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Massachusetts Institute of Technology
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Apollo Project Memo # 1259

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From: J. Gilmore

Date: 20 April 1965

Subject: Block II Moding & Programming Requirements

Functional diagrams presenting IMU-CDU Moding, Optics CDU Moding, and Rendezvous Radar Moding are shown in Figs. 1,3 and 5 respectively. All moding is initiated by computer discretes (CGC or LGC 0-volts DC, ground, thru a 2K source impedance). The CDU discrete input circuit is shown on Mode Module Schematic 2010054.

Section I, II, and III functionally describe CDU-IMU, Optics and Rondezvous Radar (R/R) moding. Section IV covers specific computer programming requirements.

I. The CDU-IMU Modes (LEM and CSM) are: (Reference fig. 1)

A. ISS CDU-ZERO Discrete: Zeros (clears) all three ISS CDU Read counters simultaneously. It also inhibits the transmission of incrementing pulses (PI) to the IMU Read counters.

B. ISS Error Counter Enable Discrete: Enables all three ISS Error Counters simultaneously (allows them to accept input pulses from computer). The error counters are normally inhibited and zeroed. The error counter enable discrete is used in conjunction with the coarse align enable discrete (C2-below) during IMU coarse alignments. It is used alone when display of only attitude error signals on the S/C FDAI is required. In the CSM it is used in conjunction with the "SIVB Take Over Discrete" to provide Steering Control Signals for Saturn guidance, see E below.

C. Coarse Align Mode:

1) Consists of the receipt of the Coarse Align Enable discrete followed by the ISS Error Counter Enable discrete.

2) Coarse Align Enable discrete: - enables a relay driver which energizes the PSA Coarse Align Relays. This connects

the coarse align error signal (D/A ladder signal and switch comparison analog error signal ($\theta_G \cdot \theta_R$)) to the PSA gimbal servo amplifier. The analog error operates as a pseudo rate feedback signal for coarse align loop stability purposes. The discrete also enables the digital feedback pulses [$\pm A 2^2$ [-160 sec)] from the CDU-A/D Section (Read counter) to the Error Counter. The feedback pulses resulting from the gimbal motion operate to drive the counter to a null, ie: a position control loop.

The presence of the coarse align enable discrete and absence of the Error Counter Enable discrete will also inhibit the Incrementing pulses (P_I) to the Read Counter.

D. Turn On Mode: (computer controlled)

1. Consists of the CDU-Zero and Coarse Align Enable discretes by the computer to the CDU.

2. The purpose of this mode is to drive the gimbals to their zero positions and hold them there during the IMU Turn-On period. The turn-on is initiated upon closure of the "ISS operate" circuit breaker and allows for a 90 sec gyro run-up period. A "ISS Operate"(+28v) discrete from the CDU signals the computer to initiate this mode.

3. In this mode the CDU error signal (θG-θR) is connected to gimbal servo amplifier. Since the read counter is zeroed, the net effect is to drive the gimbals to null the resolver signals (θG).

E. Spacecraft Control of Saturn Mode (Fig. 2)

1. This Mode is used in CSM operation only

2. It uses the three inertial subsystem CDU D/A's DC error outputs.

3. The purpose of this mode is to provide steering control signals for the guidance of the Saturn Booster vehicle by the CSM primary GN & C system (MIT G&N). This mode is intended as a backup for Earth Ascent and Translunar Injection in the event of a Saturn Guidance system Inertial Unit failure. As well as Saturn Steering in Earth Orbit.

4. The "S/C control of Saturn" mode is initiated by astronaut activation of a toggle switch on the CSM main control panel. This routes + 28V ISS power, "S/C Control of Saturn" discrete, to the CDU where it arms a set of relays that control the DC error output signals of the 3 ISS CDU's. The +28v DC is also sent via CDU cabling to the CGC. Receipt of this discrete ("S/C Control of Saturn Operate") signals the CGC to enter into the steering control of saturn program. The CGC may then send the "SIVB Take-Over" discrete to the CDU. This energizes the contro relays which connect the D/A DC outputs to the Saturn guidance electronics. After a brief delay the CGC enables the ISS error

counters, ("ISS Error Counter" discrete) and sends increments ($\Delta\theta c$) to the CDU D/A's. During Saturn Steering the CGC monitors the vehicle response via PIP's and ISS CDU's (A/D sections). The CGC then controls the booster steering by providing attitude error signals to the Saturn guidance system via the ISS-CDU D/A's. The CDU digital feedback is not used in this mode.

II. The CDU-Optics Modes (CSM only) are: (Reference Fig. 3)

A. Optics CDU-Zero discrete from the AGC:

1. Zeros (clears) both the shaft and trunnion Read counters. It also inhibits the transmission of incrementing pulses (P_I) to the optics read counters.

2. Optics zeroing is accomplished by closing a loop about the sine windings of its resolvers and thereby physically driving the shaft and trunnion to an electrical zero. OPTX zeroing may be commanded manually or by the computer. The optics CDUS do not have coarse A/D systems(in either the shaft or trunnion). To maintain CDU-optics resolver synchronization the computer program must assure that the optics has zeroed before sending the CDU-Zero discrete.

B. Optics Error Counter Enable (D/A Enable) discrete: Enables both optics error counters similtaneously. The counters are normally inhibited and zeroed. This discrete and the absence of the "Thrust Control Enable" discrete (II-C below) also enables the digital feedback pulses, $\Delta 2^2$, from the A/D section of the CDU, (160 sec-shaft, 40 sec line of sight-trunnion) to the error counter.

C. Thrust Vector Control Mode: (Fig 4)

1. This mode is used in CSM operation only

2. It uses the 2 optics D/A DC error outputs.

3. Thrust Vector Control has priority over the utilization of the 2 optics D/A's. During TVC operation an equivalent a.c. signal will be seen at the D/A output normally used for driving optics. It will be derived, however, from ISS 800 cps 1% power. The A/D section of the optics CDU's are not used by this mode.and may continue to be used for optics readout.

4. The mode allows the computer (through the CDU) to generate analog signals for positioning the service module propulsion system engine gimbals. The mode is used for thrust vector control during primary system (MIT G&N) guidance trajectory manuevers.

5. Moding operation:

The +28v DC S/C power "GN&C Autopilot Control" discrete must be present. This signal origionates from an astronaut activated select switch on the main control panel. The switch selects primary (MIT G&N) back-up (SCS) guidance. Primary guidance and control includes both Thrust Vector Control and Reaction Control System (attitude) operation. The signal is routed via the CDU to the CGC. In the CDU the voltage arms the Thrust Vector Control relays but does not energize them. In the computer this signal in conjunction with other restraints (ie: SPS Ready discrete, etc) is used to determine when the TVC program may be entered.

When TVC control is to be initiated,the CGC sends the "TVC enable" discrete to the CDU. This energizes the relays and the DC error signal outputs are then connected to the SPS engine gimbal amplifiers. It also prevents the A/D digital feedback pulses from being fed into the error counter. After a brief delay,the CGC sends the "Error Counter Enable" discrete and command increments may then be transmitted to the CDU. In TVC operation the CGC monitors S/C response via the PIPA's and ISS CDU(A/D's sections). The CGC then controls the S/C by positioning the SPS engine thru the optics CDU D/A's.

6. The "TVC Enable" discrete followed by an optics CDU Zero discrete inhibits the transmission of incrementing pulses (P_I) to the optics read counters without zeroing them. This sequence is not a flight mode. It is provided for CDU testing only.

III. Rendezvous Radar- CDU-Moding. LEM (Fig 5)

A. R/R-CDU Zero discrete:

Zeroes (clears) all three R/R Read Counters simultaneously. It also inhibits the transmission of incrementing pulses (P_I) to the R/R read counters.

B. R/R Error Counter Enable (D/A Enable) discrete.

Enables both R/R error counters simultaneously. The counters are normally inhibited and zeroed. The LGC via the CDU radar D/A's inertially position.the radar antenna. The D/A outputs provide torquing signals to gyros located on the radar inner gimbal (reflector). CDU digital feedback, therefore, is not used in radar operation.

C. Display Inertial Data discrete:

1. This mode uses the 2 D/A DC error outputs. The Display Inertial Data mode is used in the last phases of LEM powered descent. During this period the LGC via R/R CDU D/A's provides inertially derived forward and lateral velocity signals for meter display.

2. During this mode an equivalent A.C. signal will also be present at the D/A output normally used for driving the R/R (III-B above)(Switching if required must be accomplished by GAEC external to G&N).

3. The A/D section is not effected by this mode and may continue to be used for R/R angle readout. Radar operation requirements should have priority over theD/A utilization (ie: redesignation in landing with a lunar transponder).

4. Operation:

The Display Inertial Data discrete energizes relays which connect the DC error signal outputs to the LEM display meter circuity. After a brief delay the LGC sends the "Error Counter Enable discrete and computer increments may be fed into the CDU.

5. The "Display Inertial Data" discrete followed by a R/R CDU Zero discrete inhibits transmission of incrementing pulses (P_I) to the optics read counters without zeroing them. This sequence is not a flight mode. It is provided for CDU testing only.

IV. Programming & Timing Requirements:

A. Timing

1. All moding discretes must be present throughout the entire period that the mode is required.

2. There is approximately a 4 millisecond delay in CDU moding in response to a computer discrete (primarily due to the CDU discrete input circuit filter). Modes that include a relay closure (Coarse Align Enable, Display Inertial Data, etc) require a proceedural delay between discretes. These requirements are identified in B below:

3. Input pulses to the CDU error counter must be spaced a minimum of 100 microseconds apart regardless of the average input pulse rate (3200 pps). Internal synchronization within the CDU will allow acceptance of only one input pulse in each 100 microsecond period.

4. Error Counter incrementing pulse weight:

a. ISS operation, Radar, & optics shaft -160 $\widehat{sec}$ (approx.)

b. Optics trunnion - 40 $\widehat{sec}$ line of sight (approx.)

5. The CDU error counter saturates at 384 input pulses (no digital feedback connected).

6. Operational modes that include CDU digital feedback require control of computer incrementing pulse burst on-off periods to avoid counter saturation and loss of pulses. The pulse burst on-off ratio is primarily limited by optics servo or IMU velocity limits. The following are recommended burst on-off periods for a computer incrementing rate of 3200 pps:

a. Coarse Alignment - (IMU gimbals rate limited between 20-50°/sec by CDU analog error signal feedback)

ON Time - 60 millisec = (192 pulses (8.44°)/burst)

OFF Time - 480 millisec

Average Rate - 15.8°/sec

b. Optics Shaft - (max. rate approx 18°/sec)

ON Time - 60 millisec = (192 pulses (8.44°)/burst)

OFF Time - 480 millisec

Average rate - 15.8°/sec

c. Optics Trunnion - (max. rate approx. 9°/sec-line of sight)

ON Time - 60 millisec = (192 pulses (2.11°)/burst)

OFF Time - 240 millisec

Average Rate = 7.1°/sec Line sight

The on-off cycles noted above reflect recommended maximum drive rates (on off cycle ratio) for proportional control (no loss of pulses). Lower average drive rates may be effected by increasing the "off time". In Coarse Align 192 pulses/burst operation should be continued until the last positioning cycle. In optics operation lower average drive rates may also be effected by limiting the number of pulses per burst (less than 192 pulses).

7. ISS CDU-Zero or R/R CDU zero:
After removal of the CDU-Zero discrete:

a. Three seconds (period corresponding to reading a 180° gimbal angle) should be allowed for the CDU to synchronize to the gimbal angle.

b. A CDU-Zero should never be commanded during modes using digital feedback or requiring CGC closed loop operation (ie: Coarse Align, R/R or Optics positioning, TVC, etc).

b. During the synchronization period (when gimbal angle minus the CDU angle exceeds approx. 2/9°) each CDU will increment the computer at a 6400 pps rate. These pulses will appear simultaneously from all three ISS or two R/R CDU's on either the plus or minus line dependent upon polarity of the error.

8. During normal A/D operation the CDU incrementing rates will cycle between:

ISS, R/R, optics shaft-400 pps or 6.4 Kpps for gimbal rates or shaft rates exceeding 4 4/9° sec

Optics Trunnion - 400 pps or 6.4 Kpps for rates exceeding 1 1/9°/sec line of sight

More details on rate cycling and velocity errors will be presented in a follow-up memo)

B. Programming Notes (sequential delays):

1. ISS-CDU Zeroing - see IV A7.

2. ISS-Error Counter Enable (Functional description sect. I B) (driving FDAI attitude error meters only) A 4 millisec delay (minimum) between sending discrete and incrementing pulses to the CDU's is required. Attitude Error Display loop closed by CGC (no CDU digital feedback) (timing note IV A5)

3. ISS Coarse Align Mode (section I C)

a. Send Coarse Align Enable

b. 40 milli second delay (minimum) then send <u>Error Counter Enable</u>

c. 4 millisecond (minimum delay) then send inc incrementing pulses as required to CDU per timing notes section IV A6

The 40 millisecond delay allows for coarse align pull in relay transients. Four milliseconds allows for input discrete circuit delays.

4. Turn On Mode (Computer Controlled) (Sect ID).

a. Two seconds (max) after the receipt of the "<u>ISS Operate</u>" discrete send "<u>ISS CDU-Zero</u>" and "<u>Coarse Align Enable</u>" for a minimum period of 90 seconds.

b. After the 90 sec delay: 1) If it is desired to set the system on inertial (gyro) control remove both discretes. Allow 30 millisec for the CDU to synchronize to the gimbals.

(2) If it desired to initiate a coarse alignment. Remove only ISS CDU Zero and send ISS Error Counter Enable (may be affected simultaneously or sequentially). Allow 30 millisec for CDU synchronization and then send incrementing pulses as required (per B 3 above and IV A6)

5. Space Craft Control of Saturn (section I E) (CSM operation only)

On receipt of the "S/C Control of Saturn Operate" discrete the following CGC sequencing is required:

a. If ISS Error Counters are in operation, remove ISS Error Counter Enable (ie: clear counter)

b. After approx. an 1/2 second delay, send "SIVB Take Over"

c. After a 40 millisecond delay (minimum), ISS Error Counter Enable may be sent.

d. After 4 millisecond delay (minimum), $\Delta\theta c$ incrementing pulses may be sent as required to the CDU (timing notes IV A5). SIVB loop is closed by the CGC (No CDU digital feedback).

6. Optics CDU-Zero (Section II A)

To assure that CDU-optics resolver synchronization is maintained (no coarse system in optics) a computer procedural delay between receipt of the optics zero discrete and the transmission of Zero Optics CDU discrete is required. The following sequencing is applicable:

a. Optics Zero from optics moding relay to CGC

b. After a 15 second delay (corresponding to a shaft return from a 270° angle) send Zero Optics CDU

c. Hold discrete for minimum period of 5 millisecond - maximum period 300 millisec.

d. After removal of the zero optics-CDU discrete allow 200 milliseconds for the CDU to resynchronize.

e. If the Optics Zero discrete is removed before the 15 second delay has elapsed, an alarm should be issued to the astronaut via the DSKY.

f. It should be noted that during-optics zeroing (before sending the zero optics CDU discrete) the CDU will track the optics back to zero and send incrementing pulses to the CGC. After an initial satisfactory zero alignment the alternate CDU-zeroing proceedures may be implemented. The applicable ground rule for CDU-zeroing is: Trunnion angle $<|2\ 5/16°|$ line of sight and Shaft angle $<|11\ 1/4°|$.

7. Optics positioning: (section II B)

a. Send Optics-Error Counter Enable

b. allow a 4 millisec delay (minimum) then send incrementing pulses to the CDU as required per timing notes section IV A6.

8. Thrust Vector Control Mode:

a. Status of relevant input discretes to the computer:

"G&C Autopilot Control Operate"	- present
"Free"	- Not present
"Hold"	- Not present
"SPS Ready"	- present

b. With input discrete status as above and the appropriate DSKY entries made:

(1) If Optics Error Counters are in operation remove Optics-Error Counter Enable (D/A Enable) ie: clear counter and discontinue sending incrementing pulses (TVC operation has priority over optics control)

(2) Send "TVC enable" (may be sent same time as (a) above is removed.)

(3) After a 40 millisecond delay (minimum) the Optics Error Counter Enable may be sent

(4) After a 4 millisecond delay (minimum) $\Delta\theta c$ incrementing pulses may be sent as required to the CDU (timing note IV A 5) TVC Loop is closed by the CGC (No CDU digital feedback).

c. "TVC Enable discrete followed by an Optics CDU-Zero discrete inhibits the optics transmission of incrementing pulses with out clearing the optics read counter. This sequency is for CDU testing and should not be permitted during flight operations.

9. R/R CDU Zeroing - see note IV 7A.

10. R/R Positioning (section III B):

    a. send R/R - Error Counter Enable (D/A Enable)

    b. allow a 4 millisec delay (min.) then send incrementing pulses to the CDU

    c. R/R positioning loop is closed by LGC (No CDU digital feedback). see IV A5.

11. Display Inertial Data (LGC LEM Let down operations) (section III C)

    a. If R/R CGC antenna positioning is in progress (landing to transponder, etc) when the "Display Inertial Data" discrete from LEM Control panel is sent a DSKY "Alarm" should be issued. If possible, display inertial date moding (b-below) should be inhibited until an astronaut override entry is made on the DSKY.

    b. If R/R positioning is not in operation:

        (1) On receipt of the "Display Inertial Date discrete from the control panel send "Display Inertial Data Enable."

        (2) Allow a 40 millisec delay then send R/R Error Counter Enable.

        (3) Allow a 4 millisec delay (min) then send incrementing pulses to the R/R CDU error counters, "Forward and Lateral Velocity".

        (4) This display loop is closed by LGC (No CDU digital feedback) see IV A5.

VI Miscellaneous:

A. IMU-Cage:

A manual back up mode allowing the astronaut to recover a tumbling IMU by setting the gimbals to zero. Full details are covered in: Apollo Project Memo # 1149, 1 Dec 64. "Block II Imu Cage Function.

B. Auto Cage (LEM & CSM((Fig 6):

A back up mode allowing for IMU turn on when the computer is off or in standby. Under these conditions the IMU gimbals will be caged when the ISS operate circuit breaker is closed. The astronaut after allowing a procedural delay of 90 sec (gyro runup) may set the IMU on inertial control by momentarily depressing the IMU cage switch on the S/C control panel.

C. Gain Scaling for TVC, Attitude Error Displays, S/C Control of Saturn, etc are covered in various NAA, GAEC-MIT electrical ICD's. The majority of these ICD are pending sign off. A memo summarizing the gains will be issued after initial ICD signoff.

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Encls.

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J. Poundstone (2)
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B. Lund (5)
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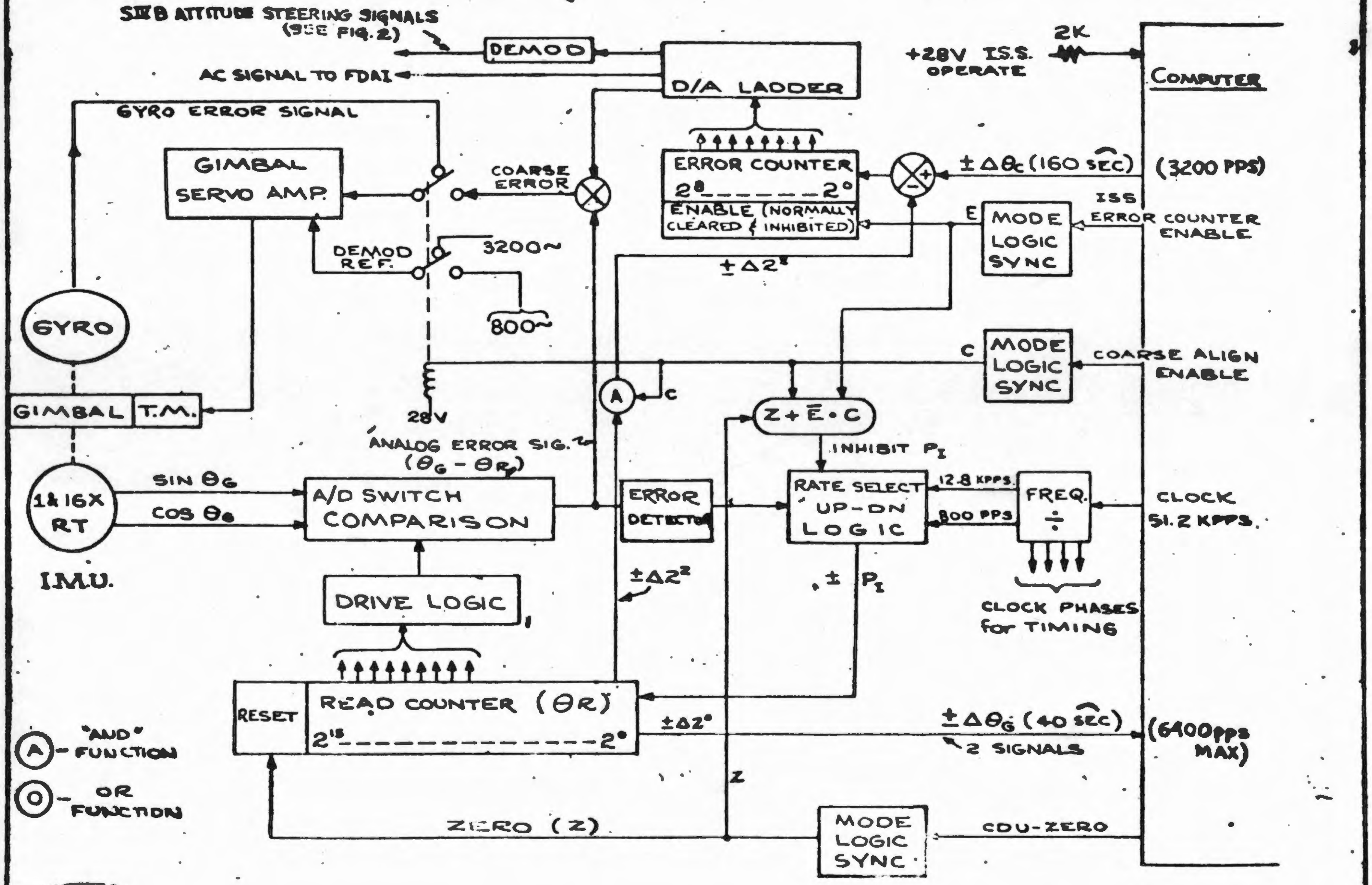
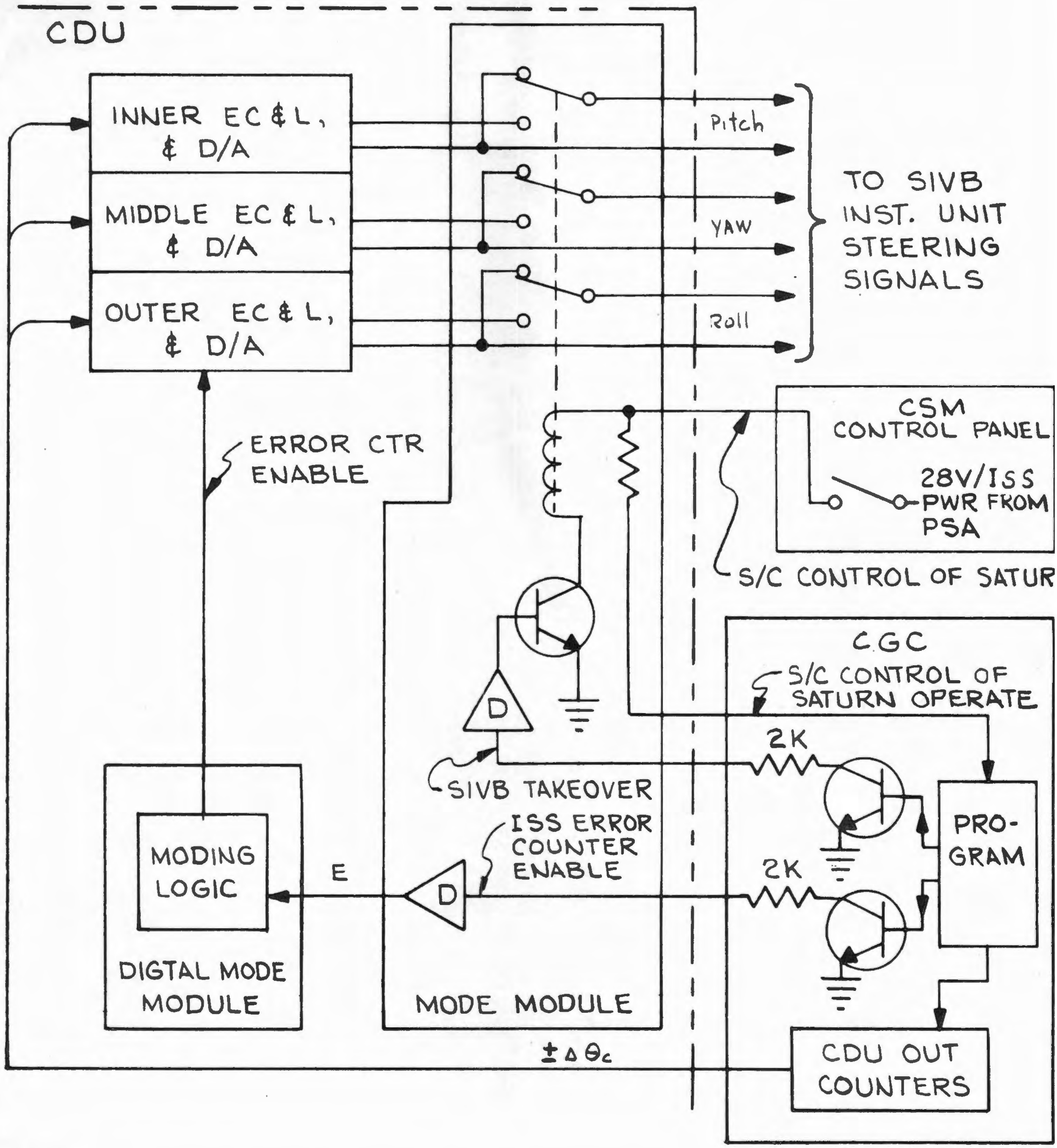
IMU-CDU MODING (CSM & LEM)

Fig. 1



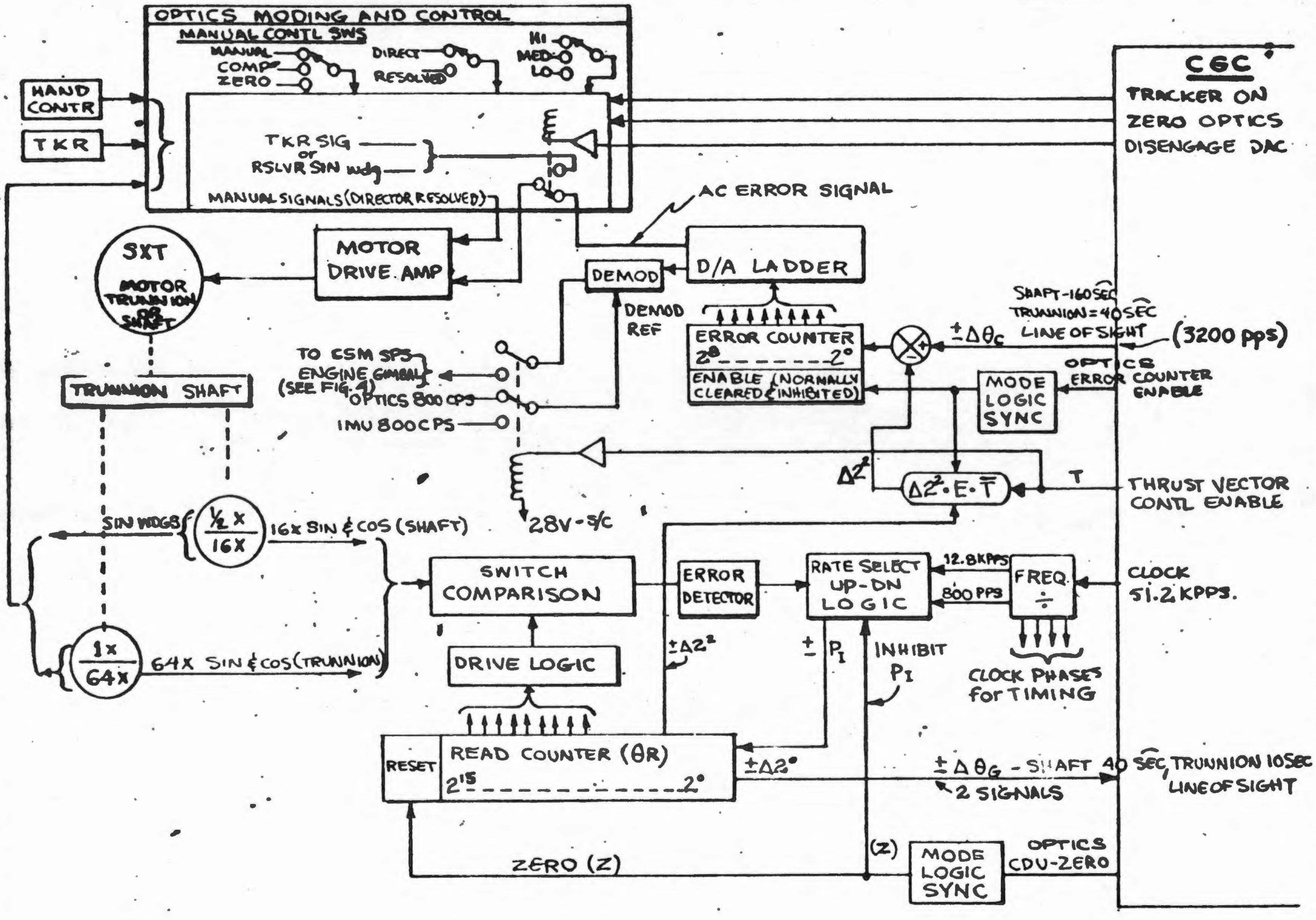


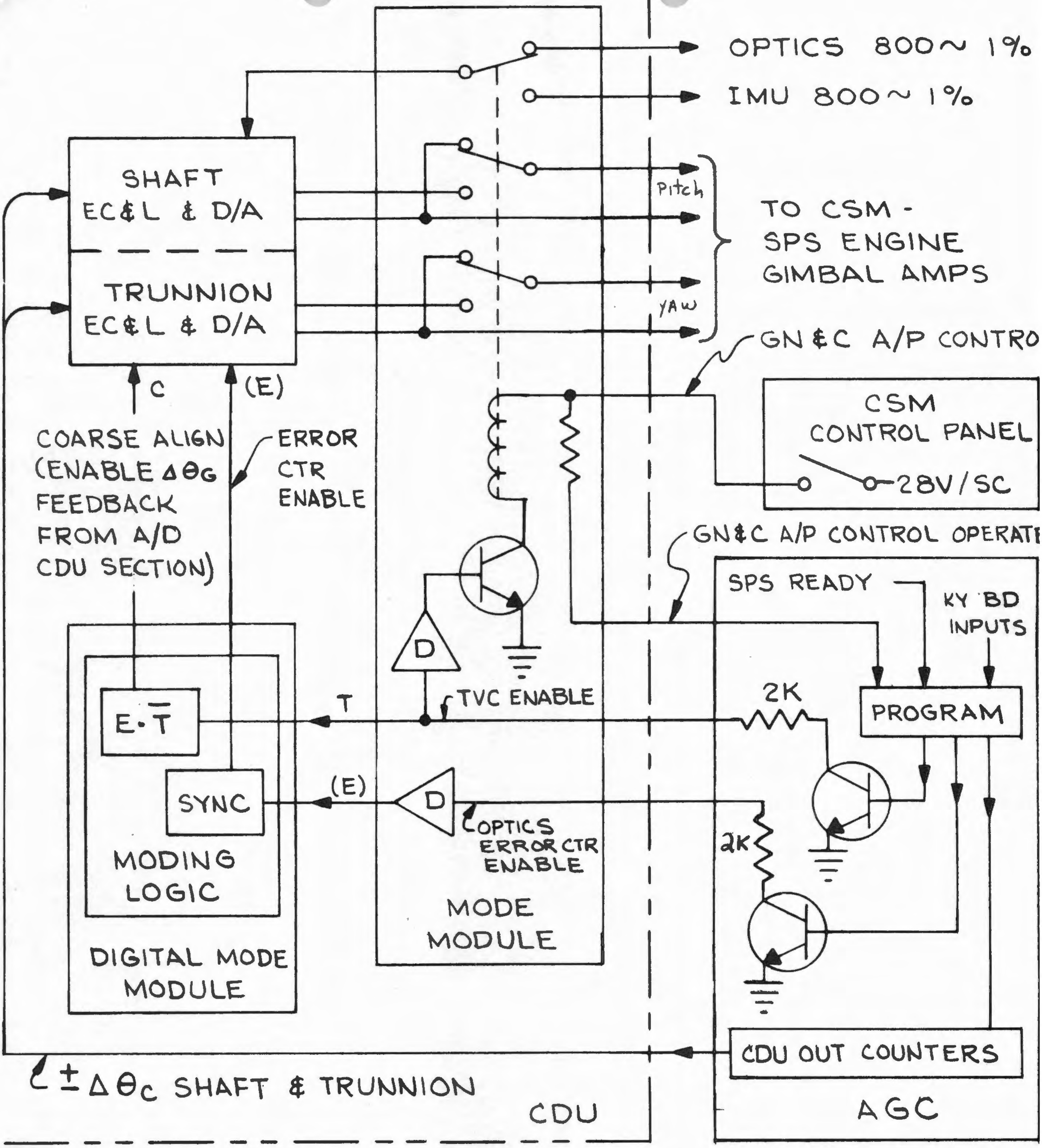
S/C CONTROL OF SATURN MODING
CSM BLOCK II

FIG-2

OPTICS - CDU MODING (CSM ONLY)

Fig. 3



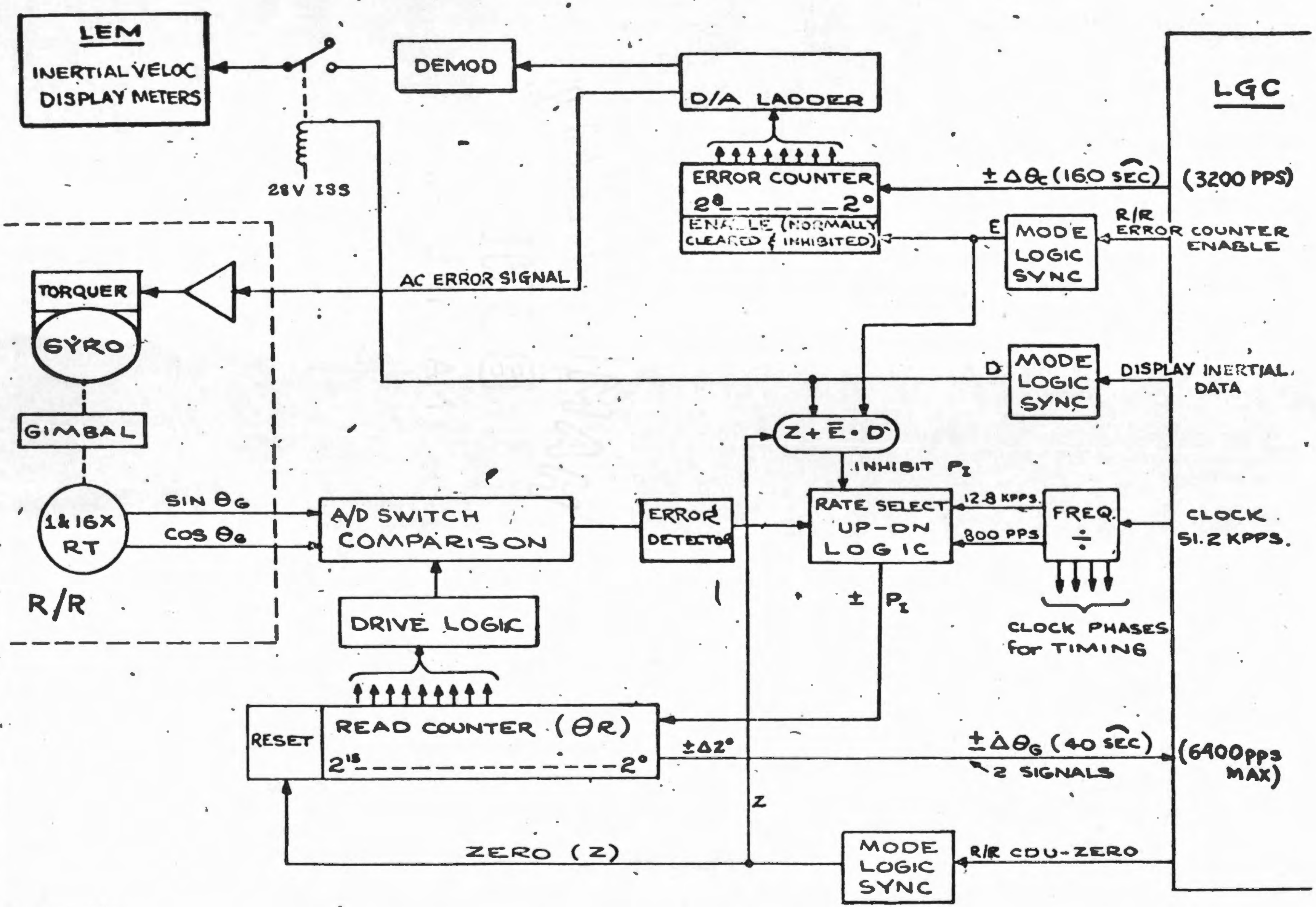


TRUST VECTOR CONTROL MODING
CSM BLOCK II

FIG-4

R/R - CDU MODING (LEM ONLY)

Fig. 5



AUTO CAGE FUNCTION

IMU TURN ON-COMPUTER OFF OR IN STANDBY

Fig. 6