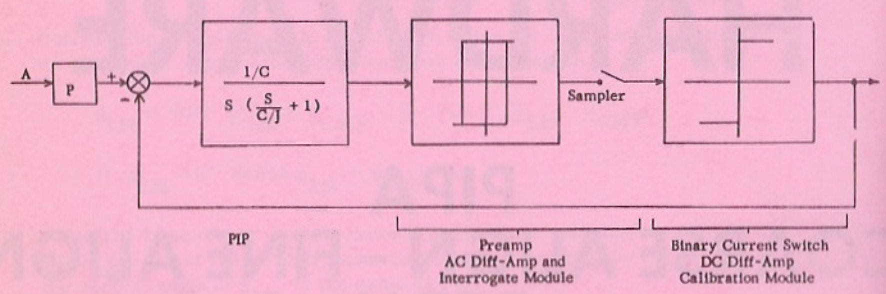
HARDWARE

PIPA
COARSE ALIGN - FINE ALIGN
ECDU
IRIG
OPTICS
OUA
AOT

PIPA LOOP



P = Pendulosity
C = Coefficient of Viscous Damping
J = Float Inertia

The PIP Signal Generator Ducosyn provides information on rotor position in the form of a 3200 hertz output. The stable limit cycle in rotor position is converted to an AC suppressed carrier modulated signal.

The PIP Preamp amplifies the SG output (14 V/V gain) and phase shifts the 3200 hertz carrier 45° lag.

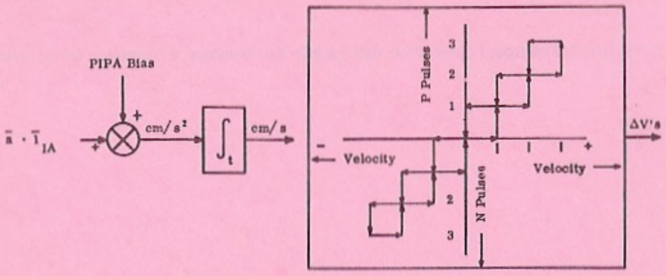
The AC Diff-Amp and Interrogate Module provides additional amplification (3050 V/V), peak detects float position, and sets a flip-flop. One state of the flip-flop indicates float position on the plus side of null and the other state means float position on the minus side of null.

The Binary Current Switch provides discrete current pulse outputs of appropriate phase as determined by the state of the flip-flop in the AC Diff-Amp Module.

The Calibration Module is the passive circuit interface between the BCS and the PIP torquer. The circuitry introduces bias and scale factor adjust capability into the PIPA loop.

The PIP Torque Ducosyn converts current pulses from the Calibration Module to torque about the PIP OA axis.

The DC Diff-Amp and PVR Module is the mechanism which regulates current and hence PIP torque to precisely controlled values.



Each ΔV Command Module = 5.85 cm/s
Each ΔV Lunar Module = 1.00 cm/s

PIPA CHARACTERISTICS

	PARAMETER		CM		LM	
1.	Maximum measurable acceleration		19.1	g's	3.26	g's
2.	Scale factor		5.85	cm/sec/pulse	1.00	cm/sec/pulse
3.	Pendulosity	P	0.25	$\frac{\text{dyne cm}}{\text{cm/sec}^2}$	0.25	$\frac{\text{dyne cm}}{\text{cm/sec}^2}$
4.	Torque to balance	T	4680	dyne cm	800	dyne cm
5.	PIP float inertia	J	14.0	$\frac{\text{dyne cm}}{\text{rad/sec}^2}$	14.0	$\frac{\text{dyne cm}}{\text{rad/sec}^2}$
6.	PIP viscous damping	C	$12\text{x}10^4$	$\frac{\text{dyne cm}}{\text{rad/sec}}$	$12\text{x}10^4$	$\frac{\text{dyne cm}}{\text{rad/sec}}$
7.	PIP break point	C/J	8550	rad/sec	8550	rad/sec
8.	PIP time constant	J/C	.117	ms	.117	ms
9.	Total torque constant		.42	dyne cm/ma^2	.42	dyne cm/ma^2
10.	Nominal torque current		105	ma	44	ma

SUSPENSION CHARACTERISTICS

1.	Radial Force	2.3 grams per .0001" min
2.	Suspension current	65 ± 6 ma the two ends (SG & TG) matched with 3 ma
3.	Phase angle of current	lags 45° ± 2.8°
4.	Suspension stiffness	30 x 10^{-3} grams/micro-inch

TYPICAL TEMPERATURE CHARACTERISTICS

1.	Scale Factor	150 ppm/°F 300 ppm/°F	CM LM
2.	Bias	.05 cm/sec^2/°F	LM/CM

°F Actual PIPA Temperature

PIPA PARAMETERS

Primary PIPA parameters are scale factor and bias. Specification values across ISS, G&N, and S/C testing are as shown in Table I-1.

Table I-1

PIPA Coefficient Stability Criteria				
Coefficient	Units	D_1	D_2	D_3
PIPA Bias (A_B)	cm/sec^2	0.50	0.70	0.90
PIPA Scale Factor SF	ppm	400	500	600

PIPA bias in a unity gravity field (A_b) must be within 0.30 cm/sec^2 of that evaluated in a zero gravity (a_b) field at the ISS level of test.

The maximum value of PIPA parameters which can be compensated for by the computer is as shown in Table I-2.

Table I-2

Coefficient	Units	Max Value (CM)	Max Value (LM)
A_b	cm/sec^2	±9.14	±12.50
SF	ppm	±1900	±1900

PIPA COMPENSATION

	Register
X PIPA Bias	1452
Y PIPA Bias	1454
Z PIPA Bias	1456

PIPA Bias CM = (.0005569) (Reg Contents in Decimal) cm/sec^2
PIPA Bias LM = (.0007628) (Reg Contents in Decimal) cm/sec^2

The correction to the PIPA's is

$$PIPA_C = (1 + SFE_I)\, PIPA_I - BIAS_I \, \Delta t$$

where

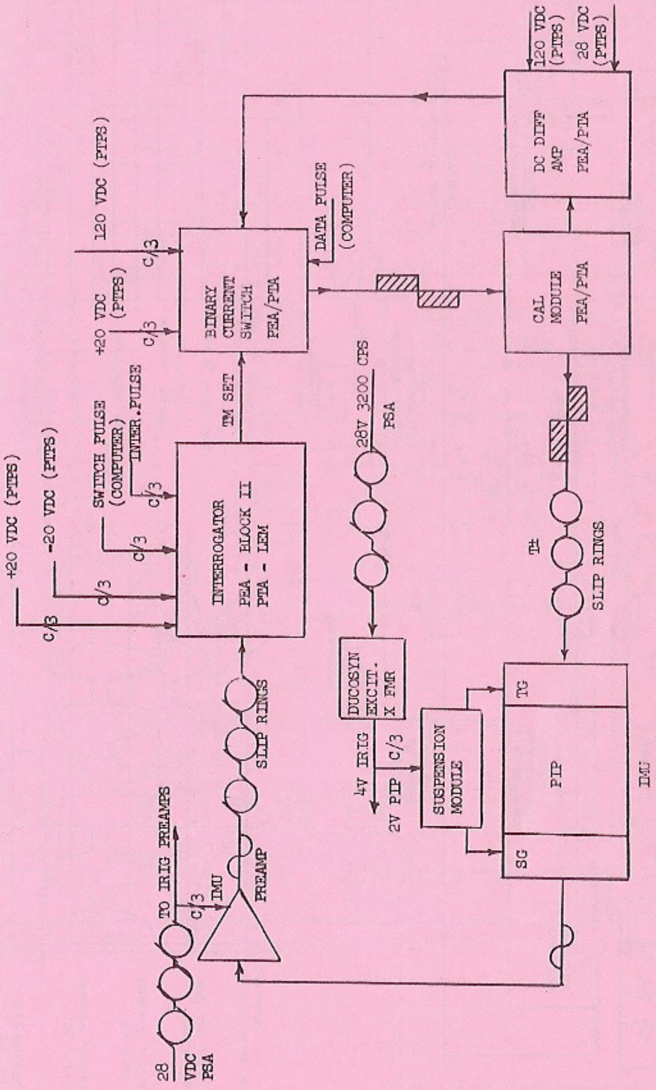
$PIPA_C$ is the compensated data for the I^{th} PIPA denoted $PIPAX_C$, $PIPAY_C$, $PIPAZ_C$

$SFE = \frac{SF - SF_{nom}}{SF_{nom}}$ (erasable load)

SF = Scale-factor $\frac{CM/Sec}{Pulse}$

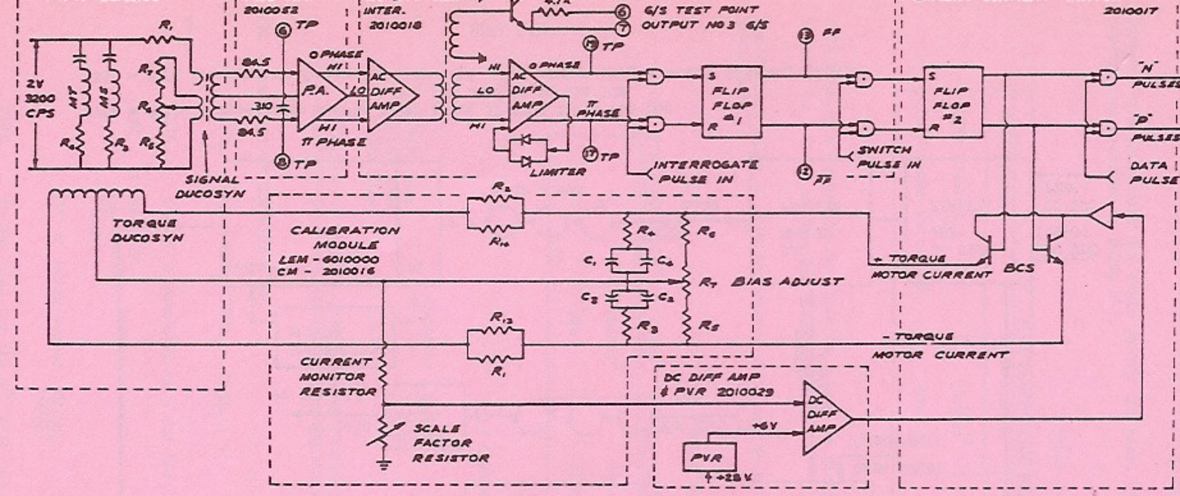
$BIAS_I$ is the bias for the I^{th} PIPA (an erasable load)

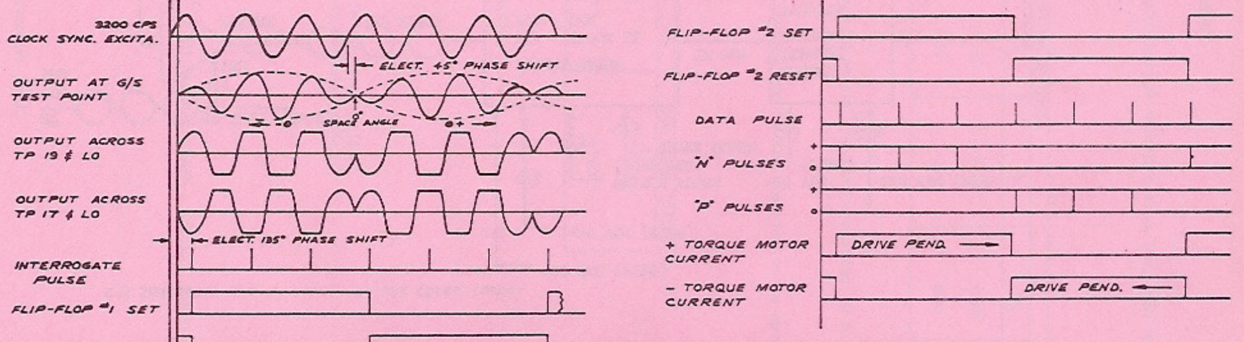
C/3 indicates assets common to all three loops.



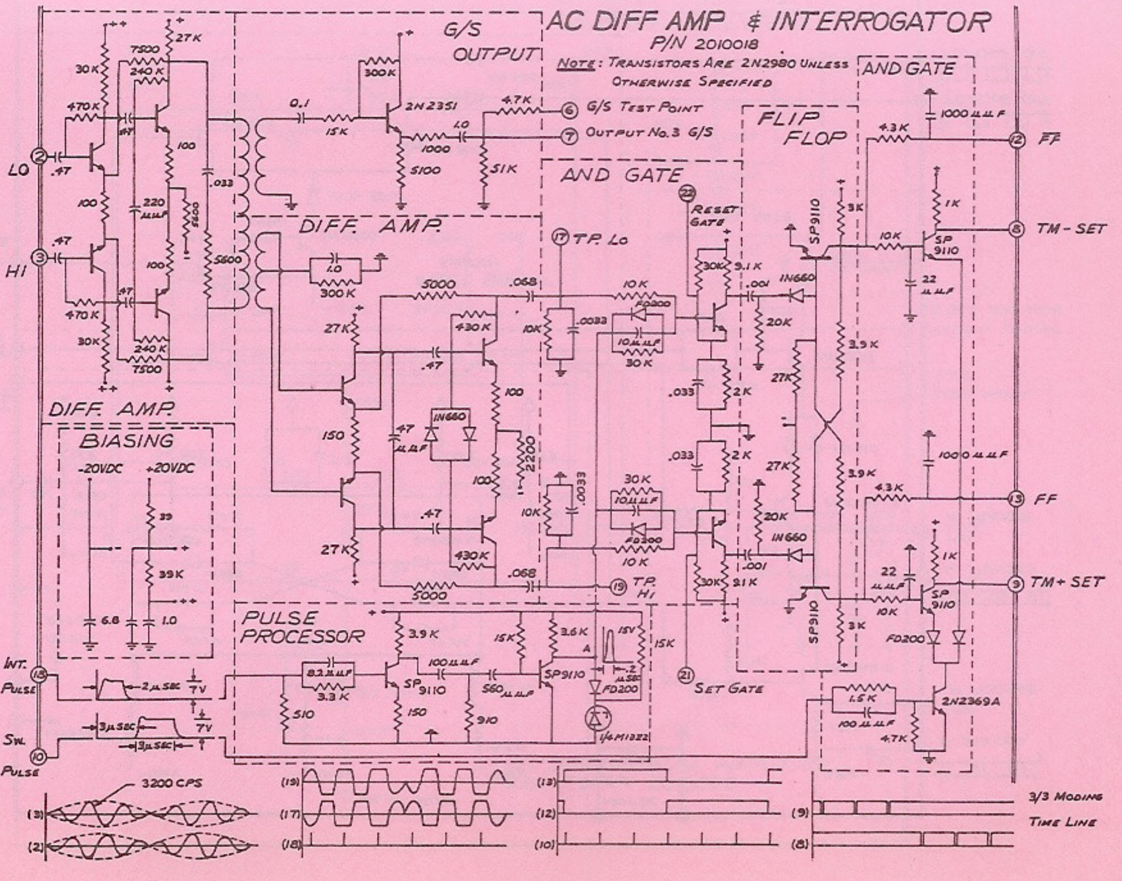
PTPS = Pulse Torque Power Supply. For Block II PTPS is in the PSA
For LEM PTPS is in the PTA
PEA = PIPA Electronics Header Assembly (CM); PTA = Pulse Torque Header Assembly (LEM).

PIPA LOOP



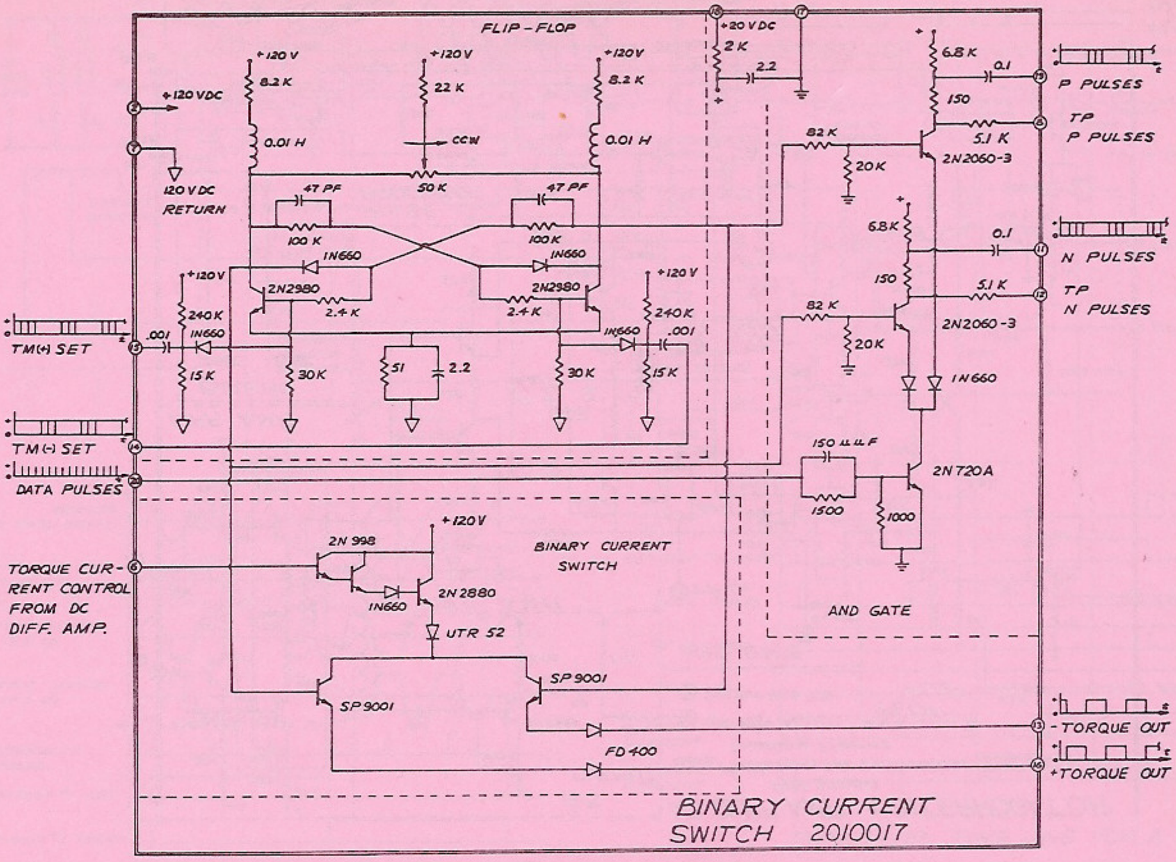


PIPA LOOP TIME LINE FOR A 3:3
MODING CYCLE

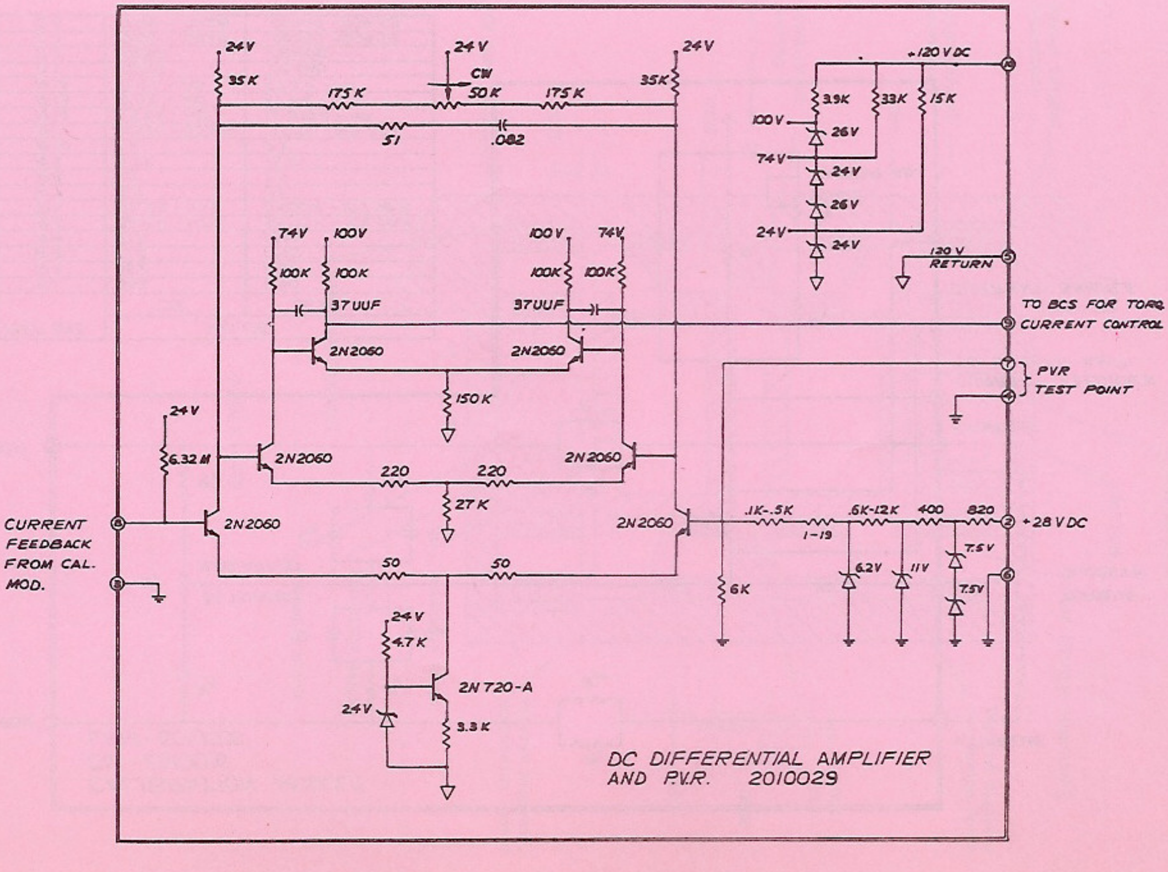


AC DIFF AMP & INTERROGATOR
P/N 2010018

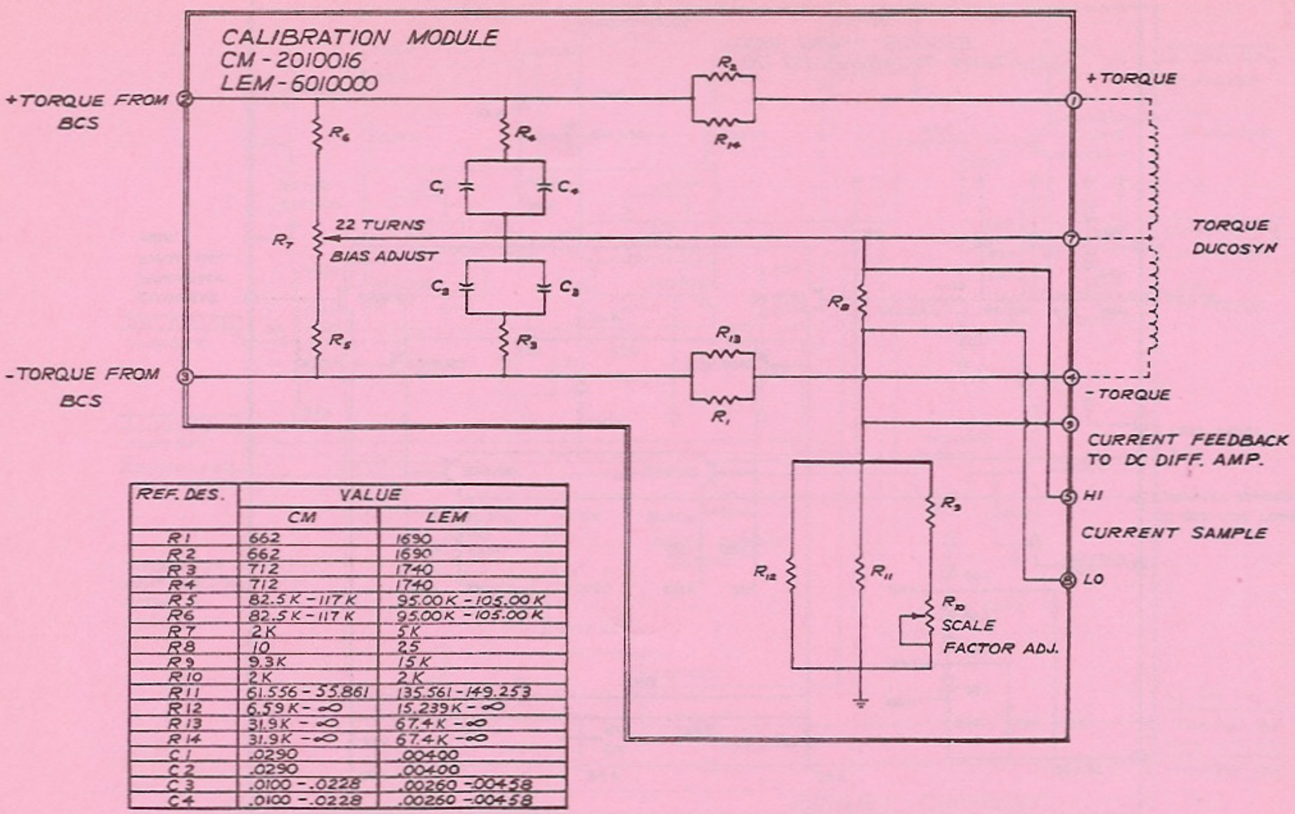
NOTE: TRANSISTORS ARE 2N2980 UNLESS OTHERWISE SPECIFIED



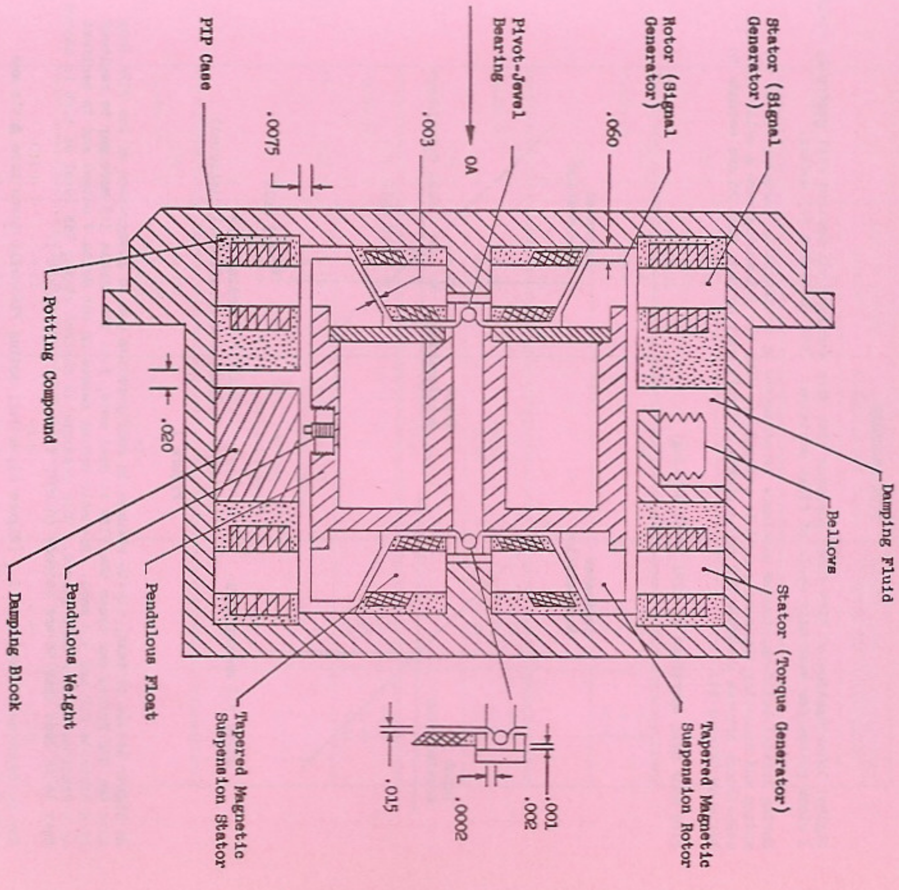
BINARY CURRENT SWITCH 2010017



DC DIFFERENTIAL AMPLIFIER AND P.V.R. 2010029



REF. DES.	VALUE	
	CM	LEM
R1	662	1690
R2	662	1690
R3	712	1740
R4	712	1740
R5	82.5K - 117K	95.00K - 105.00K
R6	82.5K - 117K	95.00K - 105.00K
R7	2K	5K
R8	10	25
R9	9.3K	15K
R10	2K	2K
R11	61.556 - 55.861	135.561 - 149.253
R12	6.59K - ∞	15.239K - ∞
R13	31.9K - ∞	67.4K - ∞
R14	31.9K - ∞	67.4K - ∞
C1	.0290	.00400
C2	.0290	.00400
C3	.0100 - .0228	.00260 -.00458
C4	.0100 - .0228	.00260 -.00458



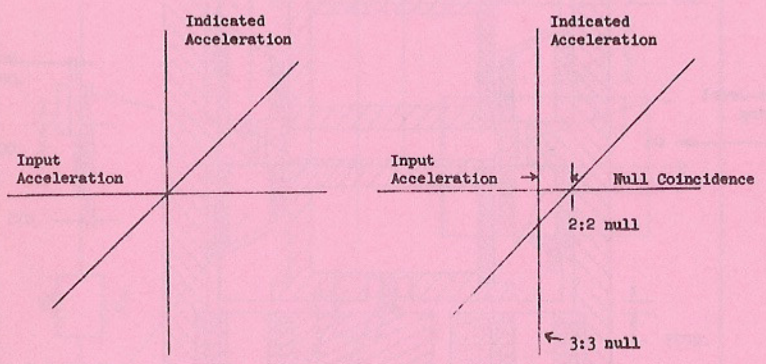
APOLLO PIP

PIPA DEADZONE

Digital interrogation of PIPA float position with zero acceleration applied will generally yield 3 clock pulses for each half cycle of float position. This is called 3:3 moding.

During initial build-up, torque unbalance is minimized by artificially inducing 2:2 or 4:4 moding and adjusting the zero g null to coincidence with the 3:3 moding zero g null. The null coincidence between a stable 2:2 and a stable 3:3 null must be less than 20 arc seconds in build-up (Figure 1).

PIPA near null operation at PIPA level testing.



Solid 3:3 moding PIPA

Solid 2:2 moding PIPA
(2:2 mode artificially achieved)

Figure 1

At higher levels of test, subtle changes in configuration due to integration of the PIPA loop into the G&N System can cause the PIPA to dual mode, i.e. the stable 3:3 mode may be replaced by a bistable 2:2 and 3:3 mode. Bistable moding causes nc net delta V output and is manifest as a deadzone to near null inputs. This deadzone is checked at the ISS level of test to assure that it is less than 50 arc seconds (0.0075 ft/sec^2 or 0.23 cm/sec^2).

For an input acceleration of A_{33} (Figure 2), a dual moding PIPA will issue zero Δ V's and mode 3:3.

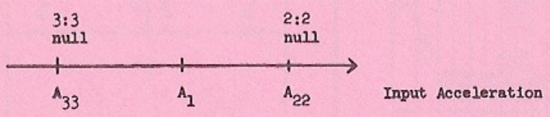


Figure 2

For an input acceleration of A_{22}, a dual moding PIPA will also issue zero Δ V's and mode 2:2.

For an input acceleration between the A_{33} and A_{22} limits, the PIPA will issue zero Δ V's and dual mode from 2:2 to 3:3 at a rate of 5 or 6 times per second. The amount of time spent in 2:2 or 3:3 moding is dependent on the input acceleration A_1.

After Apollo 12, the biases of the LM PIPA's have been set at approximately ±1.5 cm/sec^2. This prevents the PIPA's from entering the deadzone during the zero-g environment.

HISTORY OF IN-FLIGHT PIPA PERFORMANCE

		AVG IN-FLIGHT ERROR*	CHANGE FROM (PREFLIGHT) COMP	LUNAR ORBITAL DEVIATIONS	
				MINIMUM	MAXIMUM
Apollo 8	X	-0.01	-	No Lunar Orbital Variations Available	
	Y	+0.03	-		
	Z	+0.00	-		
Apollo 9	CM X	+0.02	+1.17	*** -0.39	-0.58
	Y	-0.04	+0.28	-0.32	-0.42
	Z	-0.08	-	+0.32	+0.42
	LM X	+0.01	-		
	Y	-0.15	-		
	Z	+0.01	-		
Apollo 10	CM X	0.0	-0.27	0.0	-0.36
	Y	0.0	-	0.0	-0.29
	Z	0.0	-	0.0	+0.03
	LM X	-0.06	-		
	Y	-0.12	-		
	Z	0.03	-		
Apollo 11	CM X	-	-	-0.07	-0.31
	Y	-0.02	+0.21	-0.25	+0.34
	Z	+0.03	-0.12	-0.01	+0.11
	LM X	-0.01	-		
	Y	+0.02	-0.06		
	Z	-0.03	-0.17		
Apollo 12	CM X	+0.09	-	0.0	+0.27
	Y	-0.05	-	-0.08	-0.20
	Z	0.0	-	-0.04	-0.25
**	LM X	-0.05 0.0	-0.05 Pre-DOI -0.15 Post-Ascent		
	Y	0.0 0.0	0.0 Pre-DOI -0.18 Post-Ascent		
	Z	0.0 0.0	-0.06 Pre-DOI +0.29 Post-Ascent		
Apollo 13	CM X	-0.204	-		
	Y	-0.195	-		
	Z	+0.006	-1.63		
	LM X	+1.50	-		
	Y	-1.35	-		
	Z	-1.52	-		
Apollo 14	CM X	-0.02	-0.10	-0.34	-0.55
	Y	-0.02	+0.08	-0.18	0.12
	Z	-0.02	+2.77	-0.195	-0.45
	LM X	0.3	-		
	Y	-0.35	-		
	Z	-0.14	-		
Apollo 15	CM X	0.03	-	0.04	0.13
	Y	-0.04	-	-0.09	0.16
	Z	-0.05	-	-0.18	-0.34
	LM X	0.0 Pre-Descent -0.02 Post-Ascent	0.20-Pre-Ascent 0.36 Post-Ascent		
	Y	-0.02 Pre-Descent 0.01 Post-Ascent	0.34 Pre-Ascent - Post-Ascent		
	Z	0.03 Pre-Descent -0.01 Post-Ascent	- Pre-Ascent -0.16 Post-Ascent		

*Deviations from compensation updates when made, or from preflight loads when no update was made. All units cm/s^2

**This IMU was turned off for ~27 hours on the lunar surface.

*** Earth orbit deviations.

NOTE: Variations of CM bias in lunar orbit caused by variations in coolant temperature.

IMU COARSE ALIGN LOOP

The coarse align loop drives the IMU gimbals to the angles commanded by the computer with an accuracy of ± 1.5°. The coarse align mode also acts as a caging mode when a gimbal lock condition is approached.

The three basic elements of the coarse align loop are the Digital Computer which issues angle commands ($\Delta\theta_C$) and moding discretes, the IMU, and the ECDU which encodes gimbal position and provides position and rate feedback for proper loop operation.

IMU FINE ALIGN LOOP

The fine align loop drives the IMU gimbals to the computer commanded angles ± 80" by pulse torquing the gyros. Pulse torquing is a computer controlled switching of a constant current source to a gyro torquer winding. The current produces gyro torque, a corresponding precession rate, and hence, gimbal position.

IMU INERTIAL MODE

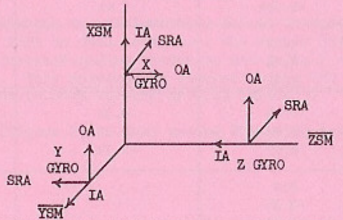
The elements of the inertial mode are the gyro, stabilization amplifier, and gimbal torque motor. The gyro senses inertial rotation about its input axis and supplies torquing to the gimbal via the stabilization amplifier to compensate for the motion.

APOLLO INERTIAL INSTRUMENTATION/STABLE MEMBER ORIENTATION DIAGRAM

Gyro drift is positive when the SM drift rate is about the positive gyro input (IA) axis.

Drift Rate About SM Axes	Gyro Drift Coefficient		
	NBD	ADIA	ADSRA
W_{XSM}	+NBDX	+ADIAX (a_{XSM})	-ADSRAX (a_{YSM})
W_{YSM}	+NBDY	+ADIAY (a_{YSM})	-ADSRAY (a_{ZSM})
W_{ZSM}	-NBDZ	+ADIAZ (a_{ZSM})	+ADSRAZ (a_{YSM})

a_{XSM}, a_{YSM}, a_{ZSM} is positive along positive stable member axes.

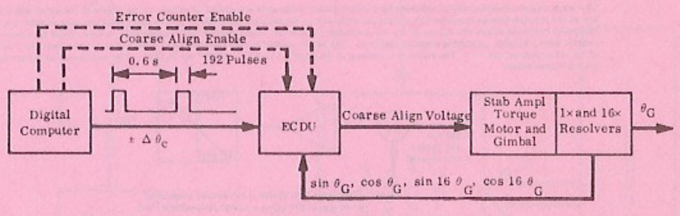


Gyro	IA Along	SRA Along	OA Along
X	$+\overline{XSM}$	$-\overline{YSM}$	$+\overline{ZSM}$
Y	$+\overline{YSM}$	$-\overline{ZSM}$	$+\overline{XSM}$
Z	$-\overline{ZSM}$	$-\overline{YSM}$	$+\overline{XSM}$

Input axes of the X, Y, Z accelerometers lie respectively along positive XSM, YSM, ZSM axes.

IMU COARSE ALIGN LOOP

The servomechanism used to achieve coarse align of the Block II IMU is shown below.



IMU Coarse Align Loop

Computer Operation

The following sequence of events is performed by the computer each time the Coarse Align program is entered.

1. Issue Coarse Align Enable. The computer sets Bit 4 of Channel 12 which issues the Coarse Align Enable discrete to the ECDU.
2. Issue Error Counter Enable. The computer sets Bit 6 of Channel 12 which issues the Error Counter Enable discrete to all three IMU axes of the ECDU.
3. Determine Command Angle. The contents of the computer gimbal angle counters are read and differenced with the desired gimbal angle to determine the command angle.
4. Issue Command Angle. Gimbal angle commands are issued in bursts of 192 pulses (8.4 degrees) at a rate of 3,200 pulses/second. Each burst requires 60 milliseconds. The delay between bursts is 540 milliseconds. If the command is not an integral multiple of 192 pulses, the remainder is issued as the last command. Gimbal commands are gated out of the computer by setting Bits 13, 14, and 15 of Channel 14. All three bits are set simultaneously, thereby allowing all three gimbals to be slewed simultaneously.
5. Determine If Command Angle Is Achieved. After gimbal commands have been issued, the computer reads gimbal position and compares the position achieved with the desired angle. If the difference is greater than 2.0 degrees, an alarm is issued.

Steps 1 through 5 constitute a computer control process which positions gimbals in an open loop sense. The computer does not check final gimbal position such that corrective commands can be issued if the desired position has not been reached. The check on final gimbal position is used to determine if an alarm condition exists.

ECDU Response to Coarse Align Enable

When addressed by the Coarse Align Enable discrete from the computer, the ECDU:

1. Provides a ground to the PSA coarse align input relays, thereby switching the stabilization amplifier inputs from IRIG outputs to the ECDU DAC output.
2. Supplies a ground for the PSA stabilization amplifier demodulator relay, thereby changing the reference excitation of the stabilization amplifier ring demodulators from 3,200 Hz to 800 Hz.
3. Provides grounds for the coarse align relay in each of the stabilization amplifiers, thereby changing stabilization amplifier servo compensation.
4. Generates an internal moding signal which enables gimbal feedback pulses ($\Delta 2^2$) to increment the error counter. This signal also changes the read counter high speed pulse rate (P_I pulses) from 12.8 kpps to 6.4 kpps.

ECDU Response to Error Counter Enable

When addressed by the Error Counter Enable discrete from the computer, the ECDU:

1. Generates an internal moding signal which allows error counter pulses ($P_E = \Delta 2^2$ or $\Delta\theta_C$) to increment the error counter. Absence of this discrete zeros the error counter and holds it there.
2. The Error Counter Enable command (E) is combined with the Coarse Align discrete (C_A) and the CDU Zero command (CDUZ) to mode the read counter in accordance with the following logic equation.

$$Y = \overline{E} \cdot C_A + CDUZ$$

where

a. The presence of Y inhibits P_I pulses from incrementing the read counter

b. $\overline{E}$ = Error Counter Enable "not"

c. C_A = Coarse Align Enable

d. CDUZ = CDU Zero Discrete

e. $E \cdot C_A$ is an "and" operation

f. + is an "or" operation

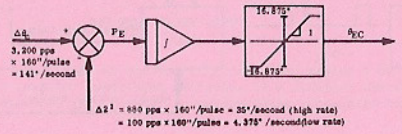
Inhibiting the read counter in this fashion will prevent gimbal drift due to residual voltages within the loop. The fine error will accumulate to a value such that the effect of residual voltages is cancelled.

ECDU Servo Control

Servoing the IMU to the correct position as commanded by the computer is achieved by a multiple loop system consisting of the error counter, a DAC, the coarse align mixing amplifier, a system of rate and switch selection logic, the read counter, and the stabilization loop.

Error Counter

The error counter provides digital differencing between gimbal commands and gimbal positions. Input pulses to the error counter are either position command pulses ($\Delta\theta_C$) from the computer or gimbal position feedback pulses ($\Delta 2^2$) from the read counter loop. Computer command pulses ($+\Delta\theta_C$) cause the error counter to count up. Read counter ($\Delta 2^2$) pulses will, in turn, count the error counter down, thereby, producing negative feedback. The error counter is also mechanized to inhibit (P_E) pulses when Bits 7 and 8 of the error counter are "1." The result is a limiting of the output at 11.25° + 5.625° or 16.875°. The total functional characteristic is shown below.



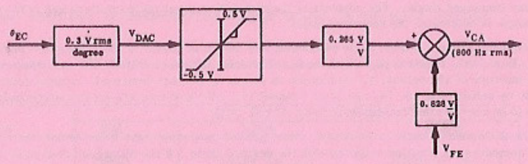
Error Counter

DAC (Digital to Analog Converter)

The DAC consists of logic switches driven by the error counter, a divide down resistive ladder network, and a scaling amplifier. The function of the DAC is to provide an 800 Hz signal whose amplitude is proportional to the angle content of the error counter. DAC sensitivity is adjusted to 0.3 Vrms/degree.

Coarse Align Mixing Amplifier

The coarse align mixing amplifier adds the fine error voltage and the DAC output with a mixing ratio of 3 to 1 in favor of the fine error input. DAC outputs to the coarse align mixing amplifier are diode-limited to 0.5 volt as shown below.



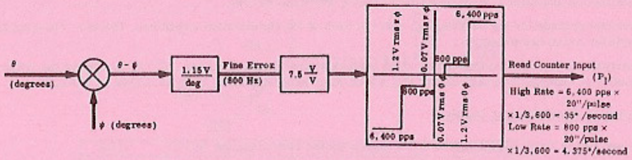
Coarse Align Mixing Amplifier

Fine System Switch Selection Logic

The fine system switch selection logic is a network of weighting resistors, summing amplifiers, and switches used to implement the trigonometric identity $-\sin(\theta - \phi) = -\sin\theta\cos\phi + \cos\theta\sin\phi$. Functionally, this network compares the gimbal angle (θ) as represented by the 16-speed resolver signals to the read counter angle (ϕ) and generates an error signal used to drive the read counter loop.

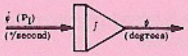
Rate Select and Up/Down Logic

Rate select and up/down logic is generated from the fine error signal (an analog measure of the error between resolver angle and read counter angle) by Schmitt trigger type level detectors. The rate select and up/down logic processes the sampled output of the Schmitt triggers to determine at which rate the read counter should be incremented. If the output of the high speed Schmitt is high (1.7-volt trigger threshold), the read counter is incremented at 6,400 pps; if the output of the fine Schmitt is high (0.1-volt trigger threshold), the rate is 800 pps. Thus, in one sample time the read counter will be incremented 1 bit at low speed or 8 bits at high speed. The functional equivalent of System Rate and Switch Selection is shown below.



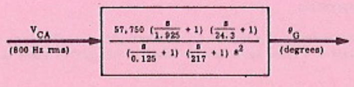
Read Counter

The read counter is a 16-stage digital counter with an IMU angle granularity of 20 seconds/bit. Inputs to the read counter are controlled by rate select and up/down logic. The output is used by the fine system switch selection logic to produce the fine error signal. Access by the computer is to the low order bit ($\Delta 2^0$). Access by the error counter is to the third order bit ($\Delta 2^2$). Functionally, the read counter is represented as an integrator with a count rate in degrees/second and an output in degrees.

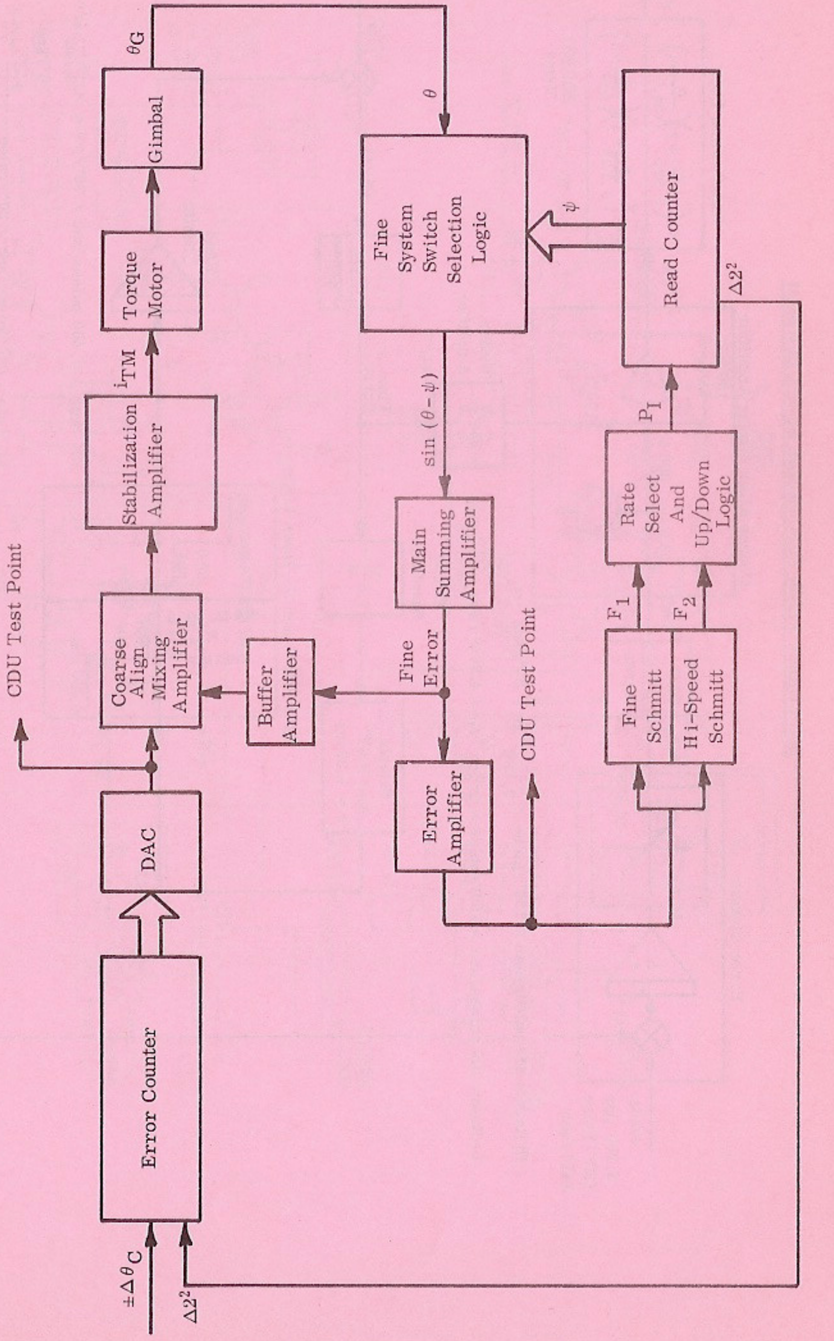


Stabilization Loop

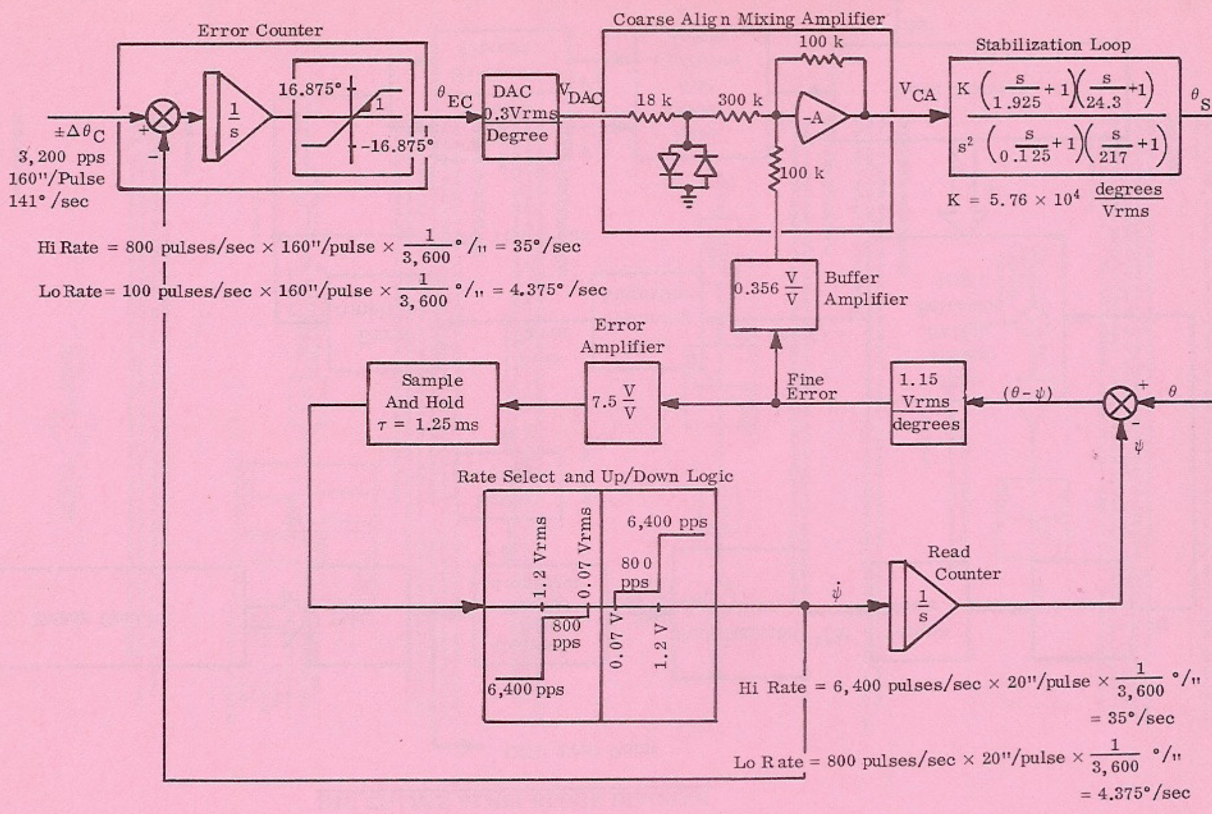
The analog part of the coarse align servomechanism consists of the stabilization amplifier, torque motor, and gimbal. The overall transfer function of the above three elements is as shown below.



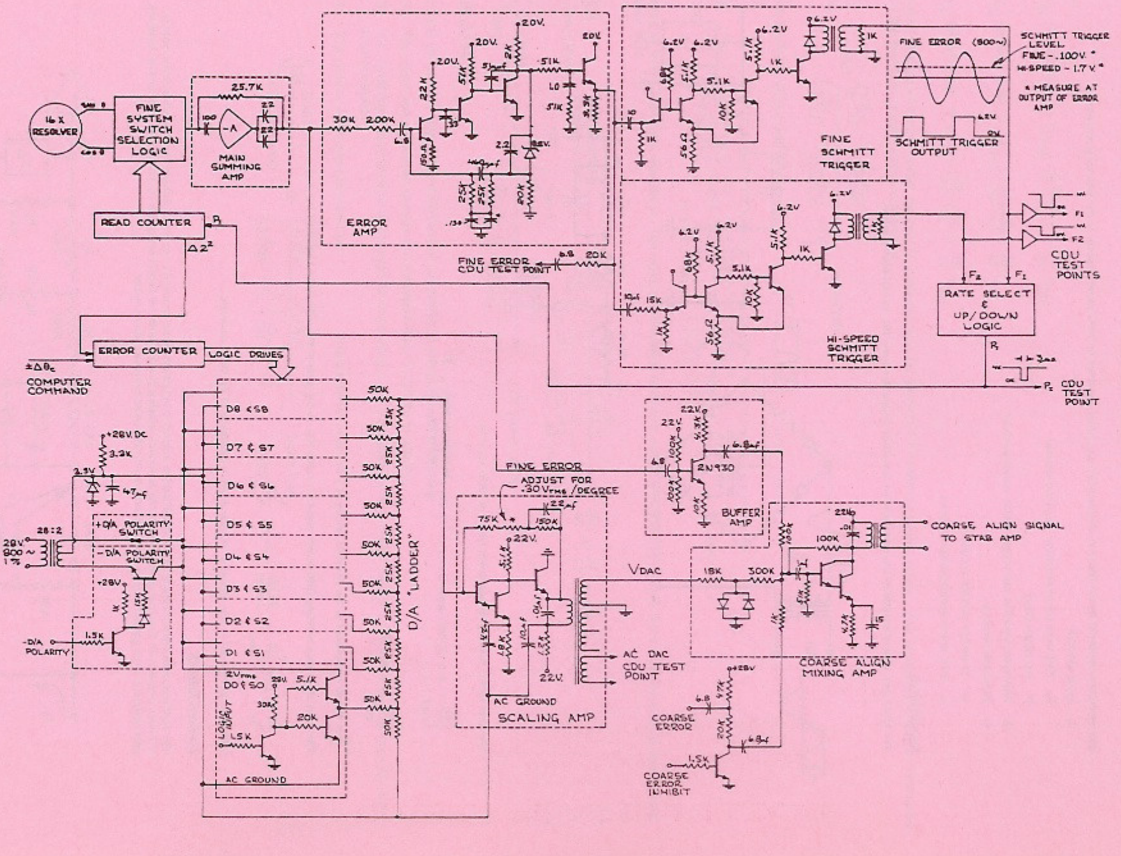
IMU COARSE ALIGN BLOCK DIAGRAM



IMU COARSE ALIGN FUNCTIONAL BLOCK DIAGRAM



ECDU COARSE ALIGN NETWORK



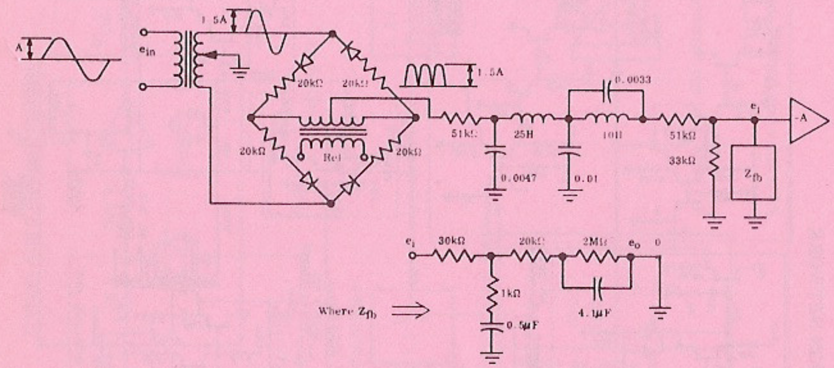
IMU INERTIAL MODE

The circuitry employed by the Block II stabilization amplifier operates on IRIG error signals in the following sequence:

1. Input network
   - a. Full wave phase sensitive ring demodulator
   - b. AC ripple filter
2. High gain amplifier and torque motor current driver
3. Feedback network
   - a. Armature current sampler
   - b. R-C servo compensation network

Input Network

The input gain characteristic of the stabilization amplifier originates from the circuit shown below.



The gain factor relating demodulator output to IRIG input is:

$$\frac{V_{dc}}{V_{rms}} = 1.5 \text{ (XFMR scale factor)} \times 1.414 \left(\frac{\text{ac peak-to-peak}}{\text{ac V rms}}\right) \times \frac{2}{\pi}^{*}$$

$$\frac{V_{dc}}{V_{rms}} = 1.35 \text{ V/V}$$

* $\frac{2}{\pi}$ is the dc component of the Fourier series of a full wave rectified signal.

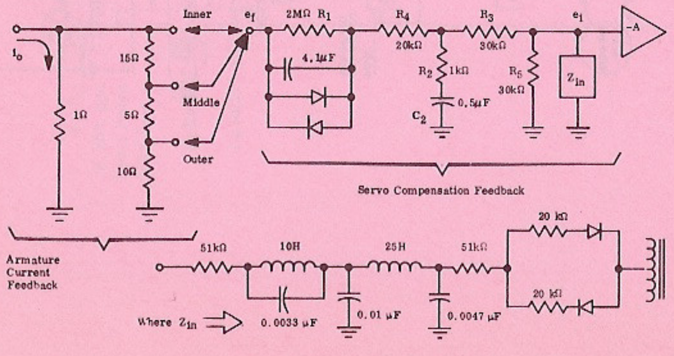
The total input gain relating IRIG error signals (3,200 Hz) to dc volts at the High Gain Amplifier input is

$$\frac{e_o}{e_{in}} = 1.35 \frac{V_{dc}}{V_{rms}} \times \frac{33 \text{ k}\Omega}{145 \text{ k}\Omega} = 0.307 \frac{V_{dc}}{V_{rms}} \text{(IRIG)}$$

Where 33 kΩ/145 kΩ is the effective "divide down" resistance of the input network.

Feedback Network

The feedback gain characteristic of the stabilization amplifier originates from armature current feedback of the gimbal drive motors. A 1-ohm resistor is inserted in series with the armature winding of each motor to detect armature current. The appropriate feedback gain unique to each gimbal loop is obtained with the divide-down networks shown below



where

$$e_{fb} \text{ (inner loop)} = (i_{TM}) \left(\frac{1 \times 30}{1 + 30}\right) = \frac{30}{31} i_{TM}$$

$$e_{fb} \text{ (middle loop)} = (i_{TM}) \left(\frac{15}{30}\right)\left(\frac{30}{31}\right) = \frac{15}{31} i_{TM}$$

$$e_{fb} \text{ (outer loop)} = (i_{TM}) \left(\frac{10}{30}\right)\left(\frac{30}{31}\right) = \frac{10}{31} i_{TM}$$

Frequency shaping of torque motor current is achieved with the passive "T" network shown above. The frequency response characteristic of the feedback compensation network is:

$$\frac{e_o}{e_{fb}} = 0.020 \frac{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{2{,}000} + 1\right)}{\left(\frac{s}{4.12} + 1\right)\left(\frac{s}{102.5} + 1\right)} \quad \text{volts/volt}$$

with the feedback diodes not conducting.

$$\frac{e_o}{i_{TM}} = \left(\frac{30}{31} \text{ or } \frac{15}{31} \text{ or } \frac{10}{31}\right) 0.020 \frac{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{2{,}000} + 1\right)}{\left(\frac{s}{4.12} + 1\right)\left(\frac{s}{102.5} + 1\right)}$$

Assuming an ideal High Gain Amplifier, the input and feedback networks can be combined as if each were working into an operational amplifier thus:

$$\frac{i_{TM}}{V_{rms\ (IRIG)}} = \frac{\text{Input Network}}{\text{Feedback Network}} = \frac{0.307}{0.020} \frac{\left(\frac{s}{4.12} + 1\right)\left(\frac{s}{102.5} + 1\right)}{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{2{,}000} + 1\right)} \left(\frac{31}{30} \text{ or } \frac{31}{15} \text{ or } \frac{31}{10}\right)$$

$$\frac{i_{TM\ (Adc)}}{V_{IRIG} \text{ (Vrms ac)}} = \frac{15 \left(\frac{s}{4.12} + 1\right)\left(\frac{s}{102.5} + 1\right)}{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{2{,}000} + 1\right)} \quad \text{A/V (inner axis)}$$

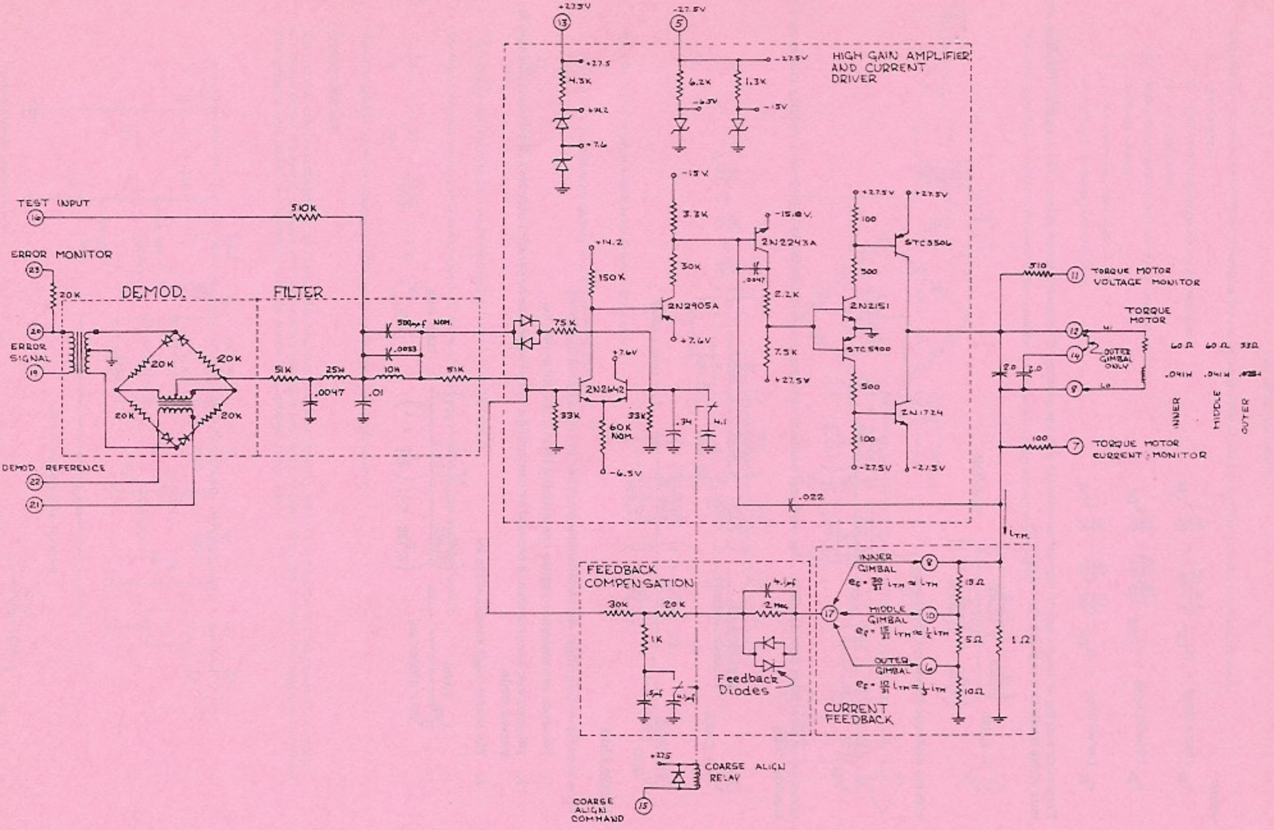
Coarse Align

When used for coarse align, the stabilization amplifier is reconfigured as follows:

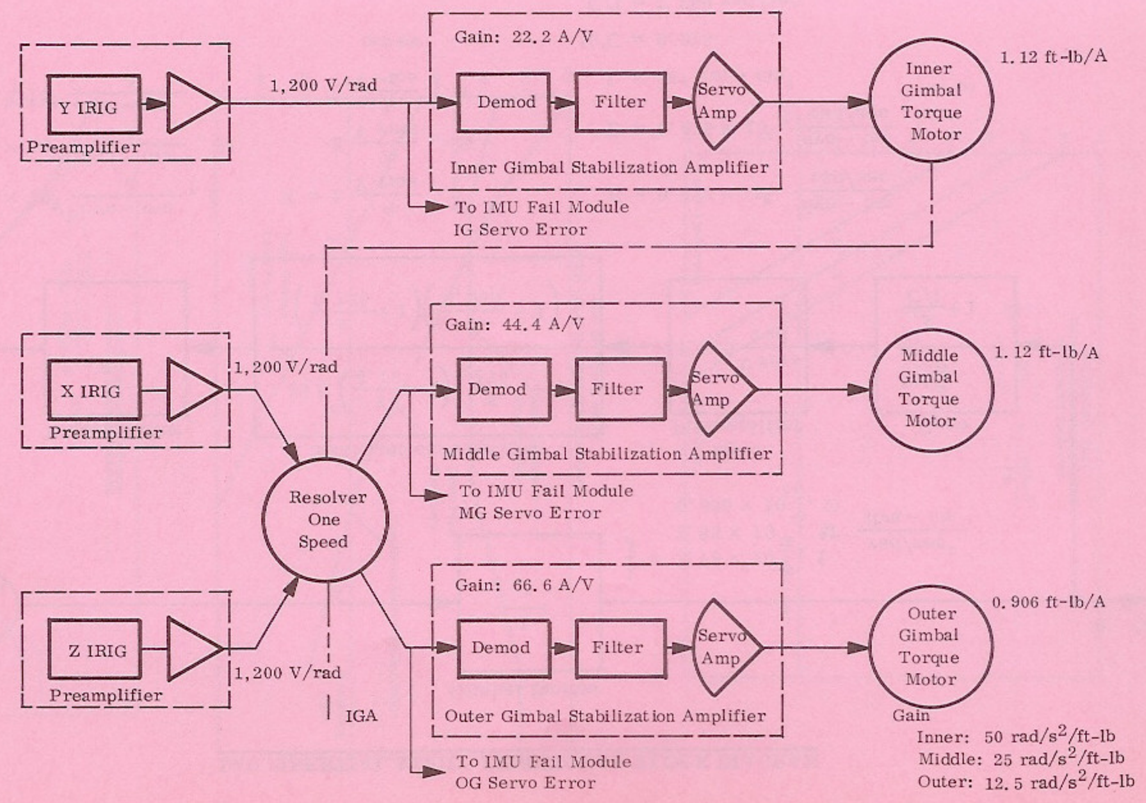
1. The input and reference signals are switched from 3,200 Hz to 800 Hz.
2. The feedback compensation is changed by connecting a 4.1 μF capacitor in parallel with the 0.5 μF capacitor used for the inertial mode.
3. The coarse align compensation is:

$$\frac{i_{TM} \text{ (Adc)}}{V_{DAC} \text{ (Vrms ac)}} = 15 \frac{\left(\frac{s}{1.925} + 1\right)\left(\frac{s}{24.3} + 1\right)}{\left(\frac{s}{0.125} + 1\right)\left(\frac{s}{217} + 1\right)} \quad \text{inner loop}$$

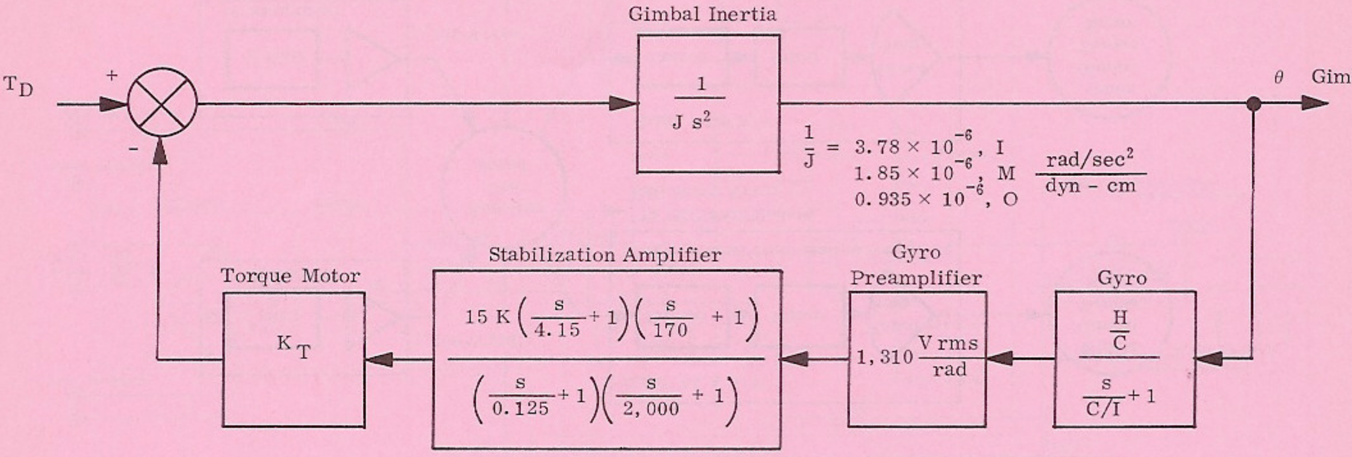
IMU STABILIZATION AMPLIFIER



IMU "INERTIAL MODE" BLOCK DIAGRAM



IMU "INERTIAL MODE" FUNCTIONAL BLOCK DIAGRAM



$K_T = 1.52 \times 10^7 \ \frac{\text{dyn - cm}}{\text{A}}$, I

$1.52 \times 10^7 \ \frac{\text{dyn - cm}}{\text{A}}$, M

$1.23 \times 10^7 \ \frac{\text{dyn - cm}}{\text{A}}$, O

$K = 1 \ \frac{\text{A}}{\text{V rms}}$, I

$2 \ \frac{\text{A}}{\text{V rms}}$, M

$3 \ \frac{\text{A}}{\text{V rms}}$, O

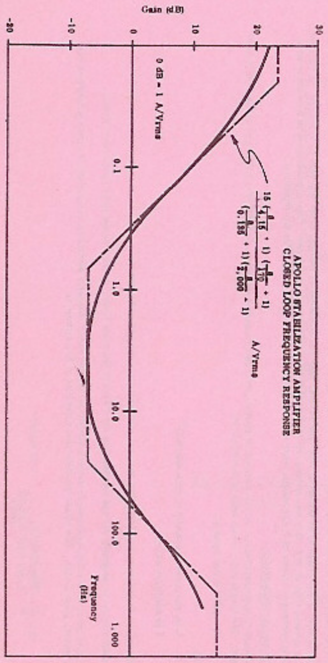
$H = 0.434 \times 10^6 \ \frac{\text{dyn - cm}}{\text{rad/sec}}$

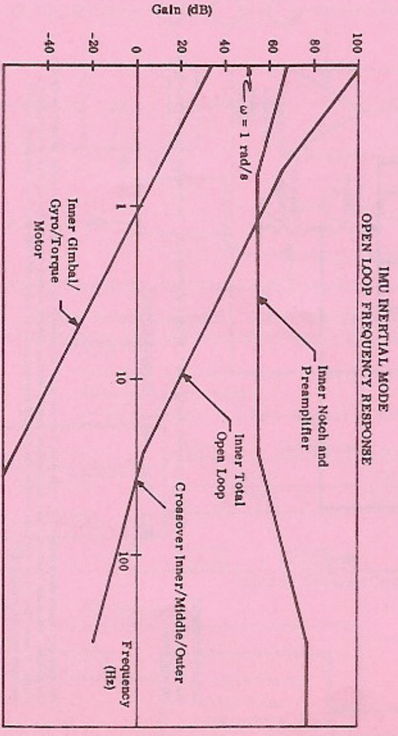
$C = 0.475 \times 10^6 \ \frac{\text{dyn - cm}}{\text{rad/sec}}$

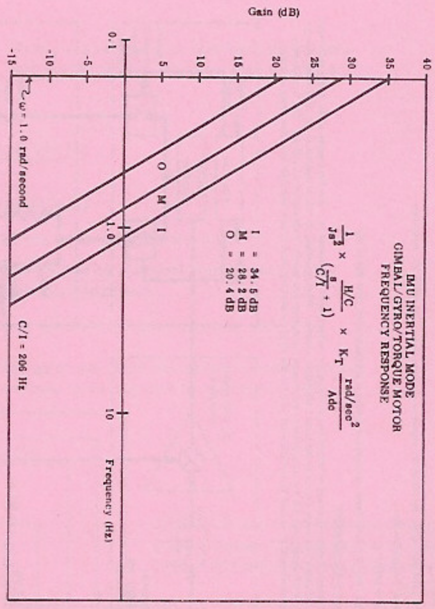
$I = 367 \text{ gm - cm}^2$

$H/C = 0.915$

$C/I = 1,290$ rad/sec


APOLLO STABILIZATION AMPLIFIER CLOSED LOOP FREQUENCY RESPONSE


IMU INERTIAL MODE OPEN LOOP FREQUENCY RESPONSE


IMU INERTIAL MODE GIMBAL/GYRO/TORQUE MOTOR FREQUENCY RESPONSE

$\frac{1}{Js^2} \times \frac{H/C}{\left(\frac{s}{C/I}+1\right)} \times K_T \ \frac{\text{rad/sec}^2}{\text{Adc}}$

GYRO PULSE TORQUING

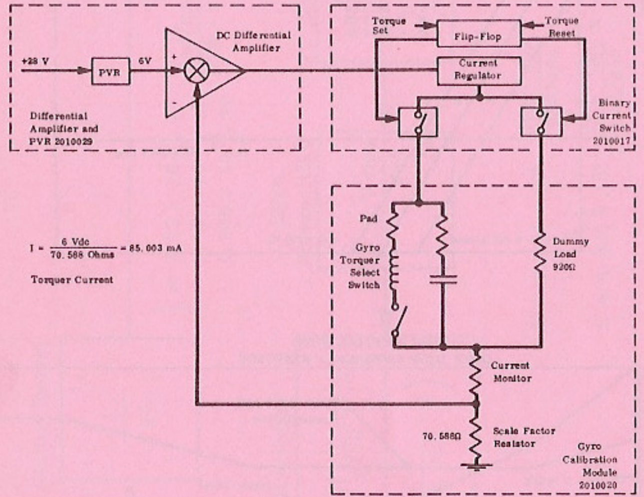
Gyro torque, its corresponding precession rate, and hence gimbal position are controlled by regulating the pulse width of gyro torquer current. In the Fine Align mode, the length of the torquer current pulse is precisely controlled by the computer to achieve a desired gimbal position.

To torque a particular gyro, the following sequence of commands is issued by the computer:

1. Gyro Torque Enable
2. Gyro Select
3. Gyro Set (the Gyro Reset command is issued at all times when Gyro Set is off)

Gyro Torque Enable Command

The Gyro Torque Enable command is issued by the computer through Bit 6 of Channel 14. The Bit 6 gates a 102.4 kHz pulse train out of the computer to a relay driver in the Gyro Calibration Module. When actuated, 28 Vdc is applied to the Precision Voltage Reference (PVR) supply and 120 Vdc is applied to the Binary Current Switch and DC Differential Amplifier. The Gyro Torque Enable command must be issued 20 milliseconds prior to the Gyro Select Command to assure ample time for relay closure.



$$I = \frac{6\ \text{Vdc}}{70.588\ \text{Ohms}} = 85.003\ \text{mA}$$

Torquer Current

Gyro Select Command

The Gyro Select command is controlled by the computer through Bits 7, 8, and 9 of Channel 14. The selection logic is shown in the following table:

BIT 7	BIT 8	BIT 9	TORQUER WINDING
0	1	0	+Y
0	1	1	-Y
1	0	0	+X
1	0	1	-X
1	1	0	+Z
1	1	1	-Z

The mode logic shown above gates a 102.4 kHz pulse train out of the computer to one of six transistor switches in the Gyro Calibration Module. This pulse train will close the transistor switch, thereby enabling torquer current when the Gyro Set command is issued. If more than one gyro is to be torqued, the order of selection is Y, Z, and X with each gyro being completely torqued before the next one is selected.

Gyro Set Command

The Gyro Set command is controlled by the computer through Bit 10 of Channel 14. This bit sets a flip-flop which gates a 3.2 kHz pulse train out of the computer to the Binary Current Switch via the Gyro Calibration Module. When actuated in this manner, gyro torque current is switched from the 920-ohm dummy load to the torque winding selected by the computer. When the desired number of set pulses has been issued, the flip-flop is reset causing current to be transferred from the torquer winding to the dummy load.

If the number of set pulses to be issued is less than 16,384, they are all issued in a single burst at a rate of 3,200 pps. If the number is greater than 16,384, they are divided into groups of 8,192 pulses plus a remainder. Gimbal positioning is then achieved by issuing successive bursts of 8,192 pulses, each separated by a 30-millisecond delay, plus the remainder.

Pulse Torque Scale Factor

The pulse torque scale factor, in arc-seconds of gimbal travel per computer set pulse, is 0.617981±1,750 ppm at the G & N level of test. The torque produced by each gyro torquer is:

$$T = Ki^2 = 4,335\ \text{dyne-cm}$$

where

K is microsyn sensitivity in dyne-cm/amp^2

i is microsyn current

Each torquer is padded to provide 4,335 dyne-cm of torque for a current of 85.003 mA.

Torquer current is precisely set and regulated by the PVR and the scale factor resistor in the Gyro Calibration Module.

The gyro pulse torque loop operates to achieve gimbal positioning under computer control by controlling the gyro precession rate and, hence, gimbal rate. The maximum slew rate capability of this system is:

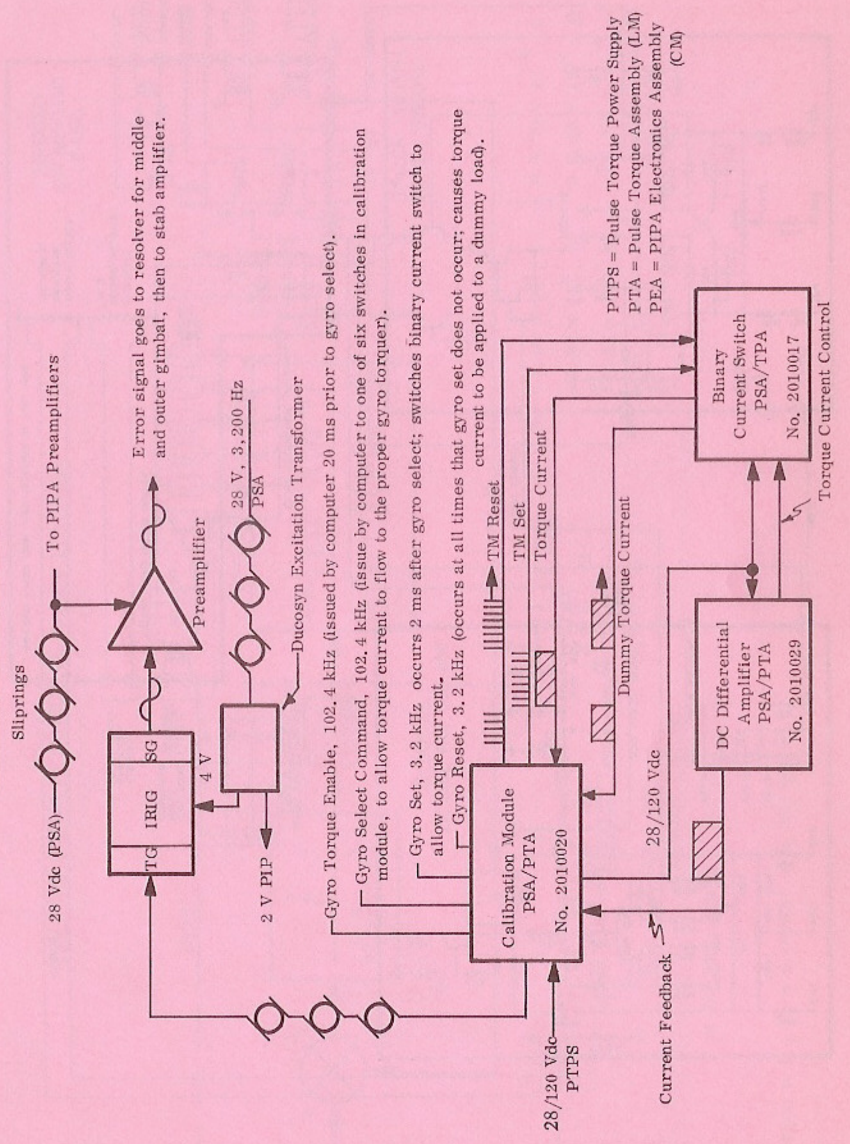
$$\dot{\theta} = \frac{T}{H} = \frac{4335\ \text{dyne-cm}}{0.434 \times 10^6\ \frac{\text{dyne-cm}}{\text{rad/s}}} = 10\ \text{mrad/s}$$

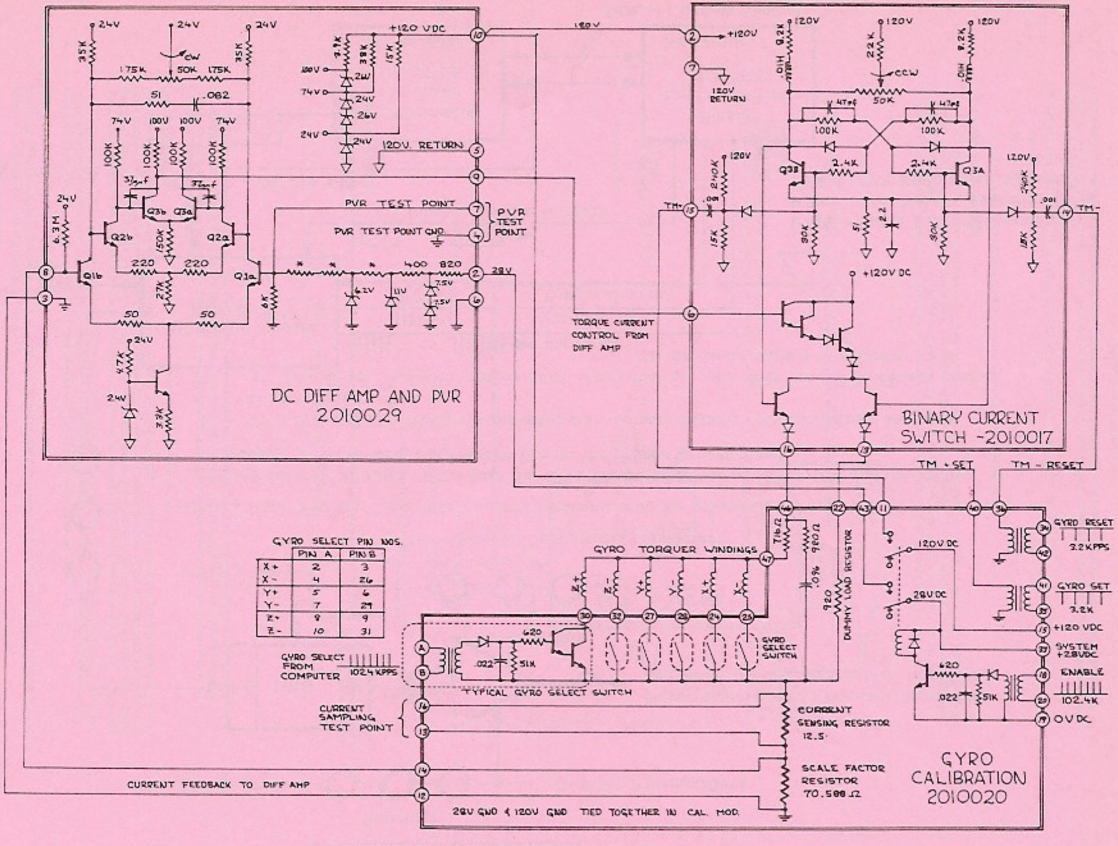
where

T = microsyn torque

H = gyro angular momentum

GYRO PULSE TORQUING LOOP

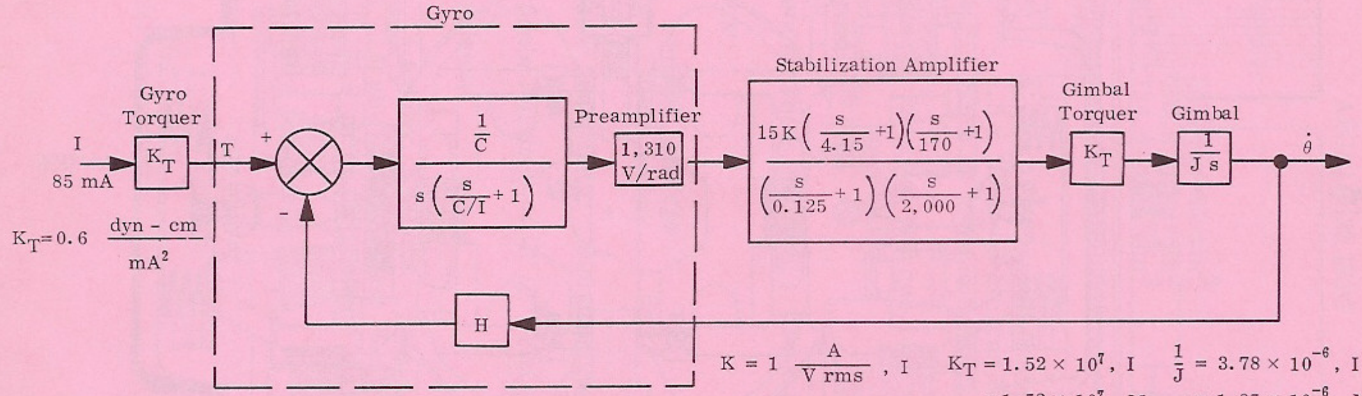




	PIN A	PIN B
X+	2	3
X-	4	26
Y+	5	6
Y-	7	29
Z+	8	9
Z-	10	31

GYRO PULSE TORQUING LOOP

IMU FINE ALIGN FUNCTIONAL BLOCK DIAGRAM



$K = 1 \ \frac{A}{V \ rms}$, I

$K = 2$, M

$K = 3$, O

$K_T = 1.52 \times 10^7$, I
$= 1.52 \times 10^7$, M
$= 1.23 \times 10^7$, O
$\frac{\text{dyn - cm}}{A}$

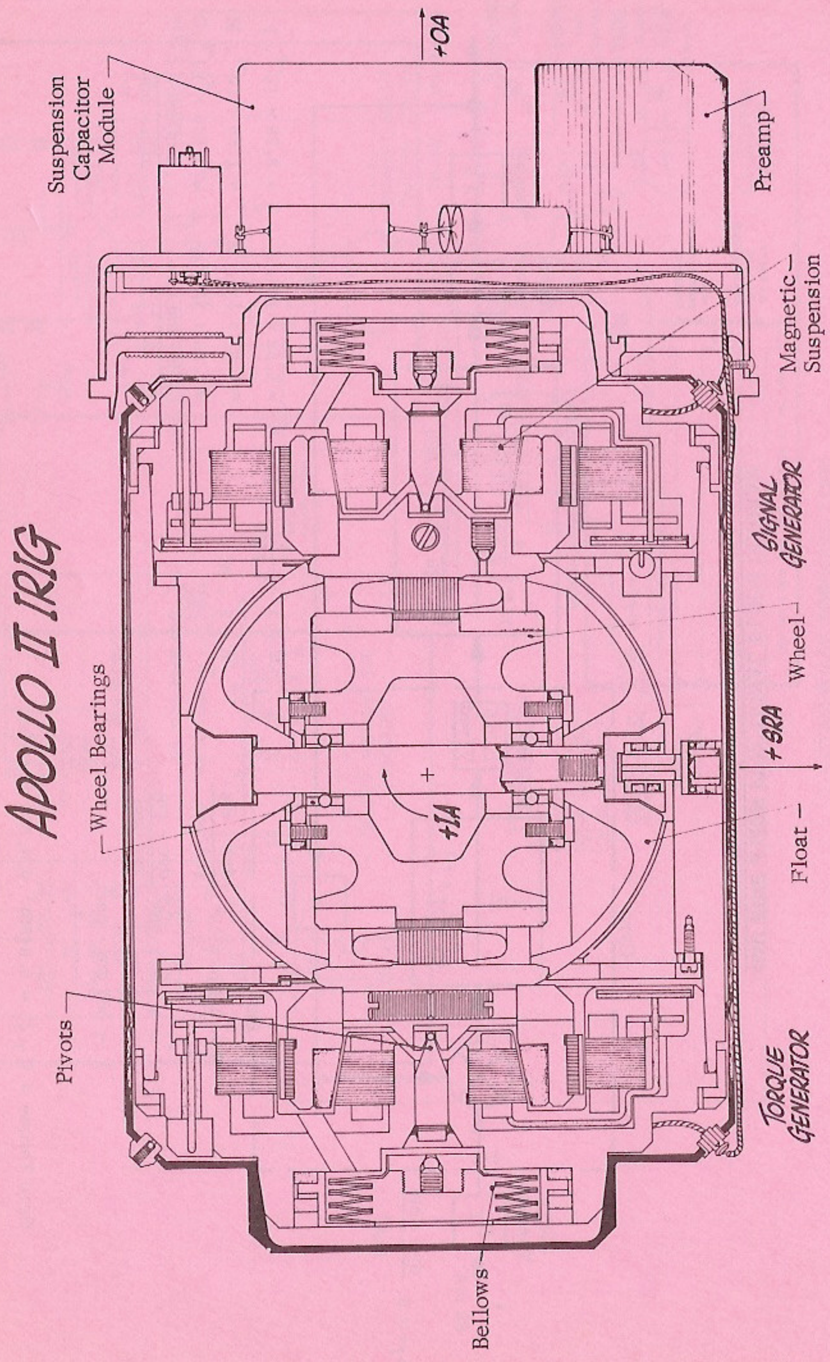
$\frac{1}{J} = 3.78 \times 10^{-6}$, I
$= 1.85 \times 10^{-6}$, M
$= 0.935 \times 10^{-6}$, O
$\frac{\text{rad/sec}^2}{\text{dyn - cm}}$

$H = 0.434 \times 10^6 \ \frac{\text{dyn - cm}}{\text{rad/sec}}$

$C = 0.475 \times 10^6 \ \frac{\text{dyn - cm}}{\text{rad/sec}}$

$I = 367 \text{ gm - cm}^2$

Gyro Torque $= K_T I^2 = 0.6(85)^2 = 4,335$ dyn - cm


APOLLO II IRIG

APOLLO 25 IRIG

Moments of Inertia:

about OA:	367.3 gram-cm^2
about IA:	650.8 gram-cm^2
about SRA:	724.9 gram-cm^2

Damping Coefficients:

about OA:	4.75×10^5 dyne-cm/rad/sec
about IA:	1.5×10^9 dyne-cm/rad/sec
about SRA:	1.5×10^9 dyne-cm/rad/sec

Wheel Excitation: 28 volts, 800 cps, 4.5 watts at synchronism

Wheel Speed: 24,000 rpm

Angular Momentum at 24,000 rpm: 434×10^3 gram-cm^2 sec

Signal Generator:

Input:	4 volts, 3200 cps
Sensitivity:	10 mv/mrad

Torque Generator Sensitivity: 0.6 dyne-cm/ma^2

Pulse Torque Scale Factor: $\pi/2^{20}$ rad/pulse at 3200 pps

Magnetic Suspension:

Input:	4 volts, 3200 cps
Stiffness:	6 gm/0.0001 inches Radial 0.8 gm/0.0001 inches Axial

Typical Temperature Sensitivity

Scale Factor:	400 ppm/$^\circ$ F
Drift:	0.2 meru/$^\circ$ F

Actual IRIG temperature

GYRO PARAMETERS

Primary gyro parameters are ADIA, ADSRA, NBD and scale factor. Specification values across ISS, G&N, and S/C testing are as shown in Table II-1.

Table II-1

Gyro Coefficient Stability Criteria					
Coefficient	Units	D1	D2	D3	Max
Acceleration Drift along the IA (ADIA)	meru/g	17	33	40	100
Acceleration Drift along the SRA (ADSRA)	meru/g	14	21	25	40
Non-Acceleration Bias Drift (NBD)	meru	6	9	11	15

Gyro scale factor limits are ± 1750 ppm.

The maximum value of gyro performance parameters which can be compensated for by the computer is shown in Table II-2.

Table II-2

Coefficient	Units	Max Value CM/LM
ADIA	meru/g	862 /630
ADSRA	meru/g	862 /630
NBD	meru	128.7

IMU GYRO COMPENSATION

The compensated PIPA data is used to compute the IRIG torquing necessary to cancel the NBD, ADIA and ADSRA gyro coefficients. The computations are

$$XIRIG = -ADIAX\ PIPAX_C + ADSRAX\ PIPAY_C - NBDX\ \Delta t$$

$$YIRIG = -ADIAY\ PIPAY_C + ADSRAY\ PIPAZ_C - NBDY\ \Delta t$$

$$ZIRIG = -ADIAZ\ PIPAZ_C - ADSRAZ\ PIPAY_C + NBDZ\ \Delta t$$

where

XIRIG, YIRIG, ZIRIG are gyro drift compensations

NBDX, NBDY, NBDZ are gyro bias drifts (an erasable load)

ADSRAX, ADSRAY, ADSRAZ are gyro drifts due to acceleration in spin reference axis (an erasable load)

ADIAX, ADIAY, ADIAZ are gyro drifts due to acceleration in the input axis (an erasable load)

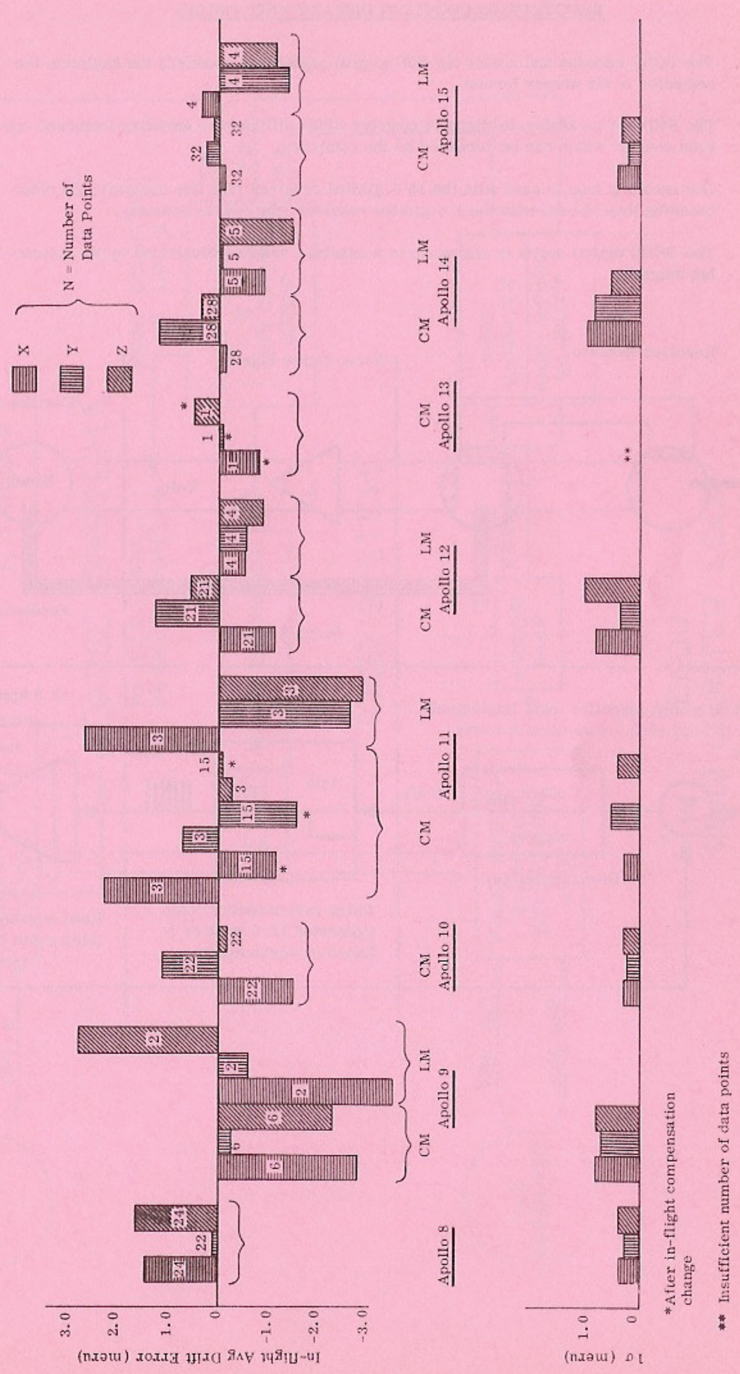
When the magnitude of any IRIG command exceeds two pulses, the commands are sent to the gyros.

During free-fall only the NBDX, NBDY, NBDZ are the relevant coefficients and the routine is so ordered that only these terms are calculated for the gyro compensation.

The computer NBD registers are 1460, 1461, and 1462 for the X, Y, and Z gyros respectively.

GYRO DRIFT NBD = (.007835) (Reg Contents in Decimal) MERU

HISTORY OF IN-FLIGHT GYRO DRIFT ERRORS



*After in-flight compensation change

** Insufficient number of data points

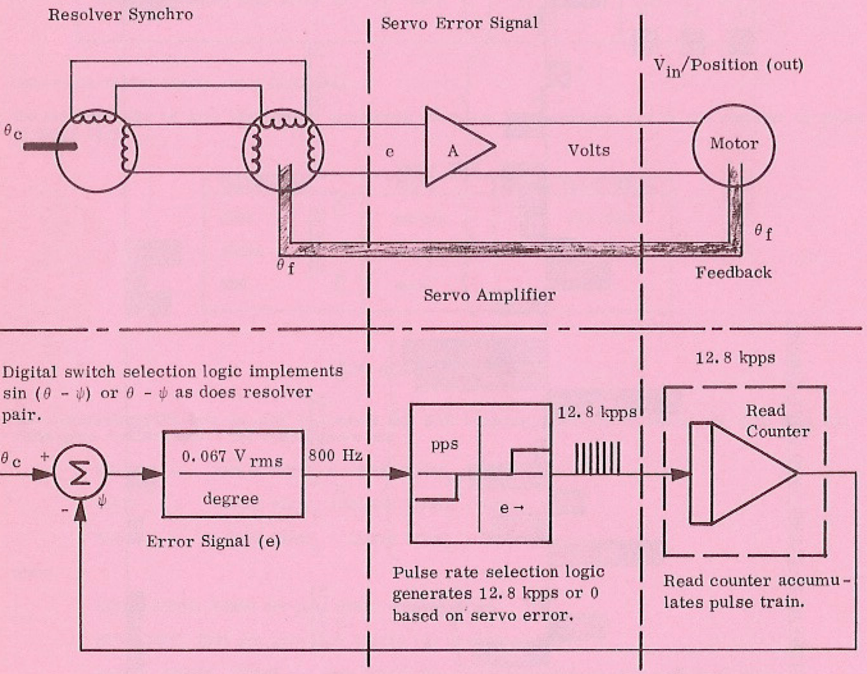
ELECTRONICS COUPLING DISPLAY UNIT (ECDU)

The ECDU encodes and scales the IMU gimbal angles and transfers the angles to the computer in the proper format.

The ECDU is an analog-to-digital converter which utilizes two encoding loops and one read counter which can be accessed by the computer.

One encoding loop is used with the 16 × gimbal resolver (the fine system); the other encoding loop is used with the 1 × gimbal resolver (the coarse system).

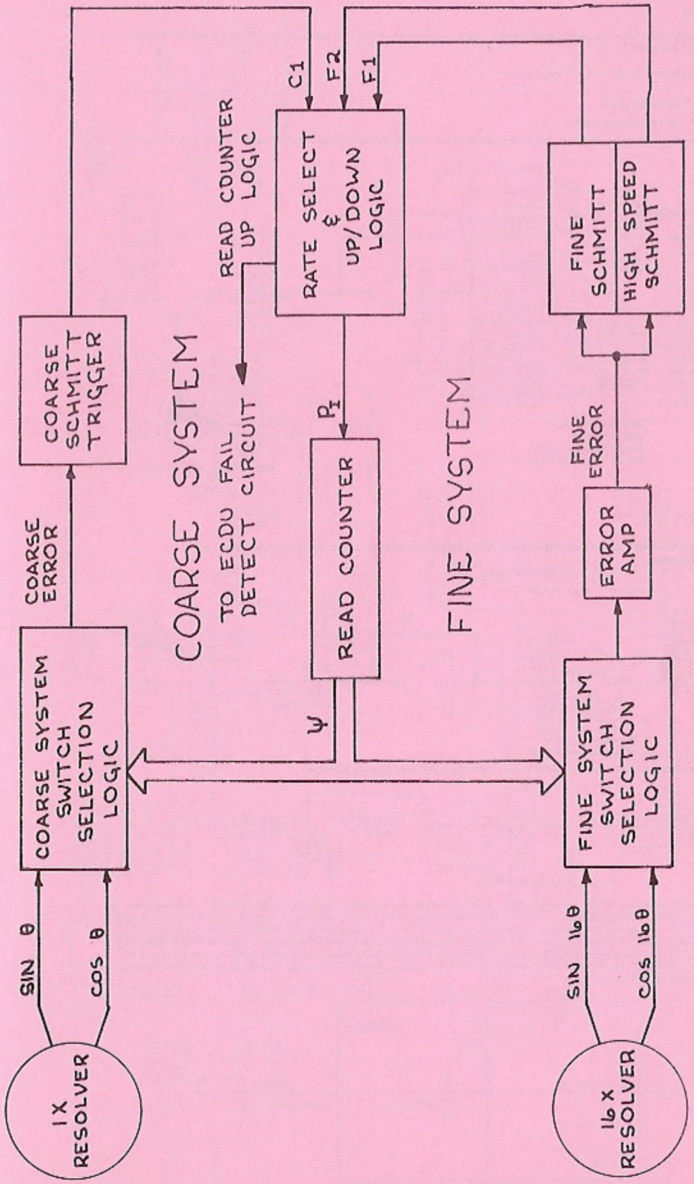
The ECDU digital servo is analogous to a resolver synchro illustrated by the following diagram.



Digital switch selection logic implements sin $(\theta - \psi)$ or $\theta - \psi$ as does resolver pair.

Pulse rate selection logic generates 12.8 kpps or 0 based on servo error.

Read counter accumulates pulse train.



ECDU
READ COUNTER LOOP
BLOCK DIAGRAM

ELECTRONIC COUPLING DISPLAY UNIT ECDU (CONTINUED)

The ECDU is an analog-to-digital converter which utilizes two encoding loops and one read counter to which the computer has access. One loop designated the "fine system" is used to encode 16× gimbal resolver angles. The other, a "coarse system," encodes 1× gimbal resolver angles.

When the difference between a gimbal resolver angle and the ECDU read counter exceeds 8.4 degrees, the "coarse system" has exclusive control of the read counter. For errors smaller than 8.4 degrees, the "fine system" has exclusive control of the read counter.

Coarse System

The coarse system utilizes a system of switch selection logic, weighting resistors, and summing amplifiers to generate a trigonometric identity of the form:

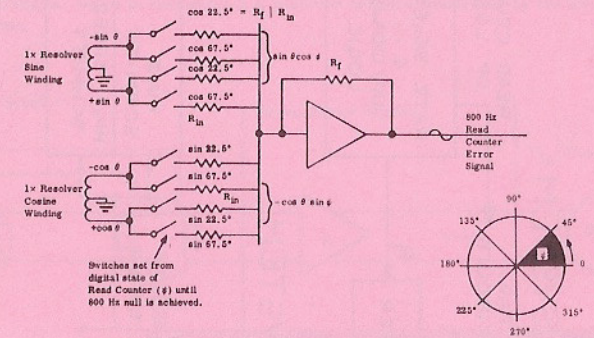
$$-\sin(\theta-\phi) = -\sin\theta\cos\phi + \cos\theta\sin\phi$$

where

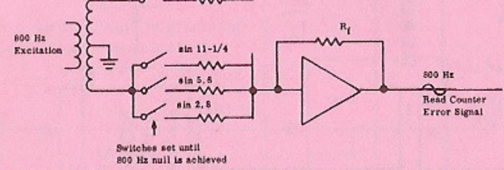
θ = the gimbal angle

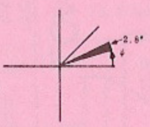
ϕ = the read counter angle

This trigonometric identity is used as an error signal to drive the read counter until ϕ has been isolated to one of eight 45-degree segme

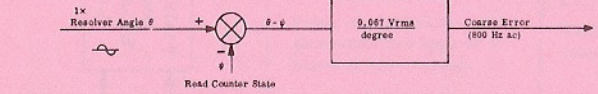


A ladder network provides an additional signal which drives the read counter until ϕ has been further isolated to one of 16, 2.8-degree segments.

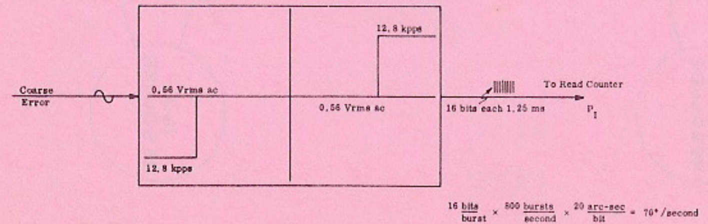




The functional equivalent of the entire coarse system error detecting logic is as shown below.



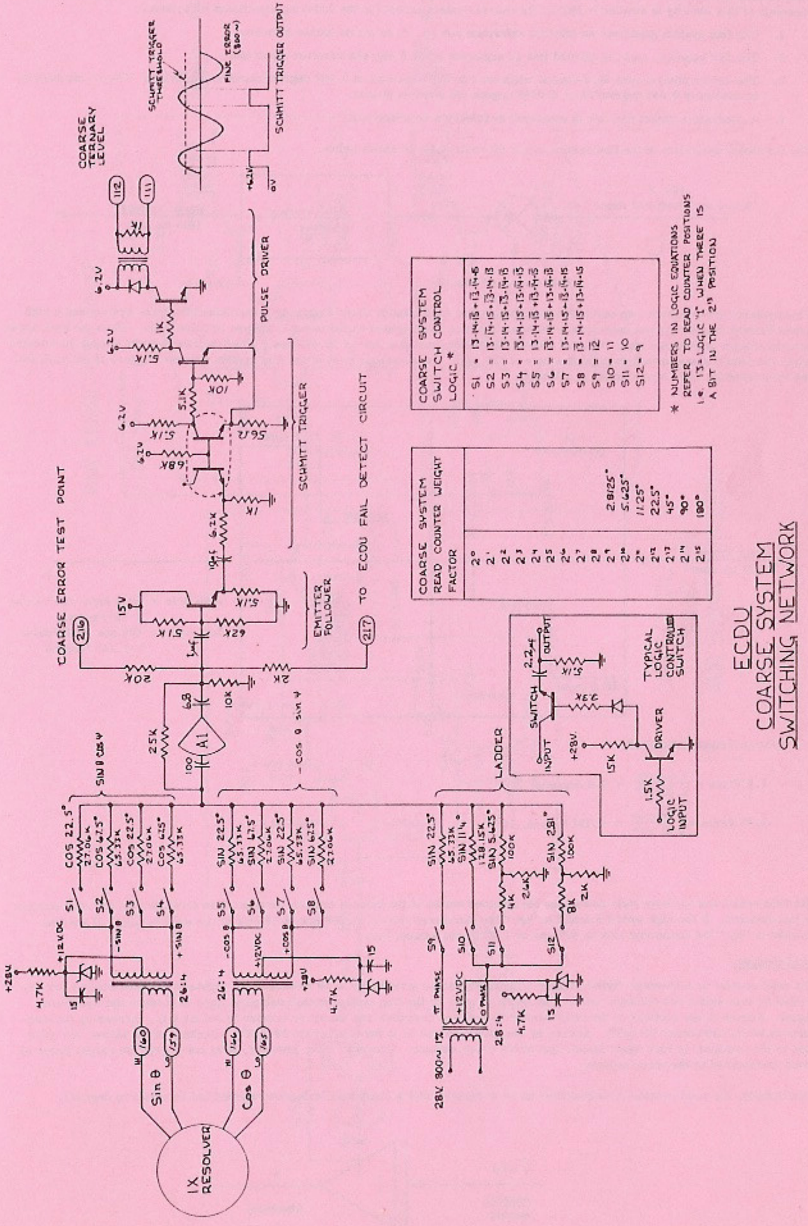
In the manner shown above, the error between the 1× resolver position and the digital state of the read counter is converted to an 800 Hz analog signal. This is converted back into a digital drive signal for the read counter by the "coarse Schmitt trigger and rate selection logic." The coarse Schmitt trigger threshold is set at 0.56 Vrms (8.4 degrees) thereby deactivating the coarse read counter loop when the error between 1× resolver position and the read counter is less than 8.4 degrees. The pulse train output of the Schmitt trigger is interrogated by a 1,600 pps impulse train. When the coarse Schmitt is detected high, the read counter is incremented at a rate of 12.8 kpps, thus reading 16 bits into the read counter in 1/800 of a second. The functional equivalent of this signal processing is shown below.



$$\frac{16\ \text{bits}}{\text{burst}} \times \frac{800\ \text{bursts}}{\text{second}} \times \frac{20\ \text{arc-sec}}{\text{bit}} = 70°/\text{second}$$

Coarse Schmitt Trigger and Rate Selection Logic

(The CM optics CDU's do not contain a coarse system.)



COARSE SYSTEM READ COUNTER WEIGHT FACTOR	
2^0	
2^1	
2^2	
2^3	
2^4	
2^5	
2^6	
2^7	
2^8	
2^9	2.8125°
2^{10}	5.625°
2^{11}	11.25°
2^{12}	22.5°
2^{13}	45°
2^{14}	90°
2^{15}	180°

COARSE SYSTEM SWITCH CONTROL LOGIC *
S1 = $13\cdot14\cdot\overline{15} + \overline{13}\cdot\overline{14}\cdot15$
S2 = $13\cdot\overline{14}\cdot15 + \overline{13}\cdot14\cdot\overline{15}$
S3 = $13\cdot14\cdot15 + \overline{13}\cdot\overline{14}\cdot\overline{15}$
S4 = $\overline{13}\cdot14\cdot15 + 13\cdot\overline{14}\cdot\overline{15}$
S5 = $13\cdot14\cdot\overline{15} + \overline{13}\cdot\overline{14}\cdot\overline{15}$
S6 = $\overline{13}\cdot14\cdot\overline{15} + 13\cdot\overline{14}\cdot\overline{15}$
S7 = $13\cdot14\cdot15 + \overline{13}\cdot\overline{14}\cdot15$
S8 = $\overline{13}\cdot14\cdot15 + 13\cdot\overline{14}\cdot15$
S9 = $\overline{12}$
S10 = 11
S11 = 10
S12 = 9

* NUMBERS IN LOGIC EQUATIONS REFER TO READ COUNTER POSITIONS I.E. 13 = LOGIC "1" WHEN THERE IS A BIT IN THE 2^{13} POSITION

ECDU
COARSE SYSTEM
SWITCHING NETWORK

ELECTRONIC COUPLING DISPLAY UNIT (ECDU) (CONTINUED)

Fine System

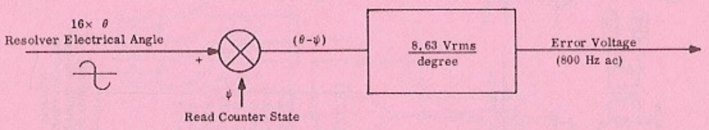
The fine system utilizes a system of switch selection logic, weighting resistors, and summing amplifiers to generate the trigonometric identity.

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

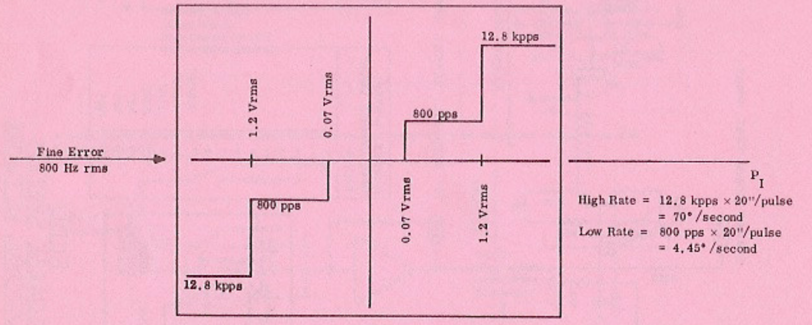
This identity is used as an error signal to drive the read counter until ψ is isolated to one of 256, 0.088-degree segments. Mechanization of this identity is similar to that of the coarse system except for the following significant differences.

1. The fine system generates an internal reference $\cos(\theta - \psi)$ to excite ladder switches.
2. The 16× resolver angle is divided into 16 segments of 22.5 degrees resolver electrical.
3. The ladder divides each 22.5-degree segment into 256 segments of 0.088 degree resolver electrical. The 1× mechanical equivalent is 0.088 degree/16 or 0.0056 degree (20 seconds of arc).
4. A quadrature reject network is employed to achieve a true loop null.

The functional equivalent of the fine system error detection logic is shown below.



Fine systems error signals are converted back into digital read counter drive signals by a fine Schmitt trigger system and a high speed Schmitt trigger system operating in tandem. Each is interrogated by the same 1,600 pps impulse train. When the high speed Schmitt trigger is detected high, the read counter is incremented at a rate of 12,800 pps. When the fine Schmitt trigger is detected high, the read counter is incremented at a rate of 800 pps. The threshold level of the fine system Schmitt triggers is set such that the rate selection logic shown below is achieved.



Schmitt Trigger Threshold

$$1.2\ \text{Vrms} \times \frac{1\ \text{degree}}{8.63\ \text{V}/°} = 2.2\ \text{degrees, } 16\times$$

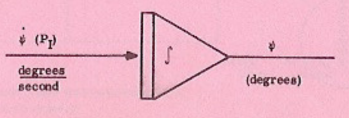
$$0.07\ \text{Vrms} \times \frac{1\ \text{degree}}{8.63\ \text{V}/°} = 0.131\ \text{degree, } 16\times$$

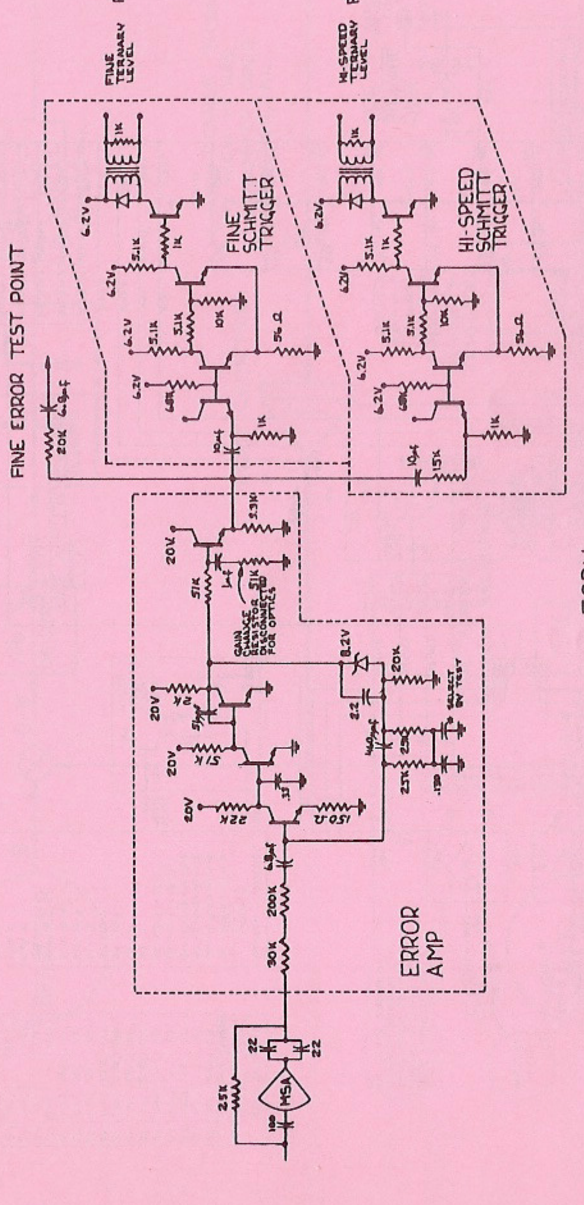
The rate select and up/down logic processes the sampled output of the Schmitt triggers to determine at which rate the read counter is incremented. If the high speed Schmitt is "on," the increment rate is 12,800 pps or 16 bits in one sample time. If the fine Schmitt is "on," the increment rate is 800 pps or 1 bit in one sample time.

Read Counter

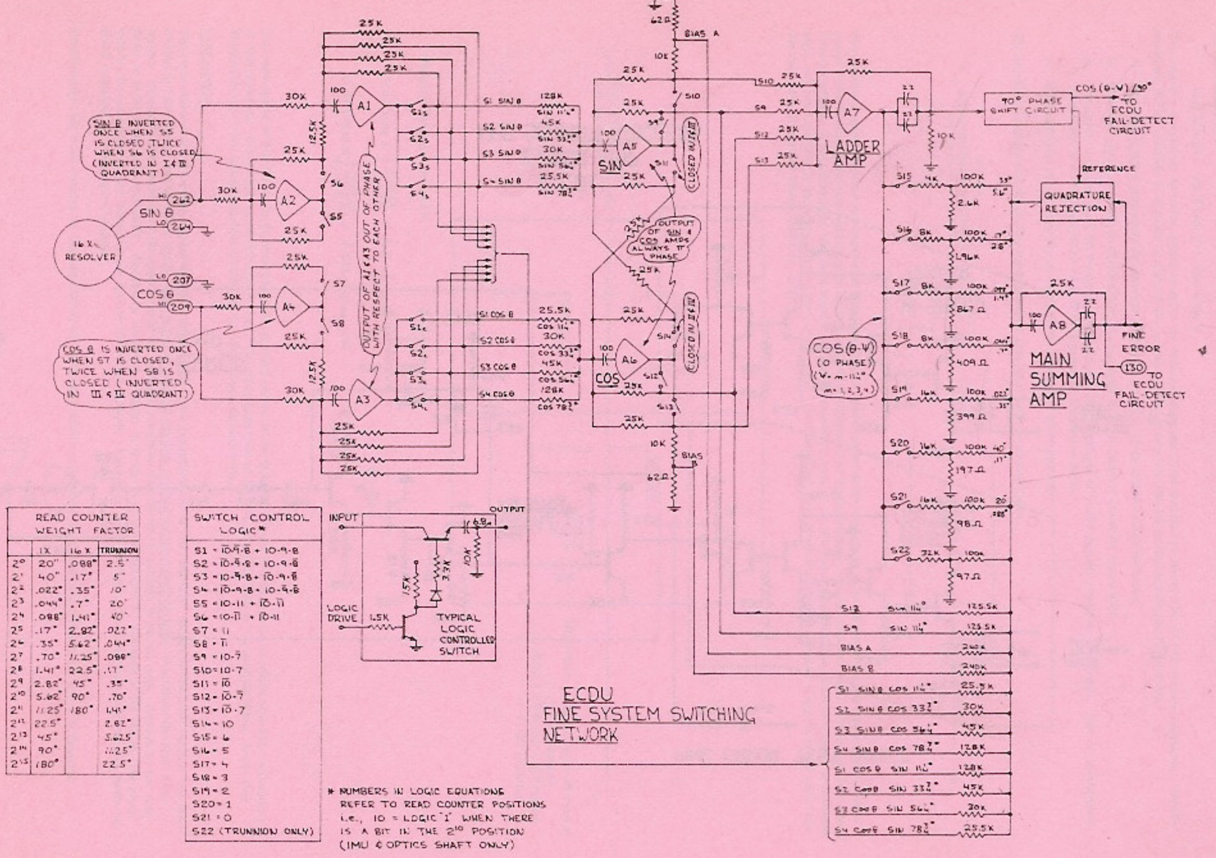
The read counter is a 16-stage digital counter with an IMU angle granularity of 20 seconds/bit. Inputs to the read counter are controlled by rate select and up/down logic. The output is used by the fine system switch selection logic to produce the fine error signal. Access to the contents of the read counter by both the computer and the error counter is serial only. Access by the computer is to the first order bit ($\Delta 2^0$). Access by the error counter is to the third order bit ($\Delta 2^2$). Because of the above, the count rate to the computer is four times faster than to the error counter. Computer bits, however, have one-fourth the weight factor of those transferred to the error counter.

Functionally, the read counter is represented as an integrator with a count rate in degrees/second and an output in degrees.





ECDU
ERROR AMP
AND SCHMITT TRIGGERS



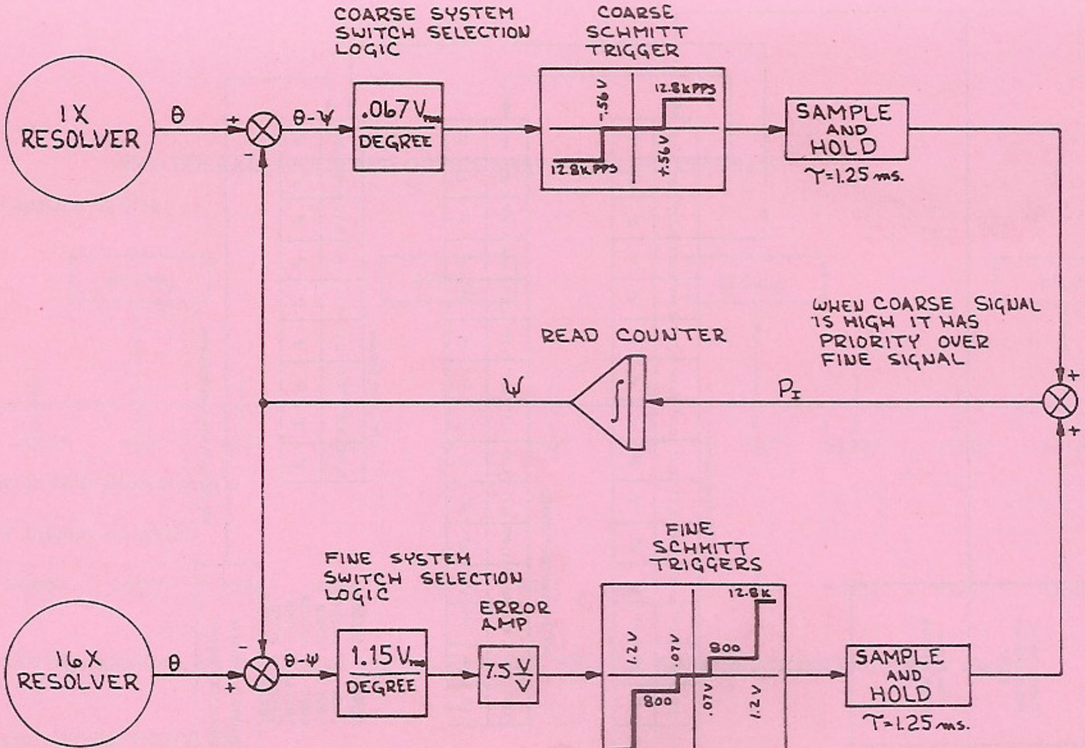
ECDU
FINE SYSTEM SWITCHING NETWORK

READ COUNTER WEIGHT FACTOR			
	1X	16 X	TRUNNION
2^0	20"	.088°	2.5'
2^1	40"	.17°	5'
2^2	.022°	.35°	10'
2^3	.044°	.7°	20'
2^4	.088°	1.41°	40'
2^5	.17°	2.82°	.022°
2^6	.35°	5.62°	.044°
2^7	.70°	11.25°	.088°
2^8	1.41°	22.5°	.17°
2^9	2.82°	45°	.35°
2^{10}	5.62°	90°	.70°
2^{11}	11.25°	180°	1.41°
2^{12}	22.5°		2.82°
2^{13}	45°		5.625°
2^{14}	90°		11.25°
2^{15}	180°		22.5°

SWITCH CONTROL LOGIC*

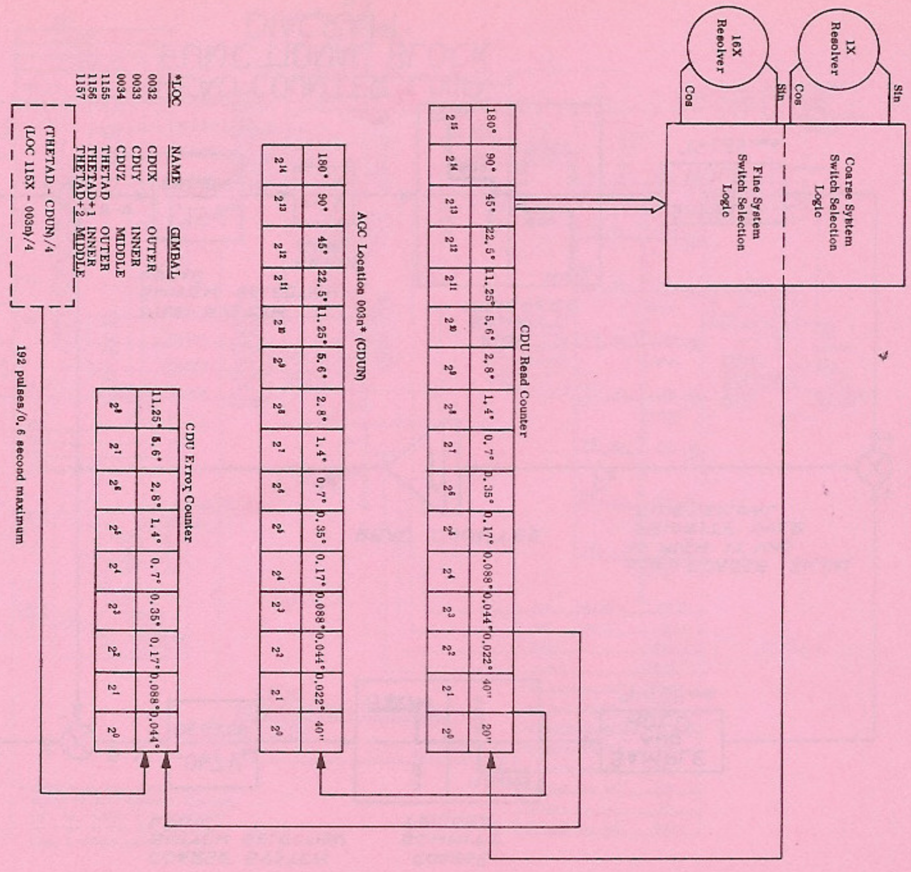
$S1 = \overline{10}\cdot\overline{9}\cdot\overline{8} + 10\cdot 9\cdot 8$
$S2 = \overline{10}\cdot\overline{9}\cdot 8 + 10\cdot 9\cdot\overline{8}$
$S3 = 10\cdot\overline{9}\cdot 8 + \overline{10}\cdot 9\cdot\overline{8}$
$S4 = \overline{10}\cdot 9\cdot 8 + 10\cdot\overline{9}\cdot\overline{8}$
$S5 = 10\cdot 11 + \overline{10}\cdot\overline{11}$
$S6 = 10\cdot\overline{11} + \overline{10}\cdot 11$
$S7 = 11$
$S8 = \overline{11}$
$S9 = 10\cdot\overline{7}$
$S10 = 10\cdot 7$
$S11 = \overline{10}$
$S12 = \overline{10}\cdot\overline{7}$
$S13 = \overline{10}\cdot 7$
$S14 = 10$
$S15 = 6$
$S16 = 5$
$S17 = 4$
$S18 = 3$
$S19 = 2$
$S20 = 1$
$S21 = 0$
S22 (TRUNNION ONLY)

* NUMBERS IN LOGIC EQUATIONS REFER TO READ COUNTER POSITIONS i.e., 10 = LOGIC "1" WHEN THERE IS A BIT IN THE 2^{10} POSITION (IMU & OPTICS SHAFT ONLY)



READ COUNTER LOOP
FUNCTIONAL BLOCK
DIAGRAM

IMU/CDU/AGC INTERFACE DIAGRAM



CDU Read Counter

2^15	2^14	2^13	2^12	2^11	2^10	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
180°	90°	45°	22.5°	11.25°	5.6°	2.8°	1.4°	0.7°	0.35°	0.17°	0.088°	0.044°	0.022°	40''	20''

AGC Location 003n* (CDUN)

2^14	2^13	2^12	2^11	2^10	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
180°	90°	45°	22.5°	11.25°	5.6°	2.8°	1.4°	0.7°	0.35°	0.17°	0.088°	0.044°	0.022°	40''

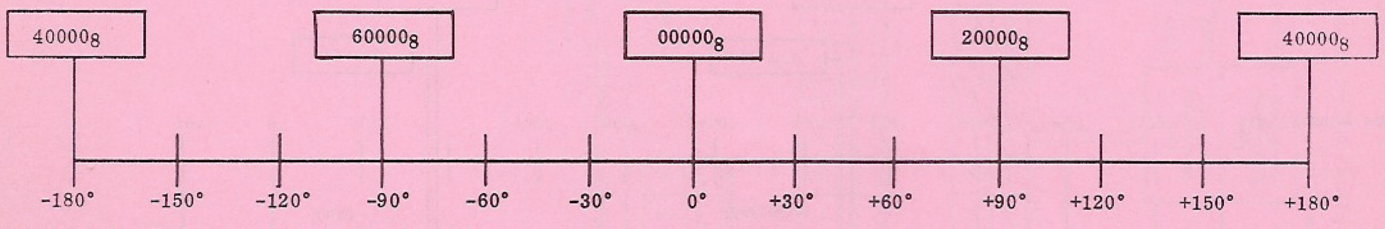
CDU Error Counter

2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
11.25°	5.6°	2.8°	1.4°	0.7°	0.35°	0.17°	0.088°	0.044°

*LOC	NAME	GIMBAL
0032	CDUX	OUTER
0033	CDUY	INNER
0034	CDUZ	MIDDLE
1155	THETAD	OUTER
1156	THETAD+1	INNER
1157	THETAD+2	MIDDLE

IMU GIMBAL ANGLE AND OPTICS SHAFT SCALING DIAGRAM

Contents of Respective Location in AGC



Actual Optics Shaft Angle or IMU Gimbal Angle

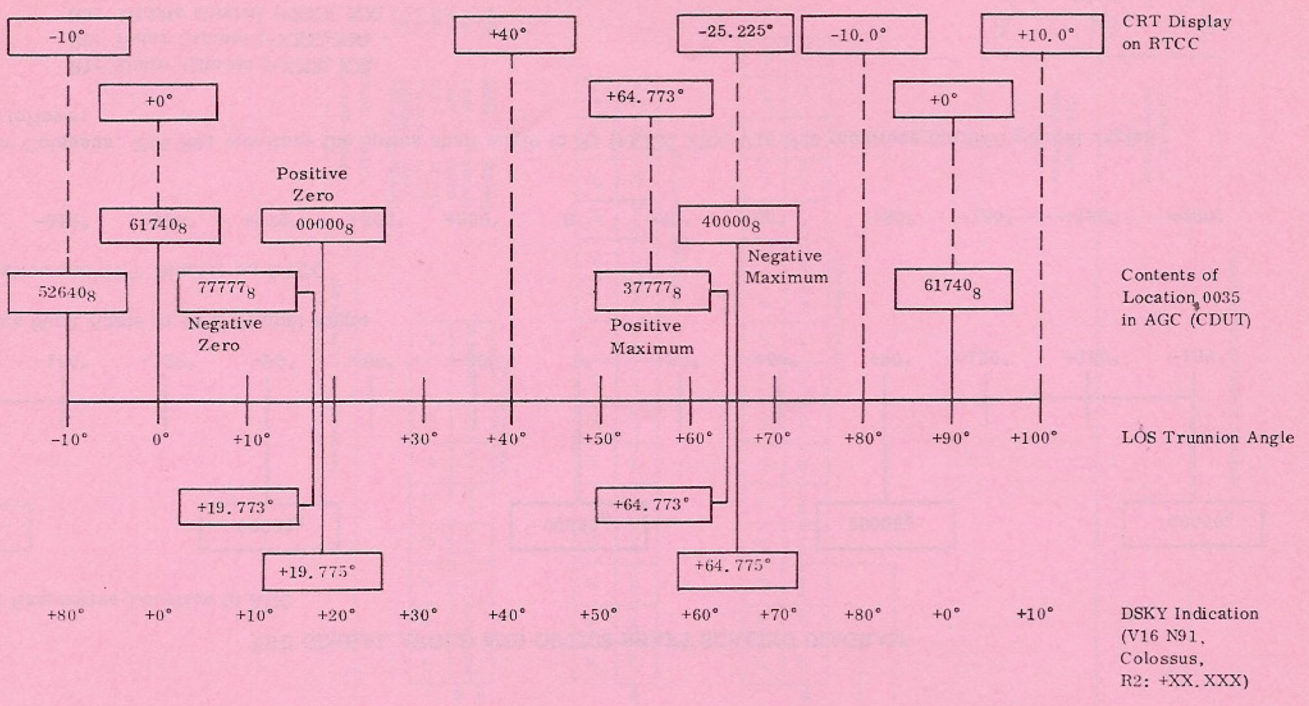
DSKY Indication and CRT Display on RTCC

+180° +210° +240° +270° +300° +330° 0° +30° +60° +90° +120° +150° +180°

NOTE: For Colossus, V16 N91 monitors the optics shaft angle in R1 (+XXX.XX); V16 N20 monitors the IMU gimbal angles as follows:

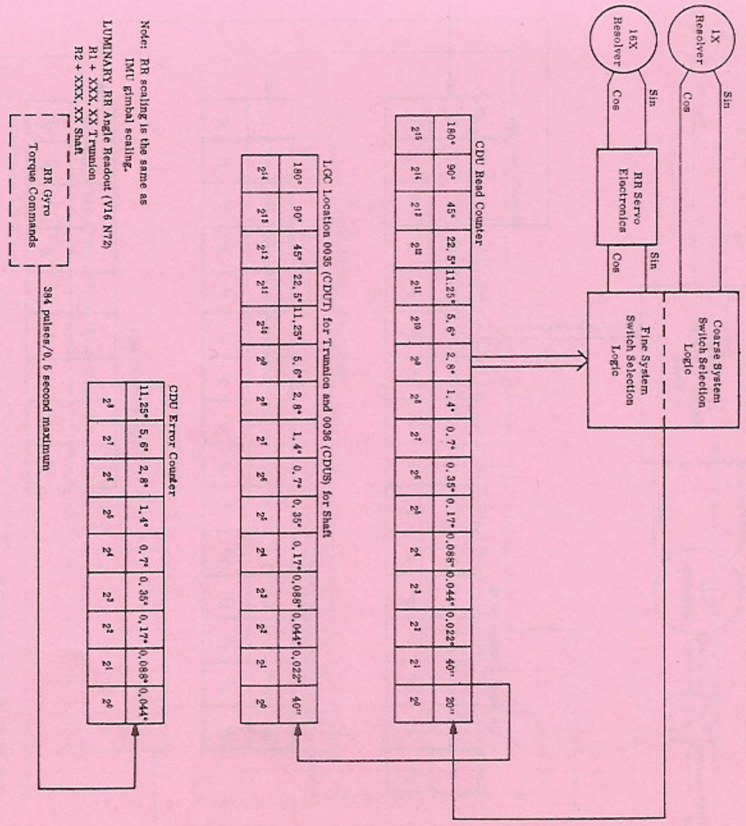
R1: Outer Gimbal (+XXX.XX)
R2: Inner Gimbal (+XXX.XX)
R3: Middle Gimbal (+XXX.XX)

OPTICS TRUNNION SCALING DIAGRAM



NOTE: CDUT (LOC 0035) is loaded with a -19.775° bias during ZERO OPTICS. This bias produces positive driving commands for angles up to +64.775° in the CMC mode. Without the bias, the CMC mode would drive the trunnion to the negative stop for command angles of 45° or greater.

RENDEZVOUS RADAR/CDU/LGC INTERFACE DIAGRAM



CDU Read Counter

180°	90°	45°	22.5°	11.25°	5.6°	2.8°	1.4°	0.7°	0.35°	0.17°	0.088°	0.044°	0.022°	40''	20''
2^{15}	2^{14}	2^{13}	2^{12}	2^{11}	2^{10}	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

LGC Location 0035 (CDUT) for Trunnion and 0036 (CDUS) for Shaft

180°	90°	45°	22.5°	11.25°	5.6°	2.8°	1.4°	0.7°	0.35°	0.17°	0.088°	0.044°	0.022°	40''
2^{14}	2^{13}	2^{12}	2^{11}	2^{10}	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

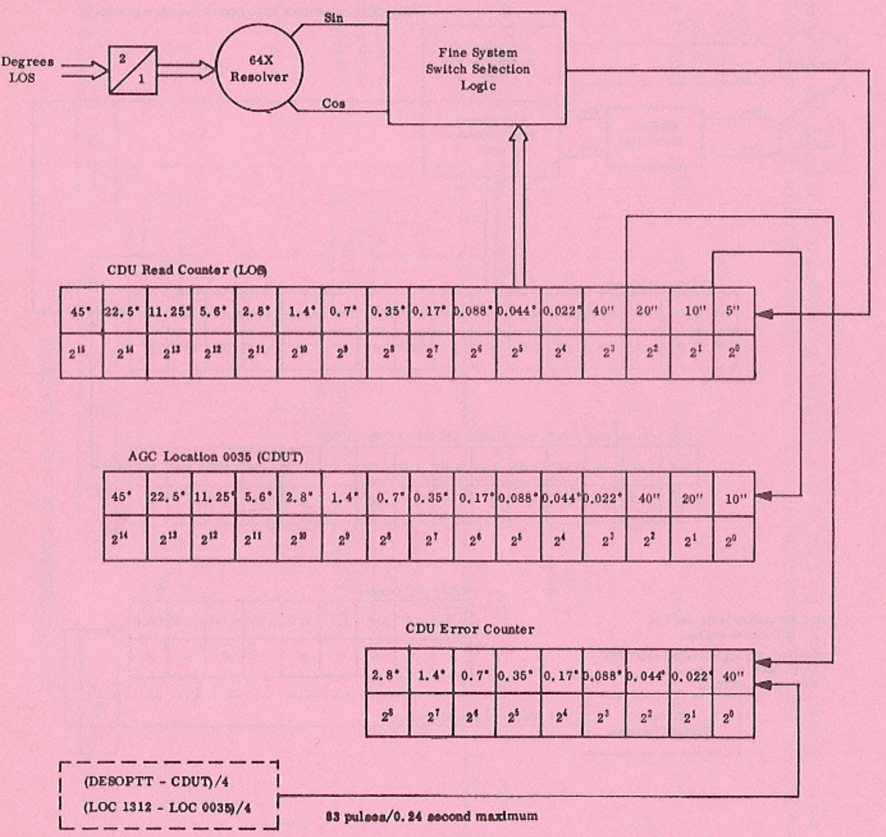
CDU Error Counter

11.25°	5.6°	2.8°	1.4°	0.7°	0.35°	0.17°	0.088°	0.044°
2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

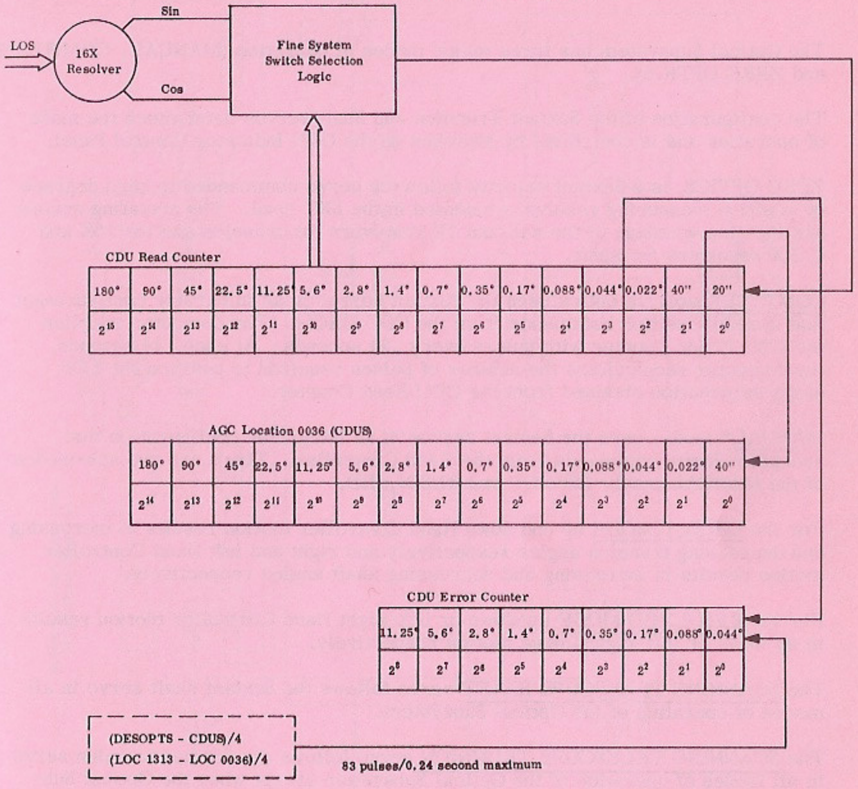
Note: RR scaling is the same as IMU gimbal scaling.

LUMINARY RR Angle Readout (V16 N72)
R1 + XXX.XX Trunnion
R2 + XXX.XX Shaft

OPTICS TRUNNION/CDU/AGC INTERFACE DIAGRAM



OPTICS SHAFT/CDU/AGC INTERFACE DIAGRAM



CM OPTICS

The Optical Subsystem has three major modes of operation (MANUAL, COMPUTER, and ZERO OPTICS).

The configuration of the Sextant Trunnion and Shaft servos determines the mode of operation and is controlled by switches on the G&N Indicator Control Panel.

ZERO OPTICS is a Sextant velocity follow-up servo commanded to zero degrees by position measuring resolvers mounted in the SXT head. The actuating errors are the sine windings of the 64X and 1X resolvers for trunnion and the 16X and 1/2 X resolvers for shaft.

COMPUTER operate optics uses the Sextant servos in an integrator configuration that accepts position commands from the CDU DAC's. The computer supplies the CDU Error Counter with pulses every .24 seconds. At each .24 seconds, the computer recalculates the number of pulses required to position the LOS using information obtained from the CDU Read Counter.

MANUAL* mode uses the Sextant servos in an integrator configuration that accepts velocity commands from the Hand Controller. There are two sub-modes of the MANUAL mode, DIRECT and RESOLVED.

For the DIRECT MODE up and down Hand Controller motion results in increasing and decreasing trunnion angles respectively and right and left Hand Controller motion results in increasing and decreasing shaft angles respectively.

For the RESOLVED MODE up-down or left-right Hand Controller motion results in up-down or left-right image motion respectively.

The SCANNING TELESCOPE SHAFT servo follows the Sextant shaft servo in all modes of operation of the Optical Subsystem.

The SCANNING TELESCOPE TRUNNION servo follows the Sextant trunnion servo in all modes of operation of the Optical Subsystem except when the Optical Subsystem is in the MANUAL mode and the TEL TRUN is set to 0° offset and 25° offset. In the 0° offset and 25° offset modes, the SCT trunnion angle is held at 0° and 25° respectively.

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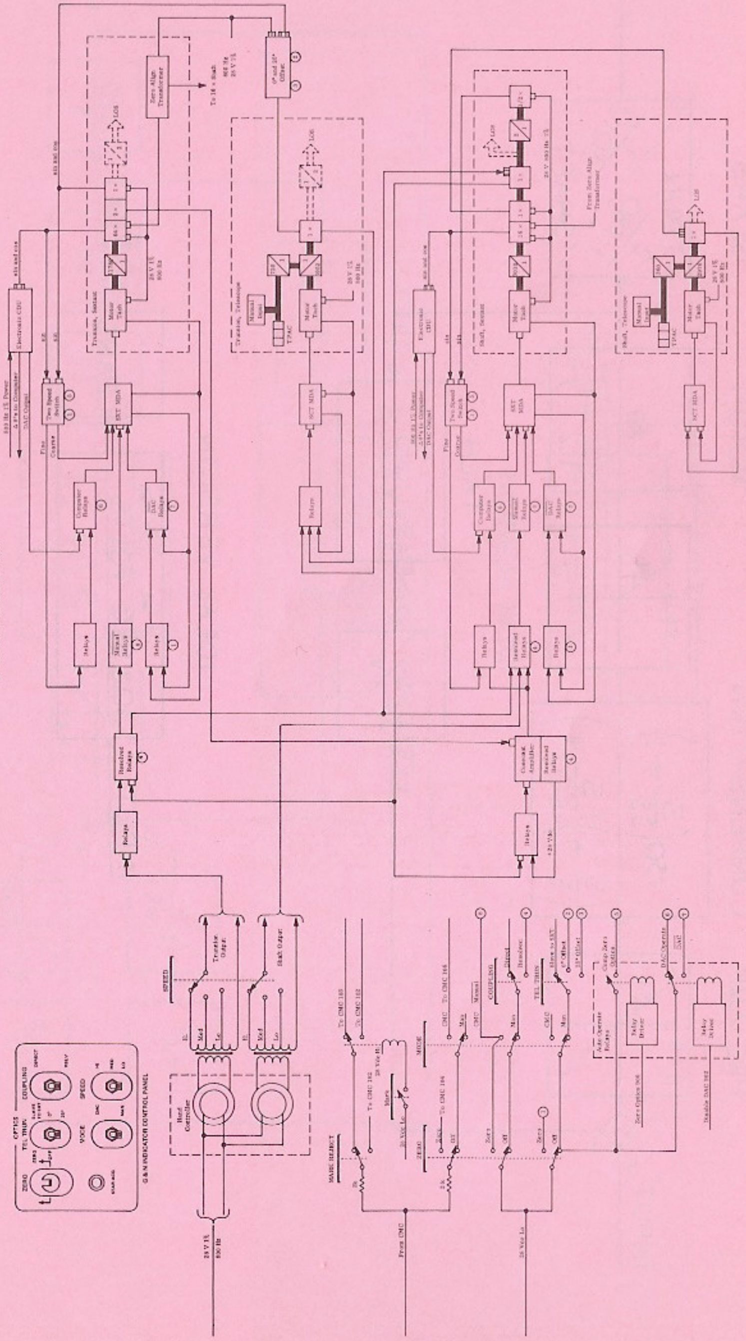
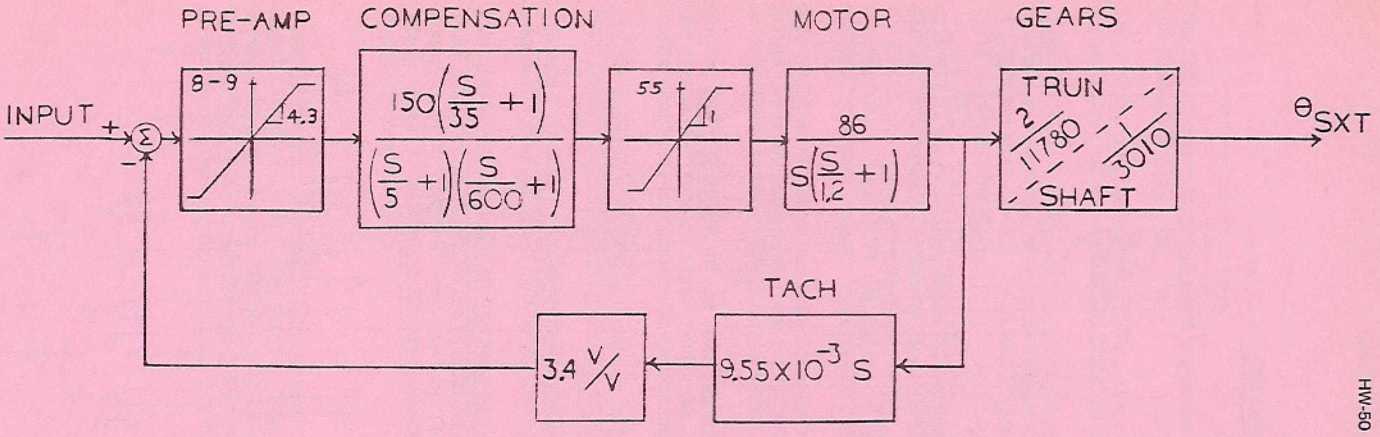
* During Program 24, the SXT integrators accept velocity commands from the Hand Controller and the CDU DAC's. The computer supplies rate commands to the shaft and trunnion CDU Error Counters (by setting bit 2 of Channel 12, Enable Optics CDU Error Counters) and inhibits feedback from the Read Counters to the Error Counters (by setting bit 8 of Channel 12, TVC Enable).

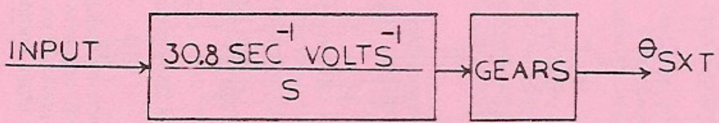


BLOCK II OPTICAL SUBSYSTEM
FUNCTIONAL DIAGRAM

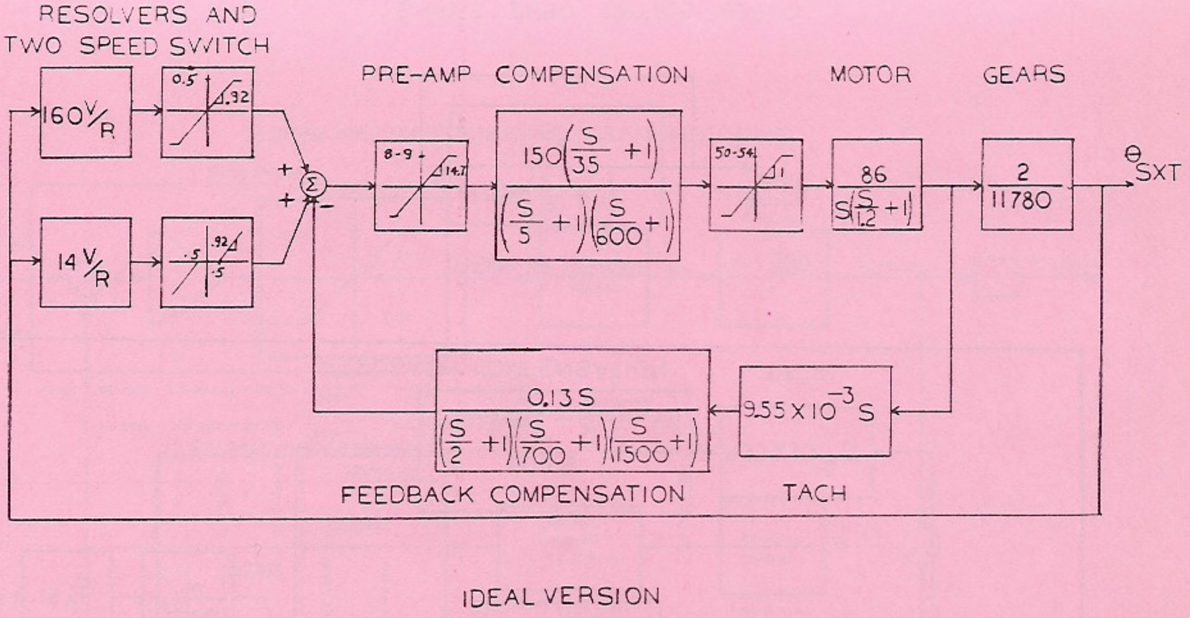


HW-50

IDEAL VERSION

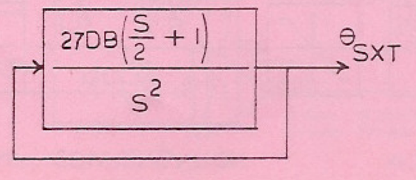


SXT INTEGRATORS

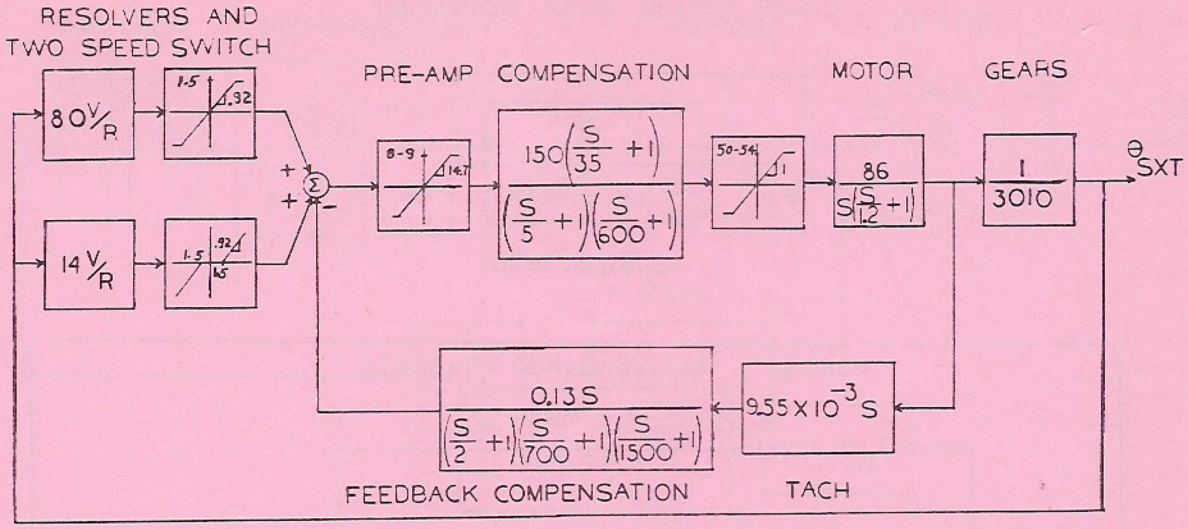


HW-51

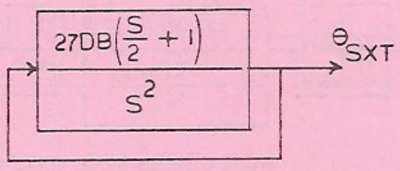
IDEAL VERSION



TRUNNION ZERO OPTICS SERVO

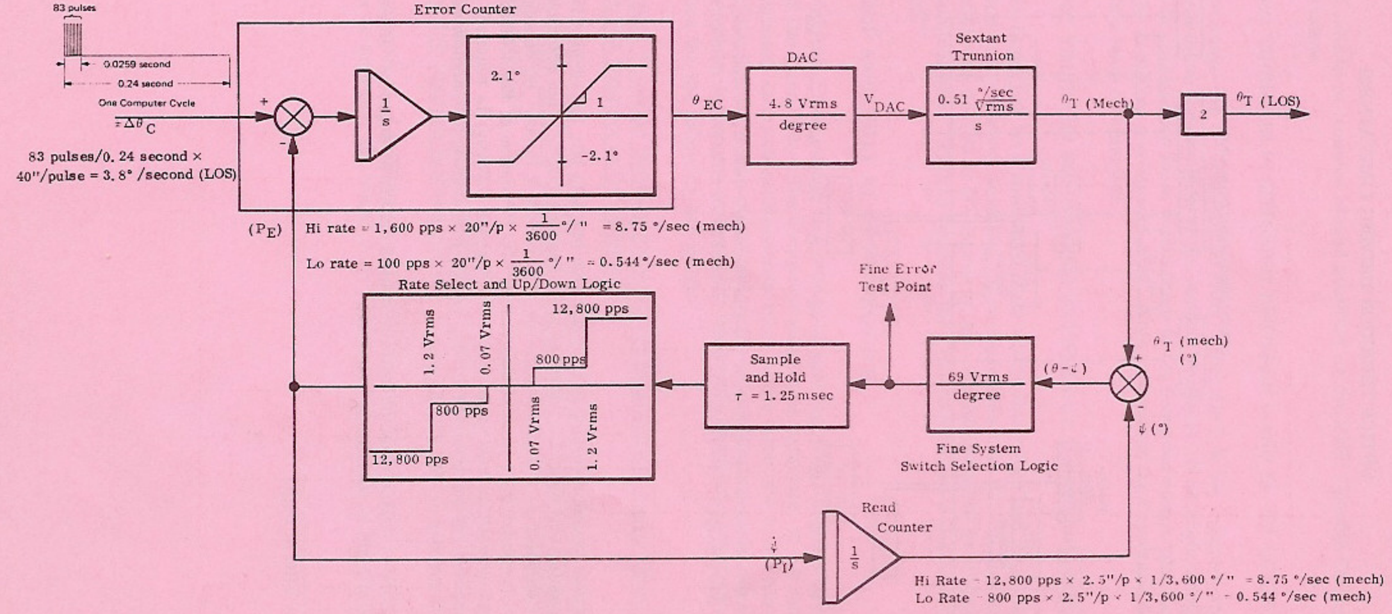


IDEAL VERSION



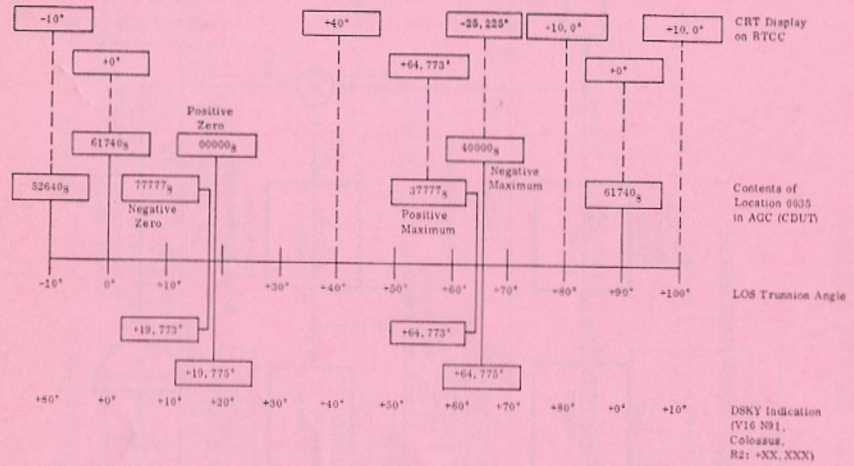
SHAFT ZERO OPTICS SERVO

TRUNNION COMPUTER OPERATE MODE FUNCTIONAL BLOCK DIAGRAM



OPTICS TRUNNION DRIVING LIMITATIONS

OPTICS TRUNNION SCALING DIAGRAM



NOTE: CDUT (LOC 0035) is loaded with a -19.775° bias during ZERO OPTICS. This bias produces positive driving commands for angles up to +64.775° in the CMC mode. Without the bias, the CMC mode would drive the trunnion to the negative stop for command angles of 45° or greater.

Since optics trunnion scaling is 9.88 arc-sec per data bit, the 14-bit CDUT register in the Computer will overflow (40000_8) at 45 degrees LOS*. This overflow is interpreted by the Computer as a negative angle when in reality it is not. By biasing the CDUT location (register 035) in the Computer by -19.775 degrees, the counter (035) will not overflow until an LOS angle of 64.775 degrees (40000_8) is reached. In this case, the Computer (optics trunnion driving routine) interprets an overflow as -45.000 degrees + 19.775 degrees or -25.225 degrees.

The maximum usable trunnion angle is approximately 57 degrees. Beyond this angle the line of sight is completely vignetted.

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*LOS = Line of Sight

The operational effects of trunnion biased overflow on the CMC Operate Optics mode is summarized below.

1. OPTICS CMC TRUNNION POSITIONING BETWEEN 0 AND 64.773 DEGREES

Any angle in this range can be commanded from within the 0 to 64.7-degree range and the Computer will drive the trunnion to the correct position. If an angle greater than 64.773 degrees is commanded from within the 0 to 64.7-degree range, the trunnion will be driven into the 0-degree mechanical stop. This is because the Computer thinks a negative angle has been commanded.

2. OPTICS CMC TRUNNION POSITIONING BETWEEN 64.775 AND 90 DEGREES

Any angle in this range can be commanded from within this range and the Computer will drive the trunnion to the correct position. If an angle less than 64.775 degrees is commanded from within the 64.775 to 90-degree range, the trunnion will be driven into the 90-degree mechanical stop. This is because the Computer thinks a positive angle has been commanded.

3. OPTICS LOOP AMBIGUITY AT 64.775 DEGREES

The Computer Operate Optics mode is a multiloop position followup servo operated under control of the Computer. The Computer supplies a maximum of 83 command pulses (0.92 degrees) each 240 milliseconds (ms) in the form of a 3,200 pps burst. The response of the Optics is then measured by the Computer once each 240 ms and appropriate correction commands are issued. This sample data loop has an ambiguity at 64.775 degrees for the following two cases.

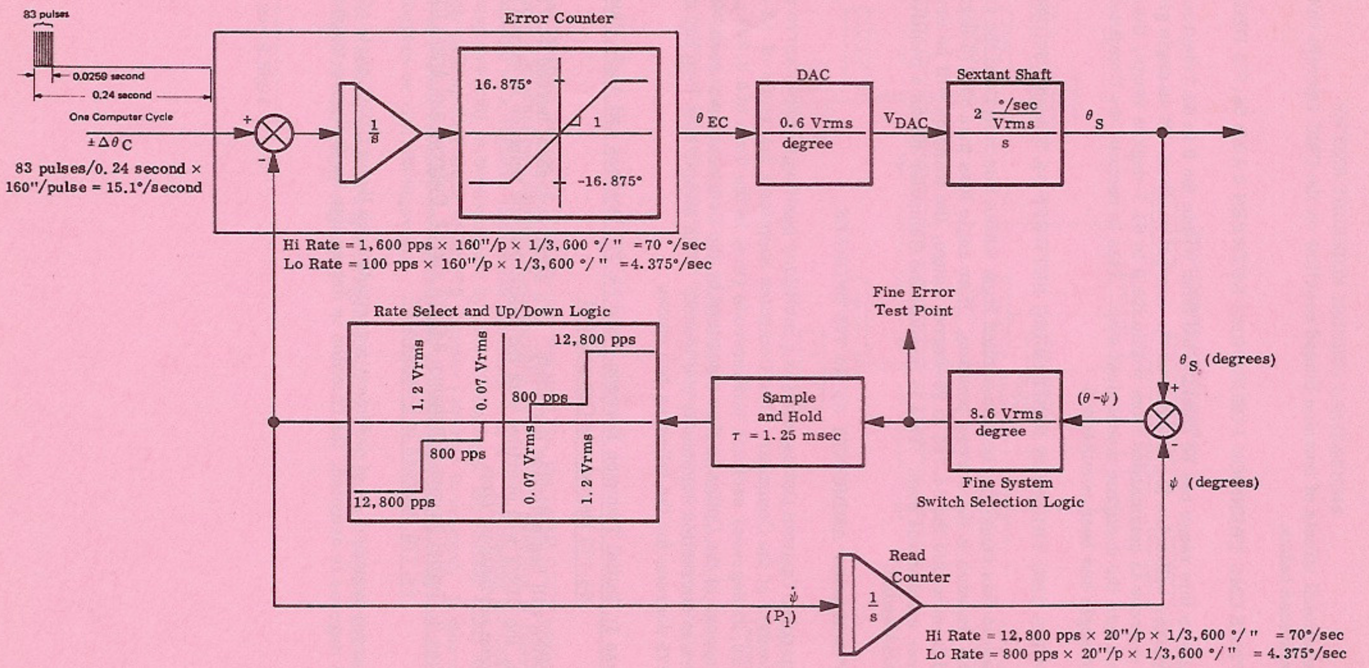
a. Case 1: Initial Trunnion Between 0 and 64.773 Degrees and Angle Close to 64.773 Degrees is Commanded

The Optics will begin driving correctly. If a servo overshoot beyond 64.773 degrees occurs, the CDUT will overflow with the result that the trunnion is driven into the 90-degree mechanical stop.

b. Case 2: Initial Trunnion Between 64.775 and 90 Degrees and Angle Close to 64.775 Degrees is Commanded

If the servo overshoot is of sufficient magnitude such that a CDUT angle of less than 64.775 degrees is detected, the trunnion is driven into the 0-degree mechanical stop.

SHAFT COMPUTER OPERATE MODE FUNCTIONAL BLOCK DIAGRAM

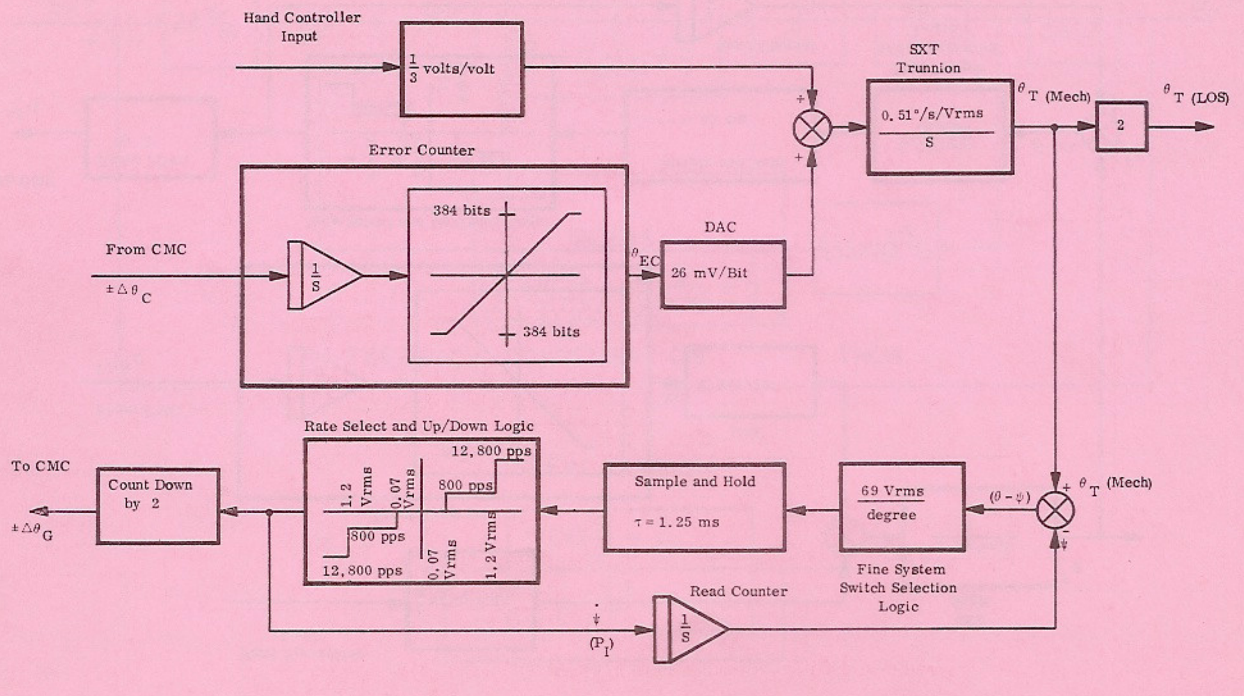


83 pulses/0.24 second × 160"/pulse = 15.1°/second

Hi Rate = 1,600 pps × 160"/p × 1/3,600 °/" = 70 °/sec
Lo Rate = 100 pps × 160"/p × 1/3,600 °/" = 4.375°/sec

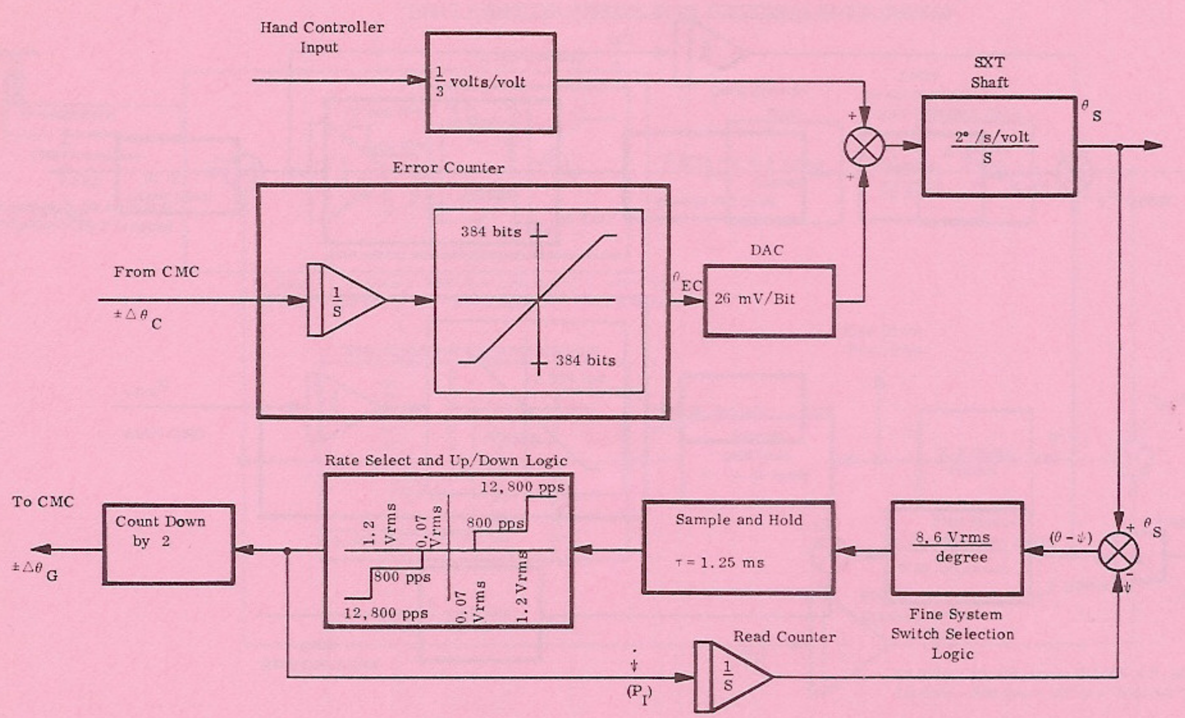
Hi Rate = 12,800 pps × 20"/p × 1/3,600 °/" = 70°/sec
Lo Rate = 800 pps × 20"/p × 1/3,600 °/" = 4.375°/sec

TRUNNION COMPUTER AIDED OPTICS (P24)

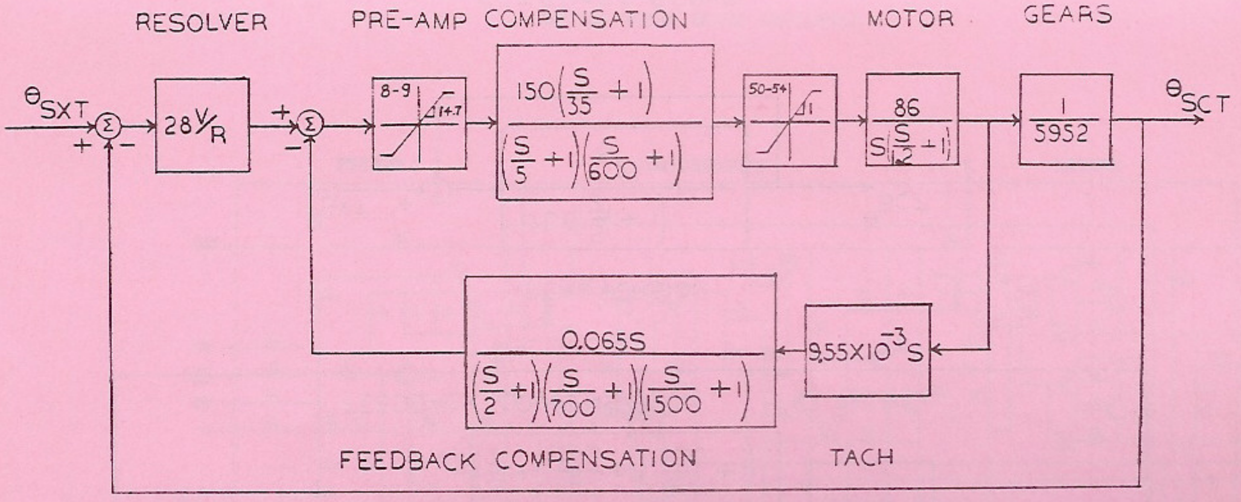


Bit 2 of Channel 12 is set to enable the Error Counter.
Bit 8 of Channel 12 is set to inhibit Read Counter to Error Counter feedback.

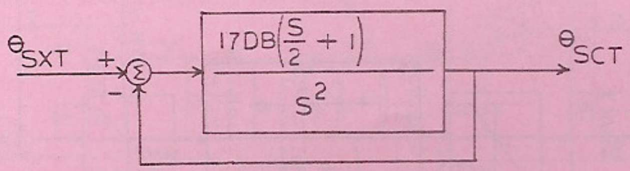
SHAFT COMPUTER AIDED OPTICS (P24)



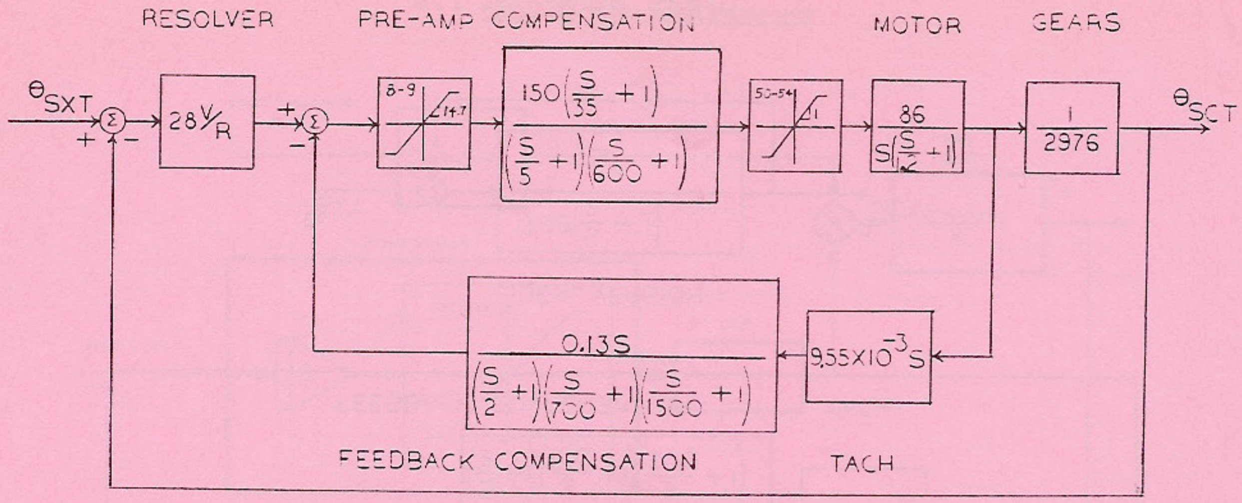
Bit 2 of Channel 12 is set to enable the Error Counter.
Bit 8 of Channel 12 is set to inhibit Read Counter to Error Counter feedback.



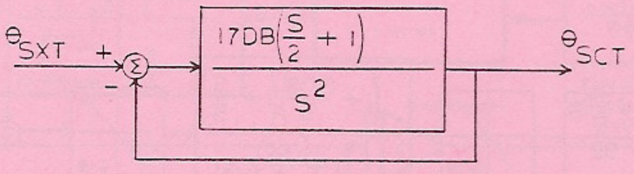
IDEAL VERSION



SCT TRUNNION SERVO

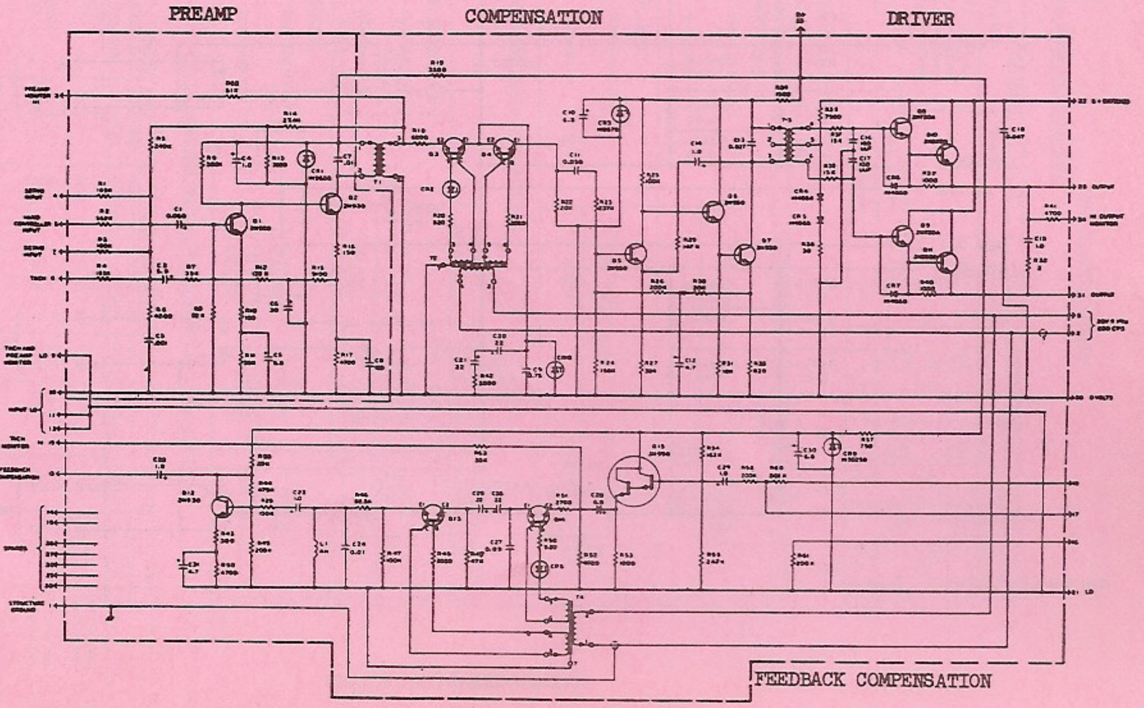


IDEAL VERSION

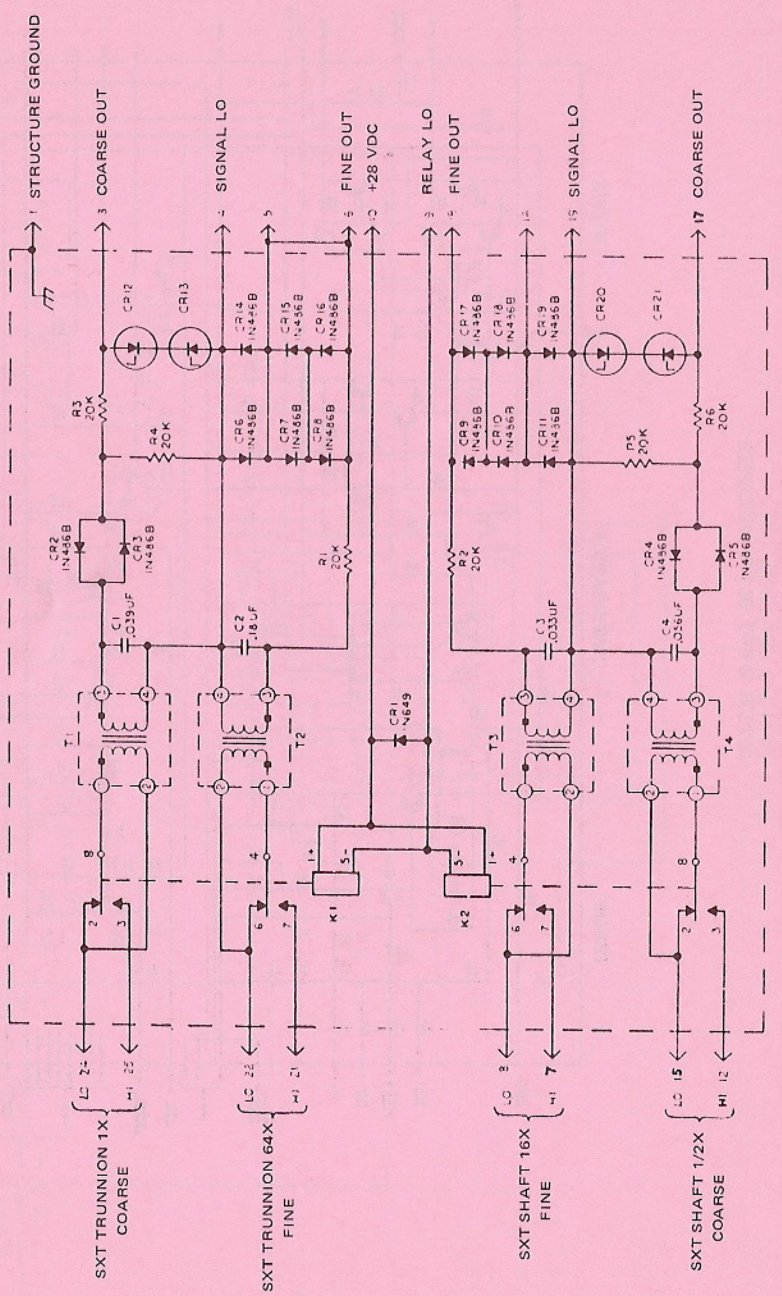


SCT SHAFT SERVO

OPTICS MOTOR DRIVE AMPLIFIER



OPTICS TWO SPEED SWITCH



BLOCK II SERVO PARAMETERS

MOTOR SPEEDS VERSUS LOS RATES

LOS RATES		MOTOR SPEEDS			
		SXT		SCT	
TRUNNION	SHAFT	rpm	rad/sec	rpm	rad/sec
10.0 deg/sec		9817	1028	4960	519
1.0 deg/sec		982	103	496	51.9
0.1 deg/sec		98	10.3	49.6	5.2
25.0 $\widehat{\text{sec}}$/sec		6.8	0.71	3.4	0.36
	19.5 deg/sec	9870	1024	9670	1013
	2.0 deg/sec	1003	105	992	104
	0.2 deg/sec	100	10.5	99	10.4
	50.0 $\widehat{\text{sec}}$/sec	7.0	0.73	6.9	0.72

SERVO SENSITIVITY

	CALCULATION	SENSITIVITY
SXT TRUNNION		
Hand Controller	$105\ \frac{\text{mr}}{\text{mv}} \times \frac{205}{3.4} \times \frac{2}{11,780}$	$1.08\ \frac{\widehat{\text{sec}}/\text{sec}}{\text{mv}}$
Tachometer	3.4×1.08	$3.68\ \frac{\widehat{\text{sec}}/\text{sec}}{\text{mv}}$
SXT SHAFT		
Hand Controller	$105\ \frac{\text{mr}}{\text{mv}} \times \frac{205}{3.4} \times \frac{1}{3010}$	$2.1\ \frac{\widehat{\text{sec}}/\text{sec}}{\text{mv}}$
Tachometer	3.4×2.1	$7.14\ \frac{\widehat{\text{sec}}/\text{sec}}{\text{mv}}$

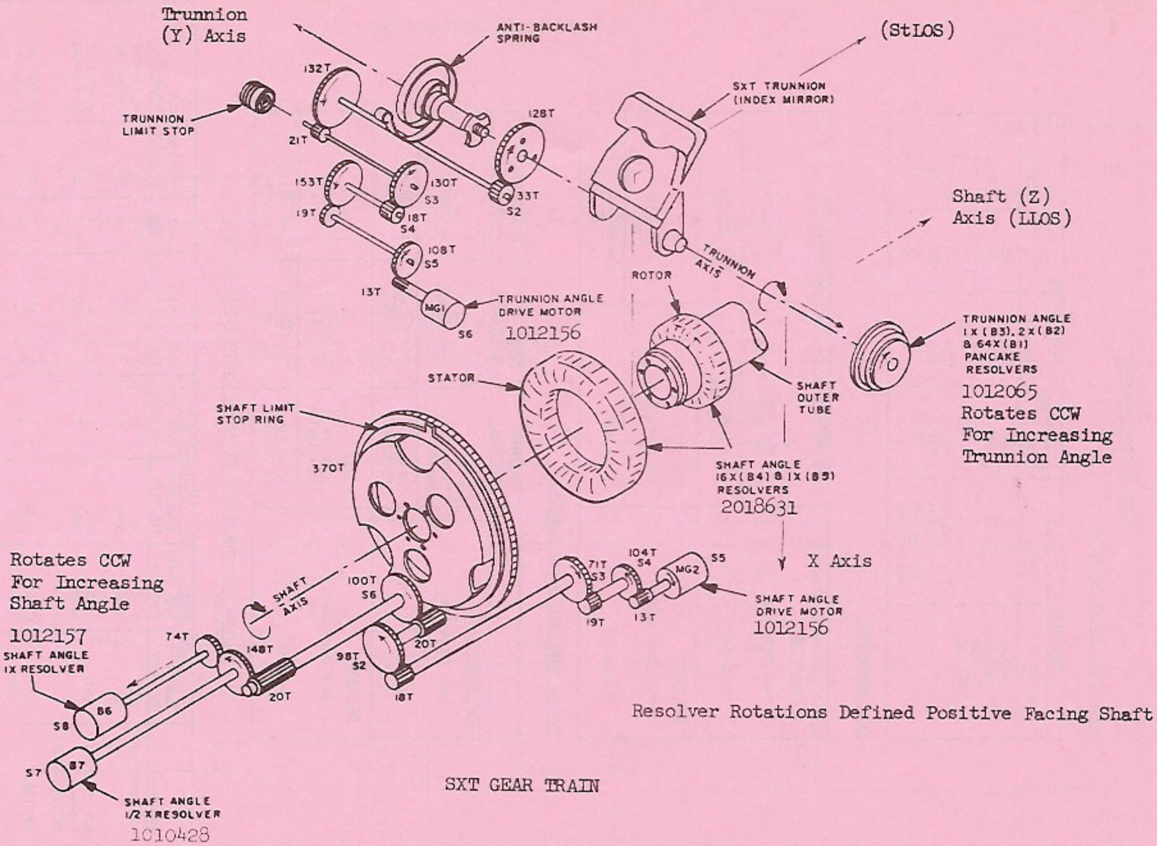
MAXIMUM CREEP RATES DUE TO RESIDUALS

	MAXIMUM RESIDUAL	SERVO SENSITIVITY	THEORETICAL MAXIMUM RATE
SXT TRUNNION			
Hand Controller	3 mv rms PS 2014550	$1.08\ \frac{\widehat{\text{sec}}/\text{sec}}{\text{mv}}$	3 $\widehat{\text{sec}}$/sec
Tachometer	15 mv rms PS 2016207	$3.70\ \frac{\widehat{\text{sec}}/\text{sec}}{\text{mv}}$	55 $\widehat{\text{sec}}$/sec
SXT SHAFT			
Hand Controller	3 mv rms PS 2014550	$2.1\ \frac{\widehat{\text{sec}}/\text{sec}}{\text{mv}}$	6 $\widehat{\text{sec}}$/sec
Tachometer	15 mv rms PS 2016207	$7.2\ \frac{\widehat{\text{sec}}/\text{sec}}{\text{mv}}$	108 $\widehat{\text{sec}}$/sec

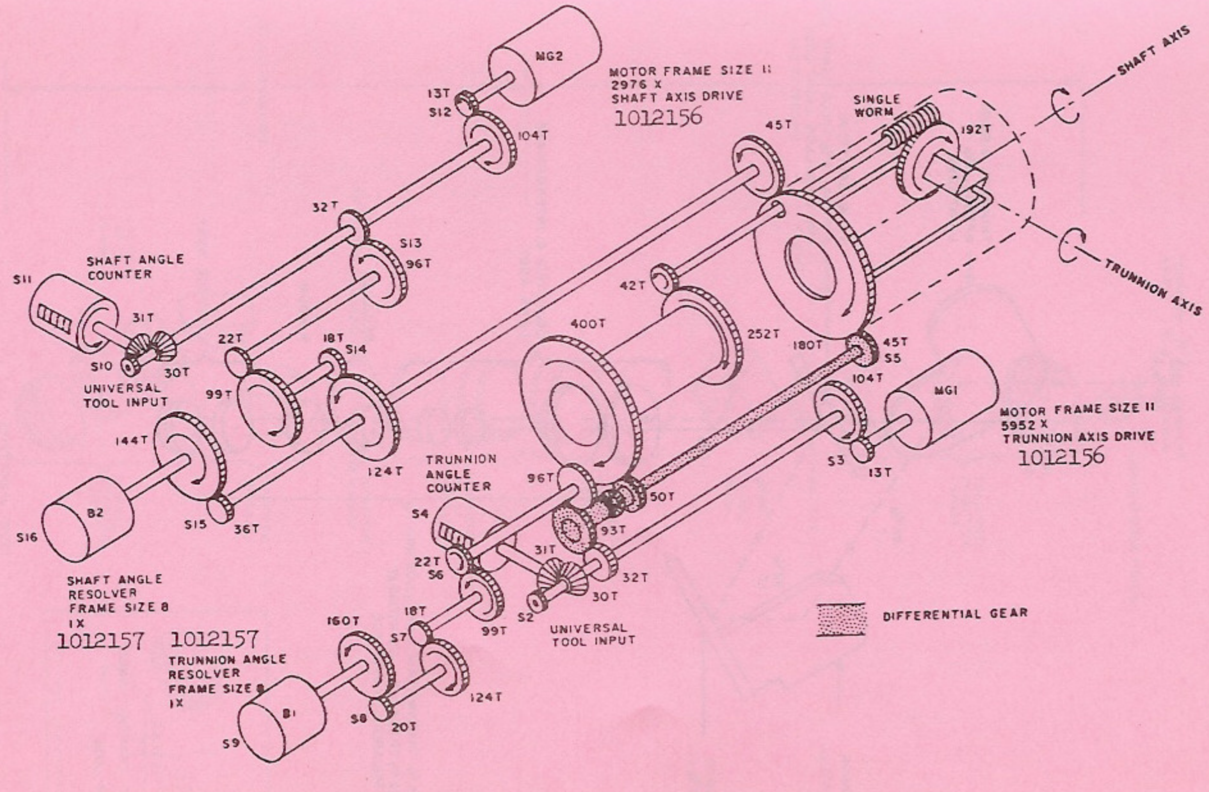
OPTICAL SUBSYSTEM PHASING (ROTATIONS DEFINED FACING SHAFT)

	Direct Mode		Resolved Mode*						
Integrator	Hand Cont. Position	Hand Cont. Position	Hand Cont. Position	Hand Cont. Position	MDA Input	Motor Rotation	Tach Output	Resolver Rotation	LOS Angle
SXT TRUNNION	DOWN UP	$0\ \phi$ $\pi\ \phi$	UP DOWN	$\pi\ \phi$ $0\ \phi$	$0\ \phi$ $\pi\ \phi$	CCW CW	$\pi\ \phi$ $0\ \phi$	CW CCW	Decreasing Increasing
SCT TRUNNION (slaved to SXT TRUNNION)	DOWN UP	$0\ \phi$ $\pi\ \phi$	UP DOWN	$\pi\ \phi$ $0\ \phi$	$\pi\ \phi$ $0\ \phi$	CW CCW	$0\ \phi$ $\pi\ \phi$	CCW CW	Decreasing Increasing
SXT SHAFT	Left Right	$0\ \phi$ $\pi\ \phi$	Right Left	$\pi\ \phi$ $0\ \phi$	$0\ \phi$ $\pi\ \phi$	CCW CW	$\pi\ \phi$ $0\ \phi$	CW CCW	Decreasing Increasing
SCT SHAFT (slaved to SXT Shaft)	Left Right	$0\ \phi$ $\pi\ \phi$	Right Left	$\pi\ \phi$ $0\ \phi$	$\pi\ \phi$ $0\ \phi$	CW CCW	$0\ \phi$ $\pi\ \phi$	CCW CW	Decreasing Increasing

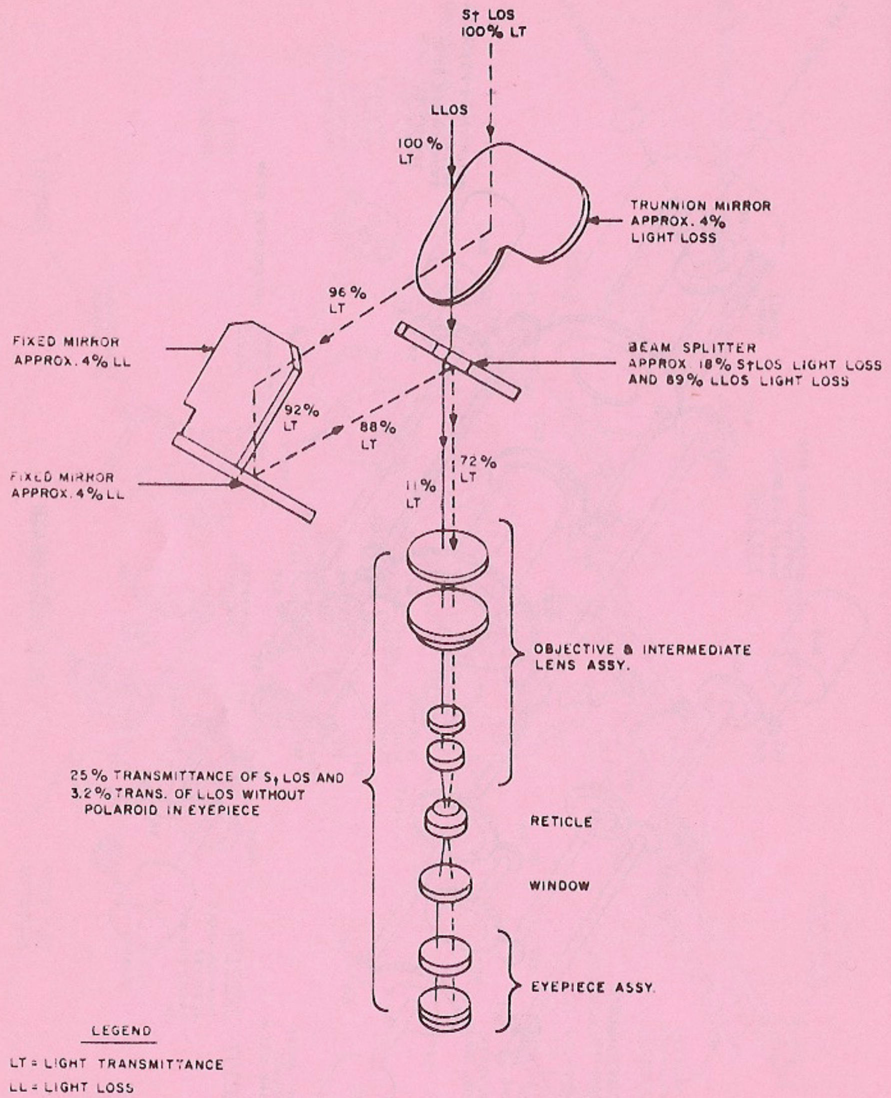
*1st quadrant only $0 < A_s < 90°$



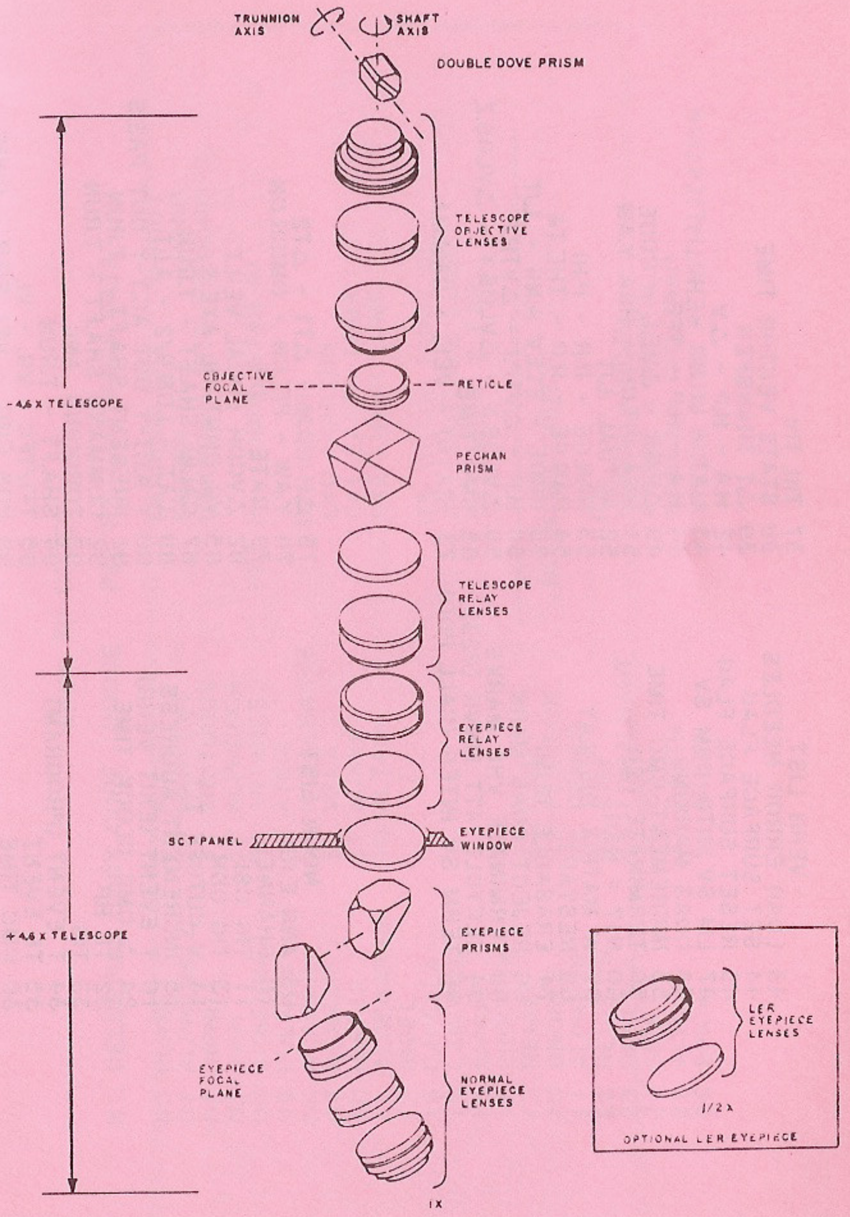
SXT GEAR TRAIN



SCT GEAR TRAIN



SXT OPTICS



SCT OPTICS

VERB LIST

43 LOAD ERROR NEEDLES
44 SET SURFACE FLAG
45 RESET SURFACE FLAG
47 LM SV INTO CSM SV
54 COAS MARKING
55 INCREMENT CMC TIME
56 TERMINATE P20
60 N17 = N20
67 W MATRIX DISPLAY
69 RESTART
74 ERASABLE DUMP
86 REJECT COAS MARK
88 TERMINATE VHF MARKS
94 RECYCLE ATT MNVR (P23)
96 TERM SV INTEG (CALL P00)

37 TIG TPI
38 STATE VECTOR TIME
39 ΔT TRANSFER
42 H.A - H.P - Δ.V
43 LAT - LO.NG - .H
44 H.A - H.P - TFF
49 ΔP.OS - ΔVE.L - CODE
51 HGA PIT.CH - HGA Y.AW
52 ACTUAL .ωT
53 RAN.GE - R.R - P.HI
54 RAN.GE - R.R - THE.TA
55 CODE - ELEV A.NG - .ωT
58 H.P - ΔVTP.I - ΔVTP.F
59 ΔVLOS.X - ΔVLOS.Y - ΔVLOS.Z
65 CMC TIME
73 H(X10) - VEL. - GAM.MA

NOUN LIST

05 ANG E.RR
10 CHANNEL
11 TIG CSI
13 TIG CDH
14 V CUTOFF TLI.
15 INCREMENT ADDRESS
16 T EVENT (EXIT VERB)
24 Δ CMC CLOCK TIME
32 TF HP
33 TIG
34 T EVENT (PROGRAM)
35 TF EVENT
36 CMC TIME

75 ΔH CD.H - ΔT1 - ΔT2
78 Y.AW - PIT.CH - OMICR.ON
79 .RATE - .DB
82 ΔVCDH LOCAL VER.T
85 VG CONTROL AXE.S
87 CALIB SHA.FT - T.RUN
89 .LAT - LON.G/2 - A.LT
90 Y A.CT-Y DOT AC.T-Y DOT PAS.S
91 PRESENT SHA.FT - T.RUN
92 COMMAND SHA.FT - T.RUN
93 TORQUING .ANG
94 SHA.FT - T.RUN
95 TFI/TFC - VG. - VI.
99 POS ERR. - VEL ER.R - CODE

NOUN 70 CODES

R1: CELESTIAL BODY CODE 000DE

00 PLANET
01 ALPHERATZ
02 DIPHDA
03 NAVI
04 ACHERNAR
05 POLARIS
06 ACAMAR
07 MENKAR
10 MIRFAK
11 ALDEBARAN
12 RIGEL
13 CAPELLA
14 CANOPUS
15 SIRIUS
16 PROCYON
17 REGOR
20 DNOCES
21 ALPHARD
22 REGULUS
23 DENEBOLA
24 GIENAH
25 ACRUX
26 SPICA
27 ALKAID
30 MENKENT
31 ARCTURUS
32 ALPHECCA
33 ANTARES
34 ATRIA
35 RASALHAGUE
36 VEGA
37 NUNKI
40 ALTAIR
41 DABIH
42 PEACOCK
43 DENEB
44 ENIF
45 FOMALHAUT
46 SUN
47 EARTH
50 MOON

P22 R2: LANDMARK DATA

LANDING SITE 10001
KNOWN SITE 10000
UNKNOWN SITE 20000

P23 R1: 000DE STAR ID

R2: 00C00
C=0 HORIZON
C=1 EARTH LDMK
C=2 LUNAR LDMK

R3: 00CD0 HORIZ ID
C=1 EARTH, 2 LUNAR
D=1 NEAR, 2 FAR

NOUN 99 CODES

R3:
00001 = RDZV
00002 = ORBITAL
00003 = CISLUNAR
00000 = NO REINITIALIZATION

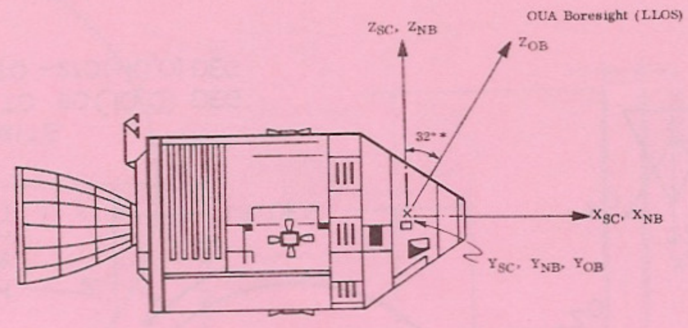
ALARM CODES (V05N09)

00110	MK REJECT ENTERED & IGNORED
00113	NO INBITS (CH 16)
00114	MORE MKS THAN DESIRED
00115	V41N91 WITH OPTICS NOT IN CMC
00116	OPTICS SW MOVED BEFORE 15 SEC
00117	V41N91 BUT OPTICS NOT READY
00120	ZERO OPTICS FIRST
00121	CDUS BAD DURING MK-REPEAT
00205	PIPA SATURATED
00206	CANNOT ZERO ICDU-WITH ALARMS
00207	NEED 90 SEC FOR ISS TURN ON
00210	IMU NOT OPERATING
00211	COARSE ALIGN ERROR > 2 DEG
00212	PIPA FAIL BUT PIPA NOT IN USE
00213	IMU NOT ON-TURN ON IMU
00214	PROGRAM USING IMU BUT IMU OFF
00217	COARSE ALIGN/TORQUING PROBLEM
00220	IMU NOT ALIGNED/NO REFSMMAT
00401	DESIRED MGA TOO LARGE
00402	DO SECOND MINKEY PULSE TORQUE
00404 *	TGT OUT OF VIEW (TRUN > 90 DEG)
00405	STAR PAIR NOT AVAILABLE
00406	P20 NOT OPERATING
00421	W MATRIX OVERFLOW
00600	NO SOLUTION ON 1ST ITERATION
00601	HP < 5.8 NM AFTER CSI
00602	HP < 5.8 NM AFTER CDH
00603	CSI TIG TO CDH TIG ΔT < 10 MIN
00604	CDH TIG TO TPI TIG ΔT < 10 MIN
00605	TOO MANY ITERATIONS
00606	CSI ΔV > 1000 LAST 2 ITERATIONS
00611	NO TIG FOR ELEV ANGLE GIVEN
00612	WRONG SPHERE OF INFL AT TIG
00613	REENTRY ANGLE OUT OF LIMITS
00777	ISS WARNING-PIPA FAIL
01102	CMC SELF TEST ERROR
01105	DOWNLINK TOO FAST
01106	UPLINK TOO FAST
01107	PHASE TABLE FAIL-ERASABLE BAD
01301	ARCSIN/ARCCOS INPUT > ONE
01407	VG INCREASING
01426	IMU UNSATISFACTORY
01427	IMU POLARITY REVERSED
01520	V37 NOT PERMITTED NOW
01600	OVERFLOW DURING DRIFT TEST
01601	BAD IMU TORQUE
01703	INSUF TIME TO INTEG-TIG SLIP
03777	ISS WARNING-ICDU FAIL
04777	ISS WARNING-ICDU & PIPA FAIL
07777	ISS WARNING-IMU FAIL
10777	ISS WARNING-IMU & PIPA FAIL
13777	ISS WARNING-IMU & ICDU FAIL
14777	ISS WARN-IMU,ICDU & PIPA FAIL
20430	ORBITAL INTEGRATION STOPPED
20607	NO CONIC SOLUTION
20610	ALTITUDE < 400K AT TIG (P37)
21204	NEG OR ZERO WAITLIST CALL
21206	TWO DISPLAYS ATTEMPTED AT ONCE
21210	TWO PROGRAMS USING AT ONCE
21302	SQRT CALLED WITH NEG ARGUMENT
21501	DSKY ALARM DURING INTERNAL USE
21502	ILLEGAL FLASHING DISPLAY
21521	KEYED P01 AFTER LIFTOFF
31104	DELAY ROUTINE IS BUSY
31201	EXEC OVERFLOW-NO VAC AREAS
31202	EXEC OVERFLOW-NO CORE SETS
31203	WAITLIST OVERFLOW-MANY TASKS
31211	CANNOT INTERRUPT EXTENDED VERB

NOTE :

00404 *	IS A PRIORITY ALARM
2XXXX	POODOO-NO RESTART LT-F37 (AVE G ON OR EXT VERB - ACTS AS BAILOUT)
3XXXX	BAILOUT-NO RESTART LT - PROGRAM CONTINUES

OUA LINE OF SIGHT TO IMU STABLE MEMBER TRANSFORMATIONS



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos AI & 0 & \sin AI \\ 0 & 1 & 0 \\ -\sin AI & 0 & \cos AI \end{bmatrix} \begin{bmatrix} \cos AM & -\sin AM & 0 \\ \sin AM & \cos AM & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AO & -\sin AO \\ 0 & \sin AO & \cos AO \end{bmatrix} \begin{bmatrix} \cos 32^* & 0 & \sin 32^* \\ 0 & 1 & 0 \\ -\sin 32^* & 0 & \cos 32^* \end{bmatrix} \begin{bmatrix} \cos AS & -\sin AS & 0 \\ \sin AS & \cos AS & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos AT & 0 & \sin AT \\ 0 & 1 & 0 \\ -\sin AT & 0 & \cos AT \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \text{St LOS} \end{bmatrix}$$

* Nominal Angle 32° 31' 23"

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos AI & 0 & \sin AI \\ 0 & 1 & 0 \\ -\sin AI & 0 & \cos AI \end{bmatrix} \begin{bmatrix} \cos AM & -\sin AM & 0 \\ \sin AM & \cos AM & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AO & -\sin AO \\ 0 & \sin AO & \cos AO \end{bmatrix} \begin{bmatrix} \cos 32^* & 0 & \sin 32^* \\ 0 & 1 & 0 \\ -\sin 32^* & 0 & \cos 32^* \end{bmatrix} \begin{bmatrix} \cos AS \; \sin AT \\ \sin AS \; \sin AT \\ \cos AT \end{bmatrix}$$

where

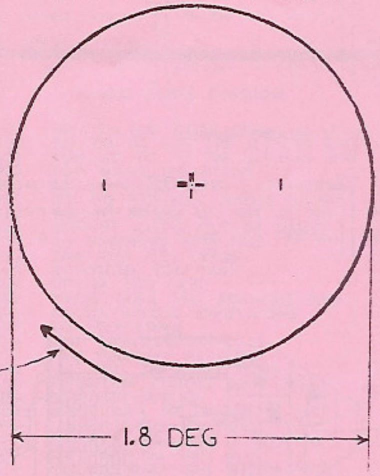
AI, AM and AO are the inner, middle, and outer gimbal angles as indicated by the CMC

AS and AT are the SXT LOS shaft and trunnion angles

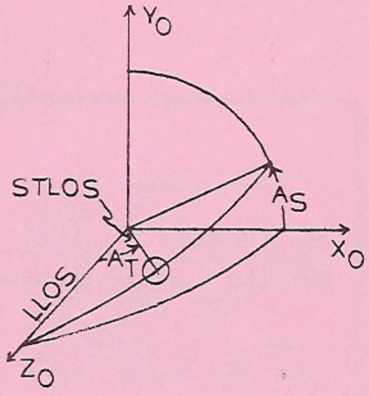
DRIVE RATES

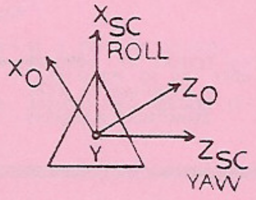
	TRUNNION	SHAFT
HI	10.0 DEG/S	19.5 DEG/S
MED	1.0 DEG/S	2.0 DEG/S
LO	0.1 DEG/S	0.2 DEG/S
MIN	25 SEC/S	50 SEC/S
CMC	3.8 DEG/S	15.1 DEG/S

SXT FIELD OF VIEW

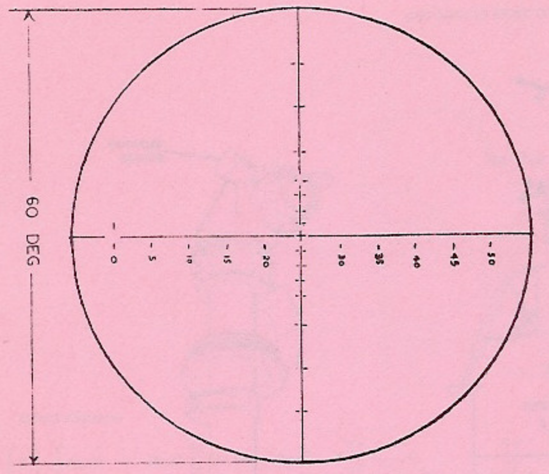


RETICLE ROTATION WITH OPTICS HAND CONTROLLER FULL RIGHT (MANUAL DIRECT MODE)

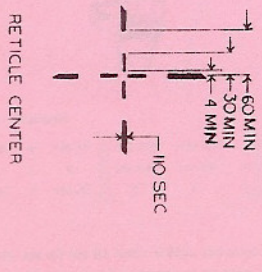




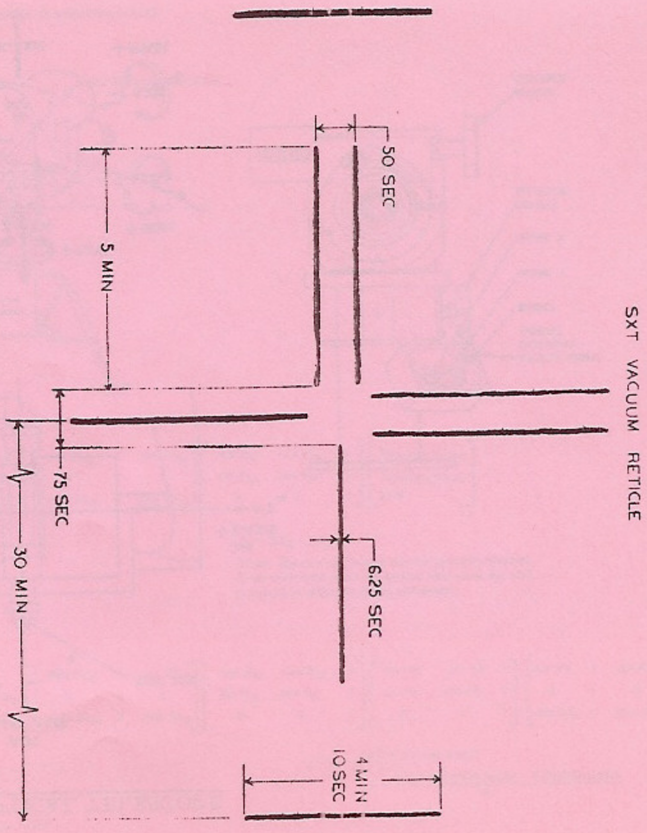
SXT LOS MECHANICAL LIMITS
TRUNNION 0(0, -10) TO 90(10,0) DEG
SHAFT 270(0, -10) TO -270(-10,0) DEG



SCT RETICLE

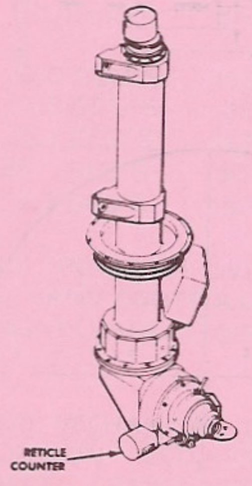


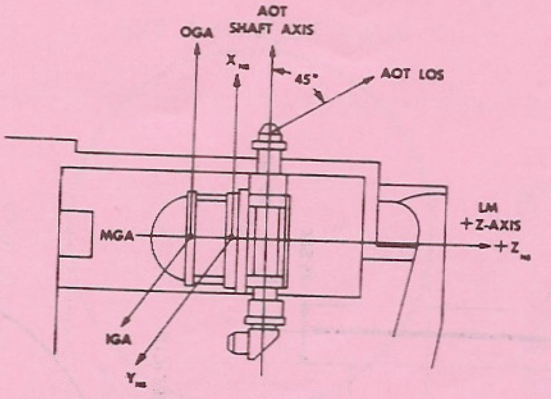
RETICLE CENTER

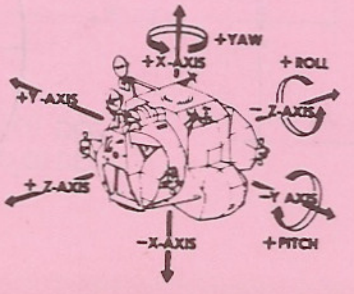


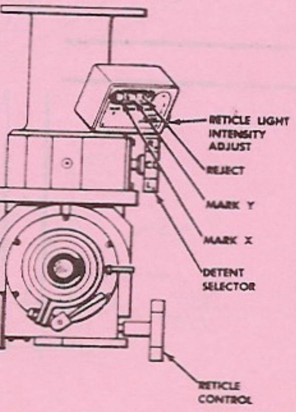
SXT VACUUM RETICLE

ALIGNMENT OPTICAL TELESCOPE

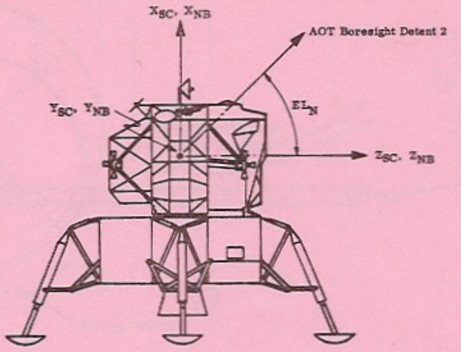








AOT LINE OF SIGHT TO IMU STABLE MEMBER TRANSFORMATIONS



Orbital Alignment

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos AI & 0 & \sin AI \\ 0 & 1 & 0 \\ -\sin AI & 0 & \cos AI \end{bmatrix} \begin{bmatrix} \cos AM & -\sin AM & 0 \\ \sin AM & \cos AM & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AO & -\sin AO \\ 0 & \sin AO & \cos AO \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AZ_N & \sin AZ_N \\ 0 & -\sin AZ_N & \cos AZ_N \end{bmatrix} \begin{bmatrix} \cos EL_N & 0 & \sin EL_N \\ 0 & 1 & 0 \\ -\sin EL_N & 0 & \cos EL_N \end{bmatrix} \begin{bmatrix} \cos R_N & -\sin R_N & 0 \\ \sin R_N & \cos R_N & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{\mathrm{Reticle\ Plane}} \\ Y_{\mathrm{Reticle\ Plane}} \\ \mathrm{LOS} \end{bmatrix}$$

N = Detent Position

$R_N = AZ_2 - AZ_N$

(Note: R_N is a correction for the apparent rotation of the star field about the optical axis when the AOT is moved to different detent positions.)

Lunar Surface Alignment

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{SM} = \begin{bmatrix} \cos AI & 0 & \sin AI \\ 0 & 1 & 0 \\ -\sin AI & 0 & \cos AI \end{bmatrix} \begin{bmatrix} \cos AM & -\sin AM & 0 \\ \sin AM & \cos AM & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AO & -\sin AO \\ 0 & \sin AO & \cos AO \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos AZ_N & \sin AZ_N \\ 0 & -\sin AZ_N & \cos AZ_N \end{bmatrix} \begin{bmatrix} \cos EL_N & 0 & \sin EL_N \\ 0 & 1 & 0 \\ -\sin EL_N & 0 & \cos EL_N \end{bmatrix} \begin{bmatrix} \cos R_N & -\sin R_N & 0 \\ \sin R_N & \cos R_N & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos AS & -\sin AS & 0 \\ \sin AS & \cos AS & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos AT & 0 & \sin AT \\ 0 & 1 & 0 \\ -\sin AT & 0 & \cos AT \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \mathrm{LOS} \end{bmatrix}$$

where

AI, AM, and AO are the inner, middle, and outer gimbal angles as indicated by the LGC

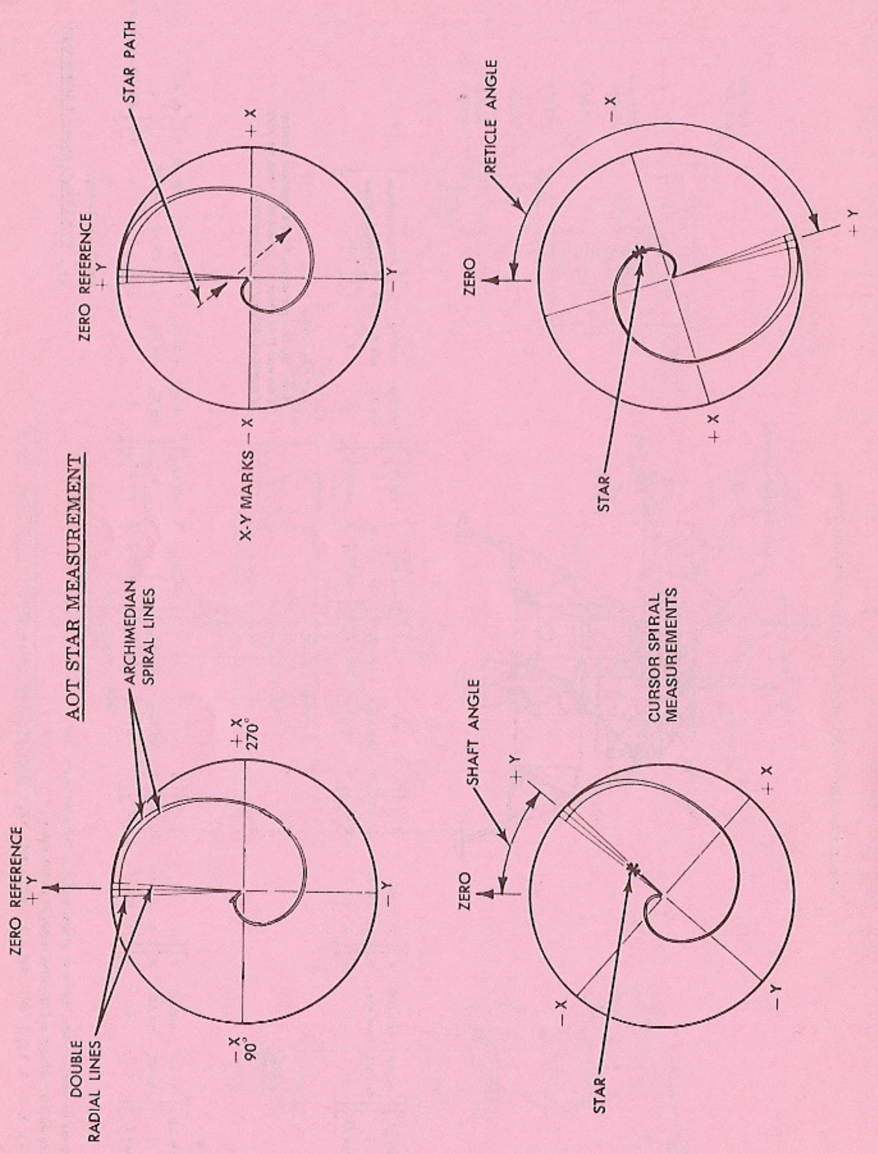
AZ_N and EL_N are the AOT azimuth and elevation angles at the Nth detent.

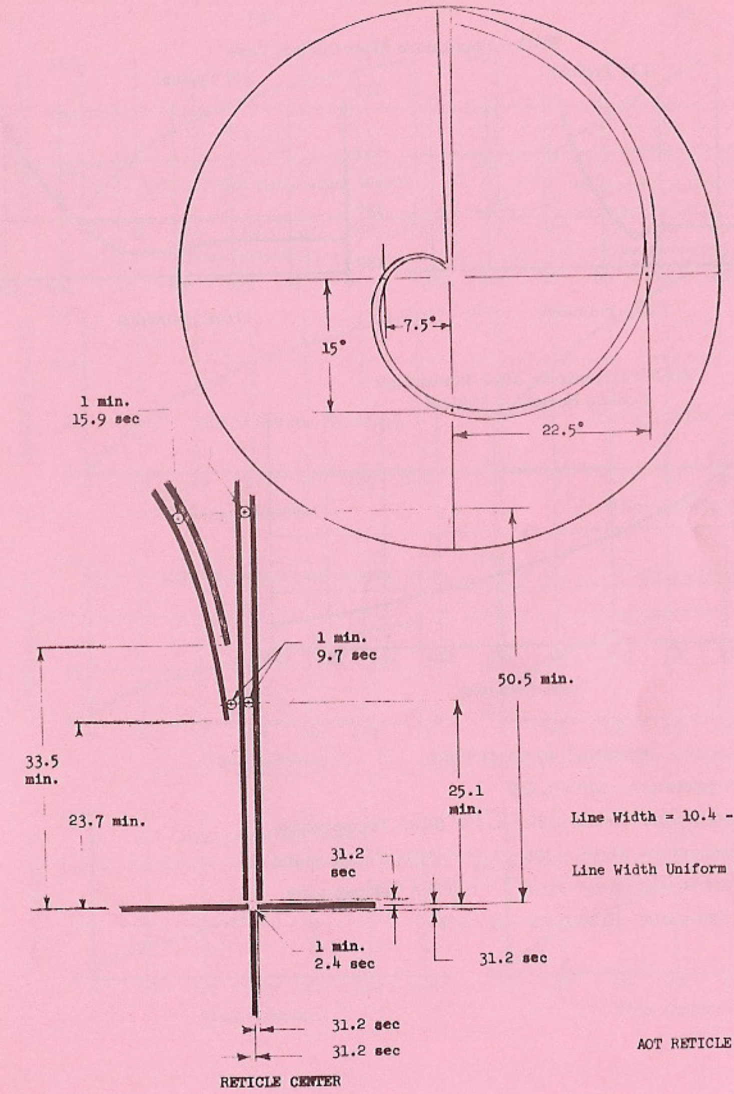
$EL_N \approx 45°$, $N = 1, 2, ---, 6$; $AZ_1 \approx -60°$; $AZ_2 \approx 0°$; $AZ_3 \approx 60°$; $AZ_4 \approx 120°$; $AZ_5 \approx 180°$; $AZ_6 \approx -120°$

AS = Y Reticle Angle

$$AT = \frac{360 + \mathrm{S\ Reticle\ Angle} - \mathrm{Y\ Reticle\ Angle}}{12}$$

AOT STAR MEASUREMENT





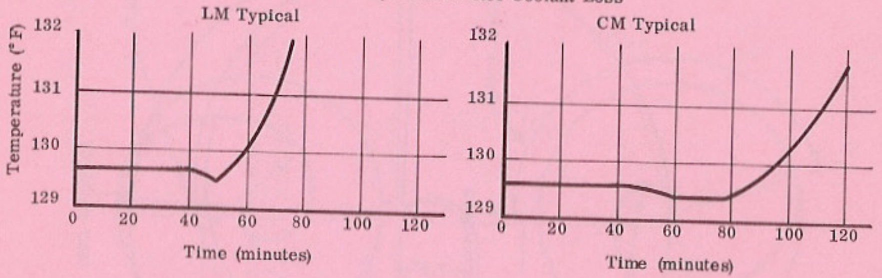
Line Width = 10.4 - 52 sec

Line Width Uniform Within 20.8 sec

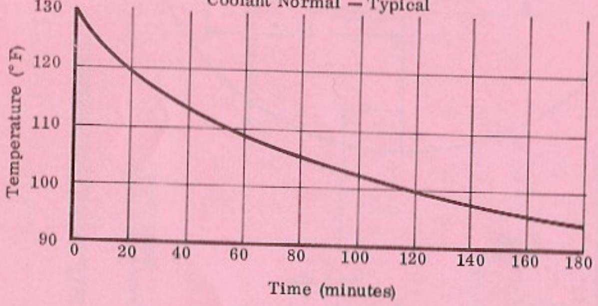
AOT RETICLE

TYPICAL IMU TEMPERATURE

PIPA Temperature After Coolant Loss



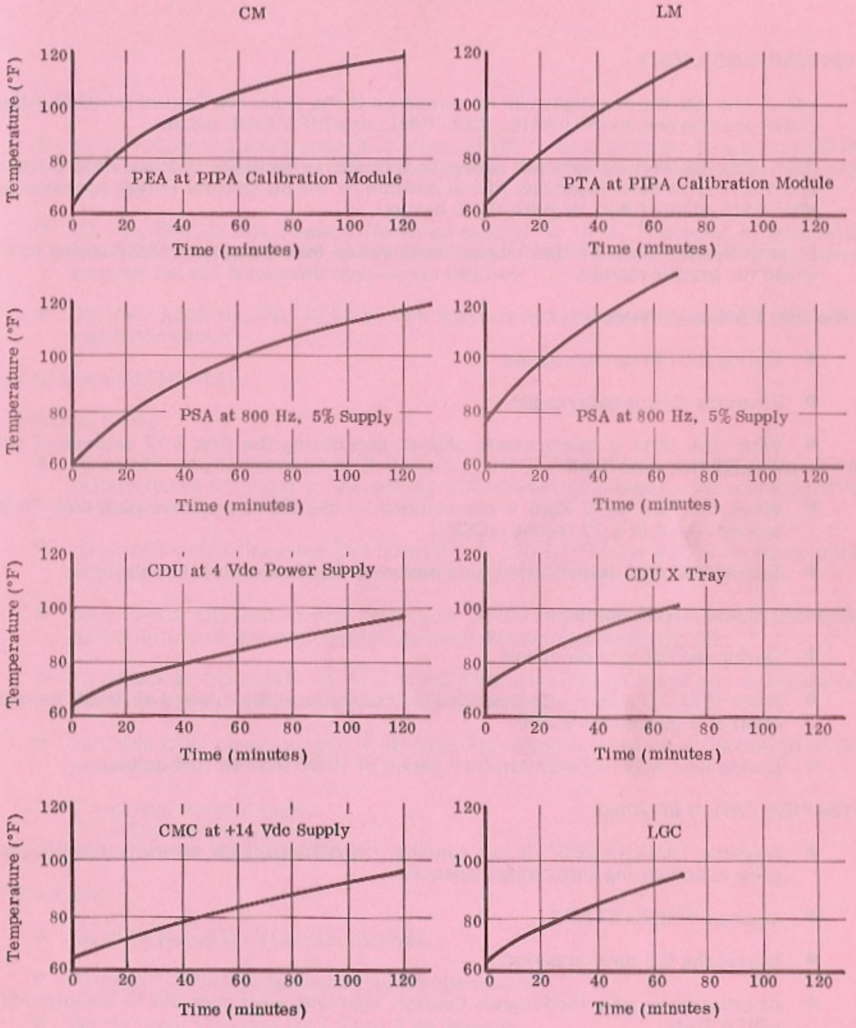
PIPA Temperature After Power Loss
Coolant Normal — Typical



NOMINAL PARAMETERS

- PIPA Temperature — 130 ± 1.5°F
- Low Temperature Alarm — 126 ± 2.5°F (PIPA Temperature)
- High Temperature Alarm — 135 ± 2.5°F (PIPA Temperature)
- Safety Thermostat Opens — 140 $^{+5}_{-2}$ °F (PIPA Temperature)
- Safety Thermostat Hysteresis — 2 - 5°F

TYPICAL HEADER TEMPERATURES AFTER COOLANT LOSS



ISS WARNING LIGHT

LM – The ISS Warning light will be turned on if the Guidance Control switch is in the PGNS position and an IMU FAIL, ICDU FAIL, or a PIPA FAIL occurs.

CM – The ISS Warning light will always be turned on in both the LEB and CMP Caution and Warning stations regardless of the position of the SC Control switch whenever an IMU FAIL, ICDU FAIL, or PIPA FAIL occurs.

In both systems each of the failures are inhibited from causing an ISS Warning to be issued for specific reasons.

The IMU FAIL is inhibited:

- During the ISS turn-on period.
- When the IMU is being caged.
- When the IMU is being coarse aligned and during the first 5.12 seconds of the ensuing fine align mode.
- When the IMU CDU Zero is commanded by the astronaut for a period of 10.56 seconds (LM) or 8.22 seconds (CSM).
- During R47 AGS Initialization for a period of 10.56 seconds (LM only).

The IMU CDU FAIL is inhibited:

- During the ISS turn-on period.
- When IMU CDU Zero is commanded by the astronaut for a period of 10.56 seconds (LM) or 8.22 seconds (CSM).
- During R47 AGS Initialization for a period of 10.56 seconds (LM only).

The PIPA FAIL is inhibited:

- Anytime "AVERAGEG" is not running. "AVERAGEG" is normally running just prior to and during a thrusting maneuver.
- During a FRESH START.
- During the ISS turn-on period.
- At other times, only the Program Caution light with error code 00212 is allowed for a PIPA FAIL.

The Program Caution light on the DSKY will always be turned on when the computer issues an ISS Warning.

IMU FAIL

- IG or MG or OG servo error $>$ 3 Vrms (0.166°) for 2 seconds. This is a 3,200 Hz signal and is detected at the input to the respective servo amplifiers (see page HW-23).
- 28 Vac, 800 Hz, 5%, Phase B (to wheel supply) $<$ 14 V. This signal is detected at the output of the power supply and is such that if any 28 Vac, 800 Hz power supplies fail the failure will show up on this line.
- 28 Vac, 3,200 Hz, 1%, $<$14 V. This signal is detected on the feedback line in the regulation circuit.

Error codes for IMU FAIL.

IMU CDU FAIL

- IG or MG or OG coarse error $>$ 2 Vrms ($\theta - \psi > 30°$). This is an 800 Hz signal and is detected at the input to the emitter follower circuit preceding the coarse Schmitt trigger (see page HW-37).
- IG or MG or OG fine error $>$1 Vrms ($\theta - \psi > 0.7°$). This is an 800 Hz signal and is detected at the output of the main summing amplifier (see page HW-40).
- IG or MG or OG read counter limit cycle $>$160 Hz. This signal is detected from the upline output of the read counter up-down counter (see page HW-35).
- IG or MG or OG $\cos(\theta - \psi)$ $<$2 Vrms. This is an 800 Hz signal and is detected at the output of the ladder amplifier (see page HW-40).
- +14 Vdc CDU power supply $<$+8 Vdc. This signal is detected at the output of the power supply.

  θ – gimbal resolver angle
  ψ – CDU read counter angle
  Error code for IMU CDU FAIL

PIPA FAIL

- No PIPA pulses for 312 microseconds.
- "+" and "-" PIPA pulses occurring simultaneously.
- No "+" and "-" pulses for 1.28 to 3.84 seconds.

OPTICS CDU FAIL

Same as IMU CDU FAIL with the exception that there is no coarse error signal.

RR CDU FAIL

Same as IMU CDU FAIL.

AGC/LGC Warning

The AGC/LGC Warning light will be turned on as a result of the following:

- Scalar Failure
- Scalar Double Failure
- AGC/LGC Power Failure
- AGC/LGC Counter Failure
- AGC/LGC V FAIL (STANDBY)
- AGC/LGC Restart (Hardware)

In addition, the Pulse Torque Power Supply Inhibit is generated every time a AGC/LGC Warning is generated. The effect is to open up the accelerometer loops and prevent any pulse torquing of gyros.

Scalar Failure

Occurs if Stage 17 of the scaler fails to produce pulses. This is the 1.28 second period scalar stage and thus a check of timing for all alarms. This failure causes immediate turn on of the AGC/LGC Warning light.

Scalar Double Failure

Occurs if the 100 pulse per second stage (.010 second period) operates at 200 pps. This provides a check on the scalar stability.

AGC/LGC Power Failure

Occurs when the prime +28 VDC power to the computer is lost. This failure causes an immediate turn on of the AGC/LGC Warning light.

Counter Failure

Occurs if counter increments happen too frequently or else fail to happen following an increment/decrement request. "Too frequently" means continuous counter requests and/or incrementing from .625 to 1.875 milliseconds.

Examples of counters are:

AGC/LGC input/output, (Time 1 and Time 2), ± CDU X, Y, Z, PIPA X, Y, Z, shaft and trunnion angles, Rate Hand Controllers R, P, Q, etc.

AGC/LGC Voltage FAIL (STANDBY)

The occurrence of a Voltage Failure while the computer is in the STANDBY mode will cause the AGC/LGC Warning light to be turned on. The causes of a Voltage Failure are given below in the RESTART section.

RESTARTS

A RESTART (hardware) and subsequent AGC/LGC Warning is generated for the following alarms:

- Oscillator Failure
- Transfer Control (TC) Trap
- Parity Alarm
- Nightwatchman Fail
- Interrupt (RUPT) Lock
- Voltage Fail

The RESTART inhibits access to memory temporarily, freezes the computer, stores in process information and then transfers control to address 4000. This address has the information address for the next instruction after a RESTART that the software programmer has provided.

In general, the programmer has chosen some particular point in a program to resume operation after a RESTART and operation continues with only small inconsequential loses of information of time and/or thrust.

Oscillator Fail

Occurs if loss of oscillator 1.024 milliseconds square wave happens. In addition a logic circuit insures a RESTART condition for a 250 millisecond interval upon transferring from STANDBY to OPERATE.

Transfer Control (TC) Trap

Occurs if too many or too few TC instructions are requested. The period for "too many" or "too few" is from 5 to 15 milliseconds in duration.

Parity Alarm

Occurs if any accessed word in fixed or erasable memory whose address is 10_8 or greater contains an even number of "ones." All locations of 10_8 or greater are stored in fixed or erasable memory with odd parity.

Nightwatchman Fail

Occurs if the computer should fail to access address 67 within a period whose duration varies from 0.64 to 1.92 seconds.

Nightwatchman assures that the computer is still operating during an extended idle period and is not tied up in some interrupt loop.

Interrupt (RUPT) Lock

Occurs if an interrupt is either "too long" or "too infrequent." The time period for "too long" or "too infrequent" varies from 140 milliseconds to 300 milliseconds.

Voltage Fail

Occurs if the AGC/LGC voltages (+28, +14, or +4 VDC) are out of limits for 157 to 470 microseconds.

These limits are:

- +28 VDC supply < 22.6 VDC or 20.3* VDC ±0.2 VDC
- +16 VDC < +14 VDC supply > +12.5 VDC
- +4.4 VDC < + 4 VDC supply > +3.65 VDC

*Two types of modules are in existence. Each computer has its own particular module.

When the computer is in the OPERATE mode a RESTART is generated for Voltage Fails. If the Computer is in the STANDBY mode, the Voltage Fail is processed through the warning filter to turn on the AGC/LGC Warning light.

All of the signals with the exception of Scalar failure or a prime power (+28 VDC) failure are processed through a buffer filter that prevents momentary transients from generating failures.

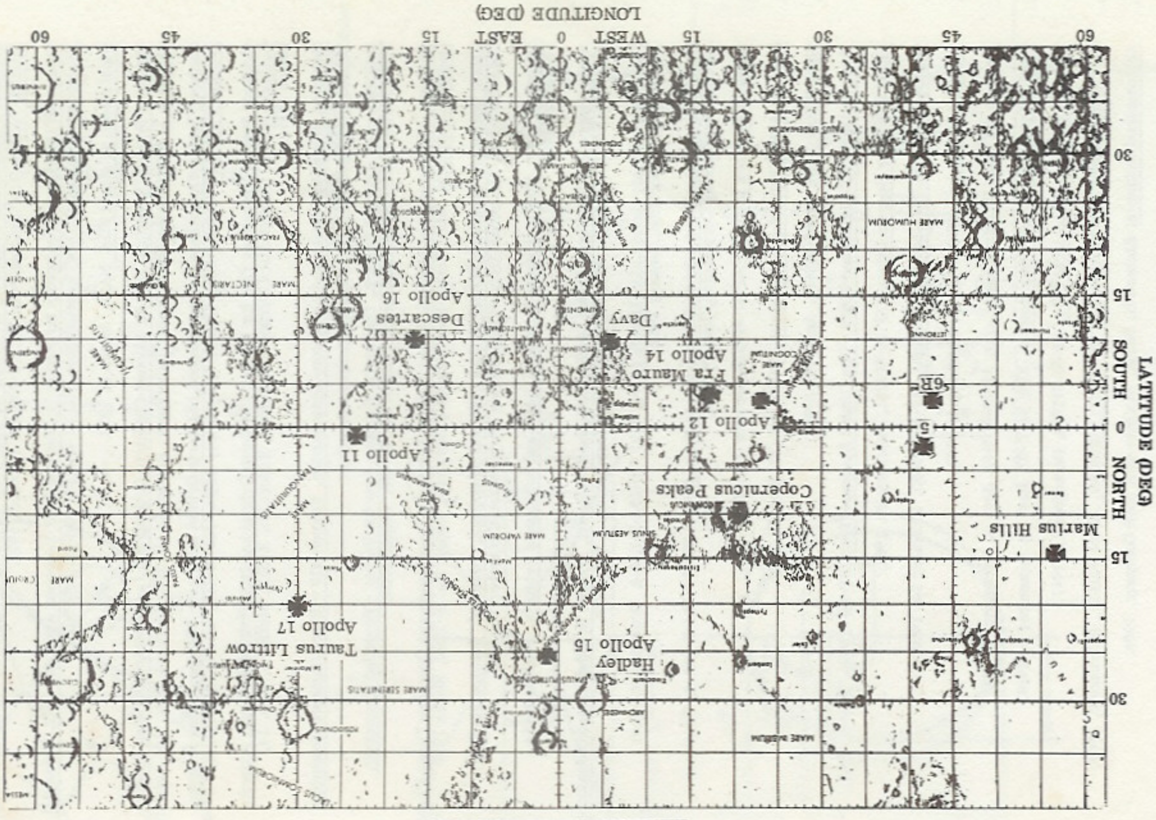
The filter operates such that an output will occur if input pulses occur at a rate of greater than 0.9 pps or 6 consecutive stretched (160 milliseconds) pulses occur or a single event longer than .960 seconds, then the AGC/LGC warning lasts for a minimum of 5 seconds.

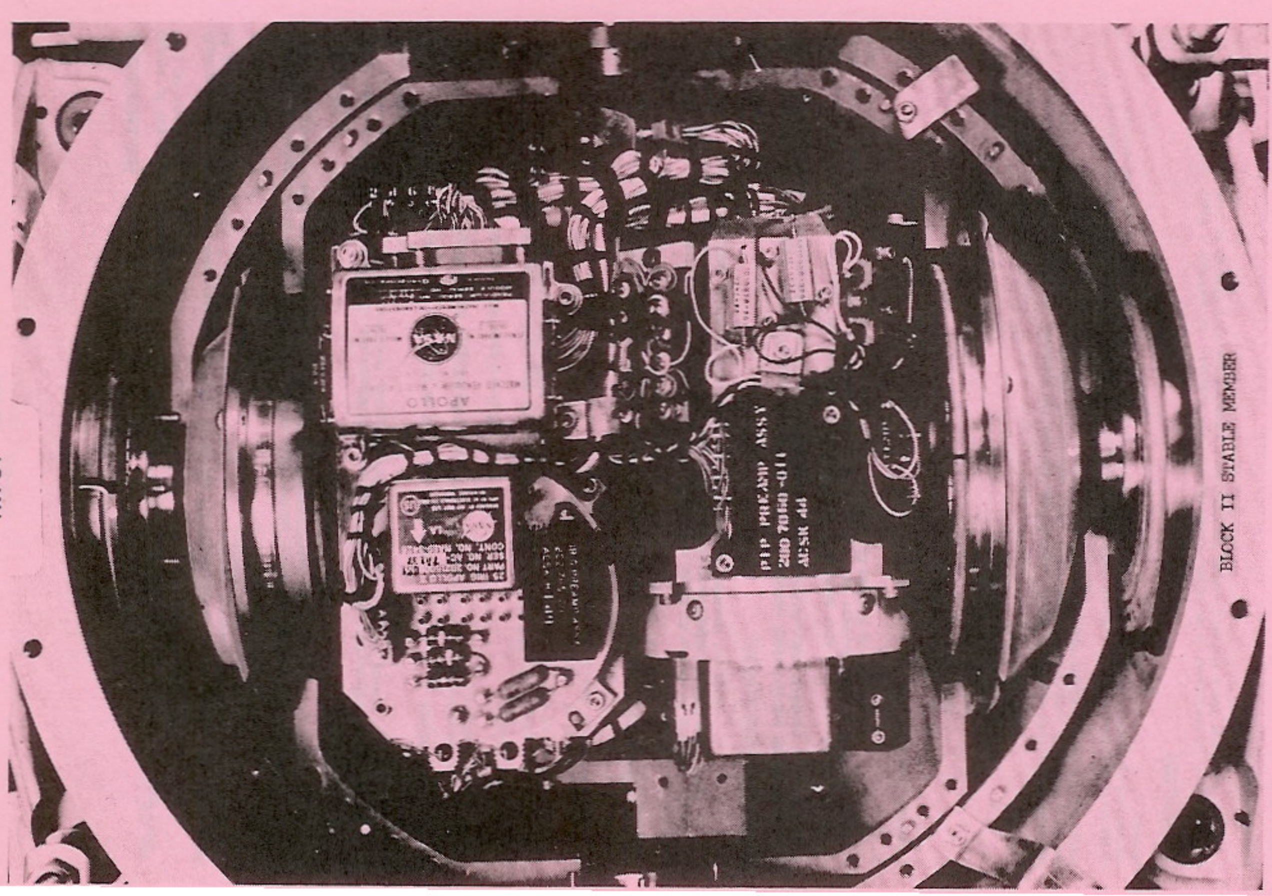
V35E - Test Lights

The computer has a test light routine, called by V35E, that tests all the lights on the DSKY. All "8's" and "+" signs are displayed along with each light turned on for 5 seconds minimum.

After the 5 seconds are completed, the lights are turned off. Note that this verb also turns off the Pulse Torque Power Supply which then causes the PIPA loops to open for approximately 5 seconds. This should be avoided if possible. The routine can be called when ISS operate is not on.

LANDING SITE LOCATIONS



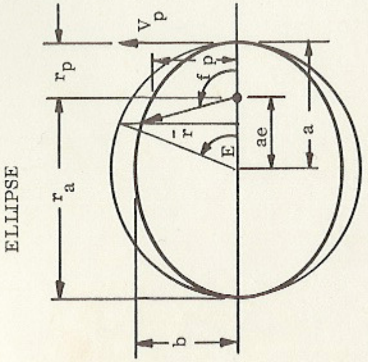


BLOCK II STABLE MEMBER

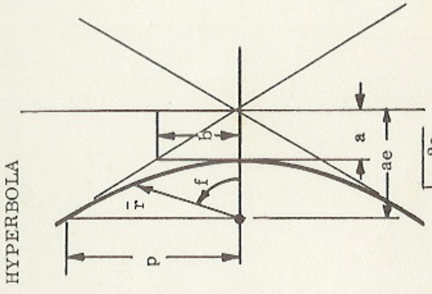
REFERENCES

1. Guidance System Operations Plan for Manned LM Earth Oribital and Lunar Missions Using Program Luminary1C, MIT Charles Stark Draper Laboratory, Report No. R-567, Section 5, November 1969.
2. Spacecraft Operational Trajectory for Apollo 16 (Mission J-2), Launched April 16, 1972, Volume I, Mission Profile, MSC Internal Note No. 72-FM-39, 14 March 1972.
3. Spacecraft Operational Trajectory for Apollo 16 (Mission J-2), Launched April 16, 1972, Volume II, Trajectory Parameters, MSC Internal Note No. 72-FM-39, 10 February 1972.
4. Final Apollo 16 Flight Plan, NASA, March 6, 1972.
5. Guidance System Operations Plan for Manned CM Earth Oribital and Lunar Missions Using Program Colossus 3, MIT Charles Stark Draper Laboratory, Report No. R-577, Section 4, Rev. 16, April 1971.
6. Guidance System Operations Plan for Manned LM Earth Orbital and Lunar Missions Using Program Luminary 1C, MIT Charles Stark Draper Laboratory, Report No. R-567, Section 4, December 1969.
7. Guidance System Operations Plan for Manned CM Earth Orbital and Lunar Missions Using Program Colossus 3, MIT Charles Stark Draper Laboratory, Report No. R-577, Section 5, Rev. 14, March 1971.
8. Guidance, Flight Mechanics and Trajectory Optimization, Volume XIV - Entry Guidance Equations, NASA CR-1013, April 1968.
9. E Guidance - A General Explicit, Optimizing Guidance Law for Rocket - Propelled Spacecraft, MIT Charles Stark Draper Laboratory, Report No. R-456, August 1964.
10. Guidance, Navigation, and Control, Lunar Module Functional Description and Operation Using Flight Program Luminary, MIT Charles Stark Draper Laboratory, Report No. E-2260, March 1969
11. Apollo Operations Handbook, Lunar Module LM5 and Subsequent, Volume I, Subsystems Data, LMA790-3-LM, Grumman Aircraft Engineering Corporation, December 15, 1968.
12. Universal Lunar Module Systems Handbook, LM 4 and Subsequent Vehicles, FCO27, NASA, 17 January 1969.
13. Apollo Operations Handbook, Lunar Module LM5 and Subsequent, Volume II, Operational Procedures, LMA 790-3-LM, Grumman Aircraft Engineering Corporation, 1 May 1969.
14. Radar Section Study Guide Lunar Module LM-4, LSG 770-154-5-LM-4, Grumman Aircraft Engineering Corporation, January 1969.
15. Control Electronics Section Study Guide Lunar Module LM-4, LSG 770-154-7-LM-4, Grumman Aircraft Engineering Corporation, January 1969.
16. Notes on the Block II ECDU, AP-M-#17329, October 23, 1967.
17. Block II 25 IRIG Pulse Torquing Circuit, XDE 34-R-20, June 30, 1967.
18. Block II Stab-Amp, AP-M-#15614, April 12, 1967.
19. Notes on G&N JDC's 12220 and 12619 - The Gimbal Response Test, AP-M-#18834, May 1, 1968.
20. ECDU Computer Operate Optics, AP-M-#18281, February 26, 1968.
21. Orbital Navigation Via Landmark Tracking, AP-M-#21695, February 24, 1969.
22. Celestial Navigation, AP-M-#21569, February 4, 1969.
23. Notes on the Block II Coarse Align Loop, AP-M-#16949, Rev. 1, November 17, 1967.
24. Block II Optical Subsystem Test Results, XDE 34-T-57, Rev. D, September 6, 1969.
25. Notes on the Block II and LEM PIPA, AP-M-#17714, December 11, 1967.
26. AOT Usage During LM Operations on the Apollo 9 Mission, AP-M-#21623, February 6, 1969.
27. Astronautical Guidance, Richard H. Battin, McGraw-Hill Book Company, 1964.
28. Apollo 16 LM Timeline Book, NASA
29. Users' Guide to Apollo GN&CS Major Modes and Routines, Rev. 3,Colossus 3 and Luminary 1E, MIT Charles Stark Draper Laboratory Report No. E-2448, May 1971.
30. Comments on Delco Apollo 15 G&N Summary, TRW A-201, 4900.5-222, July 28, 1971.

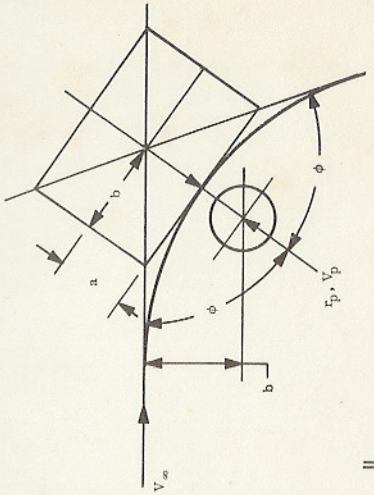
ELLIPSE



HYPERBOLA



HYPERBOLIC ENCOUNTER



		ELLIPSE	HYPERBOLA
Semiminor Axis	$b =$	$\sqrt{r_a r_p}$	$r_p \sqrt{1 + \frac{2a}{r_p}}$
Semimajor Axis	$a =$	$\frac{r_a + r_p}{2}$	$\frac{\mu}{V_\infty^2}$
Eccentricity	$e =$	$\sqrt{1 - (\frac{b}{a})^2}$ <1	$\sqrt{1 + (\frac{b}{a})^2}$ >1
Position	$r =$	$\frac{a(1-e^2)}{1 + e \operatorname{Cos} f} = a\,(1 - e \operatorname{Cos} E)$	$\frac{a(e^2 - 1)}{1 + e \operatorname{Cos} f}$
Velocity	$V =$	$[\frac{\mu}{a}\,(\frac{1 + 2e \operatorname{Cos} f + e^2}{1 - e^2})]^{1/2}$	$[\mu\,(\frac{2}{r} + \frac{1}{a})]^{1/2}$
Semilatus Rectum	$p =$	$a\,(1 - e^2)$	$a\,(e^2 - 1)$
			$V_\infty^2 = \frac{\mu}{a}$

$V_\infty^{\,2} = V_p^{\,2} - 2\,\mu/r_p = \mu/a$

$r_p\, V_p = b\, V_\infty$

$\operatorname{Tan} \phi = b/a = b\,V_\infty^{\,2}/\mu$

$\mu = GM_M \qquad ft^3/s^2$

M_M = Mass of the Moon