSBBQ	RSBBQ+1	1
36	RR CDU shaft	Actual PIPA X	1
37	Actual PIPA Y	Actual PIPA Z	1
38	Actual CDU X	Actual CDU Y	1
39	Actual CDU Z	RR CDU trunnion	1
40	Flagword 0	Flagword 1	1
41	Flagword 2	Flagword 3	1
42	Flagword 4	Flagword 5	1
43	Flagword 6	Flagword 7	1
44	Flagword 8D	Flagword 9D	1
45	DSPTAB+0	DSPTAB+1	1
46	DSPTAB+2	DSPTAB+3	1
47	DSPTAB+4	DSPTAB+5	1
48	DSPTAB+6	DSPTAB+7	1
49	DSPTAB+8D	DSPTAB+9D	1
50	DSPTAB+10D	DSPTAB+11D	1
51	Time 2	Time 1	0
52	Lat cal LM st vec X Pos MSB	Lat cal LM st vec X Pos LSB	1
53	Lat cal LM st vec Y Pos MSB	Lat cal LM st vec Y Pos LSB	1
54	Lat cal LM st vec Z Pos MSB	Lat cal LM st vec Z Pos LSB	1
55	Lat cal LM st vec X Vel MSB	Lat cal LM st vec X Vel LSB	1
56	Lat cal LM st vec Y Vel MSB	Lat cal LM st vec Y Vel LSB	1
57	Lat cal LM st vec Z Vel MSB	Lat cal LM st vec Z Vel LSB	1
58	State vector time MSB	State vector time LSB	1
59	Garbage	Desired CDU X	1
60	Desired CDU Y	Desired CDU Z	1
61	Body rate (P)	Body rate (Q)	1
62	Body rate (R)	Garbage	1
63	RR trunnion error	RR shaft error	1
64	LR vel X (raw data)	LR vel Y (raw data)	1
65	LR vel Z (raw data)	LR range (raw data)	1
66	TIGN MSB	TIGN LSB	1
67	VGX MSB	VGX LSB	1

Table 3-5A. LM Powered Downlist (Cont.)

Word No.	First Register	Second Register	Word Order Code
68	VGY MSB	VGY LSB	1
69	VGZ MSB	MGZ MSB	1
70	Central angle MSB	Central angle LSB	1
71	PIPTIME 1 MSB	PIPTIME 1 LSB	1
72	DELV X MSB	DELV X LSB	1
73	DELV Y MSB	DELV Y LSB	1
74	DELV Z MSB	DELV Z LSB	1
75	TGO MSB	TGO LSB	1
76	Commands to DECA MSB	Commands to DECA LSB	1
77	TPI time MSB	TPI time LSB	1
78	TPI delta vel X MSB	TPI delta vel X LSB	1
79	TPI delta vel Y MSB	TPI delta vel Y LSB	1
80	TPI delta vel Z MSB	TPI delta vel Z LSB	1
81	Elevation angle MSB	Elevation angle LSB	1
82	TPF time MSB	TPI time LSB	1
83	RADMODES	DAPBOOLS	1
84	Moment offset (Q)	Moment offset (R)	1
85	CADRFLSH	CADRFLSH+1	1
86	CADRFLSH+2	FAILREG	1
87	FAILREG+1	FAILREG+2	1
88	Actual CDU X	Actual CDU Y	1
89	Actual CDU Z	RR CDU trunnion	1
90	IMODES 30	IMODES 33	1
91	Channel 11	Channel 12	1
92	Channel 13	Channel 14	1
93	Channel 30	Channel 31	1
94	Channel 32	Channel 33	1
95	DSPTAB+0	DSPTAB+1	1
96	DSPTAB+2	DSPTAB+3	1
97	DSPTAB+4	DSPTAB+5	1
98	DSPTAB+6	DSPTAB+7	1
99	DSPTAB+8D	DSPTAB+9D	1
100	DSPTAB+10D	DSPTAB+11D	1

Table 3-5A. LM Powered Downlist (Cont.)

Word No.	First Register	Second Register	Word Order Code
1	Downlist I. D.	Sync Bits (77340-octal)	0
2	Lat cal CM st vec X Pos MSB	Lat cal CM st vec X Pos LSB	1
3	Lat cal CM st vec Y Pos MSB	Lat cal CM st vec Y Pos LSB	1
4	Lat cal CM st vec Z Pos MSB	Lat cal CM st vec Z Pos LSB	1
5	Lat cal CM st vec X Vel MSB	Lat cal CM st vec X Vel LSB	1
6	Lat cal CM st vec Y Vel MSB	Lat cal CM st vec Y Vel LSB	1
7	Lat cal CM st vec Z Vel MSB	Lat cal CM st vec Z Vel LSB	1
8	State vector time MSB	State vector time LSB	1
9	Garbage	Desired CDU X	1
10	Desired CDU Y	Desired CDU Z	1
11	Body rate (P)	Body rate (Q)	1
12	Body rate (R)	Garbage	1
13	RR trunnion error	RR shaft error	1
14	LR vel X (raw data)	LR vel Y (raw data)	1
15	LR vel Z (raw data)	LR range (raw data)	1
16	Time of event MSB	Time of event LSB	1
17	RR range (raw data)	RR range rate (raw data)	1
18	REFSMMAT Row 1 Col 1 MSB	REFSMMAT Row 1 Col 1 LSB	1
19	REFSMMAT Row 1 Col 2 MSB	REFSMMAT Row 1 Col 2 LSB	1
20	REFSMMAT Row 1 Col 3 MSB	REFSMMAT Row 1 Col 3 LSB	1
21	REFSMMAT Row 2 Col 1 MSB	REFSMMAT Row 2 Col 1 LSB	1
22	REFSMMAT Row 2 Col 2 MSB	REFSMMAT Row 2 Col 2 LSB	1
23	REFSMMAT Row 2 Col 3 MSB	REFSMMAT Row 2 Col 3 LSB	1
24	STARAD+0	STARAD+1	1
25	STARAD+2	STARAD+3	1
26	STARAD+4	STARAD+5	1
27	STARAD+6	STARAD+7	1
28	STARAD+8D	STARAD+9D	1
29	STARAD+10D	STARAD+11D	1
30	STARAD+12D	STARAD+13D	1
31	STARAD+14D	STARAD+15D	1
32	STARAD+16D	STARAD+17D	1
33	K factor MSB	K factor LSB	1
34	LM current weight MSB	LM current weight LSB	1

Table 3-5B. LM Coast and Align Downlist.

Word No.	First Register	Second Register	Word Order Code
35	RSBBQ	RSBBQ+1	1
36	RR CDU shaft	Actual PIPA X	1
37	Actual PIPA Y	Actual PIPA Z	1
38	Actual CDU X	Actual CDU Y	1
39	Actual CDU Z	RR CDU trunnion	1
40	Flagword 0	Flagword 1	1
41	Flagword 2	Flagword 3	1
42	Flagword 4	Flagword 5	1
43	Flagword 6	Flagword 7	1
44	Flagword 8D	Flagword 9D	1
45	DSPTAB+0	DSPTAB+1	1
46	DSPTAB+2	DSPTAB+3	1
47	DSPTAB+4	DSPTAB+5	1
48	DSPTAB+6	DSPTAB+7	1
49	DSPTAB+8D	DSPTAB+9D	1
50	DSPTAB+10D	DSPTAB+11D	1
51	Time 2	Time 1	0
52	Lat cal LM st vec X Pos MSB	Lat cal LM st vec X Pos LSB	1
53	Lat cal LM st vec Y Pos MSB	Lat cal LM st vec Y Pos LSB	1
54	Lat cal LM st vec Z Pos MSB	Lat cal LM st vec Z Pos LSB	1
55	Lat cal LM st vec X Vel MSB	Lat cal LM st vec X Vel LSB	1
56	Lat cal LM st vec Y Vel MSB	Lat cal LM st vec Y Vel LSB	1
57	Lat cal LM st vec Z Vel MSB	Lat cal LM st vec Z Vel LSB	1
58	State vector time MSB	State vector time LSB	1
59	Garbage	Desired CDU X	1
60	Desired CDU Y	Desired CDU Z	1
61	Body rate (P)	Body rate (Q)	1
62	Body rate (R)	Garbage	1
63	RR trunnion error	RR shaft error	1
64	LR vel X (raw data)	LR vel Y (raw data)	1
65	LR vel Z (raw data)	LR range (raw data)	1
66	OGC MSB	OGC LSB	1
67	IGC MSB	IGC LSB	1

Table 3-5B. LM Coast and Align Downlist (Cont.)

Word No.	First Register	Second Register	Word Order Code
68	MGC MSB	MGC LSB	1
69	STAR +0	STAR +1	1
70	STAR +2	STAR +3	1
71	STAR +4	STAR +5	1
72	REDOCTR	THETA D	1
73	THETAD+1	THETAD+2	1
74	Spare	Spare	1
75	Spare	Spare	1
76	Star I.D. 1	Star I.D. 2	1
77	Star sighting vec 1 X Pos MSB	Star sighting vec 1 X Pos LSB	1
78	Star sighting vec 1 Y Pos MSB	Star sighting vec 1 Y Pos LSB	1
79	Star sighting vec 1 Z Pos MSB	Star sighting vec 1 Z Pos LSB	1
80	Star sighting vec 2 X Pos MSB	Star sighting vec 2 X Pos LSB	1
81	Star sighting vec 2 Y Pos MSB	Star sighting vec 2 Y Pos LSB	1
82	Star sighting vec 2 Z Pos MSB	Star sighting vec 2 Z Pos LSB	1
83	RADMODES	DAPBOOLS	1
84	SUMRATE (Q)	SUMRATE (R)	1
85	CADRFLSH	CADRFLSH+1	1
86	CADRFLSH+2	FAILREG	1
87	FAILREG+1	FAILREG+2	1
88	Actual CDU X	Actual CDU Y	1
89	Actual CDU Z	RR CDU trunnion	1
90	IMODES 30	IMODES 33	1
91	Channel 11	Channel 12	1
92	Channel 13	Channel 14	1
93	Channel 30	Channel 31	1
94	Channel 32	Channel 33	1
95	DSPTAB+0	DSPTAB+1	1
96	DSPTAB+2	DSPTAB+3	1
97	DSPTAB+4	DSPTAB+5	1
98	DSPTAB+6	DSPTAB+7	1
99	DSPTAB+8D	DSPTAB+9D	1
100	DSPTAB+10D	DSPTAB+11D	1

Table 3-5B. LM Coast and Align Downlist (Cont.)

Word No.	First Register	Second Register	Word Order Code
1	Downlist I. D.	Sync Bits (77340-octal)	0
2	Lat cal CM st vec X Pos MSB	Lat cal CM st vec X Pos LSB	1
3	Lat cal CM st vec Y Pos MSB	Lat cal CM st vec Y Pos LSB	1
4	Lat cal CM st vec Z Pos MSB	Lat cal CM st vec Z Pos LSB	1
5	Lat cal CM st vec X Vel MSB	Lat cal CM st vec X Vel LSB	1
6	Lat cal CM st vec Y Vel MSB	Lat cal CM st vec Y Vel LSB	1
7	Lat cal CM st vec Z Vel MSB	Lat cal CM st vec Z Vel LSB	1
8	State vector time MSB	State vector time LSB	1
9	Garbage	Desired CDU X	1
10	Desired CDU Y	Desired CDU Z	1
11	Body rate (P)	Body rate (Q)	1
12	Body rate (R)	Garbage	1
13	RR trunnion error	RR shaft error	1
14	LR vel X (raw data)	LR vel Y (raw data)	1
15	LR vel Z (raw data)	LR range (raw data)	1
16	Spare	Spare	1
17	RR range (raw data)	RR range rate (raw data)	1
18	CDU Y at MARKTIME	CDU Z at MARKTIME	1
19	CDU X at MARKTIME	Number of marks	1
20	RR trunnion at MARKTIME	RR shaft at MARKTIME	1
21	MARKTIME MSB	MARKTIME LSB	1
22	RR range at MARKTIME MSB	RR range at MARKTIME LSB	1
23	RR range rate at MARKTIME MSB	RR range rate at MARKTIME LSB	1
24	Trunnion bias MSB	Trunnion bias LSB	1
25	Shaft bias MSB	Shaft bias LSB	1
26	CSI time MSB	CSI time LSB	1
27	CSI delta vel X MSB	CSI delta vel X LSB	1
28	CSI delta vel Y MSB	CSI delta vel Y LSB	1
29	CSI delta vel Z MSB	CSI delta vel Z LSB	1
30	Spare	Spare	1
31	Spare	Spare	1
32	REDOCTR	THETAD+ϕ	1
33	THETAD+1	THETAD+2	1
34	LM current weight MSB	LM current weight LSB	1

Downl. I

Table 3-5C. LM Rendezvous and Prethrust Downlist.

Word No.	First Register	Second Register	Word Order Code
35	RSBBQ	RSBBQ+1	1
36	RR CDU shaft	Actual PIPA X	1
37	Actual PIPA Y	Actual PIPA Z	1
38	Actual CDU X	Actual CDU Y	1
39	Actual CDU Z	RR CDU trunnion	1
40	Flagword 0	Flagword 1	1
41	Flagword 2	Flagword 3	1
42	Flagword 4	Flagword 5	1
43	Flagword 6	Flagword 7	1
44	Flagword 8D	Flagword 9D	1
45	DSPTAB+0	DSPTAB+1	1
46	DSPTAB+2	DSPTAB+3	1
47	DSPTAB+4	DSPTAB+5	1
48	DSPTAB+6	DSPTAB+7	1
49	DSPTAB+8D	DSPTAB+9D	1
50	DSPTAB+10D	DSPTAB+11D	1
51	Time 2	Time 1	0
52	Lat cal LM st vec X Pos MSB	Lat cal LM st vec X Pos LSB	1
53	Lat cal LM st vec Y Pos MSB	Lat cal LM st vec Y Pos LSB	1
54	Lat cal LM st vec Z Pos MSB	Lat cal LM st vec Z Pos LSB	1
55	Lat cal LM st vec X Vel MSB	Lat cal LM st vec X Vel LSB	1
56	Lat cal LM st vec Y Vel MSB	Lat cal LM st vec Y Vel LSB	1
57	Lat cal LM st vec Z Vel MSB	Lat cal LM st vec Z Vel LSB	1
58	State vector time MSB	State vector time LSB	1
59	Garbage	Desired CDU X	1
60	Desired CDU Y	Desired CDU Z	1
61	Body rate (P)	Body rate (Q)	1
62	Body rate (R)	Garbage	1
63	RR trunnion error	RR shaft error	1
64	LR vel X (raw data)	LR vel Y (raw data)	1
65	LR vel Z (raw data)	LR range (raw data)	1
66	TIGN MSB	TIGN LSB	1
67	DELVSLV	DELVSLV+1	1

Table 3-5C. LM Rendezvous and Prethrust Downlist. (Cont.)

Word No.	First Register	Second Register	Word Order Code
68	DELVSLV+2	DELVSLV+3	1
69	DELVSLV+4	DELVSLV+5	1
70	Central angle MSB	Central angle LSB	1
71	CDH time (MSB)	CDH time (LSB)	1
72	CDH delta vel X (MSB)	CDH delta vel X (LSB)	1
73	CDH delta vel Y (MSB)	CDH delta vel Y (LSB)	1
74	CDH delta vel Z (MSB)	CDH delta vel Z (LSB)	1
75	CDH delta altitude (MSB)	CDH delta altitude (LSB)	1
76	CDH apsis (MSB)	CDH apsis (LSB)	1
77	TPI time (MSB)	TPI time (LSB)	1
78	TPI delta vel X (MSB)	TPI delta vel X (LSB)	1
79	TPI delta vel Y (MSB)	TPI delta vel Y (LSB)	1
80	TPI delta vel Z (MSB)	TPI delta vel Z (LSB)	1
81	Elevation angle (MSB)	Elevation angle (LSB)	1
82	TPF time (MSB)	TPF time (LSB)	1
83	RADMODES	DAPBOOLS	1
84	SUMRATE (Q)	SUMRATE (R)	1
85	CADRFLSH	CADRFLSH+1	1
86	CADRFLSH+2	FAILREG	1
87	FAILREG+1	FAILREG+2	1
88	Actual CDU X	Actual CDU Y	1
89	Actual CDU Z	RR CDU trunnion	1
90	IMODES 30	IMODES 33	1
91	Channel 11	Channel 12	1
92	Channel 13	Channel 14	1
93	Channel 30	Channel 31	1
94	Channel 32	Channel 33	1
95	DSPTAB+0	DSPTAB+1	1
96	DSPTAB+2	DSPTAB+3	1
97	DSPTAB+4	DSPTAB+5	1
98	DSPTAB+6	DSPTAB+7	1
99	DSPTAB+8D	DSPTAB+9D	1
100	DSPTAB+10D	DSPTAB+11D	1

Table 3-5C. LM Rendezvous and Prethrust Downlist (Cont.)

Word No.	First Register	Second Register	Word Order Code
1	Downlist I. D.	Sync Bits (77340-octal)	0
2	LM X position	Garbage	1
3	LM Y position	Garbage	1
4	LM Z position	Garbage	1
5	LM epoch time MSB	Garbage	1
6	LM X velocity	Garbage	1
7	LM Y velocity	Garbage	1
8	LM Z velocity	Garbage	1
9	LM epoch time LSB	Garbage	1
10	CM X position cal. by LM	Garbage	1
11	CM Y position cal. by LM	Garbage	1
12	CM Z position cal. by LM	Garbage	1
13	CM epoch time MSB cal. by LM	Garbage	1
14	CM X velocity cal. by LM	Garbage	1
15	CM Y velocity cal. by LM	Garbage	1
16	CM Z velocity cal. by LM	Garbage	1
17	CM epoch time LSB cal. by LM	Garbage	1
18	COMPNUMB	UPOLDMOD	1
19	UPVERB	UPCOUNT	1
20	UPBUFF+0	UPBUFF+1	1
21	UPBUFF+2	UPBUFF+3	1
22	UPBUFF+4	UPBUFF+5	1
23	UPBUFF+6	UPBUFF+7	1
24	UPBUFF+8D	UPBUFF+9D	1
25	UPBUFF+10D	UPBUFF+11D	1
26	UPBUFF+12D	UPBUFF+13D	1
27	UPBUFF+14D	UPBUFF+15D	1
28	UPBUFF+16D	UPBUFF+17D	1
29	UPBUFF+18D	UPBUFF+19D	1
30	Spare	Spare	1
31	Spare	Spare	1
32	Spare	Spare	1
33	K factor MSB	K factor LSB	1
34	LM current weight MSB	LM current weight LSB	1

Table 3-5D. LM AGS Initialization/Update Downlist.

Word No.	First Register	Second Register	Word Order Code
35	RSBBQ	RSBBQ+1	1
36	RR CDU shaft	Actual PIPA X	1
37	Actual PIPA Y	Actual PIPA Z	1
38	Actual CDU X	Actual CDU Y	1
39	Actual CDU Z	RR CDU trunnion	1
40	Flagword 0	Flagword 1	1
41	Flagword 2	Flagword 3	1
42	Flagword 4	Flagword 5	1
43	Flagword 6	Flagword 7	1
44	Flagword 8D	Flagword 9D	1
45	DSPTAB+0	DSPTAB+1	1
46	DSPTAB+2	DSPTAB+3	1
47	DSPTAB+4	DSPTAB+5	1
48	DSPTAB+6	DSPTAB+7	1
49	DSPTAB+8D	DSPTAB+9D	1
50	DSPTAB+10D	DSPTAB+11D	1
51	Time 2	Time 1	0
52	Lat cal LM st vec X Pos MSB	Lat cal LM st vec X Pos LSB	1
53	Lat cal LM st vec Y Pos MSB	Lat cal LM st vec Y Pos LSB	1
54	Lat cal LM st vec Z Pos MSB	Lat cal LM st vec Z Pos LSB	1
55	Lat cal LM st vec X Vel MSB	Lat cal LM st vec X Vel LSB	1
56	Lat cal LM st vec Y Vel MSB	Lat cal LM st vec Y Vel LSB	1
57	Lat cal LM st vec Z Vel MSB	Lat cal LM st vec Z Vel LSB	1
58	State vector time MSB	State vector time LSB	1
59	Garbage	Desired CDU X	1
60	Desired CDU Y	Desired CDU Z	1
61	Body rate (P)	Body rate (Q)	1
62	Body rate (R)	Garbage	1
63	Spare	Spare	1
64	REDOCTR	THETAD+ϕ	1
65	THETAD+1	THETAD+2	1
66	Spare	Spare	1
67	Spare	Spare	1

Table 3-5D. LM AGS Initialization/Update Downlist (Cont.)

Word No.	First Register	Second Register	Word Order Code
68	COMPNUMB	UPOLDMOD	1
69	UPVERB	UPCOUNT	1
70	UPBUFF+0	UPBUFF+1	1
71	UPBUFF+2	UPBUFF+3	1
72	UPBUFF+4	UPBUFF+5	1
73	UPBUFF+6	UPBUFF+7	1
75	UPBUFF+8D	UPBUFF+9D	1
75	UPBUFF+10D	UPBUFF+11D	1
76	UPBUFF+12D	UPBUFF+13D	1
77	UPBUFF+14D	UPBUFF+15D	1
78	UPBUFF+16D	UPBUFF+17D	1
79	UPBUFF+18D	UPBUFF+19D	1
80	Spare	Spare	1
81	Spare	Spare	1
82	Spare	Spare	1
83	RADMODES	DAPBOOLS	1
84	SUMRATE (Q)	SUMRATE (R)	1
85	CADRFLSH	CADRFLSH+1	1
86	CADRFLSH+2	FAILREG	1
87	FAILREG+1	FAILREG+2	1
88	Actual CDU X	Actual CDU Y	1
89	Actual CDU Z	Actual CDU trunnion	1
90	IMODES 30	IMODES 33	1
91	Channel 11	Channel 12	1
92	Channel 13	Channel 14	1
93	Channel 30	Channel 31	1
94	Channel 32	Channel 33	1
95	DSPTAB+0	DSPTAB+1	1
96	DSPTAB+2	DSPTAB+3	1
97	DSPTAB+4	DSPTAB+5	1
98	DSPTAB+6	DSPTAB+7	1
99	DSPTAB+8D	DSPTAB+9D	1
100	DSPTAB+10D	DSPTAB+11D	1

Table 3-5D. LM AGS Initialization/Update Downlist (Cont.)

The entry of data may be manual or automatic. During the automatic update, the UPLINK ACTY light will be lighted. Manual update is selected by keying in V70, V71, V72, or V73 followed by operator keying into R1 by segments (XXXXXE) the required data. This is performed with a FL V21 N01 display that also displays the calculated machine address in R3.

3.5 POWER DISTRIBUTION

The LEM electrical power subsystem supplies two voltages to the PGNCS. There are +27.5 (±5) volts dc and 115 (±2.5) volts, 400 (±10) cps, ac. During mission phases in which the PGNCS is in operating modes, the +27.5 volt has minimum instantaneous steady-state of +23.5 volts. The circuit breaker interface of these voltages to the PGNCS subsystems is shown in Fig. 3-10. The LGC negative power return is connected internally to the computer chassis. All other dc returns are isolated from PGNCS chassis and are grounded by a return to the negative dc bus.

During most of the period, while the CSM and LM are docked together, LM power is supplied from the command module fuel cell. During this portion of the flight, the LGC is turned off and the ISS is in a standby state with only the temperature control system being energized (IMU STBY circuit breaker is closed). To prepare for LM/CSM separation, power is switched to the LM , the remaining PGNCS circuit breakers are then closed.

Microsyn excitation (3200 cps power supply) is operated from either the IMU OPR or LGC DSKY circuit breakers. This means the microsyn suspension system is operated continuously (except for LGC power turn off) after separation. Operating the microsyn excitation also from the IMU OPR circuit breaker insures

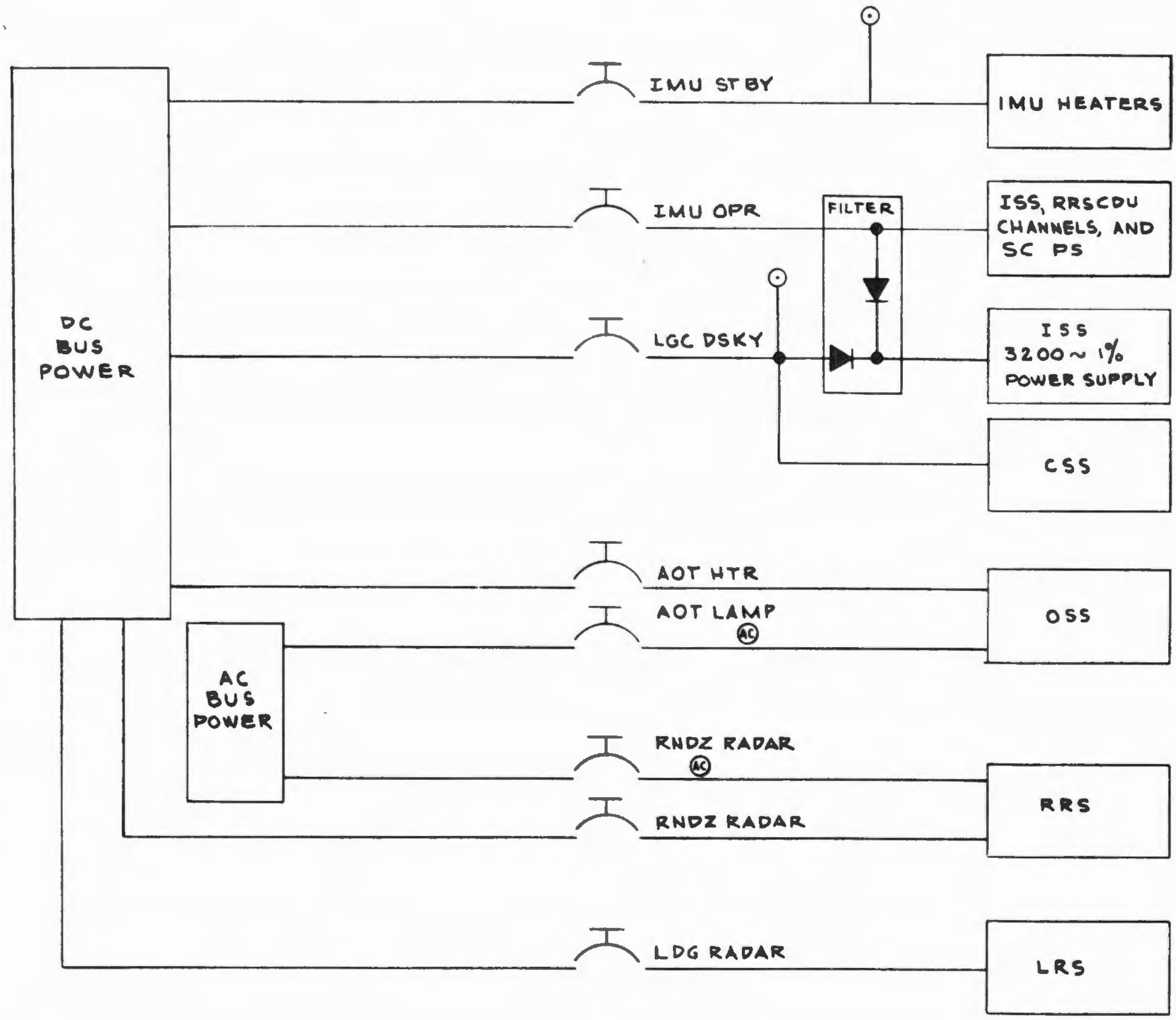


Fig. 3-10. PGNCS power distribution diagram.

stable IMU operation at any time the IMU is in operation. To prevent the accelerometers and gyros from being torqued until the suspension systems have centered the floats radially, the pulse torque power supply is inhibited both by the 90-second delay relay (see paragraph 2.1.2.1) and the LGC power on relay. This has the advantage of the time delay and not operating the accelerometers except when the LGC is turned on.

Table 3-6 lists the power required by the PGNCS subsystems at 28 volts dc.

Equipment/State	Max Power	Average Power	Min Power
IMU/Standby	80	60	40
IMU/Operate	380	300	200
LGC/Standby	12	10	8
LGC/Operate	130	110	90
AOT	5	5	5
AOT (a-c power at 115 v ac)	9.2	-	-
Total	616.2	485	343

Table 3-6. PGNCS power consumption.

3.6 Computer Input/Output Channel Interface

The LGC interfaces with the outside world in three basic ways:

1. Program Interrupts
2. Counter Interrupts
3. Input/Output Channels

The Program Interrupts inform the LGC that certain conditions exist which demand the interruption of its present course of action according to a predetermined order of priorities. The Counter Interrupts inform the LGC that one of many variables it has stored in its erasable memory requires an incremental change. These counter interrupts do not cause an interrupt in the program being processed but they do cause a 12 μsec suspension of the program during which time the counter interrupt is processed.

The input/output channels of the LGC make available to the various programs information about conditions which exist in the spacecraft environment and also provide the LGC with a means of communicating with other subsystems in the spacecraft environment. There are seven output channels (Nos. 5, 6, 10, 11, 12, 13, and 14) and six input channels (Nos. 15, 16, 30, 31, 32, and 33) in the LGC. Each of these channels contains up to 15 bits of information. These bits of information are referred to as discretes. This section contains a description of the input and output channels and a series of interface drawings showing the path each of these discretes takes to its destination or from its source, depending on the case. Also included in these drawings are all circuit breakers and switches which play a part in the completion of an action called for by the issuance of a discrete, or the deliverence of a discrete to the LGC.

3.6.1 Channel 5 and Channel 6

These two output channels have eight bit positions each, and are associated with the reaction control system (RCS) jets. These channel outputs are used to control the translational and rotational motion of the LM. A logic one in any of the bit positions will cause the appropriate reaction control system jet to be fired (see Fig. 3-11).

3.6.2 Channel 10

This output channel utilizes all 15 bit positions. By varying the discretes in the 15 bit positions of channel 10, the LGC has the capability of turning on four condition indicators on the DSKY and also turning on a combination of electro-luminescent lamps in each of the 21 display indicator positions to form any decimal digit. The three sign indicator positions associated with the three registers are also controlled by a combination of bits in this channel (see Fig. 3-12).

3.6.3 Channel 11

This output channel is used primarily to provide the LGC with additional interface with the display and keyboard. Bit location 1 is routed to a relay in the DSKY but provides an indication of an ISS warning condition to the CWEA. (See Fig. 3-13). Bit positions 2 through 7 and 10 are routed to the DSKY relays and provide the remainder of the inputs to the DSKY conditions indicators as well as providing for the flashing of the verb nouns (see Fig. 3-14). Bit positions 13 and 14 of channel 11 provide the interface necessary for control of the descent and ascent engines (see Fig. 3-15).

3.6.4 Channel 12

Output channel 12 interfaces primarily with the other portions of the Guidance Navigation and Control System. Bits 1, 2, 4, 5 and 6 of channel 12

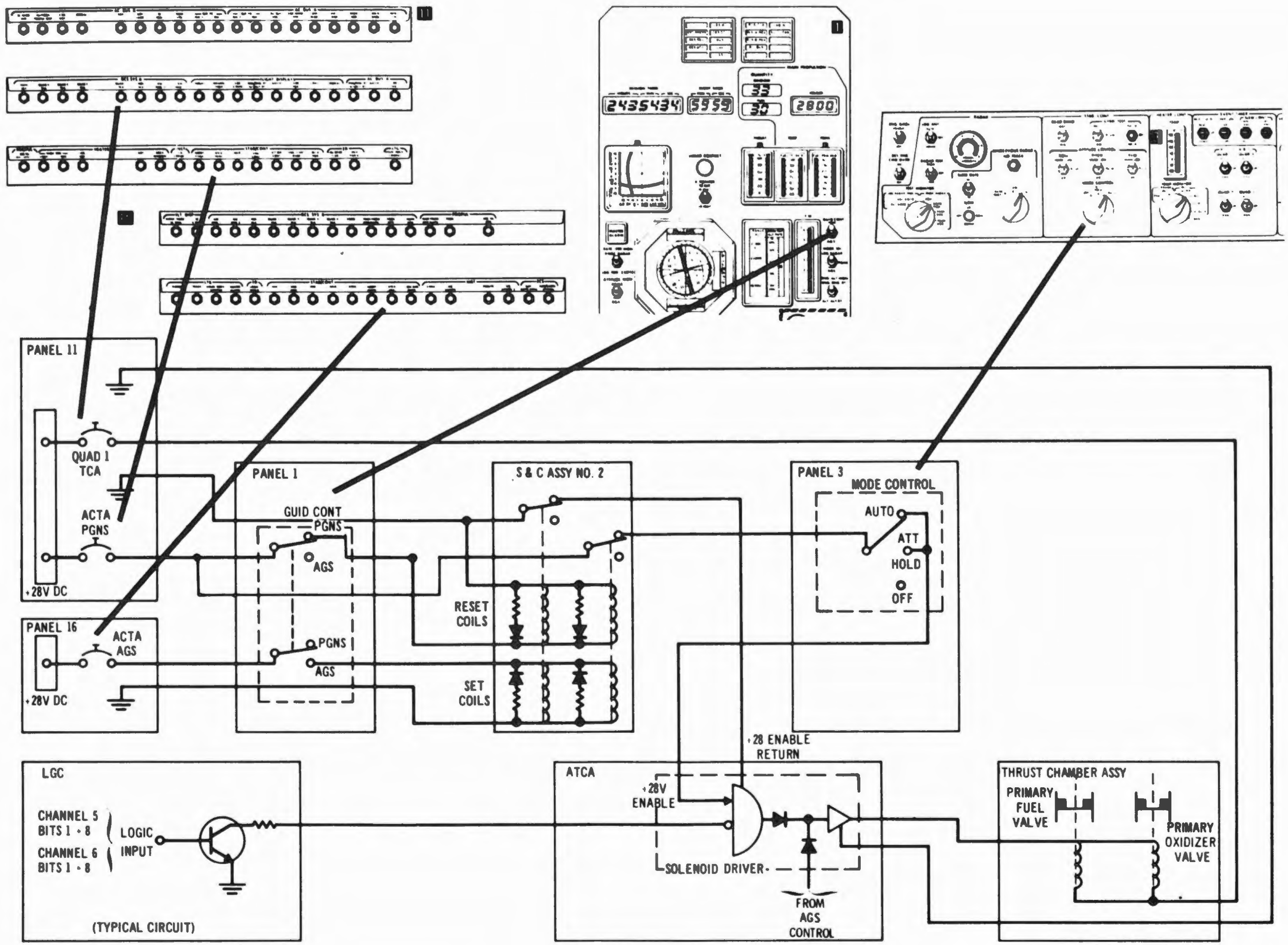


Fig. 3-11. Channels 5 and 6 Bits 1 through 8 RCS Jet Selection.

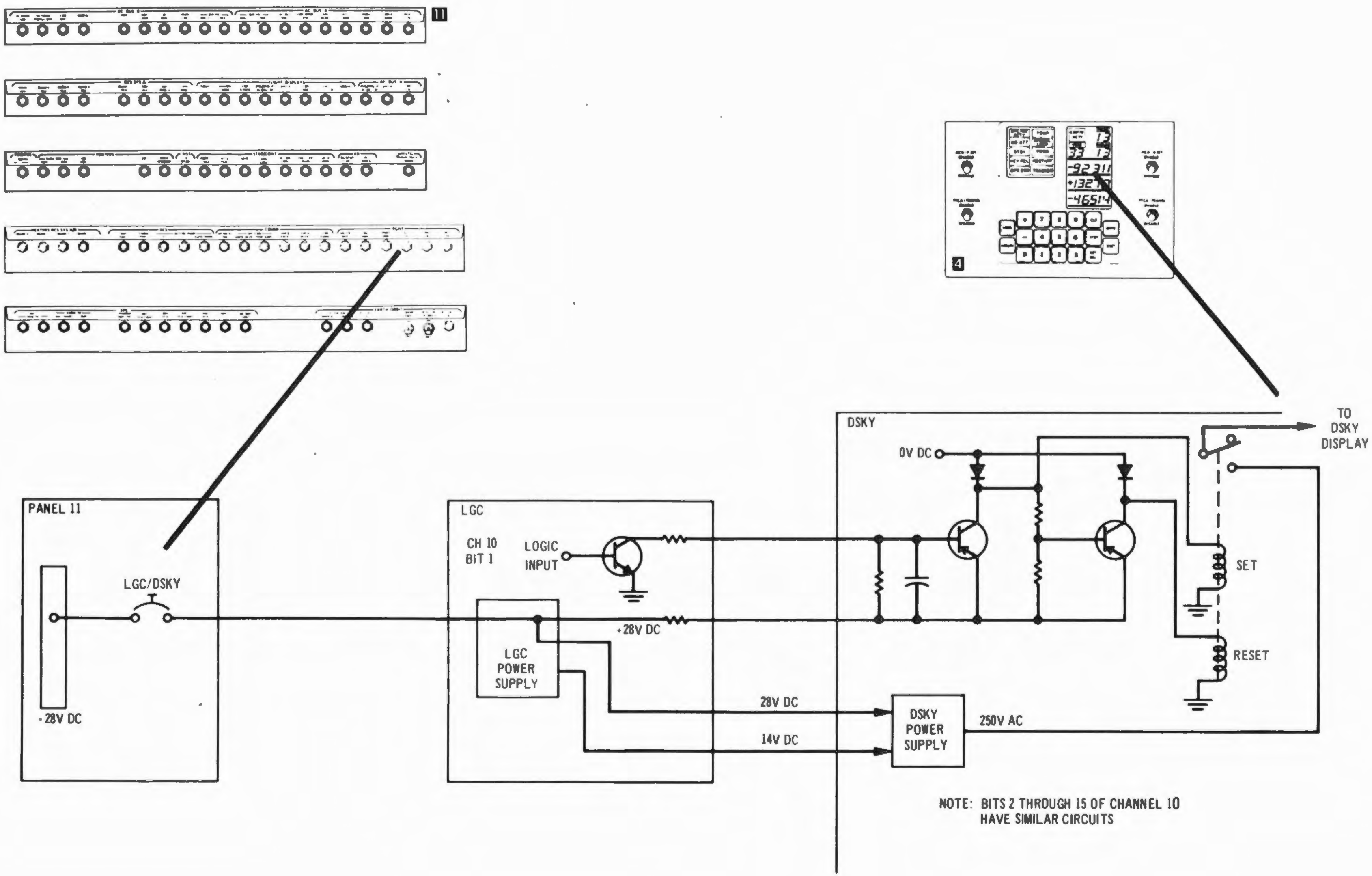


Fig. 3-12. Channel 10 Bits 1 through 15.

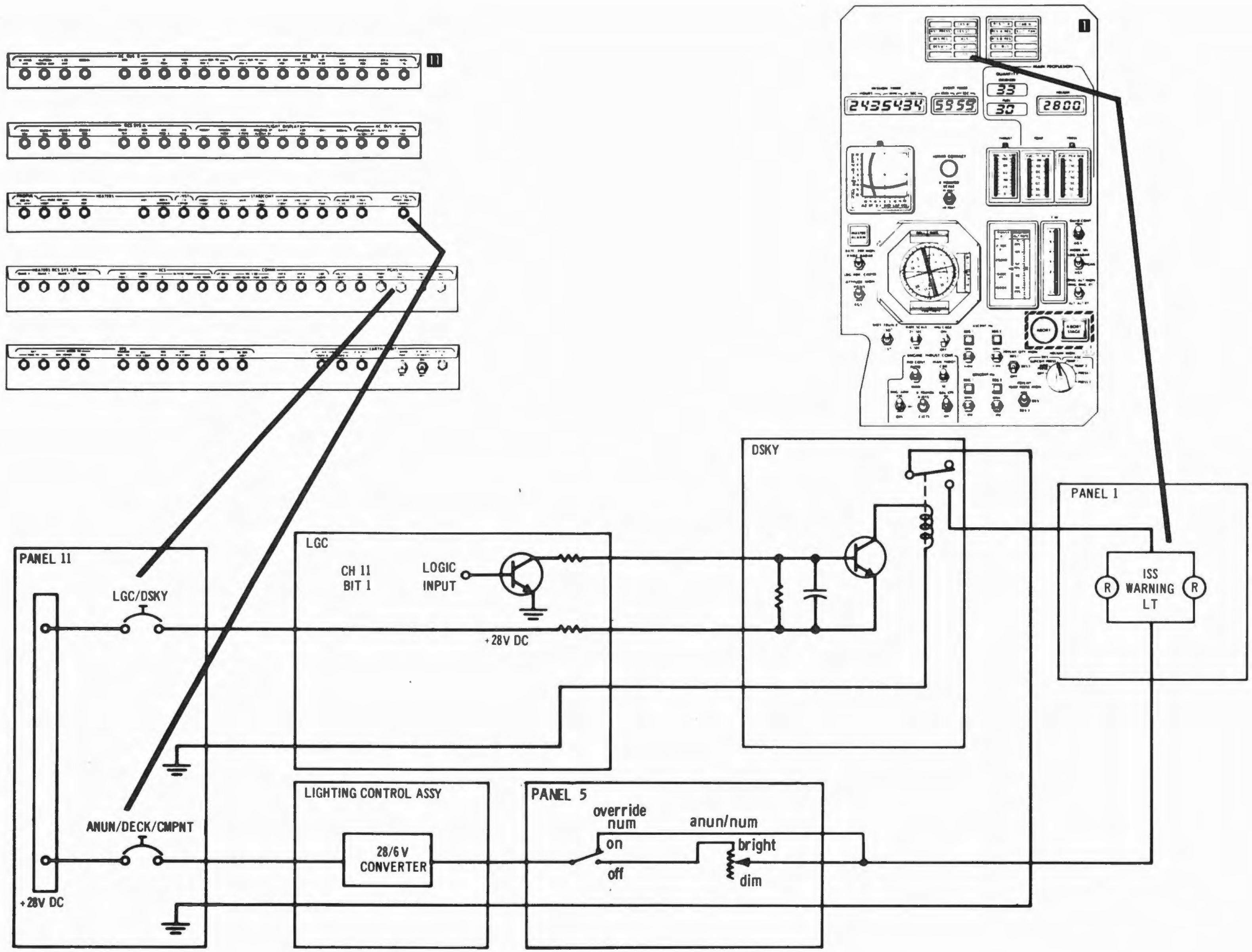


Fig. 3-13. Channel 11 Bit 1 ISS Warning.

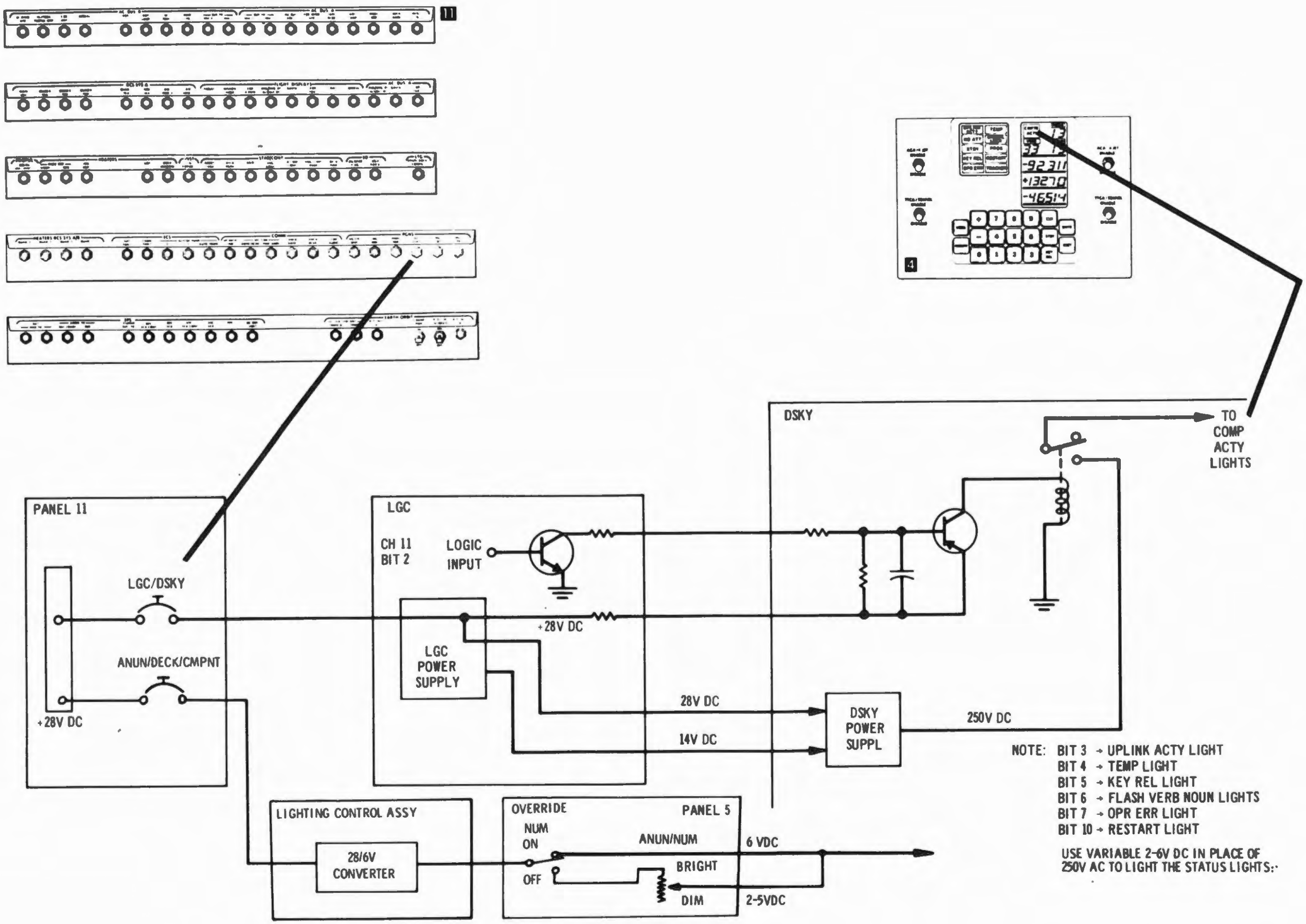


Fig. 3-14. Channel 11 Bits 2 through 7.

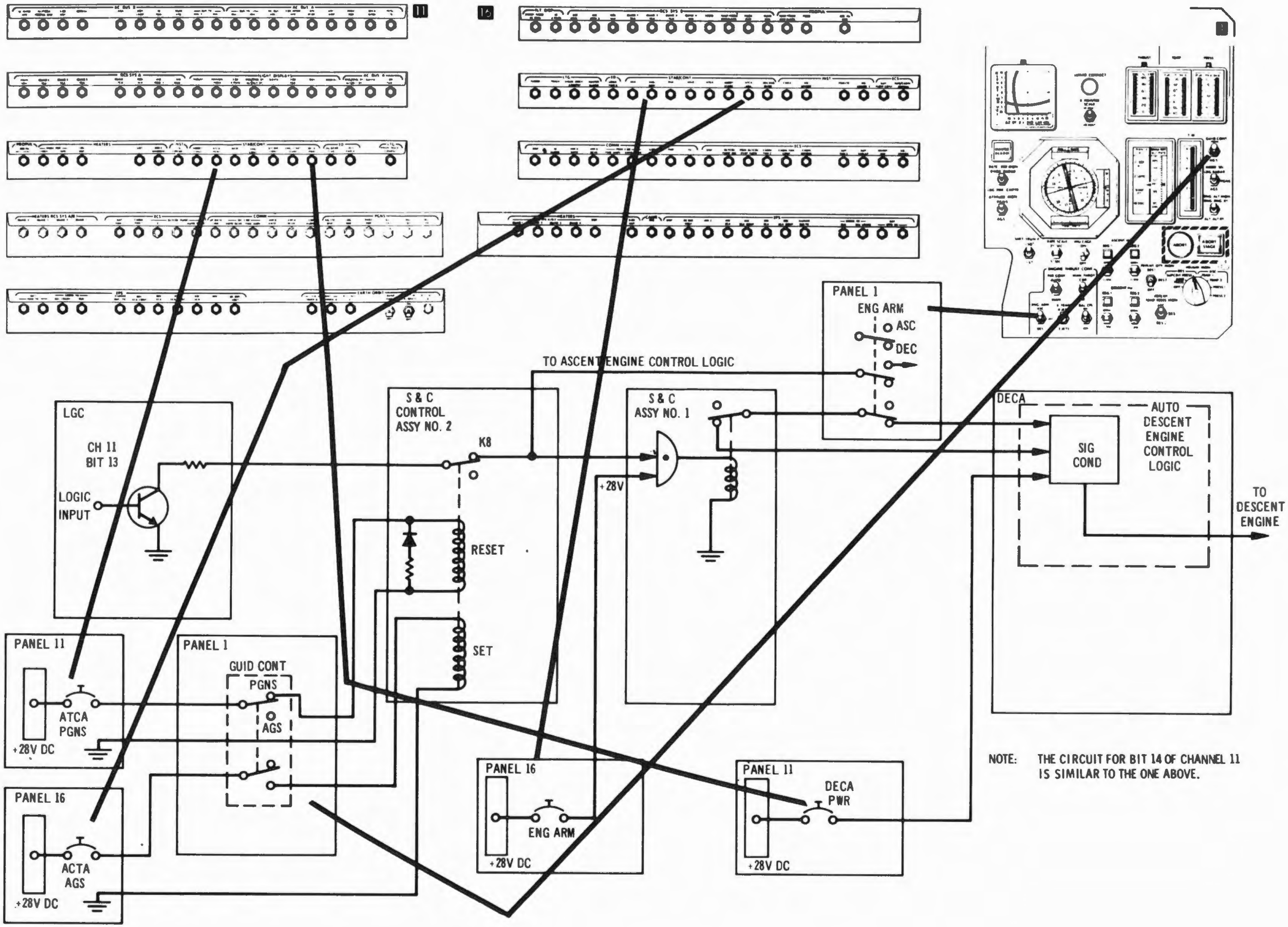


Fig. 3-15. Channel 11 Bit 13 Engine on.

interface with the CDU and are utilized by the LGC in controlling the ISS and the R. R. operation (see Fig. 3-16). Bit 8 of channel 12 also interfaces with the CDU and is used by the LGC to enable the display of information to the astronaut (see Fig. 3-17). Bit positions 9, 10, 11 and 12 of channel 12 provide the computer with an interface for controlling the pitch and roll gimbal trim of the descent engine (see Fig. 3-18). Bit position 13 of channel 12 enables the computer to change the position of the landing radar antenna (see Fig. 3-19). Bit position 14 of channel 12 enables the RR to enter the auto track mode of operation (see Fig. 3-20). Bit 15 of channel 12 controls the duration of the time delay of the turn on sequence of the IMU (see Fig. 3-21).

3.6.5 Channel 13

All 15 bit positions of this output channel are utilized by the LGC for interfacing with the rendezvous and landing radar systems and for internal control of the LGC. Using bit positions 1 through 4, the LGC selects the source of the radar data required and controls the readout of this data from the radar electronics assemblies (see Fig. 3-22). Bit positions 5, 6, 7, 8 and 9 of this channel are used by the LGC to control the processing of data in the interface circuits located in the LGC. Bits 5, 6 and 7 are associated with uplink and downlink and bits 8 and 9 are associated with rotational hand controller input control. Bit positions 10 through 15 of this channel are also used for controlling interface circuits internal to the LGC. Bit 10 generates a signal which inhibits RESTRT in the ALARM circuit. This allows various caution indicators on the DSKY to be tested. A one in bit position 11 enables the standby circuits. Bit positions 12, 13, 14 reset the interface circuits which control the rotation, translation and thruster fail program interrupts. Bit position 15 of channel 13 is used by the LGC for the generation of a signal, T6RUPT, which enables the decrementing of the TIME6 counter for reaction control program termination. There are no interface drawings for bits 5 to 15 of channel 13 since they are used internally in the LGC.

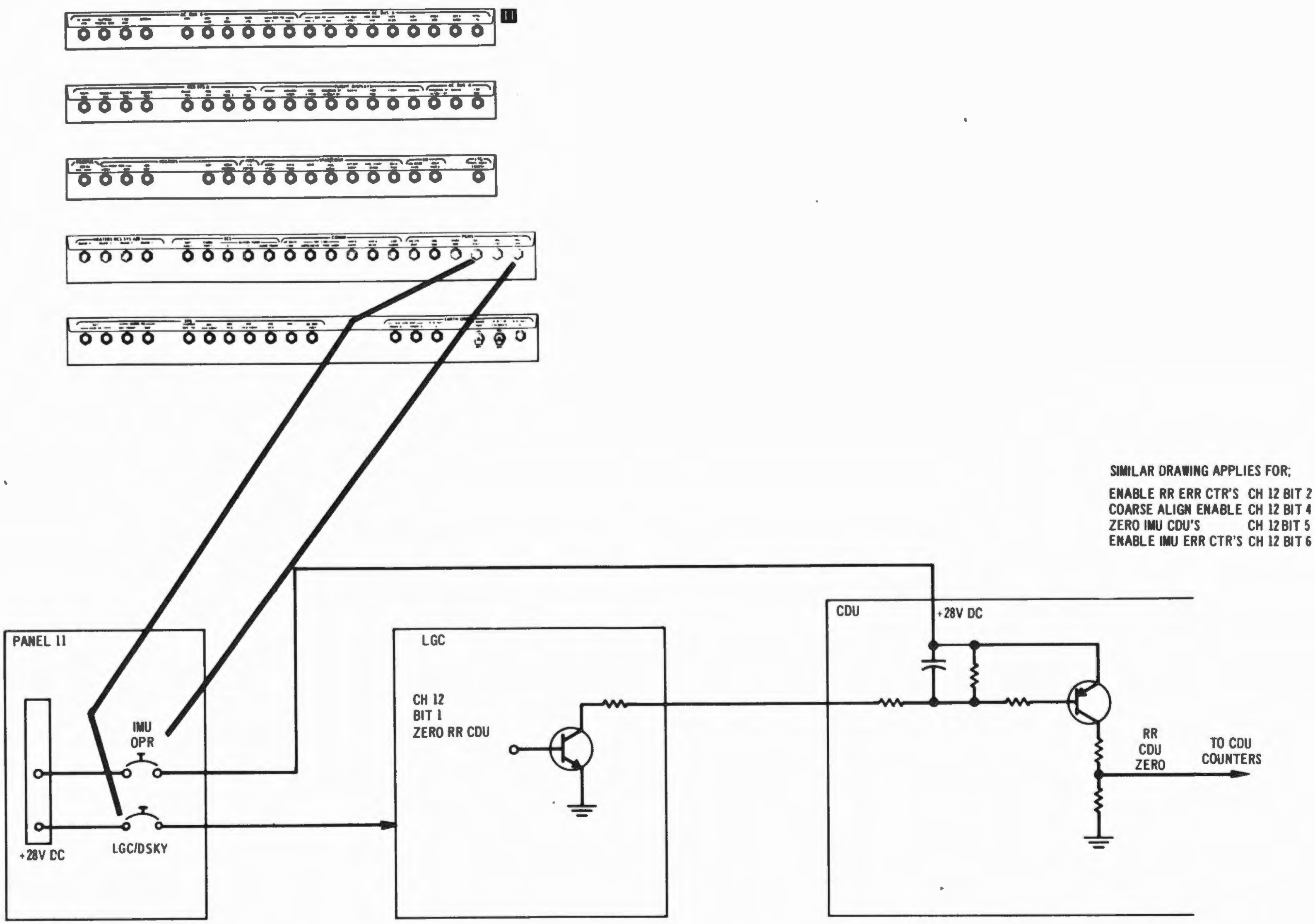


Fig. 3-16. Channel 12 Bit 1 RR CDU zero.

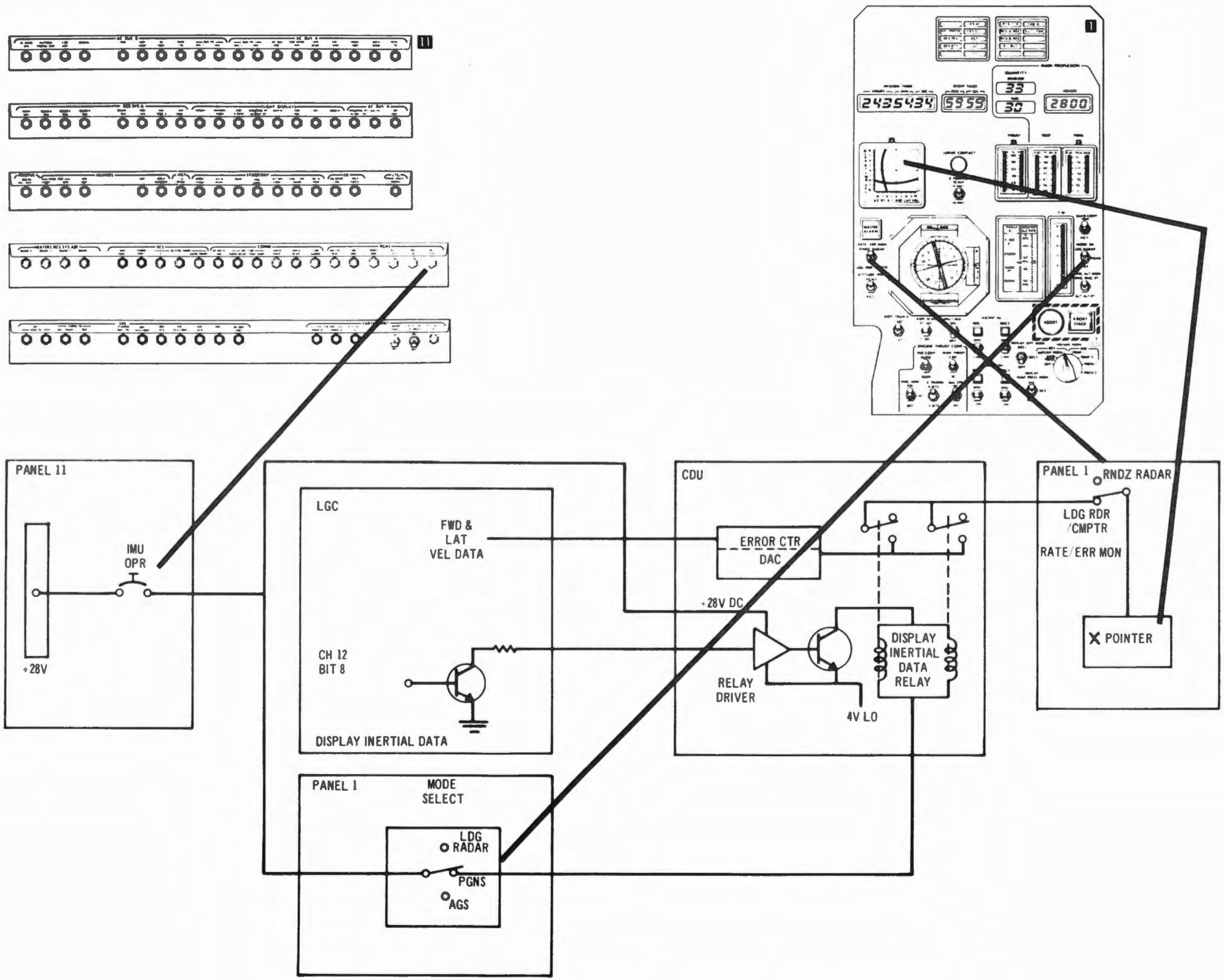


Fig. 3-17. Channel 12 Bit 8 Display Inertial Data.

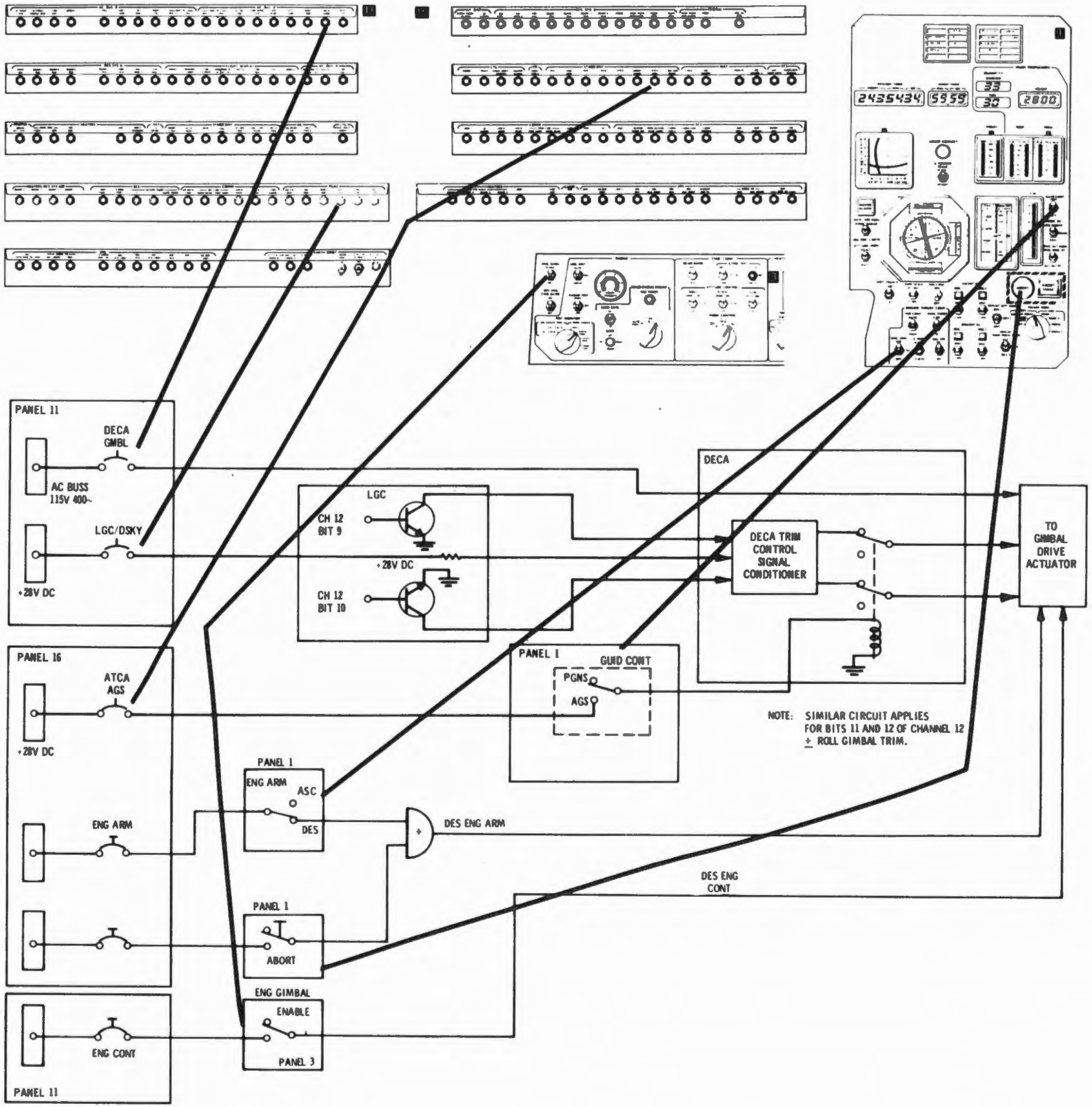


Fig. 3-18. Channel 12 Bits 9 and 10 ± Pitch Gimbal Trim.

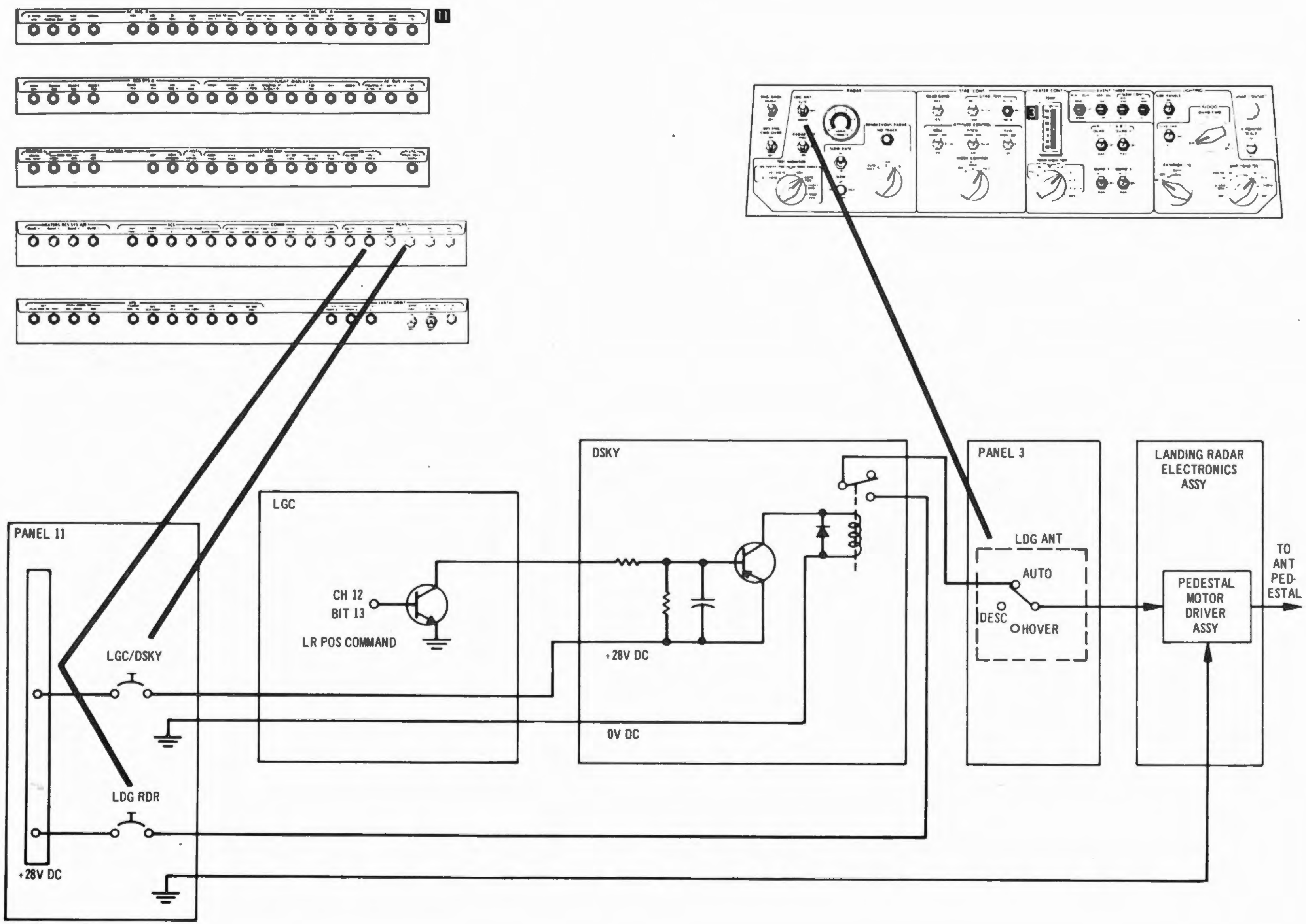


Fig. 3-19. Channel 12 Bit 13 LR Position Command

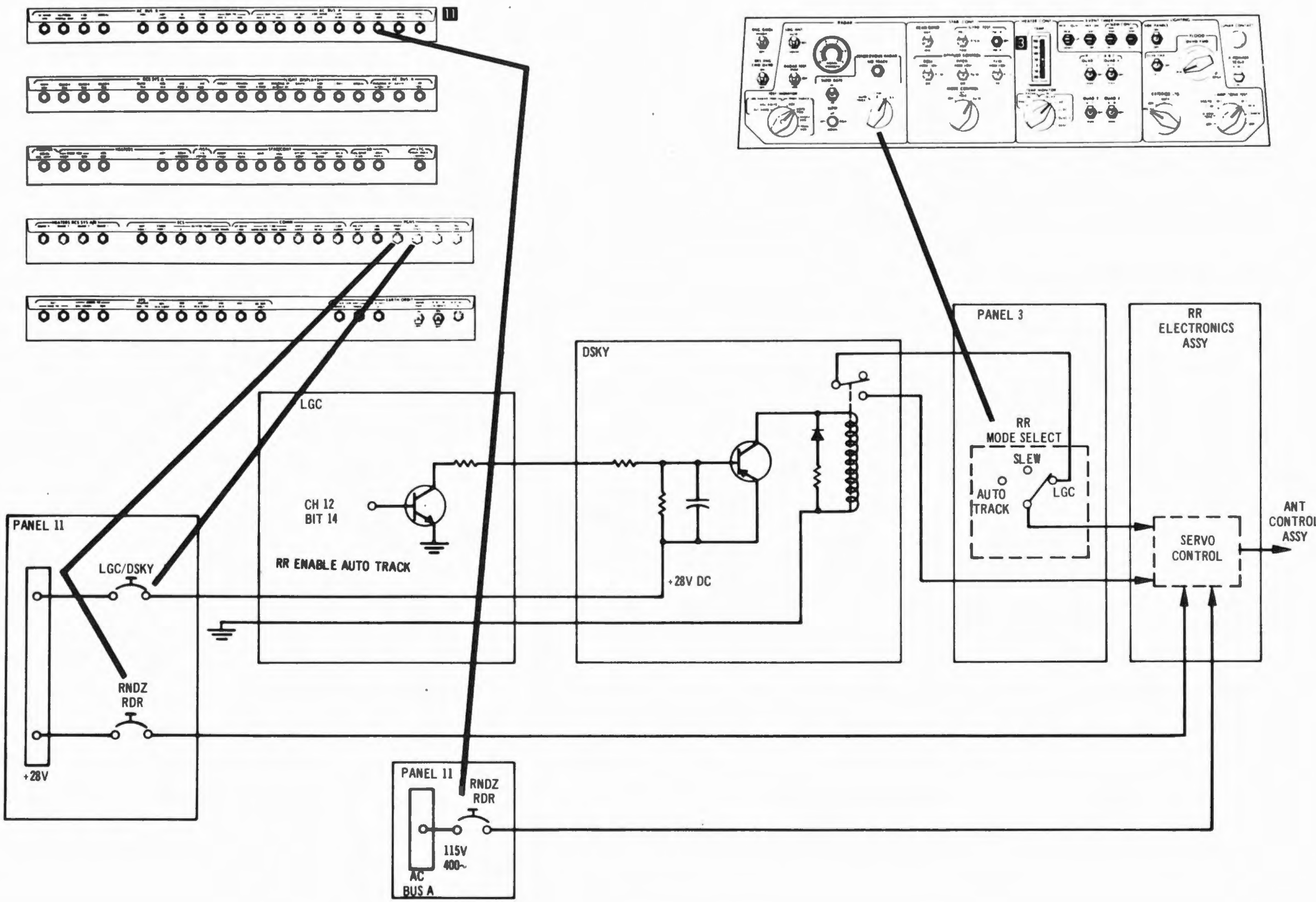


Fig. 3-20. Channel 12 Bit 14 RR Enable Auto Track.

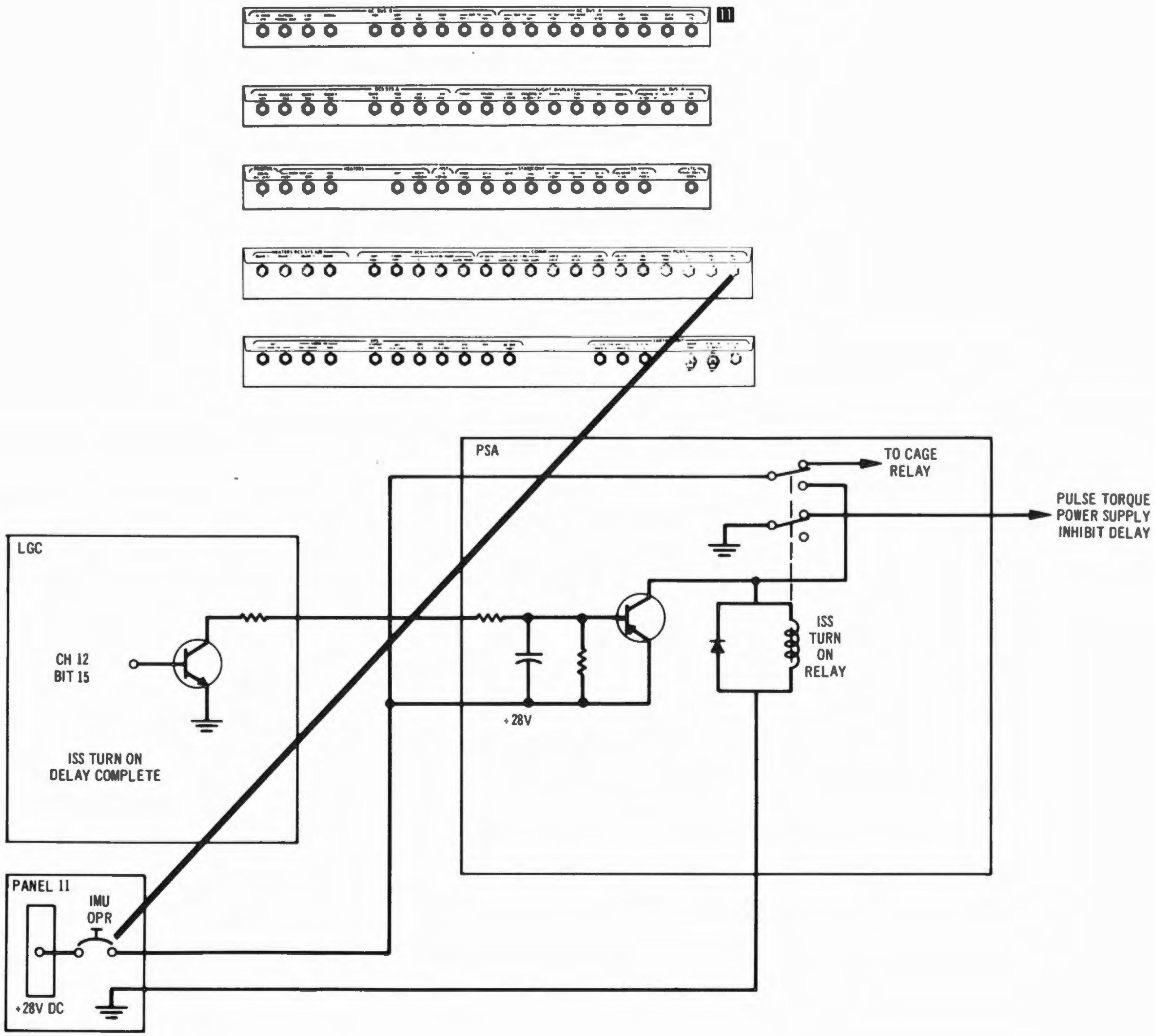


Fig. 3-21. Channel 12 Bit 15 ISS Turn On Delay Complete.

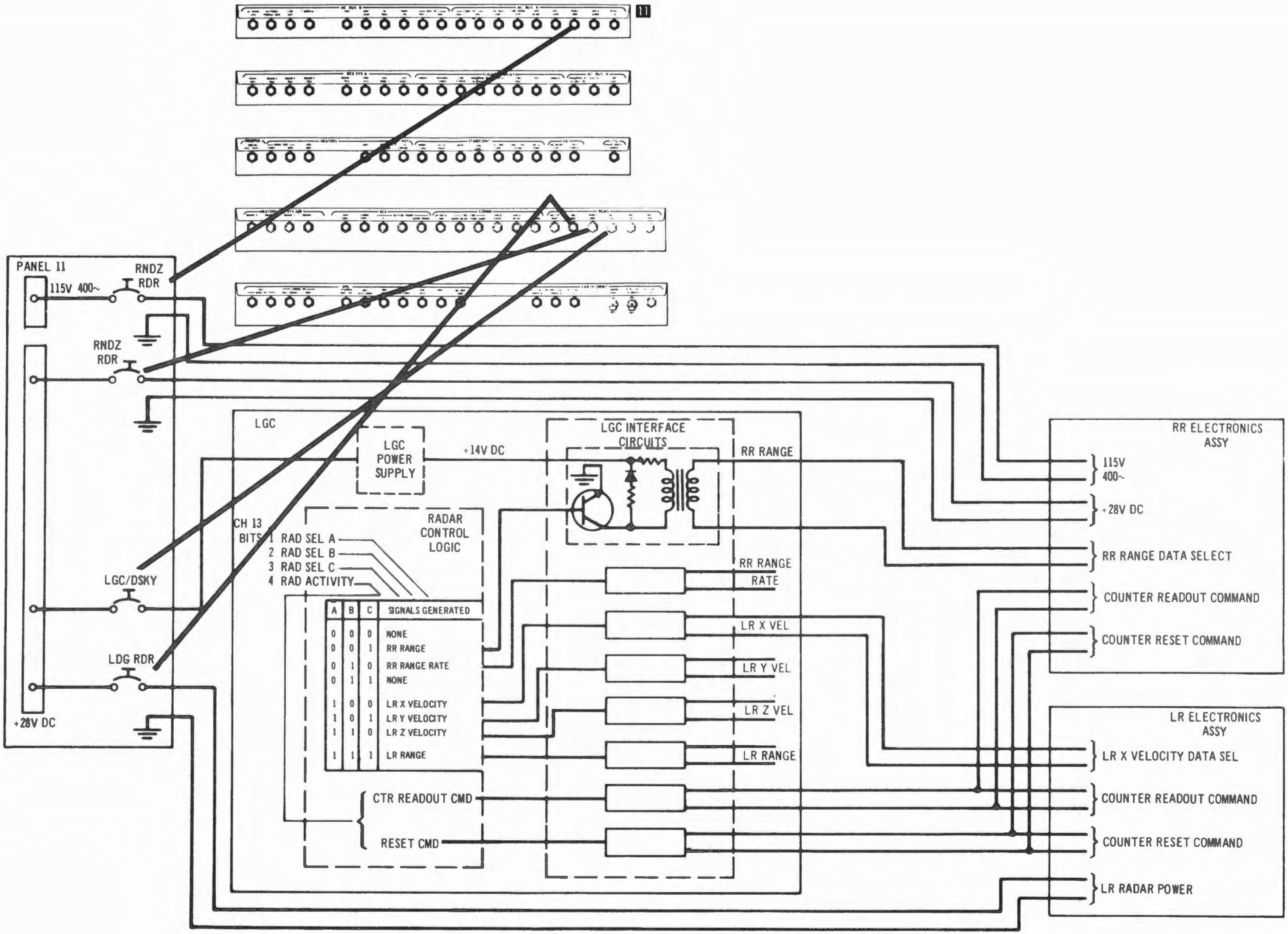


Fig. 3-22. Channel 13 Bits 1 through 4 Radar Data Select.

3.6.6 Channel 14

Channel 14 controls various areas of the LGC for the transfer of data from counters in memory to various PGNS and spacecraft systems. Bit position 1 enables the crosslink control logic which provides a serial data word to the crosslink equipment. Bit positions 2 and 3 of this channel control the interface logic in the LGC which provides the altitude and altitude rate information to the altitude/range indicator (see Fig. 3-23). Bit position 4 is utilized by the LGC to enable the gating logic within the LGC associated with throttle control of the descent engine (see Fig. 3-24). Bit positions 6 through 10 are used by the LGC to control the torquing of the gyros during fine alignment of the IMU. Bit positions 11 and 12 control the interface circuits in the LGC used to drive the RR antenna in shaft and trunnion. Bit positions 13, 14 and 15 control the interface circuits used to drive the IMU gimbals during coarse align.

3.6.7 Channel 15

This input channel is the interface between the LGC and the DSKY key codes. Whenever any key on the DSKY, except the PRO KEY, is depressed a five bit key code is sent to the LGC via channel 15, bits 1 through 5. These 5 bit positions are the only ones used in this channel.

3.6.8 Channel 16

There are 5 bit positions utilized in this input channel. Bit positions 3, 4 and 5 are the input interface between the Mark X, Mark Y and Mark Reject buttons on the CCRD and the LGC (see Fig. 3-25). Bit positions 6 and 7 are the inputs from the plus and minus rate of descent switch (see Fig. 3-26).

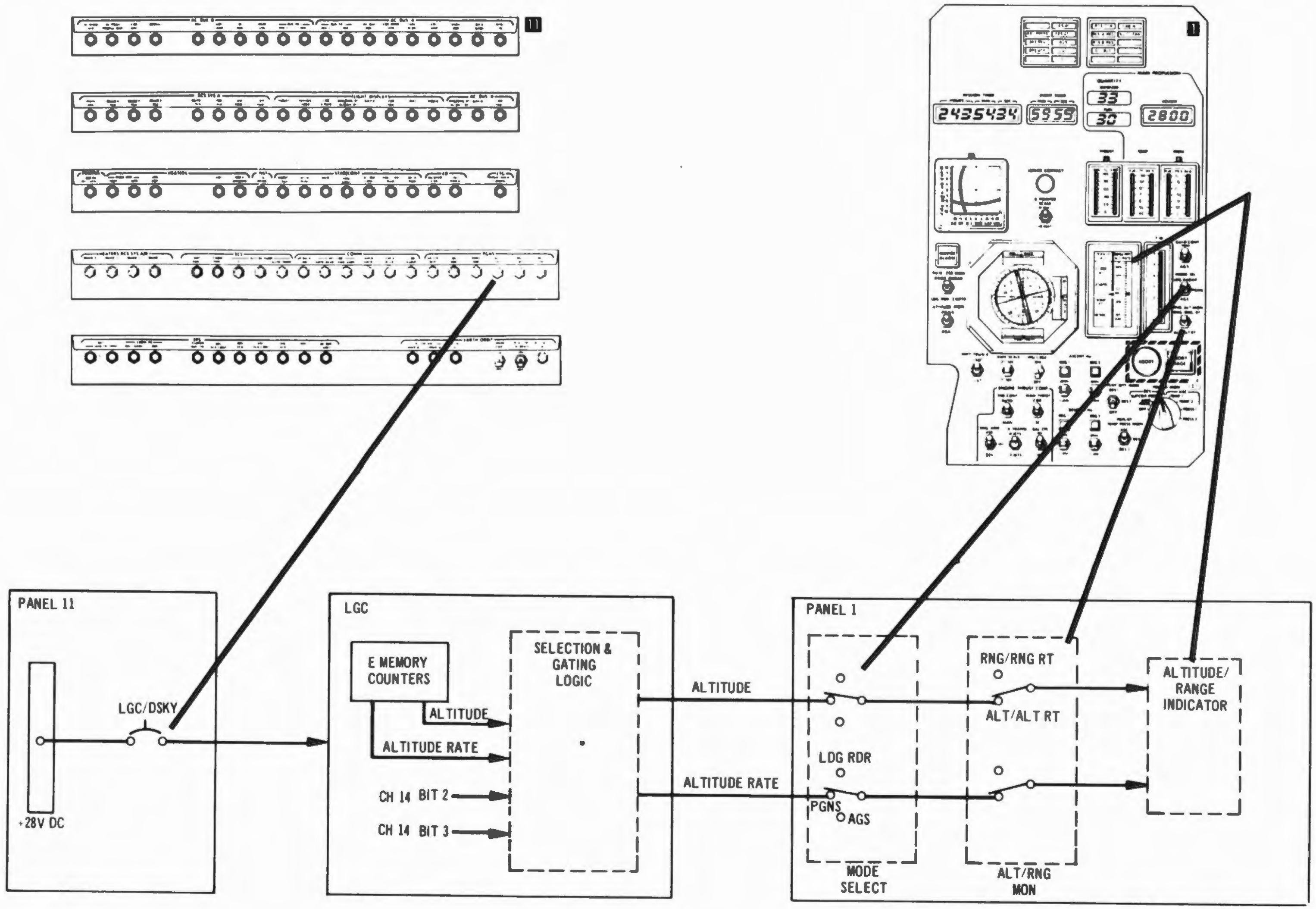


Fig. 3-23. Channel 14 Bits 2 and 3.

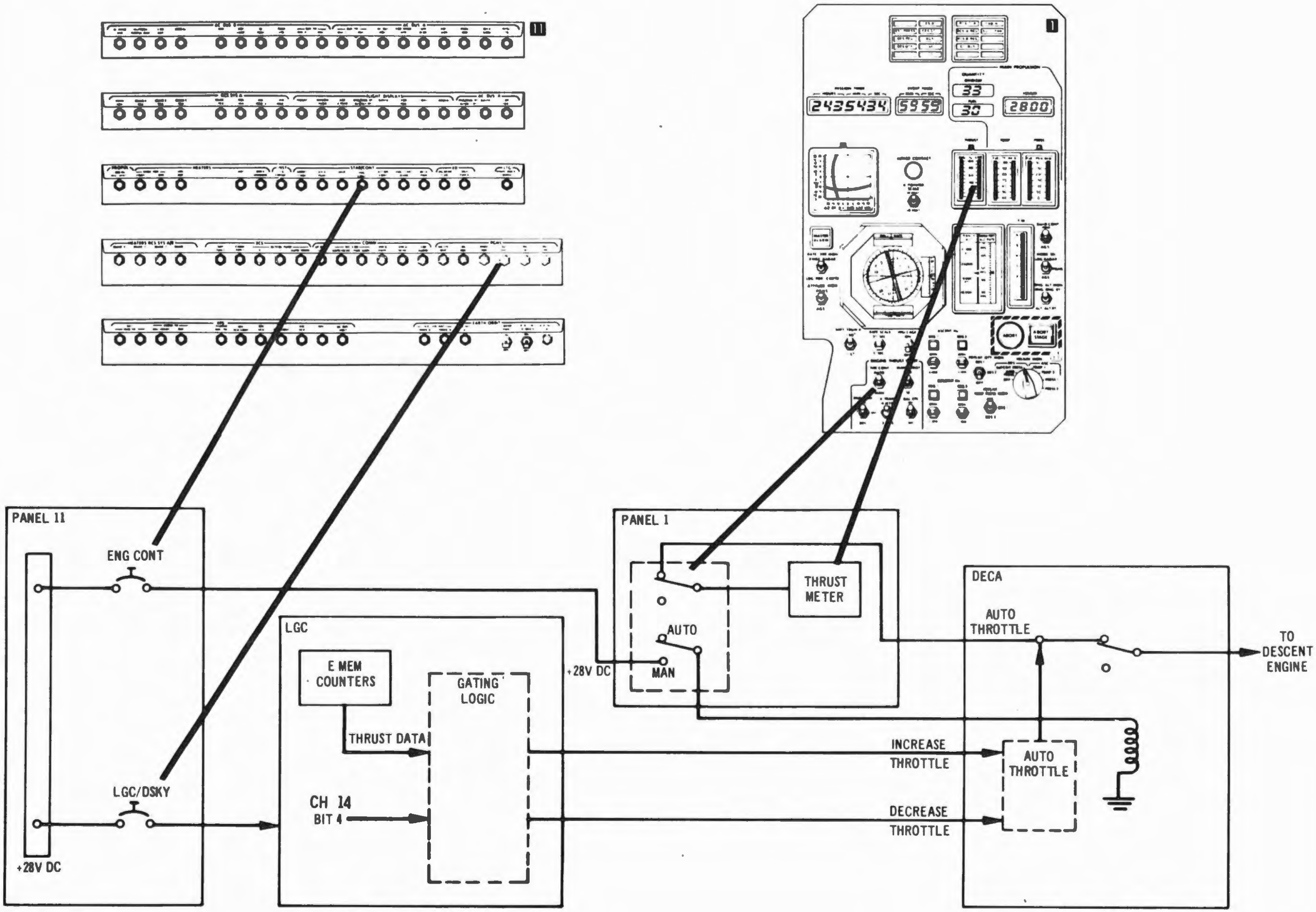


Fig. 3-24. Channel 14 Bit 4.

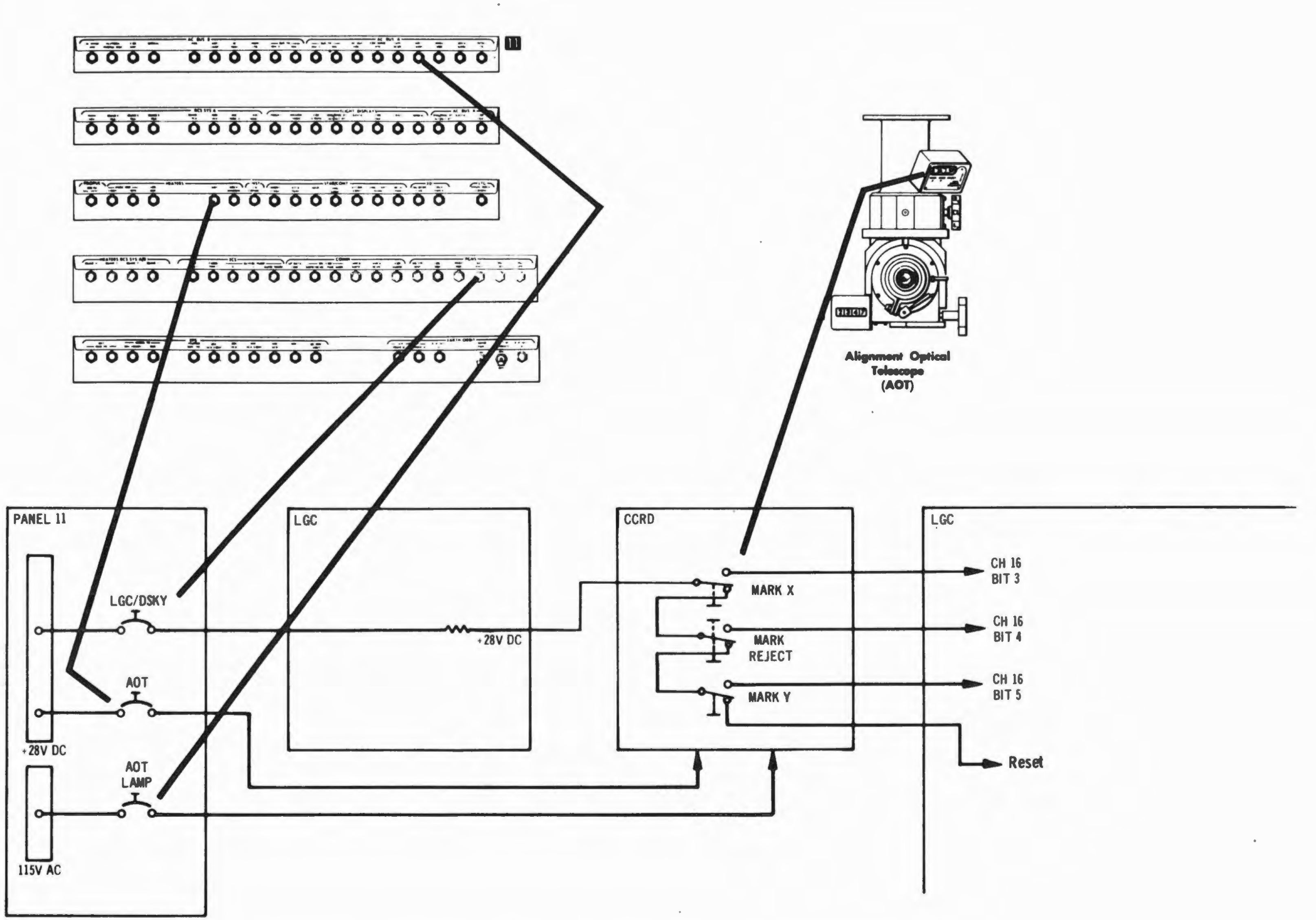


Fig. 3-25. Channel 16 Bits 3, 4 and 5.

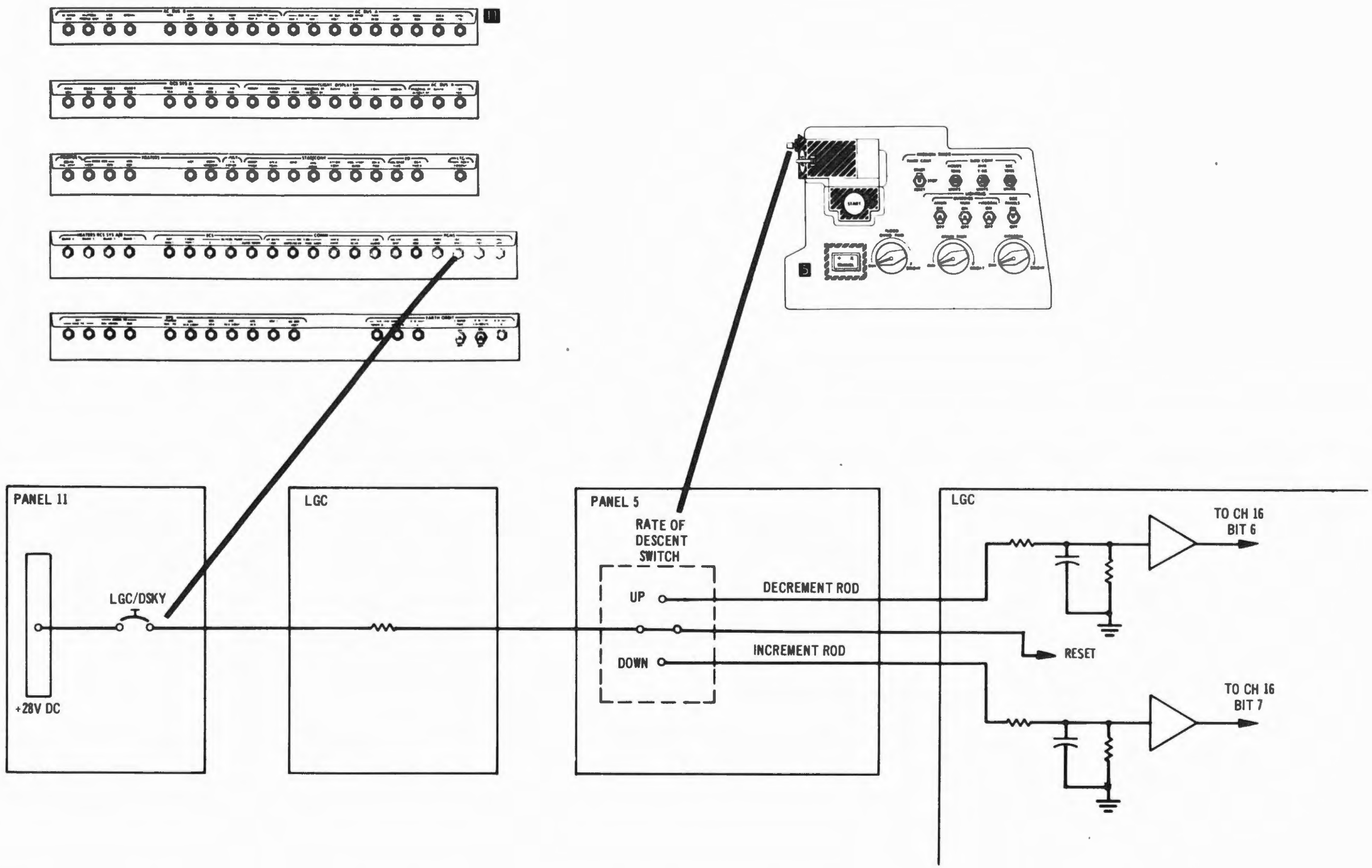


Fig. 3-26. Channel 16 Bits 6 and 7.

3.6.9 Channel 30

This input channel provides the LGC with information pertaining to the status of the inertial subsystem, the status of certain display and control panel switches and the status of the RR portions of the CDU. Bit 1 is an indication to the LGC of the status of the ABORT pushbutton (see Fig. 3-27). Bit 2 provides the LGC with an indication of the status of the descent stage separation pyrotechnics (see Fig. 3-28). Bit 3 is an indication to the LGC of the status of the engine arm switch (see Fig. 3-29). Bit 4 is an indication to the LGC of the status of the ABORT STAGE pushbutton (see Fig. 3-30). Bit 5 is an indication to the LGC of the status of the Thrust Control switch (see Fig. 3-31). Bit 6 informs the LGC of the status of the Mode Select Switch (see Fig. 3-32). Bit 7 is an indication to the LGC of the status of the RR portions of the CDU (see Fig. 3-33). Bit 8 is a spare. Bit 9 is the means by which the LGC is informed that the IMU has been turned on (see Fig. 3-34). Bit 10 informs the LGC that the Guidance Control Switch has been placed in the PGNS position (see Fig. 3-35). Bit 11 is the means by which the LGC is informed that the IMU CAGE switch has been placed to the on position (see Fig. 3-36). Bit positions 12 and 13 are inputs to the LGC from the IMU and CDU fail detect circuitry (see Figs. 3-37 and 3-38). Bit 14 of this channel is the input to the LGC that requests a 90 second delay during IMU turn on (see Fig. 3-39). Bit 15 of channel 30 is the input to the LGC from the IMU temperature monitoring circuit (see Fig. 3-40).

3.6.10 Channel 31

This channel provides the LGC with translation and rotation information. Bit positions 1 through 6 are inputs for minimum impulse commands in pitch,

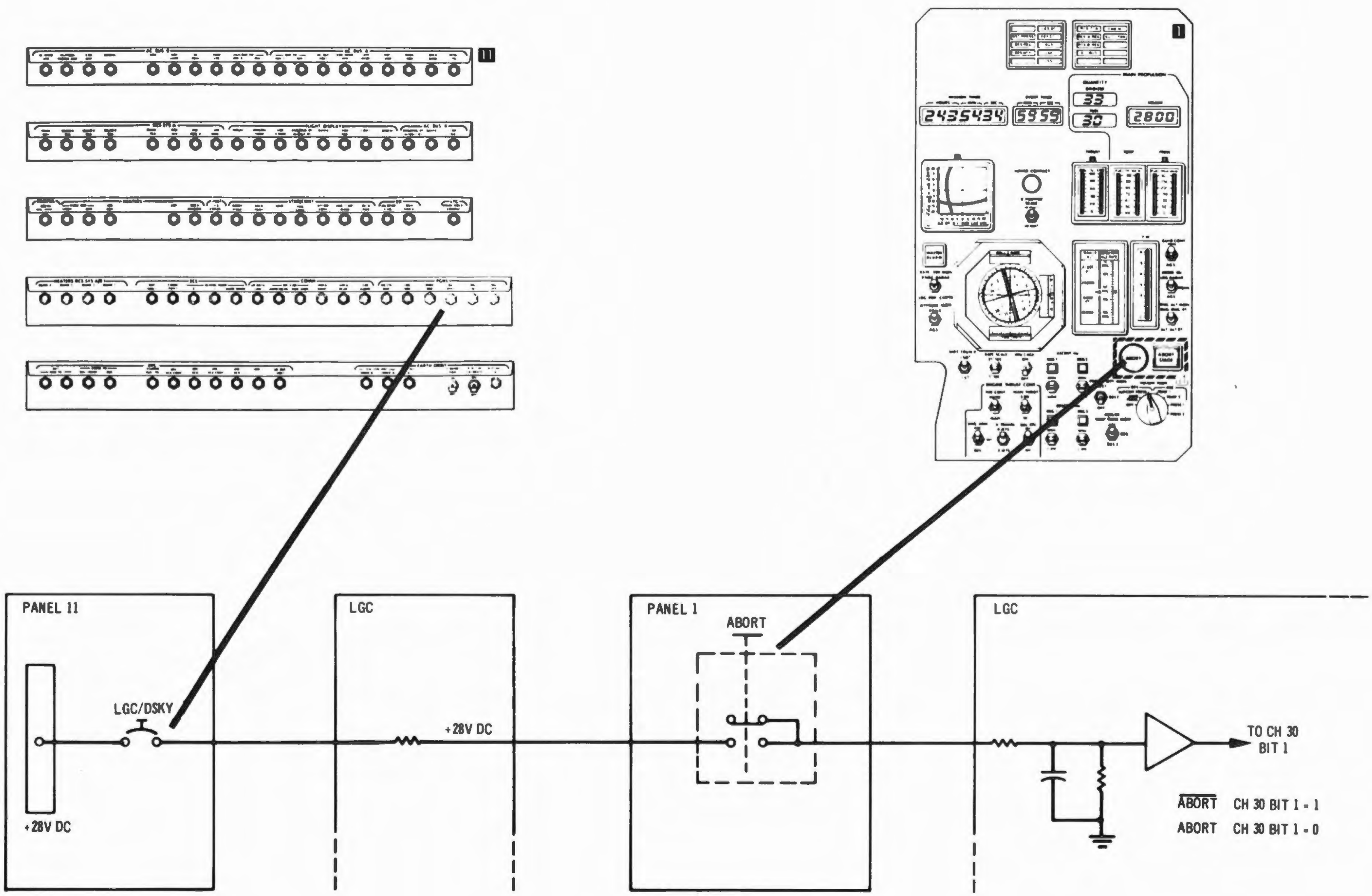


Fig. 3-27. Channel 30 Bit 1 Abort.

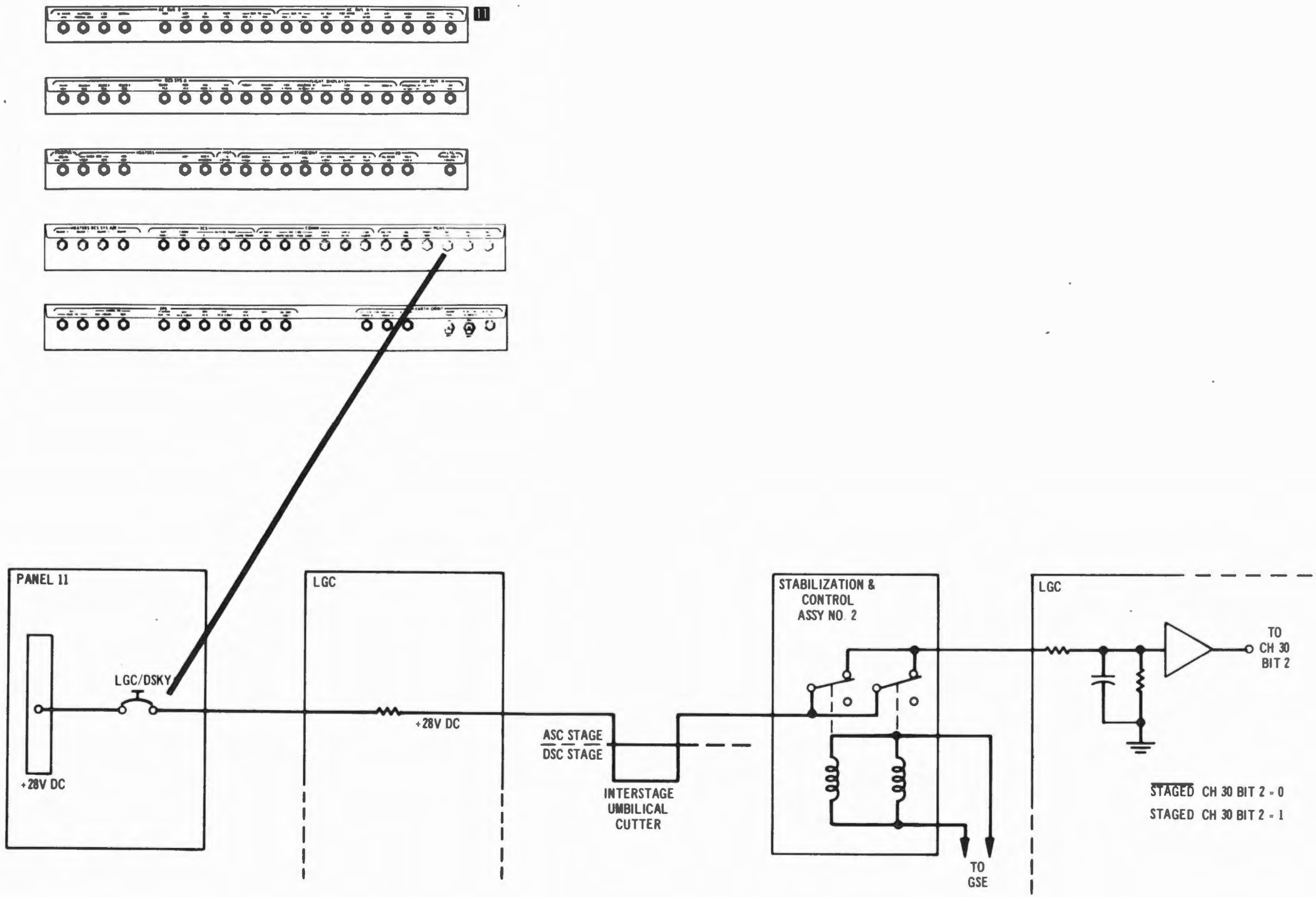


Fig. 3-28. Channel 30 Bit 2 Stage Verify.

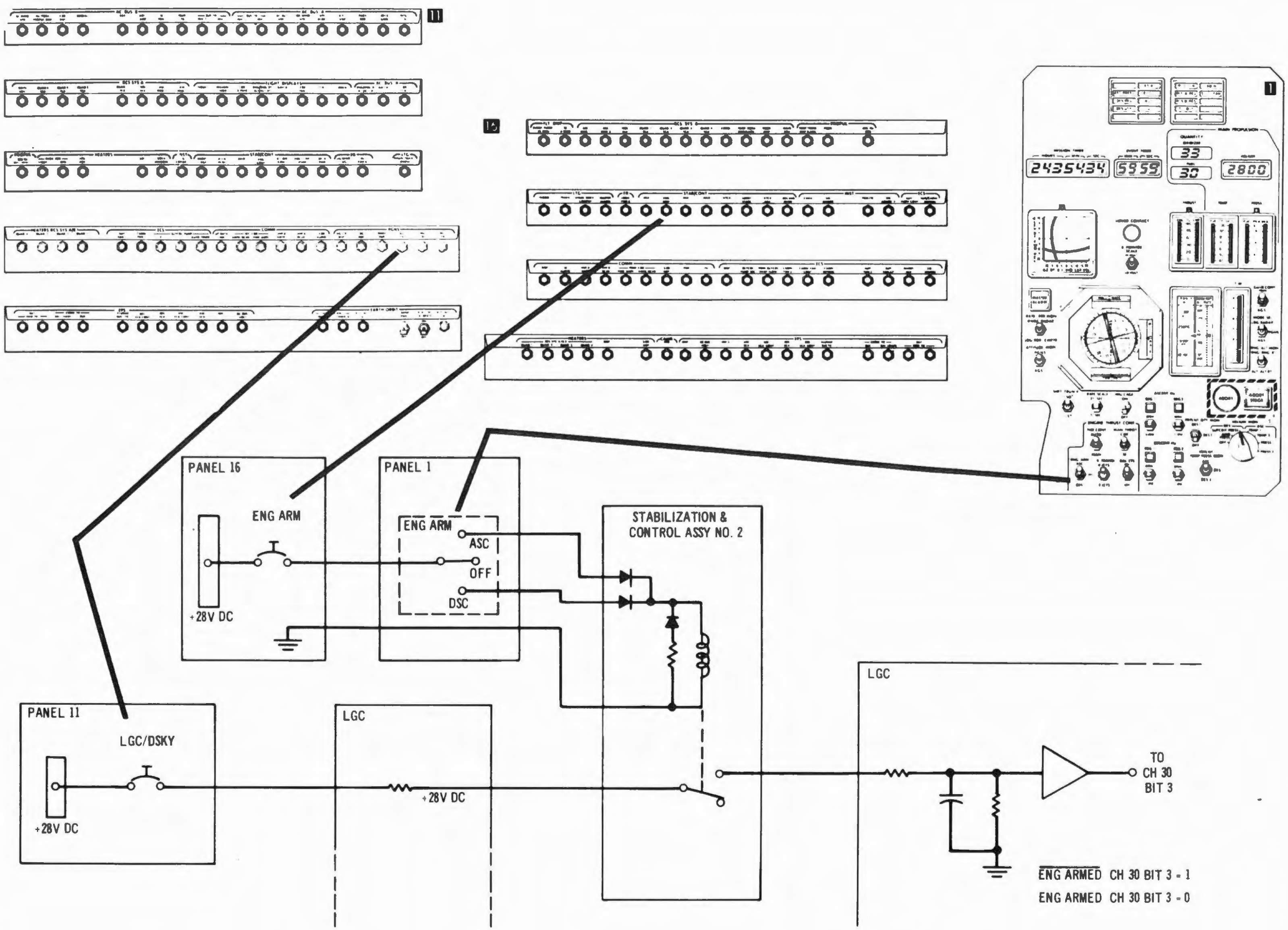


Fig. 3-29. Channel 30 Bit 3 Engine Armed.

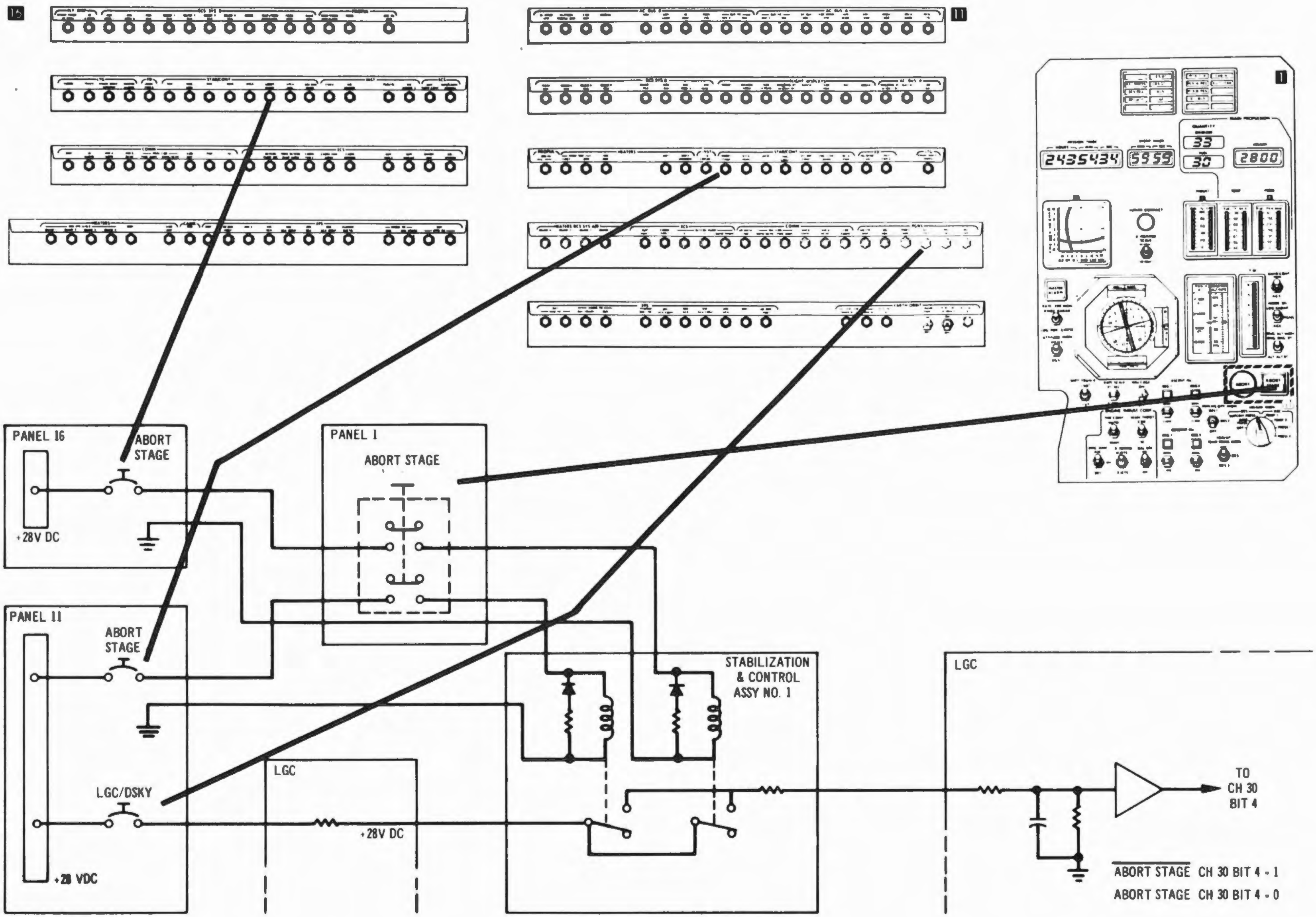


Fig. 3-30. Channel 30 Bit 4 Abort Stage.

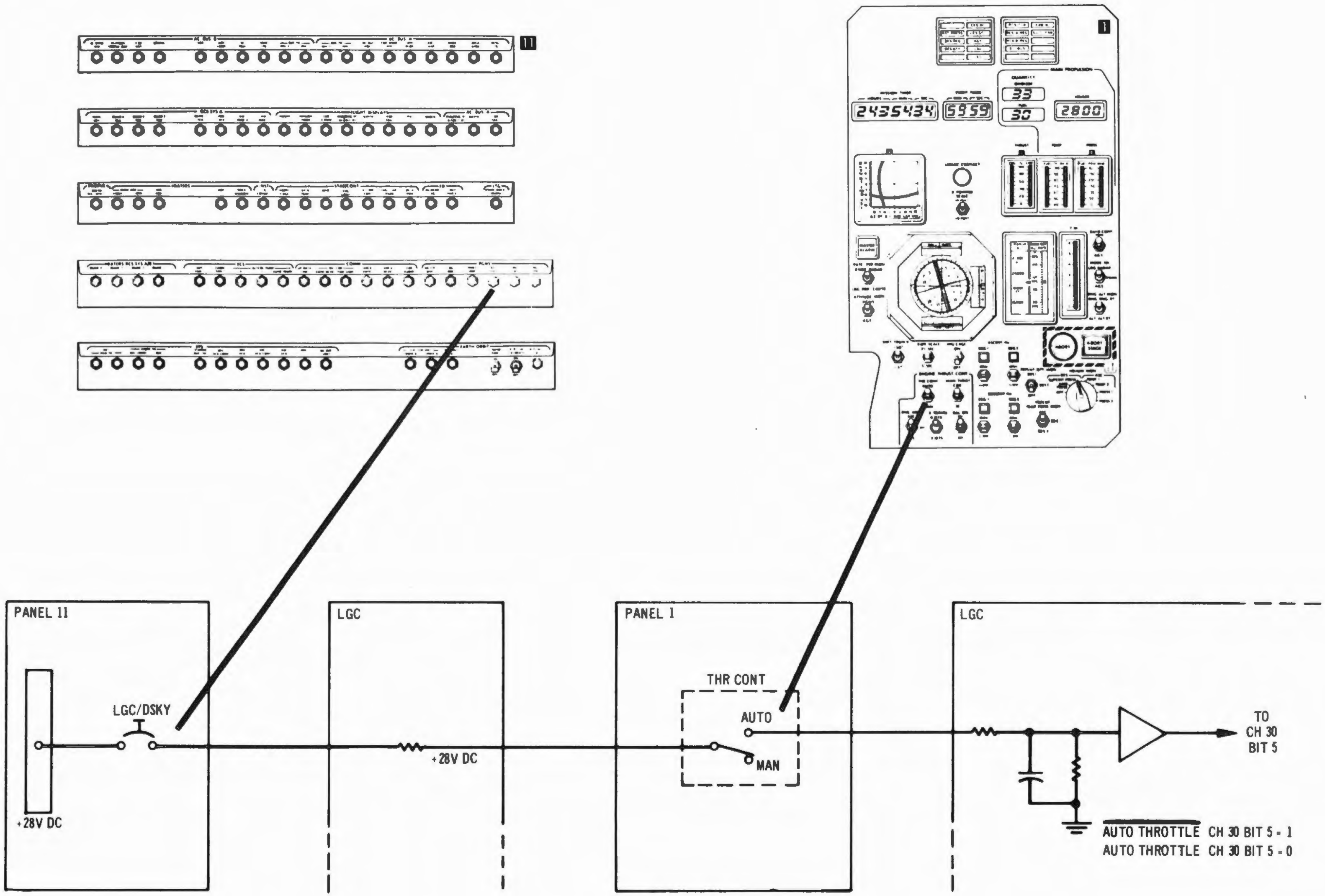


Fig. 3-31. Channel 30 Bit 5 Auto Throttle.

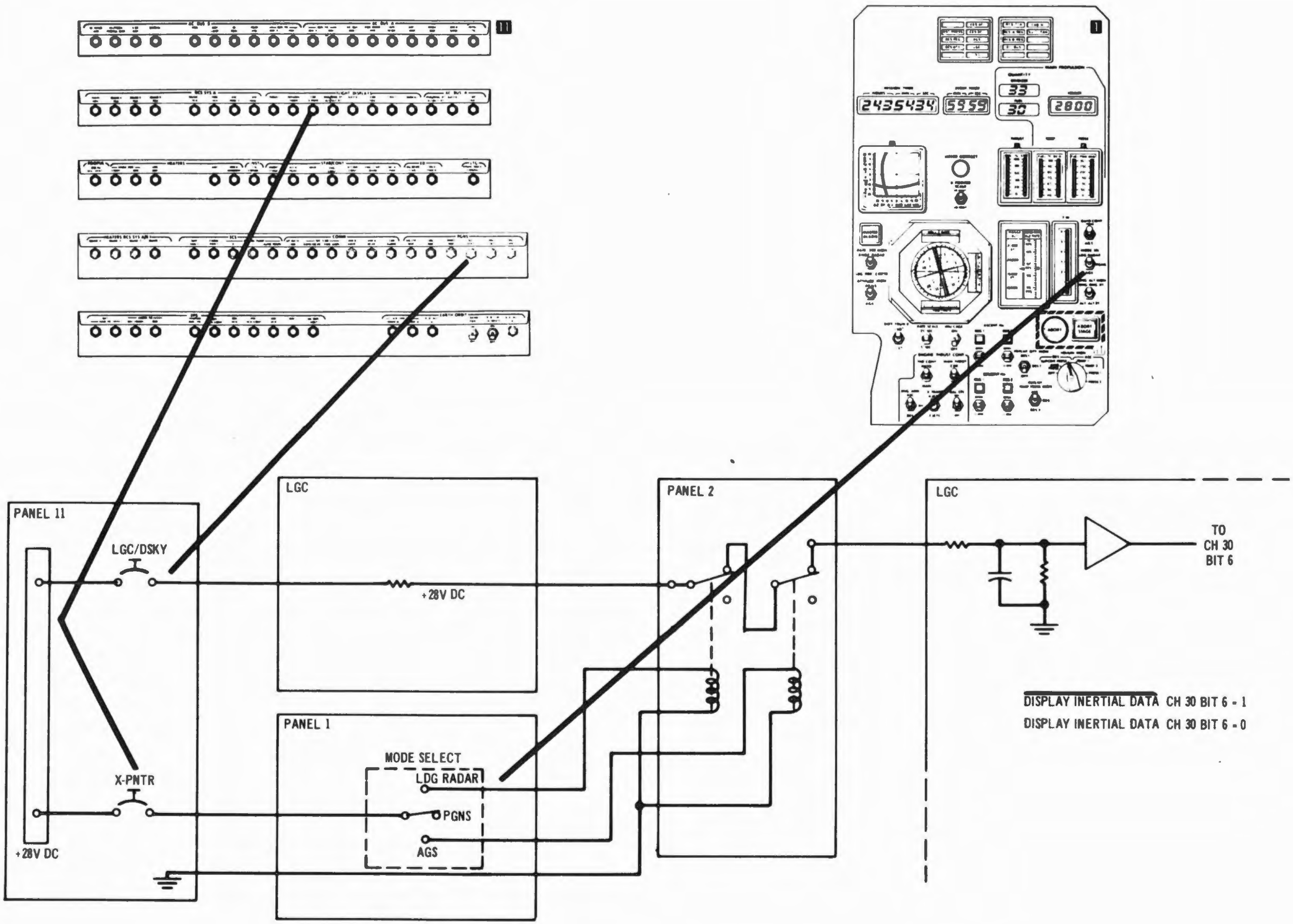


Fig. 3-32. Channel 30 Bit 6 Display Inertial Data.

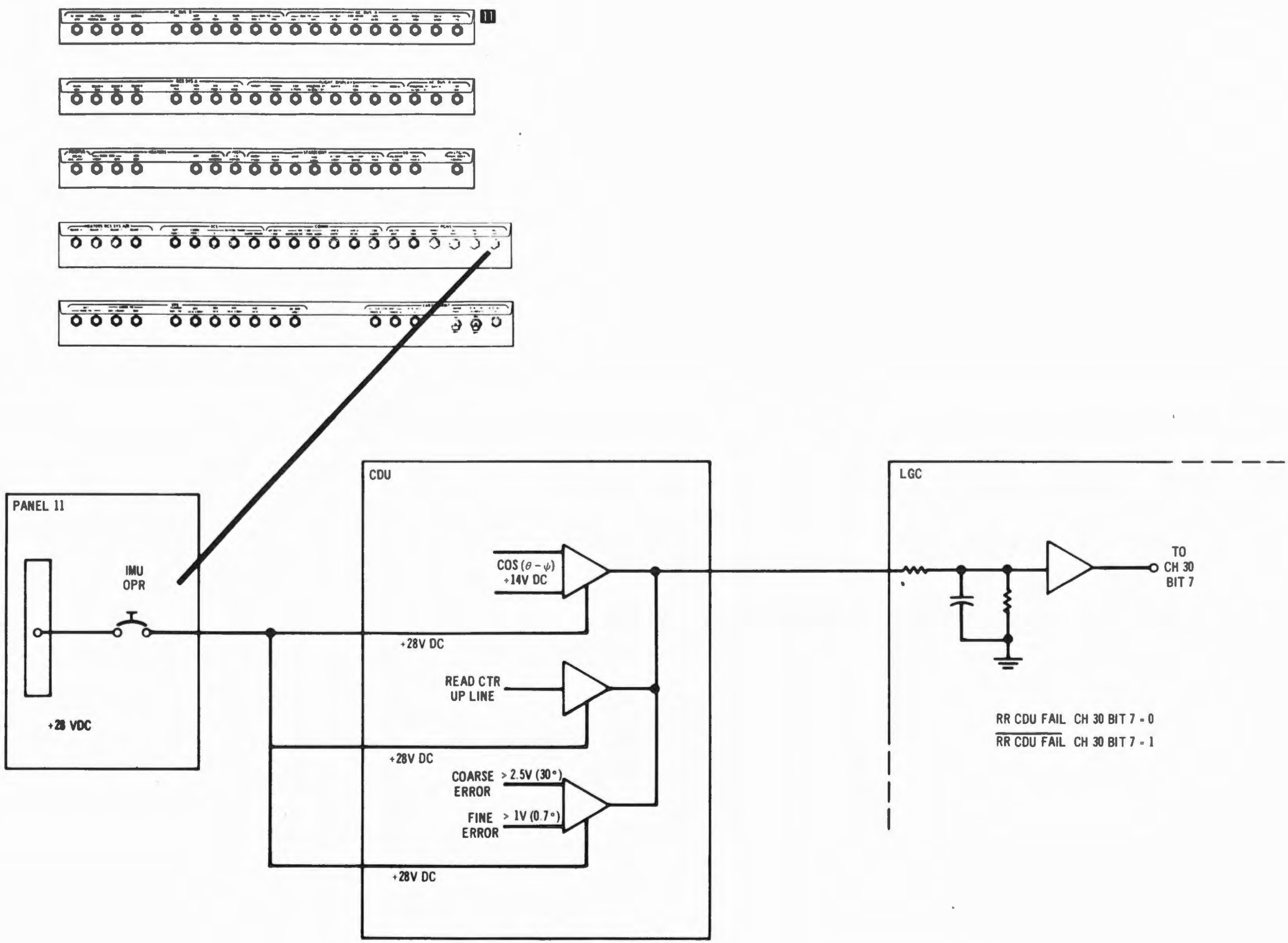


Fig. 3-33. Channel 30 Bit 7 RR CDU Fail.

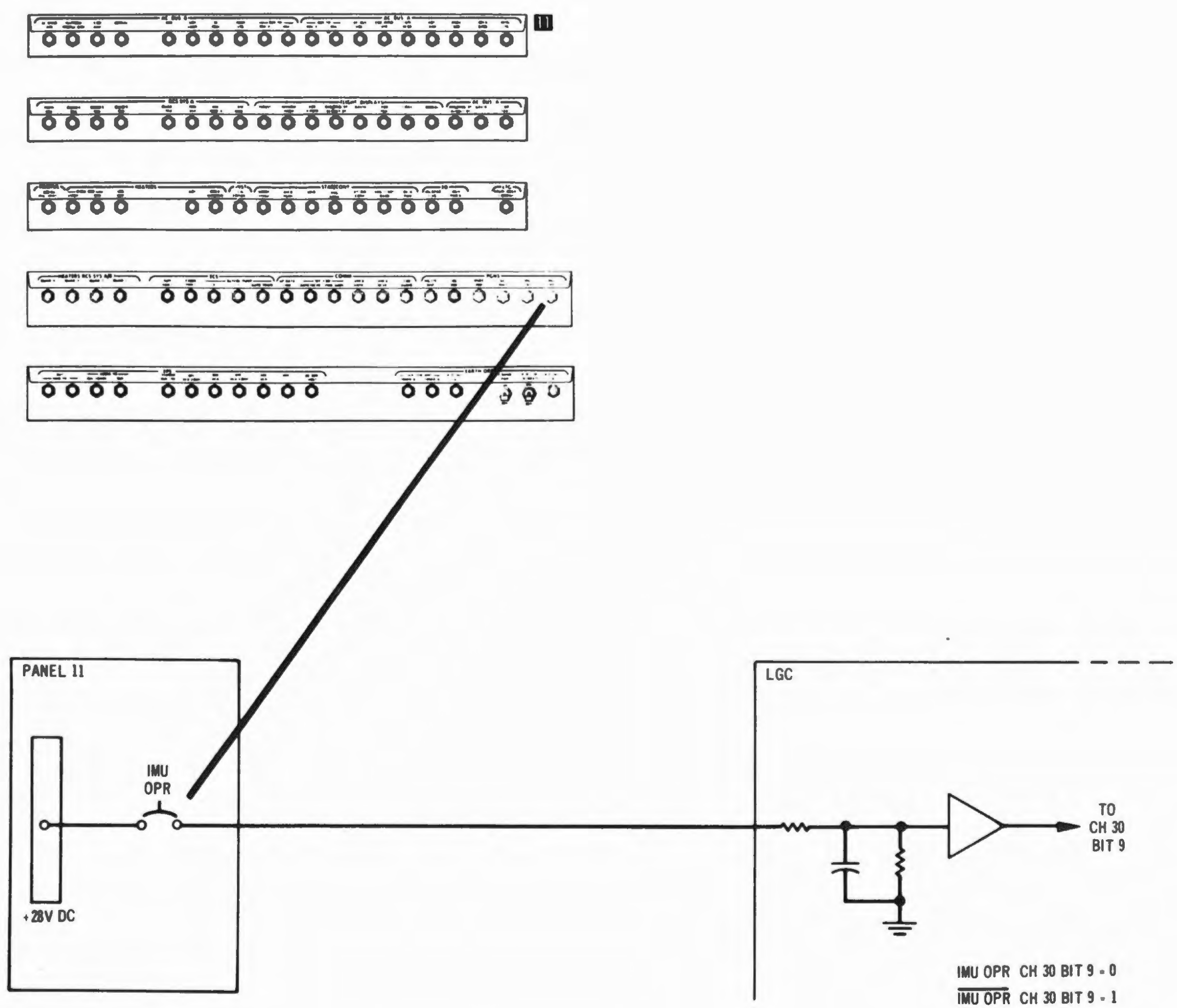


Fig. 3-34. Channel 30 Bit 9 IMU OPR.

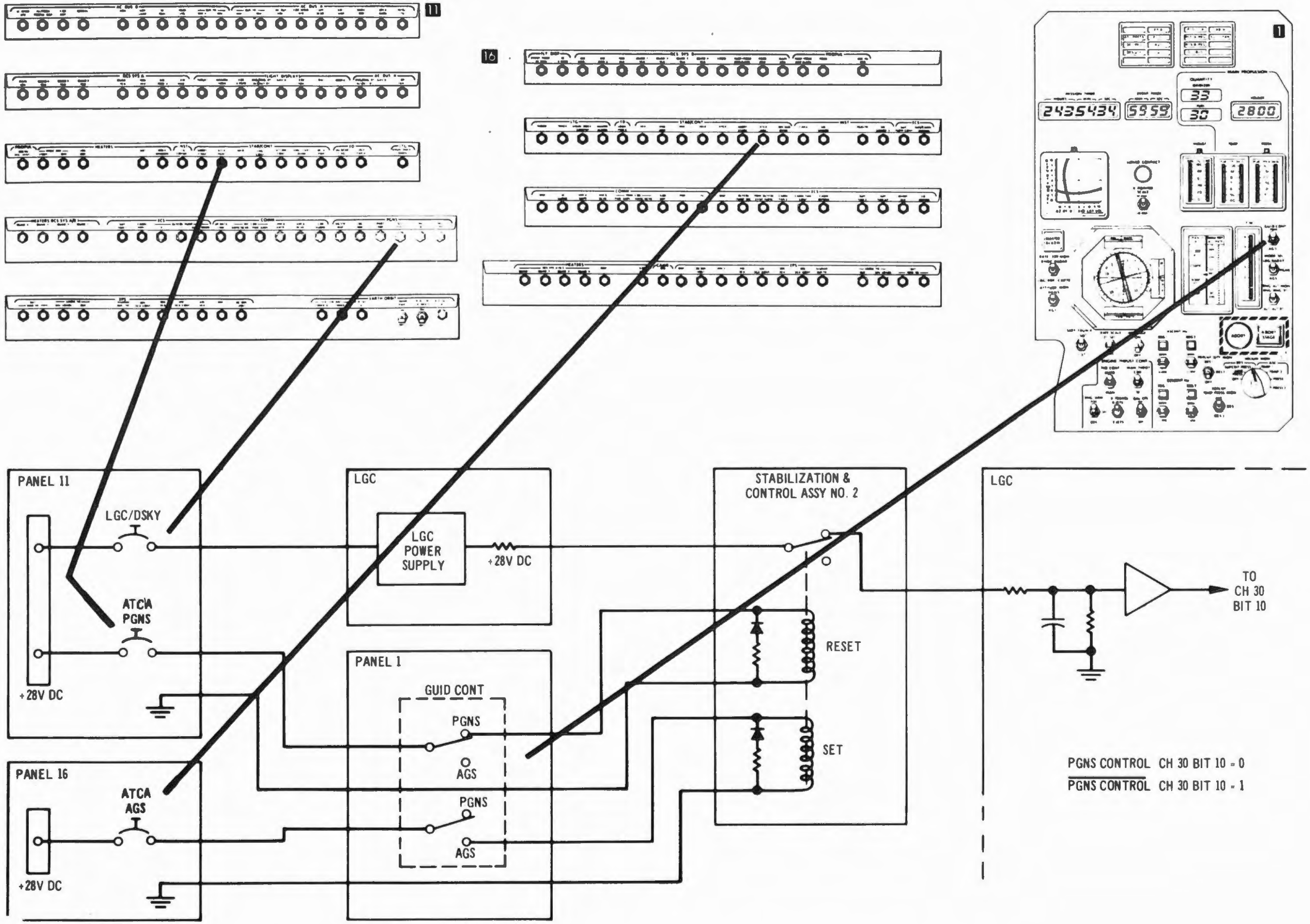


Fig. 3-35. Channel 30 Bit 10 PGNS Control.

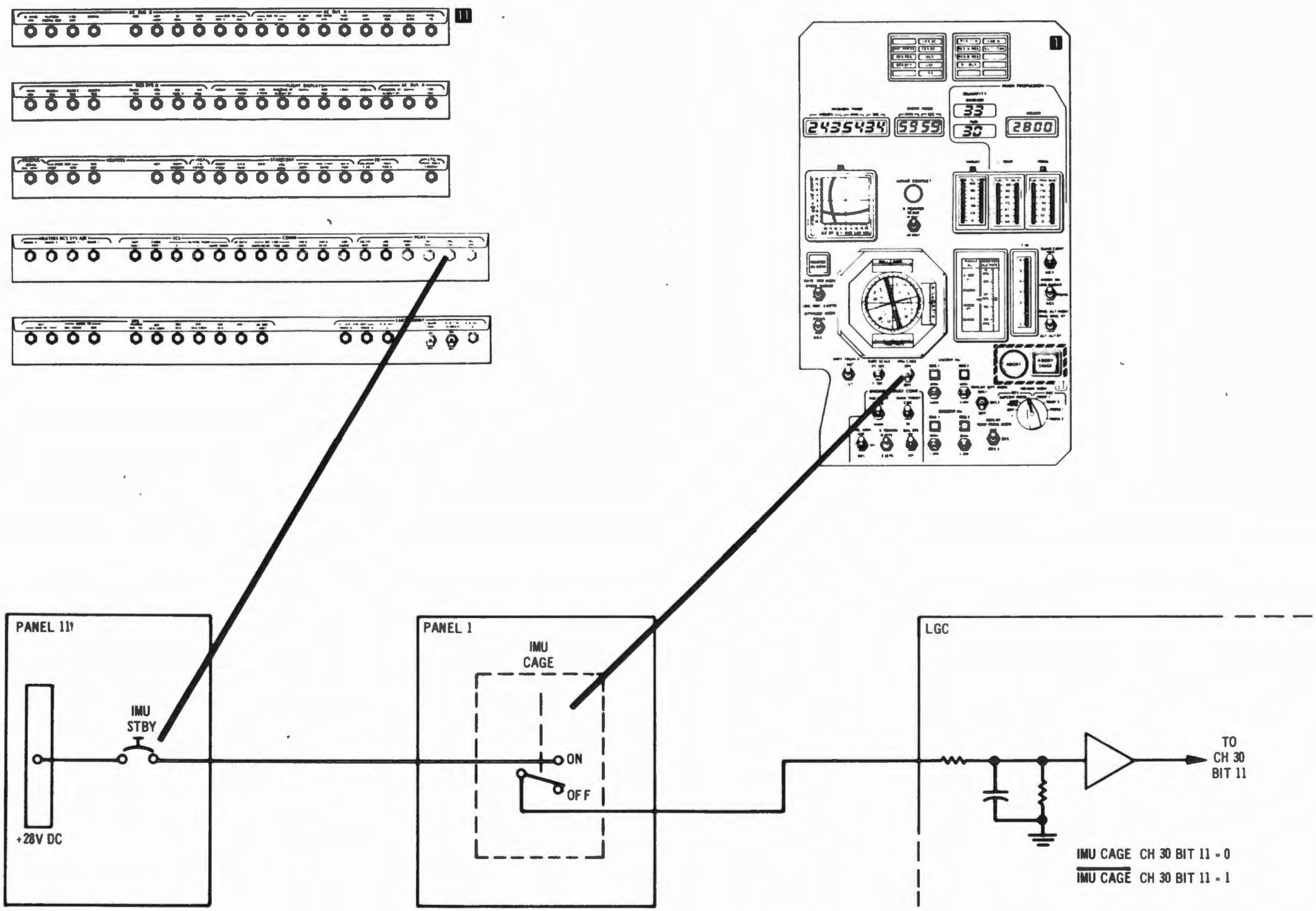


Fig. 3-36. Channel 30 Bit 11 IMU Cage.

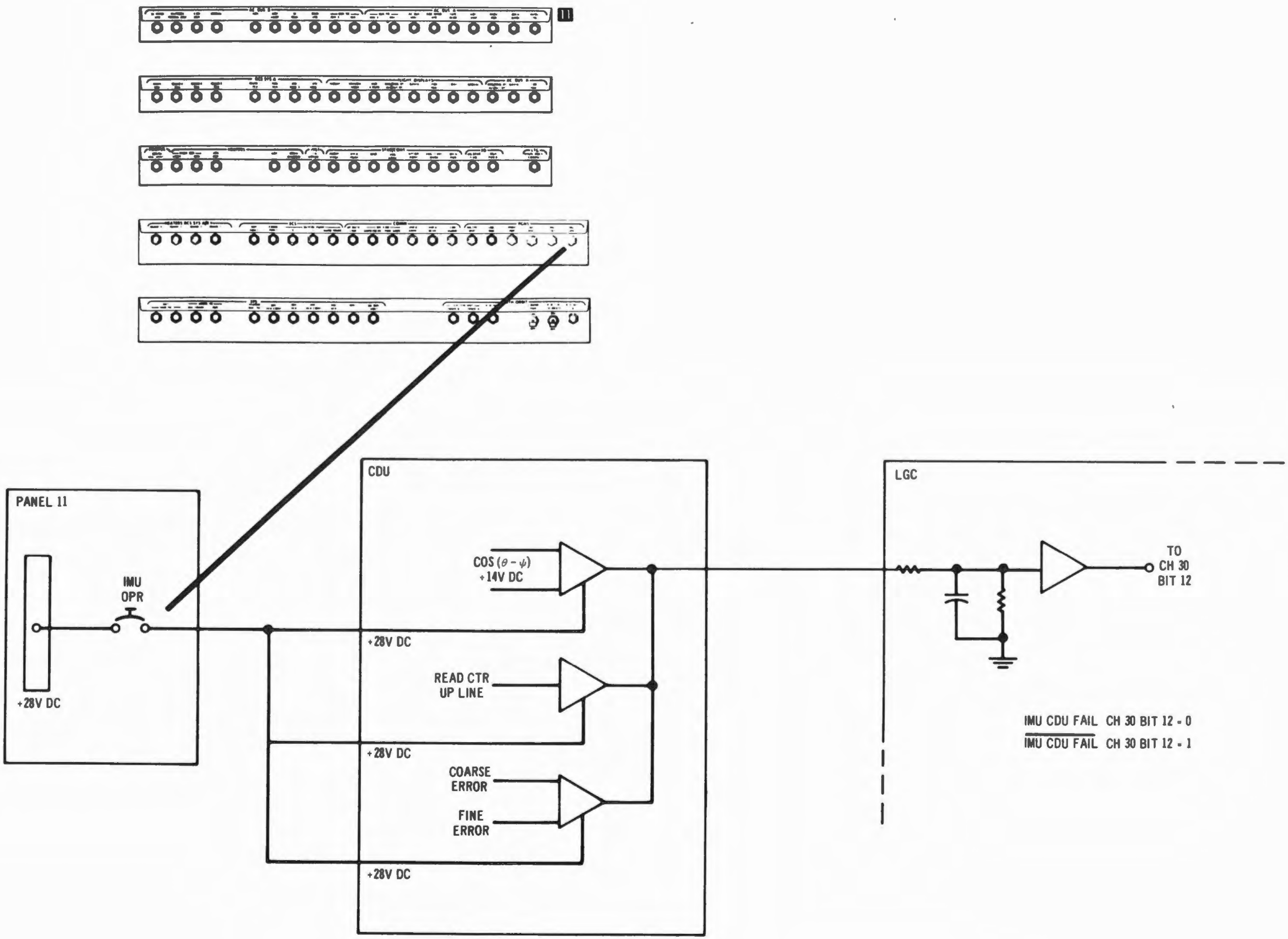


Fig. 3-37. Channel 30 Bit 12 IMU CDU Fail.

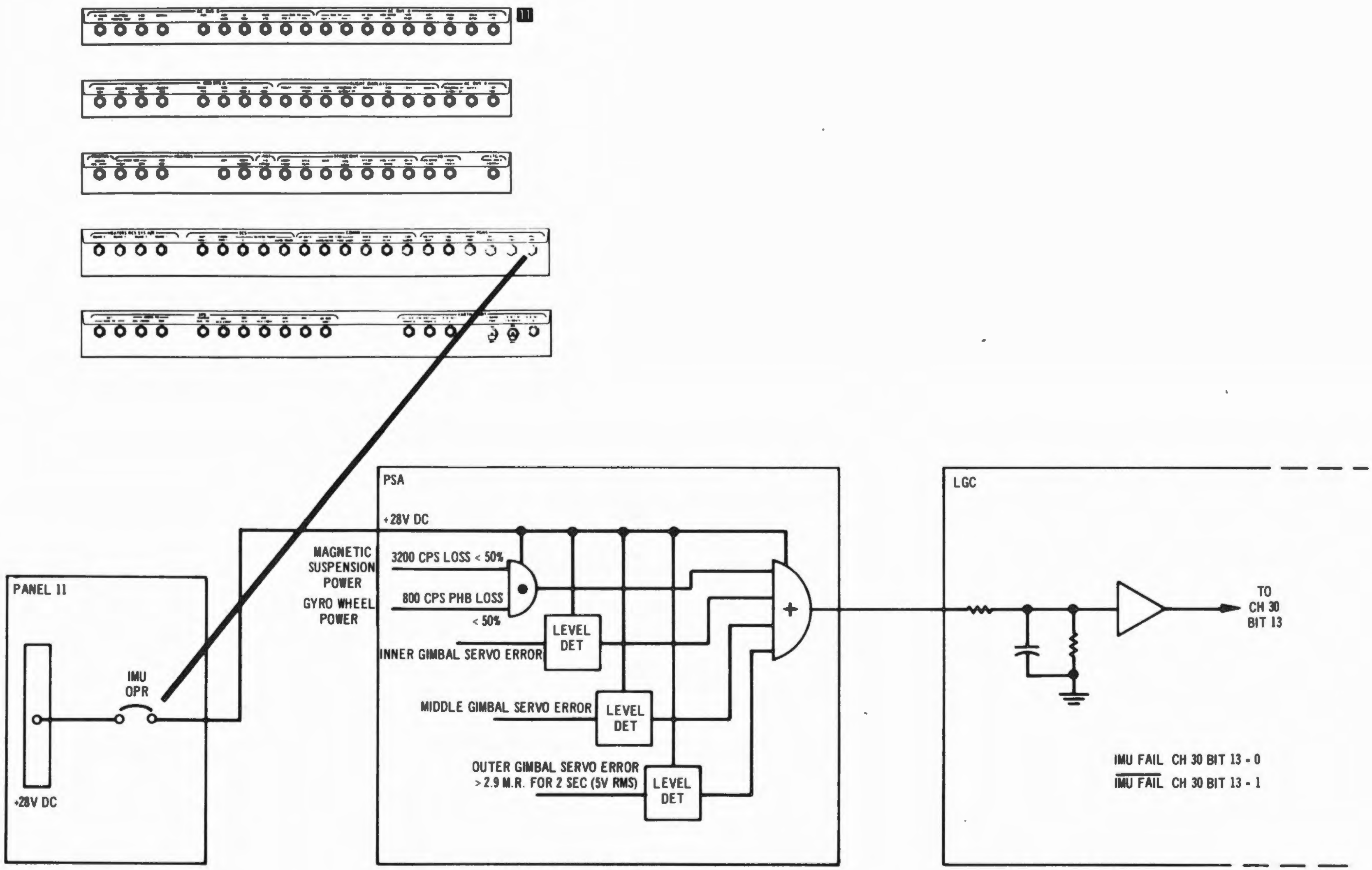


Fig. 3-38. Channel 30 Bit 13 IMU Fail.

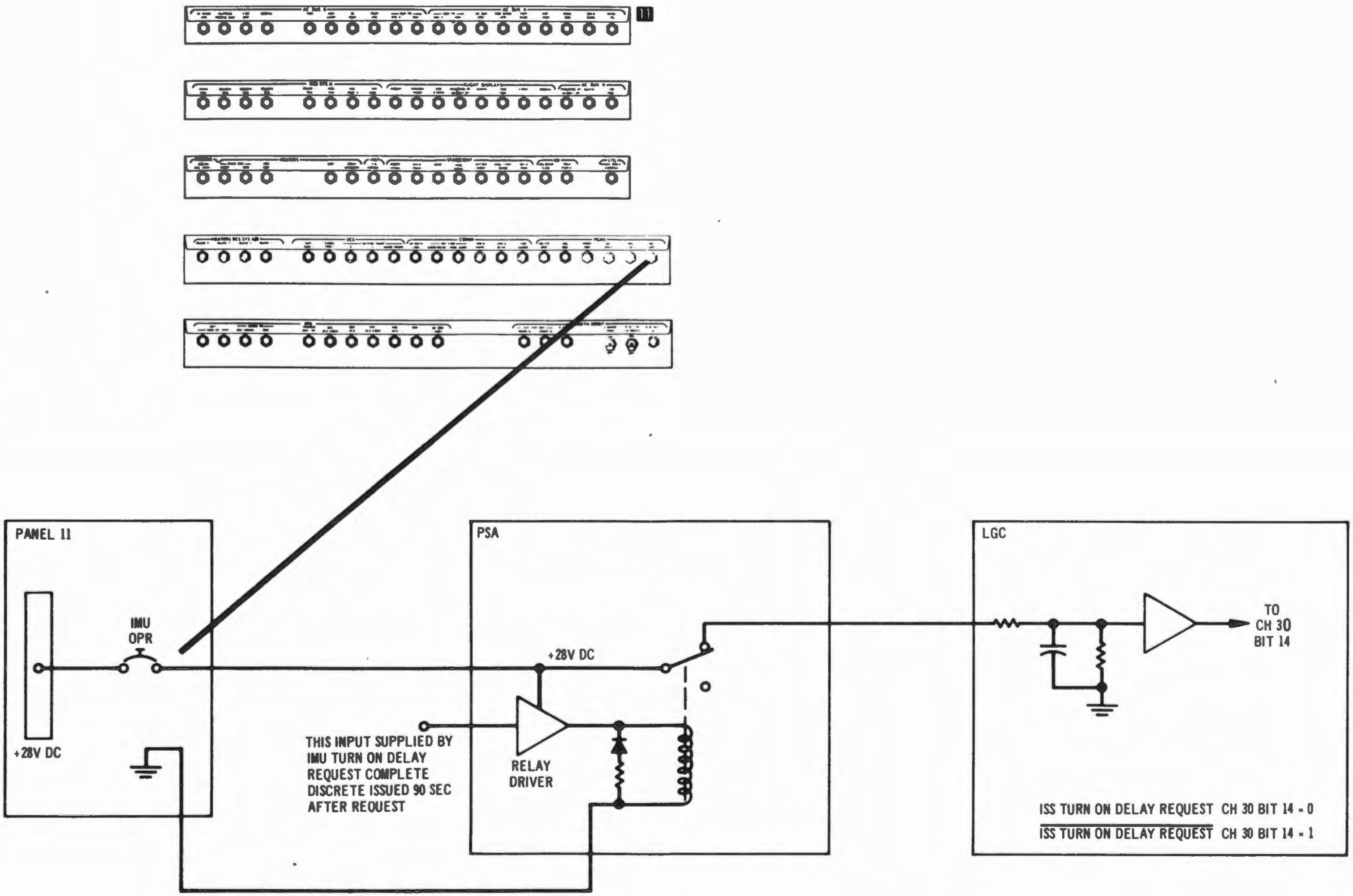


Fig. 3-39. Channel 30 Bit 14 ISS Turn On Delay Request.

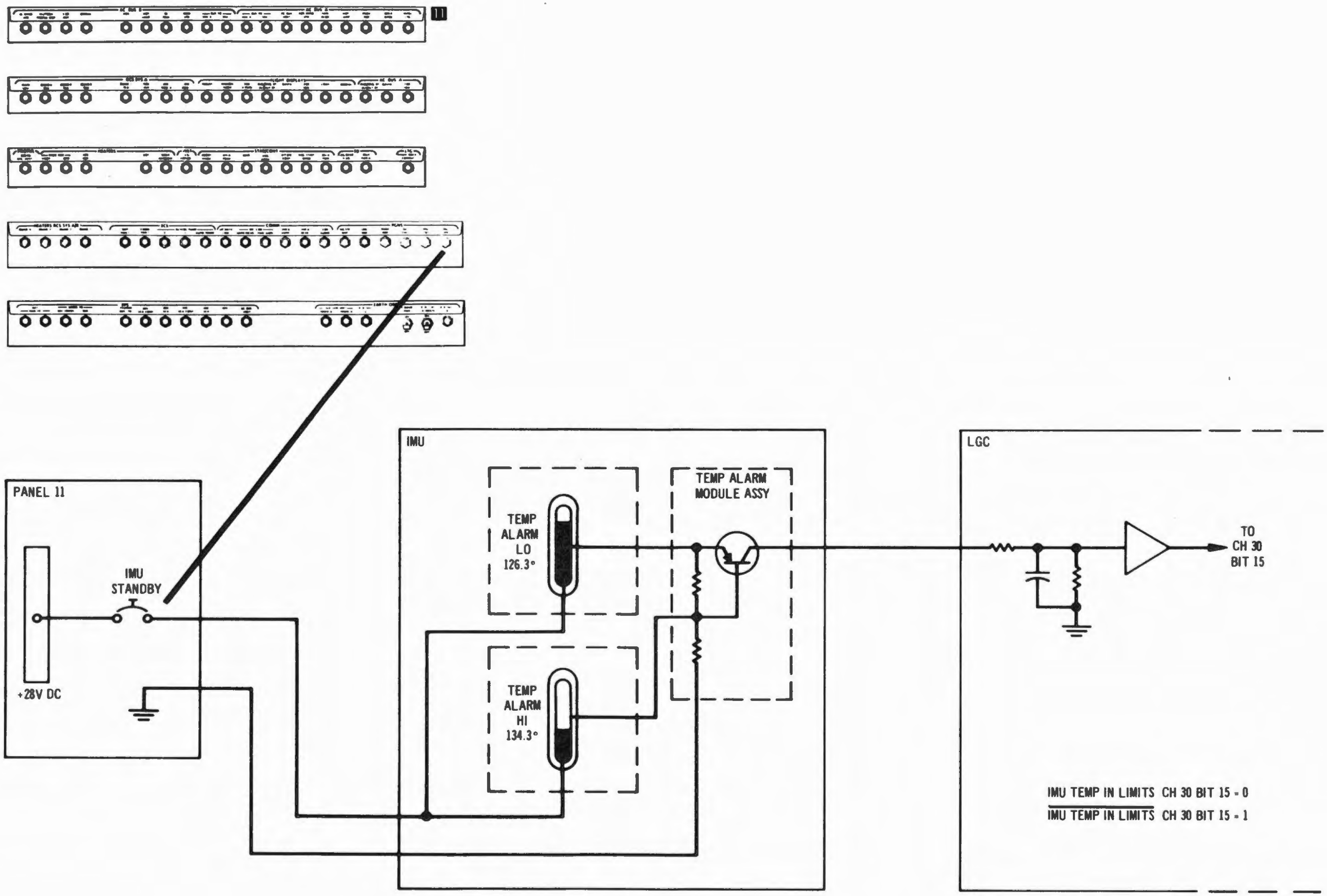


Fig. 3-40. Channel 30 Bit 15 Temperature In Limits.

roll and yaw or landing point designator inputs in elevation and azimuth (see Fig. 3-41). Bit positions 7 through 12 are inputs to the LGC from the thrust/translation control assembly, for X, Y, and Z axis translation (see Fig. 3-42). The last three bits in this channel, bits 13, 14 and 15, provide the LGC with the status of the Attitude Mode Control Switch and the Out of Detent Switch on the Attitude Controller Assembly (see Fig. 3-43).

3.6.11 Channel 32

The first eight bits of this channel, bits 1 through 8, are switch-actuated inputs informing the computer that a specific pair of the RCS thrusters have failed (see Fig. 3-44). Bit 9 is an indication to the LGC of the status of gimbal drive actuators on the descent engine (see Fig. 3-45). Bit 10 provides the LGC with an indication of an apparent gimbal failure in the positioning of the descent engine trim (see Fig. 3-46). Bit positions 11, 12 and 13 are spares and bit position 14 is an indication to the LGC that the PRO button on the DSKY has been depressed (see Fig. 3-47).

3.6.12 Channel 33

Bit location 1 of this channel is a spare. Bit positions 2, 3 and 4 provide the LGC with the status of the RR. Bit 2 informs the LGC that the RR is on and in the LGC mode. Bit 3 informs the LGC of the scale of the information coming from the RR, and bit 4 informs the LGC when the RR data is good (see Fig. 3-48). Bit positions 5, 6, 7, 8 and 9 provide the LGC with the status of the LR. Bit position 5 informs the LGC that the range data from the LR is good. Bit positions 6 and 7 indicate to the LGC the position that the landing radar antenna is in. Bit position 8 informs the LGC that the velocity data is good, and bit 9 informs the LGC of the scale of the range data (see Fig. 3-49). The remaining bit locations of channel 33 are associated with circuits internal to the LGC.

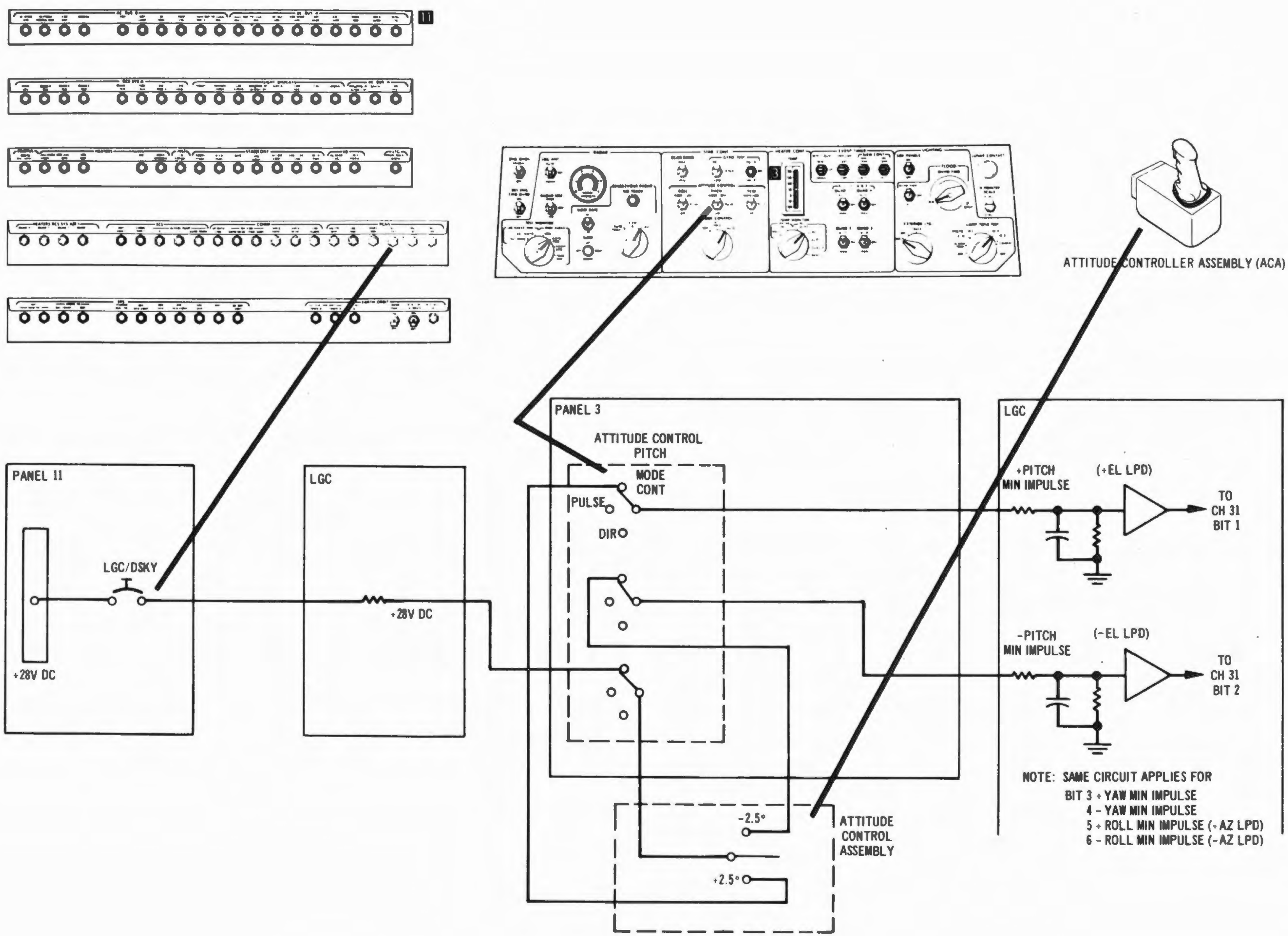


Fig. 3-41. Channel 31 Bits 1 through 6.

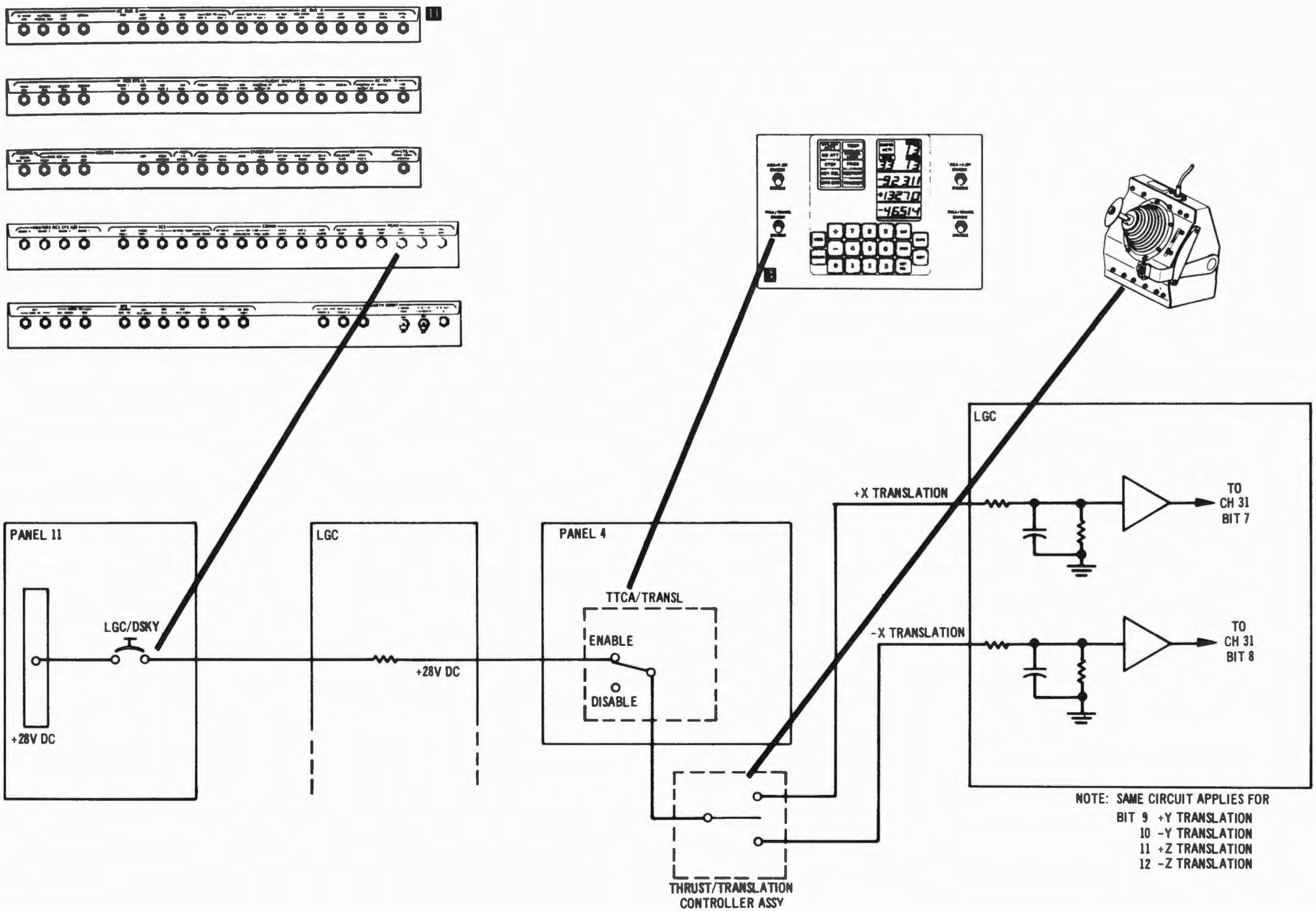


Fig. 3-42. Channel 31 Bits 7 through 12 ± Translation

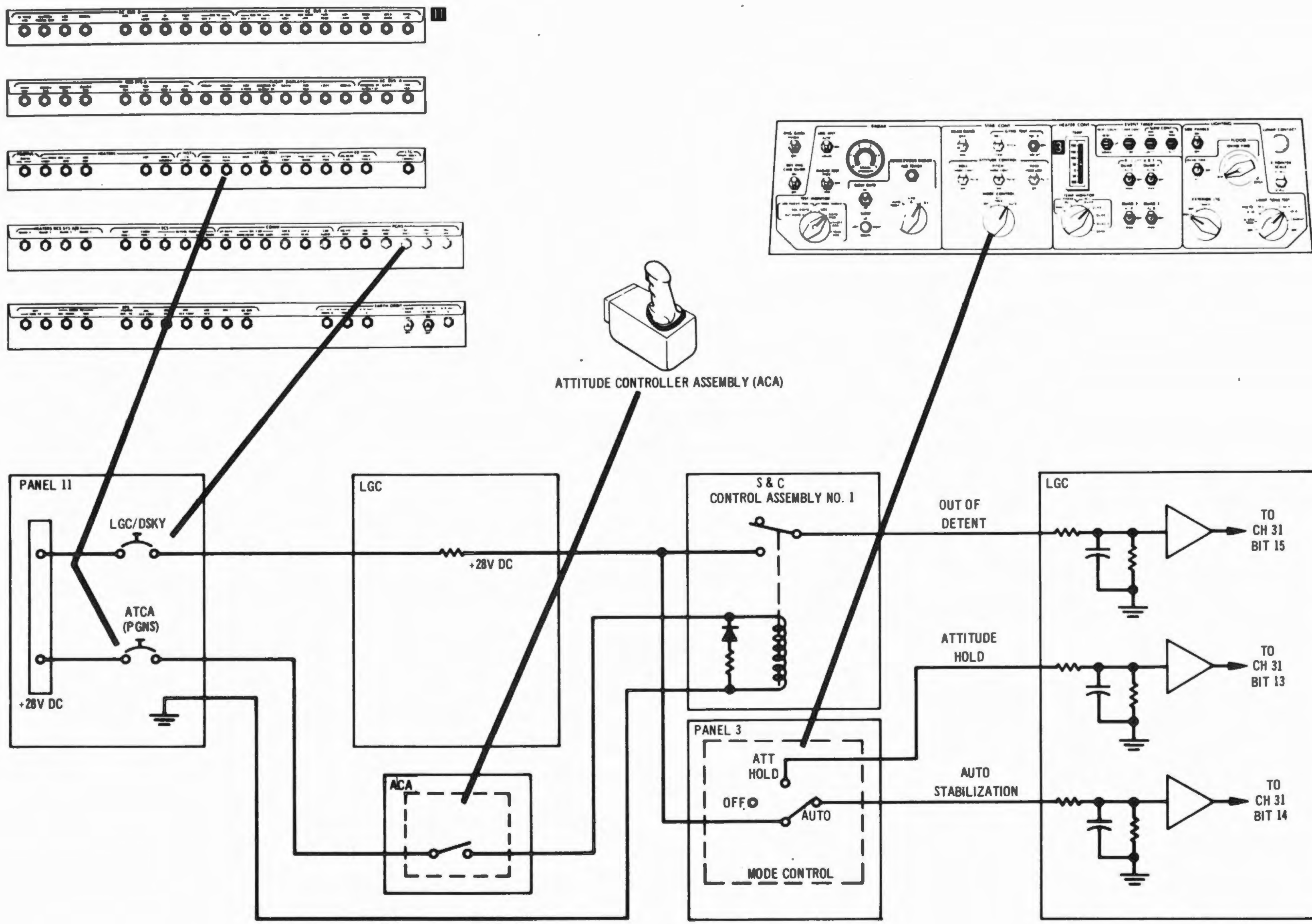


Fig. 3-43. Channel 31 Bits 13,14,15 Attitude Hold, Auto Stabilization and Out of Detent.

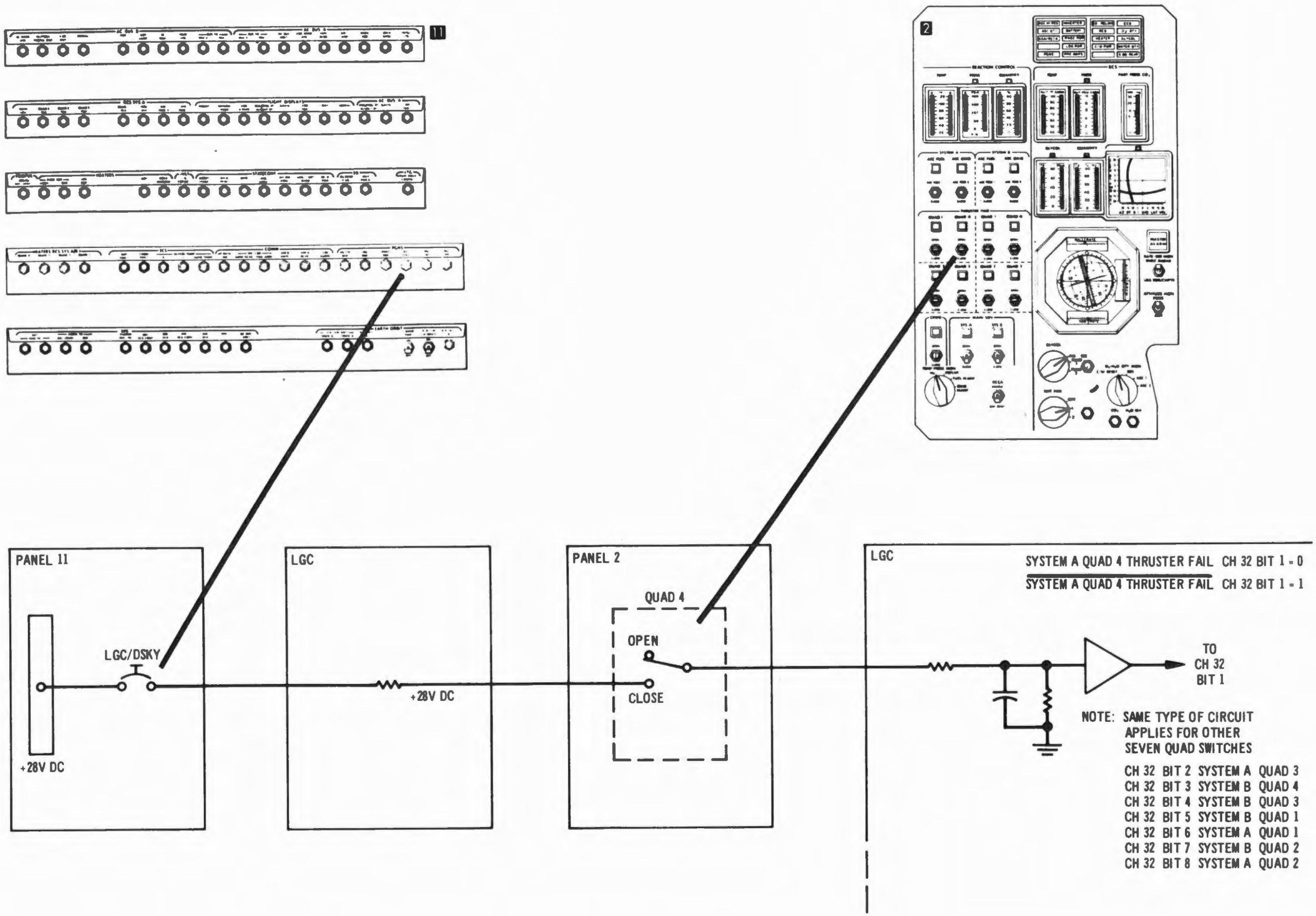


Fig. 3-44. Channel 32 Bits 1 through 8.

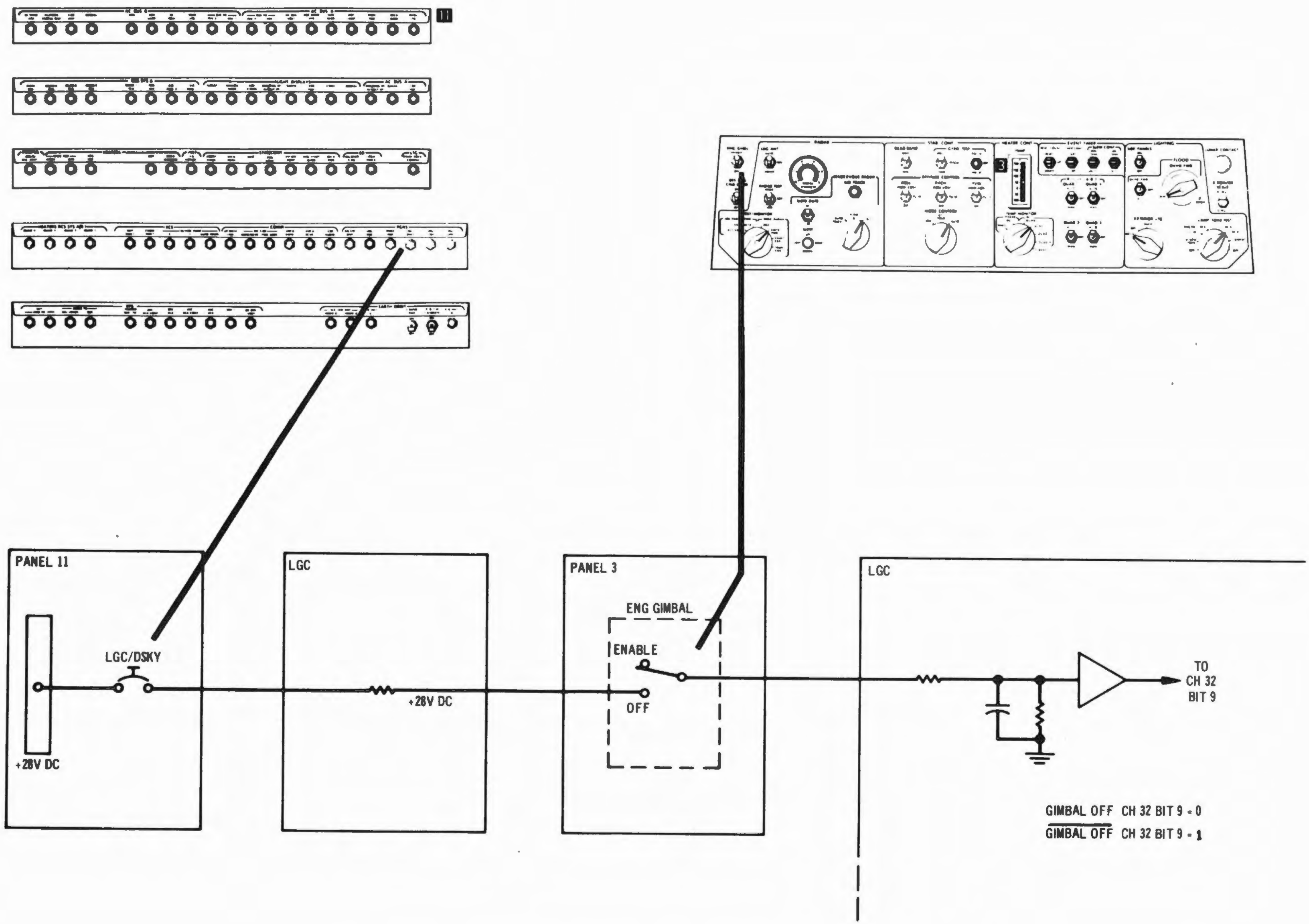


Fig. 3-45. Channel 32 Bit 9 Gimbal Off.

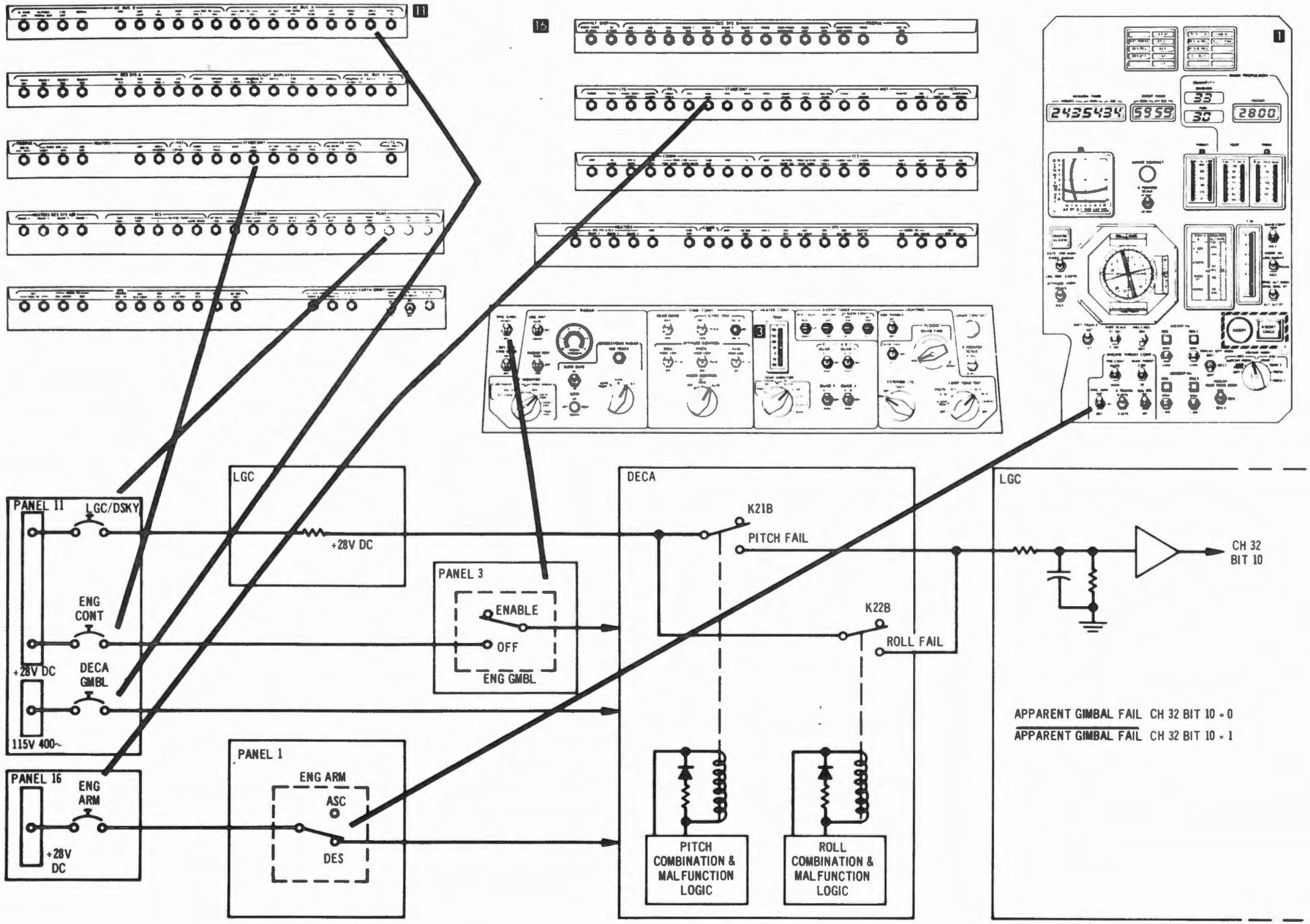


Fig. 3-46. Channel 32 Bit 10 Apparent Gimbal Fail.

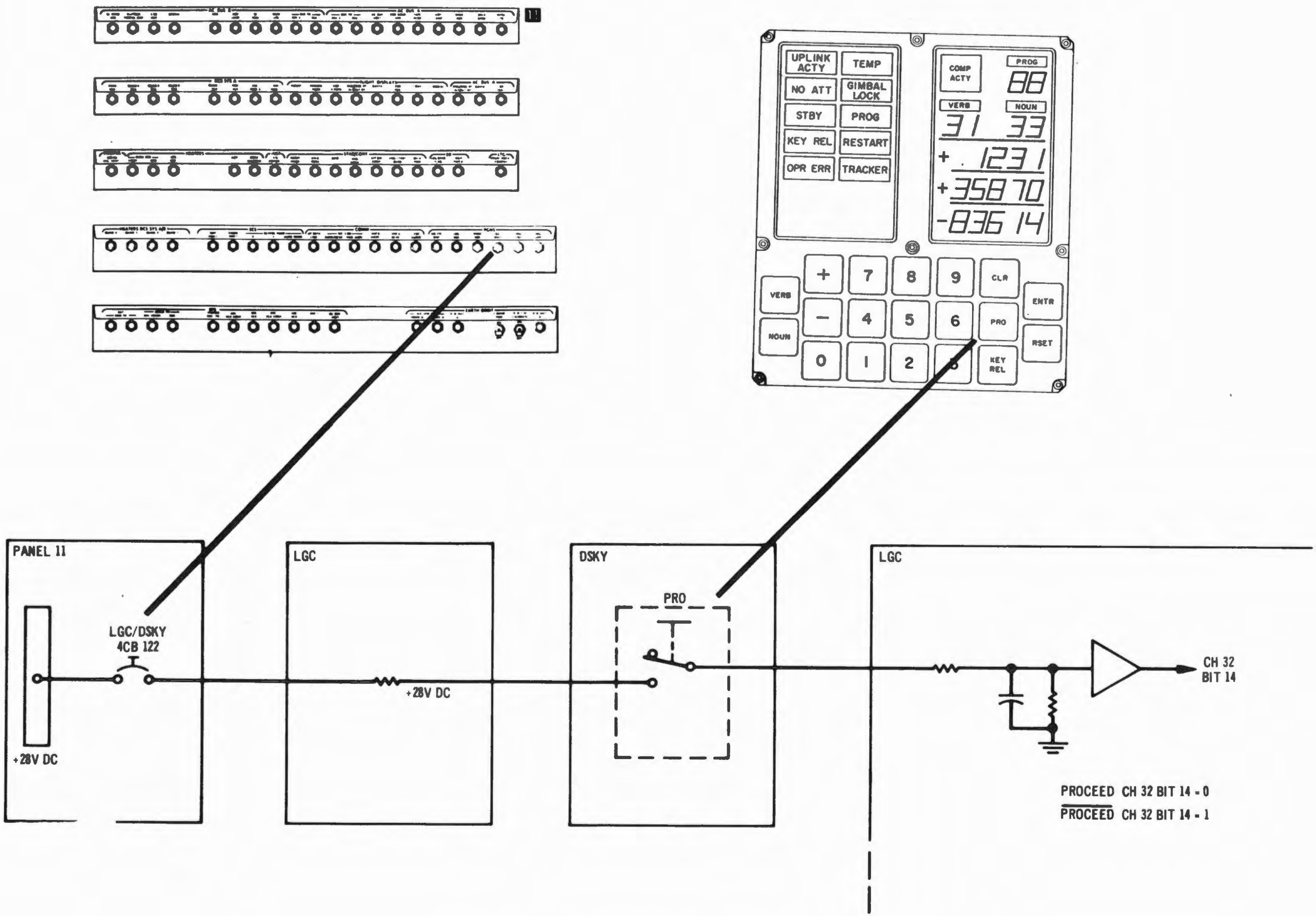


Fig. 3-47. Channel 32 Bit 14 Proceed.

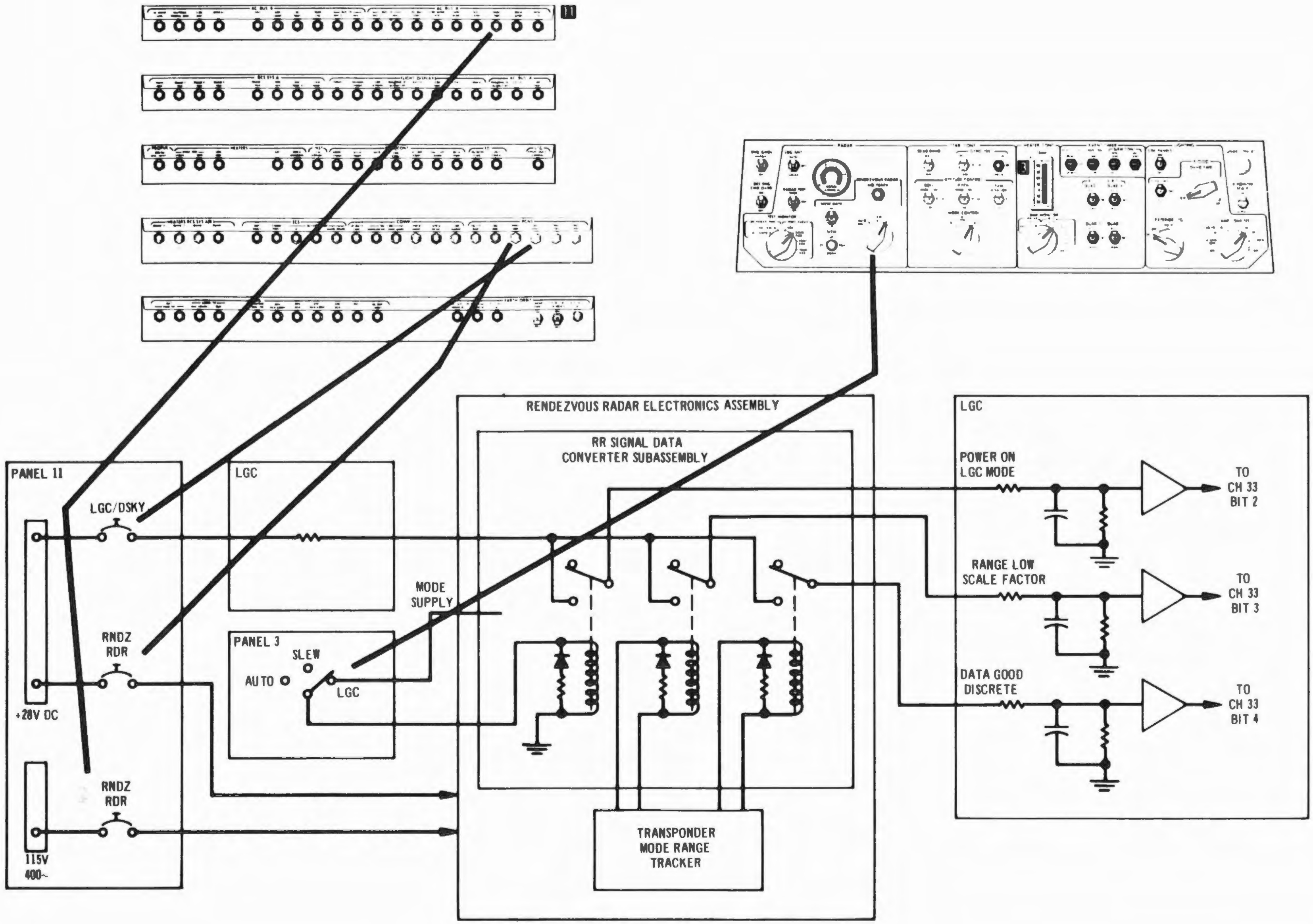


Fig. 3-48. Channel 33 Bits 2, 3 and 4.

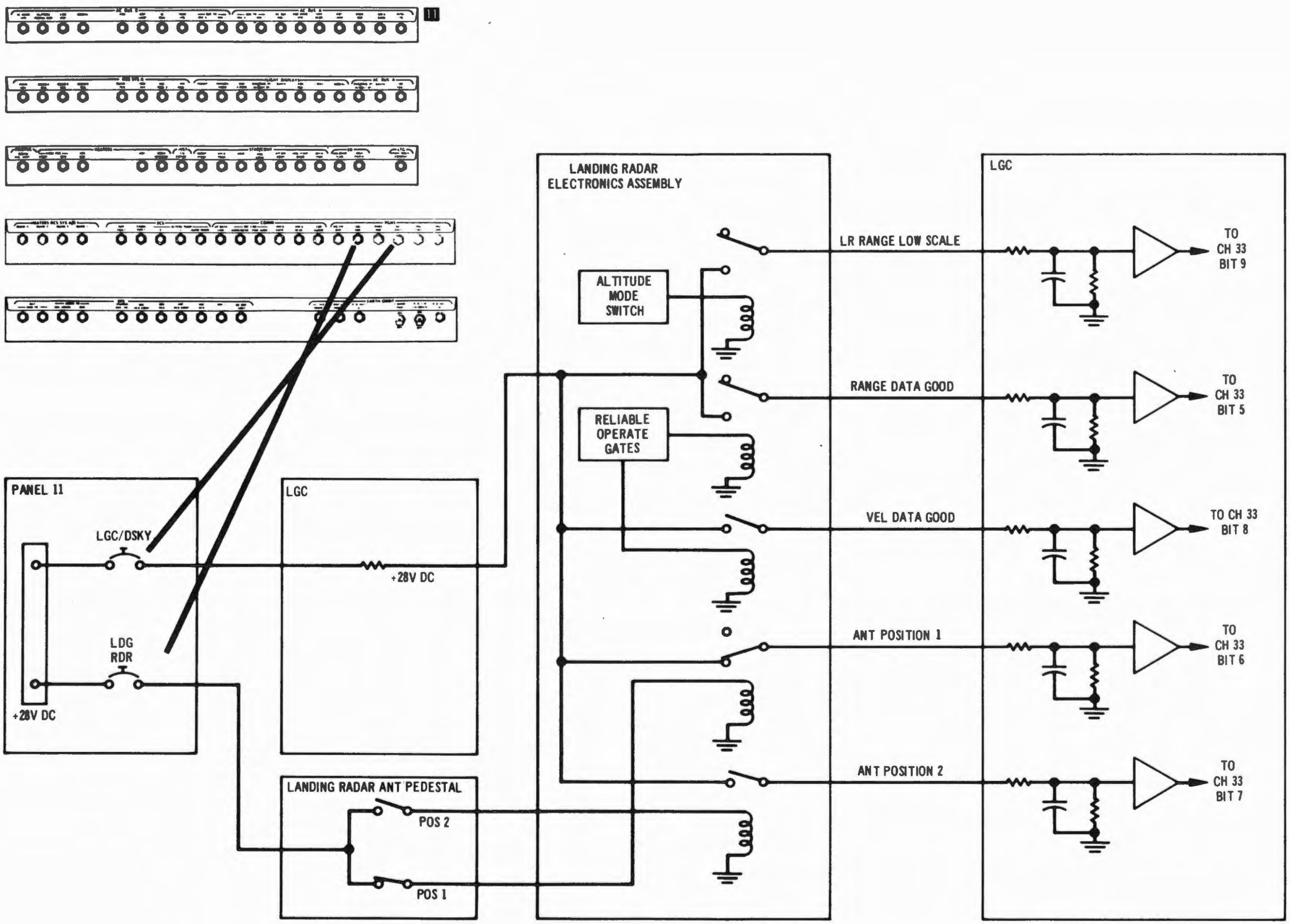


Fig. 3-49. Channel 33 Bits 5, 6, 7, 8 and 9.

SECTION 4

PERFORMANCE AND DESIGN DATA

4.1 IMU

4.1.1 Operational Data

Gyroscopes: Three 25-IRIG

Drift Rate: 2 meru max (0.03 sec/sec)

Accelerometers: Three 16-PIP

Rotation: 720 degrees/sec about the outer gimbal axis
60 degrees/sec about any arbitrary axis in passing up to 10 degrees of gimbal lock.

CDU Error: Maximum range +49.6 arc sec to -63.4 arc sec
Mean = -6.9 arc sec, Standard deviation = ±24.5 arc sec

4.1.2 Limitations and Restrictions

Gimbal lock is obtained when the middle gimbal has moved to a position such as to make the outer and inner gimbal axes nearly colinear and thereby producing stabilization loops that are unstable. When this condition is attained, the IMU stable member must be realigned. To avoid gimbal lock, the inner gimbal axis is normally positioned to the plane of any planned trajectory or attitude turning maneuver prior to thrusting. To assist in gimbal lock avoidance, the GIMBAL LOCK indicator is actuated whenever the middle gimbal angle exceeds 70°. In addition the ISS is downmoded to coarse align and the NO ATT and ISS indicators are actuated when the gimbal angle exceeds 85°.

Another IMU limitation is platform drift. Due to random errors and inaccurately corrected systematic bias, over a period of time the stabilized platform will have drifted out of alignment enough to cause serious degradation in inertial measurement accuracy. Therefore, the IMU alignment must be periodically checked and realigned to insure measurement accuracy during pending maneuvers.

Temperature restrictions also exist for the IMU. The system components have been designed to operate at specific temperatures which are maintained in stand by or operating states as long as prime power is applied. Temperature changes due to power loss or for any other reason may change gyro and accelerometer characteristics. Changes in gyro characteristics due to small variations in temperature are temporary and revert when the temperature is returned to normal. Larger changes in temperature, however, may cause permanent changes in gyro characteristics. During those mission phases in which only the IMU standby state exists possible power interruptions may occur for periods up to three minutes without system degradation. At such times that power is lost or the TEMP indicator is activated, the MSFN should be contacted to verify system performance.

4.2 LGC

4.2.1 Operational Data

Computer Type: Automatic, electronic, digital, general purpose and control

Memory: Random access

Erasable: Coincident current core; capacity = 2048 words

Fixed: Core-rope; capacity = 36,864 words

Word length: 16 bits (or 15 bits plus parity)

Number System: Binary ones complement

Circuitry Type: Flat pack NOR micrologic

Logic: Positive

Machine Instructions: 56 Total

- Regular: 42
- Involuntary: 9
- Peripheral: 5

Memory Cycle Time: 12 μ seconds

Add Time: 24μ seconds

Double Precision Add: 36μ seconds

Multiply Time: 48μ seconds

Double Precision Multiply: 480μ seconds

Divide Time: 84μ seconds

Number of Counters: 29

Basic Clock Oscillator: 2.048 mc

4.3 DSKY

4.3.1 Operational Data

The DSKY utilizes white illuminated markings with incandescent light sources. The numeric readouts are green via 24 electroluminescent sections. The advisory indicators (including UPLINK ACTY, STBY, NO ATT, KEY REL, and OPR ERR) are used to inform the crew numbers of equipment or system status, and of the operation of essential equipment or is used to attract attention and impart information of a routine nature. The component caution indicators (including

TEMP, GIMBAL LOCK, PROG, RESTART, and TRACKER) are used to inform crew members of an impending dangerous condition requiring attention but not necessarily immediate corrective action.

LIGHTED COLOR:

Component caution annunciators – Aviation yellow

Advisory annunciators – Aviation white

Numerical lights – Aviation green

BRIGHTNESS:

Pushbuttons – 0.5 (±0.2) ft Lamberts

Annunciators – 15 (±3.0) ft Lamberts

PUSHBUTTON FORCE REQUIREMENT TO ACTUATE:

21 to 26 ounces

4.4 AOT

4.4.1 Operational Data

Power: Unity

Field of View: 60 Degrees, conical

Maneuverability: Fixed in Elevation; Adjustable to three detent positions in Azimuth. Each detent position maintains the field-of-view approximately 45 degrees from the LM X-axis. The 0 detent position centers the field-of-view approximately 45 degrees from the X-axis in the LM X, Z plane. The other two detent positions offset the center of the field-of-view approximately 60 degrees in each direction from the X, Z plane.

4.4.2 Limitations and Restrictions

When a navigation star is not visible within the present AOT viewing positions, the LM attitude must be changed to acquire a navigation star. In addition, a second star must be selected which is separated from 60° to 120° from the first selected star.

A star selection routine within the LGC selects the best pair of stars for fine alignment of the IMU taking into consideration the amount of propellant required for attitude maneuvers. However, this routine does not fully consider the possibility of the star being occulted by the Earth, Moon, or Sun. Hence, the astronaut must use his own judgment and should check for light flowing from the eyepiece before looking into it.

4.5 RENDEZVOUS RADAR

4.5.1 Operational Data

Radiation Frequency: 9832.8 mc

Receiver Frequency (from Transponder): 9792 mc

Radiation Power: 240 milliwatts nominal

Receive Signal Level: -18 dbm to -122 dbm

Beam Width (Transmit and sum receive): 3.25° to 4.0°

Antenna Gain (Transmit and sum receive): 32 db (nominal)

Angular Coverage:

Mode 1: ± 55° Trunnion Angle
+ 59 to -70 Shaft Angle

Mode 2: +125° to +235° Trunnion Angle
+41° to +155° Shaft Angle

Antenna Sidelobe level: -15 db adjacent to main lobe

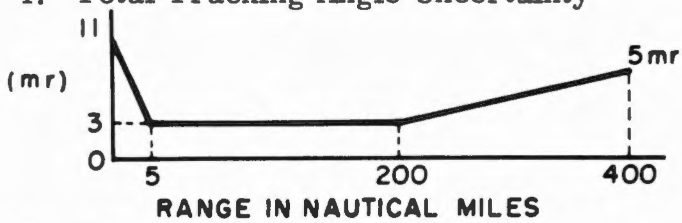
Receive Noise Figure: 10 db max

Range: 80 feet to 400 miles

Range Rate: ± 1 fps to ± 4900 fps

Random Tracking Parameters (3σ)

1. Total Tracking Angle Uncertainty



2. Range Accuracy: 1% or 80 ft

3. Range Rate Accuracy: 1.3% or 1.3 fps

Maximum Tracking Biases

1. Tracking Angle (Constant Bias): 15 mr

2. Range Bias: 80 feet for ranges $<$ 50.8 nm
   500 feet for ranges $>$ 50.8 nm

3. Range-Rate Bias: 1 fps

4.5.2 Limitations and Restrictions

During free-fall tracking, due to uncertainty in the type of rendezvous radar (RR) angle bias that will be present, a vehicle attitude restriction must be imposed for effective RR bias compensation. This attitude restriction involves controlling the LM +Z-axis to be within 30° of the tracking line of sight. Thus, the first LGC computation for tracking is determination of the line of sight (LOS) to the CSM. This is accomplished by taking the vector difference of the LM and CSM position vectors propagated to that time. If the range between the LM and CSM is greater than 400 nm, an alarm is issued since the RR is unable to provide correct range information to the LGC because of the ranging technique used in the radar. After successfully completing the range check, the LM Preferred Tracking Attitude Routine is used to align the LM +Z-axis with the LOS. At this point, if the astronaut should decide to manually change the attitude such as to roll about the Z-axis, it is essential that he recall the Preferred Tracking Attitude Routine (R6 1) to insure that the Z-axis is aligned with the LOS before proceeding. This is done to insure a sufficient period of data taking for estimation of the RR angle biases before the angle between the RR antenna and the LM + Z-axis reaches 30 degrees. During the RR data taking process, the LM is controlled to hold an approximate inertially fixed attitude by use of the 5° limit cycle. The LGC Data Read Routine is used to detect when the RR antenna is more than 30 degrees from the +Z-axis and causes the +Z-axis to be realigned with the LOS using the Preferred Tracking Attitude Routine.

Another limitation of the RR is the possibility of acquisition of the CSM with a side lobe producing erroneous data. Hence, when acquisition is first obtained, a check should be made for sidelobe acquisition.

4.6 LANDING RADAR

4.6.1 Operational Data

Type of System	
Velocity Sensor	CW, 3-beam
Radar Altimeter	FM/CW
Weight	
Specified Weight	39 lbs.
Size (L × W × H)	
Antenna Assembly	20.0" × 24.6" × 6.5"
Electronic Assembly	15.75" × 6.75" × 7.38"
Power Consumption	132 watts DC max., plus 15 watts for Ant. Ped. Act. - Ant. HTR require 34 watts nom.

Altimeter Antenna	
Type	Planar array, space duplexed
Gain	50.4 db
Beamwidth (Two-way)	3.9 degrees E plane Fore-Aft 7.5 degrees H plane Port-Stbd
Velocity Sensor Antenna	
Type	Planar array, space duplexed
Gain (Two-way)	49.2 db
Beamwidth (Two-way)	3.7 degrees E plane 7.3 degrees H plane
Transmitters	
Type	Solid State
Frequency	
Velocity Sensor	10.51 gc
Radar Altimeter	9.58 gc
Output Power	
Velocity Sensor	200 mw min. SSX output
Altimeter	175 mw min. SSX output
Altimeter Modulation	Sawooth FM
Modulation Frequency	130 cps
Deviations	± 4 mc (Lo) Alt > 2500 ft. ±20 mc (Hi) Alt < 2500 ft.

Outputs

Serial Binary to Computer

Parameter	Velocity Scale Factor	Velocity Scale Factor
	100 ms counting period	80 ms counting period
V_{xa}	-0.51519 fps/count	-0.6439875 fps/count*

Parameter	Velocity Scale Factor	Velocity Scale Factor
V_{ya}	0.96927 fps/count	1.2115875 fps/count*
V_{za}	0.69343 fps/count	0.8667875 fps/count*

NOTE: Velocity outputs are superimposed on a 153.6 kc nom. bias freq.

	Range Scale Factor 200 ms counting period	Range Scale Factor 80 ms counting period
Range > 2500 ft	2.158 ft/count	5.395 ft/count*
Range < 2500 ft	0.4317 ft/count	1.07925 ft/count*

*Calculated Radar values - actual LGC values are unknown.

Display Outputs

Analog

V_{ya}' (-200 to +200 fps)	25 mv/fps	(± 5 volts max.)
V_{za}' (-200 to +200 fps)	25 mv/fps	(± 5 volts max.)

Pulse Trains	Radar Scale Factor	Displ. Scale Factor
V_{xa}' (-500 to +500 fps)	19.439 pps/fps	20 pps/fps
Range (2500 - 25,000 ft)	2.316 pps/fps	2.32 pps/ft × Cos 15°
Range (10 - 2500 ft)	11.583 pps/fps	11.6 pps/ft × Cos 15°

Displays: (Isolated Contact Closures)

Antenna Pos. 1 Ind.

V_{xa}' Sense to 9M9

LGC: (Isolated Contact Closures)

Range Scale Factor

Antenna Pos. 1 Ind.

Antenna Pos. 2 Ind.

Velocity Data Good

Range Data Good

Instrumentation: (Contact Closures) to Caution & Warning Ind.

Range Data No Good

Velocity Data No Good

LR Power On

SECTION 5

PROCEDURAL DATA

5.1 DSKY OPERATION

5.1.1 Mission Language

The communication between crew and LGC is via the DSKY by means of verbs and nouns. Each verb or noun is represented by a two-character decimal number. The verb code indicates the operation to be performed and the noun code indicates the operand to which the operation is applied. Verb-noun displays from the LGC are provided by the DSKY indicators. Communication to the LGC is provided by verb-noun entries on the DSKY keyboard. Descriptions of the standard verbs and nouns are contained in Tables 5-1 and 5-2.

5.1.2 Display Panel

The 24 electroluminescent sections of the display panel display the active LGC program or mode of operation (PROG), the current communicating VERB and NOUN, and three data registers (R1, R2, and R3). (See Fig. 5-1) Each section is capable of displaying any decimal character or remaining blank, except for the left-most or sign section of each data register. The sign section of each data register displays a plus sign, a minus sign, or is blank.

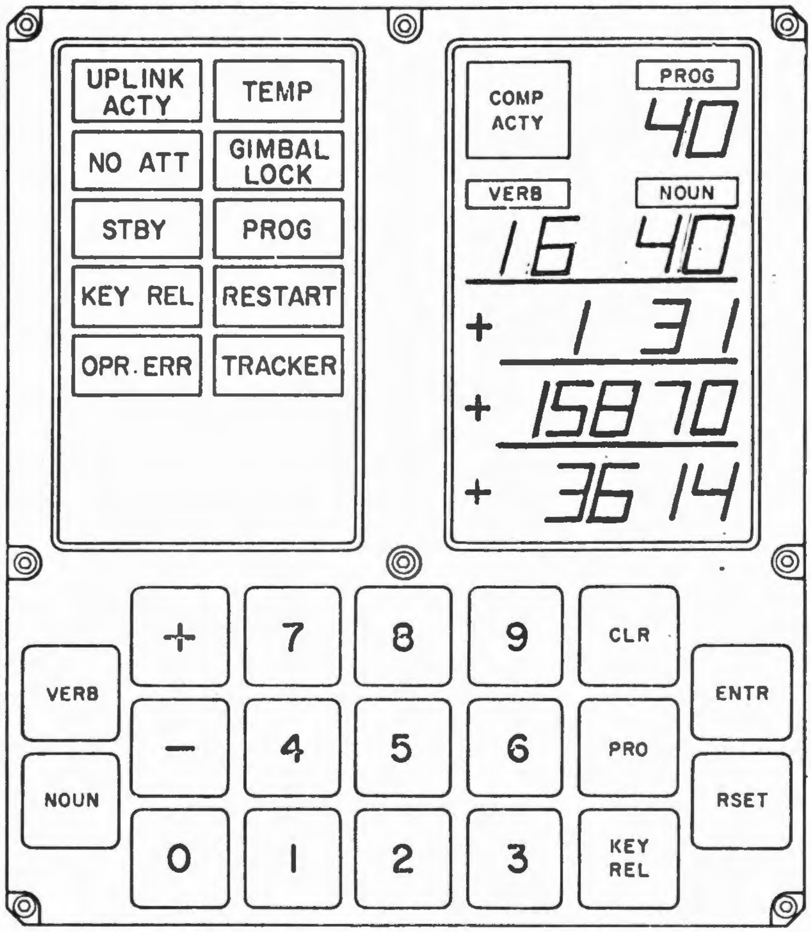


Fig. 5-1. Display and keyboard.

Verb Code	Function	Description
00	Illegal	
01	Display 1st component of:	Performs octal display of data on R1.
02	Display 2nd component of:	Performs octal display of data on R1.
03	Display 3rd component of:	Performs octal display of data on R1.
04	Display 1st and 2nd component of:	Performs octal display of data on R1, and R2.
05	Display 1st, 2nd and 3rd component of:	Performs octal display of data on R1, R2, and R3.
06	Display all components of:	Performs decimal display of data on appropriate registers. The scale factors, types of scale factor routines, and component information are stored within the machine for each noun which it is required to display in decimal.
07	Double precision decimal display:	Performs a double precision decimal display of data on R1 and R2. It does no scale factoring. It merely performs a 10-character, fractional decimal conversion of two consecutive, erasable registers, using R1 and R2. The sign is placed in the R1 sign position with the R2 sign position remaining blank. It cannot be used with mixed nouns. Its intended use is primarily with "machine address to be specified" nouns.
08	Illegal	
09	Illegal	
10	Illegal	
11	Monitor 1st component of:	Performs octal display of updated data every 1 second on R1.
12	Monitor 2nd component of:	Performs octal display of updated data every 1 second on R1.
13	Monitor 3rd component of:	Performs octal display of updated data every 1 second on R1.

Table 5-1. List of LM verbs.

Verb Code	Function	Description
14	Monitor 1st and 2nd component of:	Performs octal display of updated data every 1 second on R1 and R2.
15	Monitor 1st, 2nd, and 3rd component of:	Performs octal display of updated data every 1 second on R1, R2, and R3.
16	Monitor all components of:	Performs decimal display of updated data every 1 second on appropriate registers.
17	Monitor double precision decimal:	Performs decimal display of updated data every 1 second on R1 and R2.
18	Illegal	
19	Illegal	
20	Illegal	
21	Write 1st component into:	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on R1.
22	Write 2nd component into:	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on R2.
23	Write 3rd component into:	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on R3.
24	Write 1st and 2nd component into:	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on R1 and R2.
25	Write 1st, 2nd, and 3rd component into:	Performs data loading. Octal quantities are unsigned. Decimal quantities are preceded by + or - sign. Data is displayed on R1, R2, and R3.

Table 5-1. List of LM verbs (Cont.)

Verb Code	Function	Description
26	Illegal	
27	Fixed memory display:	This verb is included to permit displaying the contents of fixed memory in any bank. Its intended use is for checking program ropes and the bank position of program ropes.
28	Illegal	
29	Illegal	
30	Request executive:	Initiates executive program. The executive program supervises the execution of all requested jobs according to an assigned priority scheme.
31	Request waitlist:	Initiates waitlist program. The waitlist program schedules the execution of tasks which must be executed at a specific time.
32	Recycle program:	Program recycles within current computational loop.
33	Proceed without data:	Informs routine requesting data to be loaded that the operator chooses not to load fresh data, but wishes the routine to continue as best it can with old data. Final decision for what action should be taken is left to requesting routine.
34	Terminate:	Informs routine requesting data to be loaded that the operator chooses not to load fresh data and wishes the routine to terminate. Final decision for what action should be taken is left to requesting routine. If monitor is on, it is turned off.
35	Test lights:	Illuminates the lights on the display panel. Also all 8's and +'s are shown on the numerical panel. After 5 seconds, all the lights go off and the original major code number is redisplayed. The numerical panel retains 8's and +'s for display.

Table 5-1. List of LM verbs (Cont.)

Verb Code	Function	Description
36	Fresh start:	Initializes the program control softwave and the keyboard and display system program.
37	Change program to:	Change to new program according to the program code noun entry.
38	Illegal	
39	Illegal	
40	Zero:	Sets the ISS CDU registers & EMEM CDU counters to zero for 320ms. Must be used with noun 20 (ICDU) or noun 72 (RR CDU) only.
41	Coarse align:	Must be used with noun 20 (ICDU) or noun 72 (RR CDU) only.
42	Fine align IMU:	Calls up programs that perform the indicated ISS procedures.
43	Load IMU attitude error meters:	
44	Terminate continuous designate:	
45	Display W Matrix	
46	Illegal	
47	Initialize AGS:	Selects AGS initialization routine (R47). Provides the AGS with the LM and CSM state vectors and ground elapsed time. This verb also zeros the ICDU, LGC and AGS Gimbal Angle counters to insure synchronization of these counters.
48	Load A/P data:	Selects digital autopilot load routine (R03). Displays nouns 46 and 47 sequentially. With noun 46, the spacecraft configuration code appears in R1.
49	Start crew defined maneuver:	Selects crew-defined maneuver routine (R62). Provides the crew with the ability to specify a final vehicle attitude for an LGC controlled maneuver.

Table 5-1. List of LM verbs (Cont.)

Verb Code	Function	Description
50	Please perform:	This verb is used only by internal routines that wish the operator to perform a certain task. It should never be keyed in by the operator. It is usually used with noun 25, "checklist". The coded number for the checklist item to be performed is displayed in register R1 by the requesting routine.
51	Illegal	
52	Mark X reticle:	This verb is used only by internal routines that wish the operator to mark. It should never be keyed in by the operator. It requests the operator to obtain an X reticle mark of a star.
53	Mark Y reticle:	This verb is used only by internal routines that wish the operator to mark. It should never by keyed in by the operator. It requests the operator to obtain a Y reticle mark of star.
54	Please mark X or Y reticle:	This verb is used by internal routines that wish the operator to mark. It should never by keyed in by the operator. It requests the operator to obtain either an X or Y reticle mark of a star.
55	Increment LGC time (decimal):	Permits entering TEPHEM into the LGC. TEPHEM is the time of the LGC clock zero from 00:00 hour July 1 prior to the reference Besselian year.
56	Terminate Tracking:	Terminates either rendezvous tracking program (P20) or preferred tracking attitude program (P25).

Table 5-1. List of LM verbs (Cont.)

Verb Code	Function	Description
57	Illegal	
58	Illegal	
59	Illegal	
60	Display DAP attitude errors.	
61	Command LR to position 2:	Landing radar antenna is switched to the hover and letdown position.
62	Sample radar once per second	Provides suitable DSKY displays and LGC downlink information to support the self tests of the RR or LR (R04).
63	Display total attitude errors	
64	Illegal	
65	Disable u, v jets during CSM docked burns.	
66	Vehicles are attached. Move this vehicle STATE to other vehicle	
67	Illegal	
68	Illegal	
69	Cause restart	
70	Update liftoff time:	Provides an increment for the LGC check and TEPHEM.
71	Universal update, block ADR	Provides load capability for a block of sequential erasable locations.
72	Universal update, single ADR	Provides load capability for 1 through 9 individually specified locations.
73	Update LGC time (Octal)	Provides an increment for the LGC clock only.
74	Initialize erasable dump via downlink:	Entering V74 will initiate the downlink of all erasable information.
75	Enable u, v jets.	

Table 5-1. List of LM verbs (Cont.)

Verb Code	Function	Description
76	Minimum impulse command mode	A verb 76 entry by the astronaut sets A/P in minimum impulse command mode, which is sometimes used during inflight star sighting mark procedure.
77	Rate command and attitude hold mode	A verb 77 entry by the astronaut sets A/P in rate command and attitude hold mode.
78	Start LR spurious test (R77)	Provides for the readout of range and velocity data from the landing radar (LR). Also puts it on the LGC downlink during the spurious return tests.
79	Stop LR spurious test (R77)	
80	Update LM state vector	During rendezvous navigation program (P20) if initial selection of state vector to be updated was CSM, an entry of V80E will change the option to LM state vector to be updated (at any time during program).
81	Update CSM state vector	During rendezvous navigation program (P20) if initial selection of state vector to be updated was LM, an entry of V81E will change the option to CSM state vector to be updated (at any time during program).
82	Request orbit parameter display	Used for entry into orbit parameter display routine (R30).
83	Request rendezvous parameter display	Used for entry into rendezvous parameter display routine (R31). Range, range rate, and theta are displayed.
84	Start target delta V	Used for entry into target delta V routine (R32).
85	Illegal	
86	Illegal	

Table 5-1. List of LM verbs (Cont.)

Verb Code	Function	Description
87	Illegal	
88	Illegal	
89	Start rendezvous final attitude routine (R63)	Entry of V89 provides for calculation and display of the final FDAI ball angles required to point the LM +Z or +X axis at the CSM. Also will call the attitude routine (R60) for automatic maneuver capability.
90	Request rendezvous out of PLANE display routine (R36)	Provides for display, at astronaut request, of LGC calculated rendezvous out of plane parameters.
91	Compute Banksum	
92	Operate IMU performance test (P07)	
93	Enable W matrix initialization	
94	Illegal	
95	No update of either state vector	
96	Interrupt integration and go to P00	
97	Illegal	
98	Illegal	
99	Please enable engine	

Table 5-1. List of LM verbs (Cont.)

Noun Code	Description	Scale and Format	Units
00	Not used		
01	Specify address (fractional)	.XXXXX .XXXXX .XXXXX	Fractional
02	Specify address (whole)	XXXXX. XXXXX. XXXXX.	Integers
03	Specify address (degree)	XXX.XX XXX.XX XXX.XX	degrees
04	Not used		
05	Angular error/difference	XXX.XX	degrees
06	Option code	Octal only Octal only	
07	Used to set or reset selected bits in any erasable register	Octal only	
08	Alarm data	Octal only Octal only Octal only	
09	Alarm codes	Octal only Octal only Octal only	
10	Channel to be specified	Octal only	
11	Not used		
12	Not used		
13	Not used		
14	Checklist (used internally by extended verbs only)(noun 25 is pasted after display)	XXXXX. XXXXX. XXXXX.	
15	Increment address	Octal only	
16	Time of event (used by extended verbs only)	OOXXX. OOOXX. OXX.XX	hours minutes seconds

Table 5-2. List of LM Nouns

Noun Code	Description		Scale and Format	Units
17	Not used			
18	Auto maneuver ball angles		XXX. XX XXX. XX XXX. XX	degrees
19	Bypass attitude trim maneuver (desired FDAI ball angles)	Roll Pitch Yaw	XXX. XX XXX. XX XXX. XX	degrees
20	ICDU angles	Roll Pitch Yaw	XXX. XX XXX. XX XXX. XX	degrees
21	PIPA's	X Y Z	XXXXX. XXXXX. XXXXX.	pulses
22	New ICDU angles	Roll Pitch Yaw	XXX. XX XXX. XX XXX. XX	degrees
23	Not used			
24	Delta time for LGC clock		OOXXX. OOOXX. OXX. XX	hours minutes seconds
25	Checklist (used with V50) (see Table 5-3 for Checklist Codes)		XXXXX.	
26	Priority/delay, adres, bbcon		Octal only Octal only Octal only	
27	Self test switch		XXXXX.	
28	Not used			
29	Not used			
30	TIG of CSI		OOXXX. OOOXX. OXX. XX	hours minutes seconds

Table 5-2. List of LM Nouns (Cont.)

Noun Code	Description	Scale and Format	Units
31	TIG of CDH	OOXXX. OOOXX. OXX.XX	hours minutes seconds
32	Time to perigee	OOXXX. OOOXX. OXX.XX	hours minutes seconds
33	Time of ignition	OOXXX. OOOXX. OXX.XX	hours minutes seconds
34	Time of event	OOXXX. OOOXX. OXX.XX	hours minutes seconds
35	Time to go to event	OOXXX. OOOXX. OXX.XX	hours minutes seconds
36	Time of LGC clock	OOXXX. OOOXX. OXX.XX	hours minutes seconds
37	TIG of TPI	OOXXX. OOOXX. OXX.XX	hours minutes seconds
38	Not used		
39	Not used		
40	Time to ignition/cutoff VG Delta V (accumulated)	XXBXX XXXX.X XXXX.X	minutes, seconds feet/second feet/second
41	Target azimuth Target elevation	XXX.XX XX.XXX	degrees degrees
42	Apogee altitude Perigee altitude Delta V (required)	XXXX.X XXXX.X XXXX.X	nautical miles nautical miles feet/second

Table 5-2. List of LM Nouns (Cont.)

Noun Code	Description	Scale and Format	Units
43	Latitude Longitude Altitude	XXX. XX XXX. XX XXXX. X	degrees degrees nautical miles
44	Apogee altitude Perigee altitude TFF	XXXX. X XXXX. X XXBXX	nautical miles nautical miles minutes, seconds
45	Marks TTI of next burn MGA	XXXXX. XXBXX XXX. XX	 minutes, seconds degrees
46	Autopilot configuration	R1 = ABCDE, where A = 0 LM only A = 1 LM and CM B = 0 Two jet translation (RCS system A alone) B = 1 Two jet translation (RCS system B alone) B = 2 Four jet translation (RCS system A and B) C = 0 Fine scaling ACA C = 1 Normal scaling ACA D = 0 Attitude deadband of 0. 3 degrees D = 1 Attitude deadband of 5. 0 degrees E = 0 Kalcmanu rate of 0. 2 degrees/sec E = 1 Kalcmanu rate of 0. 5 degrees/sec E = 2 Kalcmanu rate of 2 degrees/sec E = 3 Kalcmanu rate of 10 degrees/sec	
47	Weight LM CSM	XXXXX. XXXXX.	pounds pounds
48	Gimbal pitch trim Gimbal roll trim	XXX. XX XXX. XX	degrees degrees
49	Delta R Delta V	XXXX. X XXXX. X	nautical miles feet/second

Table 5-2. List of LM Nouns (Cont.)

Noun Code	Description	Scale and Format	Units
50	Delta altitude CDH Delta time (CDH-CSI or TPI-CDH) Delta time (TPI-CDH or TPI-NOM TPI)	XXXX.X XXBXX XXBXX	nautical miles minutes, seconds minutes, seconds
51	Not used		
52	Central angle of active vehicle	XXX.XX	degrees
53	Not used		
54	Range Range rate Theta	XXXX.X XXXX.X XXX.XX	nautical miles feet/second degrees
55	Number of apsidal crossings Elevation angle Central angle of passive vehicle	XXXXX XXX.XX XXX.XX	 degrees degrees
56	Not used		
57	Delta R	XXXX.X	nautical miles
58	Perigee altitude (post TPI) Delta V TPI Delta V TPF	XXXX.X XXXX.X XXXX.X	nautical miles feet/second feet/second
59	Delta velocity LOS	XXXX.X XXXX.X XXXX.X	feet/second feet/second feet/second
60	Not used		
61	Not used		
62	Not used		

Table 5-2. List of LM Nouns (Cont.)

Noun Code	Description	Scale and Format	Units
63	Not used		
64	Not used		
65	Sampled LGC time	OOXXX. OOOXX. OXX. XX	hours minutes seconds
66	LR range LR position	XXXXX +000001/+000002	feet
67	LRVX LRVY LRVZ	XXXX. X XXXX. X XXXX. X	feet/second feet/second feet/second
68	Not used		
69	Not used		
70	AOT detent code/star code	Octal only Octal only Octal only	
71	AOT detent code/star code	Octal only Octal only Octal only	
72	RR trunnion angle RR shaft angle	XXX. XX XXX. XX	degrees degrees
73	New RR trunnion angle New RR shaft angle	XXX. XX XXX. XX	degrees degrees
74	Not used		
75	Not used		

Table 5-2. List of LM Nouns (Cont.)

Noun Code	Description	Scale and Format	Units
76	Not used		
77	Not used		
78	RR range RR range rate	XXX.XX XXXXX	nautical miles feet/second
79	Not used		
80	Data indicator Omega	XXXXX XXX.XX	 degrees
81	Delta V	XXXX.X XXXX.X XXXX.X	feet/second feet/second feet/second
82	Delta VX(LV) Delta VY(LV) Delta VZ(LV)	XXXX.X XXXX.X XXXX.X	feet/second feet/second feet/second
83	Delta VX(body) Delta VY(body) Delta VZ (body)	XXXX.X XXXX.X XXXX.X	feet/second feet/second feet/second
84	Delta VX(CSM) Delta VY(CSM) Delta VZ(CSM)	XXXX.X XXXX.X XXXX.X	feet/second feet/second feet/second
85	VGX (body) VGY (body) VGZ (body)	XXXX.X XXXX.X XXXX.X	feet/second feet/second feet/second
86	VGX (LV) VGY (LV) VGZ (LV)	XXXX.X XXXX.X XXXX.X	feet/second feet/second feet/second
87	Backup optics LOS azimuth Backup optics LOS elevation	XXX.XX XXX.XX	degrees degrees
88	Half unit sun or planet vector	.XXXXX .XXXXX .XXXXX	

Table 5-2. List of LM Nouns (Cont.)

Noun Code	Description	Scale and Format	Units
89	Not used		
90	Y (Rendezvous Y dot out of plane Psi parameters)	XXX.XX XXXX.X XXX.XX	nautical miles feet/second degrees
91	Not used		
92	Not used		
93	Delta gyro angles X gyro Y gyro Z gyro	XX.XXX XX.XXX XX.XXX	degrees degrees degrees
94	Not used		
95	Not used		
96	Not used		
97	System test inputs	XXXXX XXXXX XXXXX	
98	System test results and inputs	XXXXX XXXXX XXXXX	
99	RMS in position RMS in velocity	XXX.XX XXXX.X	nautical miles feet/second

Table 5-2. List of LM Nouns (Cont.)

5.1.3 Keyboard Operation

The procedure for keyboard operation is to press a sequence of seven keys as follows:

VERB V_1 V_2 NOUN N_1 N_2 ENTR

Pressing the verb key blanks the verb display on the DSKY and clears the verb code register in the LGC. The next two numerical keys pressed comprise the verb code, V_1 and V_2. These numerical characters appear in the VERB display on the DSKY as they are keyed in. In a similar manner the noun code is keyed in by pressing the noun key and two numerical keys. Pressing the ENTR (enter) key initiates the performance indicated by the verb-noun combination on the display panel. No action is taken by the LGC on the verb-noun combination until the ENTR key is pressed. Therefore, it is not necessary for the verb to be keyed in before the noun. They may be done in reverse order, or an old verb or old noun may be used without rekeying it.

If an error is noticed in either the verb or noun code before pressing the ENTR key, it can be corrected by pressing the VERB or NOUN key and keying in the correct code. The ENTR key, therefore, should not be pressed until the displayed verb and noun have been verified as being correct.

If the selected verb-noun combination requires data to be loaded by the operator, the VERB and NOUN lights start flashing (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: R1, R2, or R3. 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-numerical 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 multi-component 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. If these conditions are violated, the OPR ERR light is turned on when the ENTR key is pressed. The ENTR key must be pressed after each data word to indicate to the program that a complete numerical word has been keyed in. The VERB-NOUN lights stop flashing after the ENTR button is pressed for the last time in a loading sequence.

The CLR button is used to remove errors in loading data as it is displayed in R1, R2, or R3. It does not affect 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, pressing the CLR button clears the register being loaded, provided the CLR button is pressed before the ENTR button. Once the ENTR key is pressed, the CLR key does nothing. The only way to correct an error after the data has been 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 the register being loaded. (The CLR key may be pressed after any character, but before the ENTR button is pressed.) Consecutive CLR button actuations clear the data display register above the current one until R1 is cleared. Any attempt to clear beyond R1 is simply ignored. The CLR backing-up function operates only on data pertinent to the load verb that initiated the loading sequence. For example, if the initiating load verb were a load second component only, no backing-up action is possible.

Further signals from the numerical keys, the CLR key, and the sign keys are rejected after completion (final entry) of a data display or data load verb. At such time, only VERB, NOUN, ENTR, RSET (error reset), or KEY REL (key release) signals 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 R1, R2, or R3 has been keyed in, and at no other time. The 8 or 9 key is accepted only while loading a data word into R1, R2, or R3, which is preceded by a + or - sign.

The keyboard and display system program may be used as a subroutine by internal computer programs. However, any operator keyboard action (except RSET) makes the keyboard and display system program busy to internal routines. The astronaut has control of the keyboard and display system 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 astronaut release the keyboard and display system for internal use when he has temporarily finished with it. This is done by pressing the KEY REL pushbutton.

The RSET key is pressed whenever a DSKY failure indicator comes on. It may be used to test for the presence of a continuous alarm rather than a transient alarm. In addition to a keycode, the RSET key initiates a light reset signal which resets the alarm flip-flops in the alarm control section of the output section.

5.1.4 Monitor Verbs

There is a class of verbs called monitor verbs (11 thru 17) which updates display data every one second. Once a monitor verb is executed, the data on the display panel continues to be updated until the monitor is turned off.

The monitor is turned off by: PRO (proceed/proceed without data), V34E (terminate), an internal program initiation of the keyboard and display system program, or by a fresh start of the LGC.

Monitor action is suspended (but not ended) by the depression of any key, except RSET. This turns on the KEY REL light immediately. Monitor action continues after the keyboard and display system is released. Thus it is possible to suspend a monitor while the operator loads some data, or requests another display; and to return to the original monitor when his intervention is concluded.

After any use of the DSKY, the numerical characters (verb, noun, and data words) remain visible until the next use of the DSKY. If a particular use of the DSKY involves fewer than three data words, the data display registers (R1, R2, R3) not used remain unchanged, unless blanked by deliberate program action.

5.1.5 Internal LGC Sequences

The majority of DSKY operations are of the following categories:

1. Display – To display data to the operator. Display verbs present data computed by the mission program.
2. Load – To request a data load into the data registers
3. Please perform – To request an action from the operator who then notifies the LGC of his compliance.

4. Please mark - To request the operator to push the MARK button for an AOT sighting.

LGC initiated verb/noun combinations are either statically displayed or flashed. If static they identify data displayed only for operator information requiring no response from him. If the verb/noun is flashing, appropriate operator response is required as indicated by the verb/noun combination. In this case the internal sequence is interrupted until the operator responds appropriately, then the verb/noun flash is terminated and the internal sequence is resumed.

It is important to respond to a flashing verb/noun with only one of the proper responses or else the internal sequence that called the display may never be resumed. An appropriate operator response to a flashing verb/noun should be ENTR, V32E (recycle), PRO (proceed/proceed without data), or V34E (terminate). The internal sequence response to any one of these operator responses varies according to the verb/noun flashing.

5.1.5.1 Display-Verb/Noun Flashing

The appropriate operator response to a flashing verb/noun combination is:

1. Correct the data. Perform the appropriate load verb sequence. Upon the final ENTR, the internal sequence proceeds normally.

2. Recycle (V32E). This causes the program to return to a previous location.

3. Proceed/Proceed without data (PRO). This indicates acceptance of the displayed data, and a desire for the internal sequence to continue normally.

4. Terminate (V34E). The operator wishes the internal sequence to cease operation.

5.1.5.2 Please Load-Verb/Noun Flashing

Whenever any data is to be loaded, the Verb/Noun flashes. The flash occurs whether the data load is initiated by LGC or by the operator. The appropriate data display register (R1, R2, or R3) is blanked in anticipation of the data load. Data is loaded in five-character words and is displayed character-by-character; in one of the five-position data display registers as it is keyed in.

Numerical data is considered decimal if the five-character data word is preceded by a plus or a minus sign; if no sign is supplied it is considered octal. The plus and minus keys are accepted only when they precede the first numerical character of the data word; they are ignored at any other time. Decimal data must be loaded in full five-numerical-character words (no zeros may be suppressed); octal data may be loaded with high order zeros suppressed. If decimal is used for any component of a multicomponent load verb, it must be used for all components of that verb. No mixing of octal and decimal data is permitted for different components of the same load verb. (If this principle is violated, the OPR ERR alarm is turned on.)

The ENTR key must be pressed after each data word. This tells the program that the numerical word being punched in is complete. The flash is turned off after the last ENTR of a loading sequence is pressed.

As data is loaded, it is temporarily stored in intermediate buffers. It is not placed into its final destination, as specified by the noun code, until the final ENTR of the load sequence is punched in.

If an attempt is made to key in more than five numerical characters in sequence, the sixth and subsequent characters are simply rejected. If the 8 or 9 key is punched during octal load (as identified by lack of a sign entry), it is rejected and the OPR ERR light is turned on.

In multi-component load situations, the appropriate single component load verbs are flashed one at a time. The computer always instructs the operator through a loading sequence. The operator (or the internal program) initiates the sequences by selecting VERB 25, "load three components of: "(any noun will do) E. The verb code is changed to 21, "load first component of: "and the flash is turned on. VERB 21 continues to be flashed as the operator punched in the first word of data. When the ENTR is pressed, the verb code is changed to 22. Flashing continues while the operator punches the second data word. When ENTR is pressed, the verb code is changed to 23, "load third component", and again the flash continues while the third data word is punched in. When ENTR is pressed, the flash is turned off, and all three data words are placed in the locations specified by the noun. Throughout the changing of the verb codes, the noun code was left unchanged.

The CLR Button is used during data loading to remove errors in R1, R2, or R3. It allows the operator to begin loading the data word again. 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.) In the following discussions, the term Clearing Function will be used to mean: blanking the data display register of interest and placing +0 into the buffer storage register associated with that display register.

For single component load verbs, the CLR button depression performs the clearing function on whichever register is being loaded, provided that the CLR is punched before the data ENTR. Once the ENTR is depressed, the CLR does nothing. The only way to correct an error after the data ENTR for a single component load verb is to begin the load verb again.

For the two- or three-component load verbs, there is a backing-up feature of CLR. The first depression of the CLR key performs the clearing function on whichever register is being loaded. (The CLR may be pressed after any character, but before its ENTR.) Consecutive depressions of CLR perform the clearing function on the data display register above the current one, until R1 is cleared. Any attempts to back-up beyond R1 are simply ignored.

The backing-up of CLR operates only on whatever data is pertinent to the load verb which initiated the loading sequence. For example, if the initiating load verb was a load second component only, no backing-up action is possible.

The appropriate operator response to an internally initiated verb/noun for load therefore becomes:

a) The final ENTR of the loading sequence, after which internal sequence proceeds normally.

b) "Proceed/proceed without data" (PRO). This indicates the operator will not load the requested data and desires the internal sequence to continue as best it can.

c) "Terminate" (V34E). The operator wishes the internal sequence to cease operation.

5.1.5.3 Please Perform - Verb/Noun Flashing

This is always an internally initiated action, as operator response is always required to the "please perform" request, the verb-noun is always flashed, and the internal sequence is interrupted. The "please perform" verb 50 is usually used with the checklist noun 25 with an appropriate checklist code in register R1. Whenever V50N25 is displayed on the DSKY, it is a request for the astronaut to perform one of the following general tasks:

1) Change position of console switches
2) Start or end a task
3) Key in data on the DSKY

The specific requested task is denoted by the checklist code display in R1. Table 5-3 lists the checklist codes and the action required for the operator to accept the request. The appropriate response is:

1. ENTR to indicate that the requested action has been performed. The internal sequence continues normally.

2. PRO (proceed without data). The operator chooses not to perform the requested action, but desires the internal sequence to proceed as best it can.

3. V34E (terminate). The operator chooses not to perform the requested action and desires the internal program to cease operation.

Checklist Codes	Descriptions	Action to Accept
	Note: These codes are displayed only with Verb 50 Noun 25 (Please Perform, Checklist)	
00011	Key in Auto Optics Positioning Option	Not used in Sundance
00012	Key in Target Data	Not used in Sundance
00014	Fine alignment option	Key in PRO, define alignment
00015	Perform star acquisition	Rotate LM to position pitch axis in preferred direction. Rotate LM to acquire two navigation stars in AOT FOV. Key in ENTR.
00016	Key in terminate mark	Not used in Sundance
00017	Perform additional sightings	Not used in Sundance
00031	Key in engine on option	Not used in Sundance
00035	Perform LGC preparation	Not used in Sundance
00036	Perform Thrust termination	Not used in Sundance
00062	Switch LGC to power down	Key in PRO. Press PRO until STBY light goes on, LGC blanks DSKY displays.
00201	Switch RR mode to automatic	RR ANTENNA MODE SW - LGC. Key in PRO
00202	Key in sighting check option	Not used in Sundance
00203	Perform auto mode selection	Guidance control sw - PGNS Mode control sw - AUTO Thrust control sw - AUTO Key in PRO
00204	Key in enable gimbal trim option	Not used in Sundance
00205	Perform manual acquisition with RR	RR sw - SLEW TEST Monitor sw - RNDZ RADAR -AGC SLEW RATE sw - LO Search for CSM manually near zero shaft and trunnion angles and obtain indication in SIGNAL STRENGTH meter. Set RR antenna mode switch to AUTO TRACK and permit acquisition(NO TRACK lt goes out) Check for sidelobe. key in PRO.

Table 5-3 List of checklist codes

Whenever V04 N06 is displayed on the DSKY, it is a request for the astronaut to load an option into the DSKY between two or more alternatives. An option code, which describes the decision to be made is displayed in R1 of the DSKY. An LGC assumed option is automatically displayed in R2. If the astronaut accepts the LGC assumed option, he keys in PRO. However, if he rejects the LGC assumed option, he keys in V22E and loads the desired option. Table 5-4 lists the option codes and the associate options.

5.1.5.4 Please Mark

The "please mark" verbs (52, 53, and 54) are flashed during the in-flight sighting mark routine (R53). Verb 54 requests an AOT star mark via the computer control and reticle dimmer assembly for either the X or Y reticle. Verb 52 requests an X reticle mark and verb 53 requests a Y reticle mark.

5.1.6 Mission Program Initialization or Termination

Programs may be initiated by manual keyboard entry or by LGC uplink command. In certain cases, program initiation is automatically done by a previous program. Typical manual entry into a program is made from the LGC idling program (P00) or final automatic request terminate routine (R00). This is accomplished by keying in V37E and then the number of the required program and another E. For example, if the DPS thrusting program (P40) is desired, key in V37E 40E.

Once an automatic LGC sequence has been initiated, the astronaut always has the capability to end it at any time. This is accomplished by selection of a new program. For example, LGC idling program (P00) selection is made by V37E 00E. An active program can also be terminated by V34E or V56E. The verb 56 is generally used to terminate coasting programs (P20, P25)

Option Code	Purpose	Input for R2
	Note: These codes are displayed only with Verb 04 Noun 06	
00001	Specify IMU orientation	1 = Preferred 2 = Nominal 3 = REFSMMAT 4 = Landing site - orientation
00002	Specify vehicle	1 = This 2 = Other
00003	Specify tracking attitude	1 = Preferred 2 = Other
00004	Specify Radar	1 = RR 2 = LR
00006	Specify RR coarse align option	1 = Lock on 2 = Continuous designate

Table 5-4. List of LM option codes.

and verb 34 is used to terminate other programs.

5.1.7 Operator Alarm

The OPR ERR light is turned on when the operator performs some improper sequence of key depressions.

Illegal Verbs, Nouns, and Combinations

The simplest alarm situation is an attempt to use an undefined (or spare) verb code or noun code. The alarm light is turned on when the ENTR is pressed that attempts to execute the verb/noun combination. No further action is taken.

It is possible to choose a verb that is defined and a noun that is defined, but have the combination of verb and noun be illegal (for example, the "decimal display" verb used with a noun which is restricted to be "octal only"). The alarm light is turned on at the ENTR that attempts to execute the verb/noun combination. No further action is taken.

Violation of the following principle causes the OPR ERR to be turned on. No further action is taken.

1. An undefined (or spare) verb must not be used.
2. An undefined (or spare) noun must not be used.
3. In octal display and monitor verbs and all load verbs, the component number of the verb must not exceed the number of components in the noun. (Note, all "machine address to be specified" nouns are considered one component, except noun 01 which may be used with any verb.)
4. The octal display and monitor verbs must not be used with a "decimal only" noun.
5. The decimal display and monitor verbs must not be used with an "octal only" noun.
6. The dp decimal display and monitor verbs (07, 17) must not be used with mixed nouns (codes 55-77).
7. No load verb may be used with a noun restricted to be "no load". All nouns having split MIN/SEC scale for any component are "no load" for the entire noun.

8. An input code other than those which are defined is received from the keyboard.

9. The contents of the register used to determine which display panel character is to be lighted has exceeded its limit.

Many legal Verb/Noun combinations require the loading of additional data (either numerical or machine address). It is possible that the data supplied may itself be improper for the noun selected. Examples are: (1) the numerical data exceeds the maximum value allowed by the scale factor associated with the noun, and (2) decimal data is loaded into an "octal only" noun.

In general the offense is detected at the final ENTR of the loading sequence. The alarm is turned on and a recycle is performed back to the beginning of the loading sequence. The flash is left on, and the data display register associated with the first data word in the sequence is blanked again. It is necessary for the operator only to supply the data again; he need not attempt to re-execute the verb/noun combination. (Note, if decimal data is supplied for the address of a "machine address to be specified" noun, the alarm and recycle are performed at the ENTR immediately following the address word.)

Violation of the following principles causes the OPR ERR to be turned on, and a recycle to be performed.

1. The address keyed in for a "machine address to be specified" noun must be octal.

2. In multi-component load verbs, no mixing of octal and decimal data is permitted. All the data words loaded for a given noun must either be all octal or all decimal.

3. Octal data must not be loaded into a "decimal only" noun.
4. Decimal data must not be loaded into an "octal only" noun.
5. Decimal data loaded must not numerically exceed the maximum permitted by the scale factor associated with the appropriate component of the noun.
6. All 3 words must be loaded for the hours, minutes, seconds scale.
7. When loading with the hours, minutes, seconds scale, the minutes must not exceed 59; the seconds must not exceed 59.99; and the total number must not exceed 745 hours, 39 minutes, 14,555 seconds.
8. Two numerical characters must be supplied for the PROG Code under V37.

There are four situations which cause the Operator Error light to be turned on and the offending key depression to be simply rejected. These are:

1. An attempt to ENTR a decimal data word having fewer than five numerical characters. The ENTR is simply rejected. The flash is left on and the verb code is not advanced. Thus, it is possible to supply the remaining characters and to press the ENTR again for the same data word. Or the CLR key may be used if the operator wishes to begin loading the offending data word again.
2. An 8 or 9 is punched while loading a word which was not preceded by a plus or minus sign. The 8 or 9 is simply rejected. The remaining characters may then be supplied or the offending word removed and its loading begun again.
3. Certain Program controlled cases.
4. An attenpt to call one extended verb on top of another without allowing proper termination of the first.

5.1.8 Program Alarm

A program alarm is a program-controlled alarm that is issued when some program check is failed. The program alarm lights the PROG alarm indicator on the DSKY.

Program alarms are processed by either the program alarm routine or the program abort routine. The program abort routine is used for such operations that require an LGC restart (causing the LGC to reinitiate the program). Upon issuance of a program alarm, the associated alarm routine causes V05 N09 to be displayed and usually a five-digit error is displayed in R1 of the DSKY. This error code indicates the specific condition that causes the alarm, and thereby, provides diagnostic data for crew decisions. These error codes are listed in Table 2-2.

Occasionally more than one error code will be displayed (up to three). In which case, R2 and R3 are used as required. If no error code is present and V05 N09 is not displayed, keying in V05 N09E will call up the error code for display. The PROG alarm indicator on the DSKY will remain on until the RSET pushbutton is pressed.

5.2 LGC SEQUENCING AND CONTROL

5.2.1 Time Sharing

The building blocks of operational tasks within the LGC consist of the programs and routines. Due to the random time sequencing of many LGC tasks, the design of the building block sequences permits use of the same task at various times and in varied circumstances. The LGC is a time shared computer; whereby, priorities are internally assigned to each processing task required. This time-sharing is implemented by counter interrupts, program interrupts, and program controlled processing.

Counter interrupts have the highest priority. Whenever counter input pulses are present, the processing of any other task is temporarily suspended to permit processing of the counter pulses. Control is returned to the interrupted program upon completion of processing the counter pulses. The processing of LGC counter input pulses required approximately twelve microseconds. This involves such things as IMU gimbal angles, velocity accumulation, RR antenna angles, and LGC output pulses required to re-position the IMU stable member.

Program interrupts are caused by the occurrence of a particular event. They have the next highest priority to counter interrupts. A program interrupt can occur when it is time to process such things as input/output data, uplink data, downlink data, radar inputs, controller inputs, and AOT marks.

The lower priority is given to program controlled processing. These include the mission programs and routines in memory which utilize most of the LGC processing time. Mission programs and routines are not only interrupted by counter interrupts and program interrupts, but also by other mission programs and routines. An executive routine schedules the various programs and routines, and interrupts a current job for any of higher priority, but re-schedules the interrupted job.

5.2.2 Mission Program Classification

By means of the auxiliary and utility programs, the LGC maintains an awareness of its environment and synchronizes the LGC activities. Except for a few alarm situations, ordinarily the auxiliary and utility programs provide no direct interface to the astronaut. Direct astronaut/LGC interface is provided through the mission programs. The mission program that is currently in control of the LGC is displayed by the DSKY PROG numerical indication. The categories of LGC earth-orbit, mission programs are designated by two digit number as follows:

- 0X - Services Programs
- 2X - Coast Programs
- 3X - Prethrust Programs
- 4X - Thrust Programs
- 5X - IMU Align Programs

The services programs include LGC idling (P00), and PGNCS power down (P06).

The rendezvous navigation program (P20) is used throughout most coasting phases of the flight. It obtains CSM or LM vector updates by means of RR data. During thrusting phase or IMU re-alignment, the update capability is removed by internal LGC sequencing. Upon completion of such nonupdate phases, vector update within P20 is automatically returned. If the rendezvous radar malfunctions, the preferred tracking attitude program (P25) is selected to maintain the LM in attitude that permits CSM tracking of the LM beacon. The ground track determination program (P21) provides ground track capability without MSFN assistance. If LGC update or thrusting information is desired from a LM external source, the LGC update program (P27) is utilized.

The IMU alignment programs are IMU orientation determination (P51) and IMU realign (P52). The orientation determination program is used after IMU turn on to obtain IMU inertial orientation with respect to celestial coordinates. Establishing a known stable member orientation provides a means for the LGC to identify stable member orientation with respect to the spacecraft. From this known orientation called refsmmat, any spacecraft orientation changes are reflected as gimbal movements about the stable member and CDU read counter outputs to the LGC. Hence, the computer maintains its awareness of spacecraft attitude. To re-align the stable member to a desired thrusting orientation (a preferred orientation), or to local vertical (a nominal orientation), or to re-establish known accuracy, P52 is selected. For each of these realignment orientations, the refsmmat is re-defined to be coincident.

During a concentric rendezvous sequence, the prethrusting programs (P32, P33, P34, and P35) are performed sequentially with each followed by a thrusting program. In each of these prethrust programs, the LM is designated the active vehicle. By utilization of the position and velocity vectors of the active and passive vehicles and maneuver time inputs from the astronaut, the LGC computes maneuver parameters. If ground control of thrusting maneuvers or if the passive vehicle computes the thrust parameters, the external delta V program (P30) is used for rendezvous.

The actual PGNCS autopilot, thrust control programs are descent propulsion system program (P40), reaction control system program (P41), ascent propulsion program (P42). Prior to a PGNCS thrusting maneuver, the digital autopilot data load routine (R03) must be selected to obtain the desired digital autopilot moding. For monitoring LM acceleration during a thrusting maneuver that is not PGNCS controlled, program P47 is selected.

5.2.3 Program Descriptions and Flow

The programs and routines described in this section are those that have astronaut interface (the mission programs). The flow charts that accompany the program descriptions summarize the overall sequential computer flow. Not all internal LGC operations are shown in these diagrams. Most major discretes and flags that affect the sequential flow are shown. For purposes of this discussion, a discrete is a two-state signal (either yes or no) that informs the LGC of an external equipment operational state or is a command from the LGC to external equipment. Auxiliary and utility routines periodically review the status of these signals.

A flag is an exclusively internal signal which provides memory with the capability of checking program functional states; whereby, the sequential program flow is properly maintained. For convenience, a flag is usually described as set or reset to identify its status. Table 6-3 lists the flags and describes their functional effect.

Interfacing astronaut action and displays via the DSKY are shown within the diagrams on interconnecting lines. The flow begins at the top of each diagram and flows toward the bottom. The flow diagram format is as shown in Fig. 5-2.

5.2.3.1 LGC Idling Program (P00)

Normally, during prolonged periods in which astronaut/DSKY interfaces are not required, the LGC idling program is the mission program in control. The program is entered by Keying V37E 00E or automatically from another program (see Fig. 5-3). The average G routine which maintains the state

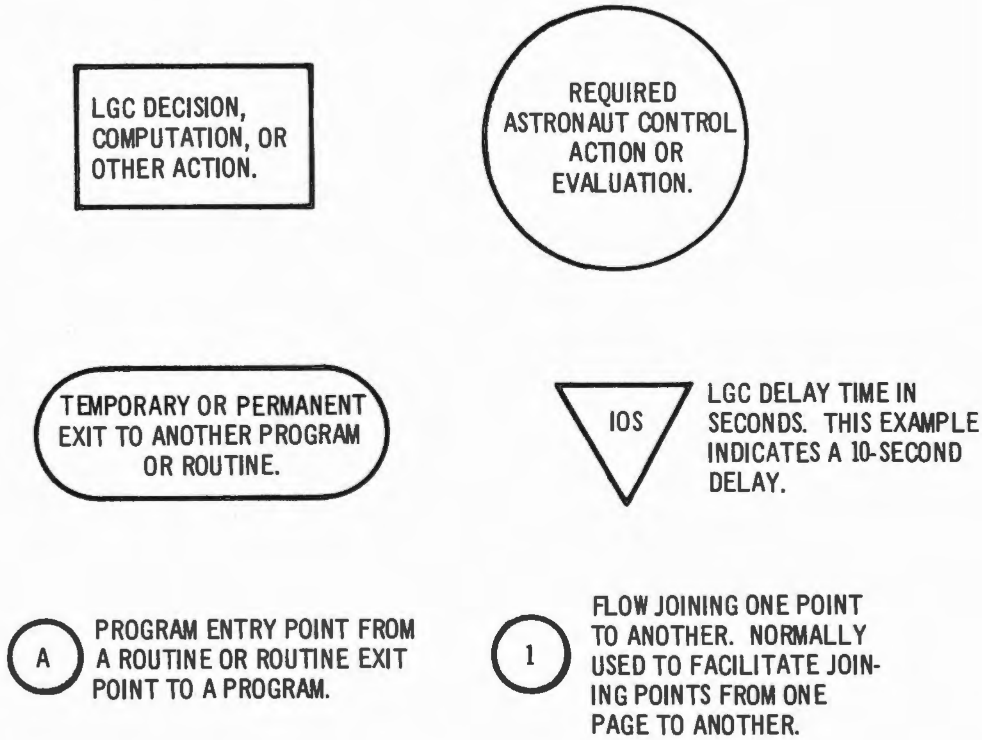
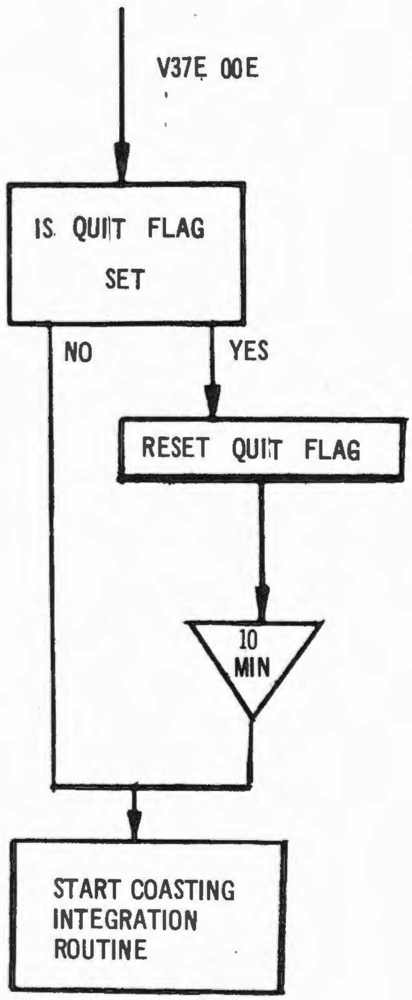


Fig. 5-2. Flow diagram symbols.



NOTE:

1. GNCS ATTITUDE CONTROL IS AVAILABLE BY MEANS OF STANDARD RCS DAP PROCEDURES.
2. ORBIT PARAMETERS WILL BE DISPLAYED BY SELECTION OF R30.
3. GNCS DATA WILL BE DISPLAYED BY MEANS OF STANDARD DSKY PROCEDURES.

Fig. 5-3. LGC idling program (P00).

vector during powered flight is terminated, and the flags which maintain the rendezvous navigation program for state vector update are reset. Every nine minutes during P00 operation the LM state vector is extrapolated forward to the present time.

5.2.3.2 LGC Power Down Program (P06)

To transfer the LGC from an operate to a standby state, the LGC power down program is selected. (See Fig. 5-4.) During LGC standby, PGNCS caution and warning indication with the exception of LGC warning are inhibited. The ISS shall not be powered down below standby (IMU STBY circuit breaker shall not be opened, except in extreme emergency) because removal of heater power can affect ISS performance.

5.2.3.3 Rendezvous Navigation Program (P20)

The rendezvous navigation program is used to control rendezvous radar operation and use of radar derived data during PGNCS operation. It provides control to point the radar at the CSM and provides ability to update either the LM or CSM state vector within the LGC on the basis of the RR tracking data.

Entry into the program is made by Keying V37E 20E. (See Fig. 5-5.) Previous to this, the radar has been energized and checked out.

The rendezvous navigation program maintains estimates of the CSM or LM state vectors during free-fall phases of the mission. During thrusting phases, the update flag is reset to terminate the state vector update process. Radar range, range rate, and tracking angle data are used by the LGC to update the selected vehicle state vector.

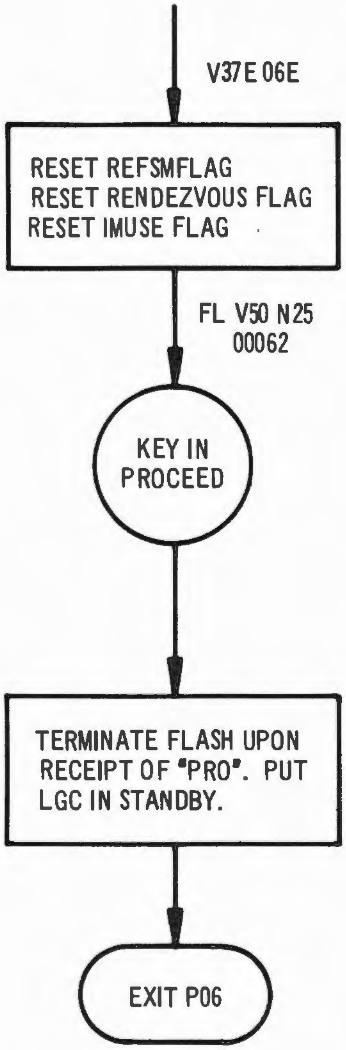


Fig. 5-4. LGC power down program (P06).

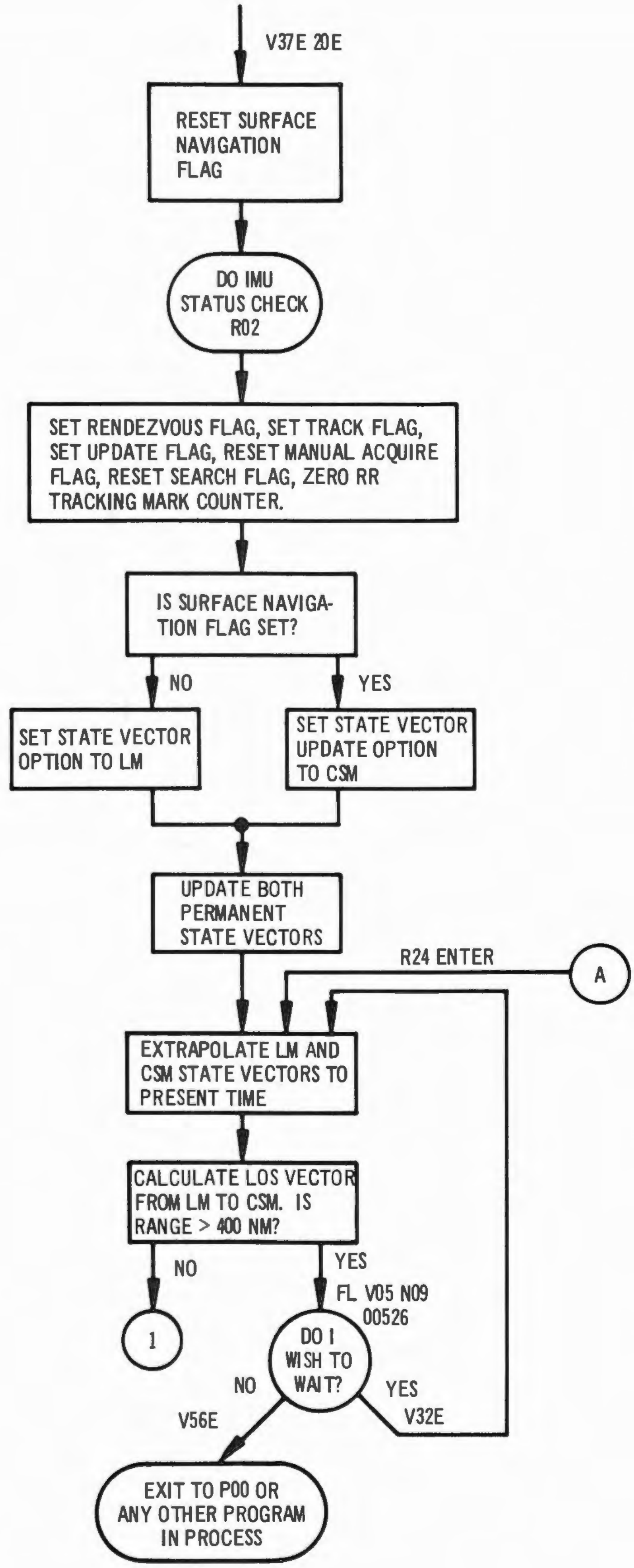


Fig. 5-5. Rendezvous navigation program (P20) (sheet 1 of 3).

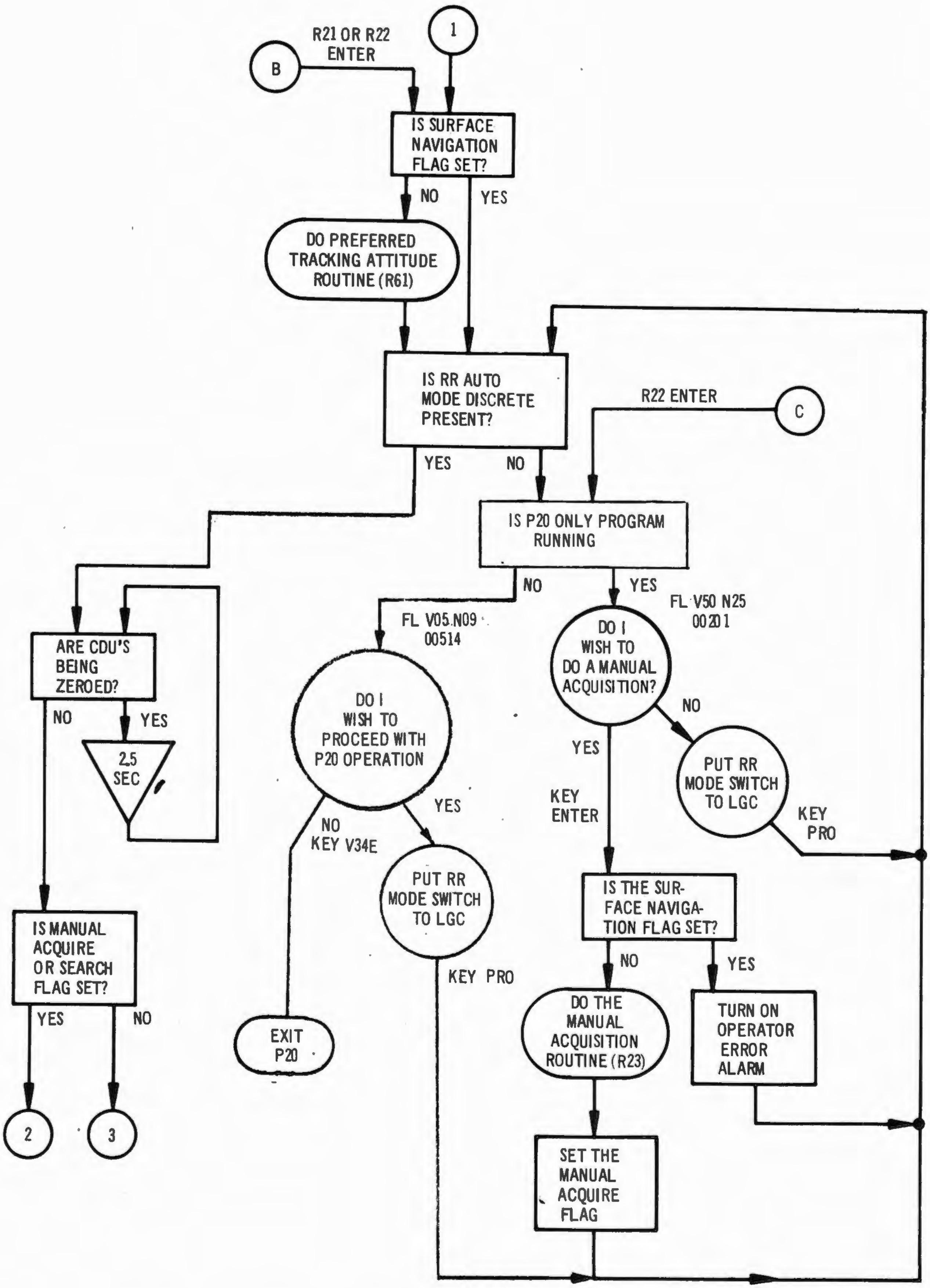


Fig. 5-5. Rendezvous navigation program (P20) (sheet 2 of 3).

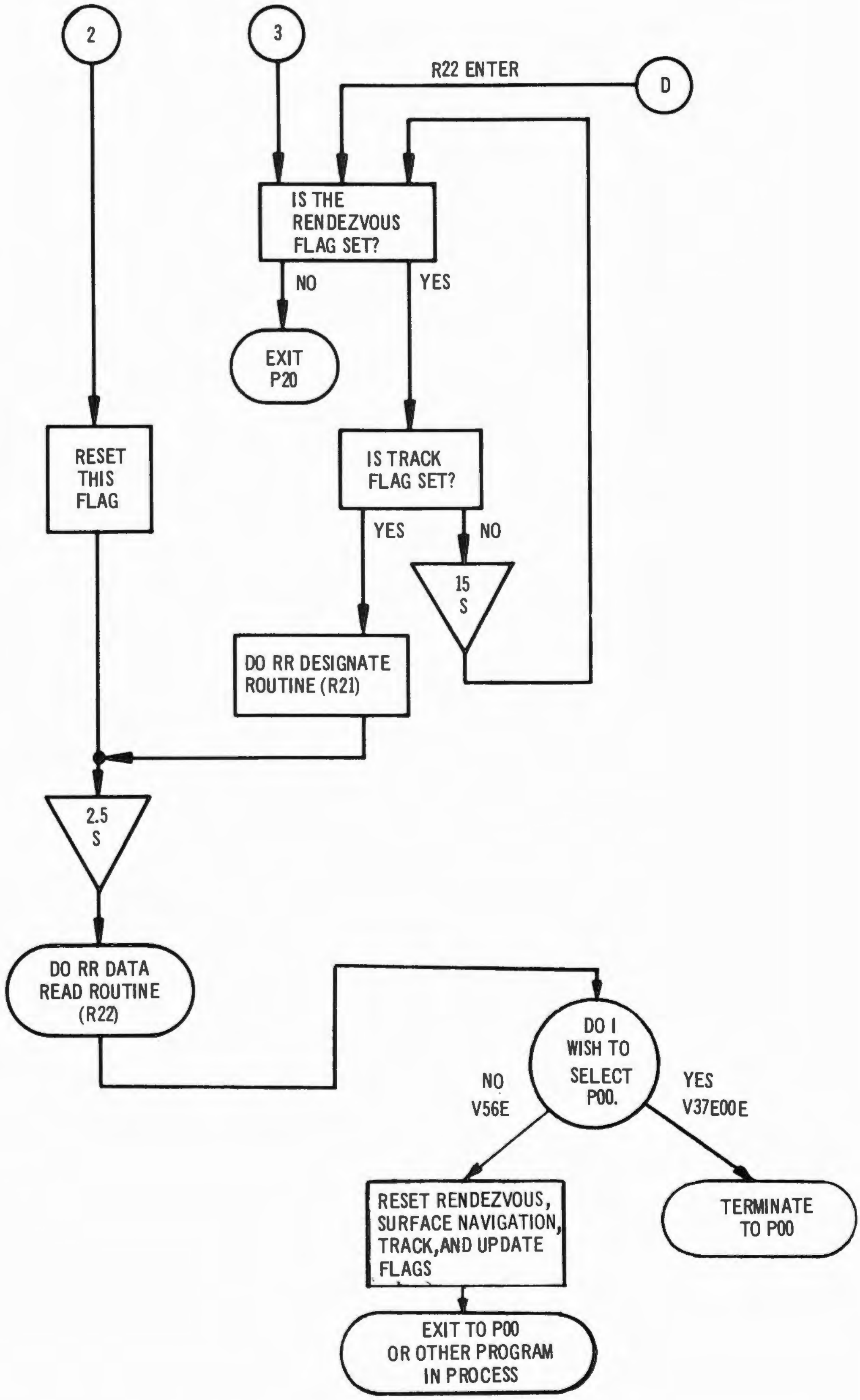


Fig. 5-5. Rendezvous navigation program (P20) (sheet 3 of 3).

One of the two vehicle state vectors can be updated by the tracking measurements. The decision of which to update is based primarily upon which vehicle has the most accurate initial state vector estimate, and which vehicle is controlling the rendezvous maneuvers. During rendezvous maneuvers, the LM state vector is the one usually updated in the LGC since the CSM orbit is normally well known and the LM is normally the active vehicle. However, the state vector to be updated can be changed at any time during P20 operation by keying in V80E or V81E.

The vehicle state vectors are updated by a powered flight navigation routine (average G routine) on the vehicle actively controlling and performing the rendezvous maneuvers. The passive vehicle estimate of the active vehicle state vector is updated by astronaut DSKY inputs of the active vehicle maneuvers received over the vehicle voice link. The passive vehicle then continues to process tracking data to update this state vector after the maneuver is made. This procedure is desired in order to maintain the most accurate estimate of vehicle state vectors at all times during a rendezvous phase.

Normally, the RR antenna mode selector is put into the LGC position for target acquisition. However, the astronaut may elect to use the manual mode (SLEW position) for acquisition. In either selection, the LGC will aid acquisition by computing the preferred attitude via R61.

The preferred tracking attitude routine (R61) is used to compute the LM attitude, which enables RR tracking of the CSM and CSM tracking of the LM beacon. The first step in LGC control of the RR is determination of the LOS to the CSM. This is accomplished by taking the vector difference of the LM and CSM position vectors propagated to that time. If the range between the LM and CSM is greater than 400 nautical miles, an alarm is issued since the RR is unable to provide correct range information to the LGC (because of the ranging technique used in the radar). After successfully completing the range check, R61 is used to align the LM +Z-axis with the LOS. This routine re-computes the LOS and then calls the attitude maneuver routine to align the LM +Z-axis along the LOS. At this point, if the astronaut should decide to manually change the attitude, such as to roll about the Z-axis, it is essential that he recall R61 to insure that the Z-axis is aligned with the LOS before proceeding with the next step. This is done to insure a sufficient period of data taking for estimation of the RR angle biases before the angle between the RR antenna and the LM +Z-axis reaches 30 degrees. During the RR data taking process, the LM is controlled to hold an approximately inertially fixed attitude by use of the 5° limit cycle. The data read routine (R22) is used to detect when the RR antenna is more than 30 degrees from the +Z-axis and causes the +Z-axis to be re-aligned with the LOS, using R61. In addition to meeting the requirements for estimating RR angle biases, it is also essential that the attitude constraints be used because of the limited radiation coverage of the LM optical beacon which must be directed towards the CSM so as to enable the astronaut in the CSM to optically sight upon it. The beacon is centered with respect to the LM +Z-axis and has a beam width of approximately 60 degrees.

Having completed R61, the LGC checks to see if the RR auto mode discrete is being received from the RR. This discrete signifies that the RR is on and has been placed under LGC control (RR antenna mode selector to LGC position). The LGC then checks to see if the manual or search flag is present. (The manual flag is set when R23 is selected and the search flag is set by R24).

To establish the desired RR antenna coverage mode, the LGC again determines the LOS. If the antenna is outside the operational limits for mode 1 (mode 1 is the earth orbit angle limits, with $\pm 55^{\circ}$ trunnion angle and $+59^{\circ}$ to -70° shaft angle), it is driven to shaft = 0° and trunnion = 0°. The designate routine (R21) is entered automatically after completion of re-positioning or without re-positioning if manual search acquisition was not selected.

The designate routine points the RR for acquisition and upon acquisition the data read routine (R22) is entered for updating. The updating process involves computing an estimated tracking measurement based on the difference between the current state vector estimates. This estimated measurement is then compared with the actual tracking measurement to form the measurement deviation. A statistical weighting vector is generated from a prior statistical knowledge of nominal trajectory uncertainties and tracking performance, plus a geometry vector, determined by the type of measurement being made. The weighting vector is defined such that a statistical optimum linear estimate of the state deviation from the estimated trajectory is obtained when the weighting vector is multiplied by the measurement deviation.

5.2.3.3.1 Power Up and Testing

The initialization of P20 sets the controls to G&N basic with the following exceptions:

CB RNDZ RDR (AC) - closed
CB RNDZ RDR - closed
CB SIG STR DISP - closed
RADAR TEST - RNDZ
RNDZ RADAR MODE - AUTO TRACK

The RR has then been switched from a standby to an operate state and the test circuit is actuated permitting testing of the radar without the presence of a cooperating transponder. The test circuit permits a check of transmitter power, phase-lock at minimum signal level, angle error detection, AGC action, range and range rate measurement. Insertion of single values of range and range-rate permit quantitative checking via the displays.

The self-check circuit is disabled when the radar is in the LGC antenna mode. When the RADAR TEST selector is set to the RNDZ position, a discrete is sent to the RR. This discrete is ANDed with another devised from the RNDZ RADAR MODE selector in either the AUTO TRACK or SLEW positions. This ANDing produces the self-test enable which activates the test oscillator. Modulation tones are superimposed on the oscillator output. The carrier is frequency multiplied and the tones are phase shifted to simulate returned energy.

To observe the test values on the SIGNAL STRENGTH meter, the TEST MONITOR switch is set to the following positions:

a) RNDZ RADAR - AGC
   Displays fixed value .
b) RNDZ RADAR - XMTR PWR
   Displays fixed value .
c) RNDZ RADAR - SHAFT ERR
   Displays amplitude equal to that displayed in TRUN ERR position.
d) RNDZ RADAR - TRUN ERR
   Displays amplitude equal to that displayed in SHAFT ERR position.

Upon conclusion of testing, the RADAR TEST switch is set to the OFF position, and the RNDZ RADAR MODE switch is set to the LGC position.

5.2.3.3.2 <u>Display Switching</u>

To provide radar monitoring displays during the RR operating state, controls have been set as follows:

SHFT/TRUN < switch - $\pm 50^{\circ}$
RATE/ERR MON switch - RNDZ RADAR
RADAR TEST switch - OFF
TEST MONITOR RNDZ RADAR switch - AGC
X - POINTER SCALE switch - HI MULT
ALT/RNG MON switch - RNG/RNG RT
MODE SEL switch - PGNS

Assuming an acquired CSM, the range and range rate are displayed by the RANGE and RANGE RATE meters on the commander's center panel. The X-pointer meters displays shaft rate on the ELEV RT FWD VEL scale and trunnion rate on the AZ RT LAT VEL scale. With the X-POINTER SCALE switch in the HI MULT position; the rates displayed are ± 20 m radians/second. In the LO MULT position, it provides a display scale of ± 2 m radians/second.

Shaft and trunnion angles are displayed on the FDAI pitch and yaw error needles respectively. Fifty degrees or greater provides full deflection. Less than full deflection needle positions are linearly proportional to shaft and trunnion angles. If the SHFT/TRUN < switch is positioned to $\pm 5^{\circ}$, full deflection will represent 5° or greater.

5.2.3.3.3 Manual Acquisition Routine (R23)

Manual acquisition is selected by the astronaut during P20, in response to the acquisition mode request (FL V50 N25, checklist code 00205). (See Fig. 5-6.) The preferred tracking attitude routine (R61) calculates the LOS from the LM to the CSM, defines the desired attitude to be along the LM +Z axis along the LOS to the CSM, and performs the attitude maneuver. The minimum deadband is set to hold the LM +Z axis within 0.3° of the established LOS. The auto track enable discrete is then issued to the RR. Although the auto track enable discrete has no effect on manual control of the radar, it is issued at this time so that there will be no loss of RR tracking after the CSM has been manually acquired and is placed under LGC control.

The manual acquisition process then entails:

1) Setting the RENDEZVOUS RADAR antenna mode selector to SLEW and the TEST/MONITOR selector to AGC.

2) Observing the attitude error needles on the FDAI while slewing with the UP, DOWN, LEFT, or RIGHT toggle switch (either HI or LO rate as warrented) until shaft and trunnion angles approach zero degrees. During this slewing process, an AGC indication should appear and approach a peak.

3) Reset RENDEZVOUS RADAR antenna mode selector to AUTO TRACK. The RR tracking errors should now drive the antenna for acquisition. Upon acquisition, the NO TRACK indicator goes out and the RR automatically maintains track.

4) Check for sidelobe acquisition by insuring that the AGS indication is maximized with a minimum indication while the shaft and trunnion angles are less than 10 degrees on the attitude error needles.

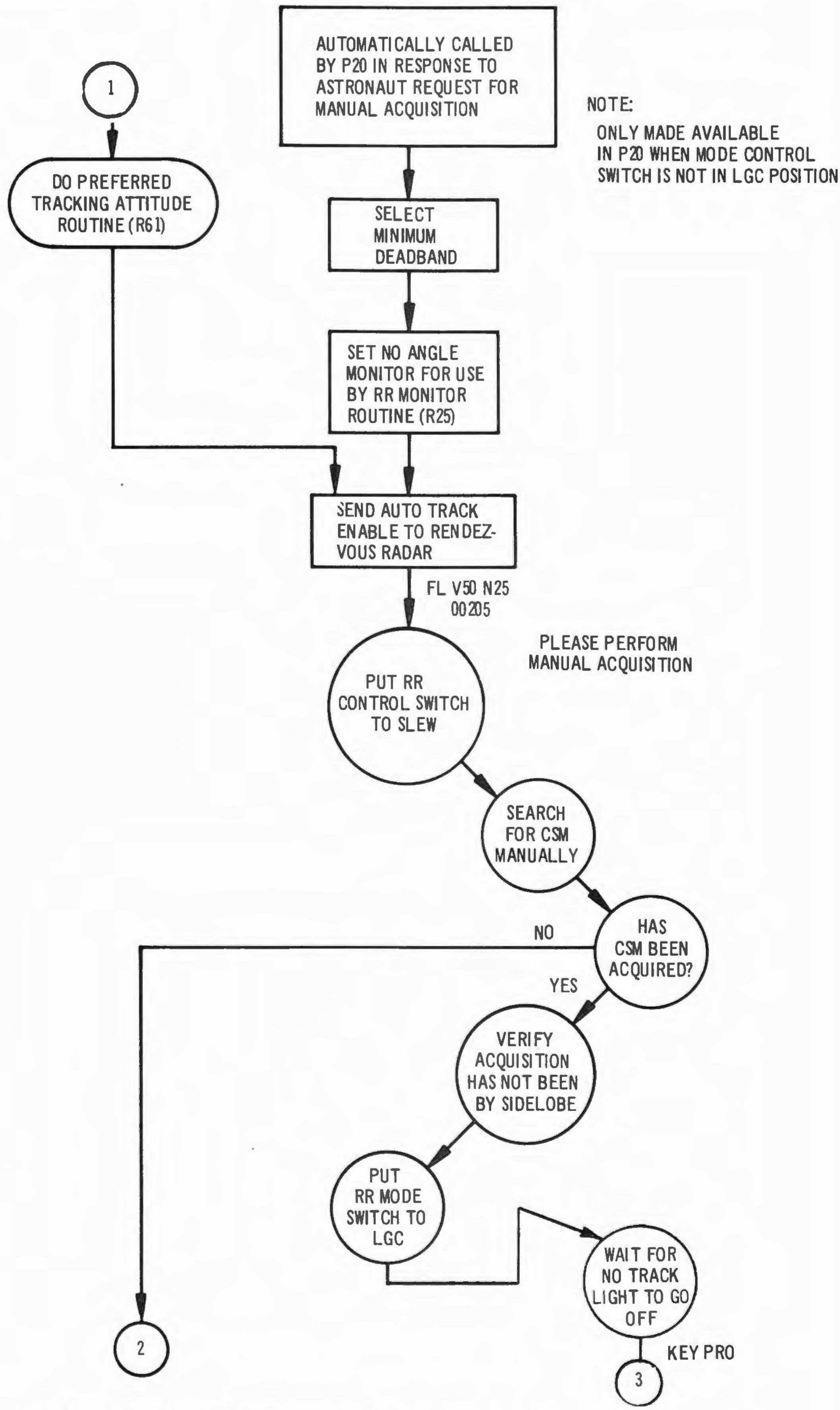


Fig. 5-6. Manual acquisition routine (R23) (sheet 1 of 2).

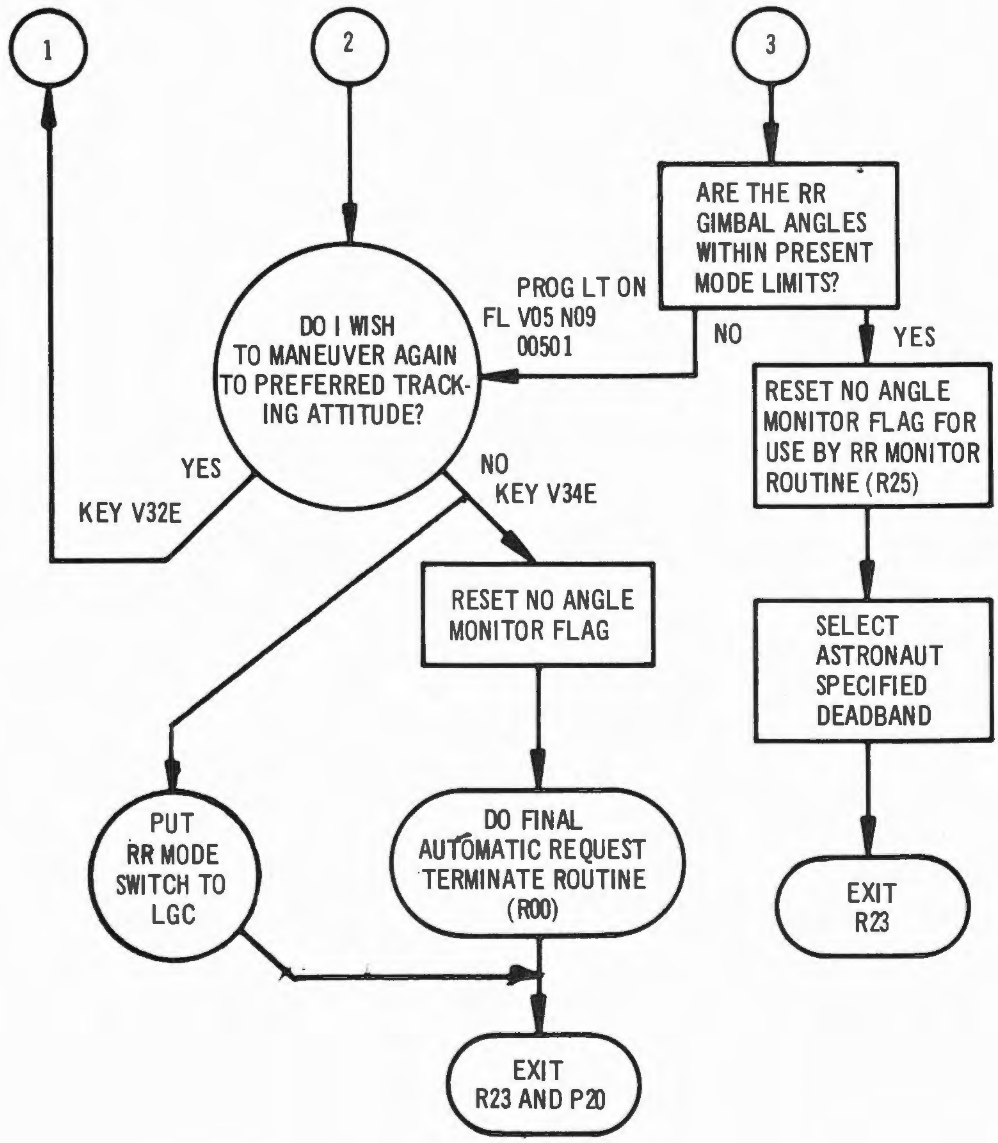


Fig. 5-6. Manual acquisition routine (R23) (sheet 2 of 2).

5.2.3.3.4 Designate Routine (R21)

The designate routine is used to position the RR antenna at the CSM until automatic acquisition of the CSM is accomplished by the radar. If manual search has not been performed, R21 is automatically entered. (See Fig. 5-7.) The LGC, by utilizing LM and CSM vector data, calculates the antenna shaft and trunnion angle commands necessary to achieve CSM acquisition. By comparison of the read counter angles and the calculated angles, the necessary pulses are entered into the CDU shaft and trunnion error counters. The LGC drives the RR antenna to the LOS with new commands being generated every half-second. When the RR is within 0.5 degrees of the LOS, the track enable discrete is issued to the RR, enabling its angle tracking servos to track the target if its range and range-rate tracking networks have already acquired the target. The routine then terminates if the data good discrete, signifying RR lockon, is received. However, if this discrete is not present, the routine will continue generating commands and checking for this discrete until the allotted time (approximately 30 seconds) has expired, at which time a search alarm is turned on. In response to this alarm, PRO is Keyed to exit to R24.

5.2.3.3.5 Data Read Routine (R22)

The data read routine is called by P20 to process the automatic RR mark data and update the selected LM or CSM vector.(See Fig. 5-8.) Requests for updating the rendezvous navigations equations are issued once per minute. Following a data request, the LGC checks to see if the track flag is present. This flag is removed during the preparation and execution of a LM ΔV maneuver when there is no desire to have the RR data read routine request RR data or call any other routine such as the RR designate of LM preferred tracking attitude routine.

If the track flag is present, the LGC checks for issuance of the RR track enable discrete and reception of the RR auto mode discrete. The

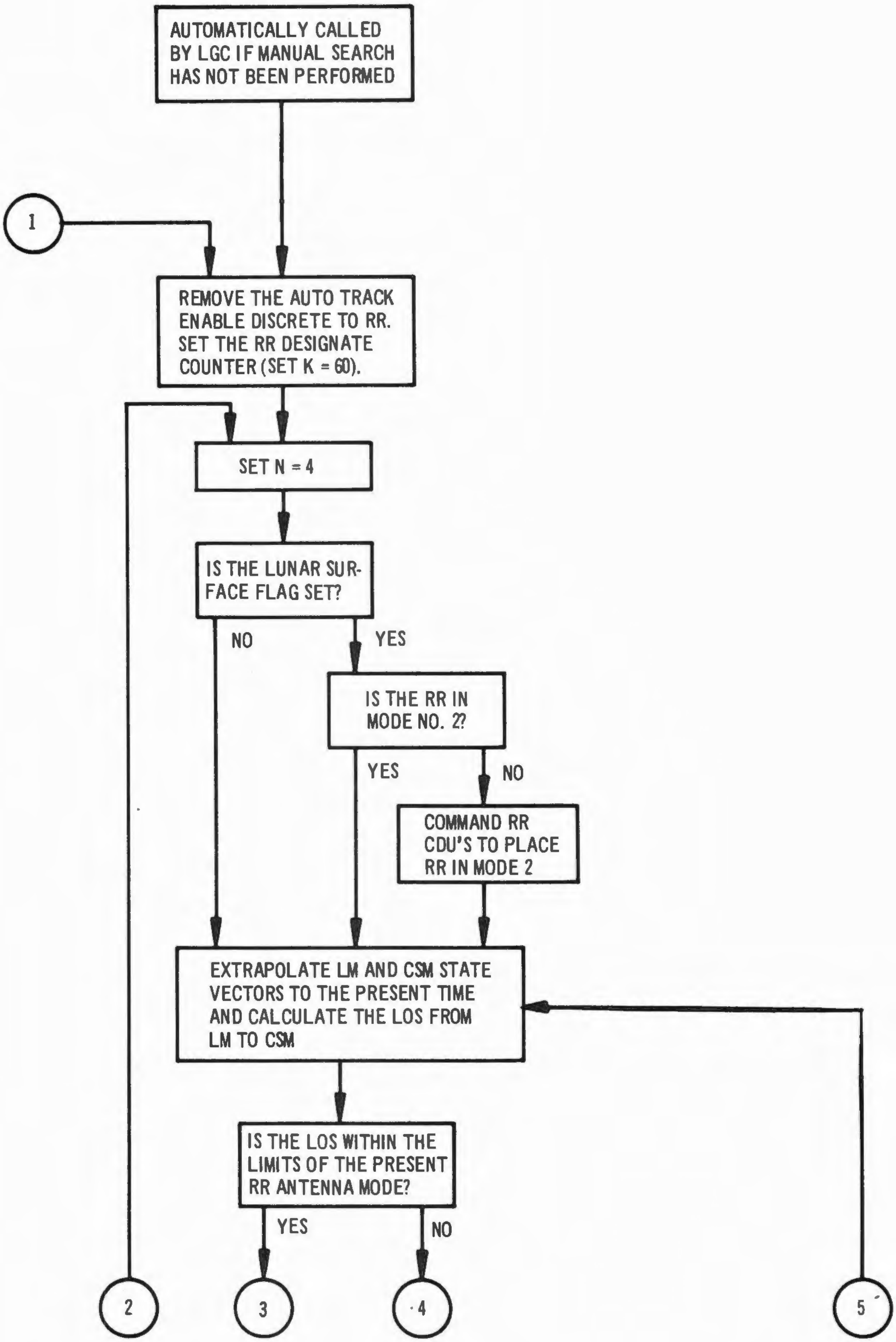


Fig. 5-7. RR designate routine (R21) (sheet 1 of 3).

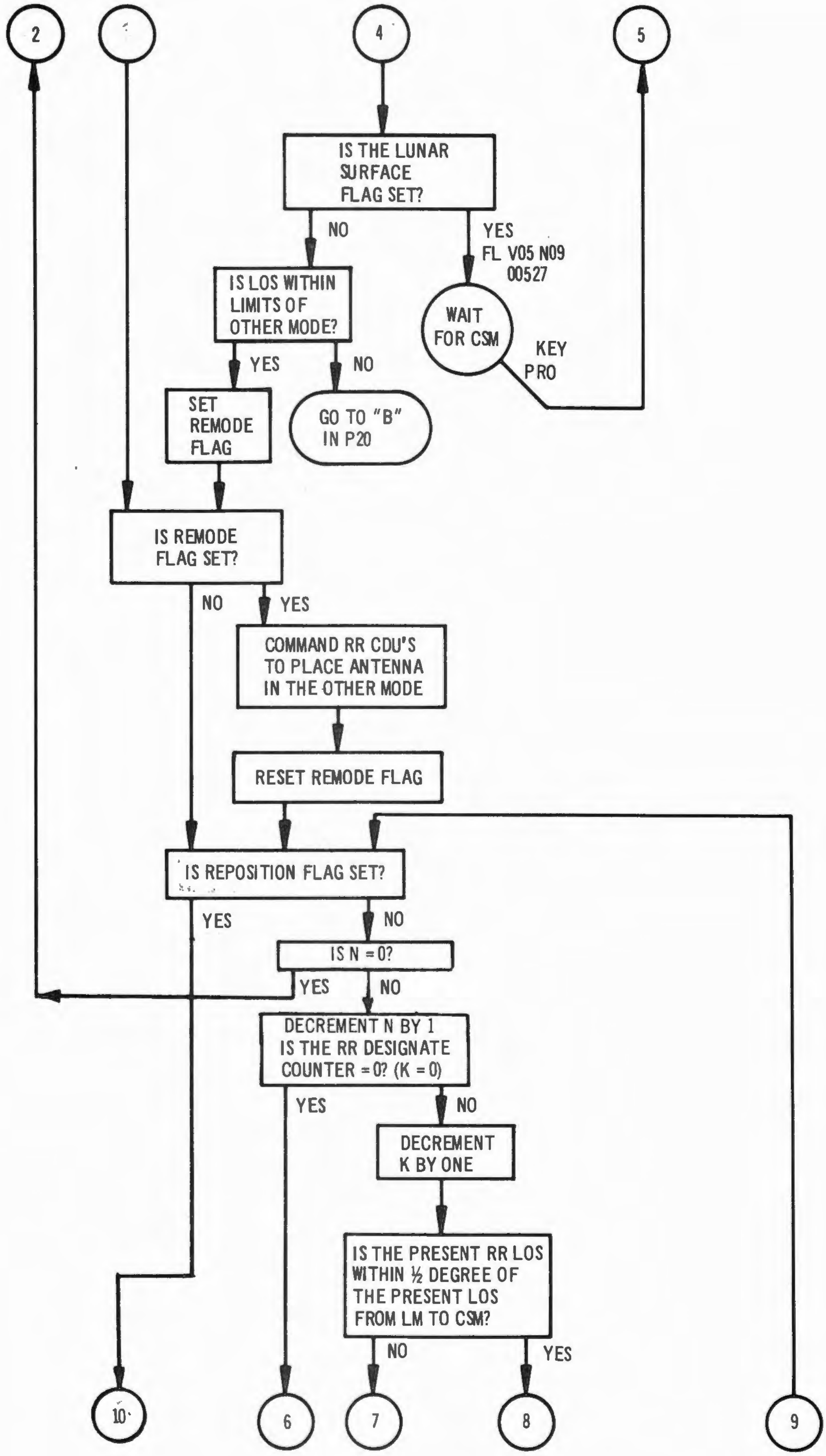


Fig. 5-7. RR designate routine (R21) (sheet 2 of 3).

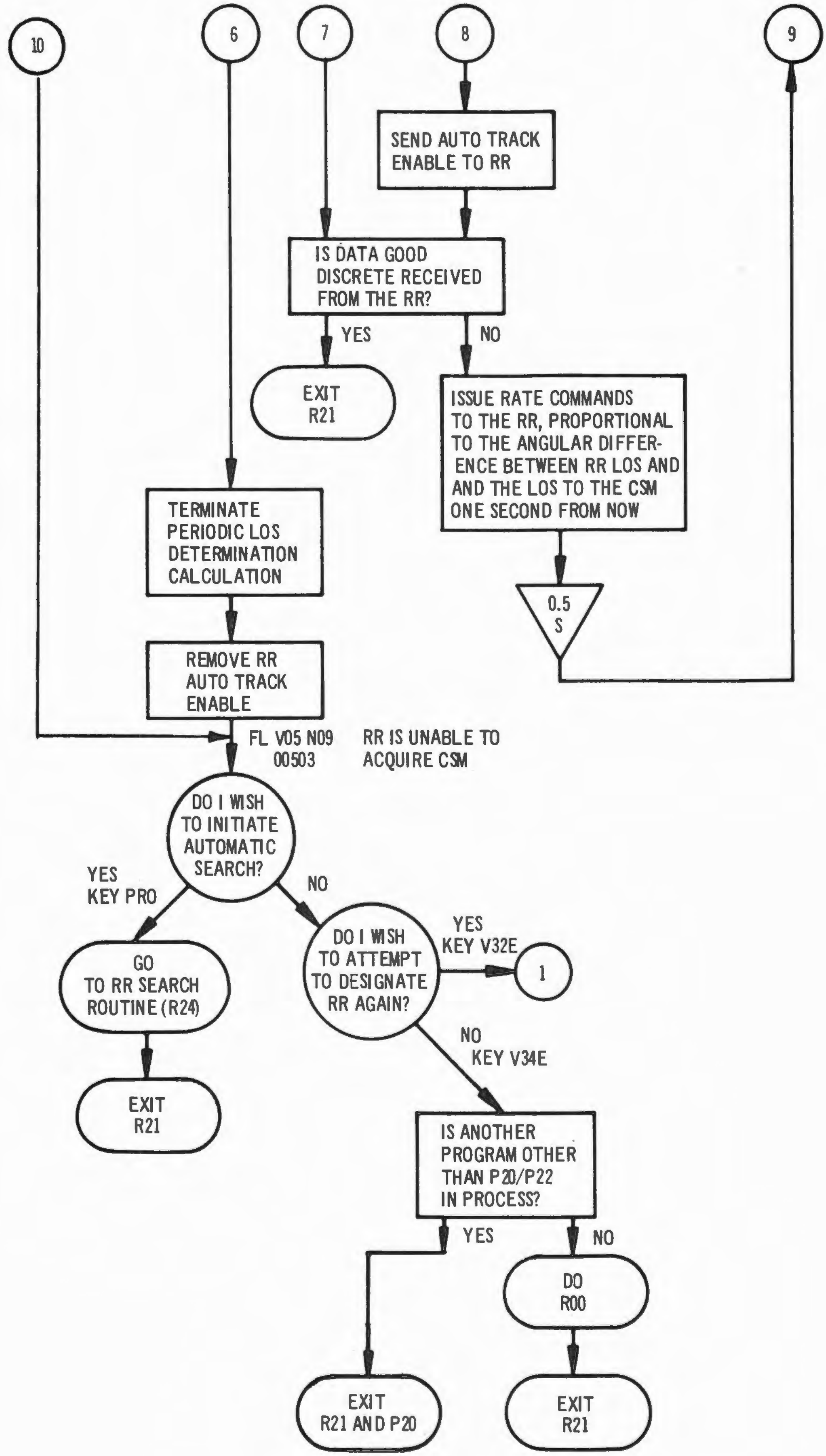


Fig. 5-7. RR designate routine (R21) (sheet 3 of 3).

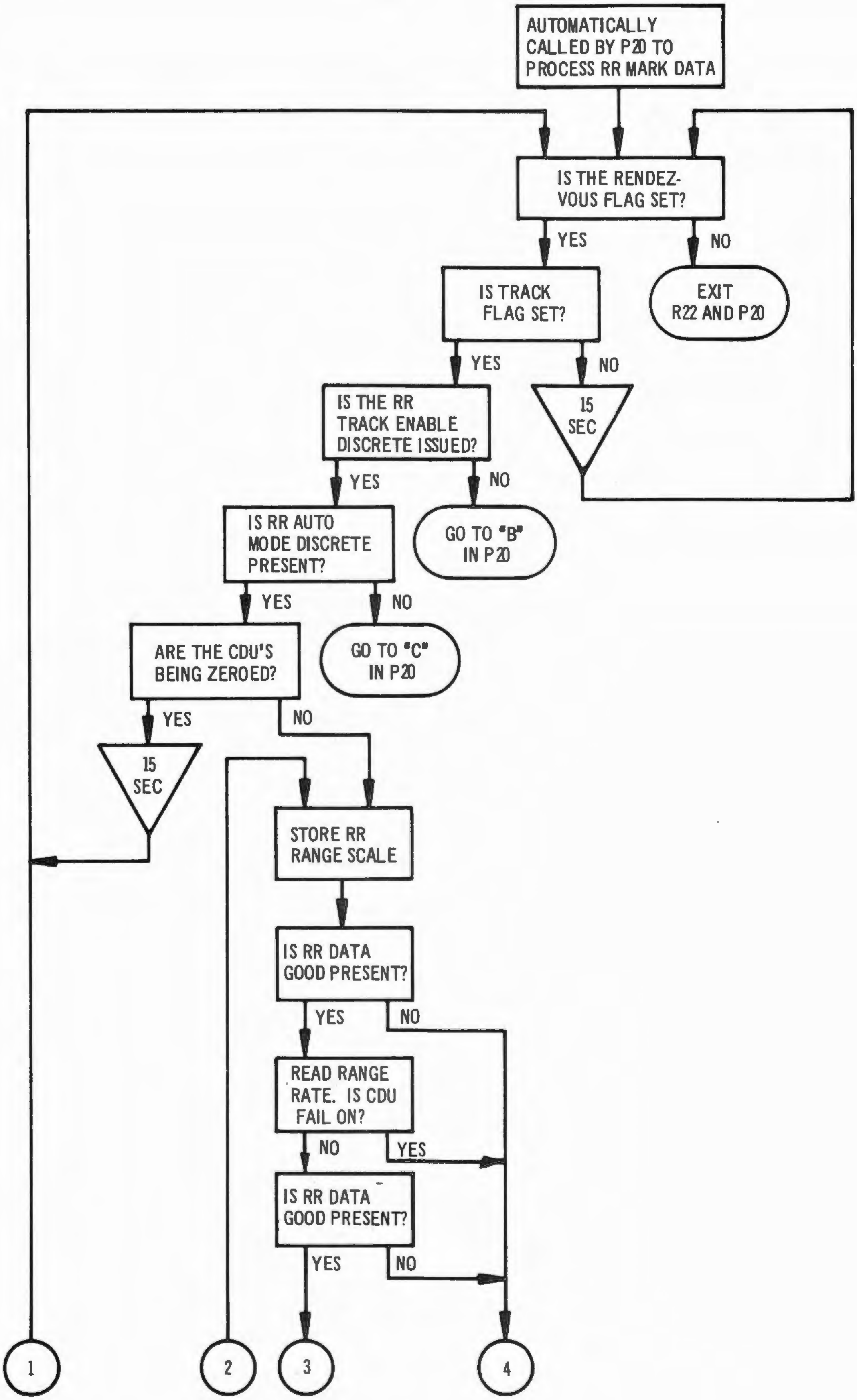


Fig. 5-8. RR data read routine (R22) (sheet 1 of 4).

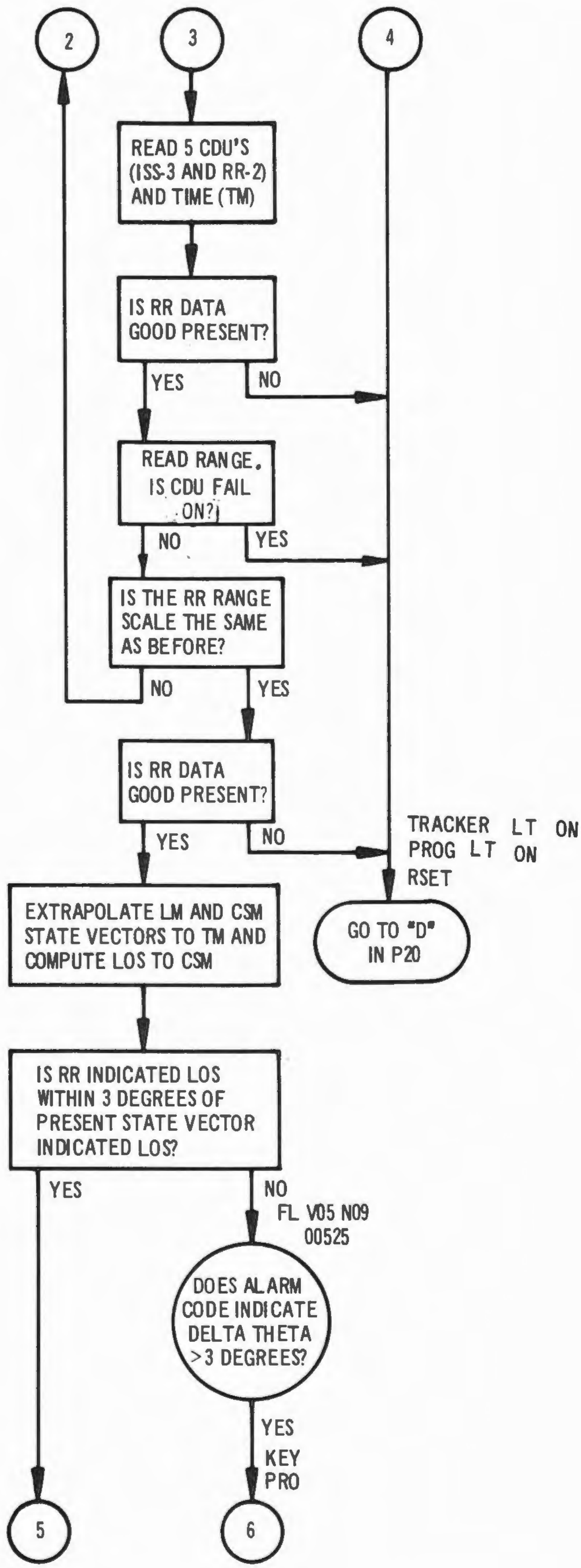


Fig. 5-8. RR data read routine (R22) (sheet 2 of 4).

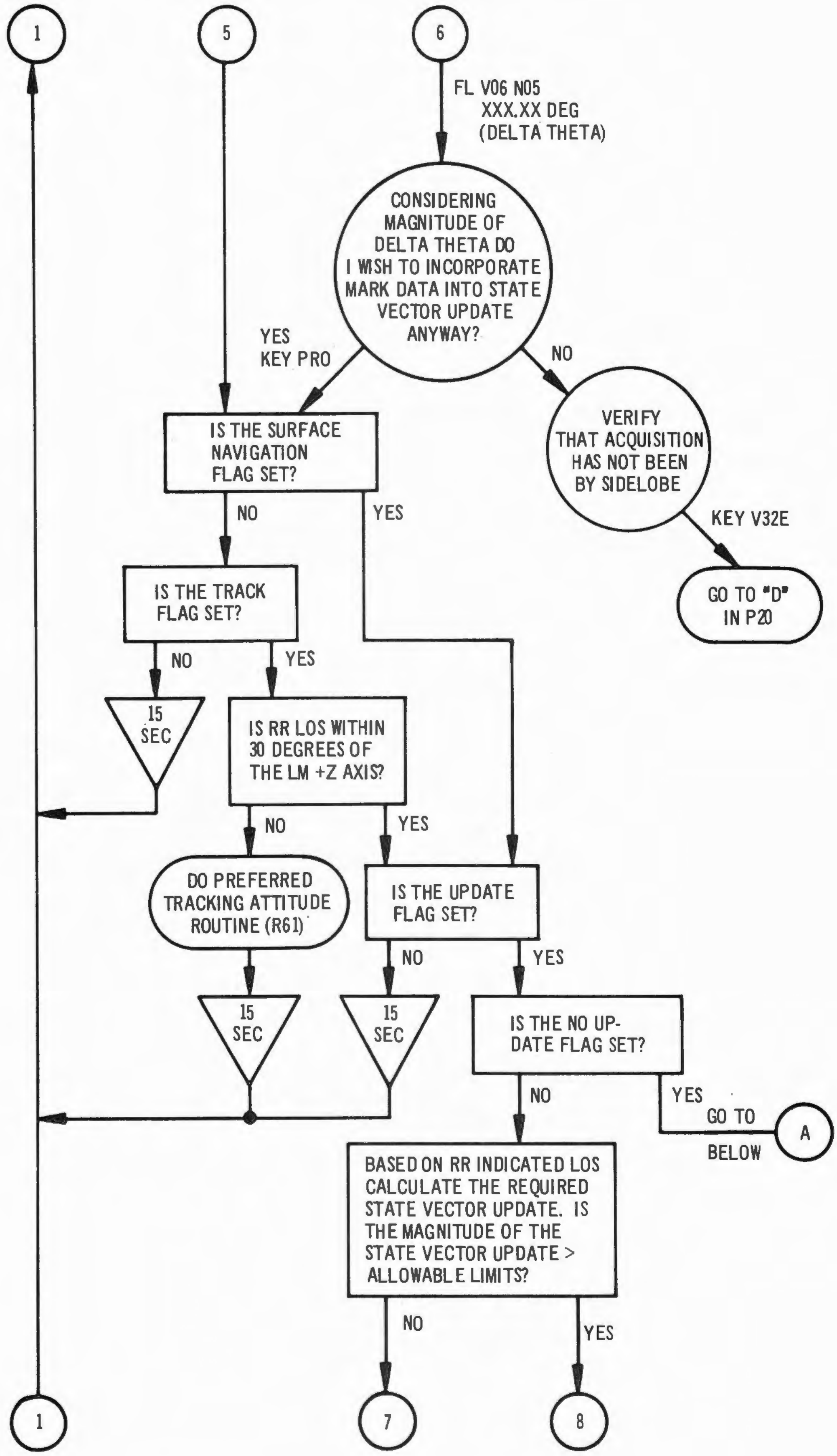


Fig. 5-8. RR data read routine (R22) (sheet 3 of 4).

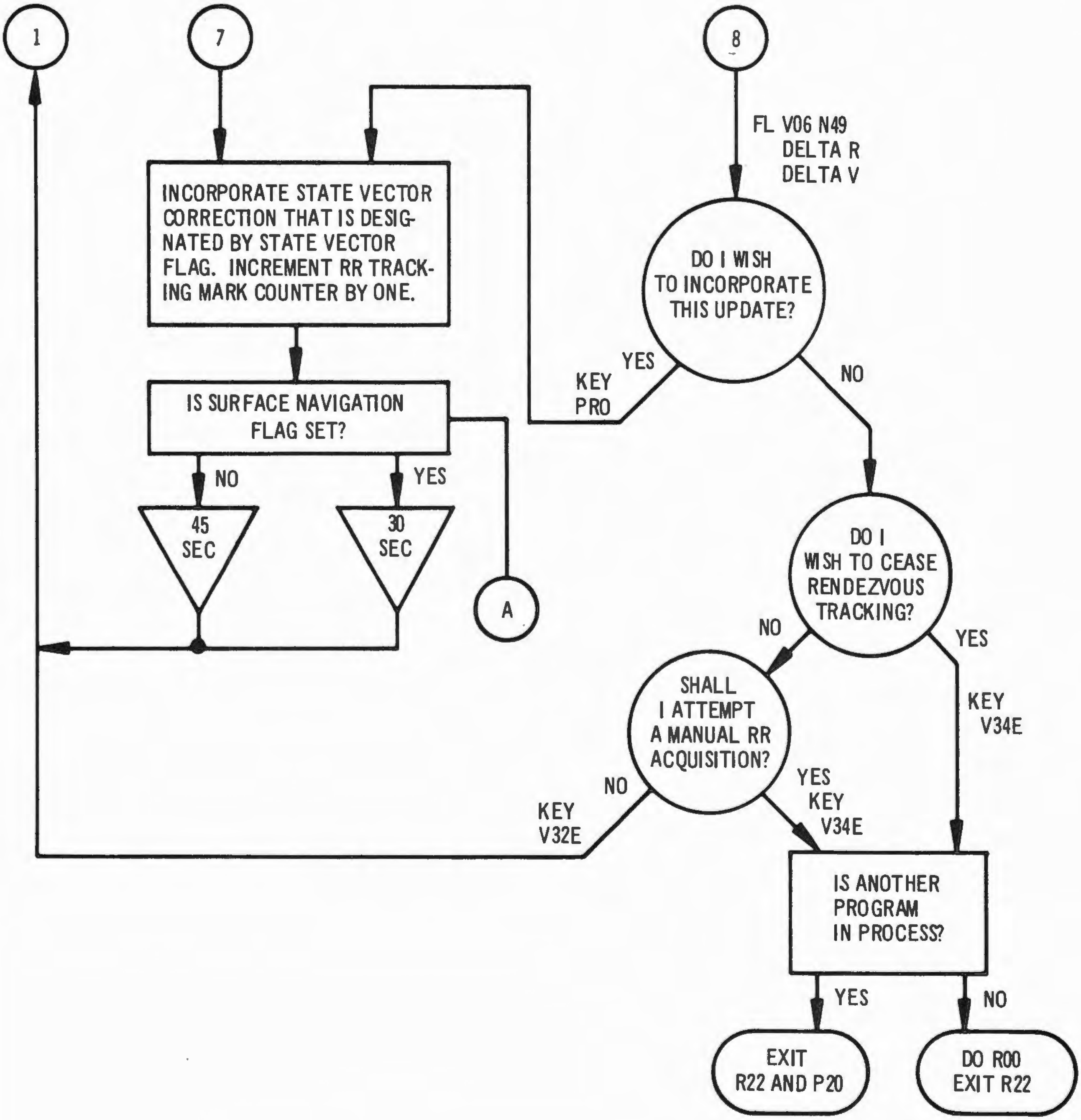


Fig. 5-8. RR data read routine (R22)(sheet 4 of 4) .

former discrete is removed and not re-issued by the RR monitor routine whenever the RR antenna angles exceed the mode 1 limits. Its absence, therefore, indicates a need to re-establish the LM preferred tracking attitude and re-designate the radar. Frequent checks are made of the RR data good discrete to insure that no RR tracking interruptions have occurred during the readout.

For RR ranges below 50.8 nautical miles, the RR issues the range low scale discrete, indicating to the LGC that a different scaling must be applied to the range scale. To insure that the correct scaling is used, the LGC checks the status of this discrete each time data is read and re-issues a complete data request if the status has changed since the last reading.

Since a given set of RR data are used to update the rendezvous navigation equations for one instant of time when the CDU angles were recorded, this instant Tm is used as the time tag for a complete set of RR data.

After the RR data are read, the LOS is determined for time Tm and compared with that indicated by the RR CDU channels. This is done to insure against sidelobe lockon. If the difference is more than 3 degrees, an alarm is issued to the astronaut who must decide whether to go to the RR designate routine (V32E) or request the LGC to proceed with the data (PRO).

Following the sidelobe check, the LGC checks to see if the update flag is present. This flag is removed when it is not desirable to use the RR data to update the navigation equations, such as during the terminal phase of rendezvous. It is removed by the LGC during a LM ΔV maneuver and by the astronaut when the CSM is performing a ΔV maneuver. The update flag differs from the track flag in that the presence of only the track flag still permits the LGC to monitor RR tracking and read RR data for purposes other than updating the navigation equations.

A FL V06 N49 display indicates that the magnitude of either of the position or velocity deviations is larger than the tracking alarm levels. The state vector is not updated, and the astronaut is alerted by the delta P display (magnitude of the difference between the position state vector before and after incorporation of current mark data) and by the delta V display (magnitude of the difference between the velocity state vector before and after incorporation of current mark data). In this case, the astronaut should place the RR under manual control and make the necessary radar operating and side lobe checks to verify main lobe lockon and tracking conditions. After returning the RR to LGC control, the astronaut again has the option of commanding a state vector update if the tracking alarm is again exceeded, or to exit the program.

5.2.3.3.6 Search Routine (R24)

The search routine generates a 5.6° by 5.6° search pattern about the estimated LOS when the RR has failed to acquire the CSM during the designate mode. This routine is automatically called by the R21 in response to the FL V05 N09, program alarm 00503 display if the astronaut keys PRO. (See Fig. 5-9). This program alarm occurs if R21 cannot drive the RR within 0.5° of the LOS after issuing commands to RR antenna servos for about 30 sec. If the astronaut has been observing the separate displays provided for the RR, he will undoubtedly know which of the above caused the lack of lockon. Since it is highly probable that the alarm was issued because of failure of the LGC to receive the data good discrete, R24 will probably be called for.

The time required to complete one cycle of the search pattern is about 42 seconds. During the generation of the search commands, the auto track enable discrete is issued to the RR so that it may acquire the target. A

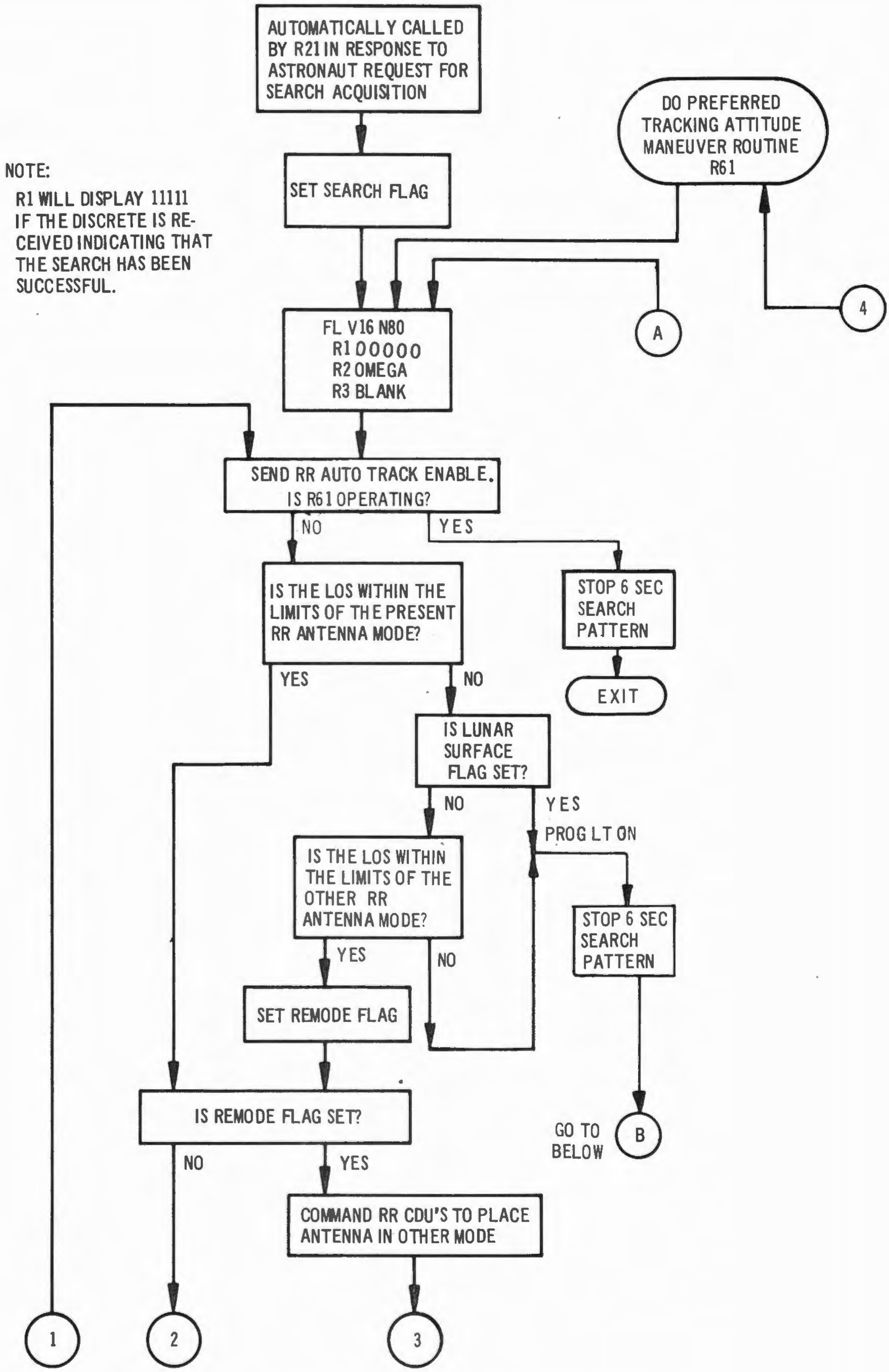


Fig. 5-9. RR search mode (R24). (sheet 1 of 3).

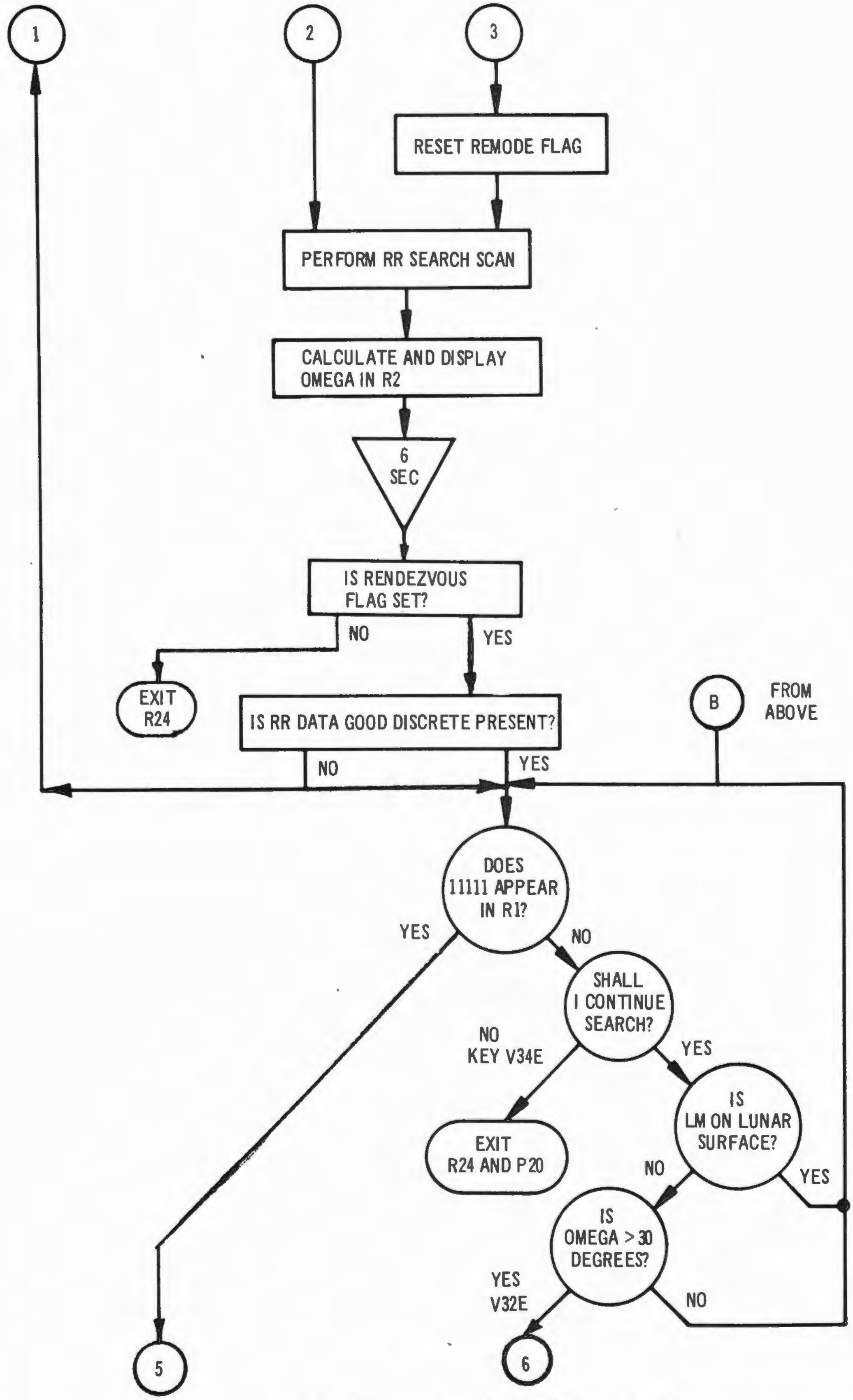


Fig. 5-9. RR search mode (R24)(sheet 2 of 3).

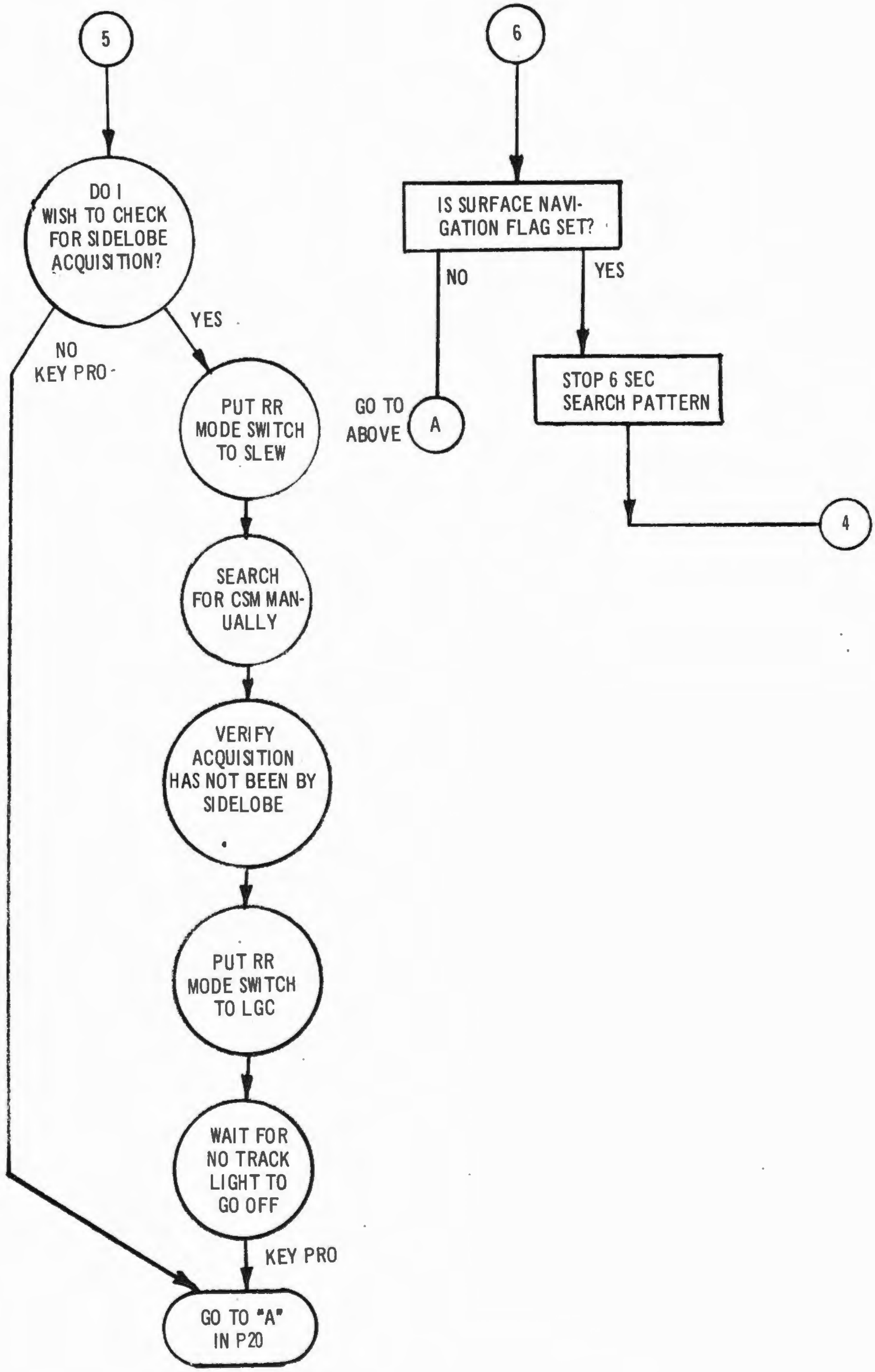


Fig. 5-9. RR search mode (R24) (sheet 3 of 3).

check is made to determine if the RR is within 30° of the LM +Z axis. If this angle exceeds 30°, the LM preferred tracking attitude routine is used to reestablish the preferred vehicle attitude before commencing with another search pattern. When the astronaut is satisfied that lockon has been achieved, he checks to see if the acquisition was obtained with the main radiation lobe of the radar. Having verified and achieved lockon with the main radiation lobe, PRO is keyed to terminate.

5.2.3.3.7 Preferred Tracking Attitude Routine (R61)

The preferred tracking attitude routine is called during P20 operation from R22, R23, R24, or from P20 proper. It is also called by the preferred tracking program (P25). Using conic equations, R61 extrapolates the LM and CSM state vectors to present time and calculates the LOS from the LM to the CSM. (See Fig. 5-10) It then defines the preferred attitude to be the LM +Z axis along the LOS to the CSM and performs the required maneuver to this preferred attitude.

5.2.3.3.8 Monitor Routine (R25)

The monitor routine is established whenever the LGC is in an operate state. This routine is under control of utility program T4RUPT, which recycles R25 approximately every half-second.

Each cycle of the monitor routine monitors the discretes associated with the position of the RENDEZVOUS RADAR antenna mode selector. (See Fig. 5-11.) If the RR CDU channels are judged to be malfunctioning, the LGC can no longer designate the radar, nor is the radar available for vector update. Program 20 should be terminated and the preferred tracking attitude program selected to maintain the preferred vehicle attitude. If the RR gimbals exceed the mode 1 limits (earth orbital operational limits), the LGC causes the antenna to be driven to the reference position (shaft = 0° and trunnion = 0°).

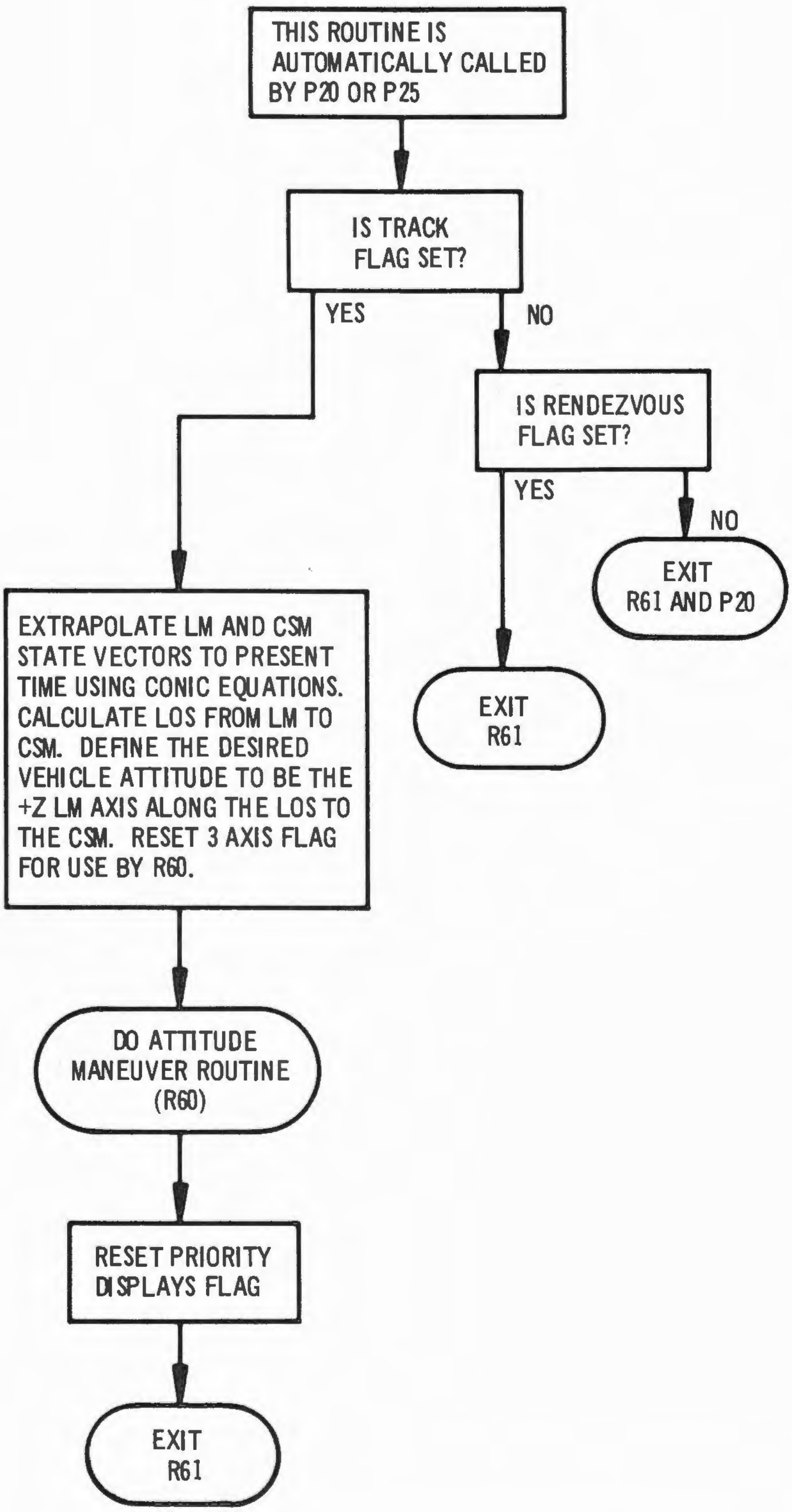


Fig. 5-10. Preferred tracking attitude routine (R61).

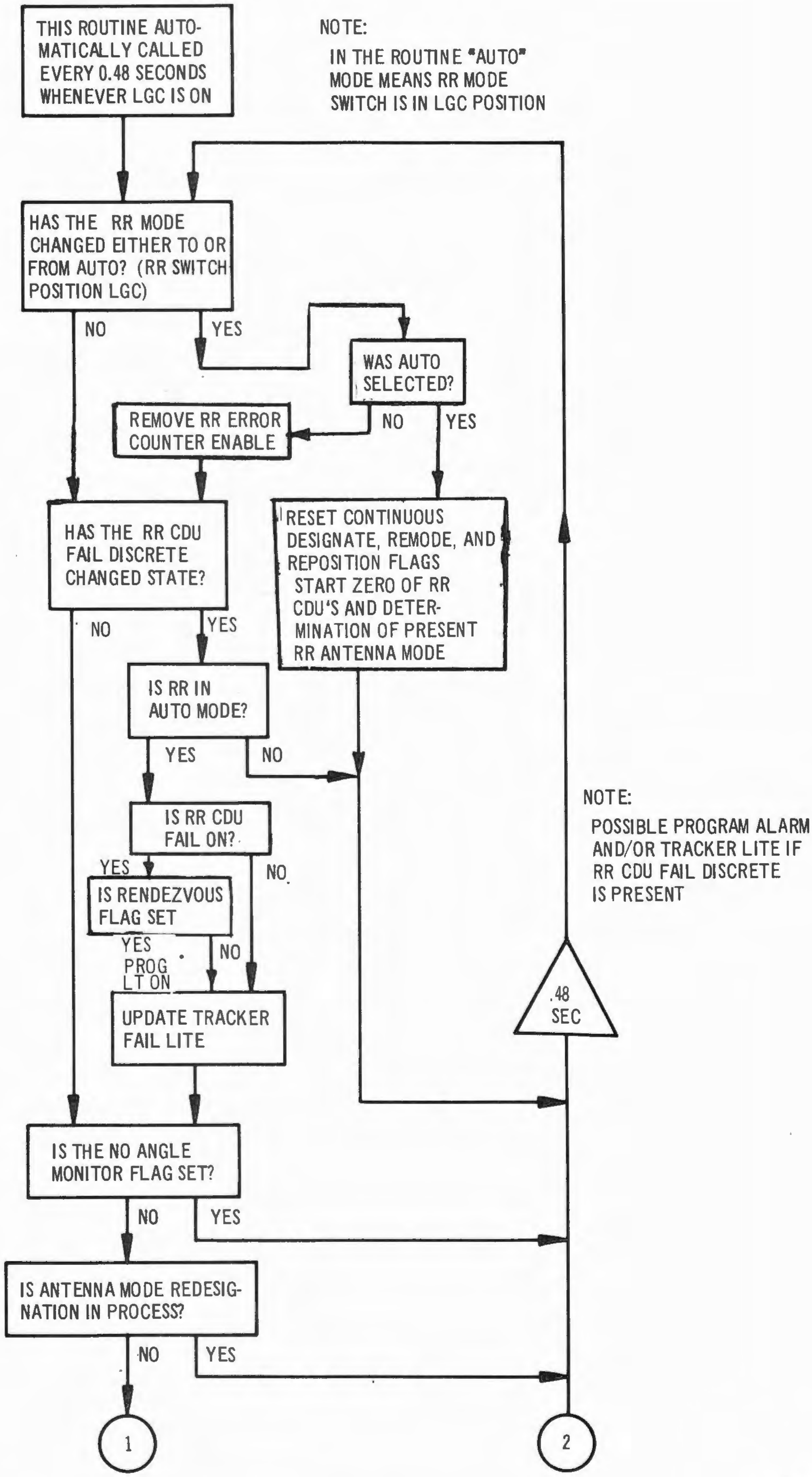


Fig. 5-11. RR monitor routine (R25). (sheet 1 of 2).

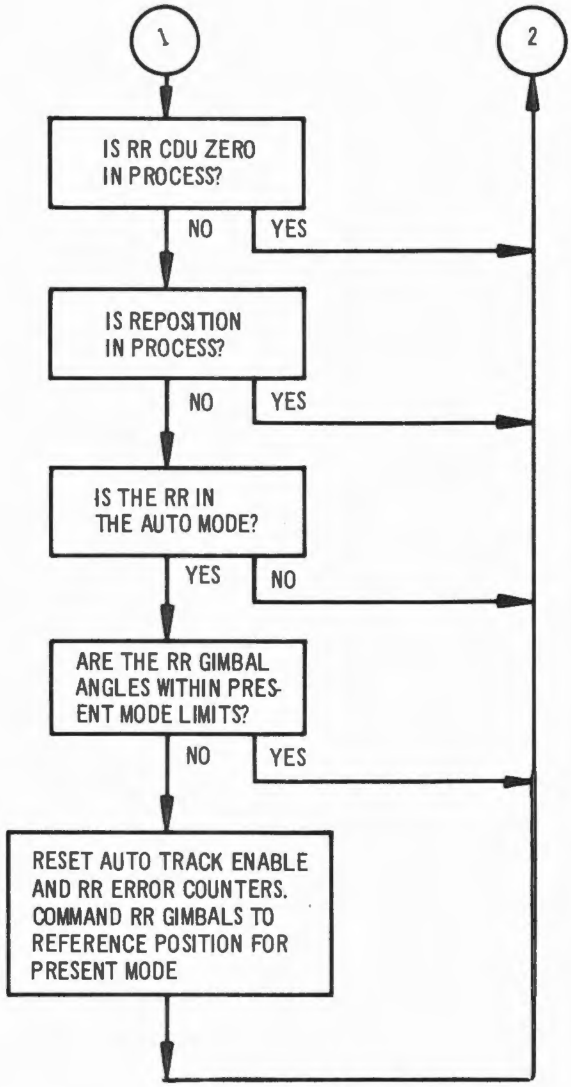


Fig. 5-11. RR monitor routine (R25) (sheet 2 of 2).

During normal RR tracking under control of P20, the angle between the LM +Z axis and the RR LOS is maintained by R22 within the 30 degree limitation. This is accomplished by LM attitude maneuvers under control of R61. Therefore, when the track flag is set (within P20), the limits defined should never be exceeded. However, R25 monitoring of RR gimbals becomes important when the track flag is reset, as during maneuvers for thrusting. If this occurs, R61 must again be performed.

5.2.3.4 Ground Track Determination Program (P21)

To provide latitude, longitude, and altitude of the LM at a specific time (T Lat Long) without ground communication, the ground track determination program is called. (See Fig. 5-12.) The output is the estimated location of the LM by extrapolation of LM state vector. Ten minute intervals of LM position from the initial displayed position can also be selected during P21.

5.2.3.5 Preferred Tracking Attitude Program (P25)

If the rendezvous radar malfunctions to preclude proper operation of P20, the preferred tracking attitude program is selected to maneuver the LM to the preferred tracking attitude and to maintain the LM in attitude permitting CSM tracking of the LM optical beacon. (See Fig. 5-13.) The desired attitude is defined by R61 to be the +Z - axis along the LOS to the CSM. The LM optical beacon FOV is a 30 degree half angle cone with the cone axis parallel to the LM +Z - axis. The program continues to maintain the preferred tracking attitude until the astronaut selects termination by V37E 00E or V56E.

5.2.3.6 LGC Update Program (P27)

To insert update data into the LGC by digital uplink transmission or by DSKY Keyboard entry, the LGC update program is selected. Four categories of LGC update exist:

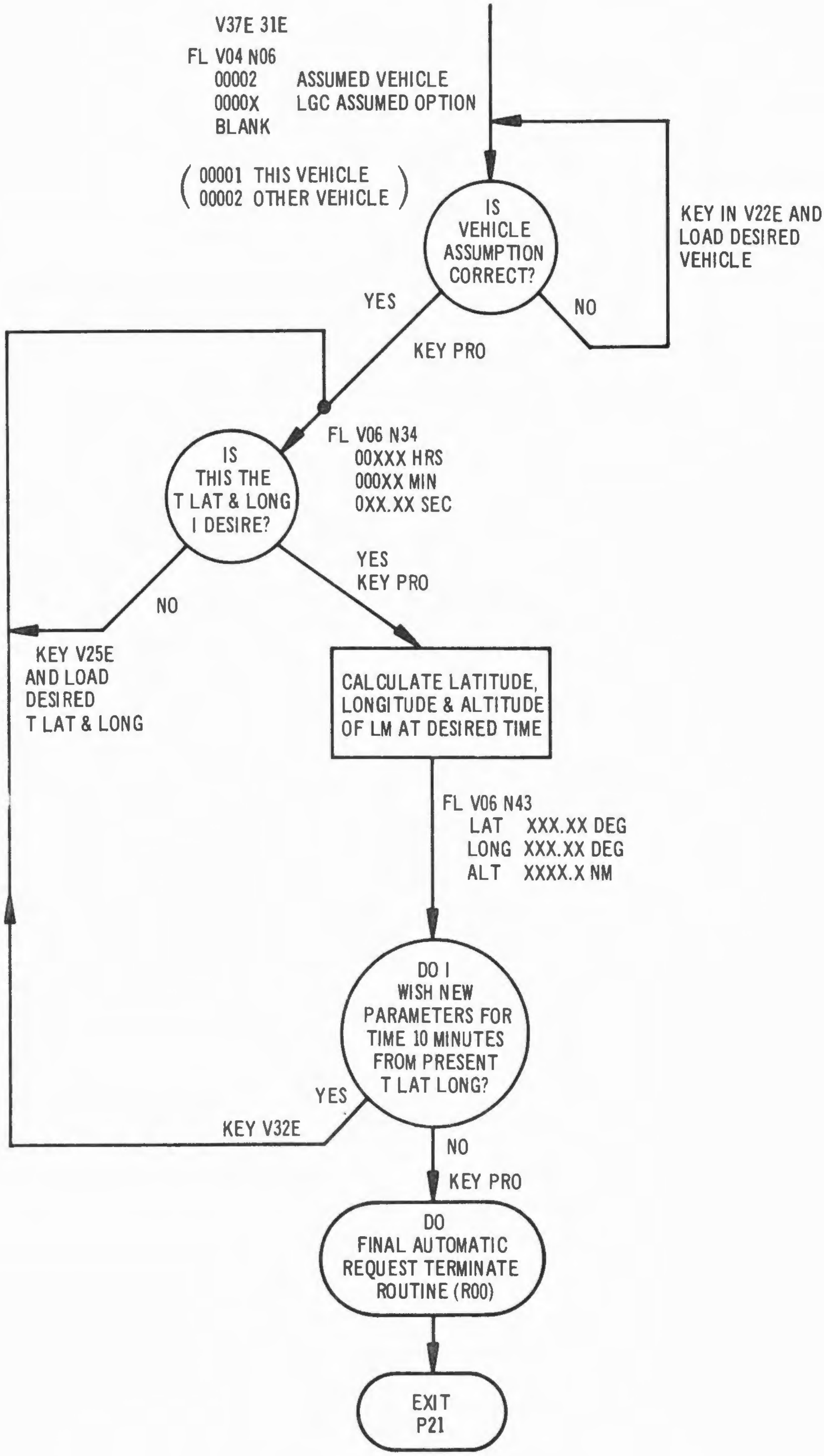


Fig. 5-12. Ground track determination (P21).

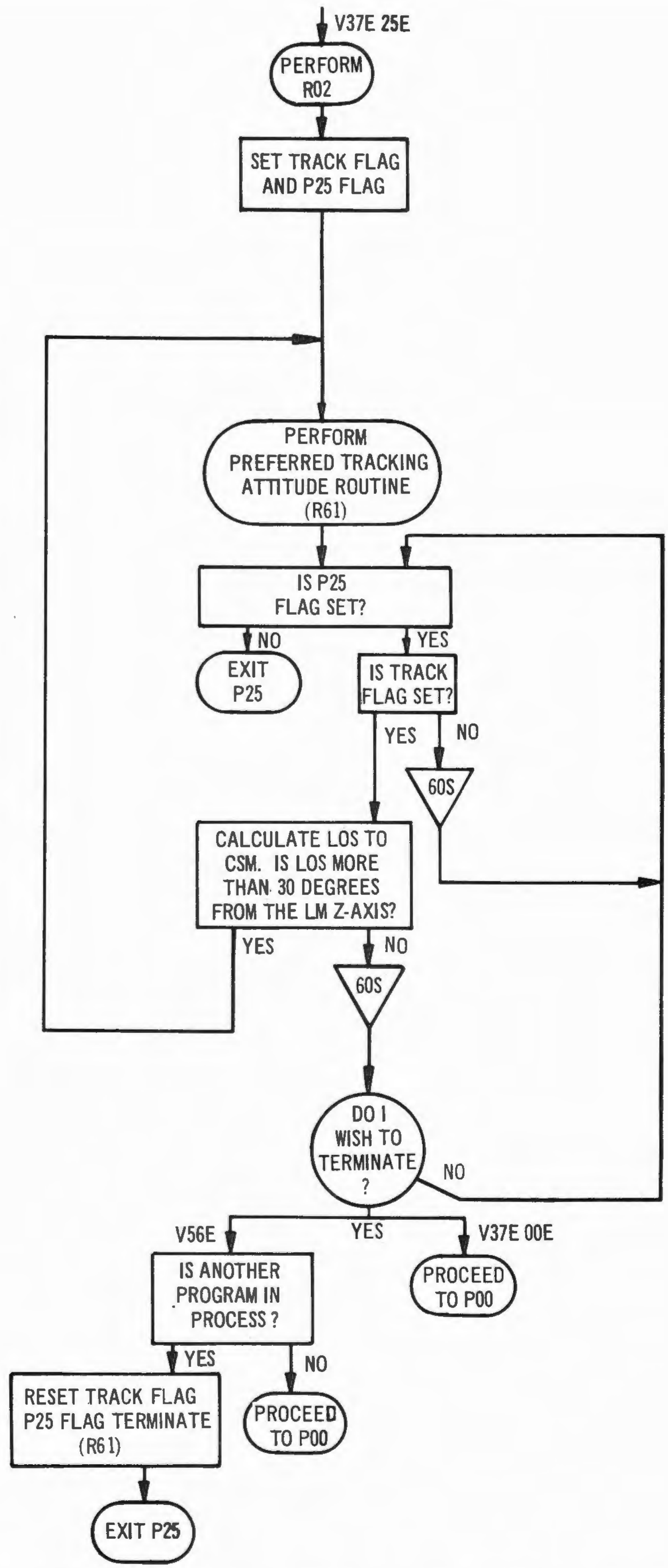


Fig. 5-13. Preferred tracking attitude program (P25) flow diagram.

1) Increment LGC clock and tephem (V70)

2) Octal increment of LGC clock only (V73)

3) Load capability for a block of sequential erasable locations (1-18 inclusive locations whose address is specified) (V71)

4) Load capability for 1 through 9 inclusive individually specified erasable locations (V72).

Figure 5-14 illustrates the LGC logic for the manual entries. Automatic update has similar flow within the LGC, but astronaut actions are performed by uplink loading from the ground that maintains DSKY codes identical to DSKY Keyboard originated codes.

State vector updates for either the CSM or LM are made by the V71E.

If a load is verified as correct, a V33E is keyed and the LGC transfers the load for computation. If the contents of one or more registers are in error, V34E may be keyed to terminate or the octal identifier of the register in error may be keyed in and its contents reloaded. This latter procedure may be repeated any number of times until all registers are correctly loaded and then PRO is keyed. With automatic update, the procedure is the same, except load verification is made via the digital downlink.

To load the LGC for an external delta V maneuver, the V72 entry is made.

5.2.3.7 External Delta V Program (P30)

To accept targeting parameters from a source external to the LGC, the external delta V program is selected. (See Fig. 5-15.) It converts the impulsive change-in-velocity required for a maneuver to inertial components and computes perigee and apogee. The targeting parameters inserted into the LGC are impulsive delta V along LM local vertical axes at GET I and the time from GET I (TF GET I). These targeting parameters may be inserted into the LGC via digital uplink (P27 selection) or by DSKY Key in.

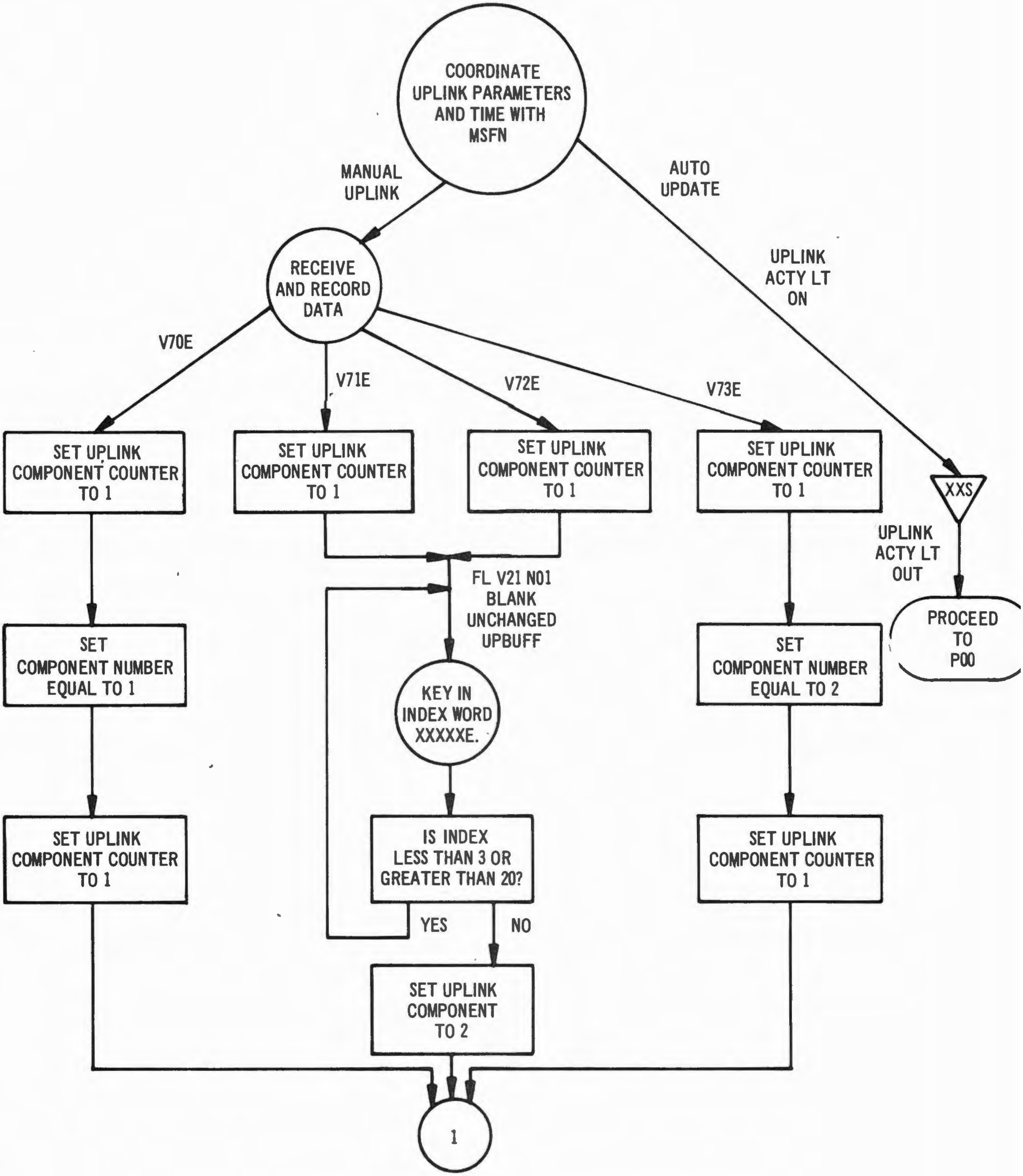


Fig. 5-14. LGC update program (P27) flow diagram (sheet 1 of 2).

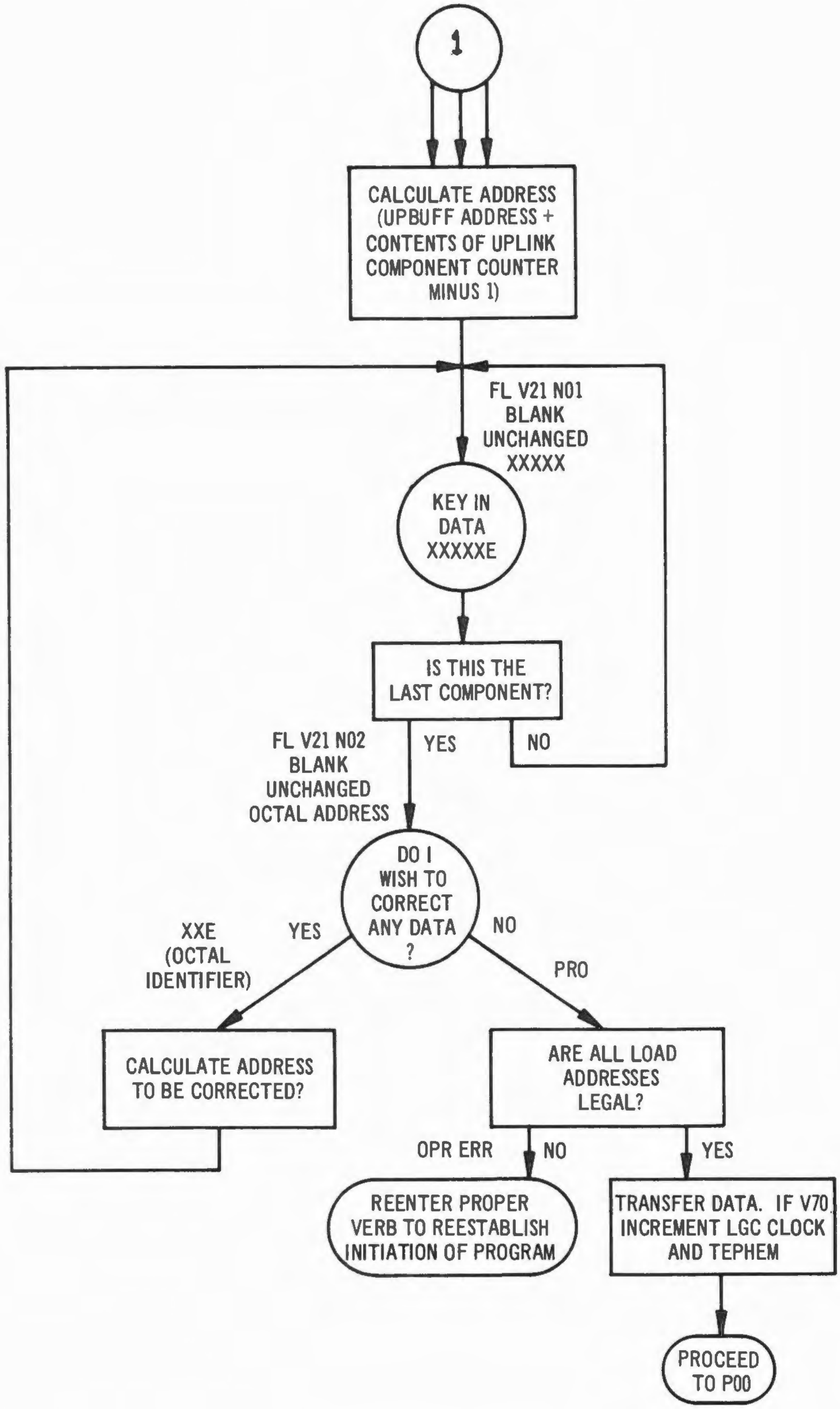


Fig. 5-14. LGC update program (P27) flow (sheet 2 of 2).

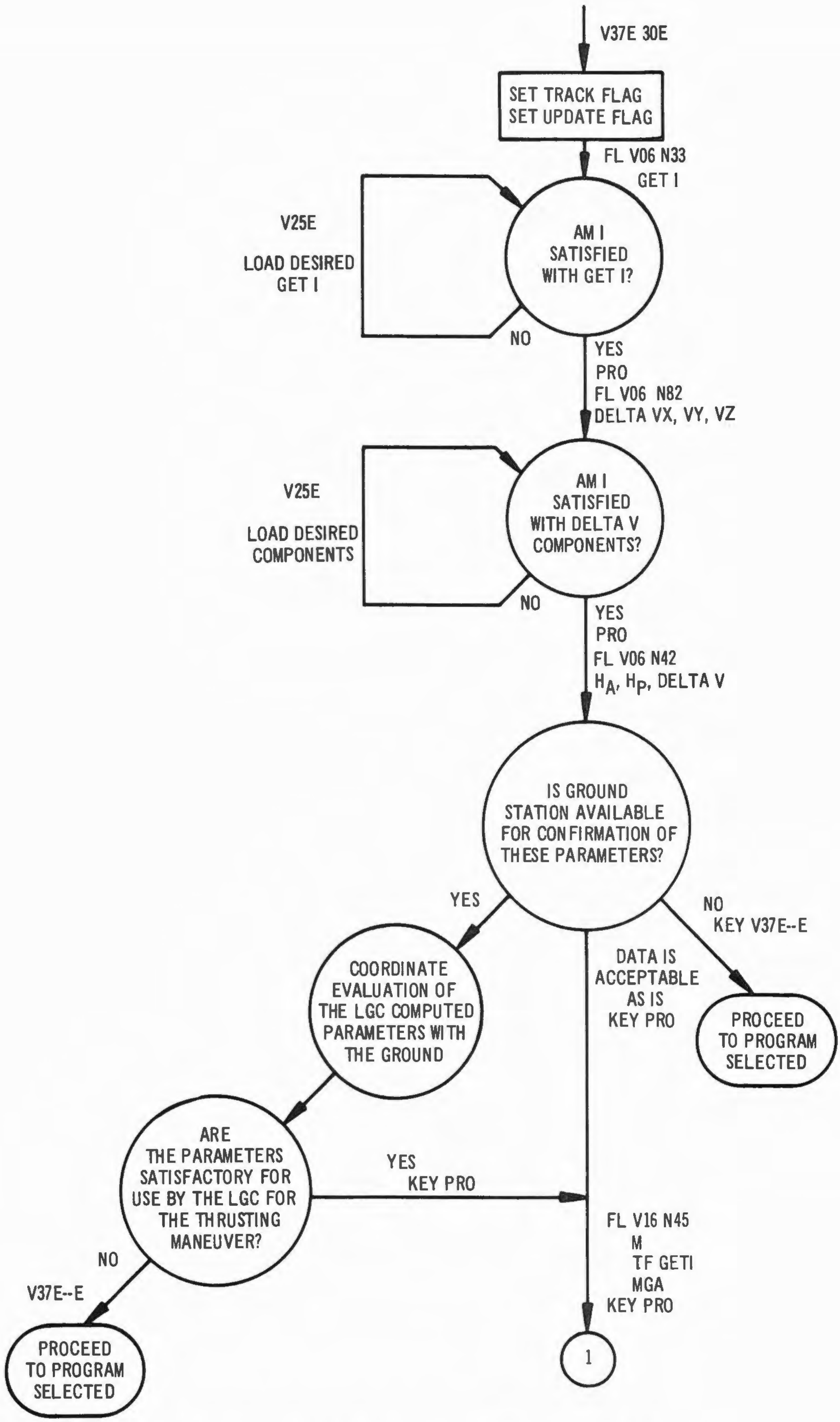


Fig. 5-15. External delta V program (P30) (sheet 1 of 2).

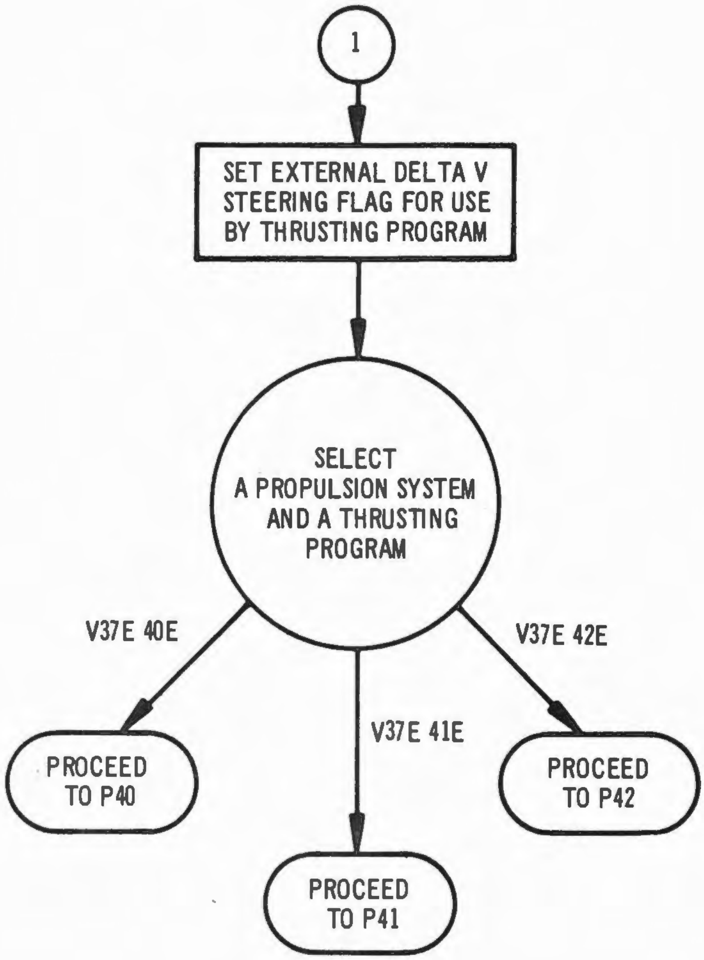


Fig. 5-15. External delta V program (P30) (sheet 2 of 2).

5.2.3.8 Co-elliptic Sequence Initiation Program (P32)

The co-elliptic sequence initiation program calculates all the required parameters associated with all the concentric flight plan maneuvers, including the co-elliptic sequence initiation (CSI), the constant delta altitude (CDH), and the transfer phase initiation (TPI).

Upon entry into P32, the astronaut loads the parameters associated with concentric flight plan. (See Fig. 5-16.) The LGC then computes the associated maneuver parameters. They are computed with the following restrictions:

1) At a selected TPI time, the LOS from the LM to the CSM is selected to be a prescribed angle from the horizontal plane defined at the active position.

2) The perigee, altitude of the orbit following CSI and CDH must be greater than 85 nautical miles.

3) The time from CSI to CDH must not be less than 10 minutes.

4) The time from CDH to TPI must not be less than 10 minutes.

5) The CSI and CDH maneuvers are assumed to be parallel to the plane of the CSM orbit.

6) The first maneuver (CSI) must be such that the impulsive ΔV is in the LM horizontal plane defined at initiation of CSI.

7) CDH delta V is selected to minimize the variation of the altitude difference between the orbits.

If the restrictive conditions are not fully met, an alarm is issued and the flight plan maneuvers must be re-loaded. If they are met, the computed target parameters are put on downlink and are also displayed on the DSKY. Upon approval of the target parameters, a decision is made on whether to incorporate present state vector (if P20 is in process), and the final computation cycle is entered. The target parameters are re-computed and again inserted on the

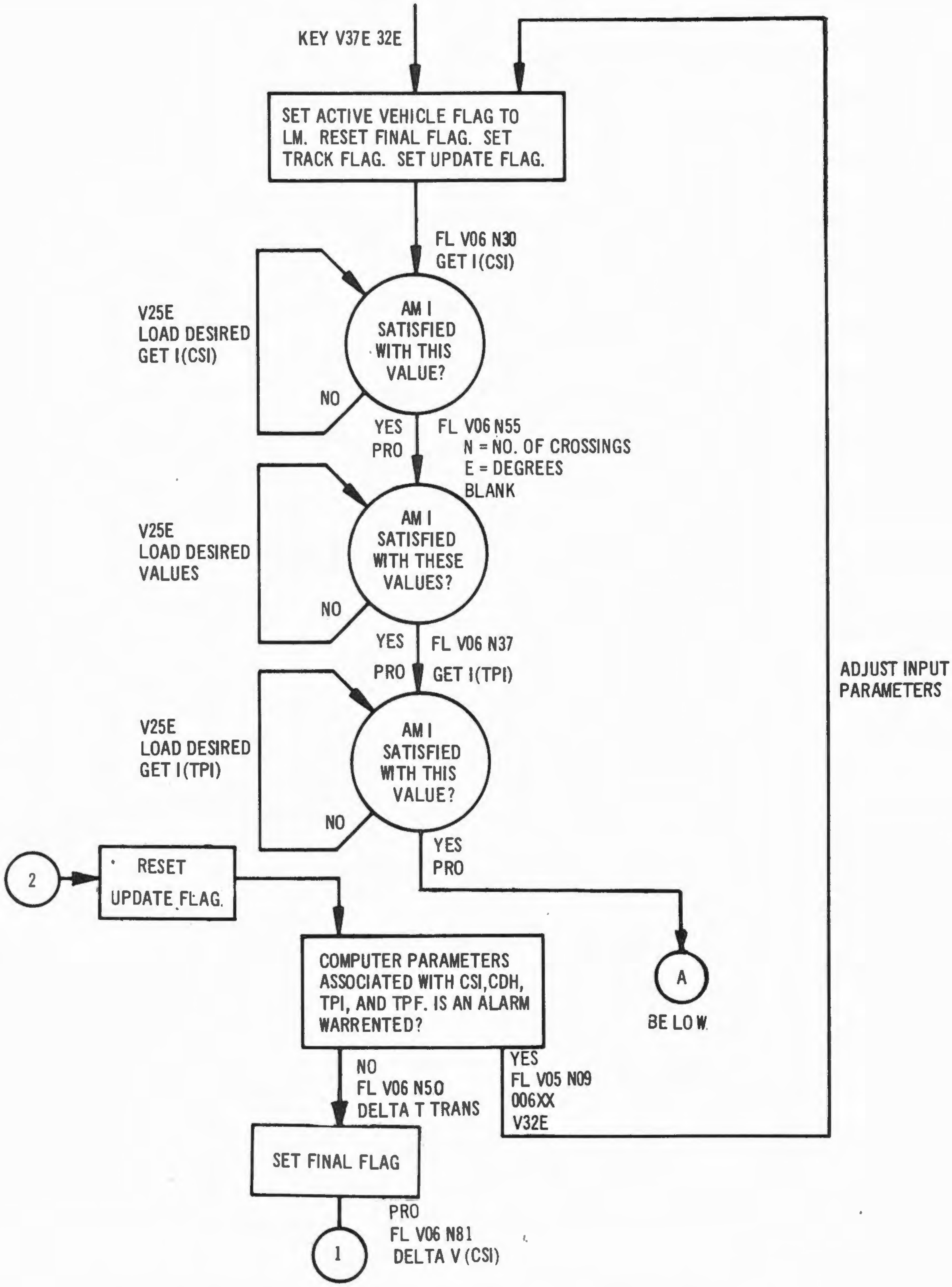


Fig. 5-16. Co-elliptic sequence initiation program (P32) (sheet 1 of 2).

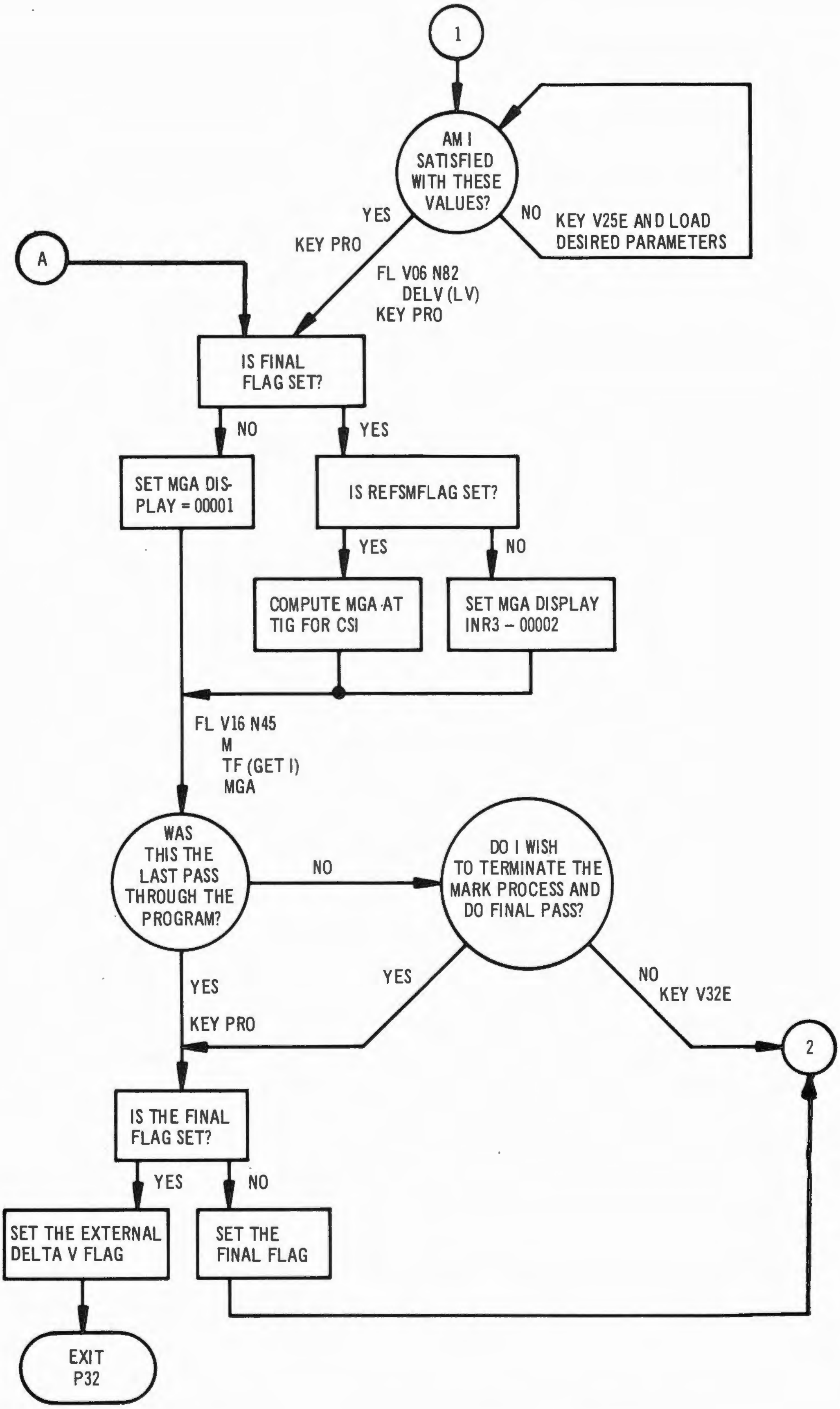


Fig. 5-16. Co-elliptic sequence initiation program (P32) (sheet 2 of 2).

downlink. Approval of the final computed target parameters provides to memory the CSI target parameters for the selected thrusting program.

5.2.3.9 Constant Delta Altitude Program (P33)

The constant delta altitude program calculates all the required parameters associated with all the concentric flight plan maneuvers, except CSI. (See Fig. 5-17.) Functionally, the procedural flow is similar to P32; and unless the inputs to P33 are changes from those values inserted in P32, the calculated parameters for the remaining maneuvers of the concentric flight plan will vary only slightly from those originally calculated and displayed due to the continuous radar updating.

5.2.3.10 Transfer Phase Initiation Program (P34)

The transfer phase initiation program calculates the required delta V and other initial parameters required by the LGC for LM execution of the TPI maneuver. (See Fig. 5-18.) Functionally, the procedural flow is similar to P32; and unless the inputs to P34 are changed from the values inserted in P32 and/or P33, the calculated parameters for the remaining maneuvers of the concentric flight plan will vary only slightly from those originally calculated and displayed due to the continuous radar updating.

5.2.3.11 Transfer Phase (Midcourse) Program (P35)

Computation of the required delta V and other initial conditions required for LM execution of the next possible midcourse correction is performed by the transfer phase program. (See Fig. 5-19.) If the time to intercept (TF Int) is less than 10 minutes, P35 is exited to P47 for monitoring of the manual maneuver.

Program P35 does not set the external delta V flag; thereby, setting the conditions for lambert steering. Lambert steering computes the velocity required to travel from position one to position two given a fixed trajectory time of flight.

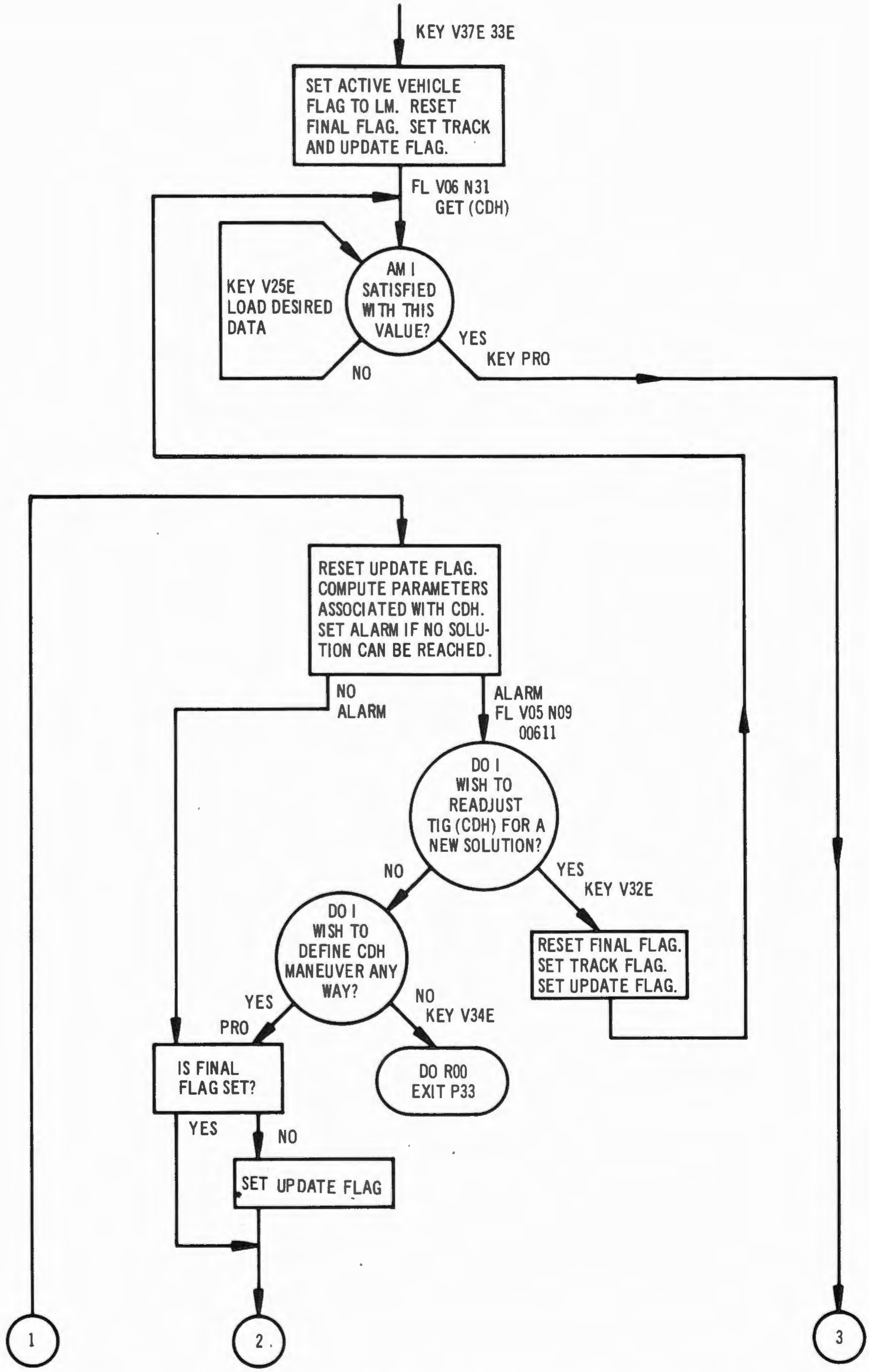


Fig. 5-17. Constant delta altitude program (P33) (sheet 1 of 2).

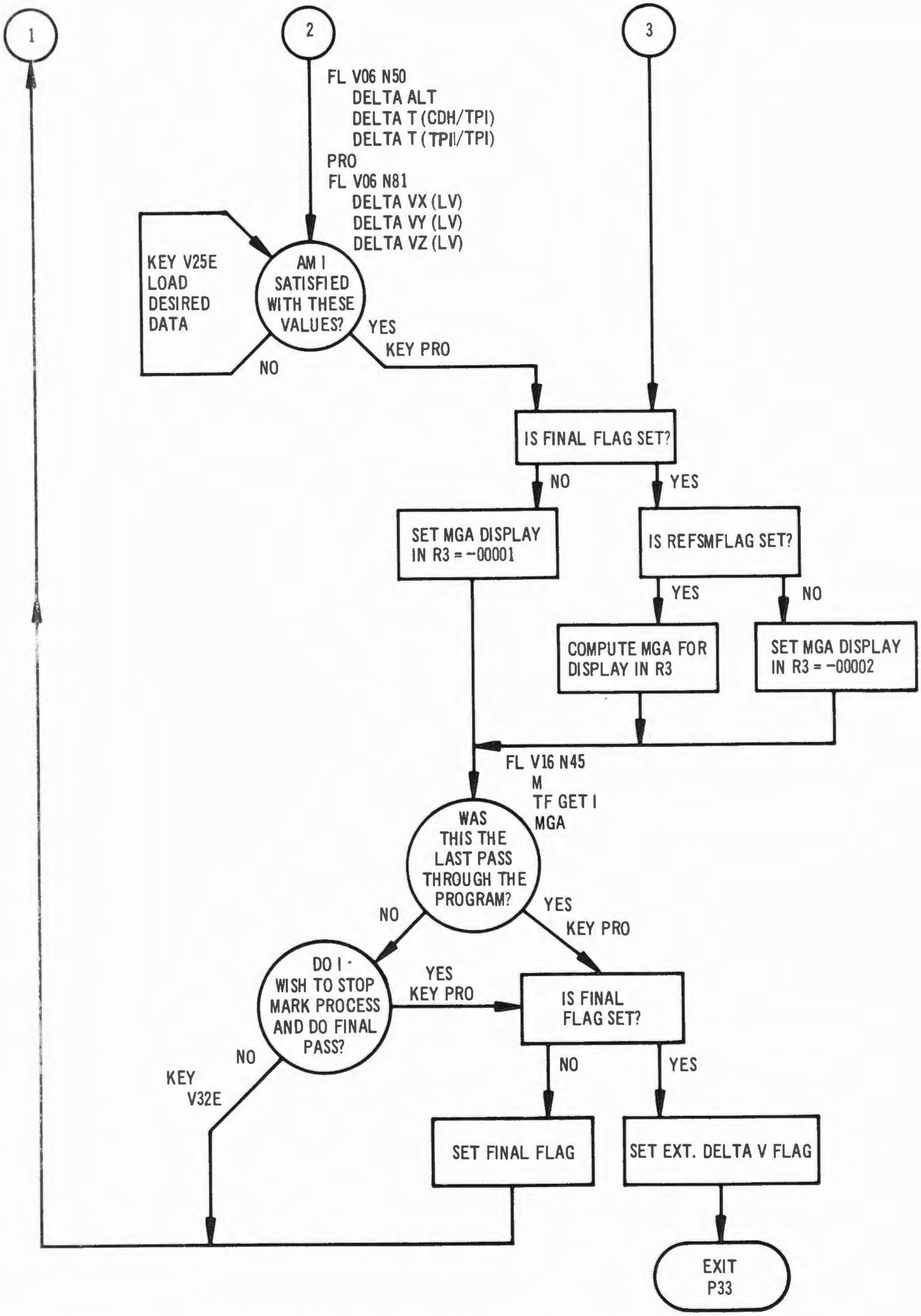


Fig. 5-17. Constant delta altitude program (P33) (sheet 2 of 2).

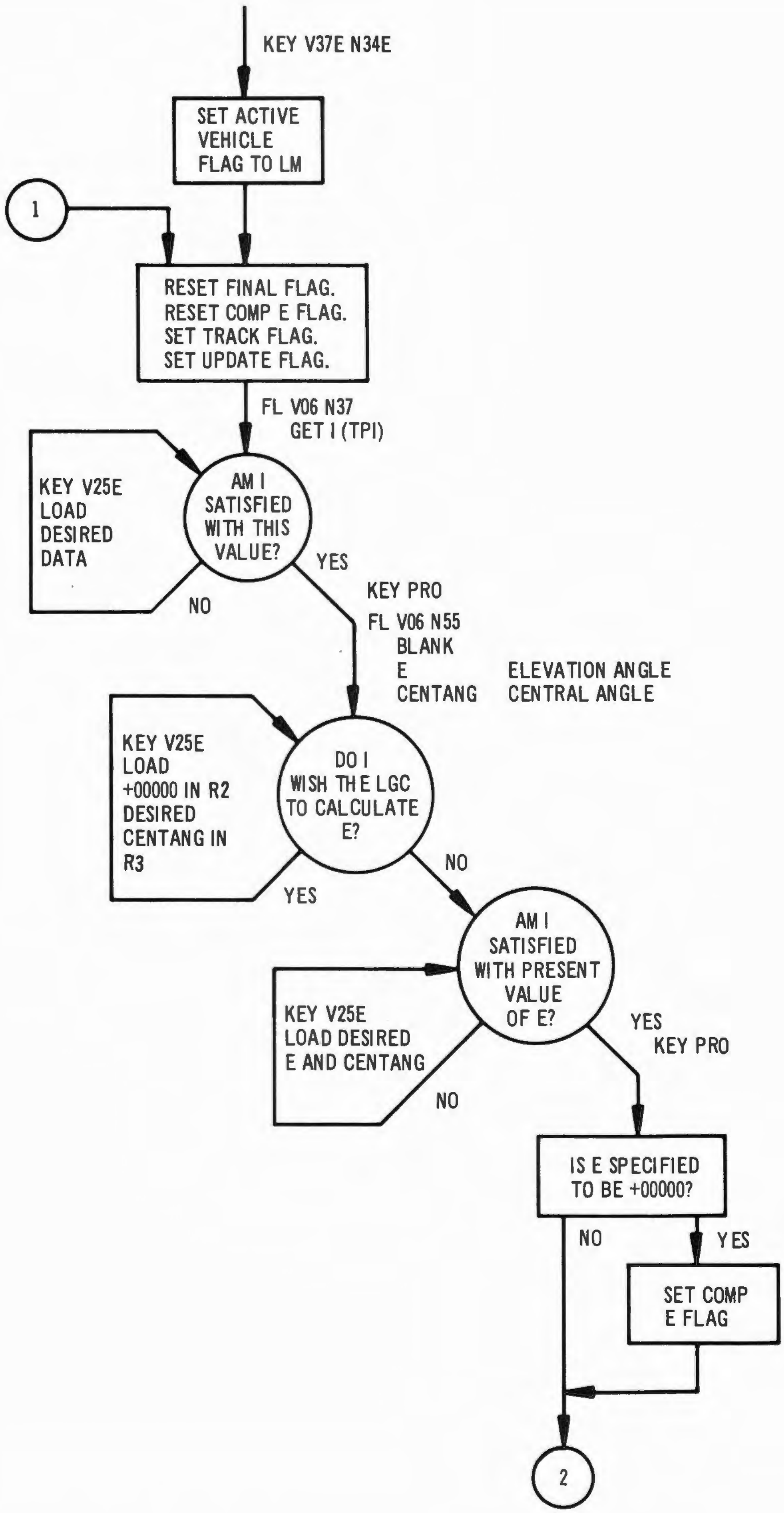


Fig. 5-18. Transfer phase initiation program (P34) (sheet 1 of 3).

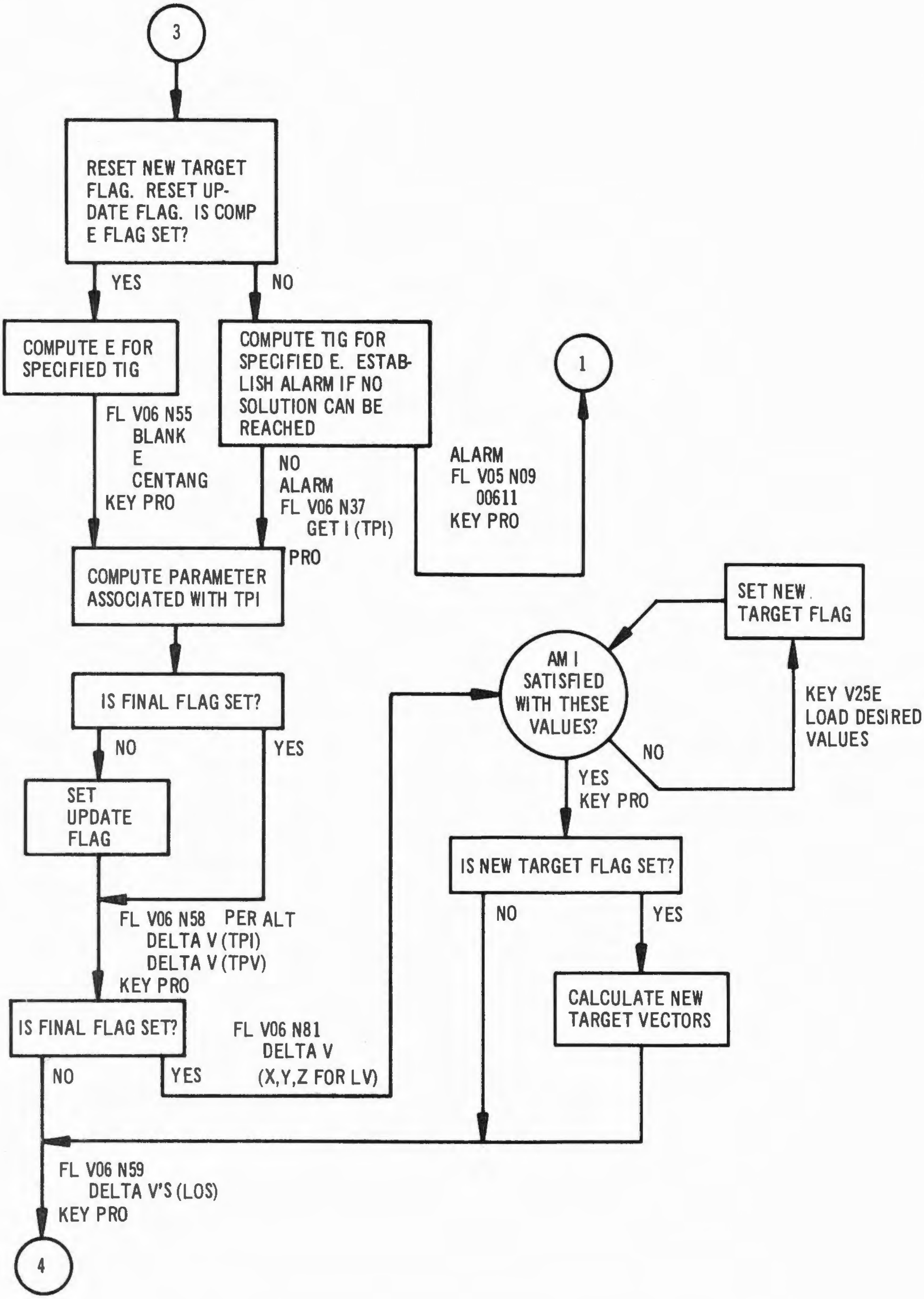


Fig. 5-18. Transfer phase initiation program (P34)(sheet 2 of 3).

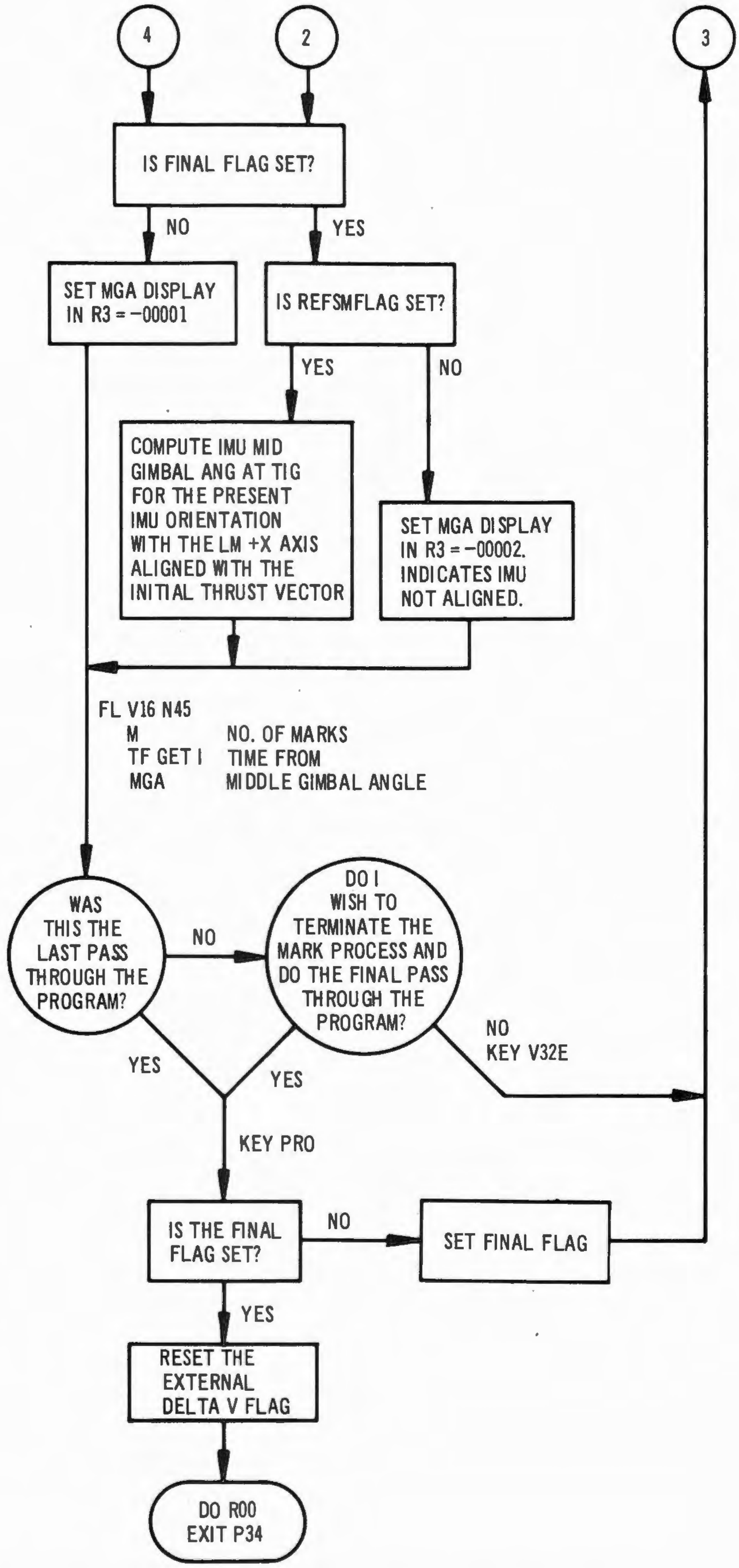


Fig. 5-18. Transfer phase initiation program (P34) (sheet 3 of 3).

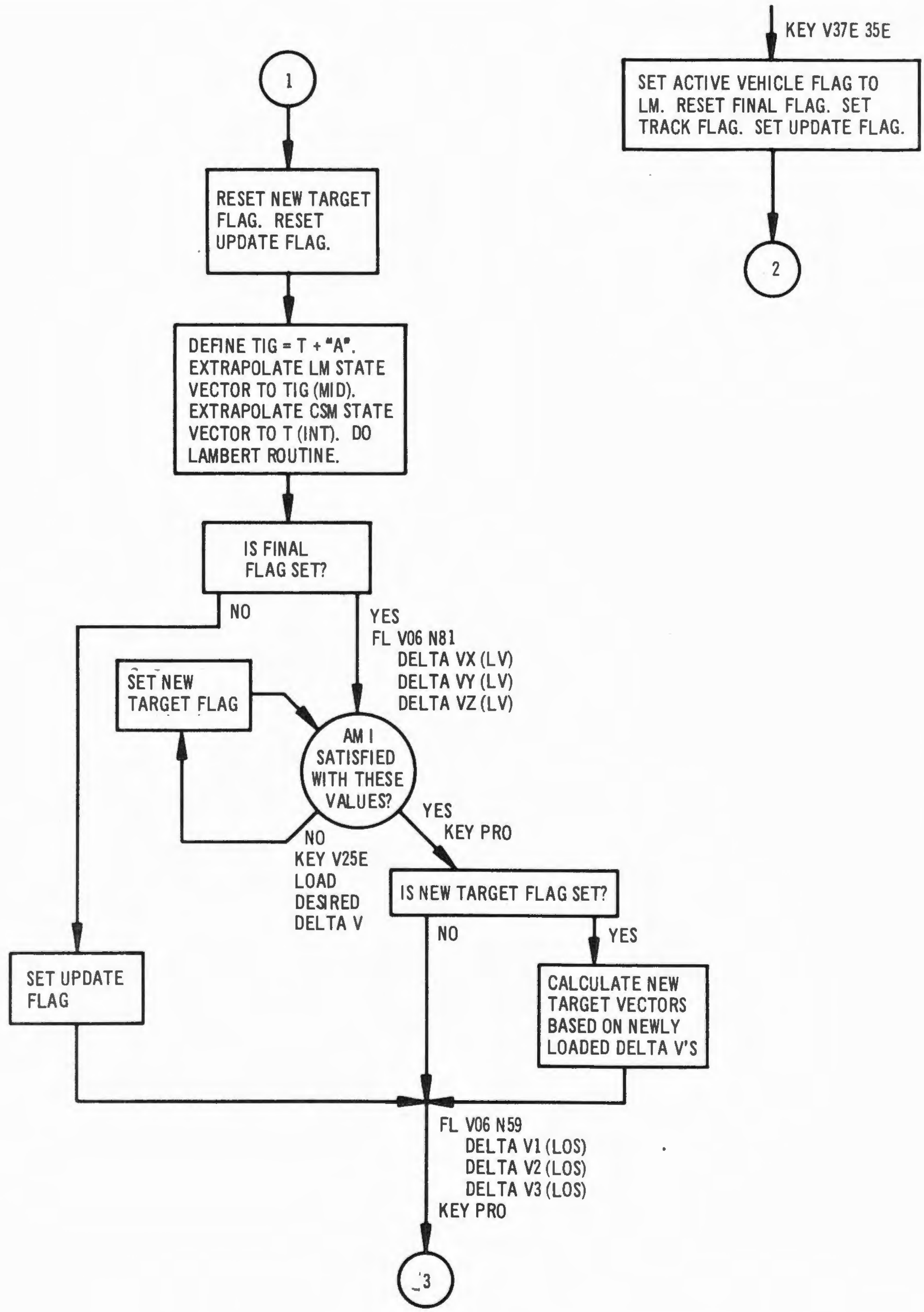


Fig. 5-19. Transfer phase (midcourse) program (P35) (sheet 1 of 2).

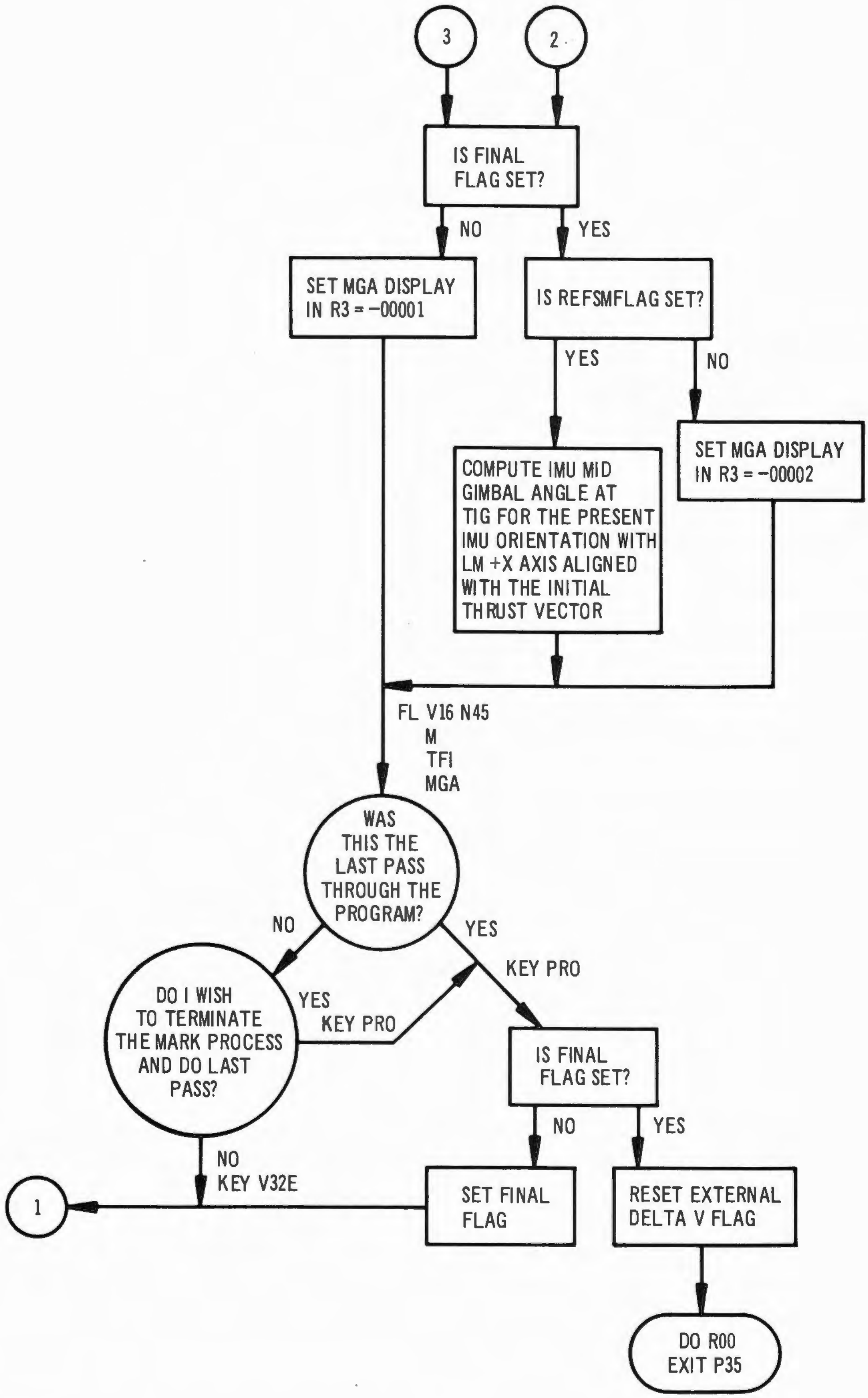


Fig. 5-19. Transfer phase (midcourse) program (P35) (sheet 2 of 2).

5.2.3.12 DPS Program (P40)

The DPS program provides PGNCS control during a descent propulsion system maneuver, including countdown, thrusting, and thrust termination. It computes a preferred IMU orientation and a preferred LM attitude for the thrusting maneuver. It also calculates and displays the IMU gimbal angles which would result from the present IMU orientation if the vehicle is maneuvered to the preferred LM attitude for thrusting. Prior to P40 entry, the IMU has been in the operate state for at least 15 min. and the target parameters have been calculated and stored by prior execution of a prethrusting program (P3X). The required steering equations have been identified by this prethrust program as either the lambert or external delta V steering.

Associated with any of the thrusting programs are the powered flight guidance routines. The objective of these guidance routines is to keep track of the vehicle state vector during thrusting maneuvers, and to control or steer the thrust direction such that the desired cut-off conditions are achieved. The powered flight navigation program used to maintain an estimate of the vehicle state vector during all thrusting conditions is referred to as the average G routine. The basic powered flight guidance concept used for the earth-orbit maneuvers is a velocity-to-be-gained concept with cross product steering. All powered maneuvers controlled by the PGNCS autopilot are controlled by one of two major powered flight guidance programs which use the cross-product steering concept. The first of these major powered flight programs is the rendezvous intercept maneuver routine which is targeted from a lambert routine and is used to control TPI and the rendezvous midcourse correction maneuvers. The second is the external delta V maneuver routine which is used for all other PGNCS controlled maneuvers.

Program P40 is selected at least five minutes before lgnition time. (See Fig. 5-20). For the initial thrust direction and engine gimbal angles, the preferred IMU orientation is computed . The IMU gimbal angles with the present inertial orientation and preferred vehicle attitude are then computed. The next action is to set the one degree deadband into the RCS DAP then perform the LM attitude maneuver is performed. The final LM attitude is computed to point the trimmed engine bell in the initial thrust direction. A two jet ullage is initiated 7.5 seconds prior to DPS ignition.

5. 2. 3. 13 RCS Program (P41)

The RCS program computes a preferred IMU orientation and a preferred LM attitude for an RCS thrusting maneuver. It will perform the vehicle maneuver to the thrusting position or will provide suitable displays for manual execution in attitude hold. It also calculates and displays the gimbal angles which would result from the present IMU orientation if the vehicle is maneuvered to the preferred LM attitude for thrusting. Prior to P41 entry, the IMU has been in the operate state for at least one hour, and the target parameters have been calculated and stored in the LGC by prior execution of a prethrusting program (P3X). The required steering equations have been identified by this prethrust program as either lambert or external delta V steering.

Program P41 is selected at least five minutes before ignition time. (See Fig. 5-21). A translational axis option is made and the components of VG vector are resolved along the present LM axes. If the gimbal axes are acceptable, the attitude maneuver with R60 control is performed.

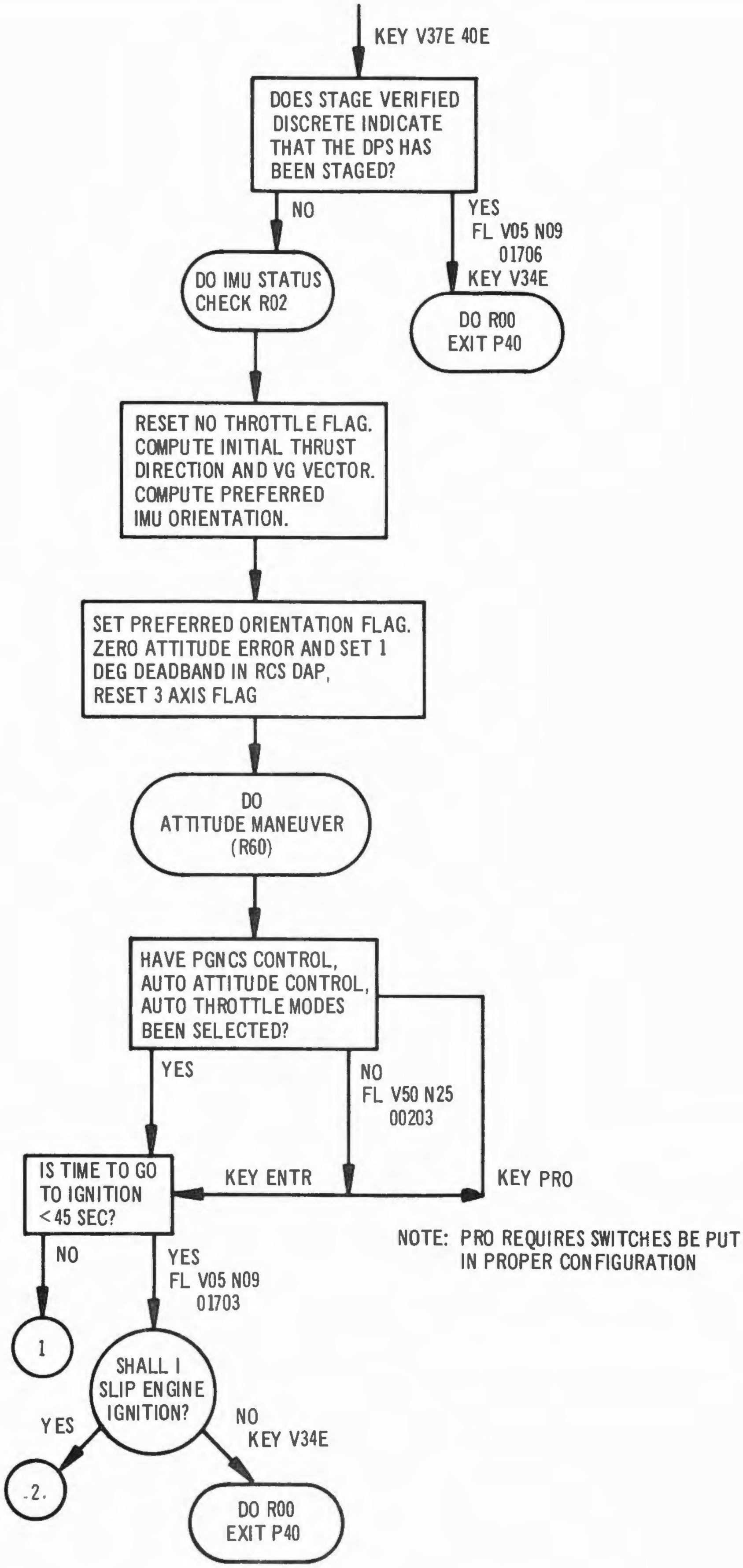


Fig. 5-20. DPS program (P40)(sheet 1 of 4).

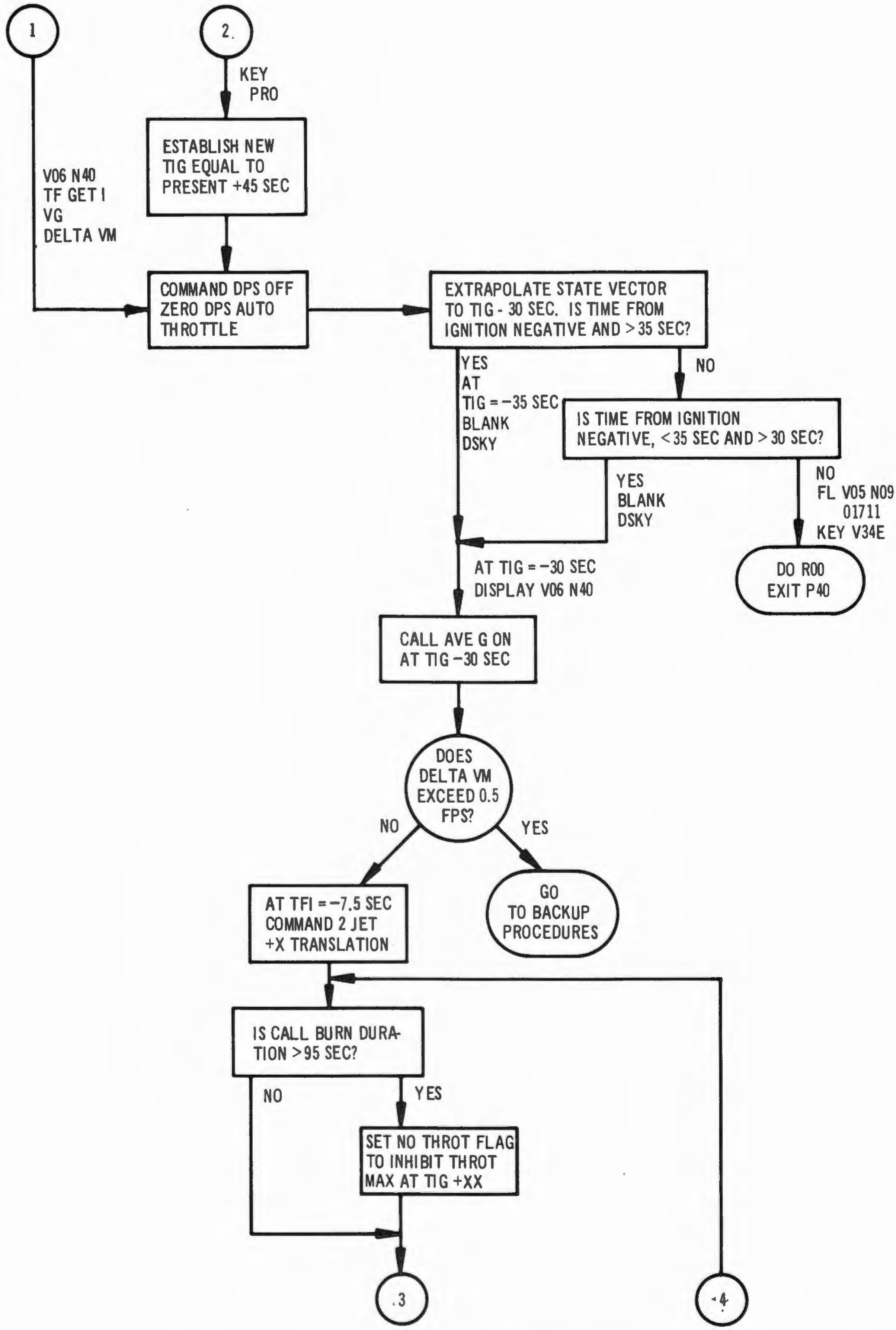


Fig. 5-20. DPS program (P40) (sheet 2 of 4).

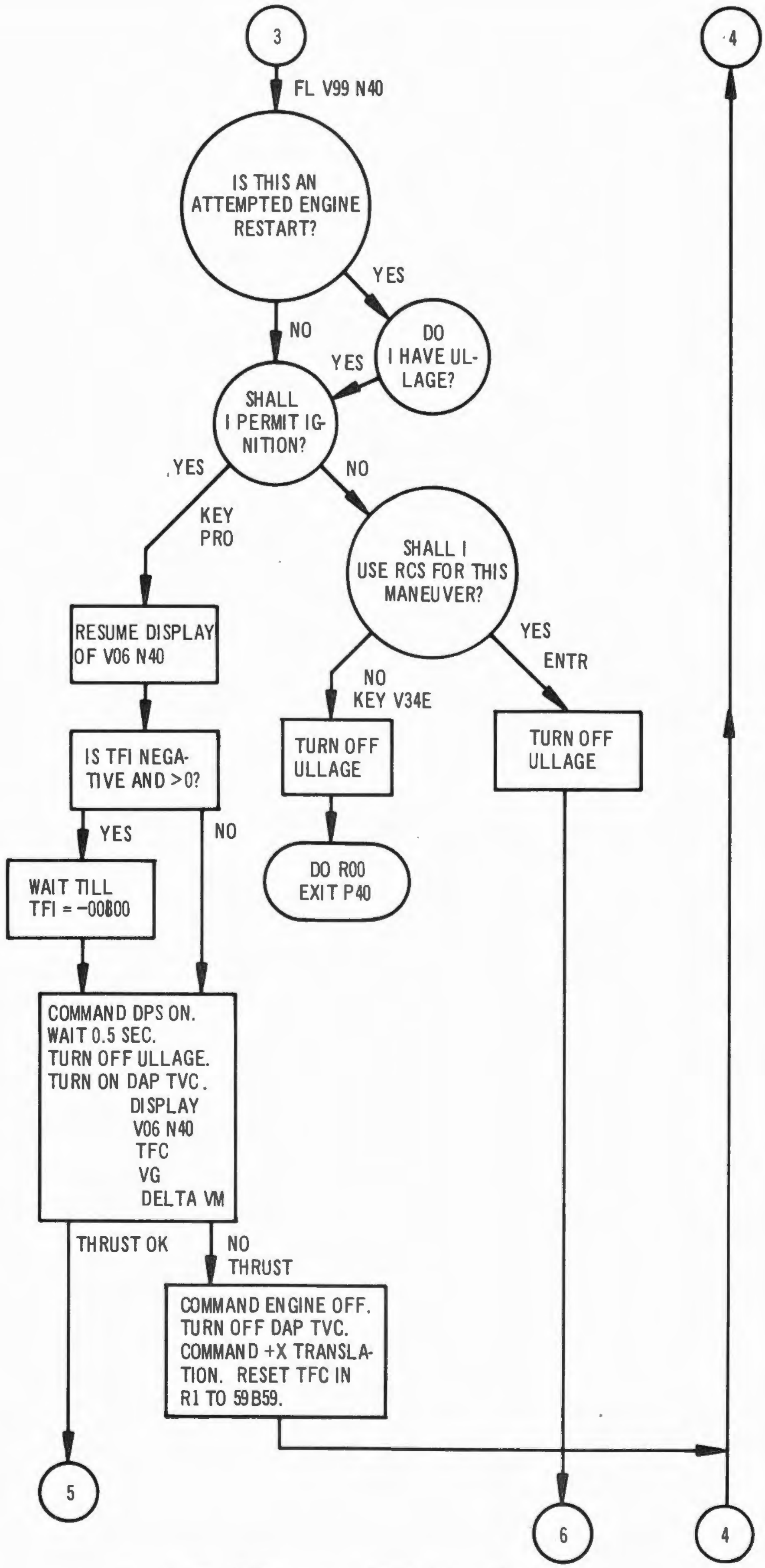


Fig. 5-20. DPS program (P40) (sheet 3 of 4).

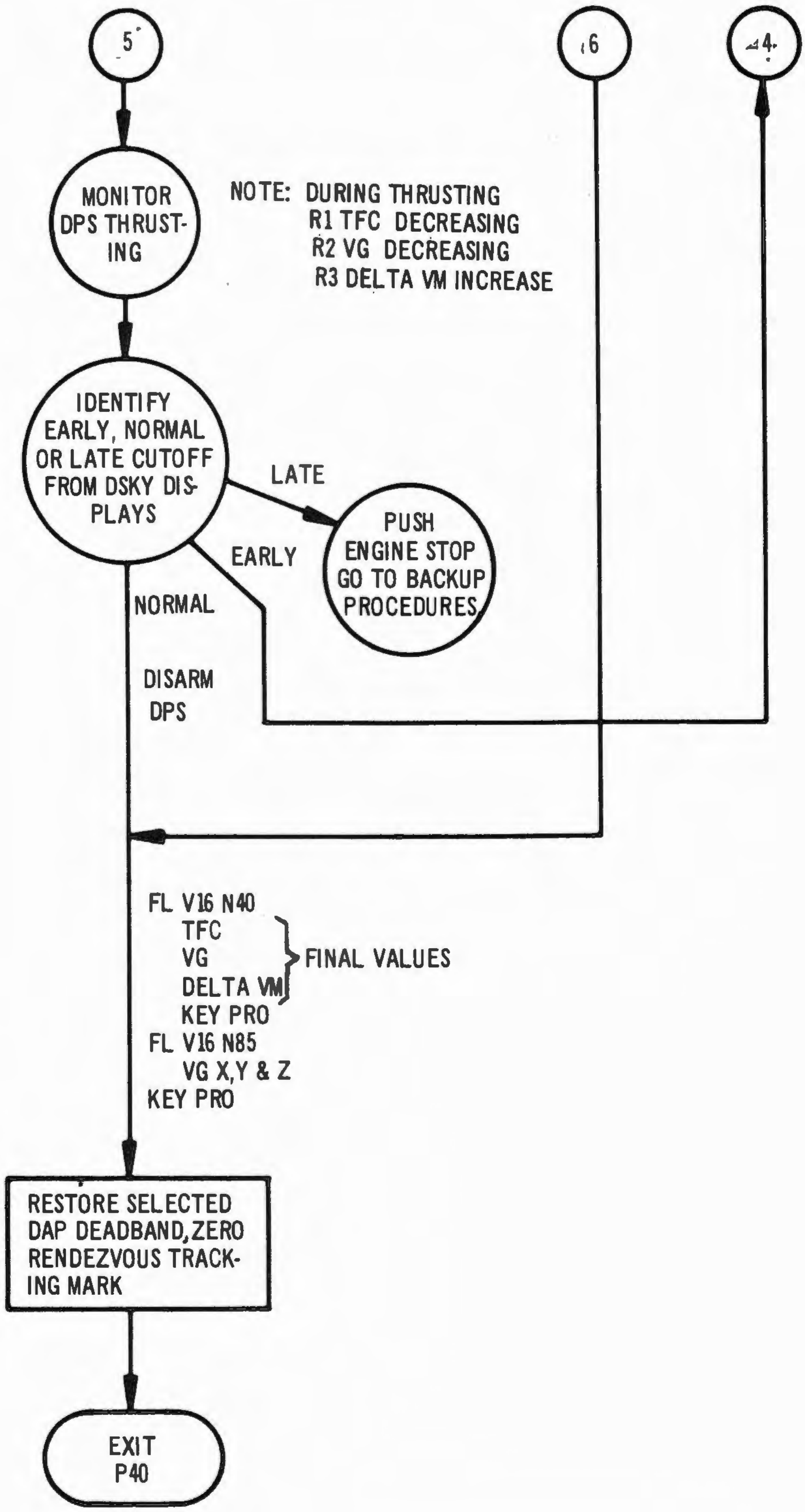


Fig. 5-20. DPS program (P40) (sheet 4 of 4).

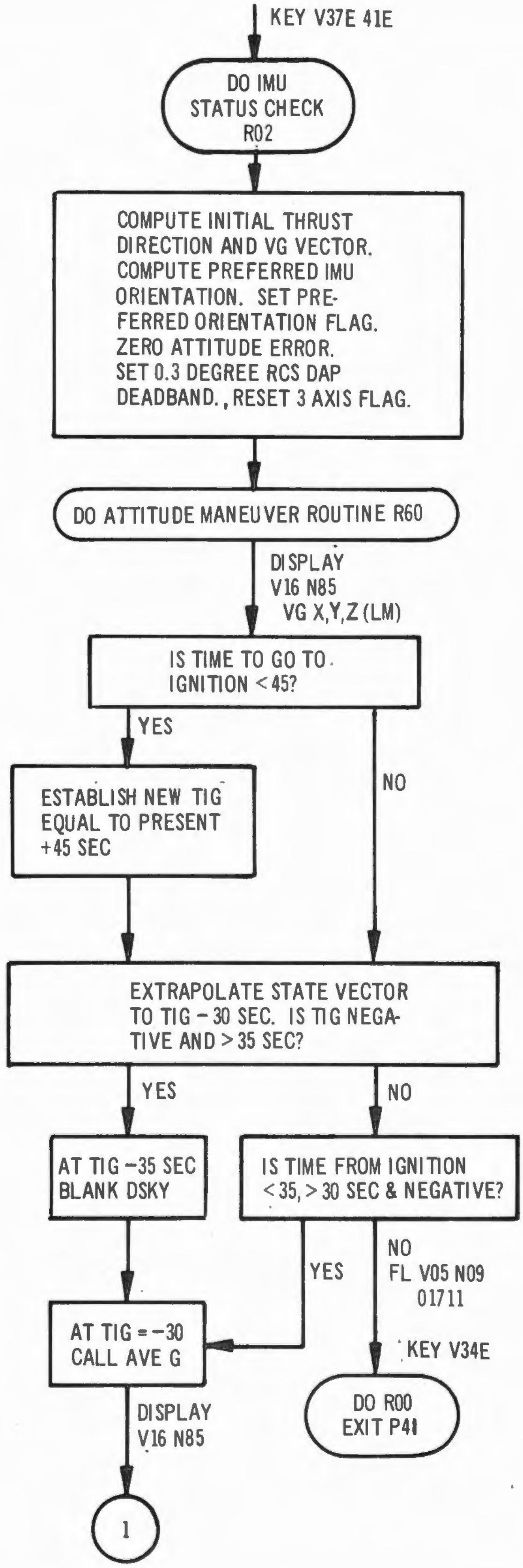


Fig. 5-21. RCS program (P41) (sheet 1 of 2).

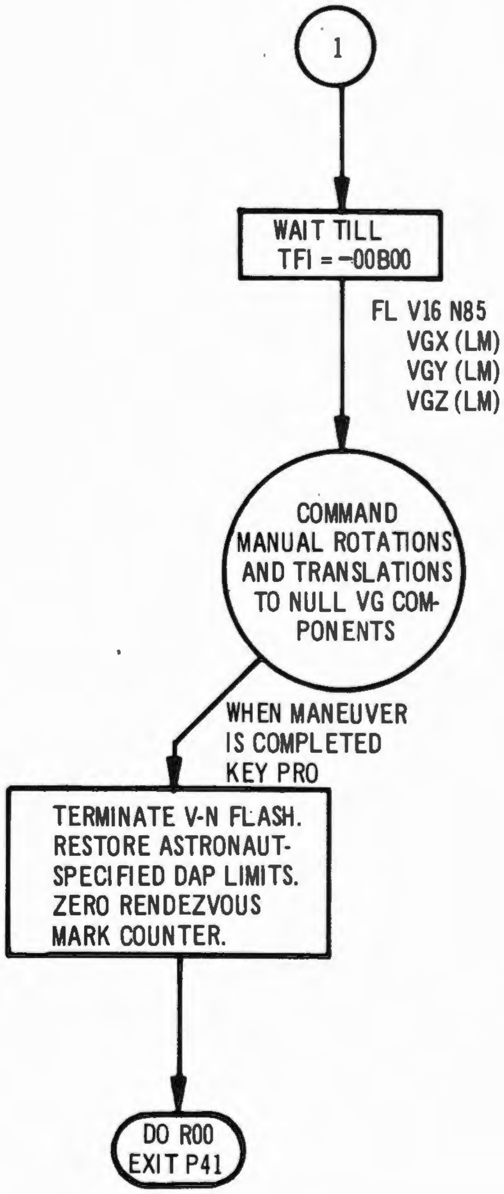


Fig. 5-21. RCS program (P41) (sheet 2 of 2).

5.2.3.14 APS Program (P42)

The APS program provides PGNCS control during an ascent propulsion system maneuver, including countdown, thrusting, and thrust termination. It computes a preferred IMU orientation and a preferred LM attitude for the thrusting maneuver. It also calculates and displays the IMU gimbal angles which would result from the present IMU orientation as the vehicle is maneuvered to the preferred LM attitude for thrusting. Prior to P42 entry, the IMU has been in the operate state for at least 15 min., and the target parameters have been calculated and stored by prior execution of a prethrusting (P3X) program. The required steering equations have been identified by this prethrust program as either lambert or external delta V steering.

P42 Is selected at least 5 minutes before ignition. The DAP data load routine (R03) has been performed prior to selection of P42. For initial thrust direction, the preferred IMU orientation is computed. The IMU gimbal angles with the present inertial orientation and preferred vehicle attitude are computed then utilized.

Two jet ullage is performed, beginning 3-5 seconds before APS ignition. During the burn the X-axis override option provides the crew with the ability to exercise manual control about the X LM axis with the attitude controller even though the PGNCS Attitude Control mode is auto. When the controller is returned to detent the PGNCS Damps the Yaw rate to approximately 1 degree/second, stores the yaw attitude when the yaw rate is damped, and then maintains that attitude. See (Fig. 5-22.)

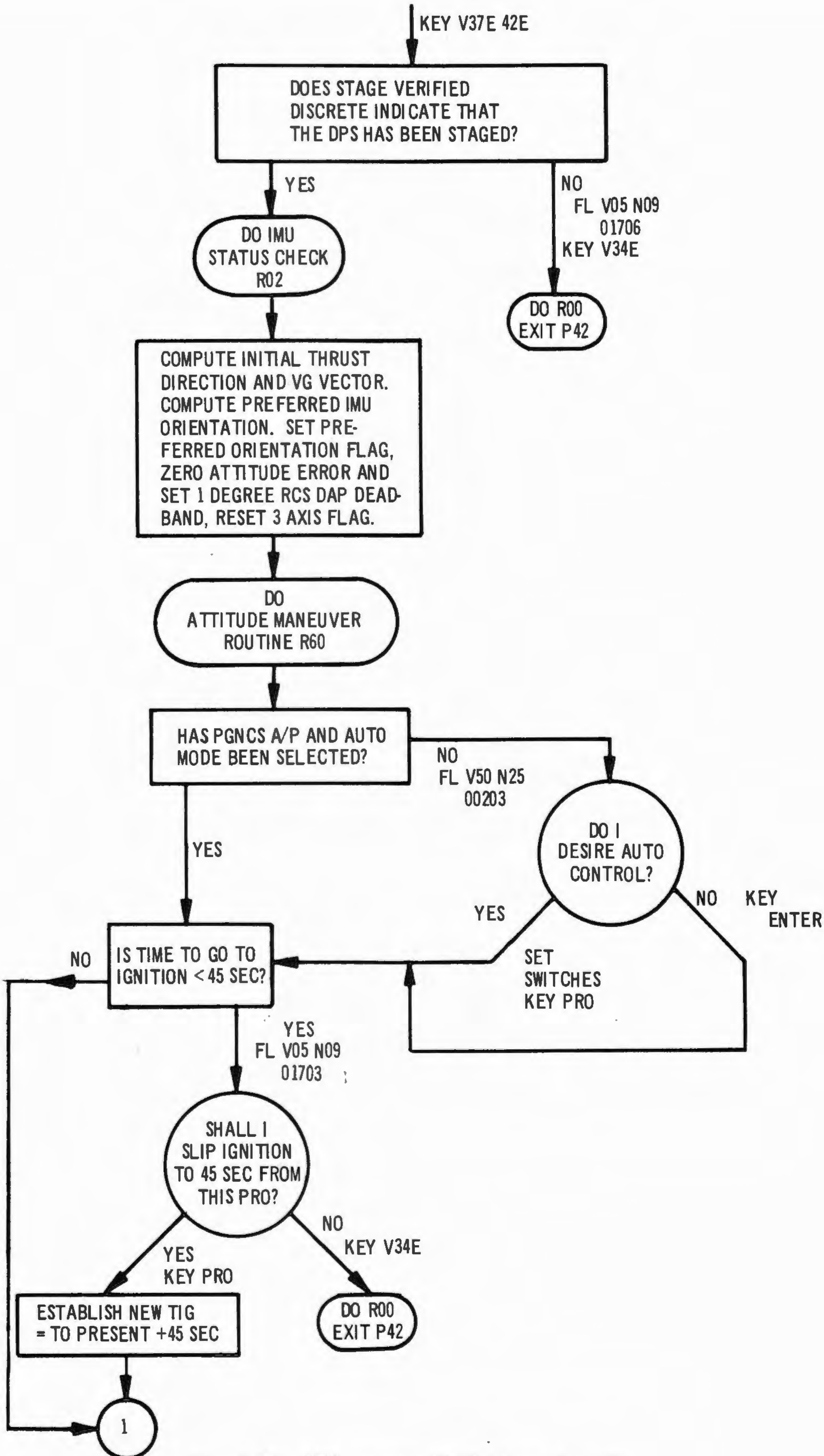


Fig. 5-22. APS program (P42) (sheet 1 of 3).

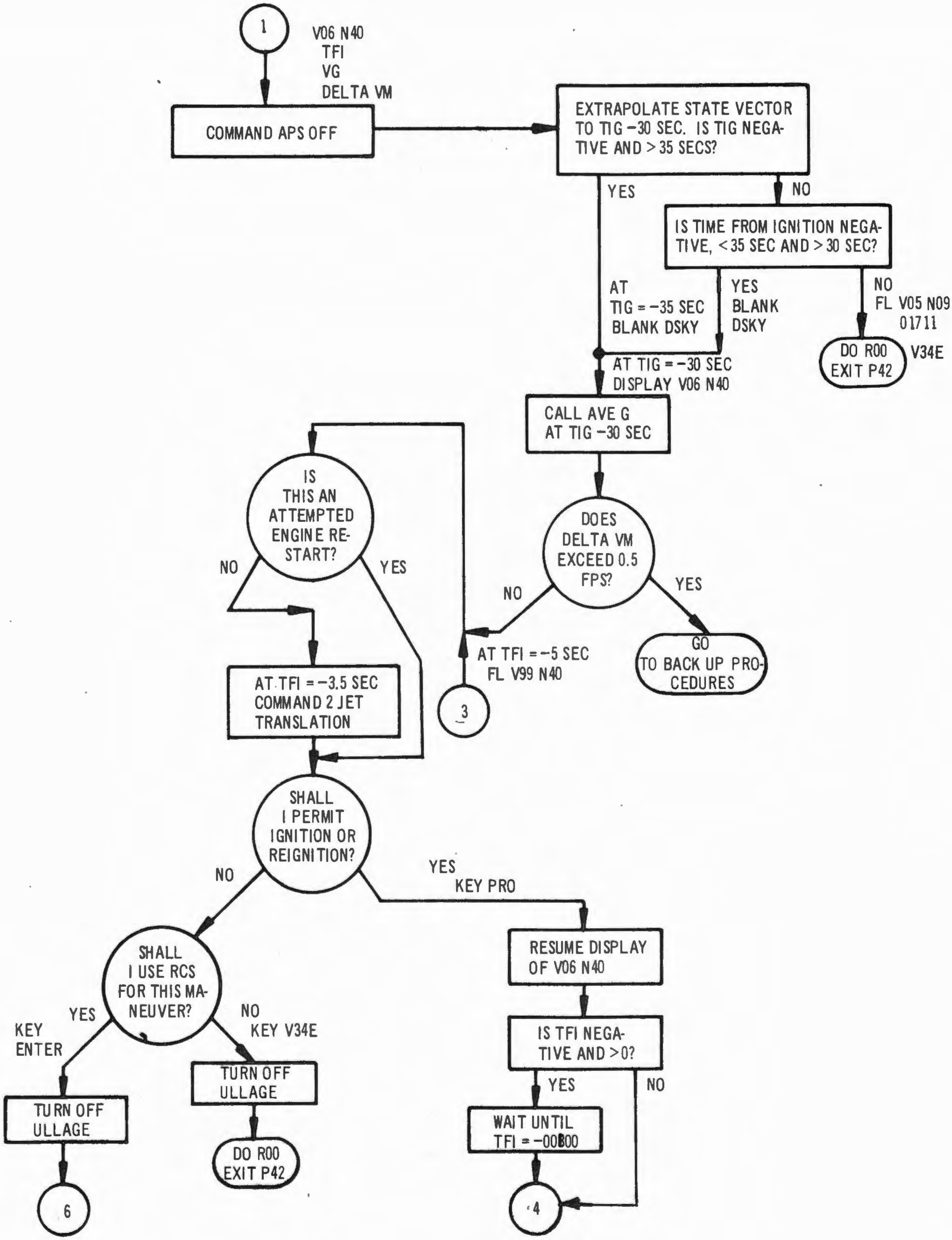


Fig. 5-22. APS program (P42) (sheet 2 of 3).

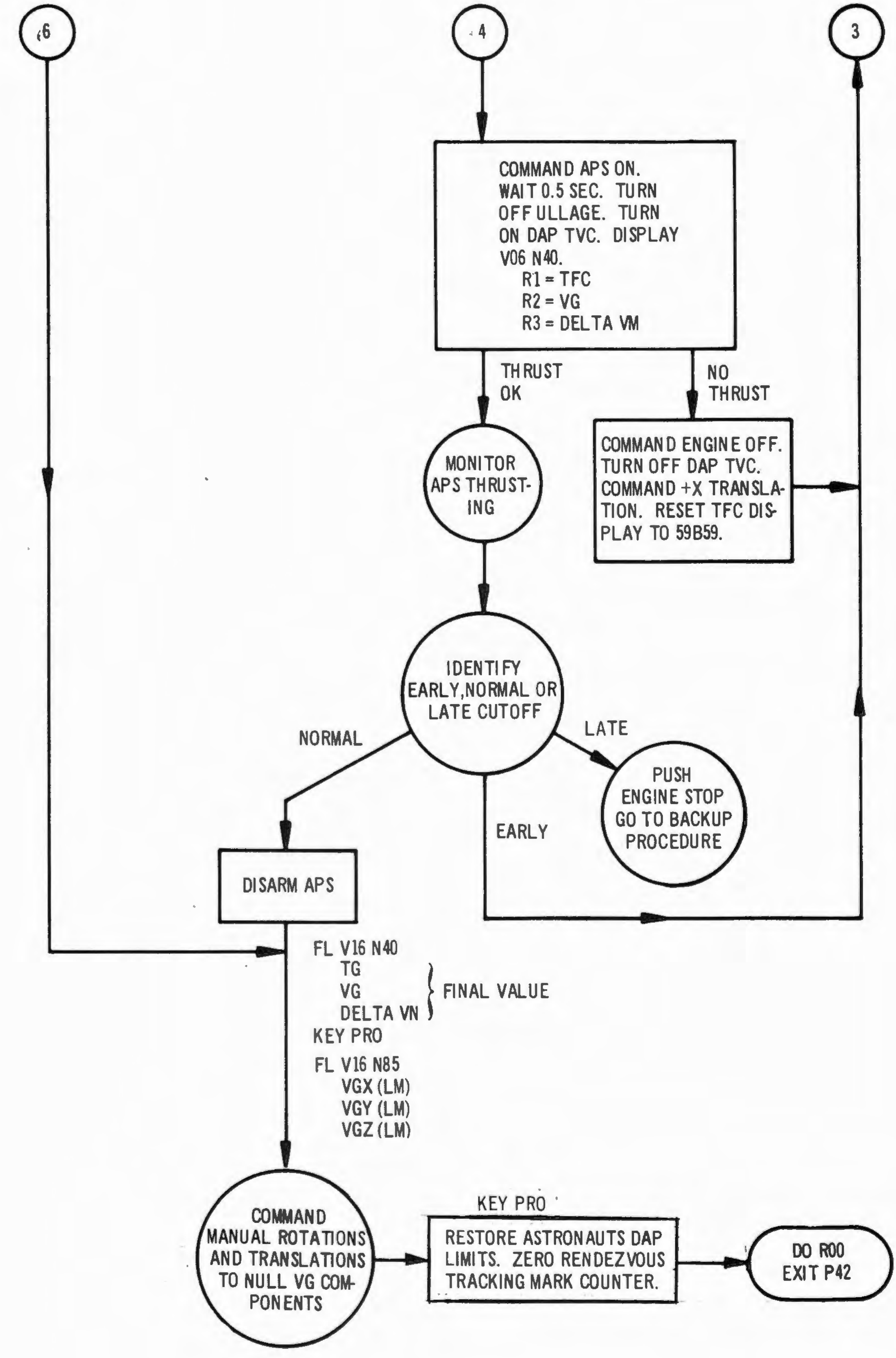


Fig. 5-22. APS program (P42) (sheet 3 of 3).

5.2.3.15 Thrust Monitor Program (P47)

If a thrust maneuver is performed without PGNCS control, P47 can be selected to monitor vehicle acceleration. It also displays delta V applied to the LM during thrusting. Monitoring for gimbal lock avoidance must be performed by the astronaut during this program. Program P47 is normally selected during the rendezvous final phase at least one minute before the thrusting maneuver that is not PGNCS controlled. (See Fig. 5-23.) Range, range rate, and theta may be displayed during this program by Keying V83E to call the rendezvous parameter display routine (R31).

5.2.3.16 IMU Orientation Determination Program (P51)

The IMU Orientation Determination Program is used to determine the orientation of the IMU. This program is performed after ISS start up or upon loss of refsmmat (known orientation).

Upon entry into the program, the AOT is energized for R53 performance and a check is made of the ISS zero flag to insure the IMU is energized. (See Fig. 5-24.) Ordinarily, the astronaut would then decide upon one of two logic flows. Subsequent IMU alignment decisions are greatly simplified if P51 is performed in a manner that provides an inertially stabilized IMU at an orientation facilitating future LGC programs. Hence, time and RCS fuel may be saved if a preferred direction can be obtained with two stars visible in the AOT FOV. in which case, a coarse alignment would probably be performed to obtain 0, 0, 0, gimbal angles at this preferred direction. The coarse alignment, thereby, provides an inertially fixed platform in an orientation advantageous to future maneuvers.

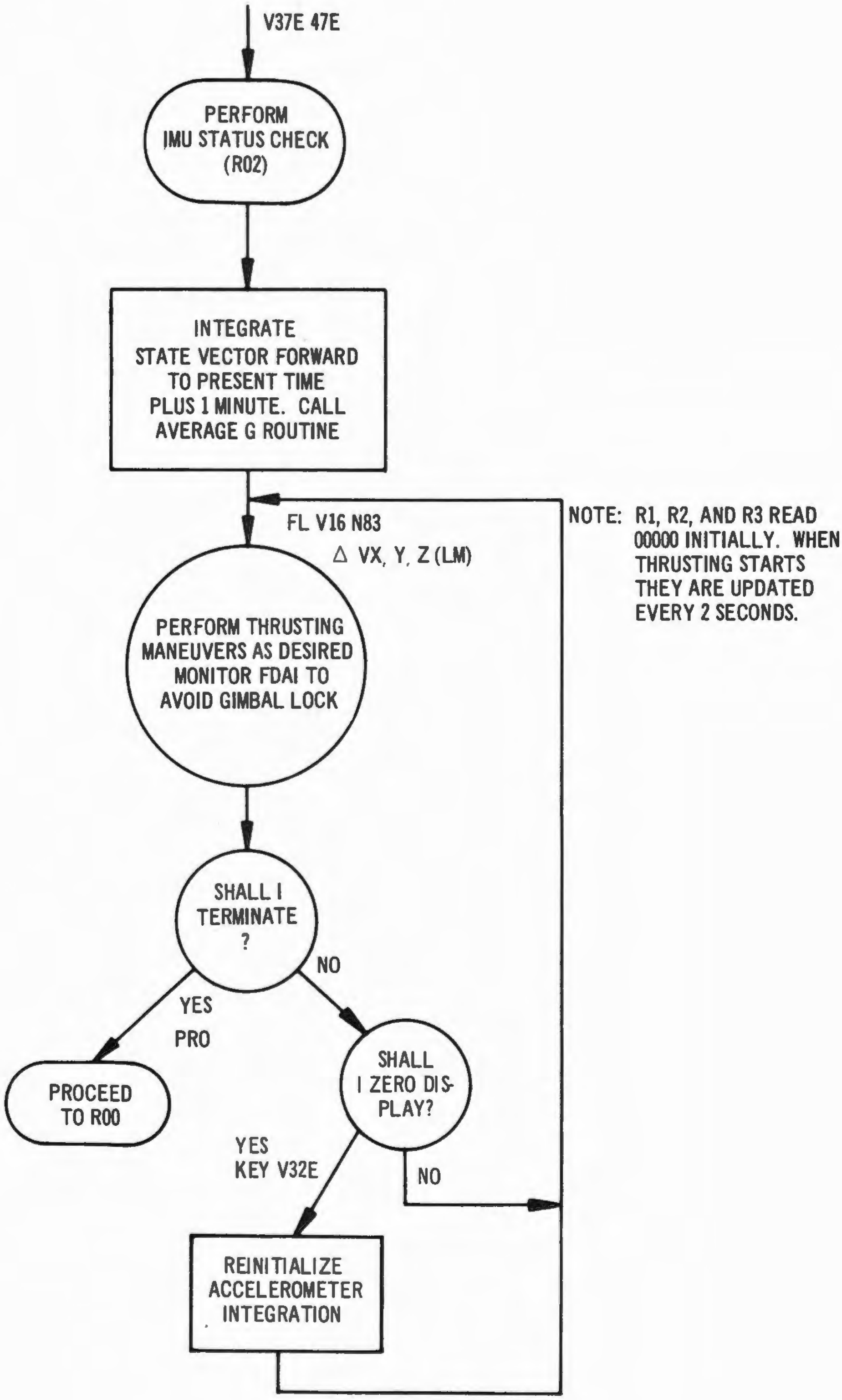


Fig. 5-23. Thrust monitor program (P47)

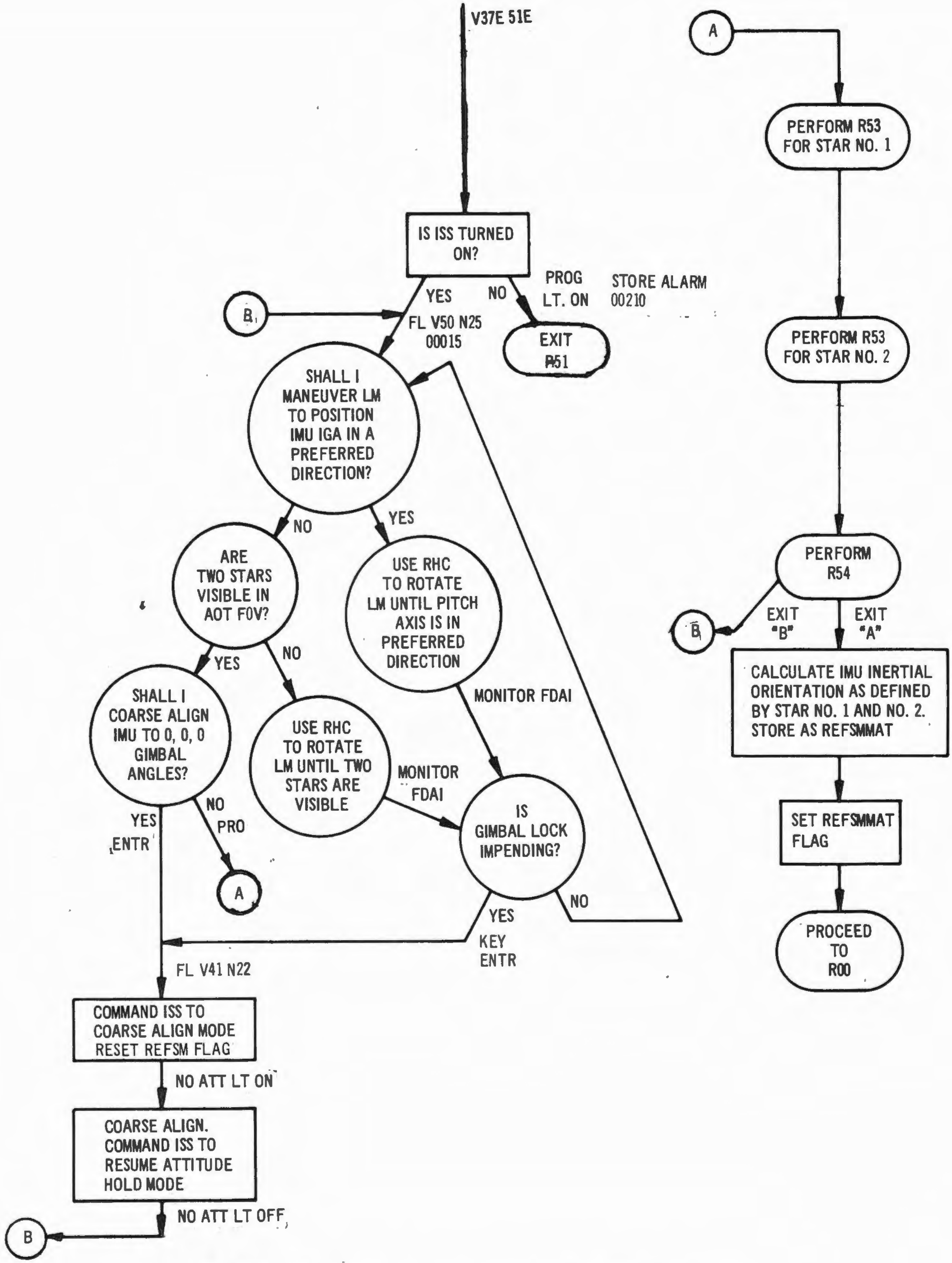


Fig. 5-24. IMU orientation determination program (P51) flow diagram.

In any logic flow case, sighting marks are then taken on two stars and the star vectors are used to calculate the IMU inertial orientation which is stored as refsmmat.

5.2.3.16.1 Sighting Mark Routine (R53)

From P51 or from the fine alignment routine (R51) within P52, the sighting mark routine is called. (See Fig. 5-25.) The astronaut loads the appropriate star code and AOT detent code, zeros the reticle counter, sets the PGNCS in attitude hold to obtain an attitude deadband, and Keys V76 to place the DAP in the minimum impulse mode. Optical sightings are then made on a given star by varying the LM attitude so that the star will cross the X and Y reticle lines near the center of view. The astronaut depresses the X or Y button when the star crosses the corresponding reticle line. If a MARK button is inaccurately depressed, a depression of the REJECT button cancels the previous mark.

When the star coincides with one of the reticle lines, this defines a plane containing a star. Once the location of the star has been established in two separate planes, the LOS to the star can be obtained by solving for the intersection of these two planes. Multiple sighting to a star can also be taken to average the LOS vector.

5.2.3.16.2 Signal Data Test Routine (R54)

Within P51 or from the fine alignment routine (R51) within P52, the signal data test routine is called to test the accuracy of star sightings. (See Fig. 5-26.) This routine calculates the angle difference between two stars using the measured data versus the actual data. The star difference angle is held in display until a DSKY entry is made.

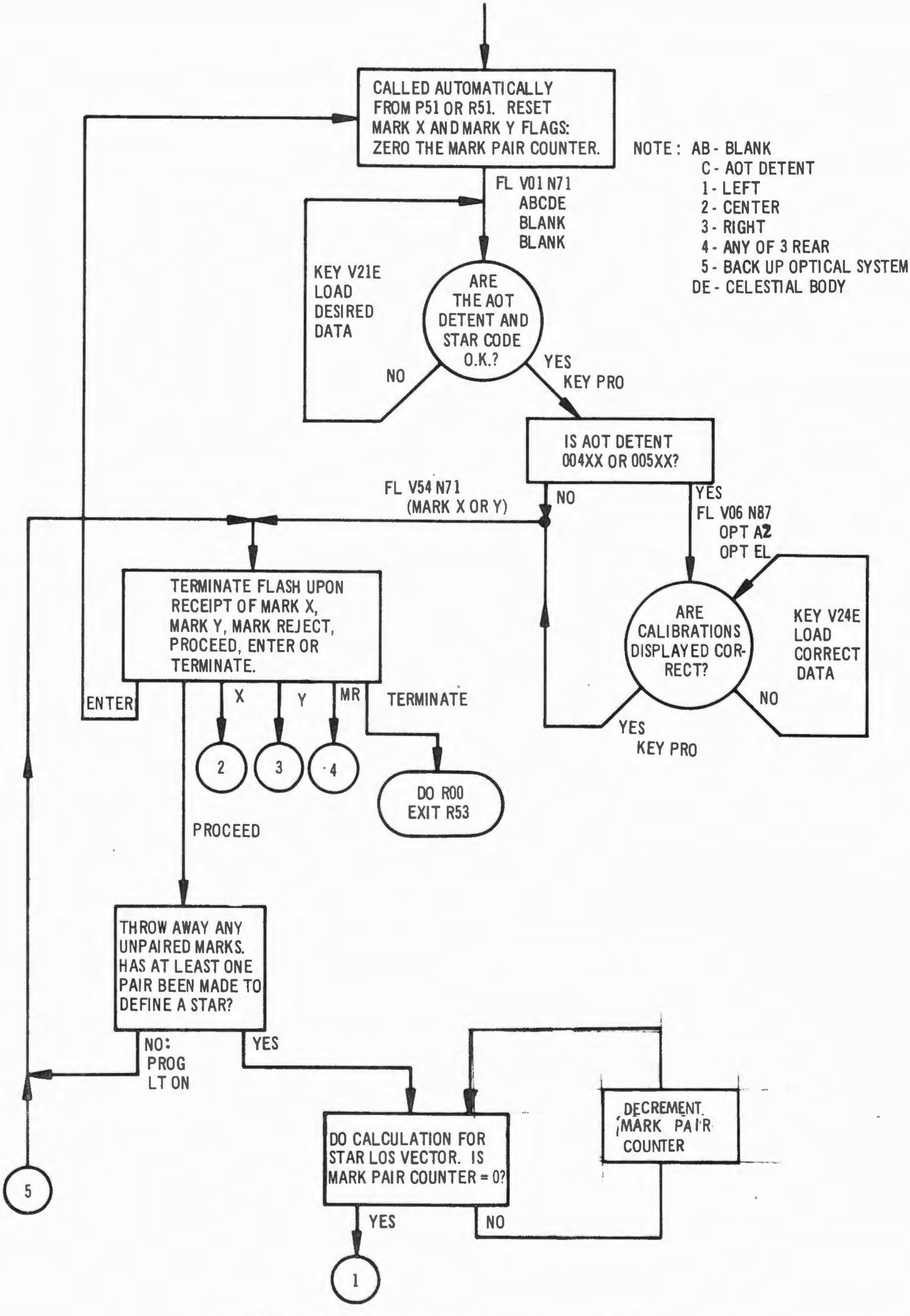


Fig. 5-25. Sighting mark routine (R53) (sheet 1 of 3).

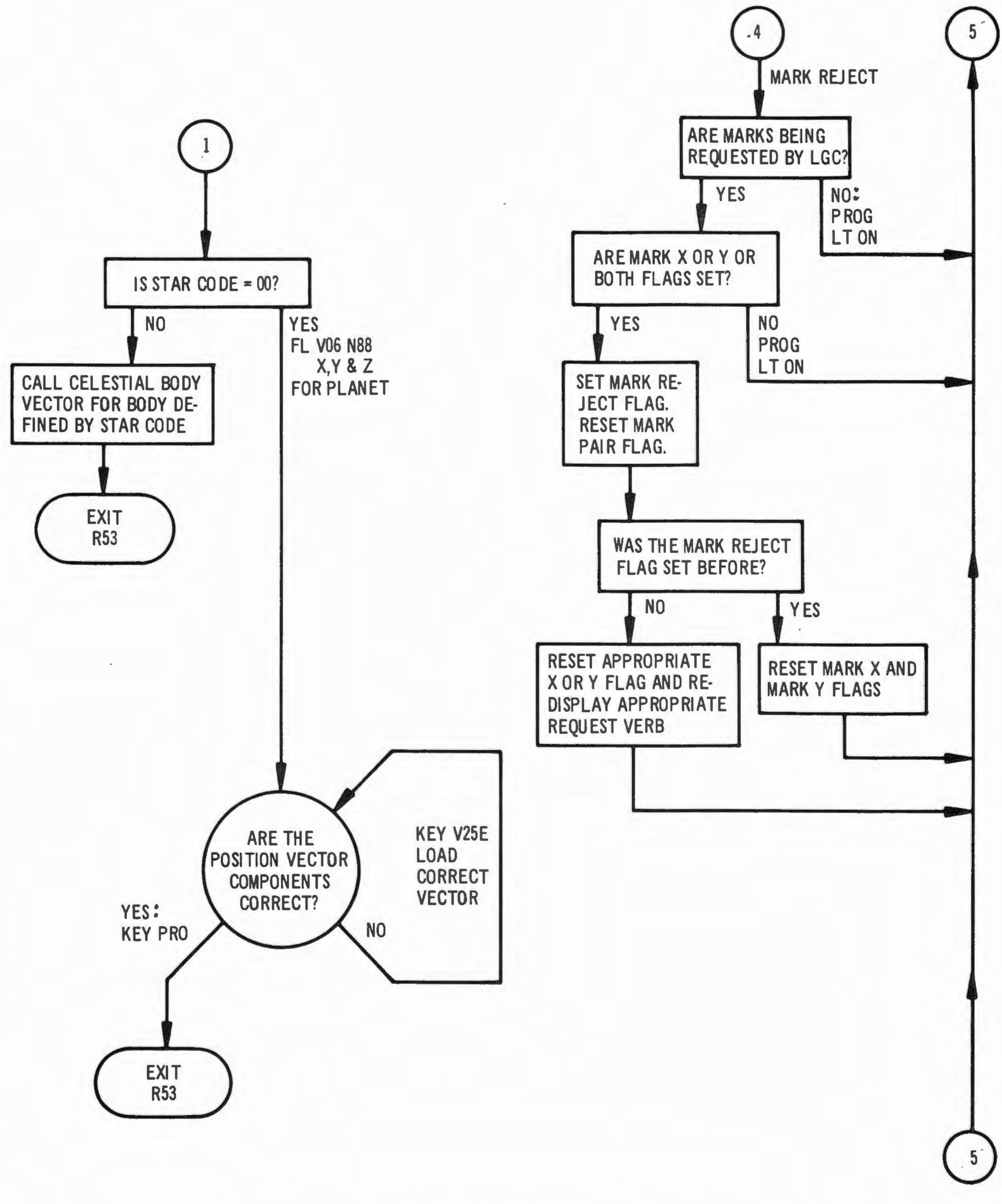


Fig. 5-25. Sighting mark routine (R53) (sheet 2 of 3).

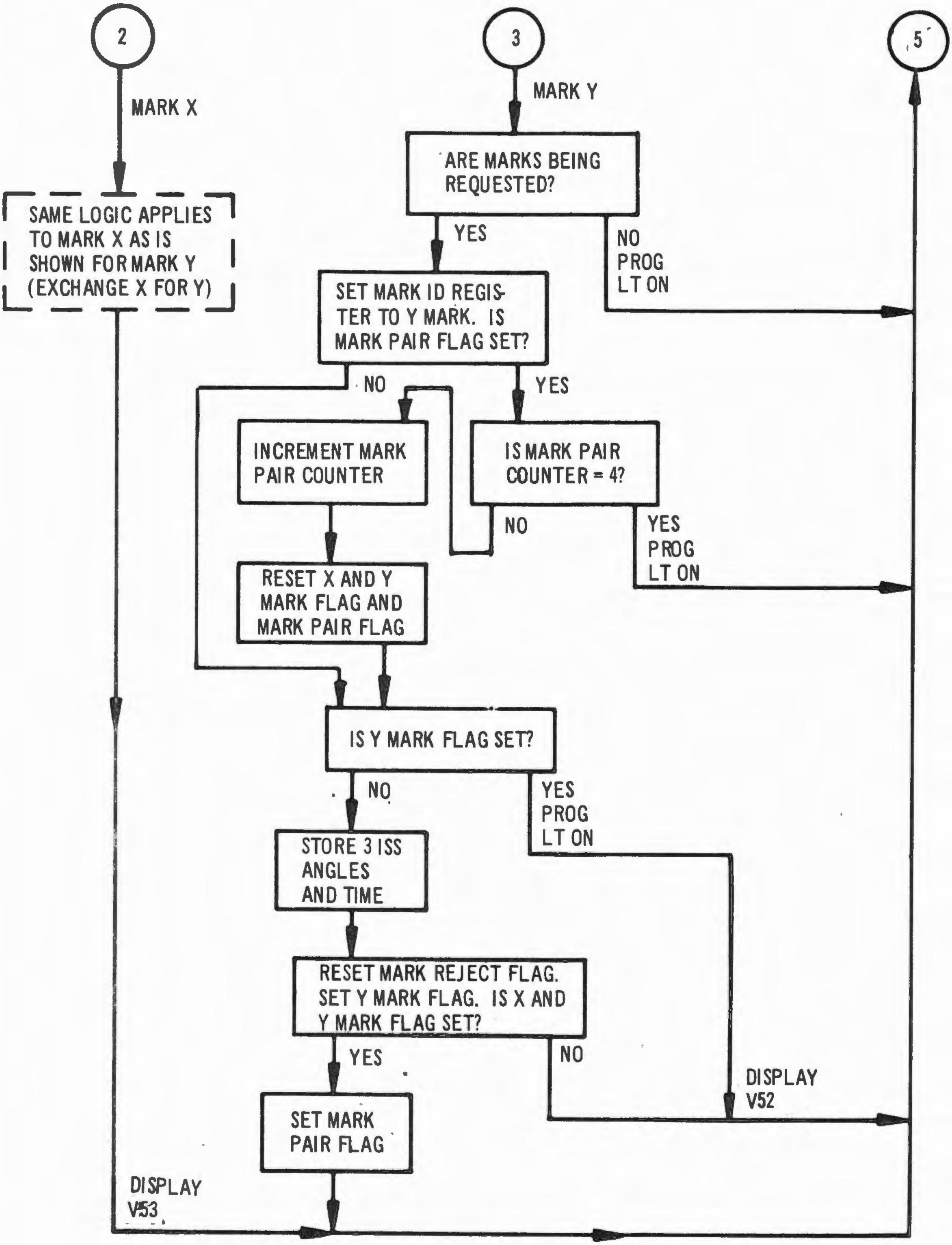


Fig. 5-25. Sighting mark routine (R53) (sheet 3 of 3).

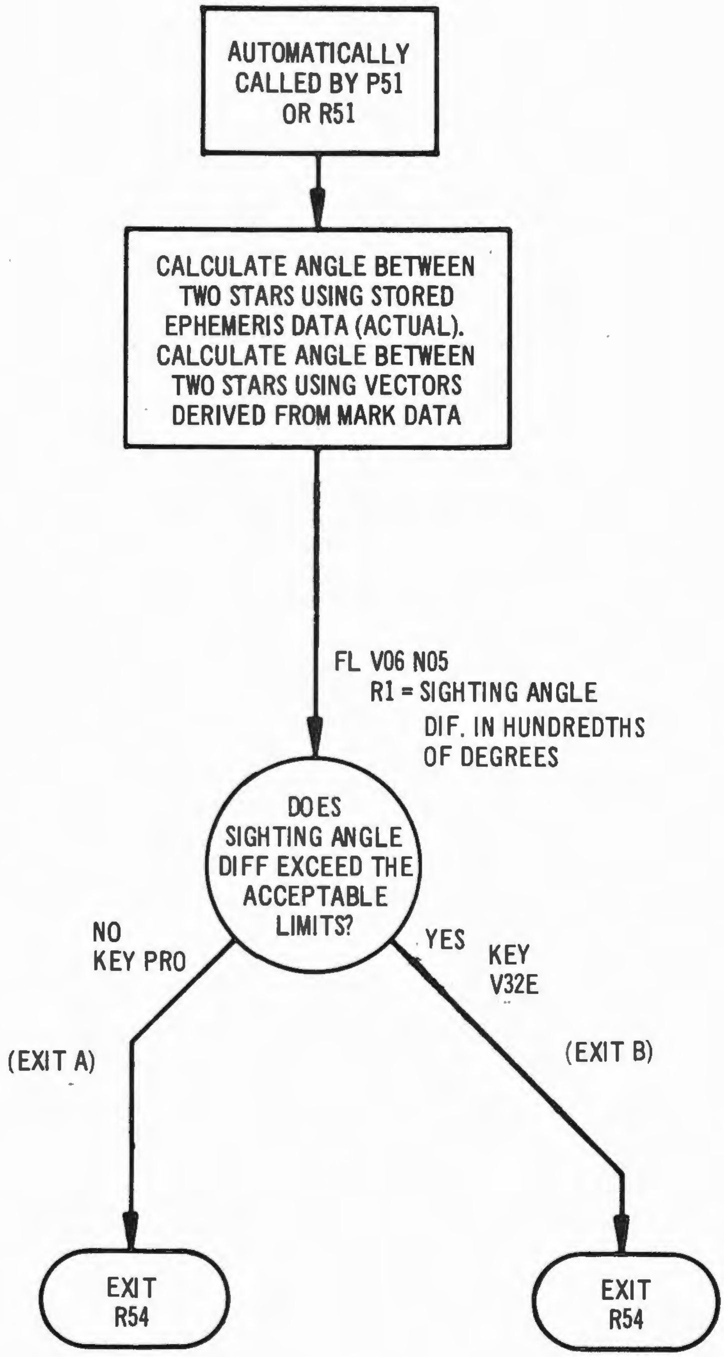


Fig. 5-26. Signal data test routine (R54) flow diagram.

5.2.3.17 IMU Realign Program (P52)

Alignment of the IMU from a known alignment to one of three orientations selected is accomplished within the IMU realign program. The three orientations are preferred, nominal, or refsmmat.

The preferred orientation is an optimum orientation for a previously calculated maneuver. The IMU stable member axes are inertially stabilized at an orientation closely aligned to the LM axes (that is, $Xsm \simeq X_{LM}$, $Ysm \simeq Y_{LM}$, and $Zsm \simeq Z_{LM}$). Within the thrusting programs P40, P41, and P42, the preferred orientation is calculated and the preferred flag set. The advantage of the preferred orientation is that the maneuver can be performed without excessive MGA and thereby avoid gimbal lock.

The nominal orientation is an alignment of the stable member to local vertical providing a heads up alignment often more suitable for manual control. The Xsm axis is aligned to the geocentric radius vector, and the Ysm axis is aligned to the cross product of the geocentric radius vector and the inertial velocity vector.

It is assumed that some time prior to entry into P52 that the ISS in on and orientation determination (P51) has previously been performed. The present IMU orientation may differ from what it was aligned to due to gyro drift. Hence, P52 may also be selected for realignment.

P52 is shown in Fig. 5-27. In response to the IMU orientation selection request (FL V04 N06, option code 00001), the astronaut loads the IMU orientation desired. If the preferred orientation is selected, the appropriate flag must be previously set by a thrusting program. If the nominal orientation is selected, the keyed in T(Align) time is the GET at which vehicle position and velocity vectors are selected to define IMU and LM nominal orientation, and the LGC selected T(Align) time is time of ignition (if known) or current time. If the refsmmat

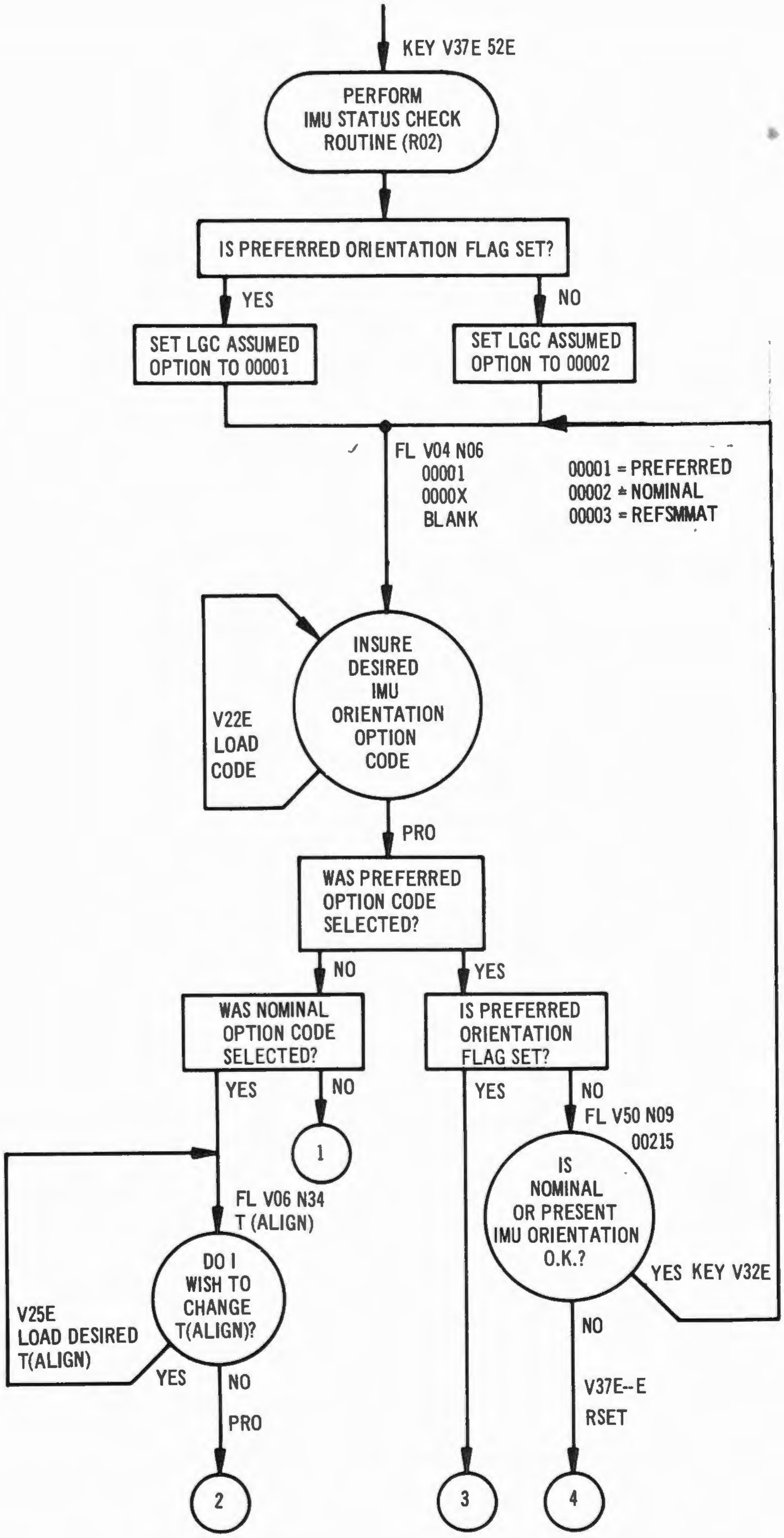


Fig. 5-27. IMU realign program (P52) flow diagram (sheet 1 of 2).

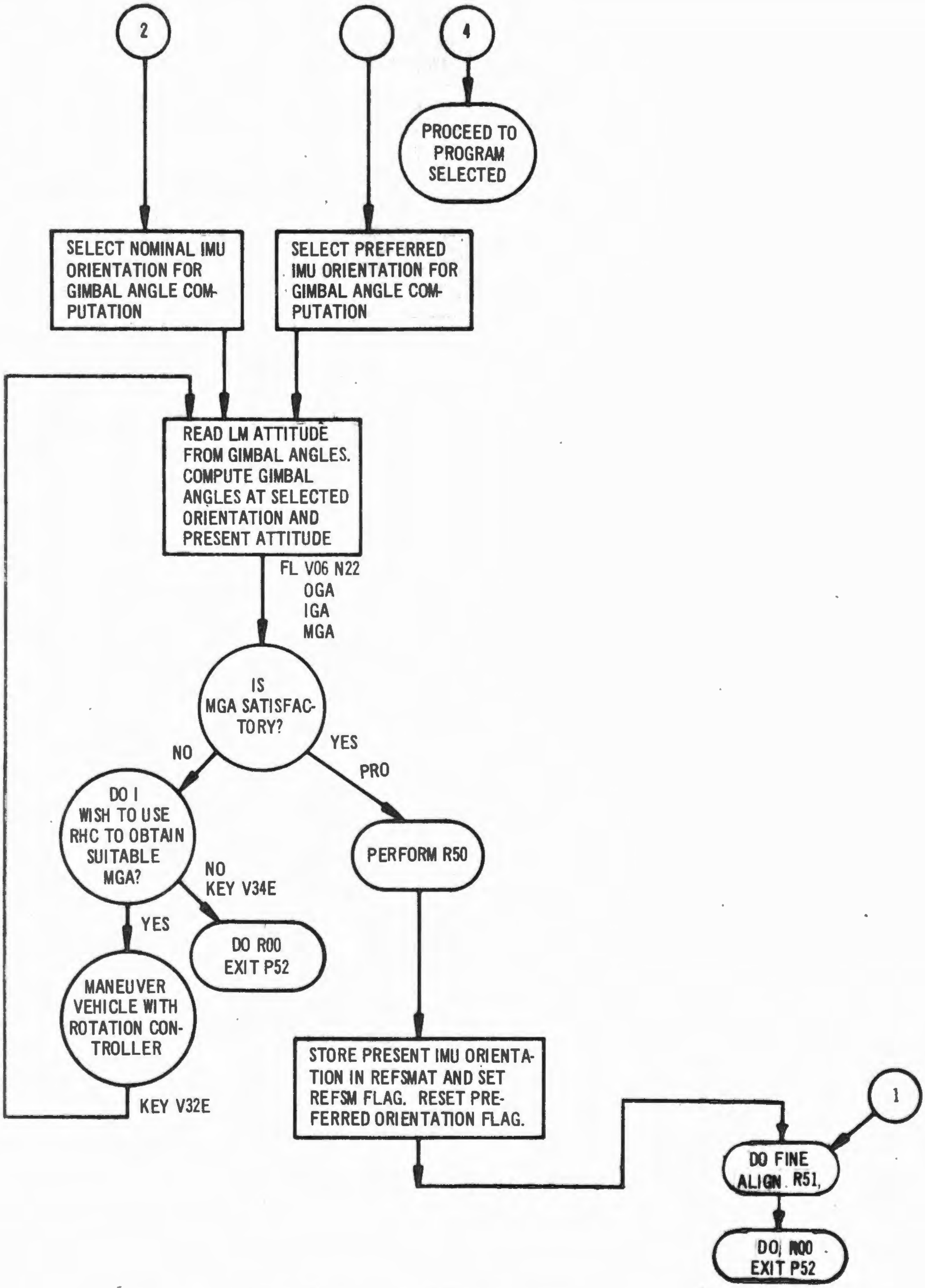


Fig. 5-27. IMU realign program (P52) flow diagram (sheet 2 of 2).

orientation is selected, coarse align routine (R50) is not performed as the system varies from the previous alignment only by gyro drift. With preferred or nominal orientation selected, coarse alignment is performed to inertially stabilize the platform at the selected orientation. The refsmmat flag is then also set as the preferred or nominal orientations are known orientations.

A maneuver is then made to acquire the suitable stars for the fine alignment routine (R51). An internal star selection routine aids the selection of the best pair of stars for fine alignment taking into consideration the amount of propellant required for the attitude maneuver. The routine first selects a suitable star not occulted by the earth, moon, or sun which is closest to the center of the AOT FOV. The remaining stars, also not occulted by the earth, moon, or sun, are then checked to see if one is available which is separated from the first star by at least 50° and is within 100° of the AOT Field Center. If two stars are unavailable, a program alarm is flashed. If they are available, the star codes are flashed in the beginning of fine alignment by the automatic optics positioning routine (R52).

5.2.3.17.1 Coarse Align Routine (R50)

Coarse alignment of the IMU is performed by R50. (See Fig. 5-28.) This routine is automatically selected by P52 to inertially stabilize the platform at either the preferred or nominal orientation. It obtains through the ICDU read counters present IMU orientation and calculates the orientation of the vehicle. The desired orientation is obtained from storage and the required final gimbal angle changes are determined. If any of the gimbal angle changes are greater than 1 degree, the ISS is switched to the coarse align mode by the LGC issuing the ISS error counter enable and coarse align discretes. (The ISS may also be put into the coarse align mode in P51.) Attitude hold of the vehicle is terminated, and the LGC enters into each error counter the number of pulses necessary to produce the desired analog drive signals. The NO ATT light is on for approximately

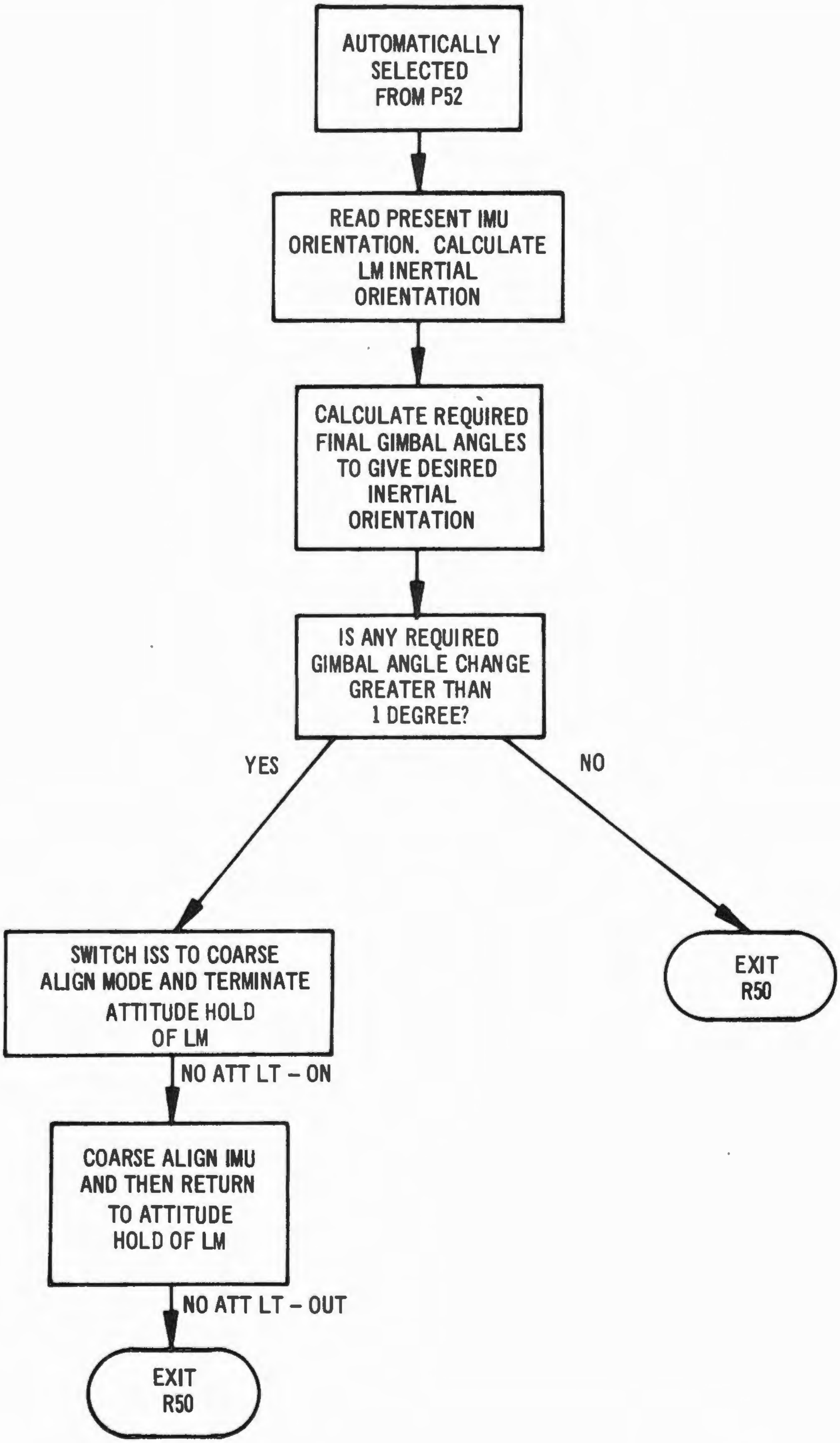


Fig. 5-28. Coarse align routine (R50) flow diagram.

15 seconds. At the conclusion of this period, the error counters are zeroed and the discretes removed so that the ISS enters the inertial reference mode.

5.2.3.17.2 Fine Alignment Routine (R51)

Fine alignment of the IMU to a desired inertial orientation is performed by the fine alignment routine. (See Fig. 5-29.) This routine sequentially calls up R52 for automatic optics positioning and R53 (see section 5.2.3.16.1) for sighting makrs for the first selected star. These routines are then repeated for a second star. The accuracy of the star sighting is then checked by R54 (see section 5.2.3.16.2) which is followed by the gyro torquing routine (R55) to torque the gyros accurately to the calculated stable member attitude.

5.2.3.17.3 Automatic Optics Positioning Routine (R52)

During fine alignment, the automatic optics positioning routine is used to maneuver the LM attitude so that a selected star will be available within the AOT FOV. Upon entry into the routine, the display star code is the one recommended by the internal star selection routine. (See Fig. 5-30.) If another star is desired, its star code must be loaded into the DSKY via a V21E. The desired vehicle attitude is then defined to be the center AOT LOS along the LOS to this selected star. The attitude maneuver is performed by R60 to this LOS.

5.2.3.17.4 Gyro Torquing Routine (R55)

The inflight fine alignment to calculate the gyro torquing angles, to display these angles, and to align the stable member to the calculated orientation is performed by the gyro torquing routine. Upon entry into R55, the torquing angles for each gyro are calculated. (See Fig. 5-31.) The LGC has been monitoring the associated ICDU read counters. Line of sight data obtained from R53 is transformed into stable member coordinates. From the difference between the actual gimbal

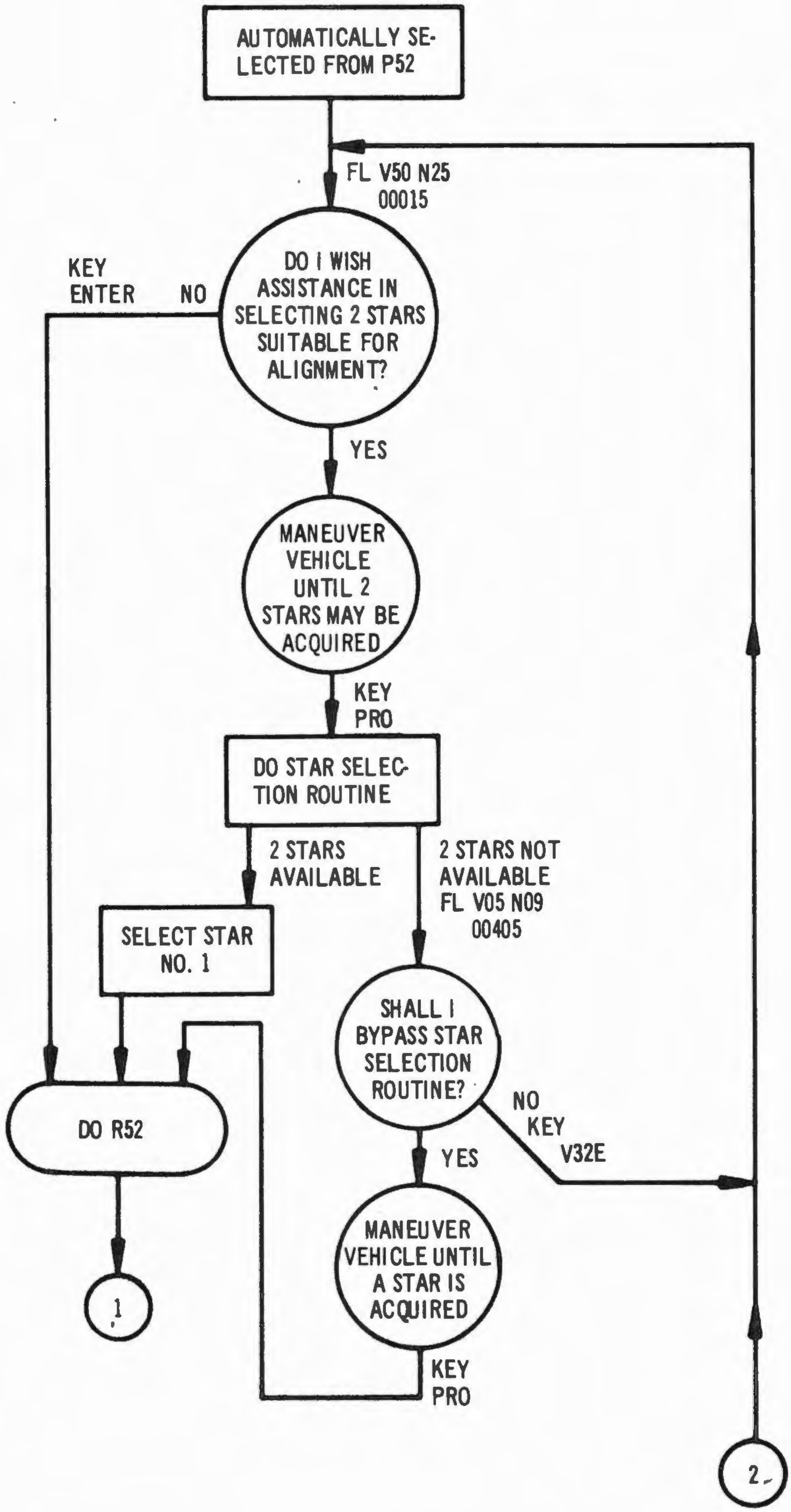


Fig. 5-29. Fine alignment routine (R51) (sheet 1 of 2).

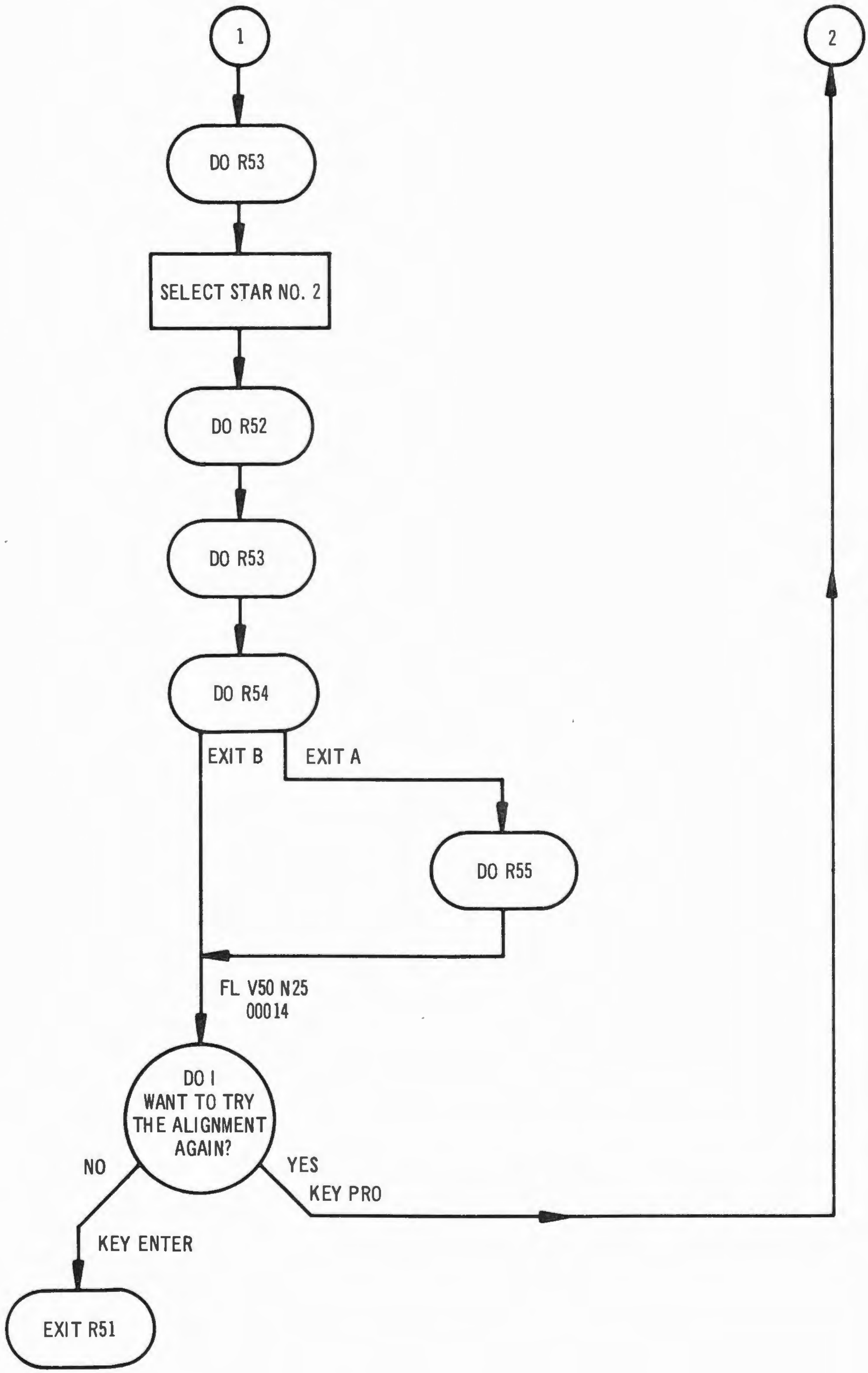


Fig. 5-29. Fine alignment routine (R51) (sheet 2 of 2).

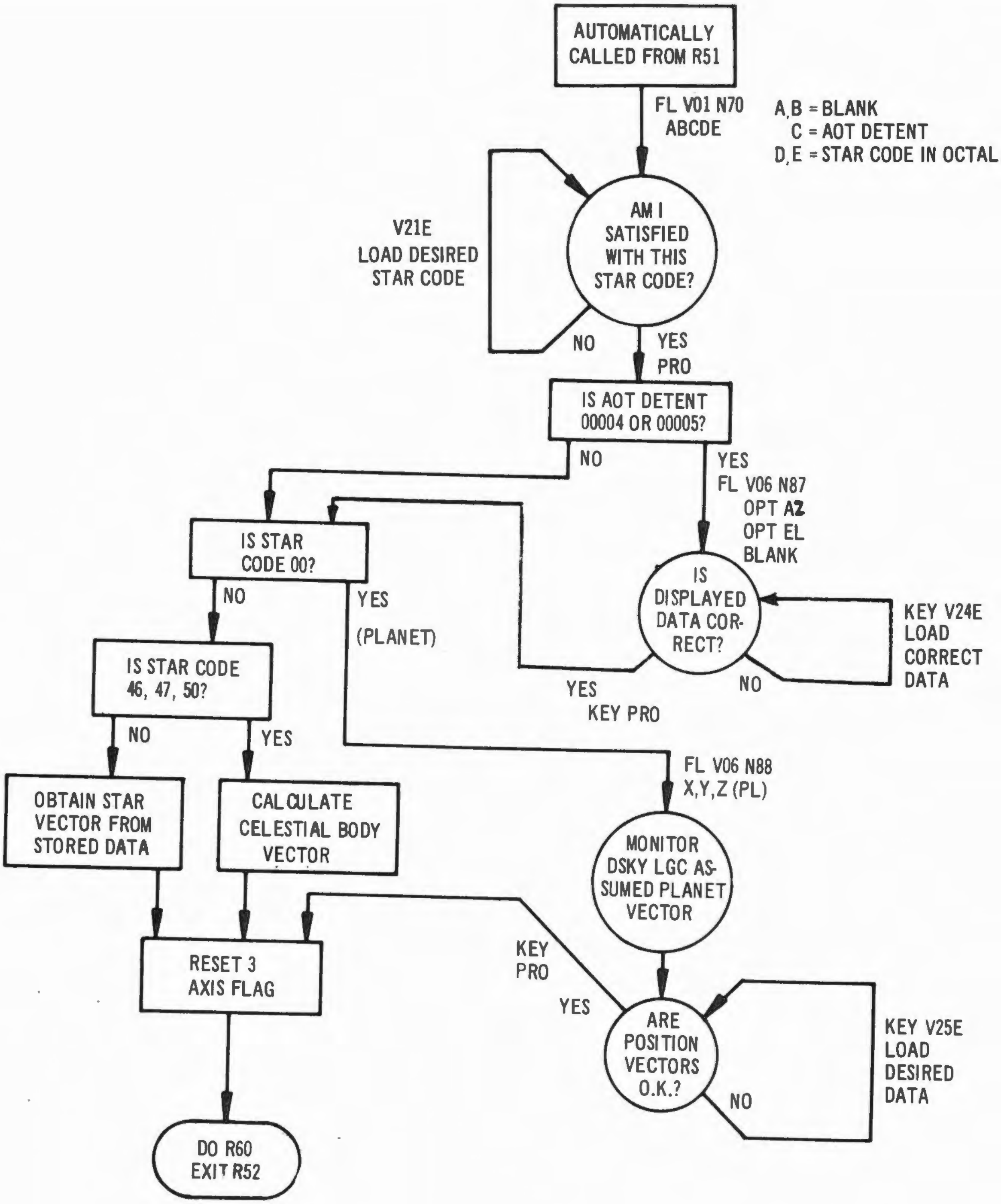


Fig. 5-30. Auto optics positioning routine (R52).

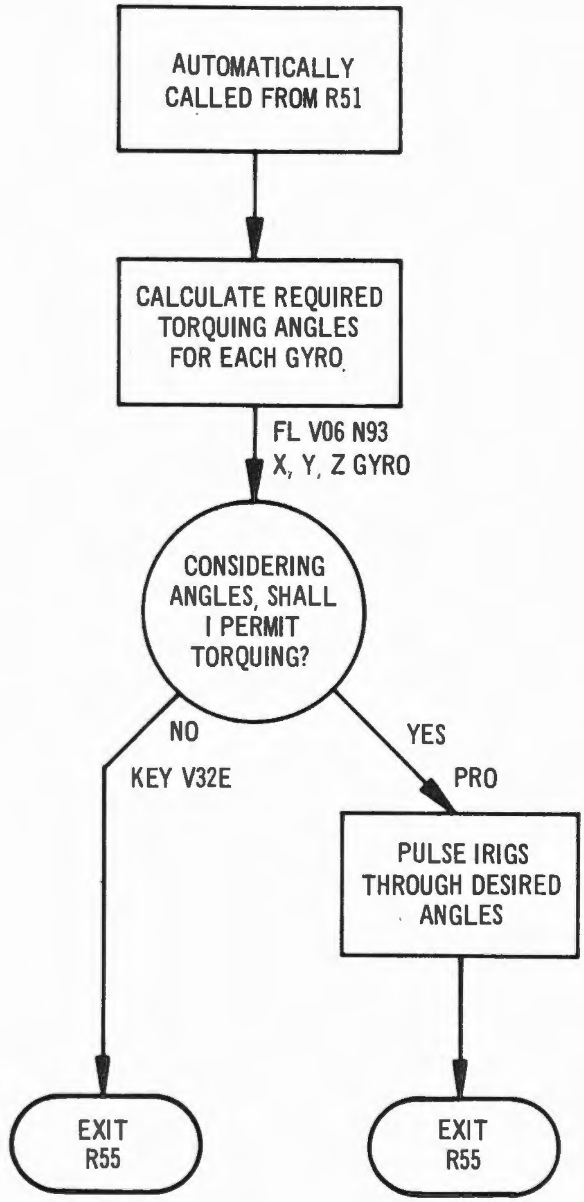


Fig. 5-31. Gyro torquing routine (R55) flow diagram.

angle and the desired gimbal, the LGC computes the angular rotation about each stable member axis necessary to change the stable member to the desired coordinate frame. The angles through which each gyro must be torqued are displayed in the DSKY registers. Upon reception of PRO in response to this display, the LGC generates the gyro torquing pulses to each gyro. Upon completion of torquing, stable member orientation may be checked with another set of star sightings.

5.2.3.18 Final Automatic Request Terminate Routine (R00)

This routine provides an exit for programs and an option to select any program desired. (See Fig. 5-32.) The V37 flash is a request for a new program selection. Upon keying in the new program (V37E XXE), R00 checks to insure all conditions are satisfactory for this new program selection.

5.2.3.19 IMU Status Check Routine (R02)

The IMU status check routine is integrated into each program where a need exists to check whether the IMU is turned on and whether it is aligned to an orientation known by the LGC. (See Fig. 5-33.) This is accomplished by checking the refsmmat flag (set within P51 or P52) and the ISS zero flag. If the IMU is not turned on or orientation is not known, a request is made for appropriate program selection. Programs that perform the status check are the thrusting, the prethrusting, the rendezvous navigation and preferred tracking attitude.

5.2.3.20 Digital Autopilot Data Load Routine (R03)

The digital autopilot data load routine is called by Keying V48E. (See Fig. 5-34.) This routine is selected prior to performing a PGNCS autopilot, thrusting maneuver. The autopilot configuration is selected, and the vehicle weights are confirmed. From the weight data, the LGC computes the inertias. If the descent stage is attached a request is then made to trim the descent engine gimbals. In the worst case, this trimming should require less than 2 minutes.

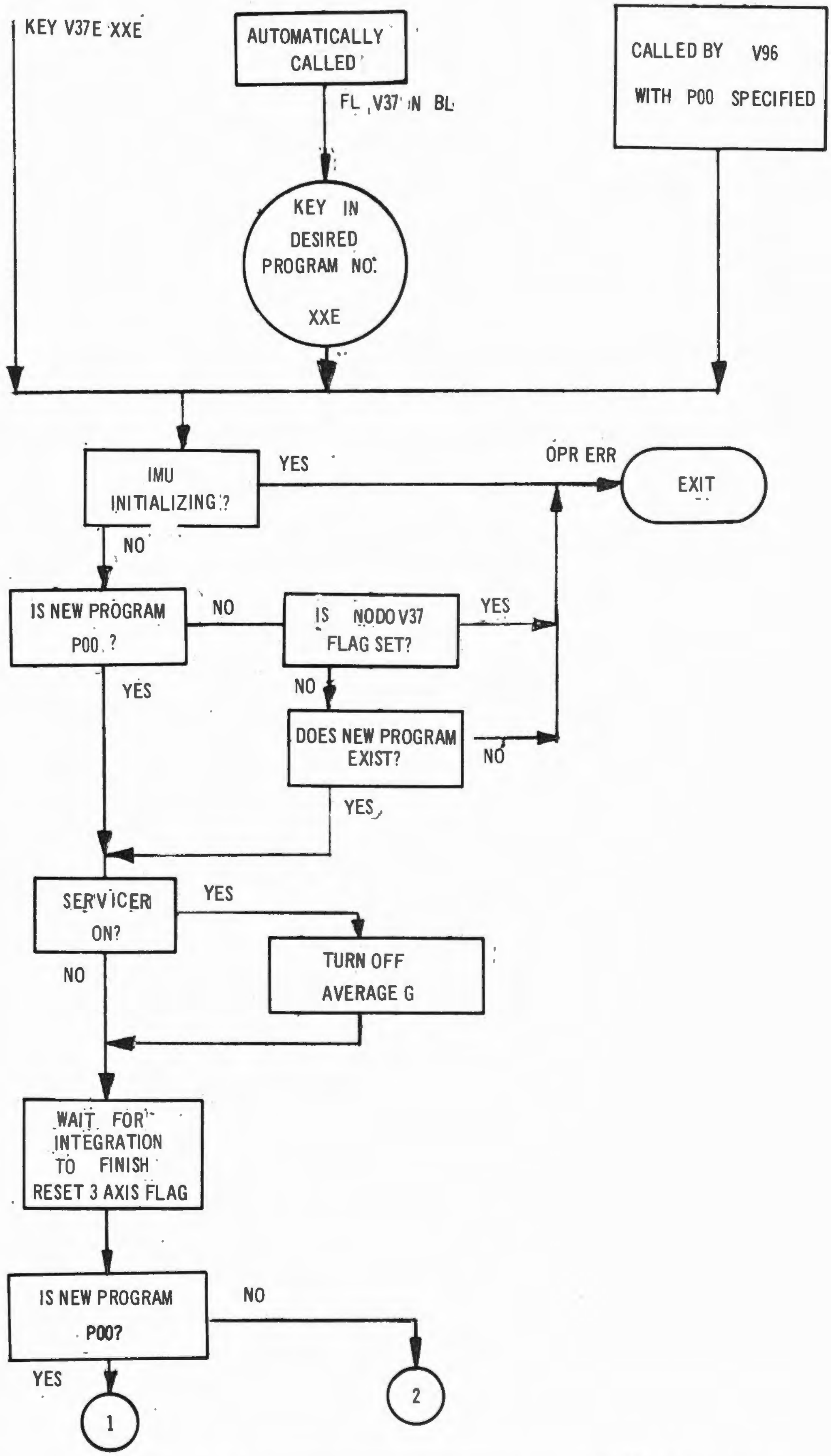


Fig. 5-32. Final automatic request terminate routine (R00) (sheet 1 of 2).

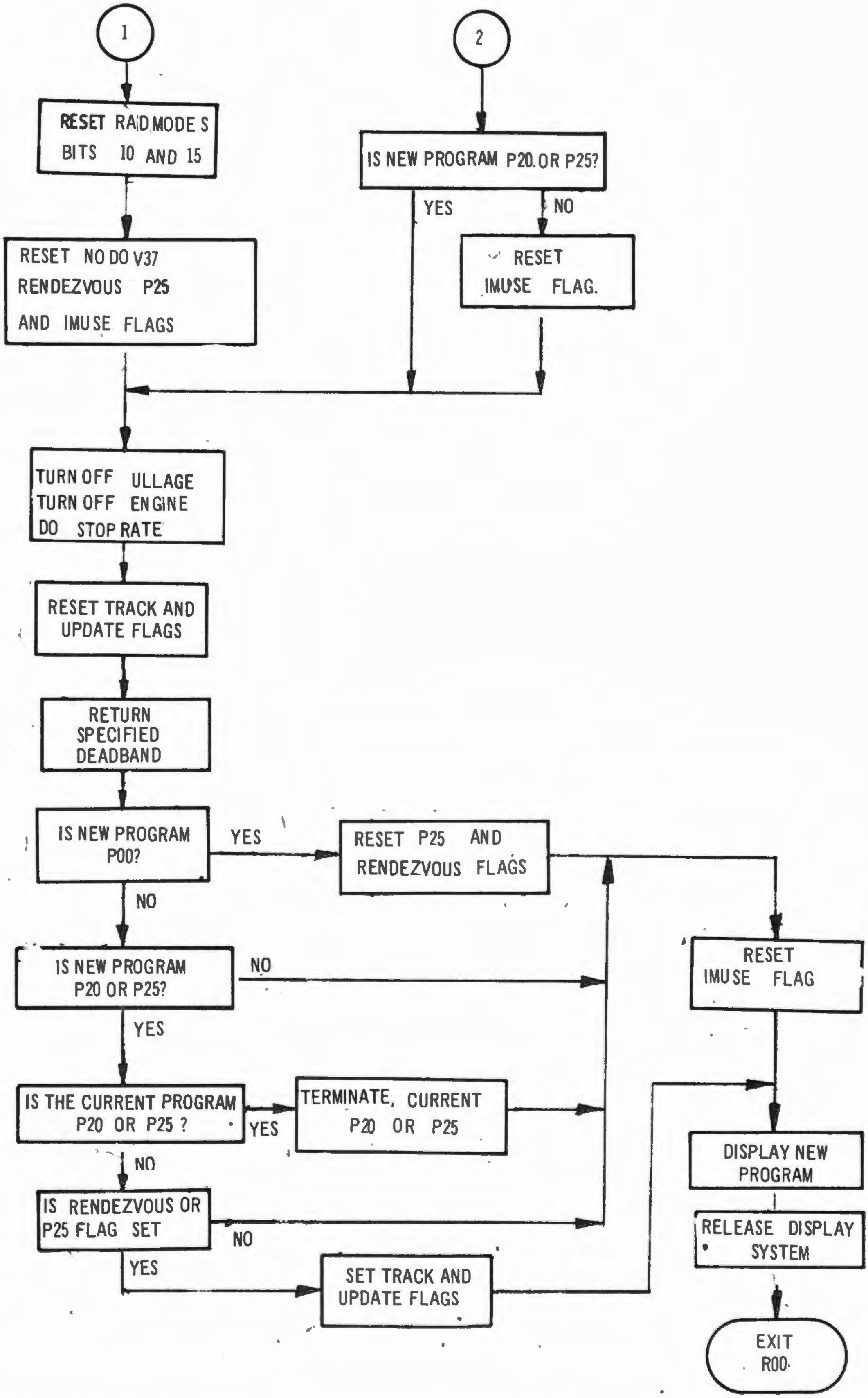


Fig. 5-32. Final automatic request terminate routine (R00) (sheet 2 of 2).

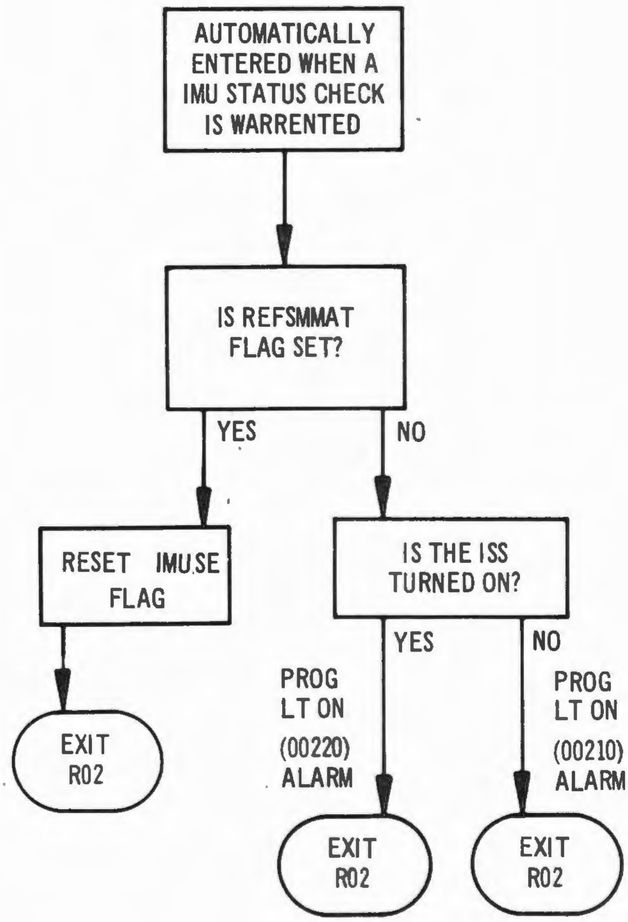


Fig. 5-33. IMU status check routine (R02) flow diagram.

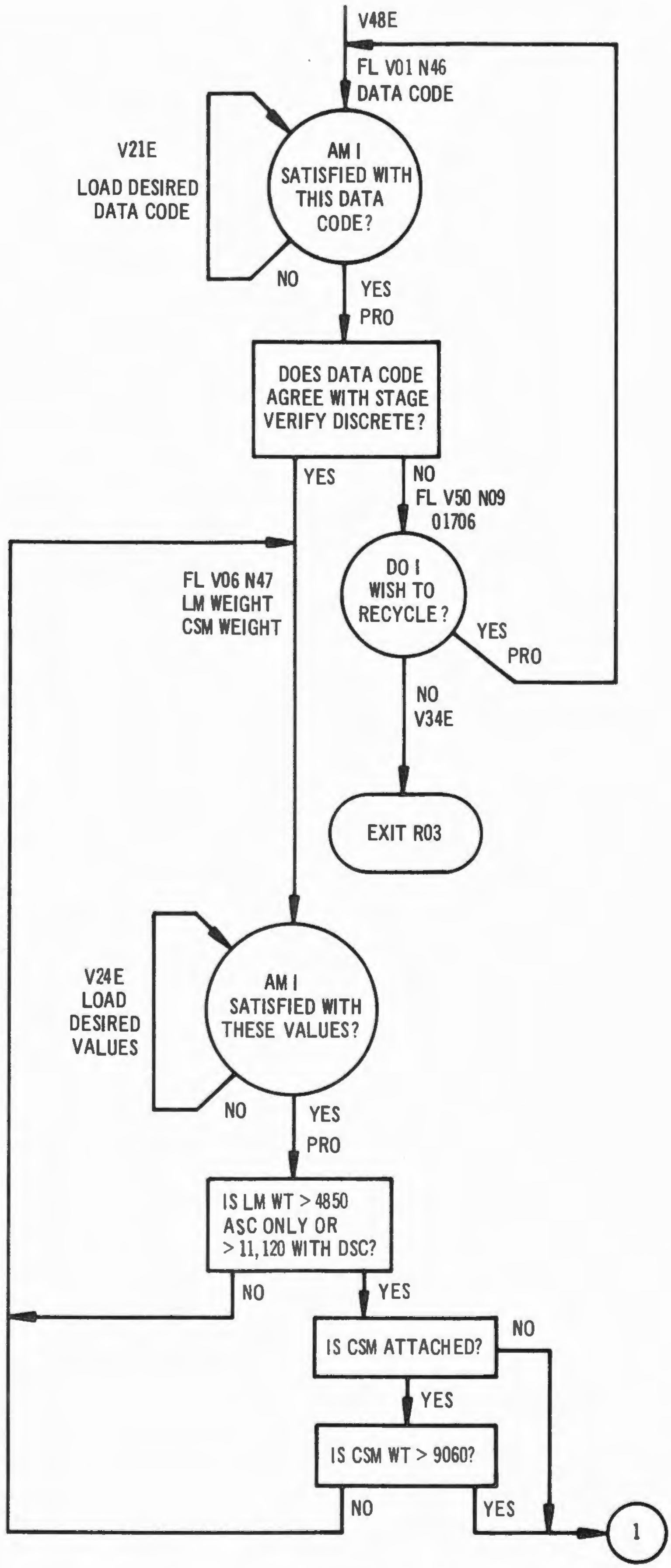


Fig. 5-34. Digital autopilot load (R03) (sheet 1 of 2).

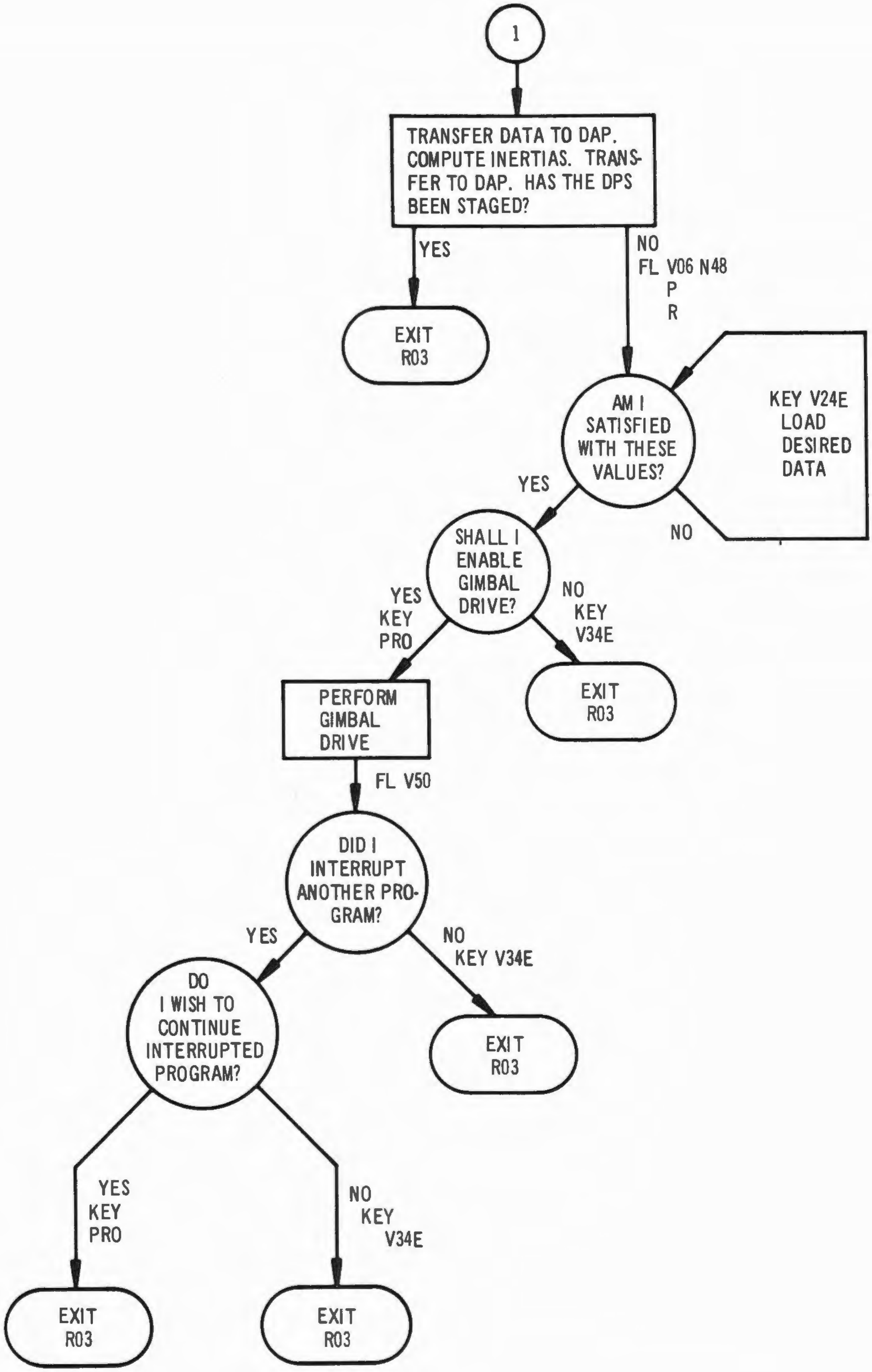


Fig. 5-34. Digital autopilot load (R03) (sheet 2 of 2).

5.2.3.21 RR/LR Self Test Routine (R04)

The RR/LR self test routine is called by keying in V62E. (See Fig. 5-35.) This routine is selected to provide suitable DSKY displays and LGC downlink information to support the self tests of the rendezvous or landing radar.

5.2.3.22 Orbit Parameter Display Routine (R30)

To display the apogee altitude, the perigee altitude, and the time of free fall to 300,000 feet altitude above the launch pad radius, the orbit parameter display routine is called. (See Fig. 5-36.) This routine may be called by keying V82E. If the perigee altitude is less than or equal to 300,000 feet, the time to perigee is also displayed.

5.2.3.23 Rendezvous Parameter Display Routine (R31)

To display the range and range rate between the CSM and LM and to display the angle between the LM +Z axis and the local horizontal plane at the present time, the rendezvous parameter display routine is called by keying V83E. (See Fig. 5-37.) Range and range rate are calculated on the basis of LM and CSM state vectors. The RR is not required to be operating.

5.2.3.24 Target Delta V Routine (R32)

To notify the LGC that the CSM has changed its orbital parameters by execution of a thrusting maneuver and to also provide to the LGC the CSM delta V applied for updating the CSM state vector, the target-delta V routine is called by keying V84E. (See Fig. 5-38.) If P20 is in process, this routine must be selected prior to the CSM thrusting maneuver. If R32 is selected during state vector updating within P20, the vector updating process is temporarily terminated until the CSM delta V is incorporated into the CSM state vector.

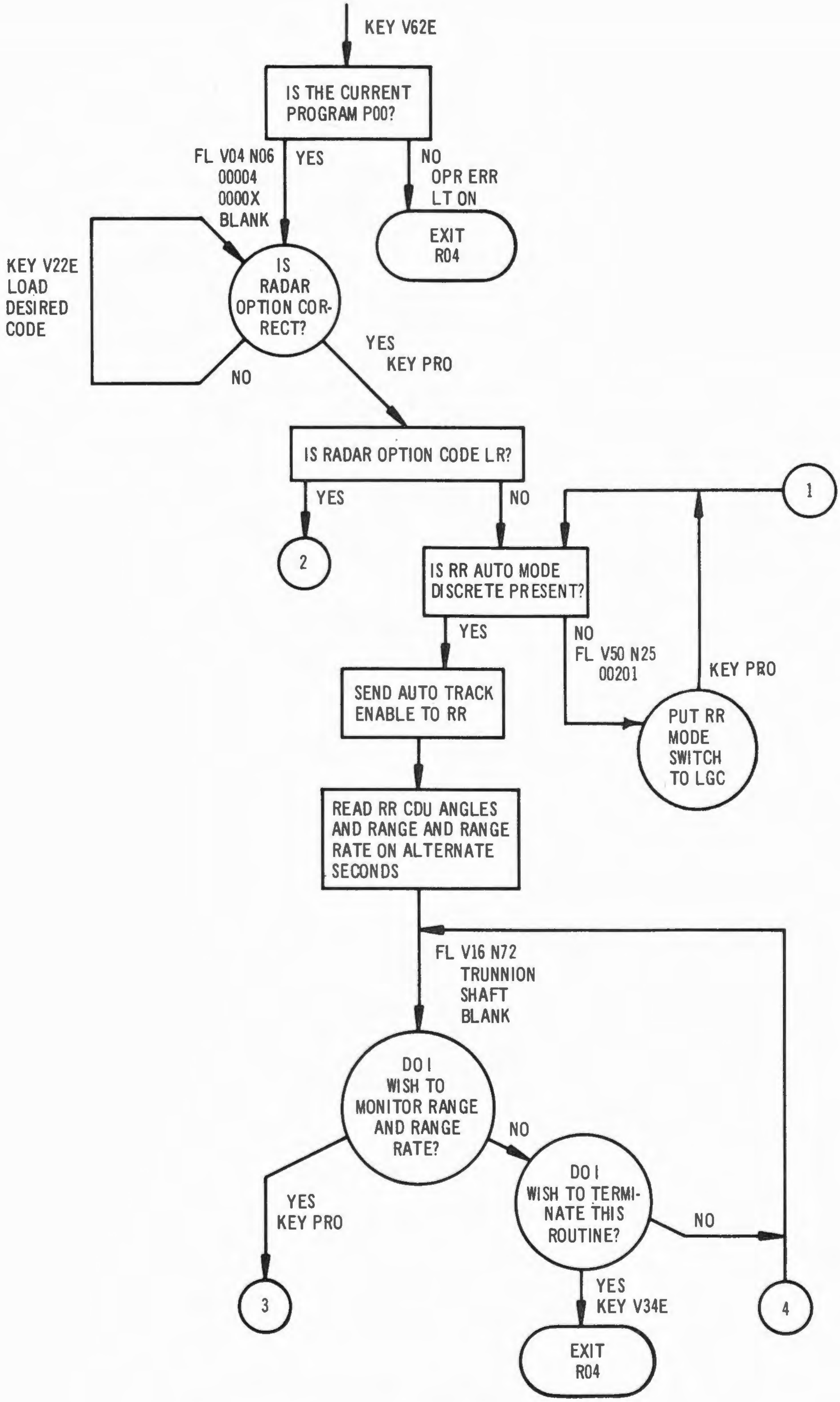


Fig. 5-35. RR/LR self test routine (R04) (sheet 1 of 2).

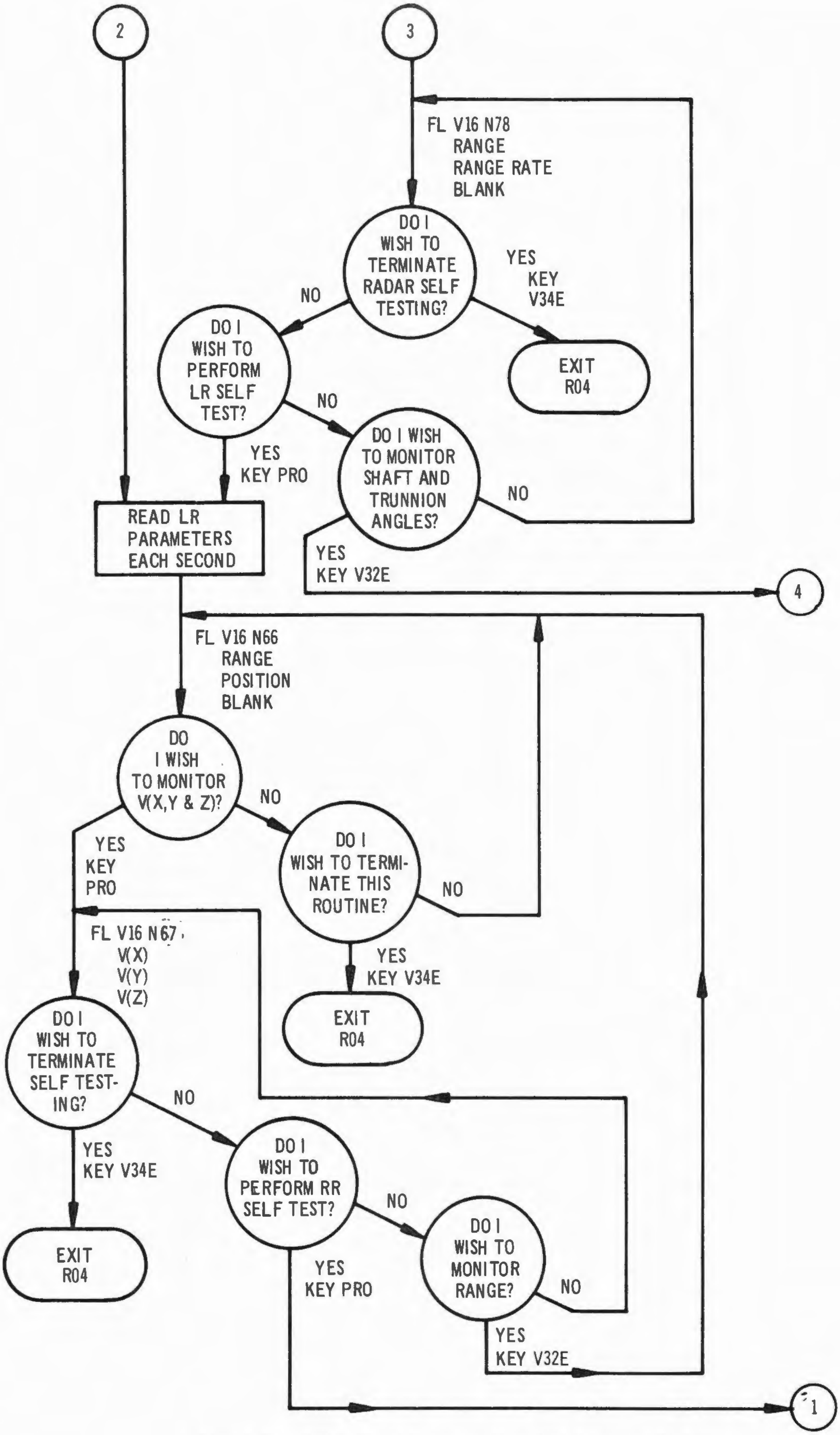


Fig. 5-35. RR/LR self test routine (R04) (sheet 2 of 2).

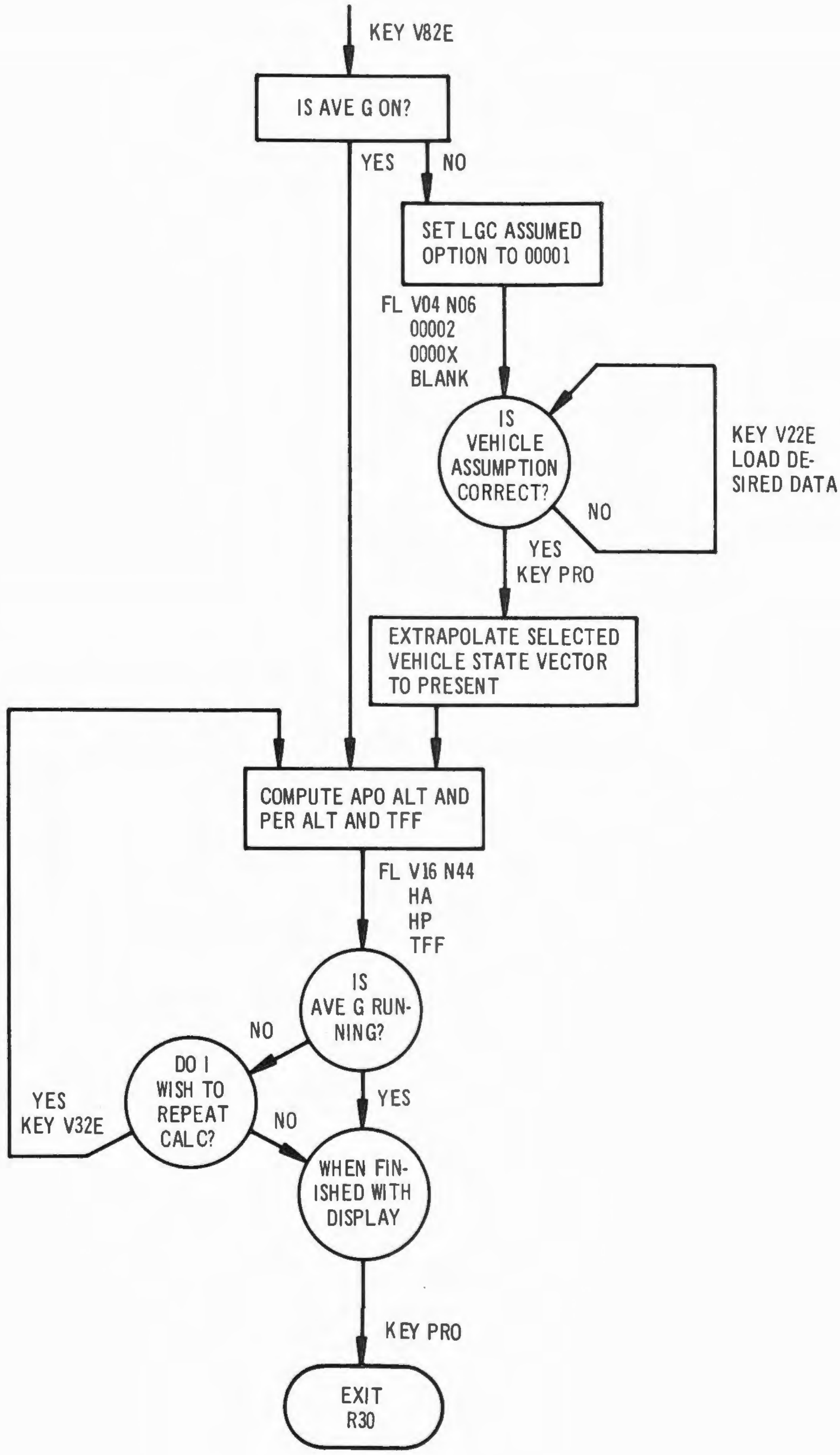


Fig. 5-36. Orbit parameter display routine (R30).

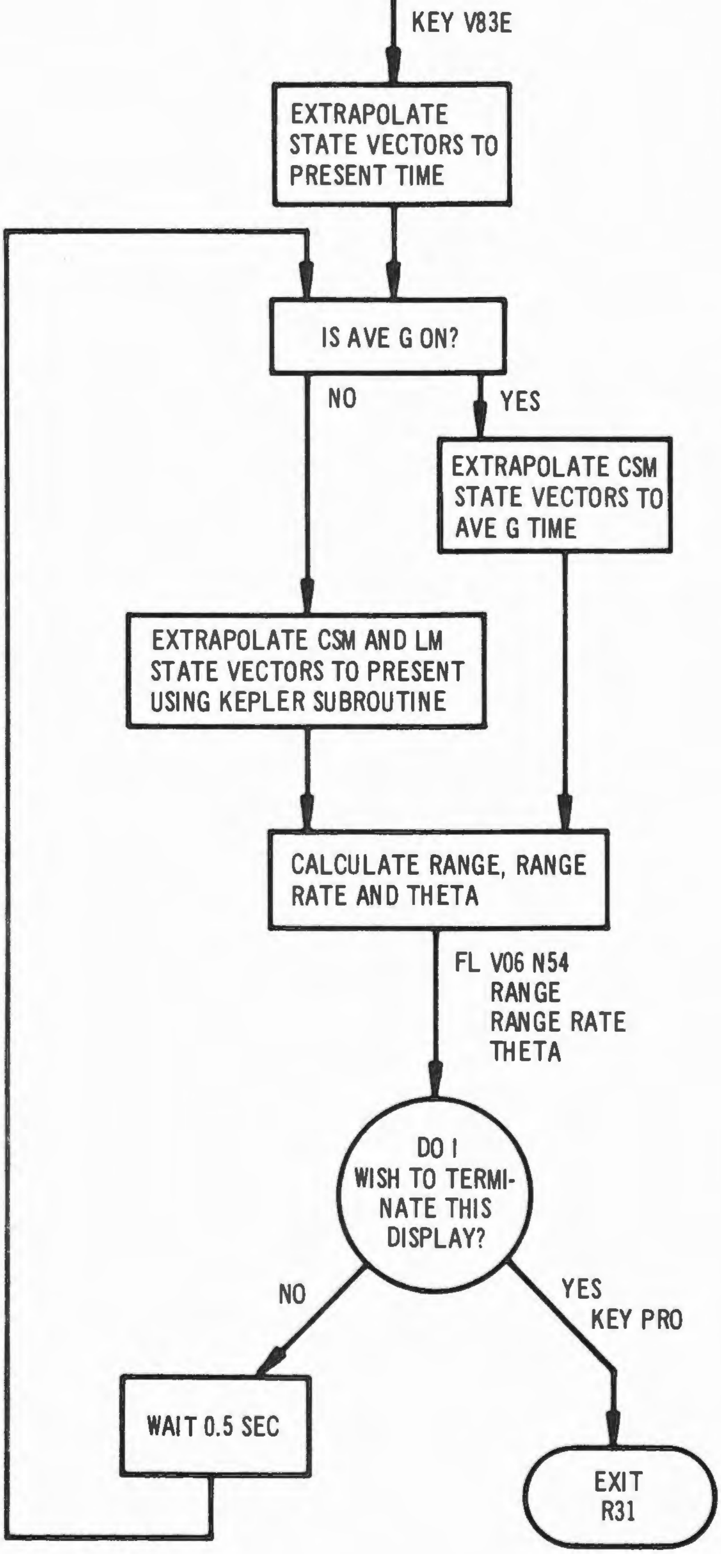


Fig. 5-37. Rendezvous parameter display routine (R31).

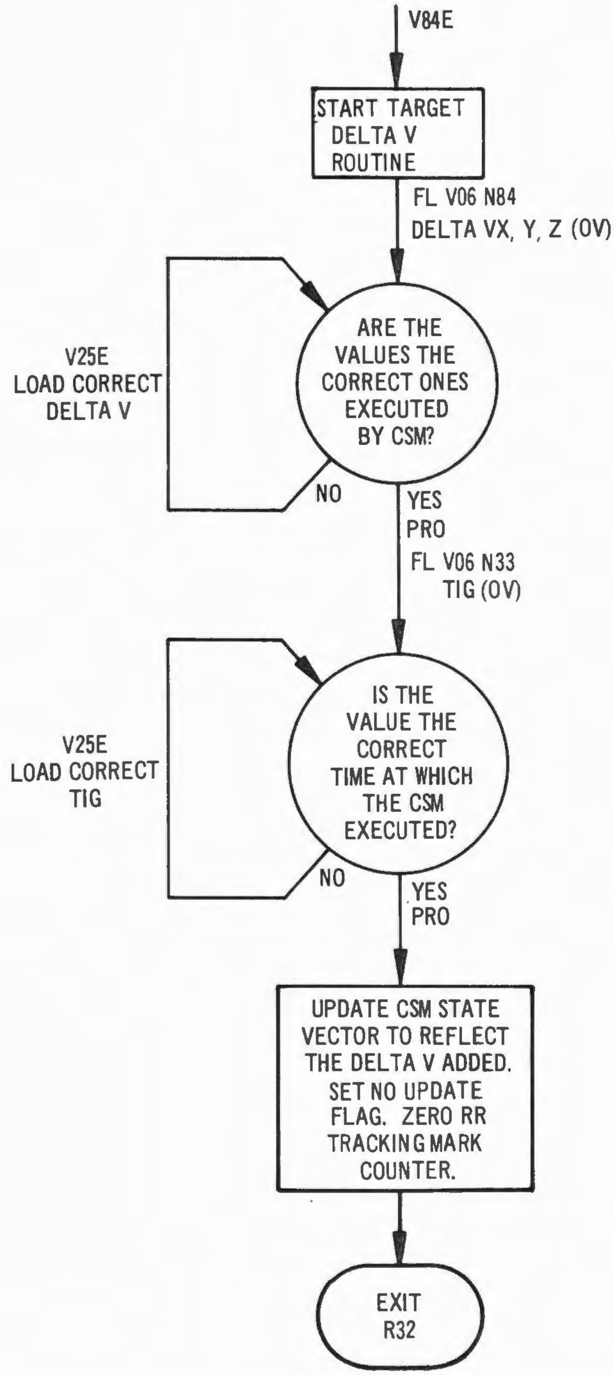


Fig. 5-38. Target Delta V routine (R32) flow diagram.

5.2.3.25 LGC Clock Synchronization (R33)

The LGC/CMC clock synchronization routine is entered by keying in V06 N65. (See Fig. 5-39.) Upon keying an ENTR the LGC records the contents of the LGC clock at the time of the ENTR. The crew members in both vehicles will synchronize by voice the time of the ENTR into their respective DSKY's and will then get the time displayed so a comparison can be made.

5.2.3.26 Rendezvous Out-of-Plane Display Routine (R36)

Rendezvous out-of-plane display routine is entered by keying in V90 (see Fig. 5-40). The LGC displays at the request of the astronaut, the LGC calculated out of plane parameters; Y, Y dot, and Y and Y dot represent the out-of-plane position and velocity. The third display is the angle between the line of sight and the forward direction, measured in the local horizontal plane.

5.2.3.27 AGS Initialization Routine (R47)

The AGS initialization routine is entered by keying in V47 (see Fig. 5-41). This routine provides the AGS electronics assembly with the LM and CSM state vectors.

5.2.3.28 Attitude Maneuver Routine (R60)

To perform a LM or CSM/LM attitude maneuver, the attitude maneuver routine is called by the program in process. It is called by P40, P41, P42, & R61. The final attitude has been stored by the calling program and is usually defined as a specific body fixed vector and direction in space in which this vector is to be aligned.

The attitude maneuver may be performed automatically by the PGNCS or performed manually with an optional final automatic PGNCS controlled trim

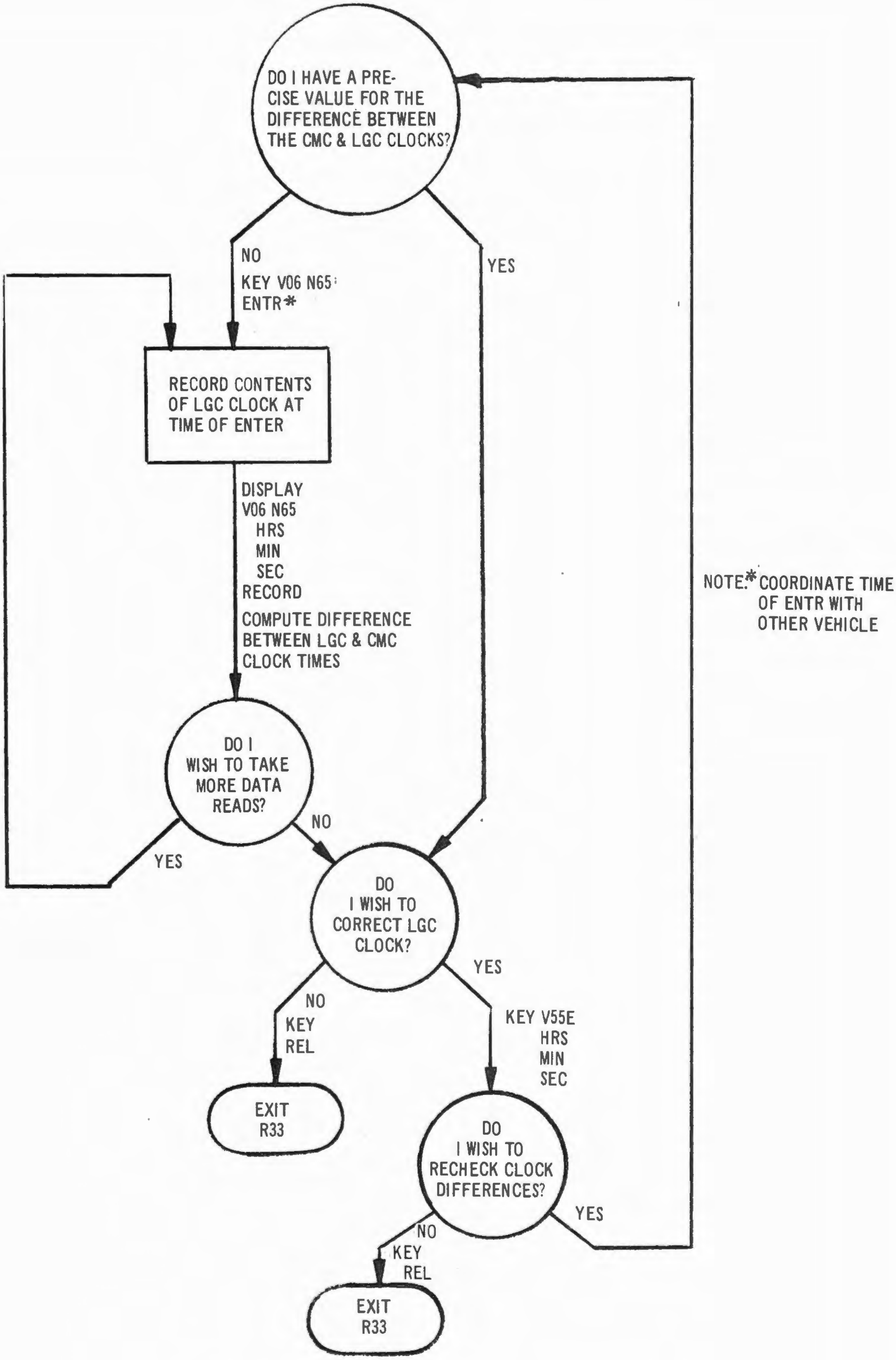


Fig. 5-39. LGC/CMC clock synchronization routine (R33).

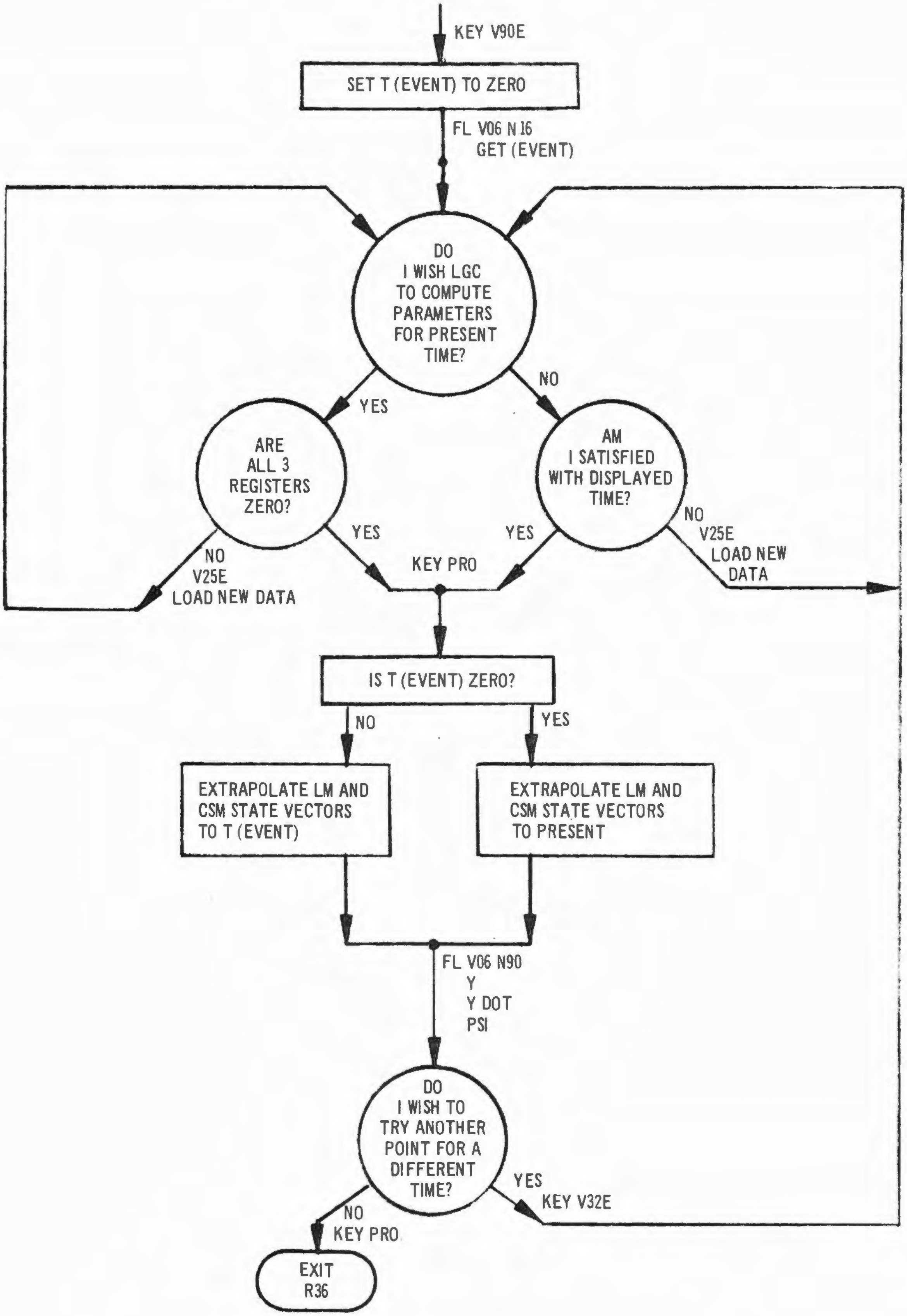


Fig. 5-40. Rendezvous out-of-plane display routine (R36).

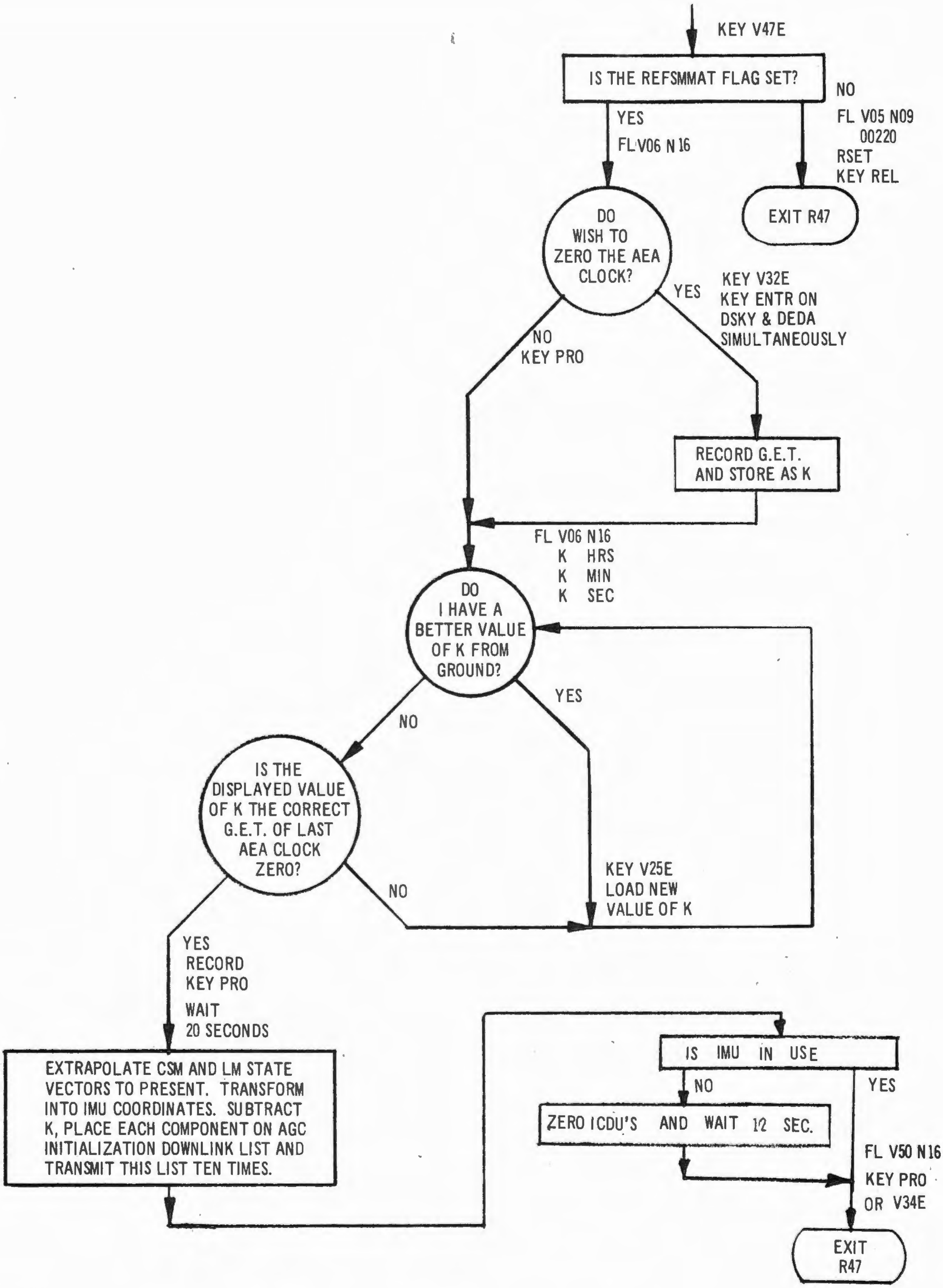


Fig. 5-41. AGS initialization routine (R47).

maneuver. (See Fig. 5-42.) This optional trim maneuver should be considered essential for maneuvers to DPS or APS thrusting.

The final vehicle attitude is calculated to meet the attitude specification in such a way as to conserve RCS fuel and constrain any unspecified degree of freedom. Hence, the PGNCS capability to perform an automatic maneuver is compromised if the LM attitude is changed by manual inputs after the initial trim maneuver is performed. The maneuver rate and the vehicle configuration have been entered into the LGC by DSKY entry within R03 prior to R60 being called.

A manual maneuver must be monitored on the FDAI ball to avoid gimbal lock. Prior to the automatic maneuver, the LGC calculates the possibility of gimbal lock; however, the automatic maneuver should also be monitored. Hence, during the automatic maneuver any ACA inputs are interpreted by LGC as a manual override which causes termination of the LGC calculated maneuver.

5.2.3.29 Crew-Defined Maneuver Routine (R62)

The crew-defined maneuver routine is entered by keying in V49E. (See Fig. 5-43.) This routine provides the crew with the ability to specify a final vehicle attitude for use by an LGC controlled attitude maneuver.

5.2.3.30 Rendezvous Final Attitude Routine (R63)

The rendezvous final attitude routine is entered by keying in V89E. (See Fig. 5-44.) This routine calculates and displays the final FDAI ball angles required to point the LM +Z or +X axis at the CSM.

5.2.3.31 LR Spurious Test Routine (R77)

The landing radar spurious test routine is entered by keying in V78E. (See Fig. 5-45.)

This routine reads out the range and velocity data from the landing radar and puts it on the LGC downlink.

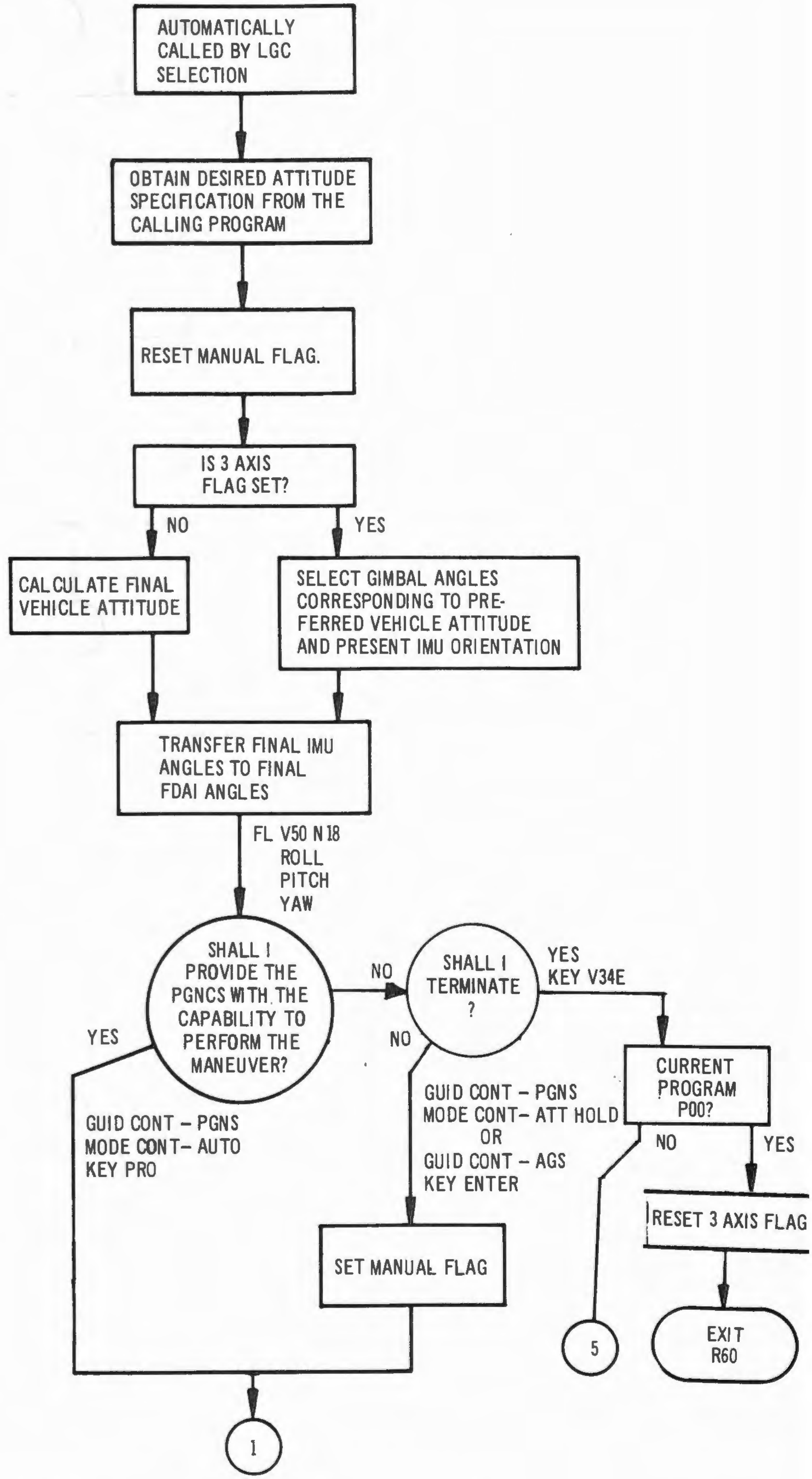


Fig. 5-42 Attitude maneuver routine (R60) (sheet 1 of 3).

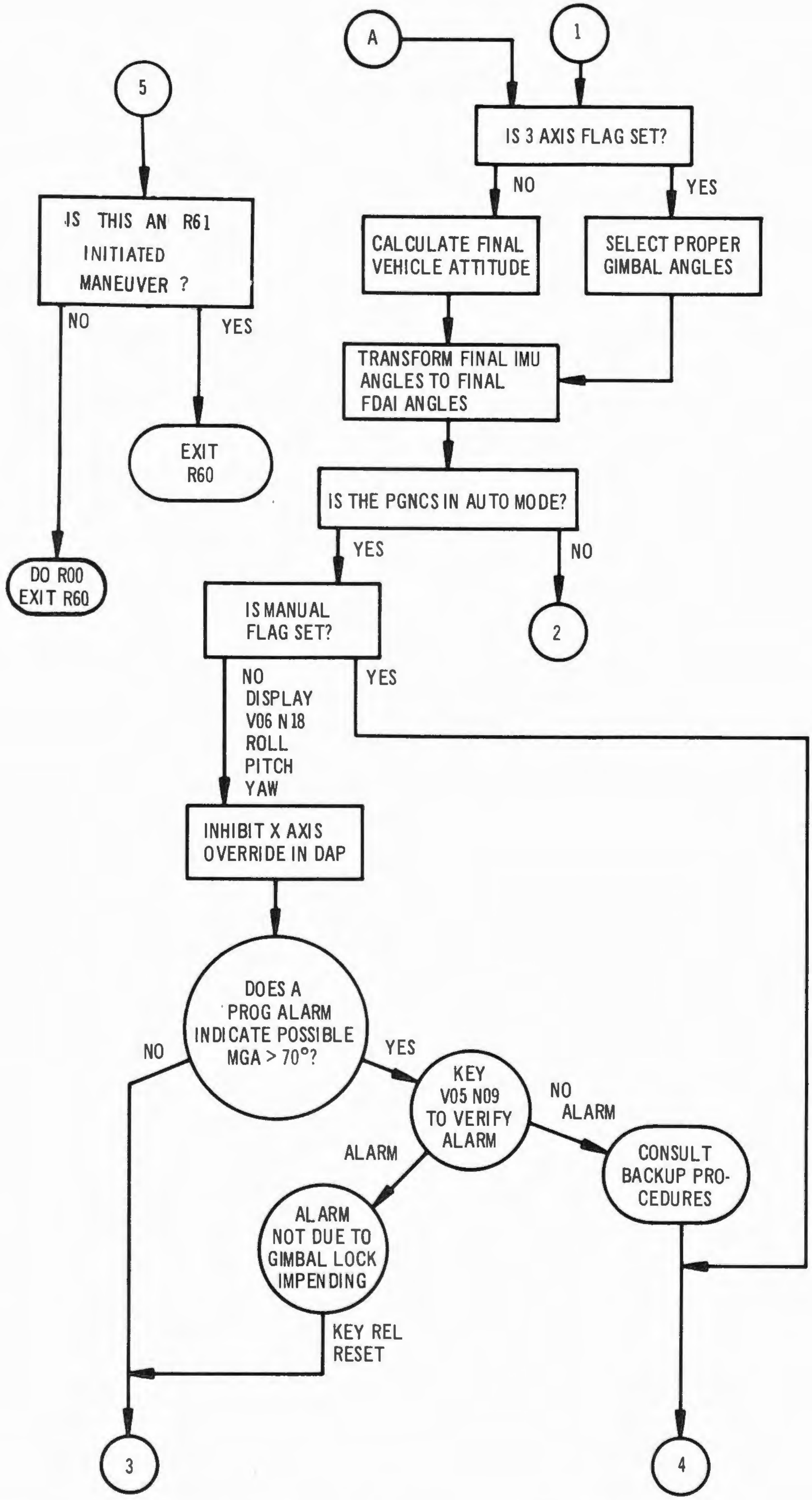


Fig. 5-42 Attitude maneuver routine (R60) (sheet 2 of 3).

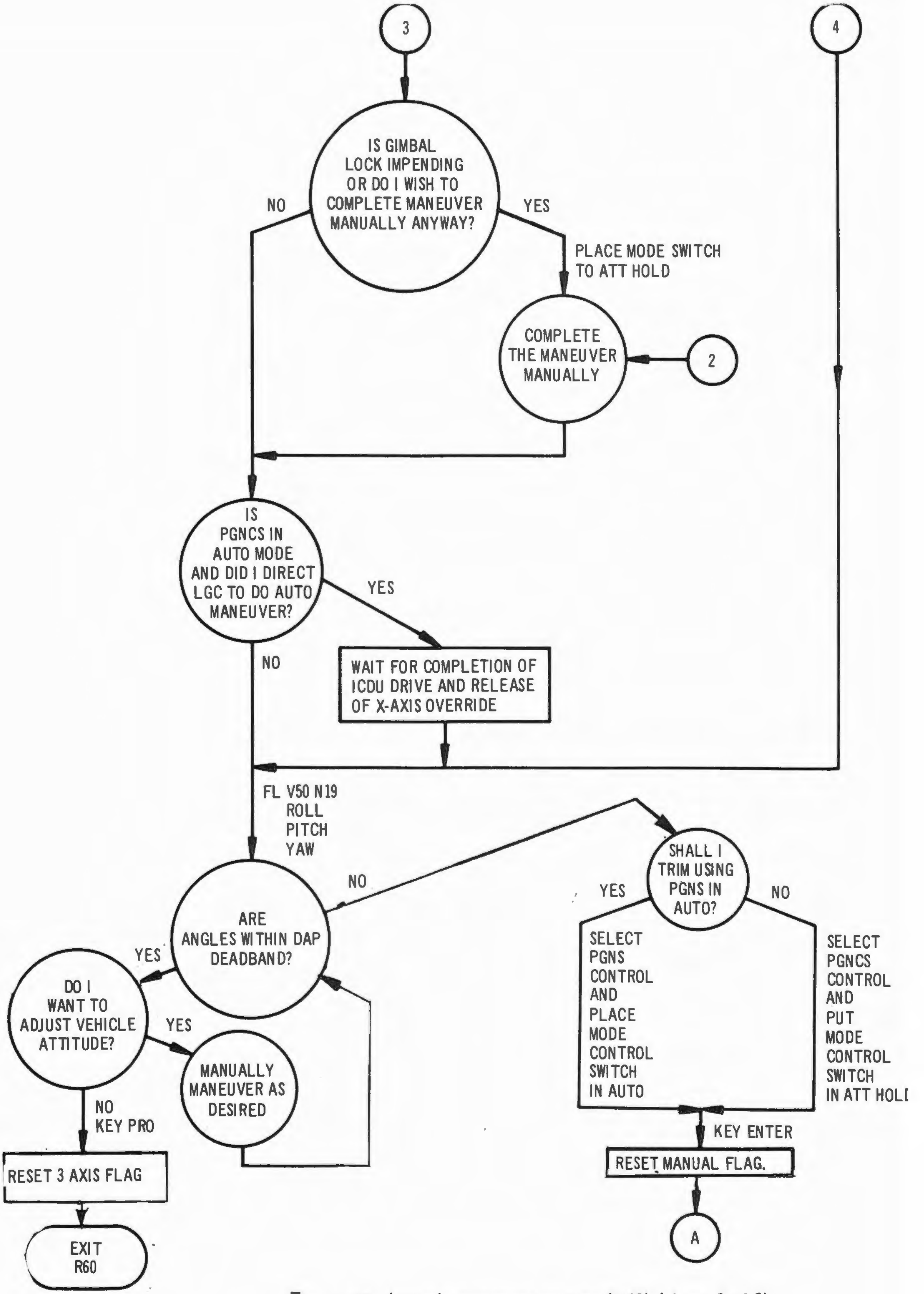


Fig. 5-42 Attitude maneuver routine (R60) (sheet 3 of 3).

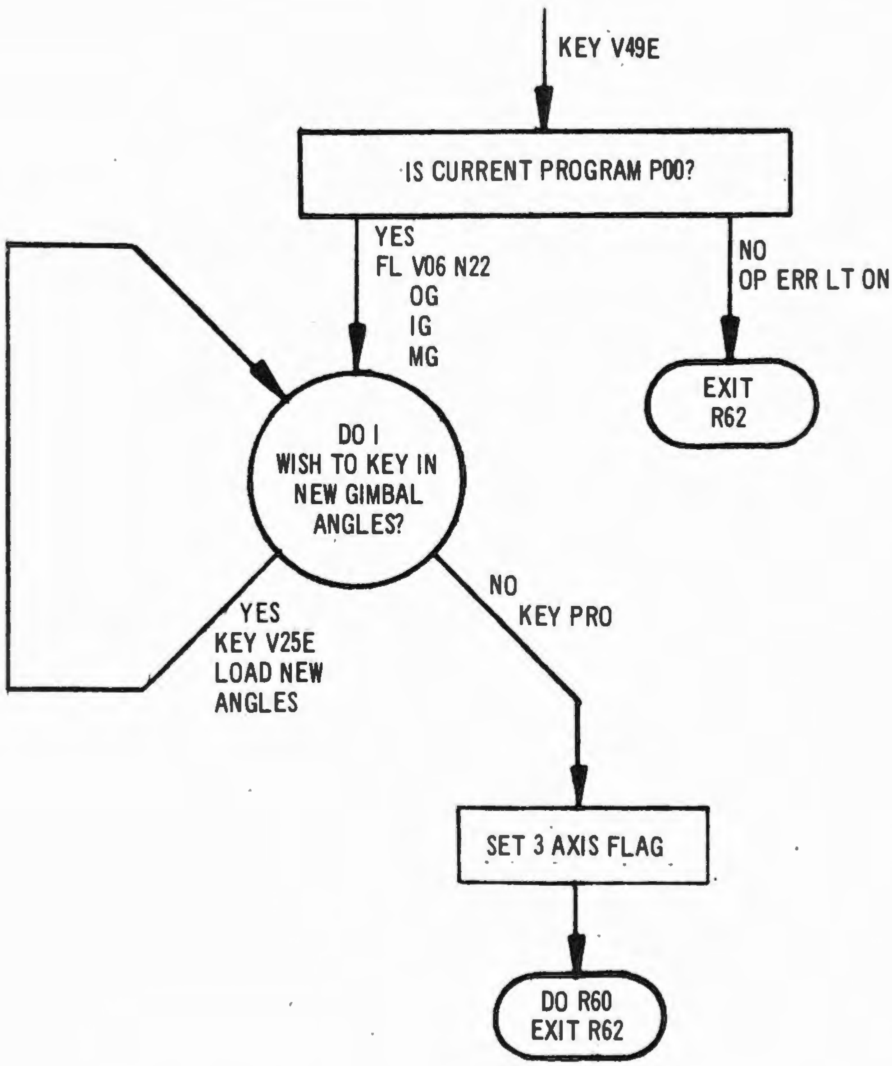


Fig. 5-43. Crew-defined maneuver routine (R62).

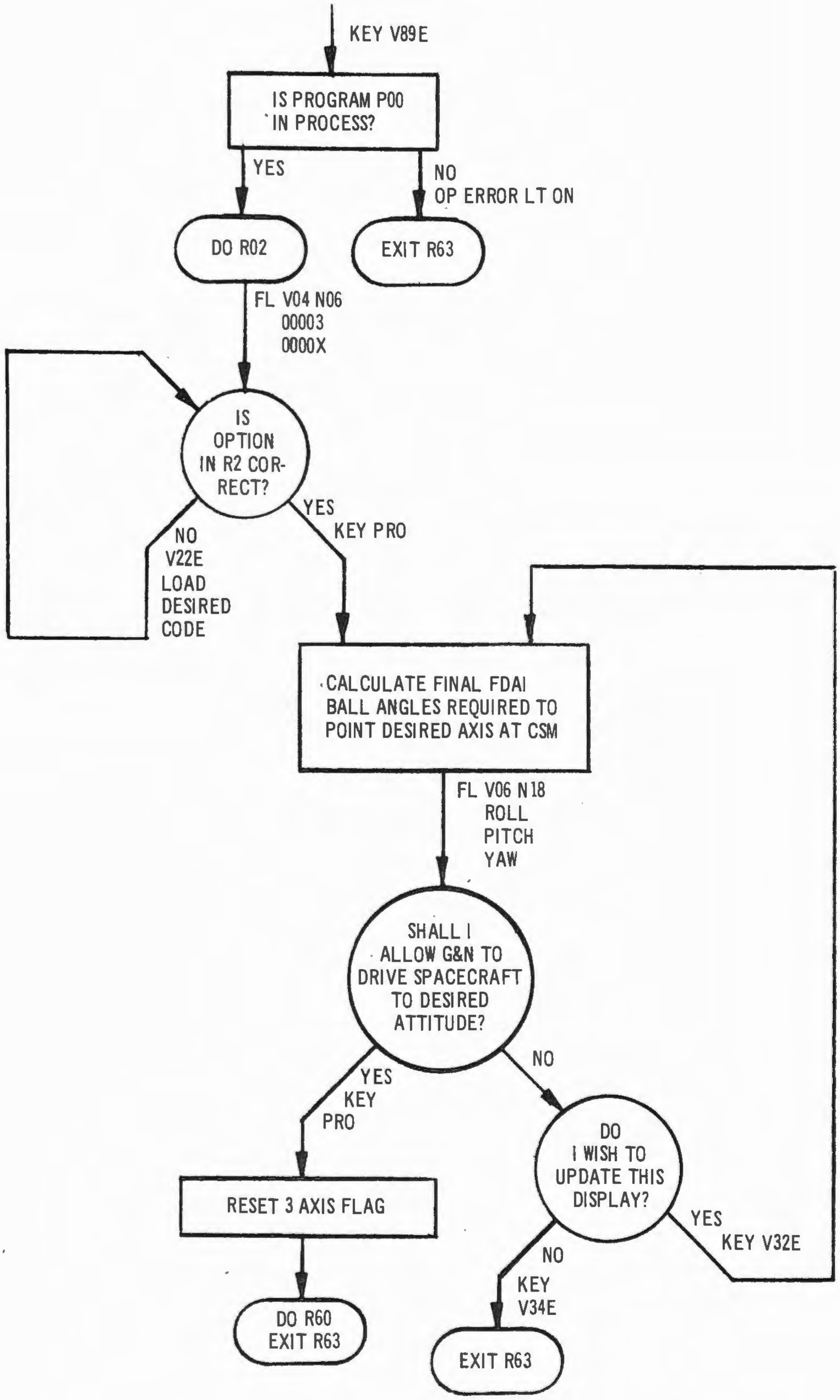


Fig. 5-44. Rendezvous final attitude routine (R63).

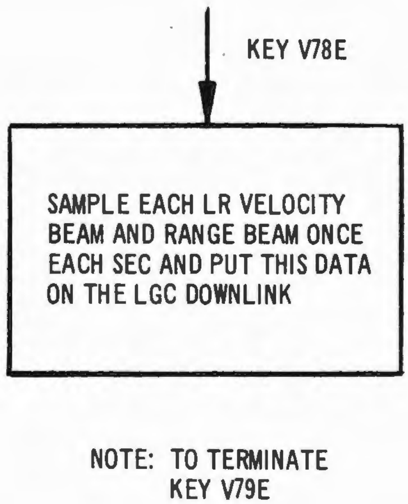


Fig. 5-45. LR spurious test routine (R77).

5.2.3.32 Nonroutine Extended Verbs

A number of extended verbs are provided to call up LGC tasks which are not classified as routines. They provide the LGC with extra capabilities not used in normal operations. Most of them can not be used while another extended verb (including callable routines) is active.

5.2.3.32.1 Fresh Start Extended Verb (V36). This verb (Fig. 5-46) provides the crew with the capability of commanding a LGC fresh start. This can be done at any time the LGC is on. However, if it is commanded during state vector integration, the state vector may be invalidated. Although REFSMMAT is not disturbed, the REFSMMAT flag is reset, since this routine resets all flags. An IMU orientation determination program (P51 or P53) must be performed to re-establish the REFSMMAT flag. A fresh start may also be forced by simultaneously pressing the RSET and MARK REJECT pushbuttons. A fresh start should not be commanded unnecessarily.

5.2.3.32.2 IMU-CDU Zero Extended Verb (V40 N20). This verb-noun (Fig. 5-47) is used to synchronize the ISS CDU counters and the CDU counters in the computer. It also switches the IMU from the coarse align to the fine align mode. It cannot be entered when the IMU is in coarse align mode with a gimbal lock. It is primarily intended for ground use. For in-flight alignment the IMU alignment programs P51 and P52 should be used.

5.2.3.32.3 RR-CDU Zero Extended Verb (V40 N72). This verb-noun (Fig. 5-48) is used to zero the RR CDU's, and to determine the mode of the RR antenna. This extended verb is selected by DSKY entry and can be selected at any time.

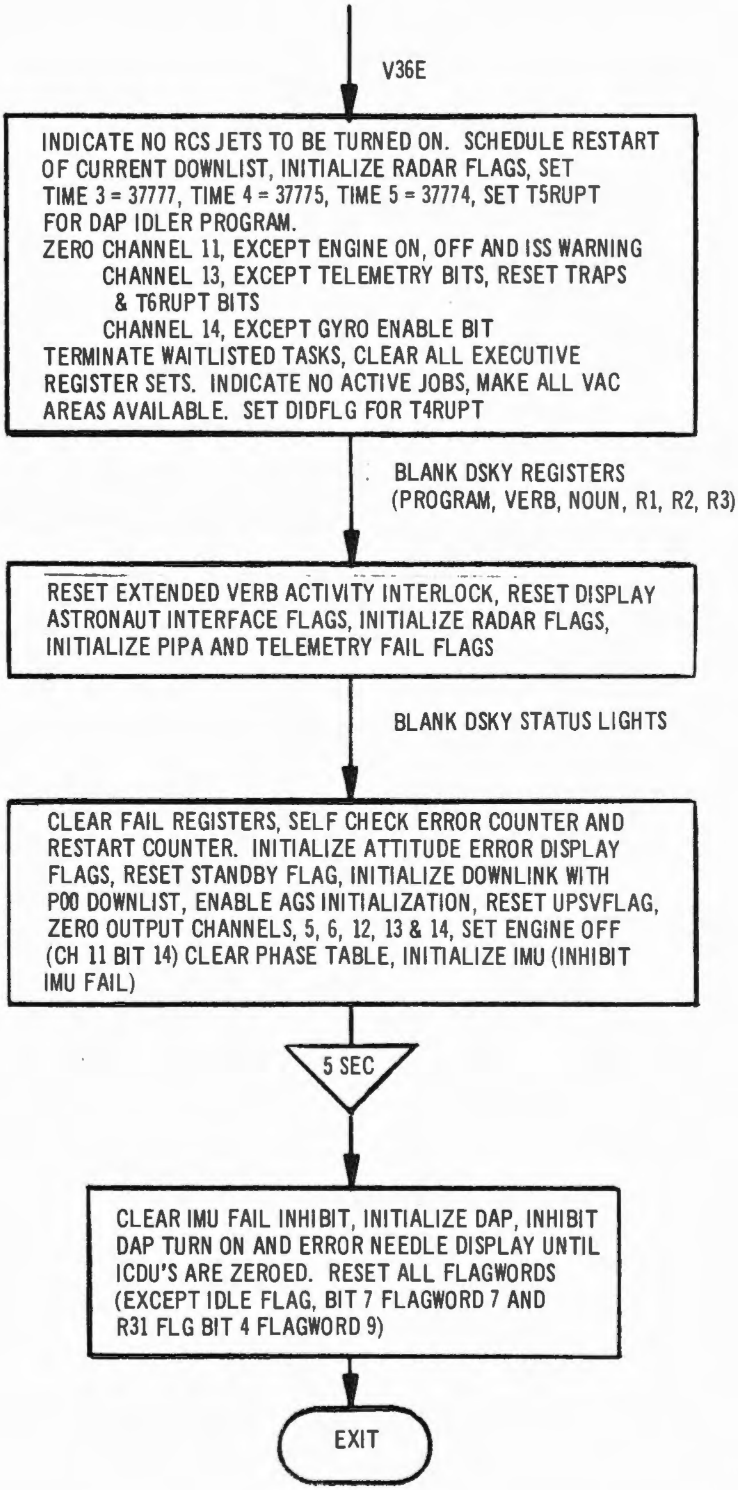


Fig. 5-46. Fresh start (V36).

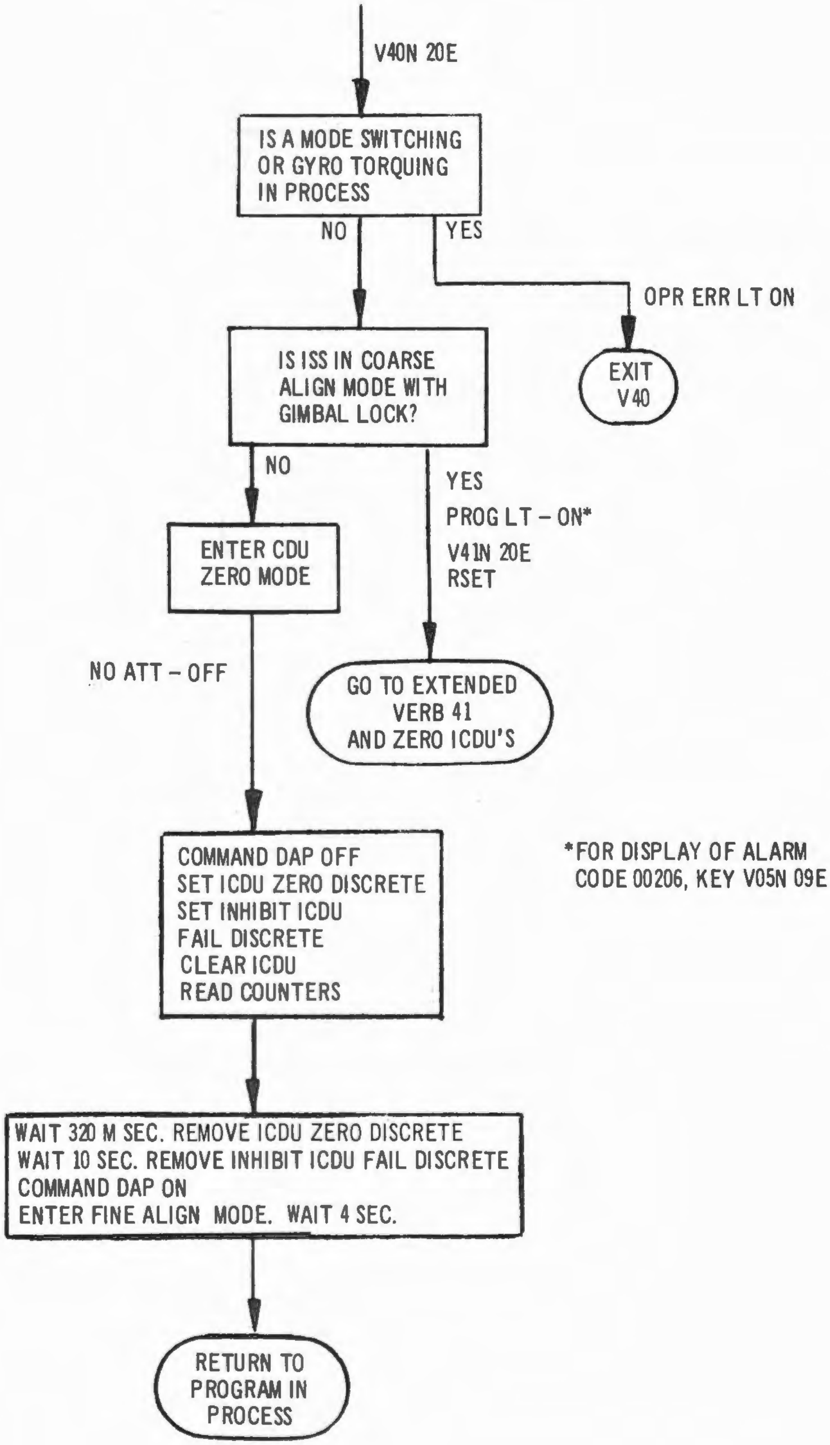


Fig. 5-47. ICDU-zero extended verb (V40).

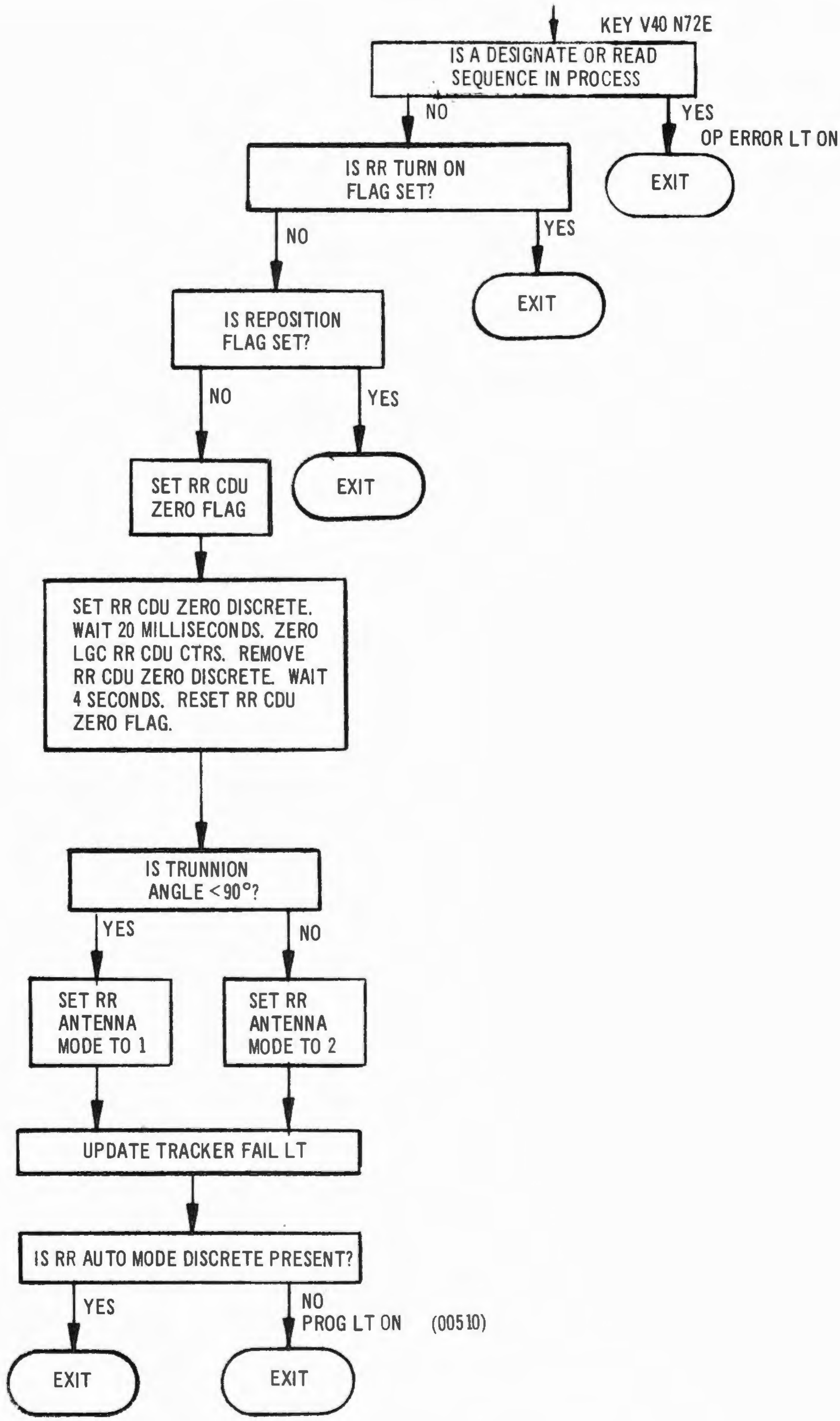


Fig. 5-48. RR CDU zero extended verb (V40 N72).

5.2.3.32.4 Coarse Align ISS Extended Verb (V41 N20). This verb-noun (Fig. 5-49) is used to align the IMU to an orientation specified by the operator. It can be used to align the gimbals to zero when in coarse align mode with a gimbal lock (when V40 cannot be used). The operator loads the gimbal angles or the change in gimbal angles desired. The IMU is then aligned accordingly. This verb can only be used when no other extended verb is active.

5.2.3.32.5 Rendezvous Radar Coarse Align Extended Verb (V41 N72). This verb-noun (Fig. 5-50) is used to drive the rendezvous radar shaft and trunnion to angles specified by the astronaut. The process may be selected only when no other extended verb is active and may not be selected if P20 or P22 is running.

5.2.3.32.6 Torque Gyros Extended Verb (V42). This verb (Fig. 5-51) is used to fine align the stable member by torquing the gyros. The process is crew selected by DSKY entry and may be selected only when no other extended verb is active.

5.2.3.32.7 Load IMU Attitude Error Needles Extended Verb (V43). This verb (Fig. 5-52) is used to load astronaut specified angles into the FDAI error needles. The operator loads the angles desired and these are displayed on the FDAI error needles. The maximum angle that can be loaded is 16.88 degrees; any angle greater than that is interpreted at 16.88 degrees. This verb can only be entered from P00. It cannot be entered if another extended verb is active except prior to liftoff.

5.2.3.32.8 W Matrix RMS Error Display. This verb (Fig. 53) provides a means of displaying W Matrix Information and reintializing the W Matrix if desired.

5.2.3.32.9 Increment LGC Time Extended Verb (V55). This verb (Fig. 5-54) provides the crew with the capability to change the LGC clock time. This routine serves as a backup method to program P27 for updating the LGC clock time.

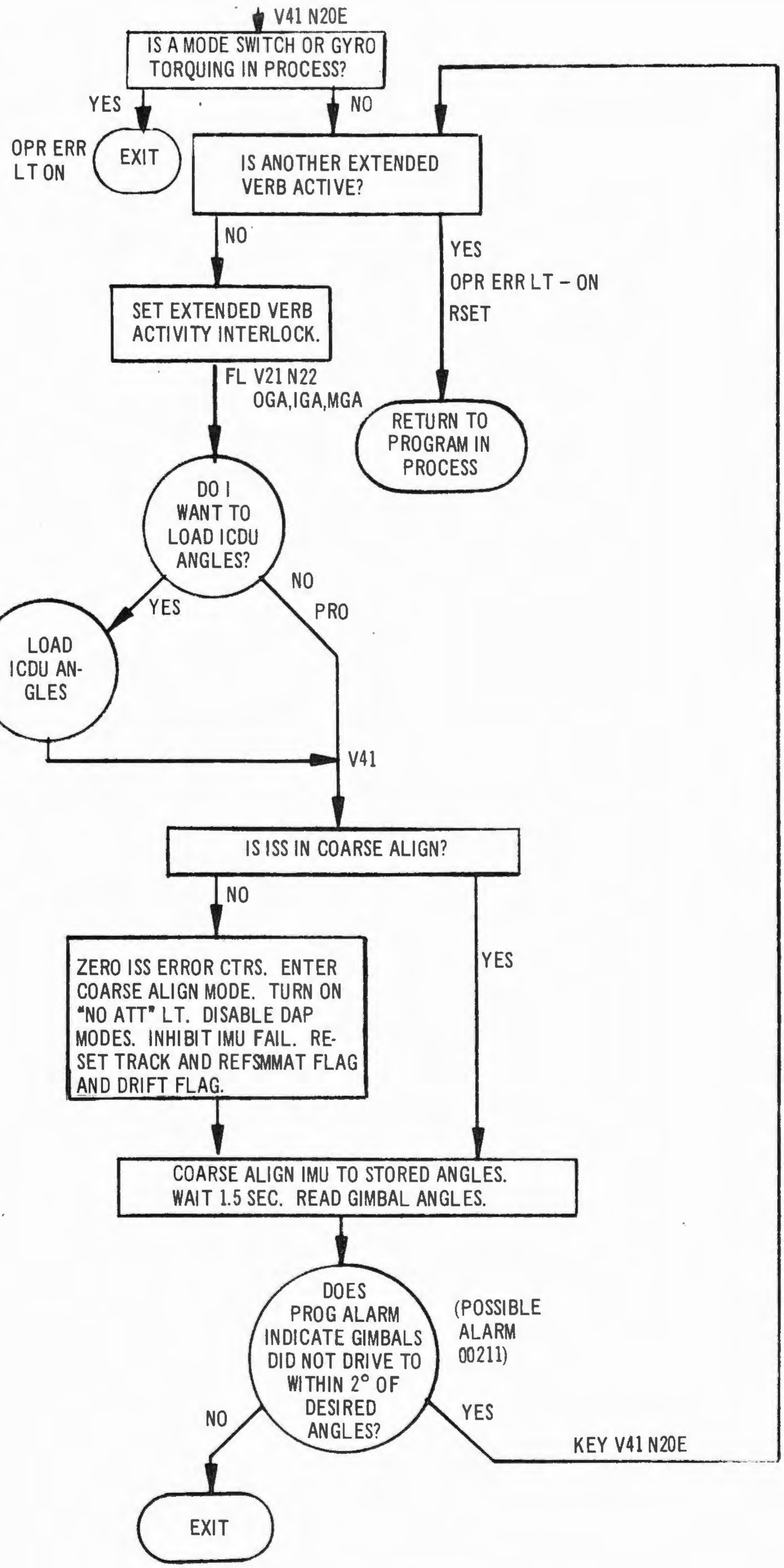


Fig. 5-49. Coarse align extended verb (V41 N20).

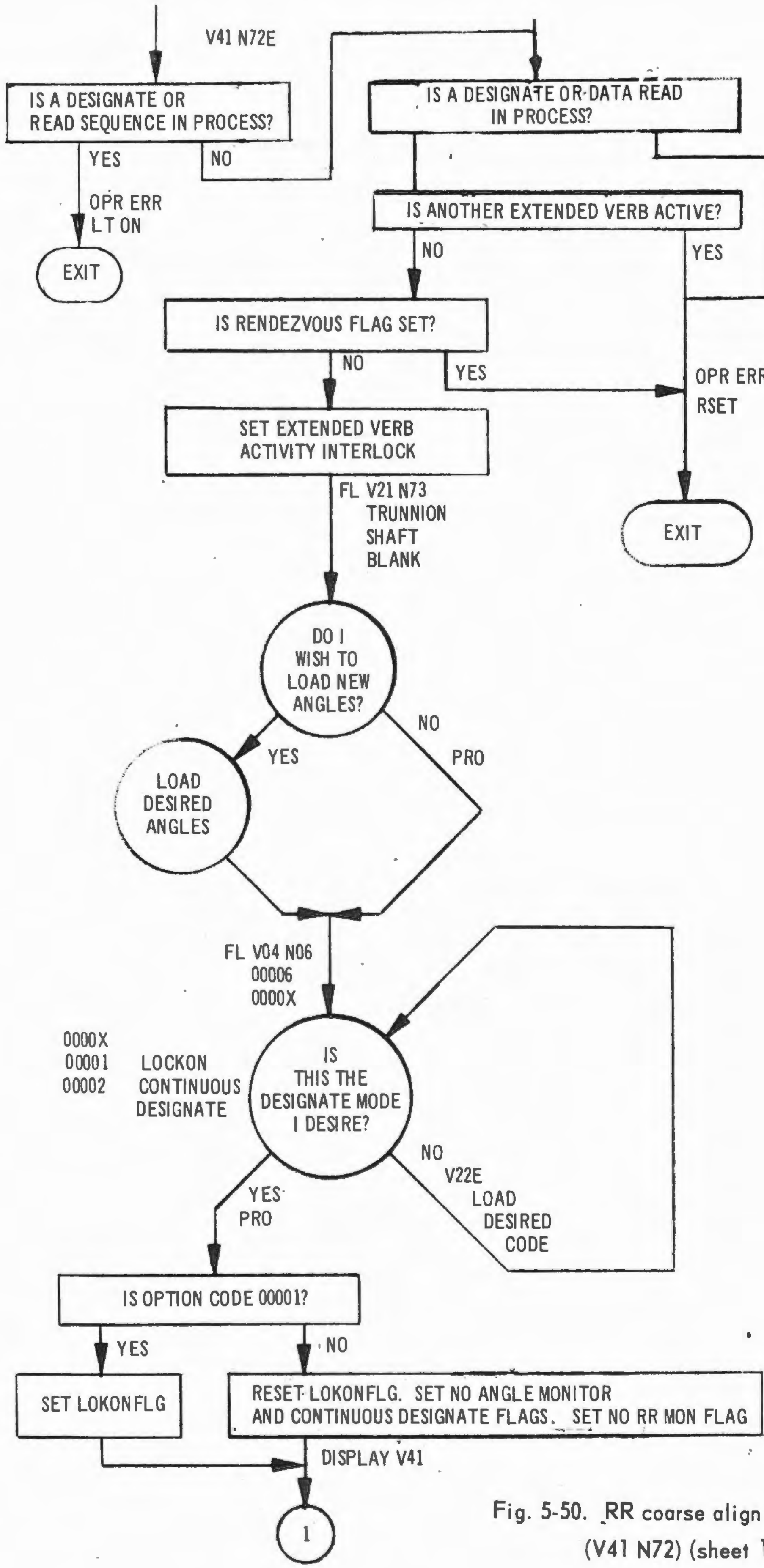


Fig. 5-50. RR coarse align extended verb (V41 N72) (sheet 1 of 4).

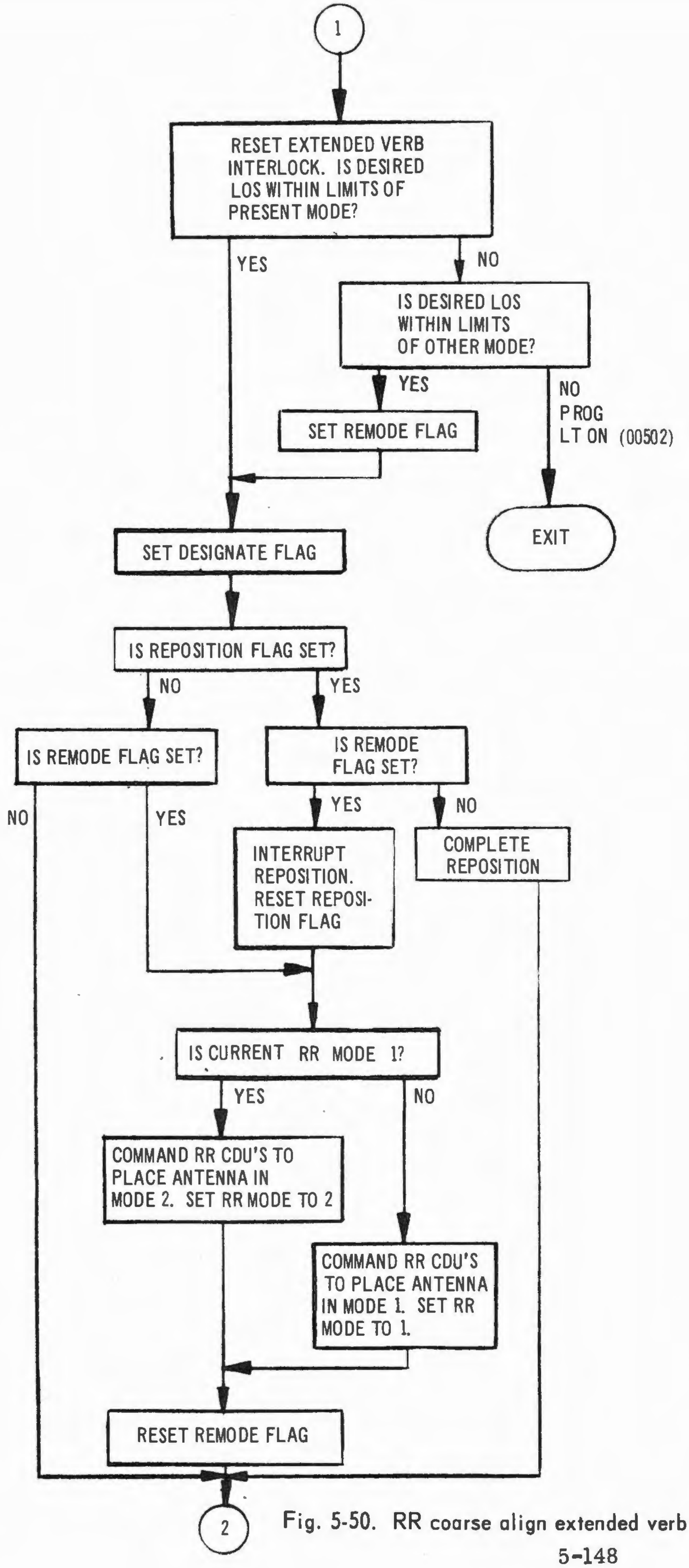


Fig. 5-50. RR coarse align extended verb (V41 N72) (sheet 2 of 4).

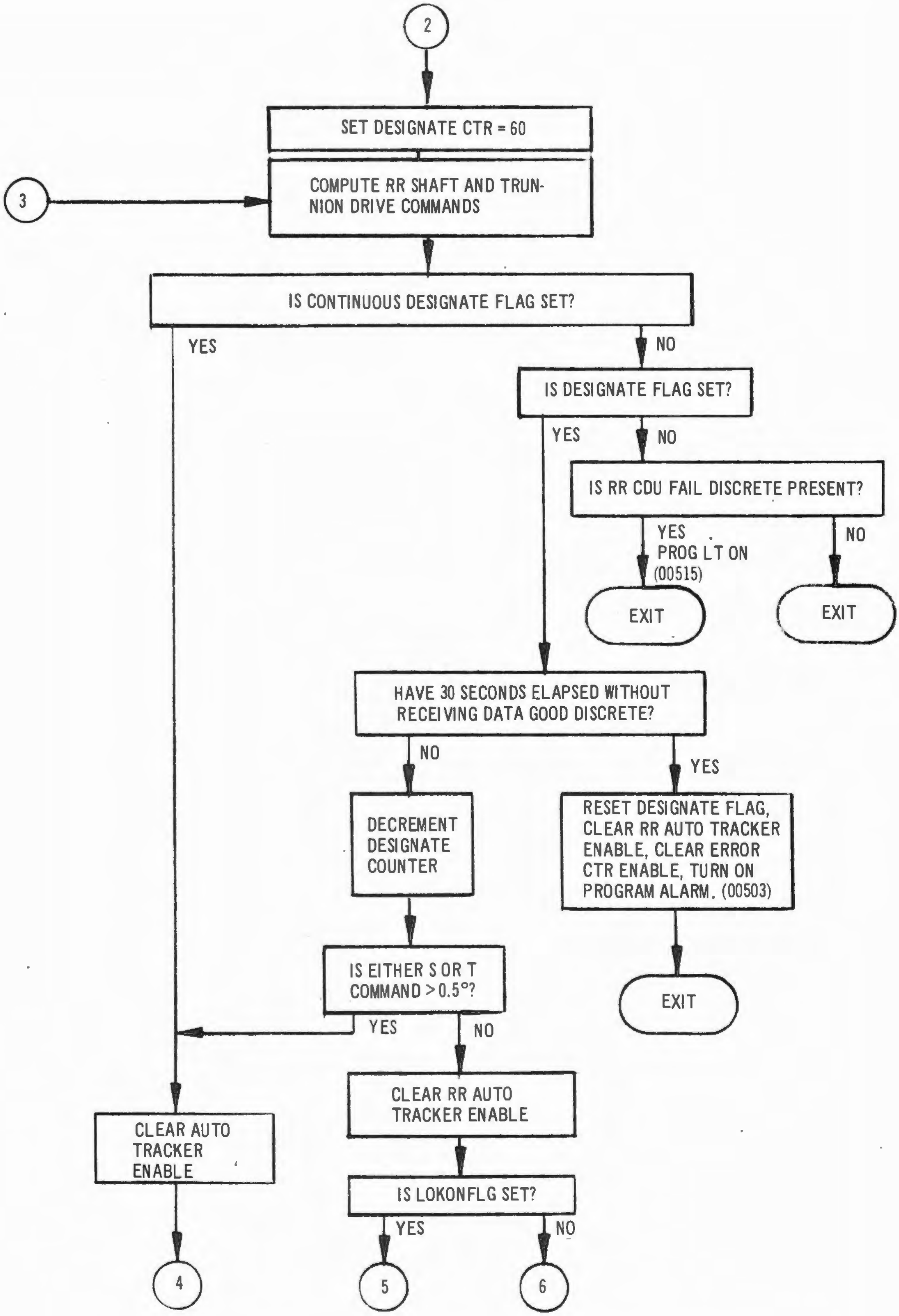


Fig. 5-50. RR coarse align extended verb (V41 N72) (sheet 3 of 4).

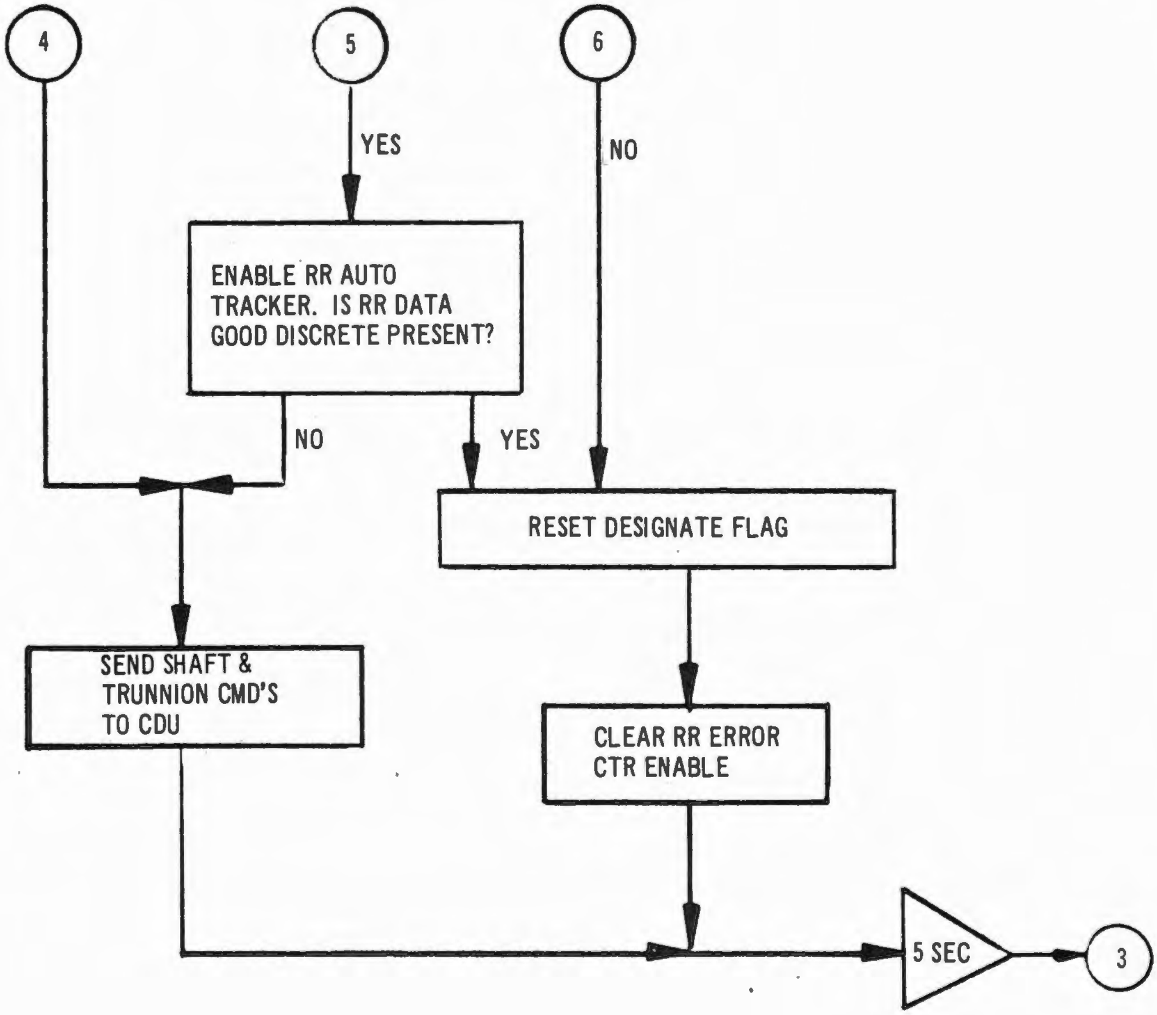


Fig. 5-50. RR coarse align extended verb (V41 N72) (sheet 4 of 4).

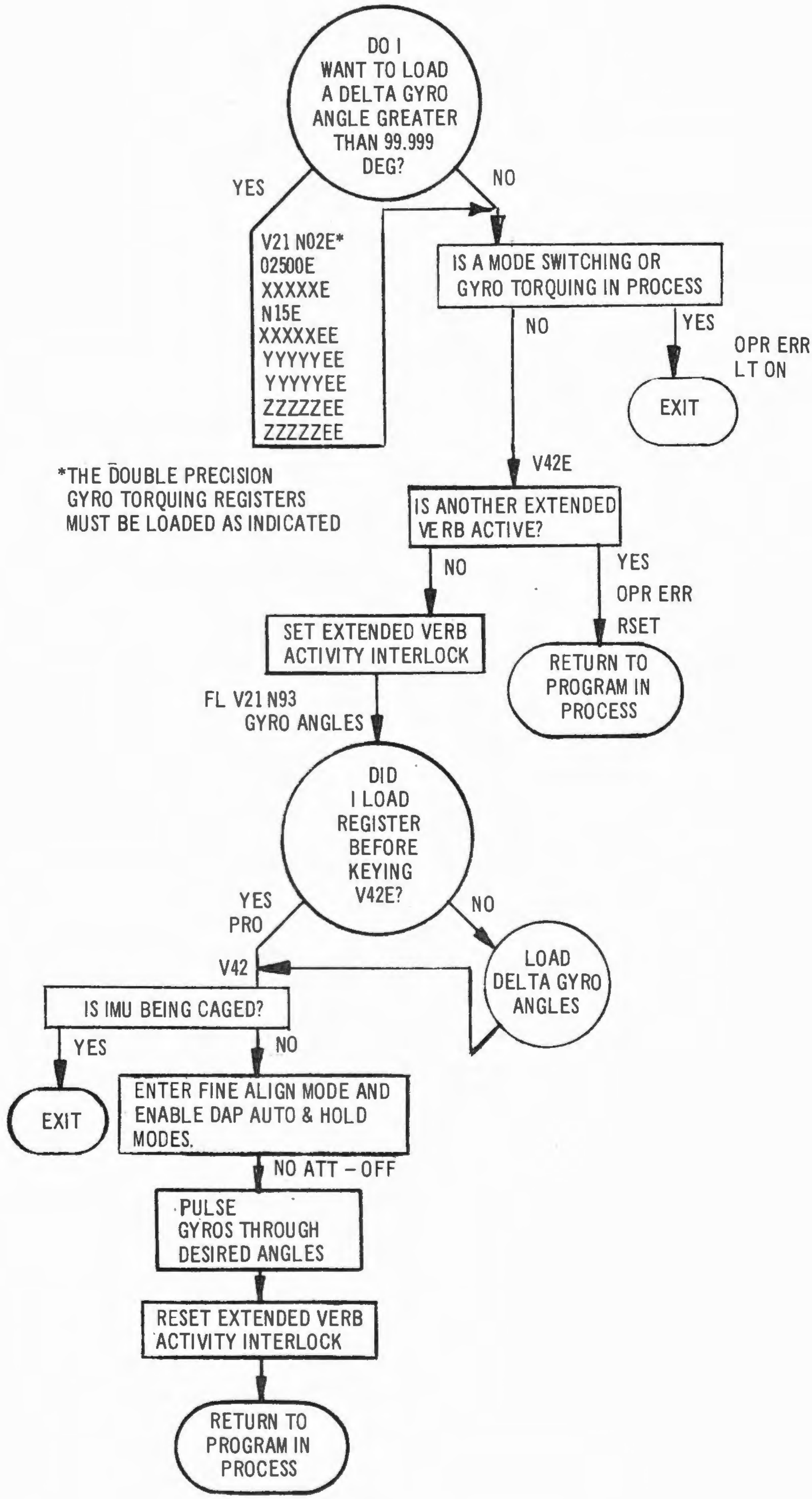


Fig. 5-51. Fine align extended verb (V42).

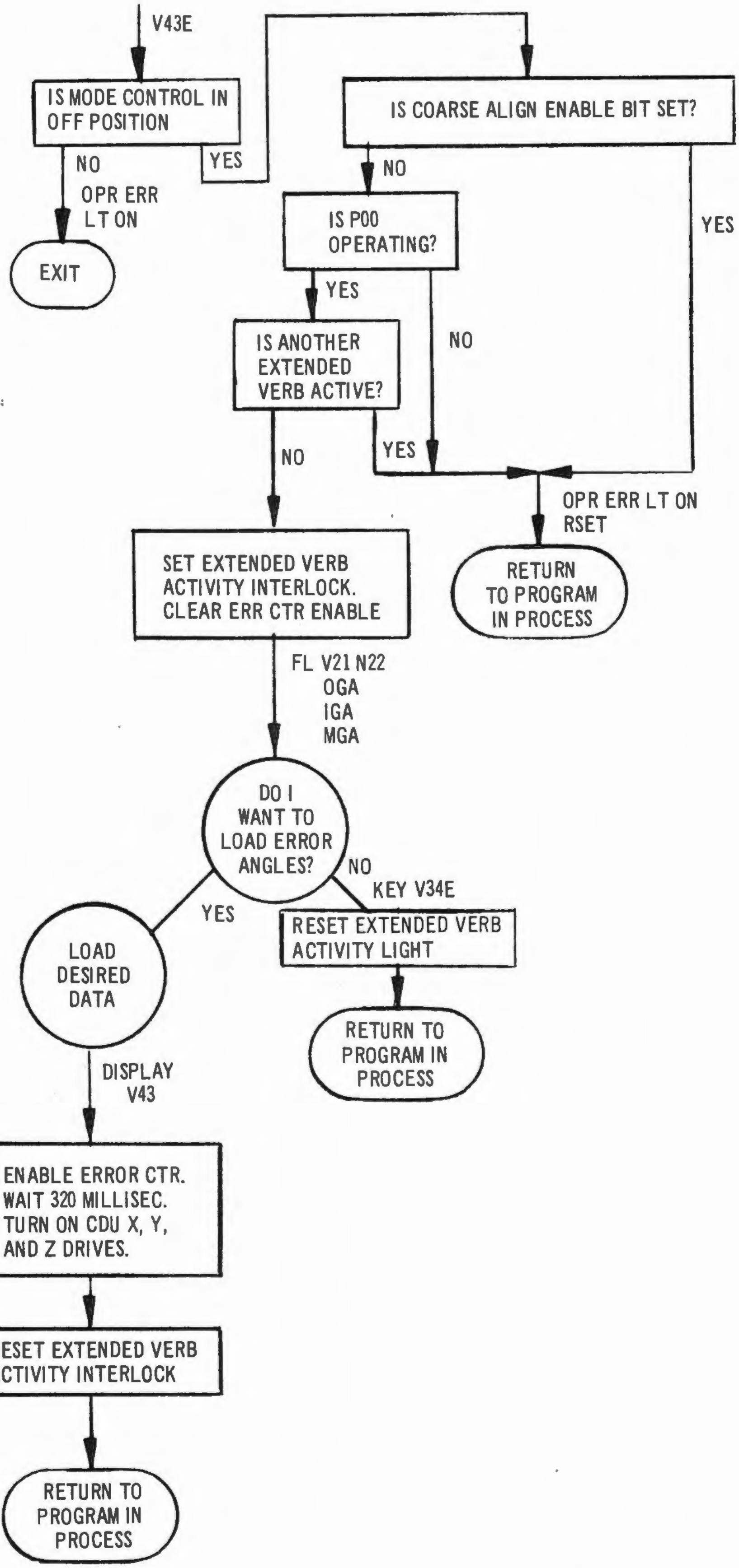


Fig. 5-52. Load IMU attitude error needles extended verb (V43).

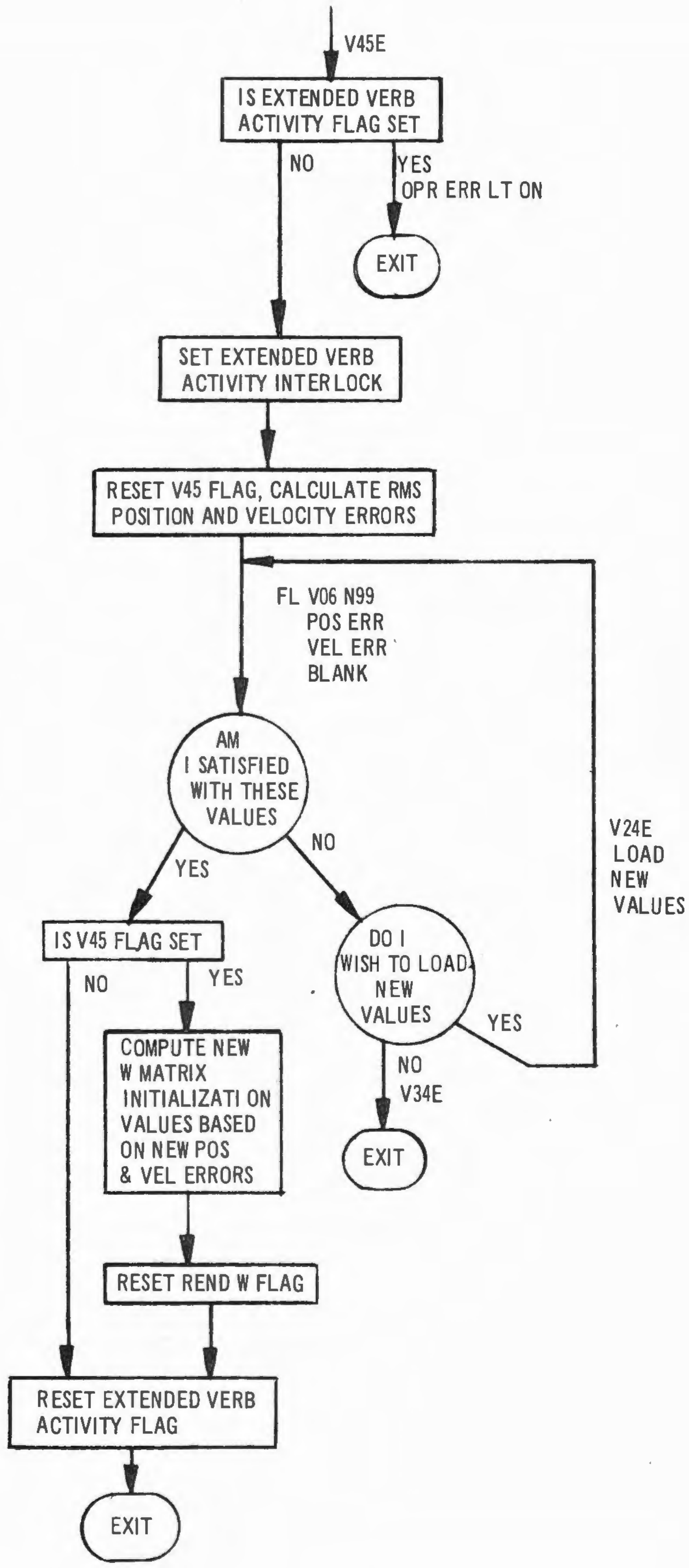


Fig. 5-53 W matrix RMS error display (V45)

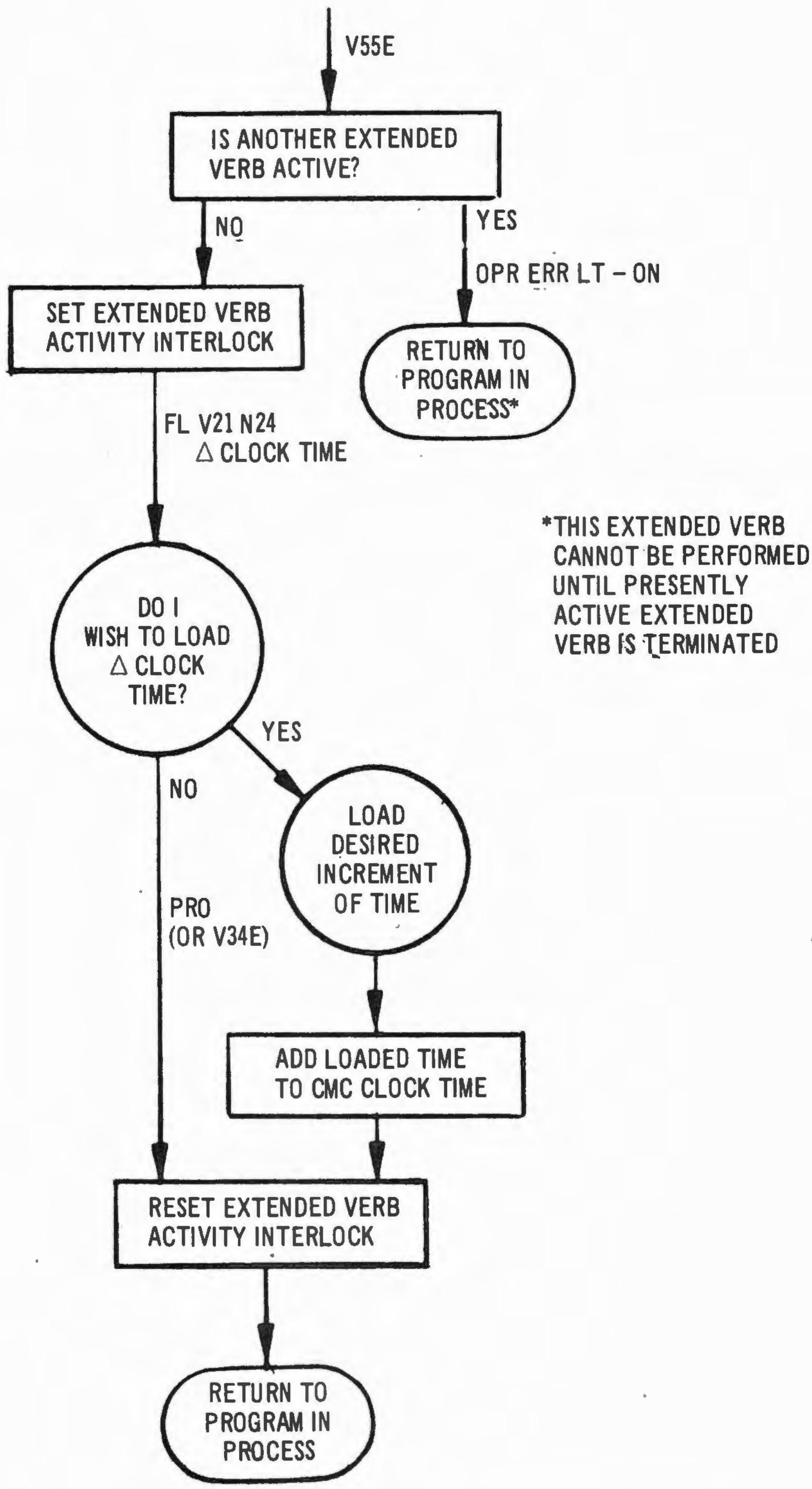


Fig. 5-54. Increment LGC time extended verb (V55).

5.2.3.32.10 Command LR to Position 2 Extended Verb (V61). This verb (Fig. 5-55) drives the landing radar to position two (final approach). The process may be selected only when no other extended verb is active.

5.2.3.32.11 Restart Extended Verb (V69). This verb (Fig. 5-56) is used to force an LGC restart. The V69E does not directly command a restart but forces the LGC into a transfer control trap which in turn causes a restart.

5.2.3.32.12 Initialize Erasable Dump Via Downlink Extended Verb (V74). This verb (Fig. 5-57) starts the downlink of all eight banks of erasable memory. The astronaut can choose to have the banks downlinked one, two, or four times. This choice can be made before or after entering V74. All other downlink activity is inhibited during the verb. Once the process is started, it can only be terminated by running to completion, by keying V69E for a restart, or by keying a fresh start (V36E). The last is not recommended since it also invalidates the stored state vector and resets the REFSMMAT flag.

5.2.3.32.13 Minimum Impulse Extended Verb (V76). This verb (Fig. 5-58) enables the minimum impulse mode of the DAP. The minimum impulse mode will remain enabled until cancelled by rate mode selection or a fresh start. This verb may be selected at any time.

5.2.3.32.14 Rate Command Extended Verb (V77). This verb (Fig. 5-59) enables the rate command mode of the RCS DAP. The rate command mode will remain enabled until cancelled by minimum impulse mode selection. The process may be selected any time.

5.2.3.32.15 Enable W-Matrix Initialization Extended Verb (V93). This verb (Fig. 5-60) permits the crew to enable W-matrix initialization. It does this by resetting the RENDWFLG or ORBFLAG flags. These flags reset indicate that the W-matrix is invalid and must be reinitialized.

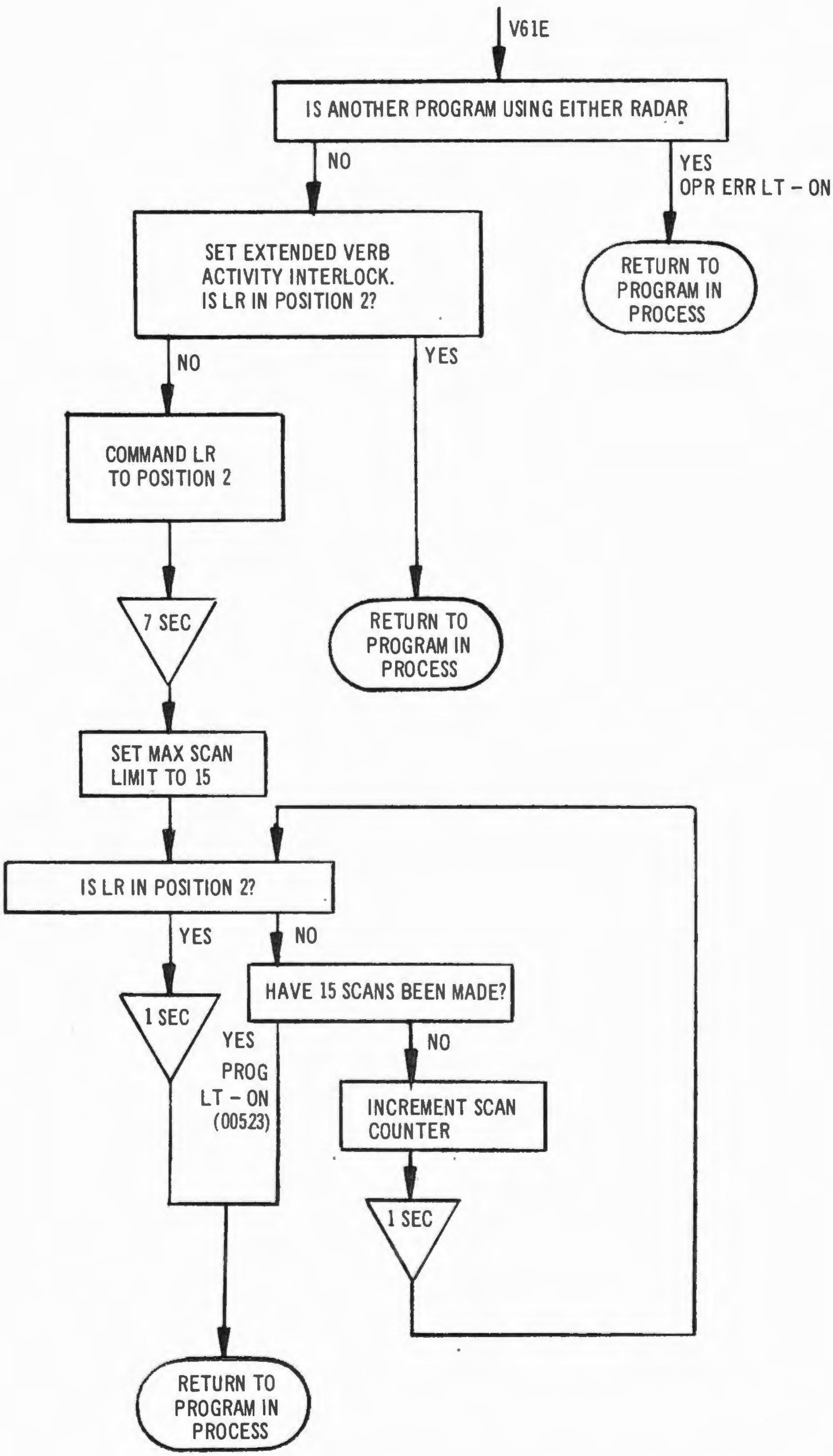


Fig. 5-55. Command LR to position 2 extended verb (V61).

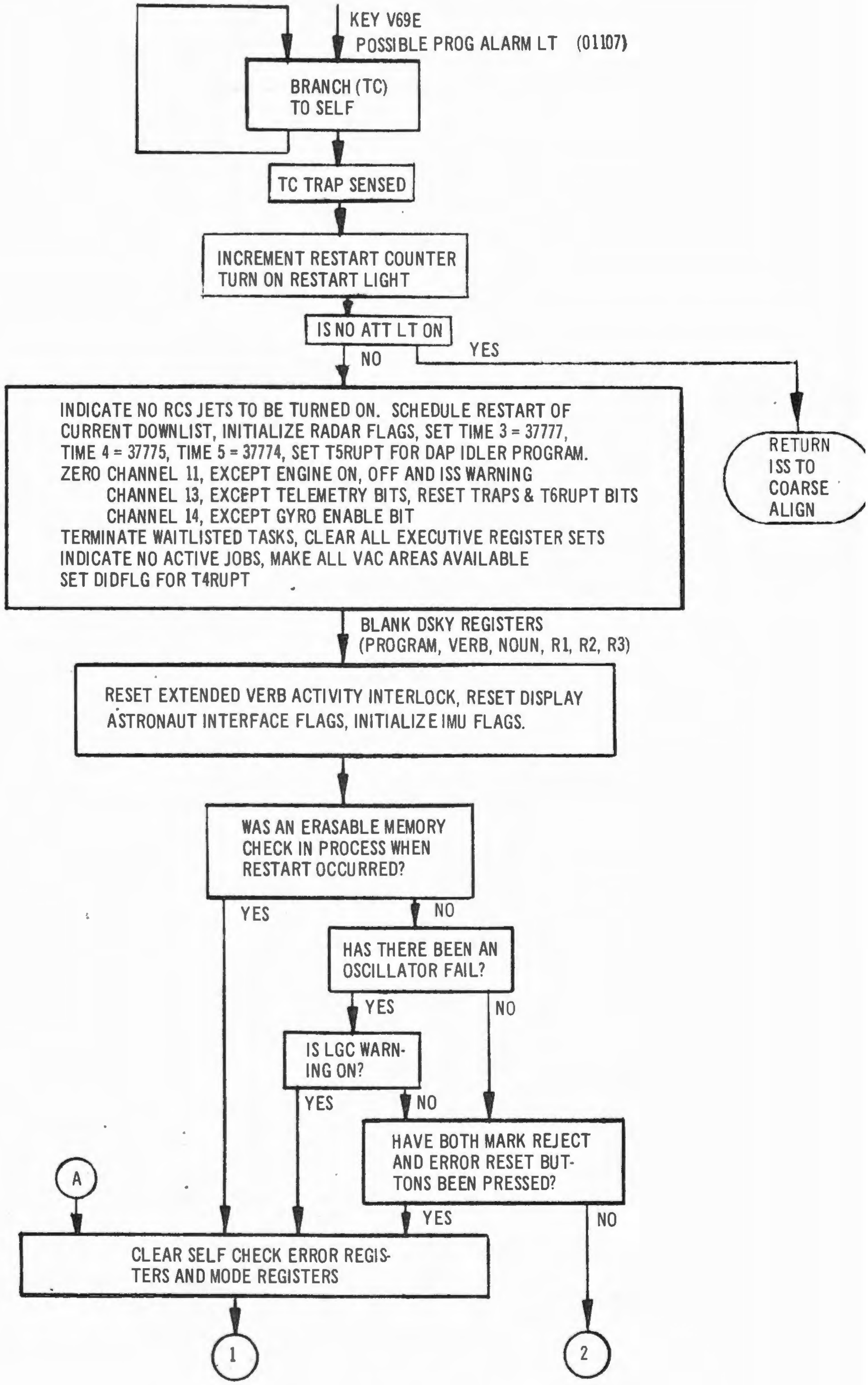


Fig. 5-56. Restart extended verb (V69) (sheet 1 of 2).

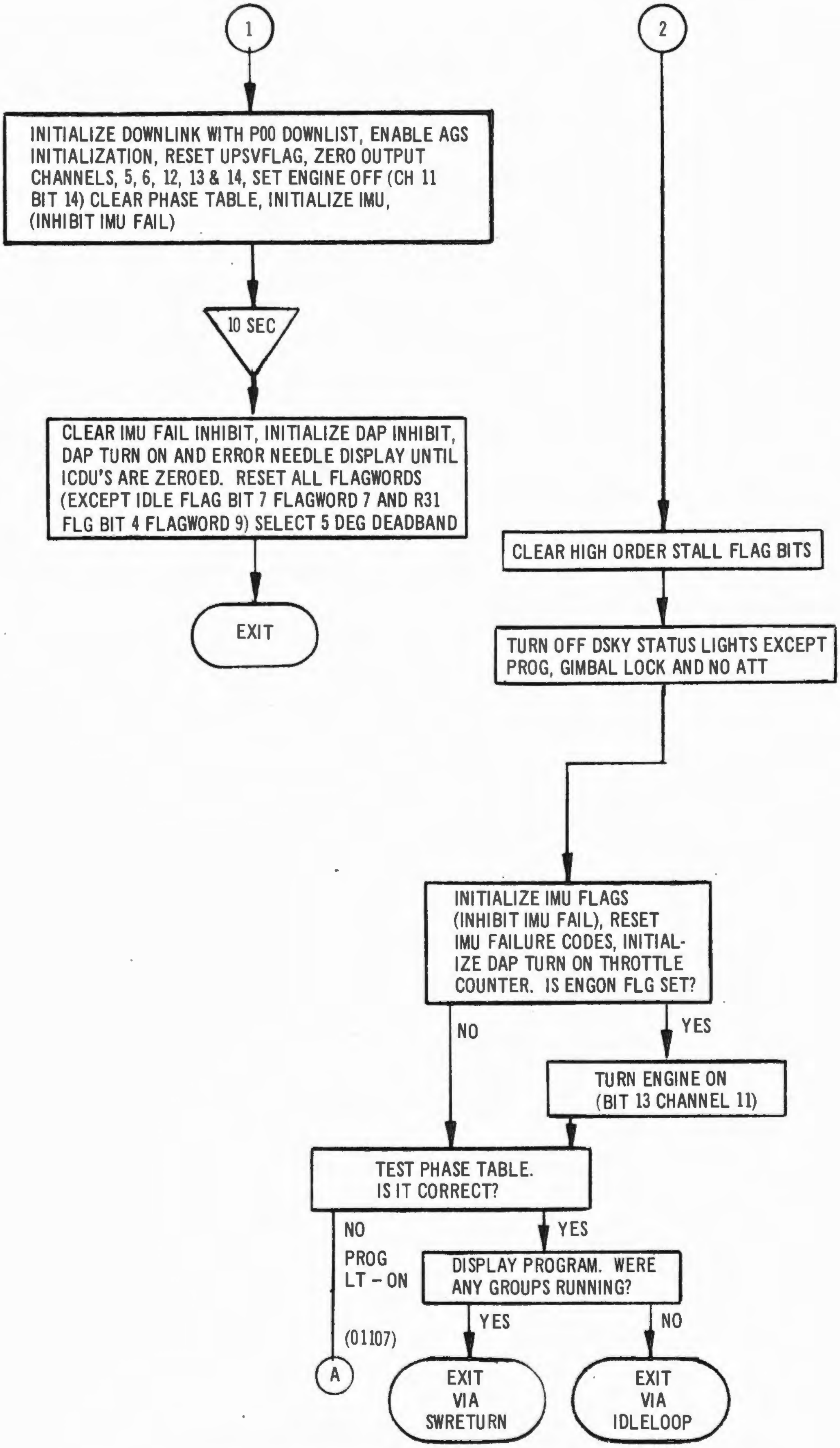


Fig. 5-56 Restart extended verb (V69) (sheet 2 of 2).

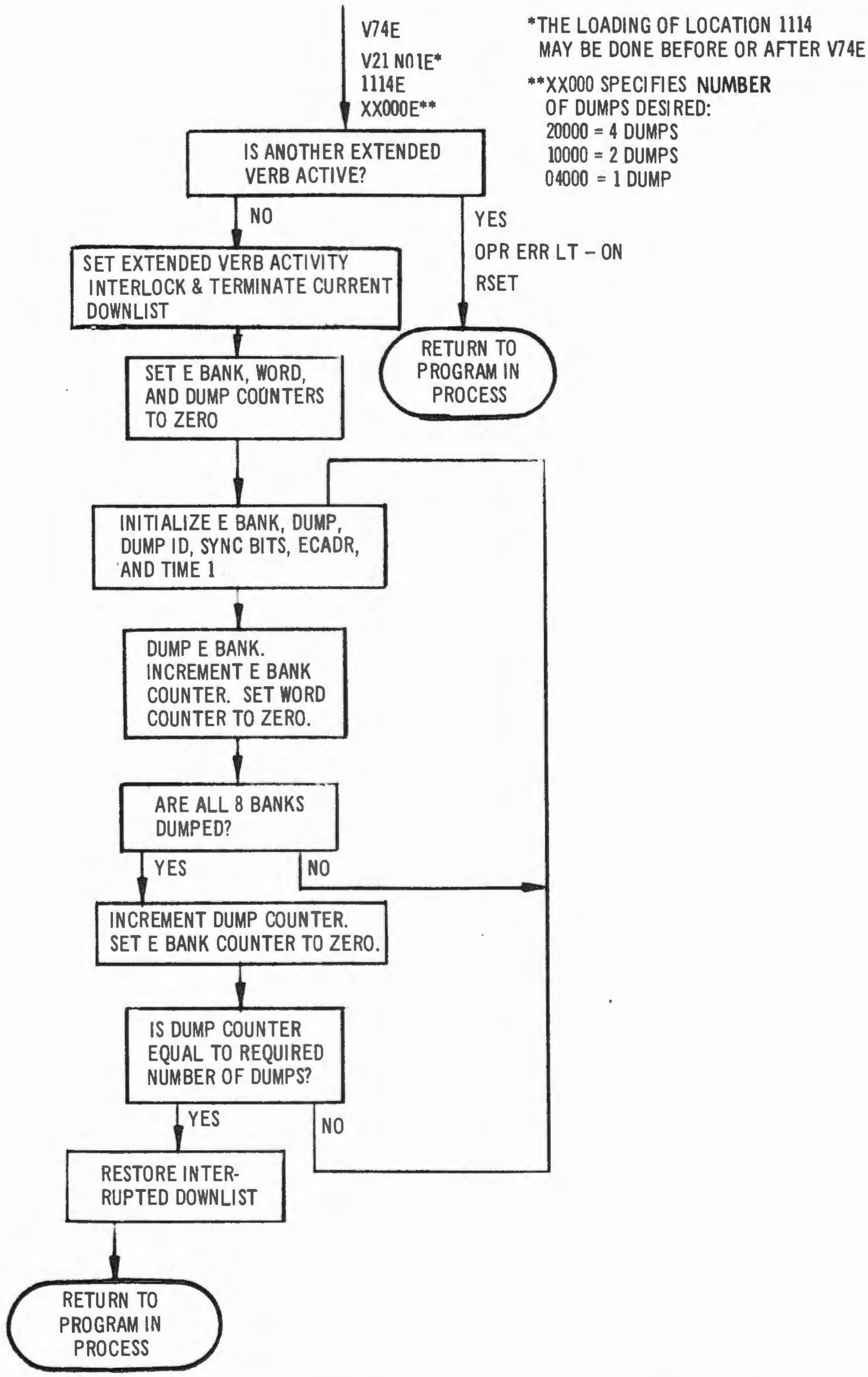


Fig. 5-57. Initialize erasable dump via downlink extended verb (V74).

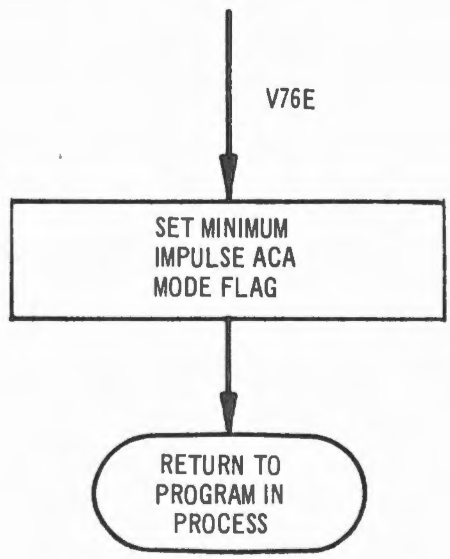


Fig. 5-58. Minimum impulse mode extended verb (V76).

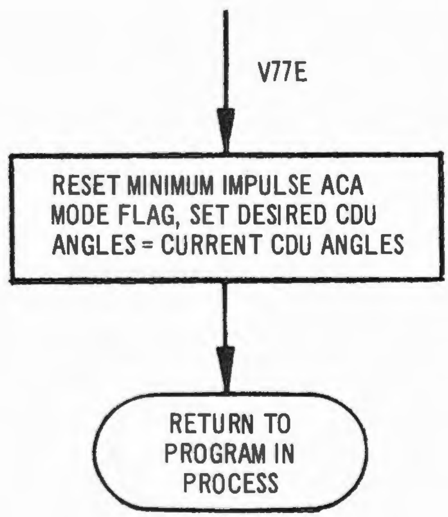


Fig. 5-59. Rate command extended verb (V77).

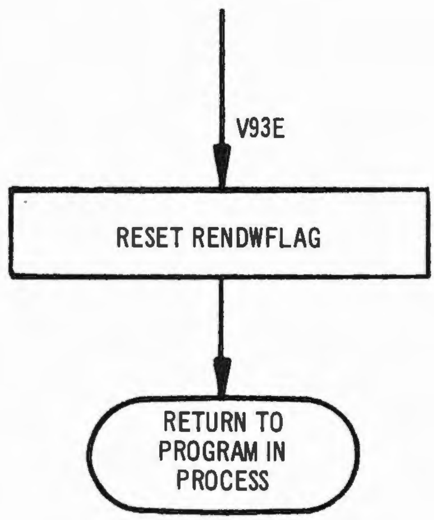


Fig. 5-60. Enable W-matrix initialization extended verb (V93).

5.2.3.32.16 Suspend State Vector Integration Extended Verb (V96). This verb (Fig. 5-61) allows the crew to suspend integration of the state vector during P00. This capability is very useful if the LGC had been in standby mode for a long period of time. When the LGC is brought back to operate mode, the idling program (P00) will begin integrating the state vector to the present time. Integration over the long shut down period is time consuming and diminished in accuracy. This verb can be used to suspend integration until after a state vector update is received from the ground. Program P00 integrates the state vector about every 10 minutes. This verb suspends integration for one 10-minute cycle only.

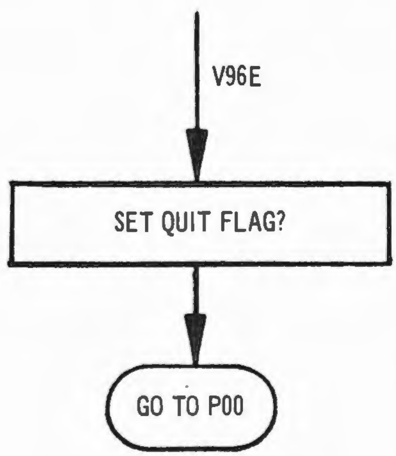


Fig. 5-61 Suspend state vector integration extended verb (V96).

SECTION VI

FLIGHT OPERATION PROCEDURES

6.1 BACKUP PROCEDURES

The procedures of this section are intended to supplement the normal checklist procedures contained in section 6.4, which comprises Volume II of this report.

6.1.1 Turn On and Shut Down Procedures

The following procedures are the normal power up and power down procedures for the various PGNCS equipment.

6.1.1.1 LGC Power Up Procedure

This procedure assumes the LGC is in the standby mode. The LGC should never be powered down below standby mode, after initial subsystem activation.

1. Press PRO button.
   STBY light goes out.
   Program 06 is displayed.
2. Key V37E 00E.
   Program display changes to 00.
3. If state vector is to be updated, key V96E to suspend state vector integration for ten minutes. Repeat as often as necessary until update is received.
   Perform LGC update program, P27.
4. Select desired program (key V37E XXE).

6.1.1.2 LGC Power Down Procedure

Perform program P06 (key V37E 06E). Do not power down LGC below standby mode. Do not leave LGC in standby mode for more than 23 hours. The

IMU should be shut down prior to LGC power down.

6.1.1.3 IMU Turn On Procedure

This procedure assumes IMU standby power is on. IMU standby power should never be turned off, except in extreme emergency. LGC should be powered up before the IMU; for emergency IMU turn on while LGC is not operating, see paragraph 6.3.2.

1. If STBY light is on, perform LGC power up procedure (paragraph) 6.1.1.1).
2. Close IMU OPR circuit breaker.
   NO ATT light comes on for 90 seconds.
3. When NO ATT light goes out, select an IMU alignment program (usually P51).

6.1.1.4 IMU Shut Down Procedure

Open IMU OPR circuit breaker.

Do not remove IMU standby power, except in extreme emergency.

6.1.1.5 RR Turn On Procedure

1. Place RR heater operate CB "ON".
   (STBY CB is "ON" from Launch). Monitor temperature meter to insure RR temperature remains less than + 150°F.
   (Wait 1000 seconds minimum before proceding).
2. Close RR power circuit breaker.

6.1.1.6 RR Turn Off Procedure

Open RR power circuit breaker.

6.1.1.7 LR Turn On Procedure

1. LR heater CB is on from launch.
   (Monitor LR antenna temperature on heater temperature meter to insure temperature remains within + 55° to + 70°F).
2. Close LR power circuit breaker.

6.1.1.8 LR Turn Off Procedure

Open LR power circuit breaker.

6.1.2 LGC Self Check

The LGC self check consists of two tests which may be commanded individually or together. The first test checks the LGC's ability to properly address and read into and out of each bit in erasable memory.
Test 2 adds all the cells of each bank of fixed memory and compares the sum to the bank number. They must be the same to pass the test.

During performance of LGC self check it is recommended that certain erasable addresses be monitored. These include the following:

1363 (ALMCADR) - One greater than the address which contains the instruction to go to the ERRORS routine. It is loaded only when an error is detected.

1365 (ERCOUNT) - Number of errors since last time address was zeroed by self check or fresh start.

1366 (SCOUNT) - Number of times one of the two tests of self check was begun since last time address was zeroed.

1367 (SCOUNT + 1) - Number of times erasable memory was successfully tested in self check since last time address was zeroed.

The following procedure is recommended for in-flight performance of self check:

1. Command P00:

   Key: V37E 00E

2. Zero ERCOUNT, SCOUNT, and SCOUNT +1:

   Key: V25 N01E
   1365E
   ENTR
   ENTR
   ENTR

3. Start monitor of ERCOUNT, SCOUNT, and SCOUNT +1:

   Key: V15 N01E
   1365E

4. Command self check:

   Key: V21 N27E
   10E
   KEY REL

5. Monitor register R2 (SCOUNT):

   Normal indication: 00001 for about 13 seconds

   00002 for about 52 seconds

   00003 for about 13 seconds

   (successful self check go to step 7)

   Abnormal indication: PROG light comes on.
   R2 stops before 00003.
   (Go to step 6)

6. Record results:

   Record R1 (ERCOUNT), R2 (SCOUNT), and R3 (SCOUNT +1)

   Key: V05 N09E
   Verify alarm code 01102

   Key: V05 N08E
   Record R1 (ALMCADR)

7. Terminate self check:

   Key: V21 N27E
   OE

   If PROG light is on, key RSET.

8. Use following table for diagnosis of failure.

Recorded SCOUNT	Action to take	Probable trouble
00001	1. Key: V01 N01E 1374E 2. Record R1 (SKEEP 4) 3. Key: ENTR 1377E 4. Record R1 (SKEEP 7) 5. Transmit ALMCADR, SKEEP 4, and SKEEP 7 to MSFN. 6. Terminate use of LGC	Erasable memory problem. Don't use LGC.
00002	Perform SHOW BANKSUM (para. 6.1.2). Transmit bank number of failed bank to MSFN.	Fixed memory trouble. LGC not useable.

6.1.3 Fixed Memory Check (SHOW BANKSUM):

SHOW BANKSUM is an LGC routine which checks all the cells in each fixed memory bank. The test adds all the cells for each bank and displays the sum in R1. The bank number is displayed in R2. These values must be equal for a successful test. If they are not, the bank has an error in it.

Perform SHOW BANKSUM as follows:

1. Command P00:

   Key: V37E 00E

2. Check first bank:

   Key: V91E

   Monitor: Flashing V05 N01
   R1 – Sum of cells in bank
   R2 – Bank number

3. If R1 and R2 are the same, check next bank:

   Key: PRO

4. Repeat steps 2 and 3 for each succeeding bank until the last bank (43) has been checked.

5. If R1 and R2 differ for any bank, record bank number and transmit to MSFN. Terminate use of LGC after completion of test, until further notice by MSFN.

6. To terminate SHOW BANKSUM:

   Key: V34E

6.1.4 LGC Input-Output Channel Check

To determine the state of discretes to or from the LGC, the input and output channels can be checked. This is done as follows:

1. Key: V01 N10E

2. Key: XXE, where XX is the number of the channel desired.

3. Monitor R1, which contains the 15 binary bits of the channel in octal.

To determine the state of each bit, the octal number in the register must be converted to binary. This needn't be done for the entire register, but only for the octal digit that contains the bit in question. Bits 1, 2, and 3 of the channel word appear in digit E (first from the right) of R1; bits 4, 5, and 6 ... in digit D; bits 7, 8, and 9 ... digit C; bits 10, 11, and 12 ... digit B; and bits 13, 14, and 15 ... digit A. The following is an octal to binary conversion list:

Octal	Binary
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

Table 6-1 contains the bit assignment for the output channels and Table 6-2 for the input channels. The fourth column from the right gives the octal digit of R1 which contains the bit in column two. The last column contains those octal numbers which indicate that the bit is active. It should be noted that the output channels and input channels 15 & 16 use positive logic; i.e., an active bit is a one and an inactive bit is a zero. The other input channels use negative logic; i.e., an active bit is a zero and an inactive bit is a one.

Table 6-1. LGC Output Channels Bit Assignment (sheet 1 of 3)

Channel	Bit	Description	DSKY Digit Position	Numerals with which Bit is Present
5		Channel 5 contains pitch, roll and translation RCS jet commands as follows:		
	1	#1 RCS 4U (-P +R -X)	E	1, 5
	2	#2 RCS 4D (+P -R +X)	E	2, 6
	3	#5 RCS 3U (+P +R -X)	E	4, 5, 6
	4	#6 RCS 3D (-P -R +X)	D	1, 3, 5
	5	#9 RCS 2U (+P -R -X)	D	2, 3
	6	#10 RCS 2D (-P +R +X)	D	4, 5
	7	#13 RCS 1U (-P -R -X)	C	1
	8	#14 RCS 1D (+P +R +X)	C	2
6		Channel 6 contains yaw and Y and Z translation RCS jet commands as follows:		
	1	#7 RCS 3F (+Yaw +Z)	E	1, 5
	2	#3 RCS 4F (-Yaw -Z)	E	2, 6
	3	#15 RCS 1F (+Yaw -Z)	E	4, 5, 6
	4	#11 RCS 2F (-Yaw +Z)	D	1, 3, 5
	5	#12 RCS 2S (+Yaw +Y)	D	2, 3
	6	#8 RCS 3S (-Yaw -Y)	D	4, 5
	7	#4 RCS 4S (+Yaw -Y)	C	1
	8	#16 RCS 1S (-Yaw +Y)	C	2

Table 6-1. LGC Output Channels Bit Assignment (sheet 2 of 3)

Channel	Bit	Description	DSKY Digit Position	Numerals with which Bit is Present
11	1	ISS warning	E	1, 3, 5, 7
	2	Computer activity	E	2, 3, 6, 7
	3	Uplink activity	E	4, 5, 6, 7
	4	Temperature caution	D	1, 3, 5, 7
	5	Key release flash	D	2, 3, 6, 7
	6	Verb-Noun flash	D	4, 5, 6, 7
	7	Operator error flash	C	1, 5
	8	Spare		
	9	Test connector outbit	C	4, 5
	10	Caution reset	B	1
	11	Spare		
	12	Spare		
	13	Engine on	A	1, 3
	14	Engine off	A	2, 3
12	1	Zero RR CDU	E	1, 3
	2	Enable RR error counter	E	2, 3
	3	Spare		
	4	Coarse align enable	D	1, 3, 5, 7
	5	Zero ICDU's	D	2, 3, 6, 7
	6	Enable IMU error counter	D	4, 5, 6, 7
	7	Spare		
	8	Display inertial data	C	2, 6
	9	-Pitch gimbal trim	C	4, 6
	10	+Pitch gimbal trim	B	1, 3, 5, 7
	11	-Roll gimbal trim	B	2, 3
	12	+Roll gimbal trim	B	4, 5
	13	LR pos command	A	1, 3, 5, 7
	14	RR enable auto track	A	2, 3, 6, 7
	15	ISS turn on delay complete	A	4, 5, 6, 7

Table 6-1. LGC Output Channels Bit Assignment (sheet 3 of 3)

Channel	Bit	Description	DSKY Digit Position	Numerals with which Bit is Present
13	1	Radar select c	E	1, 3, 5, 7
	2	Radar select b	E	2, 3, 6, 7
	3	Radar select a	E	4, 5, 6, 7
	4	Radar activity	D	1, 3, 5, 7
	5	Inhibit uplink	D	2, 3, 6, 7
	6	Block inlink	D	4, 5, 6, 7
	7	Downlink word order	C	1, 3
	8	RHC counter enable	C	2, 3
	9	Spare		
	10	Test alarms	B	1, 3, 5, 7
	11	Enable standby	B	2, 3, 6, 7
	12	Reset rotation control trap	B	4, 5, 6, 7
	13	Reset translation control trap	A	1, 3, 5, 7
	14	Reset minimum impulse trap	A	2, 3, 6, 7
	15	Enable T6 rupt	A	4, 5, 6, 7
14	1	Outlink activity	E	1, 3, 5, 7
	2	Altitude rate select	E	2, 3, 6, 7
	3	Altitude meter activity	E	4, 5, 6, 7
	4	Trust drive activity	D	1, 5
	5	spare		
	6	Gyro enable	D	4, 5
	7	Gyro select A	C	*
	8	Gyro select B	C	*
	9	Gyro minus sign	C	*
	10	Gyro activity	B	1, 3, 5, 7
	11	Drive shaft CDU	B	2, 3, 6, 7
	12	Drive trunnion CDU	B	4, 5, 6, 7
	13	Drive ICDU Z	A	1, 3, 5, 7
	14	Drive ICDU Y	A	2, 3, 6, 7
	15	Drive ICDU X	A	4, 5, 6, 7

*Digit 3 indicates gyro axis selected as follows:

0 - None	2 - +Y	4 - None	6 - -Y
1 - +X	3 - +Z	5 - -X	7 - -Z

Table 6-2. LGC Input Channels Bit Assignment (sheet 1 of 3)

Channel	Bit	Description	DSKY Digit Position	Numerals with which Bit is Present
15	1-5	Channel 15, bits 1 through 5, contain the keycode from the DSKY. It appears in digits D and E of the register as an octal number (0 through 37).		
16	1	Spare		
	2	Spare		
	3	LM mark X	E	3
	4	LM mark Y	D	2, 4, 6
	5	LM mark reject	D	4, 5
	6	Descent +	D	3
	7	Descent -	C	1
30	1	Abort	E	0, 2, 4, 6
	2	Stage verify	E	0, 1, 4, 5
	3	Engine armed	E	0, 1, 2, 3
	4	Abort stage	D	0, 2, 4, 6
	5	Auto throttle	D	0, 1, 4, 5
	6	Display inertial data	D	0, 1, 2, 3
	7	RR CDU fail	C	2, 6
	8	Spare		
	9	IMU operate	C	2, 3
	10	G/N control of S/C	B	0, 2, 4, 6
	11	IMU cage	B	0, 1, 4, 5
	12	ICDU fail	B	0, 1, 2, 3
	13	IMU fail	A	0, 2, 4, 6
	14	ISS turn on request	A	0, 1, 4, 5
	15	IMU temperature within limits	A	0, 1, 2, 3
31	1	+EL(LPD), +PMI	E	2, 6
	2	-EL(LPD), -PMI	E	1, 5
	3	+YMI	E	1, 2
	4	-YMI	D	2, 4
	5	+AZ(LPD), +RMI	D	4, 5
	6	-AZ(LPD), -RMI	D	2, 3

Table 6-2. LGC Input Channels Bit Assignment (sheet 2 of 3)

Channel	Bit	Description	DSKY Digit Position	Numerals with which Bit is Present
31 (cont.)	7	+X translation	C	2, 6
	8	-X translation	C	1, 5
	9	+Y translation	C	1, 2, 3
	10	-Y translation	B	2, 4, 6
	11	+Z translation	B	4, 5
	12	-Z translation	B	2, 3
	13	Attitude hold	A	2
	14	Auto stabilization	A	1
	15	Attitude control out of detent	A	1, 2, 3
32	1	Thruster 2-4 fail	E	0, 2, 4, 6
	2	Thruster 5-8 fail	E	0, 1, 4, 5
	3	Thruster 1-3 fail	E	0, 1, 2, 3
	4	Thruster 6-7 fail	D	0, 2, 4, 6
	5	Thruster 14-16 fail	D	0, 1, 4, 5
	6	Thruster 13-15 fail	D	0, 1, 2, 3
	7	Thruster 9-12 fail	C	0, 2, 4, 6
	8	Thruster 10-11 fail	C	0, 1, 4, 5
	9	Gimbal off	C	0, 1, 2, 3
	10	Apparent gimbal fail	B	6
	11	Spare		
	12	Spare		
	13	Spare		
	14	Proceed	A	5
33	1	Spare		
	2	RR power on/auto	E	1, 4, 5
	3	RR range low scale	E	1, 3
	4	RR data good	D	0, 2, 4, 6
	5	LR data good	D	0, 1, 4, 5
	6	LR position 1	D	0, 1, 2, 3
	7	LR position 2	C	0, 2, 4, 6

Table 6-2. LGC Input Channels Bit Assignment (sheet 3 of 3)

Channel	Bit	Description	DSKY Digit Position	Numerals with which Bit is Present
33 (cont.)	8	LR velocity data good	C	0, 1, 4, 5
	9	LR range low scale	C	0, 1, 2, 3
	10	Block uplink input	B	0, 2, 4, 6
	11	Uplink too fast	B	0, 1, 4, 5
	12	Downlink too fast	B	0, 1, 2, 3
	13	PIPA fail	A	0, 2, 4, 6
	14	Warning	A	0, 1, 4, 5
	15/16	OSC alarm	A	0, 1, 2, 3

6.1.5 Erasable Memory Verification and Update

The contents of any erasable memory address may be checked. This is useful in determining the condition of flags or the value of pertinent parameters.

Any address may be checked as follows:

1. Key: V01 N01E
   XXXXE, where XXXX is address desired

2. Monitor R1 for contents of address.

The data displayed in R1 is octal, to determine the state of an individual bit (such as when checking a flagword) an octal to binary conversion is necessary just as in checking the input-output channels (see para. 6.1.3).

The contents of erasable memory addresses can be changed; however, great care must be exercised to prevent destroying valid data by keying an incorrect address. Update erasable memory as follows:

1. Command P00:

   Key: V37E 00E

2. Start update:

   Key: V21 N01E

3. Load address:

   Key: XXXXE, where XXXX is address to be loaded

4. Load data:

   Key: XXXXXE, where XXXXX is data to be loaded in octal

5. If more than one nonsequential address is to be loaded, repeat steps 3 and 4 until all addresses are loaded.

6. If a number of sequential addresses are to be loaded, after the first data load,

   Key V15E

   and repeat step 4 until all addresses are loaded.

After loading data verify data word as follows:

1. Start data display:

   Key: V01 N01E

2. Load address:

   Key: XXXXE, where XXXX is address of data to be verified

3. Verify data word in R1.

4. If the data in a number of sequential addresses are to be verified,

   Key: N15E

   Verify second data word in R1

   Key: ENTR

   Verify third data word in R1

   Key: ENTR

   Continue process until all data words are verified.

6.1.6 PIPA Bias Check

The PIPA bias can be checked and updated as follows:

1. Set digital event timer (DET) to zero.

2. Obtain SC rates of less than 0.1 degree per second.

3. Key: V25 N21E
   ENTR
   ENTR
   ENTR
   V06 N21

4. Simultaneously key ENTR and start DET.

5. Record PIPA counts R1, R2, and R3.

   R1 - X axis PIPA
   R2 - Y axis PIPA
   R3 - Z axis PIPA

6. When DET reads 00:32 key ENTR.

7. Record PIPA counts as in step 5.

8. Compute PIPA bias for each axis as follows:

   $$\frac{N_F - N_I}{100} = \text{PIPA bias}$$

   where: N_F is number of counts for an axis recorded in step 7.

   N_I is number of counts for same axis recorded in step 5.

9. Check presently stored bias as follows:

   Key: V06 N01E
   1452E
   Record X axis PIPA bias from R1.

   Key: 1454E
   Record Y axis PIPA bias from R1.

   Key: 1456E
   Record Z axis PIPA bias from R1.

10. Compute difference between measured (step 8) and stored (step 9) values of PIPA bias for each axis. If the values differ by more than ±19200 perform step 11; if not, go to step 12.

11. Key: V21 N01E
    14XXE, where 14XX is address of applicable PIPA bias as indicated in step 9
    XXXXXE, where XXXXX is measured (step 8) value of PIPA bias

12. Key: V37E 00E

6.1.7 Gyro Drift Test

Gyro drift can be determined from the gyro torquing angles. The test requires at least two hours for accurate performance. Attitude changes during the test do not effect the test results. Test procedures are as follows:

1. Perform IMU realign program P52.
2. During gyro torquing routine (R55), record gyro torquing angles (FL V06 N93) and time (to nearest 2 minutes), and command gyro torquing (PRO).
3. After two hours repeat steps 1 and 2.
4. The last recorded torquing angles is the gyro drift in degrees to the nearest 0.001 degree. Convert to MERU by the following formula:

$$D = \frac{\text{Torquing angle (deg)}}{\text{Time (hours)}} \times 67 \text{ meru}$$

6.1.8 Flagword Monitor and Change

The status of LGC flags may be monitored by the following procedure, except during P27. The state of any flag, except those in bit positions 1, 2, and 3, may be changed by this procedure:

1. Monitor desired flagword:

   Key: V11N01E

   Key: Flagword address (CADR) of desired flagword as follows.

Flagword	Address
0	74E
1	75E
2	76E
3	77E
4	100E
5	101E
6	102E

Flagword	Address
7	103E
8	104E
9	105E
10	106E
11	107E

Check flag status in R1.

The data displayed in R1 is in octal, to determine the state of an individual flag, an octal to binary conversion is necessary just as in checking the input-output channels as described in paragraph 6.1.3. Flagwords are listed in Section 2 of R-557.

Continue with rest of procedure only if changing a flag state is desired.

2. Store flag change program in erasable memory:

   Key: V25 N01E
   300E
   XXXXE, where XXXX equals
   7714 to set flag and
   7734 to reset flag
   XXXXZE, where XXXX is octal number of bit to be inserted and Z is the flagword number.
   4634E

3. Establish stored program as a task:

   Key: V25 N26E
   1E
   300E
   0E
   V31E

4. Monitor flagword: Repeat step 1.

6.2 MALFUNCTION PROCEDURES

Table 6-3 lists PGNCS caution and warning and other malfunction indications and the corrective action to be performed for each.

To test the reliability of DSKY alarm indicators (GIMBAL LOCK, PROG, TRACKER, TEMP, and RESTART) key in V35E on the DSKY keyboard. This will also light the UPLINK ACT, KEY REL, OPR ERR, NO ATT, and STBY indicators and display 8's and +'s on the numerical panel. After five seconds, these displays go out.

Table 6-3 also provides corrective action for alarm codes which appear with program alarms (PROG indicator lighted). Alarm codes which are caused by procedural errors are not included in Table 6-3. A complete list of Sundance program alarms is given in Table 2-2.

Table 6-4 provides special subroutines used in conjunction with the malfunction procedure of Table 6-3.

6.3 EMERGENCY PROCEDURES

6.3.1 Tumbling IMU

1. Position IMU CAGE switch to the on (up) position until gimbals settle at the zero position (about 5 seconds); then set to off (down) position.
2. Perform IMU orientation determination program (P51).

6.3.2 IMU Turn On When LGC Not Operating

1. Check that IMU OPR and IMU STBY circuit breakers are closed.
2. Wait 90 seconds.
3. Momentarily (about 5 seconds) set IMU CAGE switch to on (up) position, then return to off (down) position.

The IMU is then aligned to the spacecraft axes. To align the IMU to a particular inertial orientation:

Maneuver spacecraft to desired orientation and cage IMU (step 3 above).

SYMPTOM	PROCEDURE	REMARKS

SYMPTOM

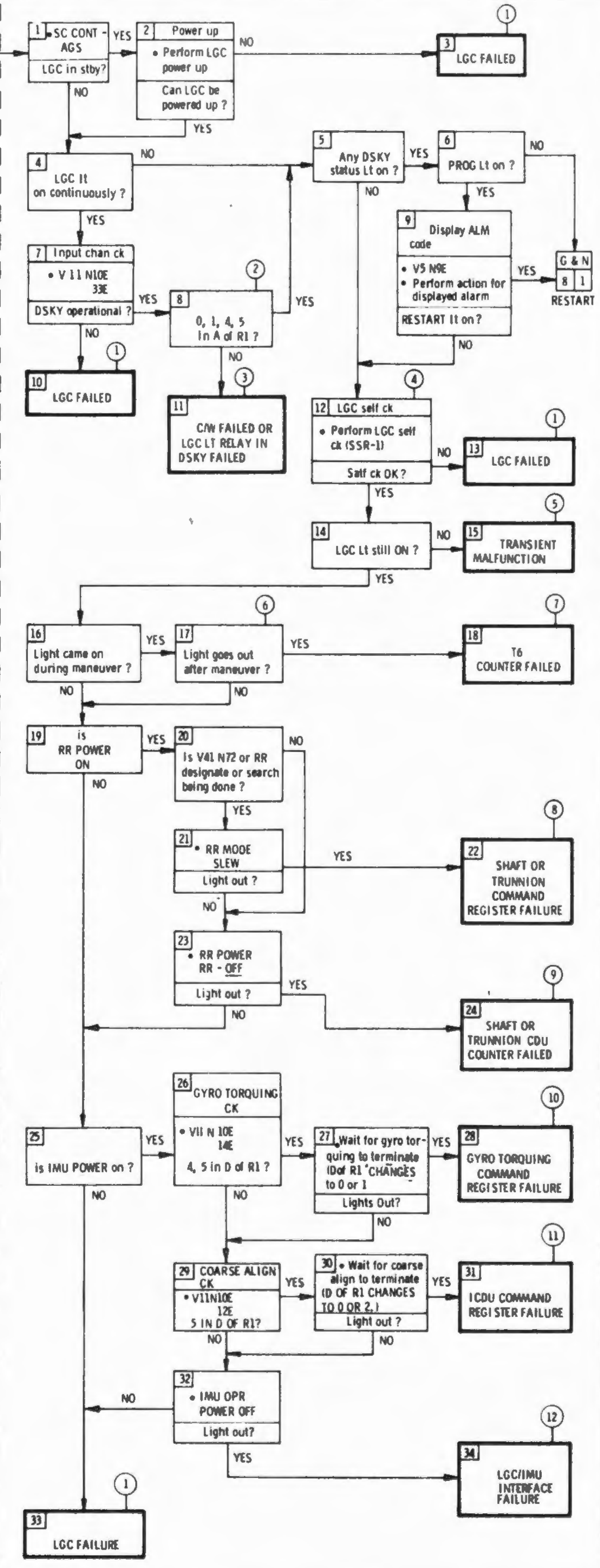
1 G & N

LGC

RED

Lighted in STBY and OPR modes by:
Prime power failure or Scaler failure.
Lighted for 5 sec in STBY or OPR modes by repeated (>0.9 pps) issuance of counter failure or double/ frequency scaler failure.
Lighted for 5 sec only in OPR mode by repeated (>0.4 pps) restarts.
Restart is caused by:
RUPT LOCK
TC TRAP
OSCILLATOR FAIL
PARITY FAIL
NIGHTWATCHMAN
or VOLTAGE FAIL.
Lighted for 5 sec only in STBY mode by repeated (>0.9 pps) issuance of VOLTAGE FAILURE of + 28v, + 14v, or + 4v power supplies.

PROCEDURE



REMARKS

(1) All LGC Functions Lost.

(2) This R1 readout indicates no LGC FAIL signal to LGC

(3) Subsequent LGC malfunction indication Lost

(4) If DSKY will not accept inputs, force a restart by simultaneously pressing RESET and MARK REJECT pb's.

(5) Transient condition could have existed in either LGC or C/W system.

(6) Do not use LGC control for attitude maneuvers.

(7) RCS DAP unusable; the T6 counter controls DAP jet firing time.

(8) Display of forward & Lateral Velocity & RR Designate Lost.

(9) RR/LGC interface lost.

(10) IMU cannot be fine aligned.

(11) IMU cannot be coarse aligned. Align by caging and/or fine align.

(12) Use IMU for attitude reference only.

Table 6-3. G&N Malfunction Procedures

SYMPTOM	PROCEDURE	REMARKS

SYMPTOM

2

ISS

RED

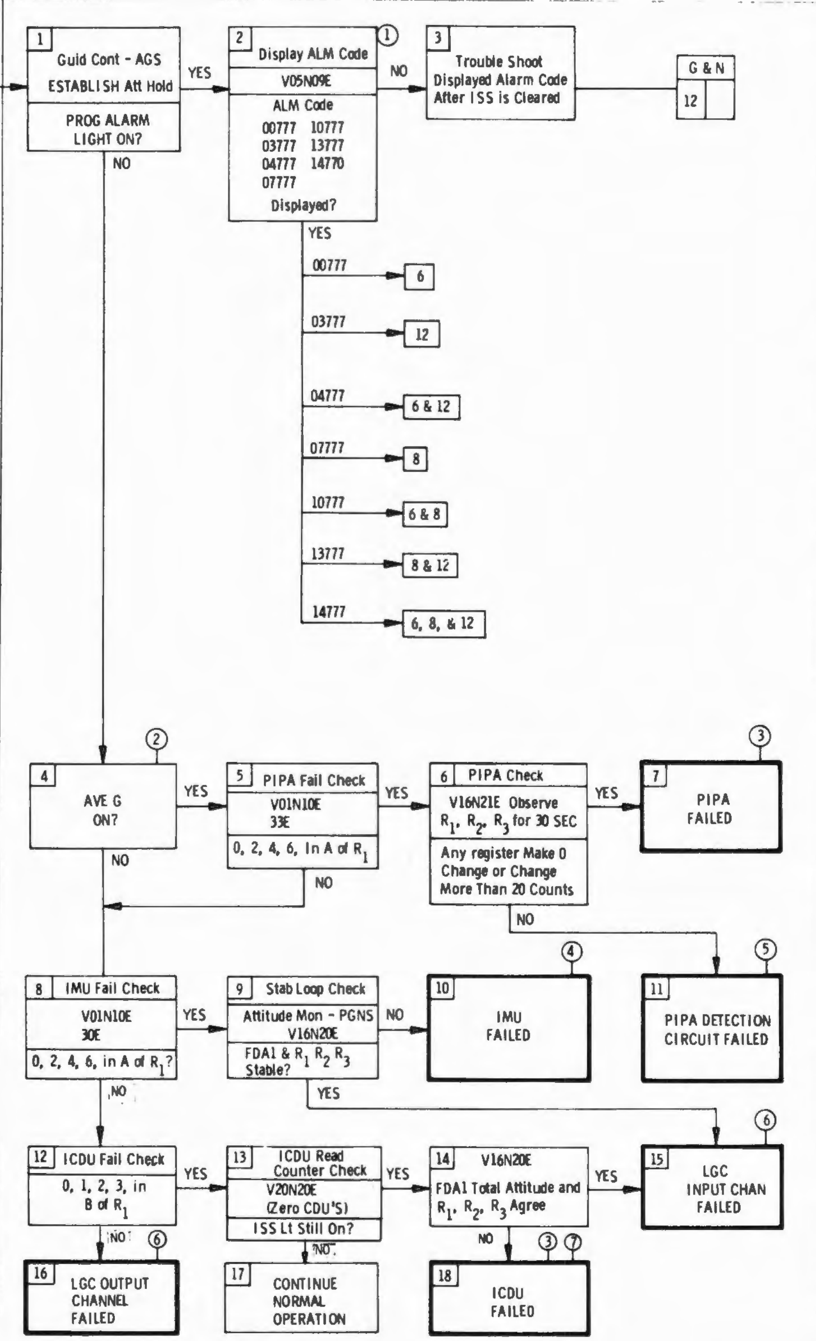
LIGHTED BY:
PIPA FAIL DURING THRUSTING
IMU FAIL, OR
ICDU FAIL

PIPA FAIL IF:
NO PIPA PULSES FOR 312.2 μ SEC BOTH + AND - PULSES, OR A LONG TIME (1.28 to 3.84 SEC) WITHOUT AT LEAST ONE + AND ONE - PULSE

IMU FAIL IF:
ANY GIMBAL SERVO ERROR > 2.9 MILLI-RADIANS FOR 2 SEC OR MORE, LOSS OF 3200 CPS PWR OR LOSS OF GYRO WHEEL PWR.

ICDU FAIL IF:
FINE ERROR > 1.0 VRMS, COARSE ERROR > 2.5 VRMS, READ COUNTER LIMIT CYCLE > 160 CPS COS (θ-φ) < 2. OV, OR + 14V PWR SUP FAILURE

PROCEDURE



REMARKS

① The alarm codes shown indicate causes of the ISS alarm. Some of these alarm codes indicate more than one cause for the ISS alarm. The alarms codes with multiple indications will require entrance into the remaining procedure at more than one point to verify all possible causes.

② PIPA Failure During Ave G will cause an ISS Lite which will go out upon Termination of AVE G.

③ LGC Monitor & Control of Thrusting & Computations Using ΔV Lost.

④ All IMU functions Lost.

⑤ Subsequent PIPA Malfunction indication Lost.

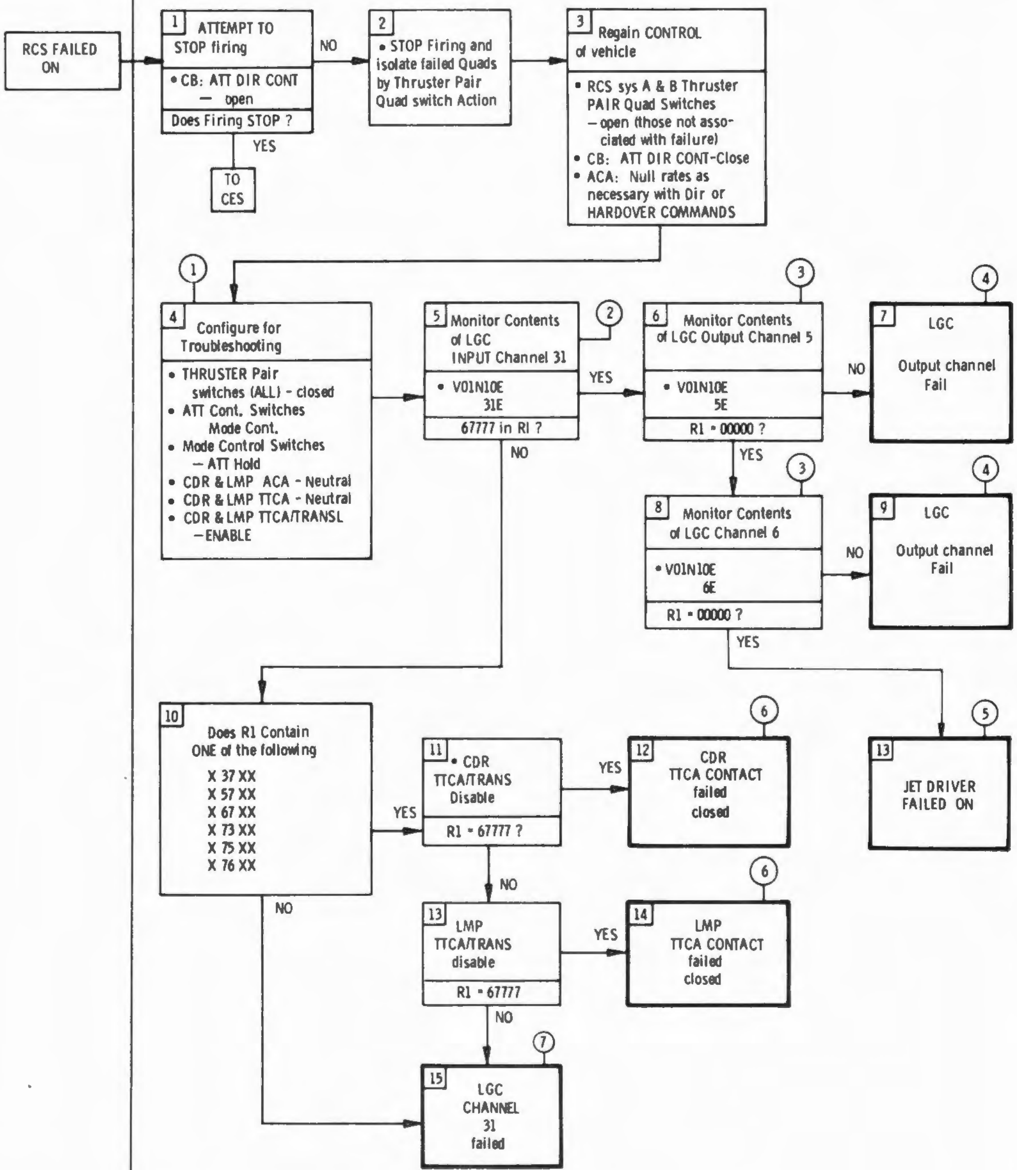
⑥ Subsequent indications of ISS failure lost.

⑦ IMU May be Used as a Total Attitude Reference only, LGC IMU Attitude Interface Lost.

Table 6-3. G&N Malfunction Procedures (Cont.)

SYMPTOM	PROCEDURE	REMARKS

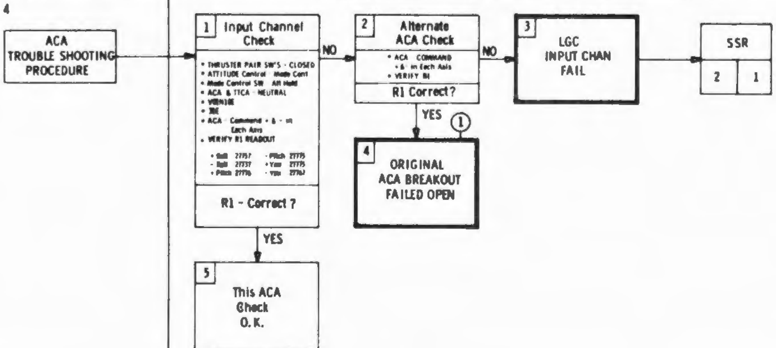
3



REMARKS

1. Closing Thruster Pair Quad Sw's sets Thruster fail bits in CHANNEL 32 and Prevents LGC from issuing jet ON COMMANDS.
2. R_1 will display 67777 when no minimum impluse or translation commands are present in channel 31.
3. R_1 will display 00000 when no jet COMMANDS are present.
4. LGC Control of affected RCS Jet Lost.
5. Use of affected RCS Thruster Pair Lost.
6. Use of affected TTCA for Translation is Lost.
7. Use of LGC for Translation is lost.

4



REMARKS

(1) Capability of this ACA's 2, 5 switches (Pulse or LPD) Lost in affected axis.

Table 6-3. G&N Malfunction Procedures (Cont.)

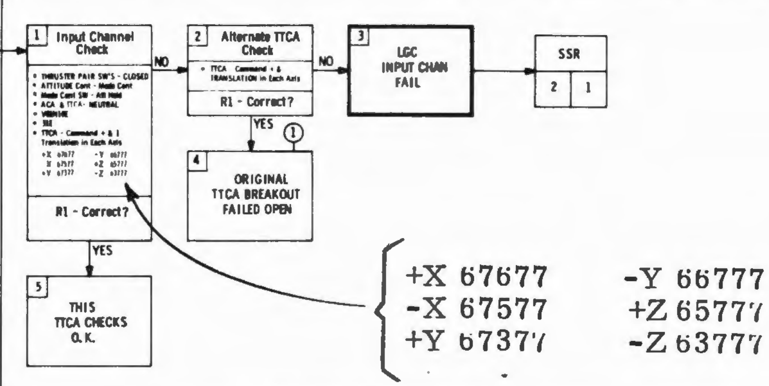
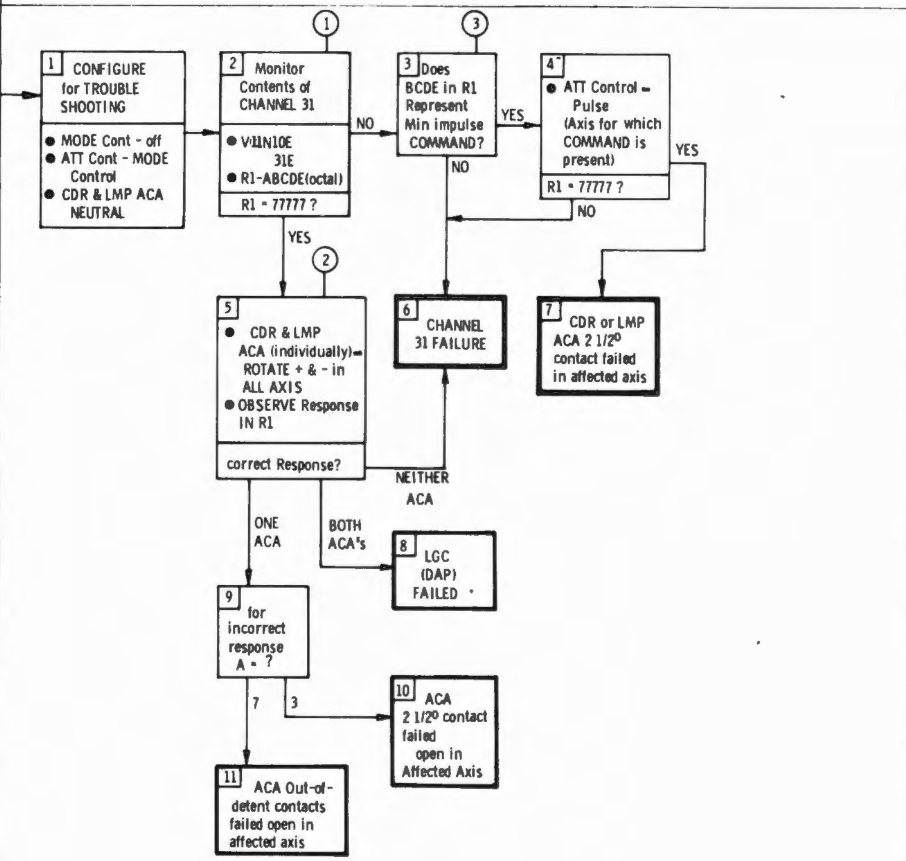
SYMPTOM	PROCEDURE	REMARKS
5 TTCA TROUBLE SHOOTING PROCEDURE		(1) Leave TTCA/TRANSL Switches in Last Position to Isolate Failed TTCA.
6 MIN IMP TROUBLE SHOOTING PROCEDURE		1. When switch configuration is as in block 1, R_1 = 77777 is normal Display. 2. Correct R_1 displays for minimum impulse commands: ABCDE -Roll 37737, +Roll 37757, -Yaw 37767, +Yaw 37773, -Pitch 37775, +Pitch 37776 3. Display representing command present will be the same as in "2" above except A=7 (because ACA is not out-of-detent)

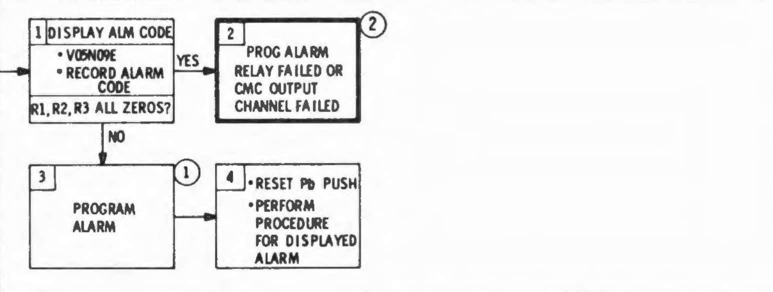
Table 6-3. G&N Malfunction Procedures (Cont.)

SYMPTOM	PROCEDURE	REMARKS

7

Symptom: PROG — YELLOW

LIGHTED BY LGC PROGRAM ALARM OR BY BAD PIPA READING DURING NONTHRUSTING MODES



Remarks:

(1) PROGRAM ALARMS ARE OF THREE CLASSES:

- MAIN ALARM-ALARM CODE DISPLAYED. PROGRAM HALTS AWAITING CREW ACTION.
- SIDE ALARM-ALARM CODE NOT DISPLAYED. PROGRAM CONTINUES
- RESTART ALARM-ALARM CODE NOT DISPLAYED. PROGRAM EXECUTES A RESTART.

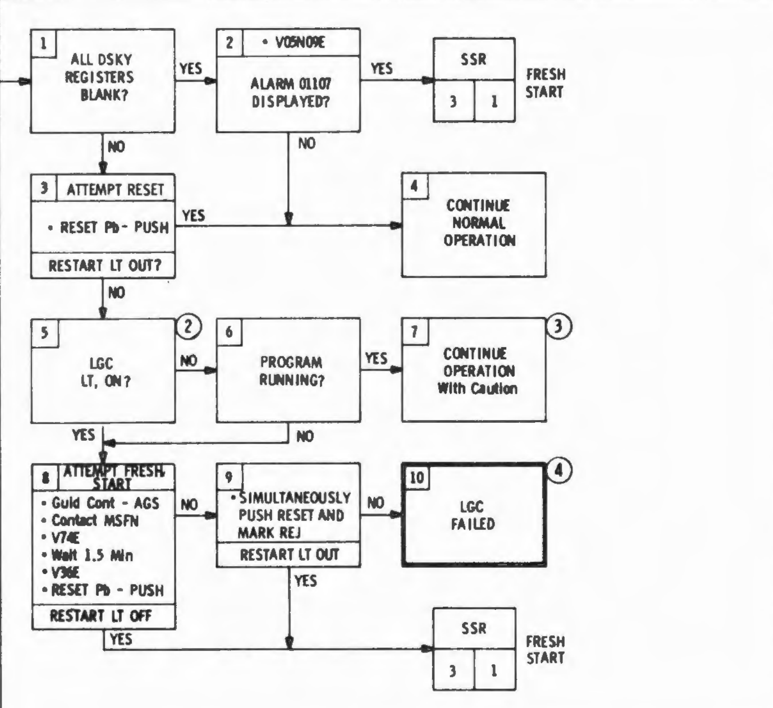
(LGC CAN STORE MULTIPLE AL . FIRST ALARM APPEARS IN R1; SECOND IN R2; LAST IN R3. A 4 IN A OF R3 INDICATES MORE THAN THREE ALARMS)

(2) ALL PROGRAM ALARM INDICATIONS LOST

8

Symptom: RESTART (1) — YELLOW

LIGHTED BY ANY OF FOLLOWING:
PARITY FAIL,
RUPT LOCK,
TC TRAP,
NIGHT WATCHMAN
OR
VOLTAGE FAIL



Remarks:

(1) If Program Lt is on Perform Alarm Procedure before Proceeding.

(2) Restarts at a higher rate than 0.9 pulses/sec will trigger LGC light. Restarts at a rate higher than 0.6 pulses/sec will sustain LGC light.

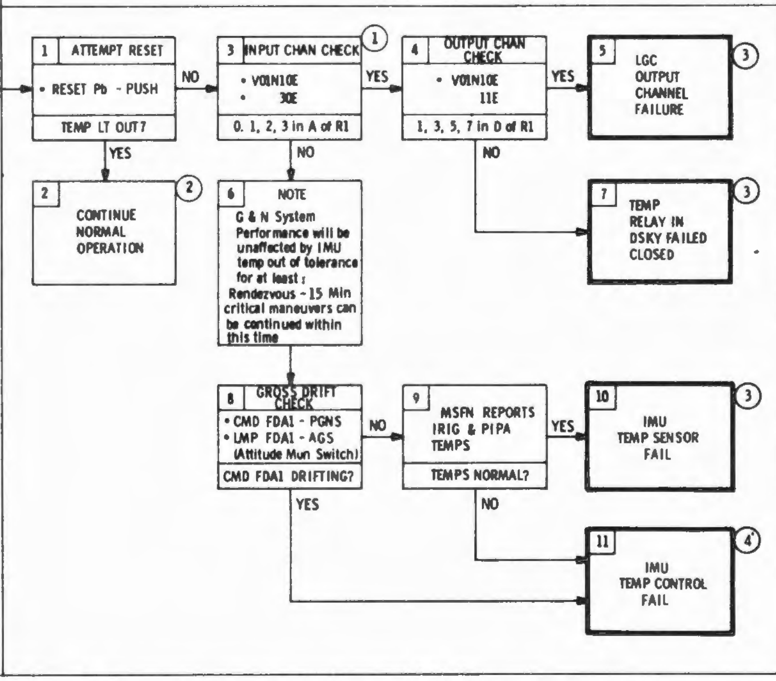
(3) Recurring Restarts at a rate insufficient to trigger LGC light.

(4) ALL LGC Functions Lost.

9

Symptom: TEMP — YELLOW

LIGHTS WHEN IMU TEMPERATURE IS OUT OF LIMITS. <126 OR >134°F



Remarks:

(1) This R1 readout indicates IMU temperature within limits

(2) Transient abnormal condition

(3) ALL IMU Temp abnormal indications Lost. Temp available from MSFN only.

(4) IMU may be used as long as FDAI indicates that the IMU is STABLE.

Table 6-3. G&N Malfunction Procedures (Cont.)

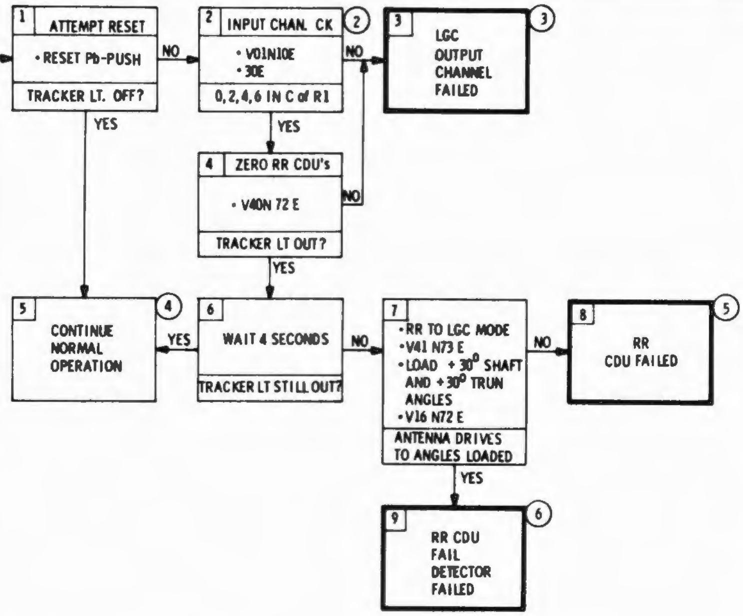
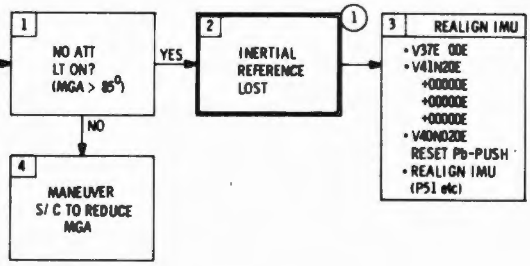
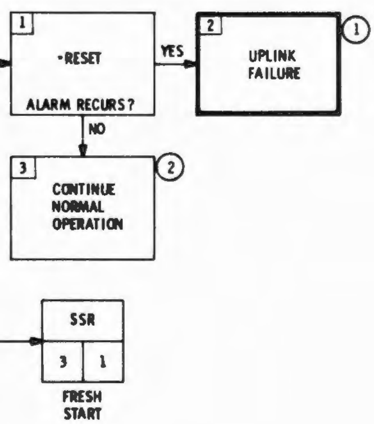
SYMPTOM	PROCEDURE	REMARKS
10 (1) TRACKER YELLOW LIGHTED BY RR CDU FAILURE RR DATA NOT GOOD LR DATA NOT GOOD RR CDU FAILURE COARSE ERROR HIGH FINE ERROR HIGH COS (θ - ψ) > 30° UP LINE HIGH 14 VDC ±4 VDC RR DATA NOT GOOD RANGE TRACKER $\overline{ACQ}$ FREQ TRACKER $\overline{ACQ}$ LR DATA NOT GOOD RANGE DATA NOT GOOD VEL DATA NOT GOOD		(1) LIGHT SIGNIFICANT ONLY DURING RR OR LR USE. (2) THIS R1 Readout indicates a RR CDU FAILURE. (3) ALL TRACKER ABNORMAL INDICATIONS LOST (4) TRANSIENT ABNORMAL CONDITION (5) Due to an abnormal condition within RR CDU Channels, RR is not operative under LGC Control or is not available for STATE VECTOR UPDATE. However RR is operative in SLEW and AUTO TRACK MODES. (6) Abnormal RR CDU indication Lost.
11 GIMBAL LOCK YELLOW LIGHTS WHEN MGA > 70°		(1) IMU IN COARSE ALIGN AND MUST BE REALIGNED TO A NEW INERTIAL REFERENCE.
12 ALARM CODES (continued) 01106 UP TELEMETRY TOO FAST 01107 PHASE TABLE DOES NOT AGREE AFTER RESTART		(1) Perform Subsequent LGC ground updates by voice link. (2) Uplink data being sent when alarm occurred should be retransmitted.

Table 6-3. G&N Malfunction Procedures (Cont.)

SYMPTOM	PROCEDURE	REMARKS
12 ALARM CODES 00207 ISS TURN ON NOT PRESENT FOR 90 SECONDS	[1] • REINITIATE ISS TURN ON — ALARM RECURS? YES → [2]; NO → [4] [2] • V01N10E • 30E — 1 OR 5 INA OF R1 FOR 90 SEC. AFTER G&N POWER IMU CB SET TO ON — NO → [3]; YES → SSR 1 1 LGC SELF CHECK [3] ISS FAILURE (1) [4] CONTINUE NORMAL OPERATION	(1) ISS TURN ON DELAY REQUEST DISCRETE NOT BEING RECEIVED BY LGC
00210 IMU NOT OPERATING 00213 IMU NOT OPERATING WITH TURN ON TURN ON REQUEST	[1] • PERFORM IMU TURN ON — ALARM RECURS? YES → [2]; NO → [4] [2] • V01N10E • 30 E — 2 OR 3 IN C OF R1? — NO → [3]; YES → SSR 1 1 LGC SELF CHECK [3] ISS FAILURE (1) [4] CONTINUE NORMAL OPERATION	(1) ISS OPERATE DISCRETE NOT BEING RECEIVED BY LGC
00211 COARSE ALIGN ERROR	[1] IS ALIGNMENT PROGRAM (P51, P52) RUNNING (1) — YES → [2]; NO → [4] [2] • CONTINUE ALIGNMENT • RECORD GYRO TORQUING ANGLES — ANY TORQUING ANGLES > 10°? — YES → [3] [3] • PERFORM FINE ALIGN CHECK P52 → [5] [4] COARSE ALIGN PROBLEM (2) [5] CONTINUE NORMAL OPERATION	(1) 00211 WILL ONLY OCCUR DURING COARSE ALIGNMENT EITHER BY AN AUTHORIZED PROGRAM OR BY A DSKY COMMAND (V41N20) (2) IMU MUST BE ALIGNED BY AN ALIGNMENT PROGRAM (BY GYRO TORQUING RATHER THAN BY COARSE ALIGN)
00212 PIPA FAIL	G&N 2 5	(1) IMU USABLE only as a Backup attitude Reference.
00217 BAD RETURN FROM STALL ROUTINE	[1] • RESET Pb-Push • REINITIATE CURRENT PROGRAM — ALARM RECURS? YES → [2]; NO → [3] [2] ISS MODE SWITCHING FAILURE (1) [3] CONTINUE NORMAL OPERATION	(2) Downlink data Transmitted at time of alarm may not be correct.
01105 DOWN TELEMETRY TOO FAST	[1] • RESET Pb PUSH (2) — ALARM RECURS? YES → [2]; NO → [3] [2] DOWNLINK FAILURE [3] CONTINUE NORMAL OPERATION	

Table 6-3. G&N Malfunction Procedures (Cont.)

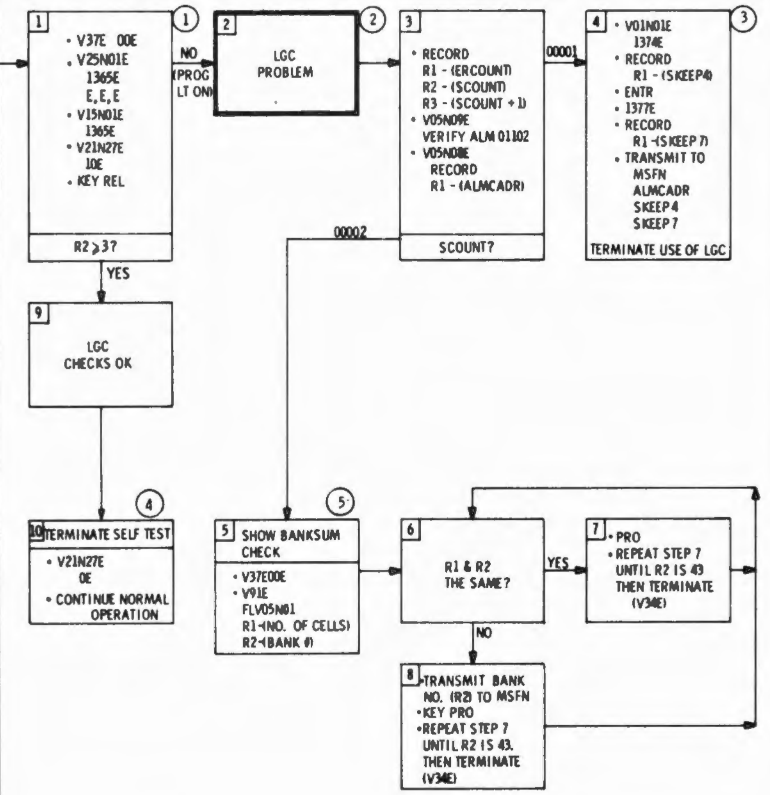
SYMPTOM	PROCEDURE	REMARKS
12 ALARM CODES (continued)		
01103 UN USED CCS BRANCH EXECUTED	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01104 DELAY ROUTINE BUSY	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01201 NO VAC AREAS AVAILABLE	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01202 NO CORE SET AREAS AVAILABLE	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01203 WAITLIST OVERFLOW	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01206 2ND JOB ATTEMPS TO GO TO SLEEP VIA DSKY PROGRAM	1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01207 NO VAC AREAS AVAILABLE FOR MARKS	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01210 2 PROG TRYING TO USE SAME DEVICE	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01211 ILLEGAL INTERRUPT OF EXTENDED VERB	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01301 ARCSIN/ ARCCOS INPUT TOO LARGE	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01302 SQ. ROOT CALLED WITH NEGATIVE ARGUMENT	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01501 DSKY ALARM DURING INTERNAL USE	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01502 ILLEGAL USE OF FLASHING DISPLAY	→ 1 • RESET Pb-PUSH → SSR 1 1 LGC Self TEST	
01407 VG INCREASING	1 • TERMINATE THRUSTING • RESET Pd-PUSH • CHECK ORBITAL PARAMETERS AND INITIATE ORBIT CHANGE TARGETING & THRUST AS NECESSARY	

Table 6-3. G&N Malfunction Procedures (Cont.)

SYMPTOM	PROCEDURE	REMARKS

1

LGC SELF TEST



REMARKS:

(1) R2 00001 for 13 sec
R2 00002 for 52 sec

(2) SUBSEQUENT USE OF LGC IS DEPENDENT ON MSFN EVALUATION OF SELF TEST DATA

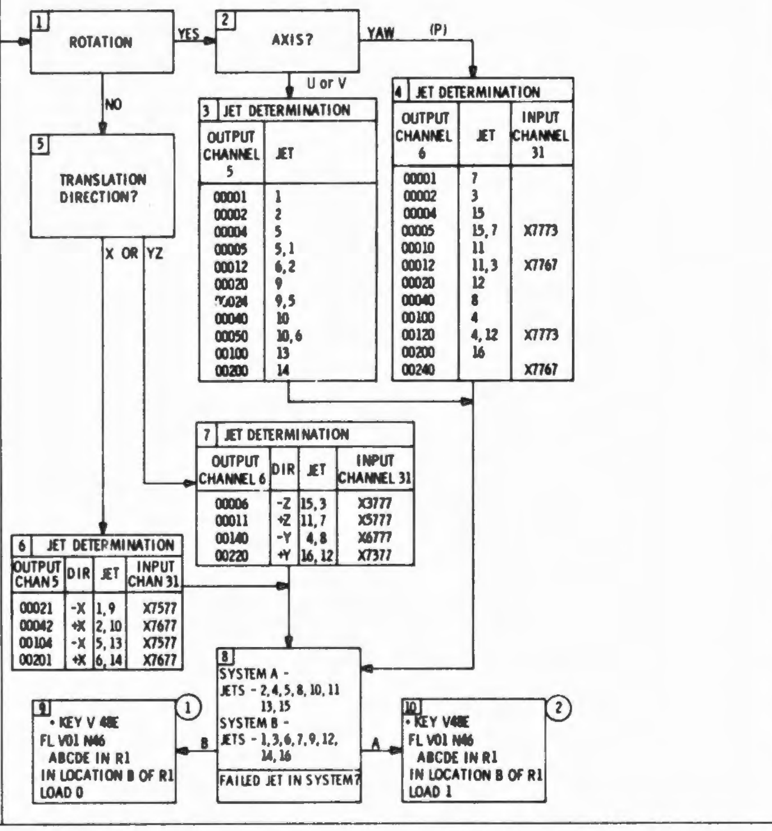
(3) PROBLEM IS IN ERASEABLE MEMORY.

(4) LGC self check tests only erasable and fixed memory: other internal LGC problems cannot be determined by LGC self dheck.

(5) Problem is in fixed Memory.

2

LGC QUAD FAIL



3 JET DETERMINATION

OUTPUT CHANNEL 5	JET
00001	1
00002	2
00004	5
00005	5, 1
00012	6, 2
00020	9
00024	9, 5
00040	10
00050	10, 6
00100	13
00200	14

4 JET DETERMINATION

OUTPUT CHANNEL 6	JET	INPUT CHANNEL 31
00001	7	
00002	3	
00004	15	
00005	15, 7	X7773
00010	11	
00012	11, 3	X7767
00020	12	
00040	8	
00100	4	
00120	4, 12	X7773
00200	16	
00240		X7767

7 JET DETERMINATION

OUTPUT CHANNEL 6	DIR	JET	INPUT CHANNEL 31
00006	-Z	15, 3	X3777
00011	+Z	11, 7	X5777
00140	-Y	4, 8	X6777
00220	+Y	16, 12	X7377

6 JET DETERMINATION

OUTPUT CHAN 5	DIR	JET	INPUT CHAN 31
00021	-X	1, 9	X7577
00042	+X	2, 10	X7677
00104	-X	5, 13	X7577
00201	+X	6, 14	X7677

REMARKS:

(1) SUBSEQUENT TRANSLATION WILL BE 2 JET USING SYSTEM A.

(2) SUBSEQUENT TRANSLATION WILL BE 2 JET USING SYSTEM B.

Table 6-4. Special Subroutines Procedures

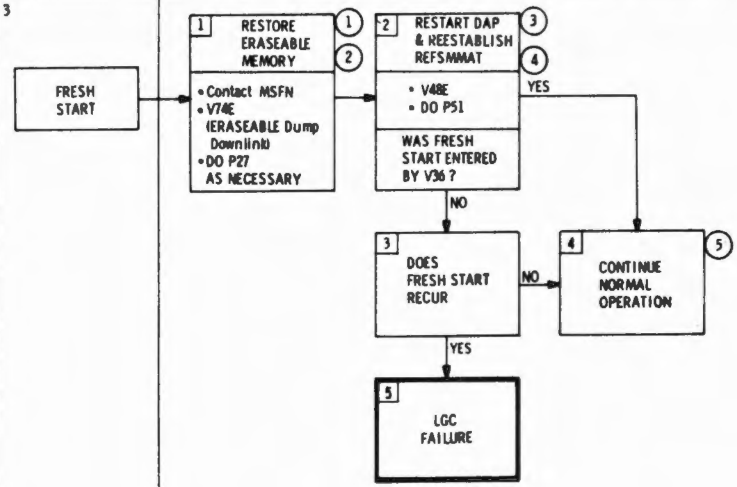
SYMPTOM	PROCEDURE	REMARKS
3		(1) State vector and LGC time should be updated. All non-pad-loaded parameters, except time & state vector, will be properly updated by LGC program in their proper sequence as if LGC had been turned on when Fresh Start occurred. (2) Extended V74 permits MSFN to examine all pertinent erasable locations to determine if any parameters need reloading. (3) DAP is shut off by Fresh Start & must be re-initiated by V46. (4) The REFSMMAT flag is reset by Fresh Start & the stored REFSMMAT may be invalid, so P51 & P52 must be performed. (5) All Flagwords are reset by Fresh Start. The proper flags are set again by the performance of the LGC programs in normal sequence.

Table 6-4. Special Subroutines Procedures (Cont.)

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