2.3.2.3 Subsystems.

The attitude reference, attitude control, and thrust vector control subsystems are described in the following paragraphs. The description covers the purpose and functions of each subsystem, and the integrated association with other systems. Figures 2.3-3 and 2.3-4, provide simplified block, and flow diagrams of the three subsystems and figure 2.3-5 shows the switching logic and functions which affect the three subsystems.

2.3.2.3.1 Attitude Reference Subsystem.

The purpose of the attitude reference subsystem (figures 2.3-4 and 2.3-5) is to relate the S/C attitude in terms of its geometric X, Y, and Z coordinate system to an arbitrarily chosen coordinate system with a fixed reference frame. The relation between the two coordinate systems represents inertial attitude and is presented to the astronauts by visual display.

Visual observation of inertial attitude is necessary to perform manual maneuvers or for monitoring automatic operations. The flight director attitude indicator (FDAI), located on the S/C main display console, displays the information required for the manual and automatic operations. The information displayed includes S/C total attitude, attitude error in three axes, and rotational rates in three axes. The information displayed by the FDAI is obtained from either the G&N system or the SCS.

There are two attitude references associated with the attitude reference subsystem: primary and backup. The primary reference is obtained through the mechanization of subsystems within the G&N system. The backup reference is mechanized within the SCS. Each of the attitude reference loops contain three basic elements: a computer, an inertial reference device, and a visual display.

Attitude Reference/G&N. To obtain an inertial reference using the G&N system, the astronauts, the G&N optics subsystem, the inertial and computer subsystems, and the MSFN are integrated to form a closed loop system.

The G&N system is used to determine inertial attitude and position and initiates alignment of the stable element of the IMU to the desired inertial reference initially established by optical sightings.

After IMU alignment, the IMU in conjunction with the AGC can provide inertial-referenced attitude hold and, if required, inertial-referenced velocity changes. Translational velocities are sensed by accelerometers mounted on the IMU stable element. The AGC processes the accelerometer signals to update velocity and change information for TVC functions.

In addition to the optical alignment of the IMU, the astronauts can use the computer subsystem to establish IMU alignment.

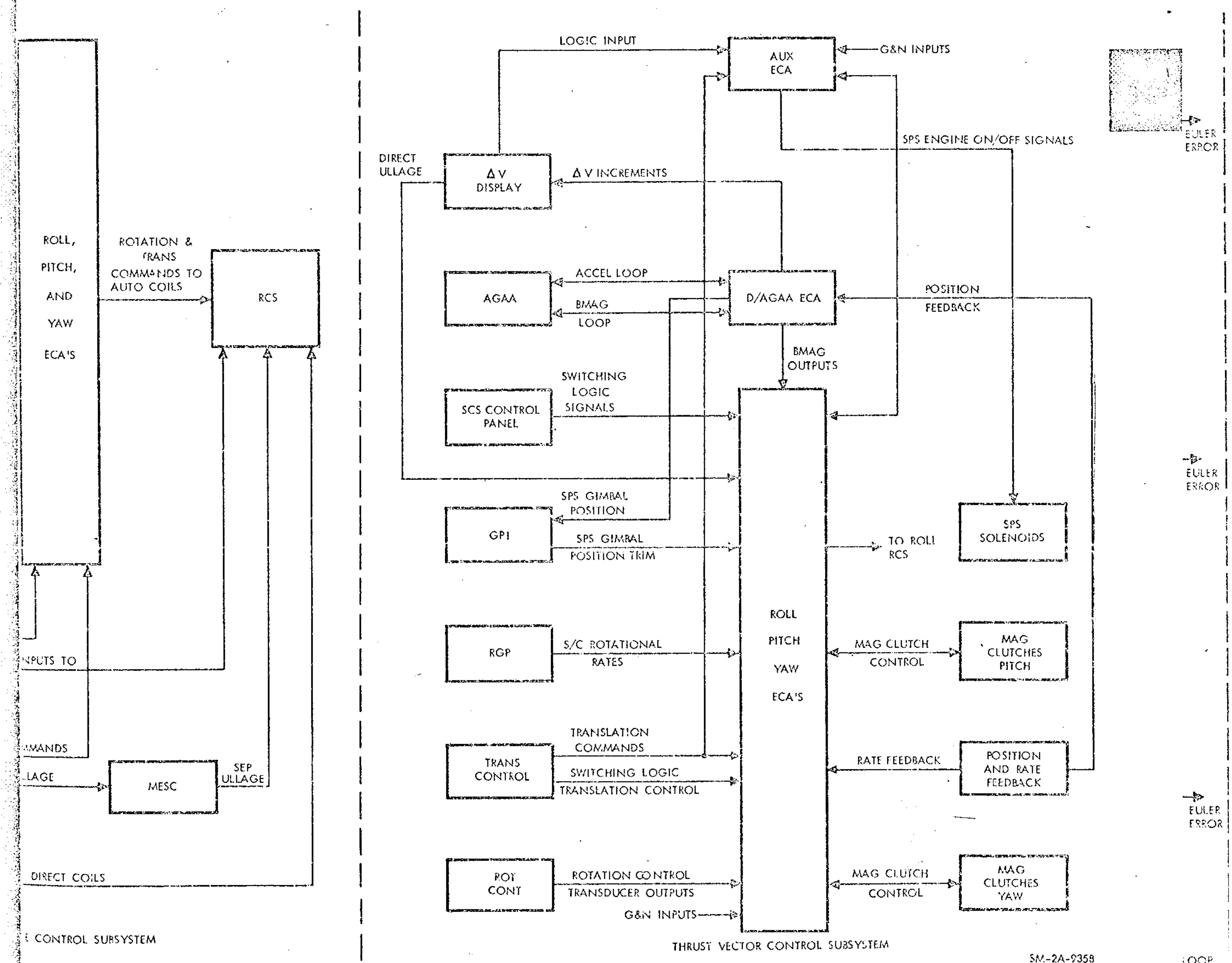
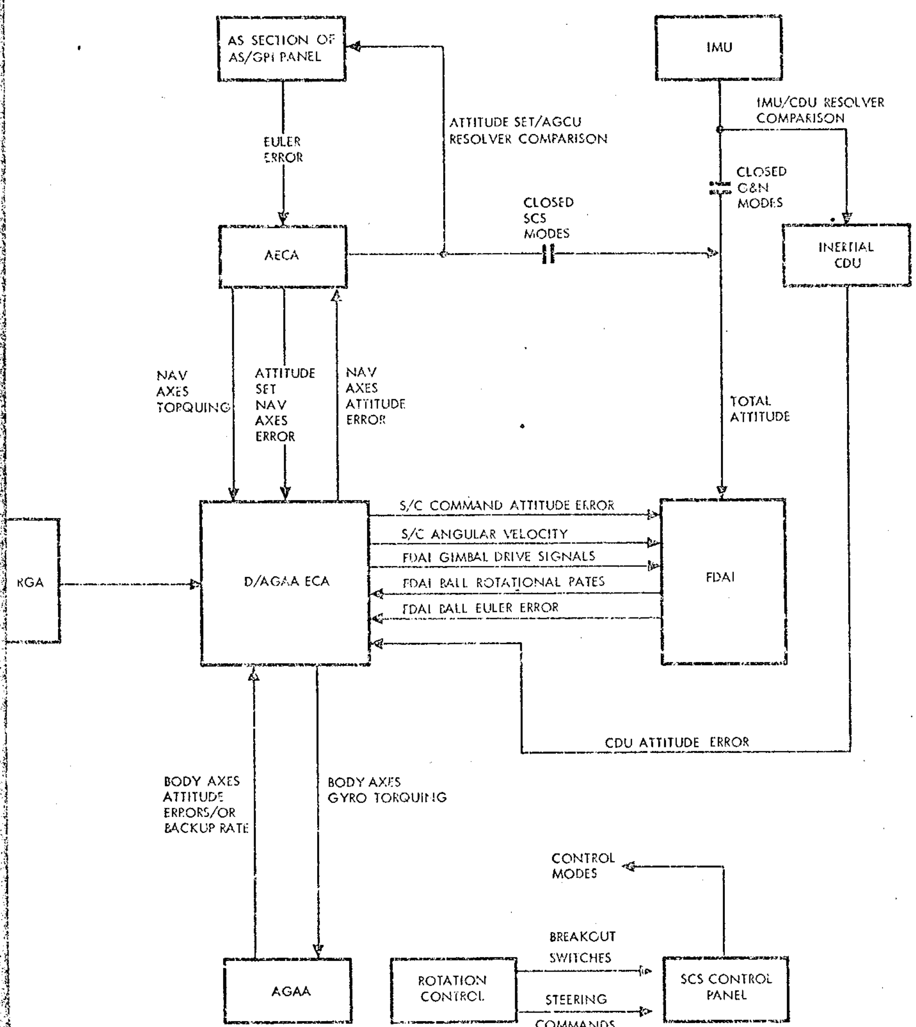
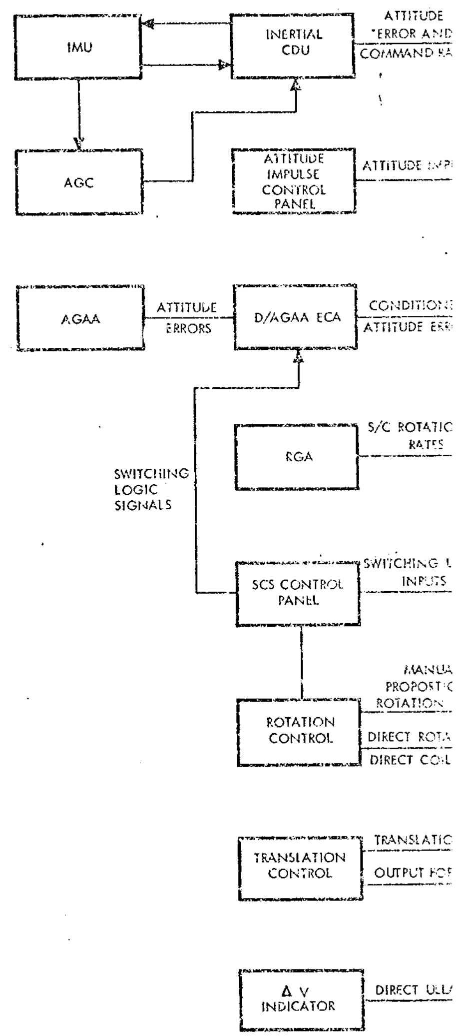
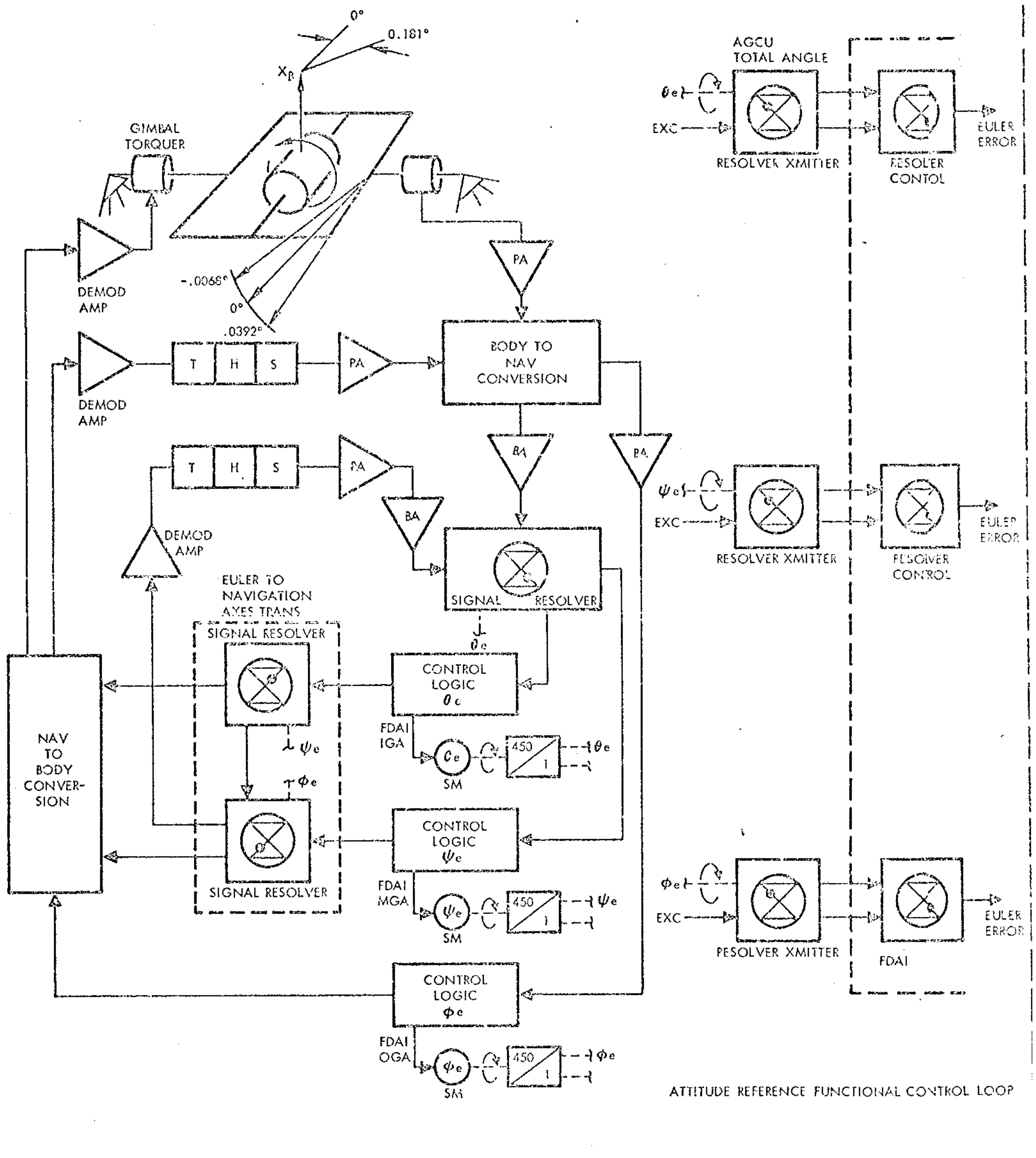


Figure 2.3-3. SCS Functional Block Diagram

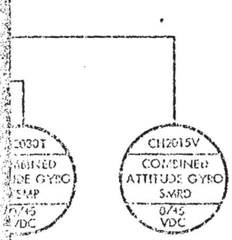


ATTITUDE REFERENCE SUBSYSTEM

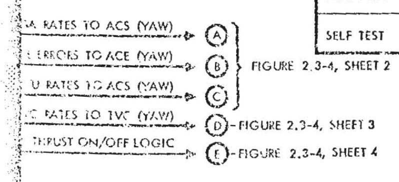




ATTITUDE REFERENCE FUNCTIONAL CONTROL LOOP



MAJOR MODE	K1 ORBIT RATE	K2 FDAI ALIGN	K3 G&N R, P, Y ATT SINE COS	K4 AGCU CAGED	K5 AGCU ALIGN	K6 AGCU P/Y ERROR	K7 R G&N ERR/AGCU W/H G&N P ERROR Y ERR G&N BODY	K8 G&N P, Y ERR S.F.	K9 R, P, Y ERROR AGAA	K10 R, P, Y B/U RATE	K11 MTVC RT OUT	K12 R, P, Y RATE	K13 R & Y/P S.F.
MONITOR			•	•	•		•	•	•	•			
G&N ATTITUDE CONTROL			•	•	•		•		•				
SCS ATTITUDE CONTROL													
SCS LOCAL VERTICAL	•			•									
G&N ΔV			•				•		•				
SCS ΔV													
G&N ENTRY			•	•	•		•		•				
SCS ENTRY													•
INTEGRATED MODE FUNCTIONS													
CSS				•	•								
MINIMUM IMPULSE CONTROL				•	•								
TRANSLATION CONTROL "CW" SWITCH				•	•								
MTVC										•	•	•	
B/U RATE - R, P, & Y									•	•		•	
.05G MANUAL (SCS ENTRY)				•	•				•				
CHANNEL DISABLE (SCS ATT CONT)				•	•								
ATT SET SW ON (SCS MODES)						•			•				
FDAI ALIGN		•											
SELF TEST												•	•



NOTE: For Switching Logic Details, See Figure 2.3-5, Sheet 2

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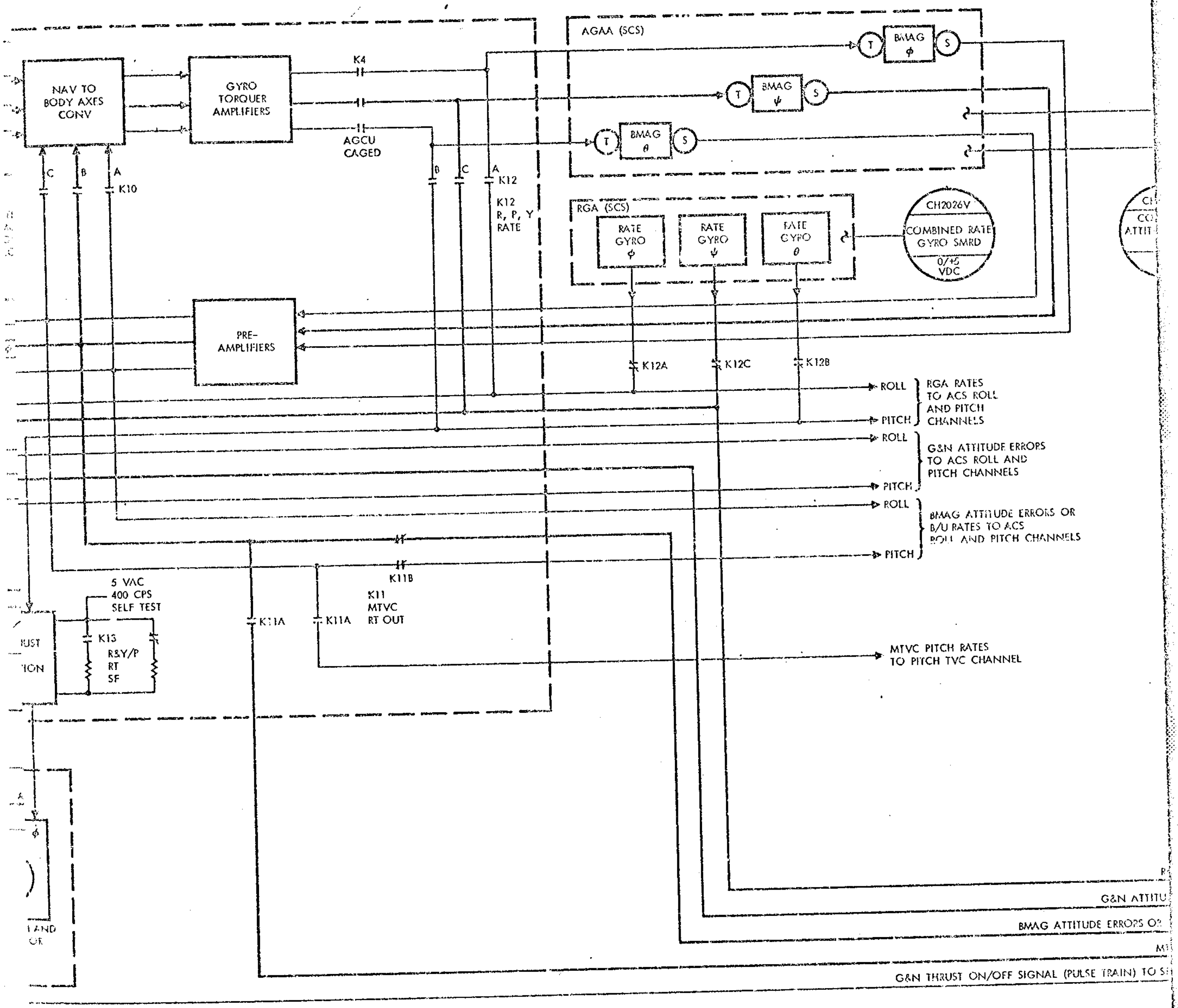
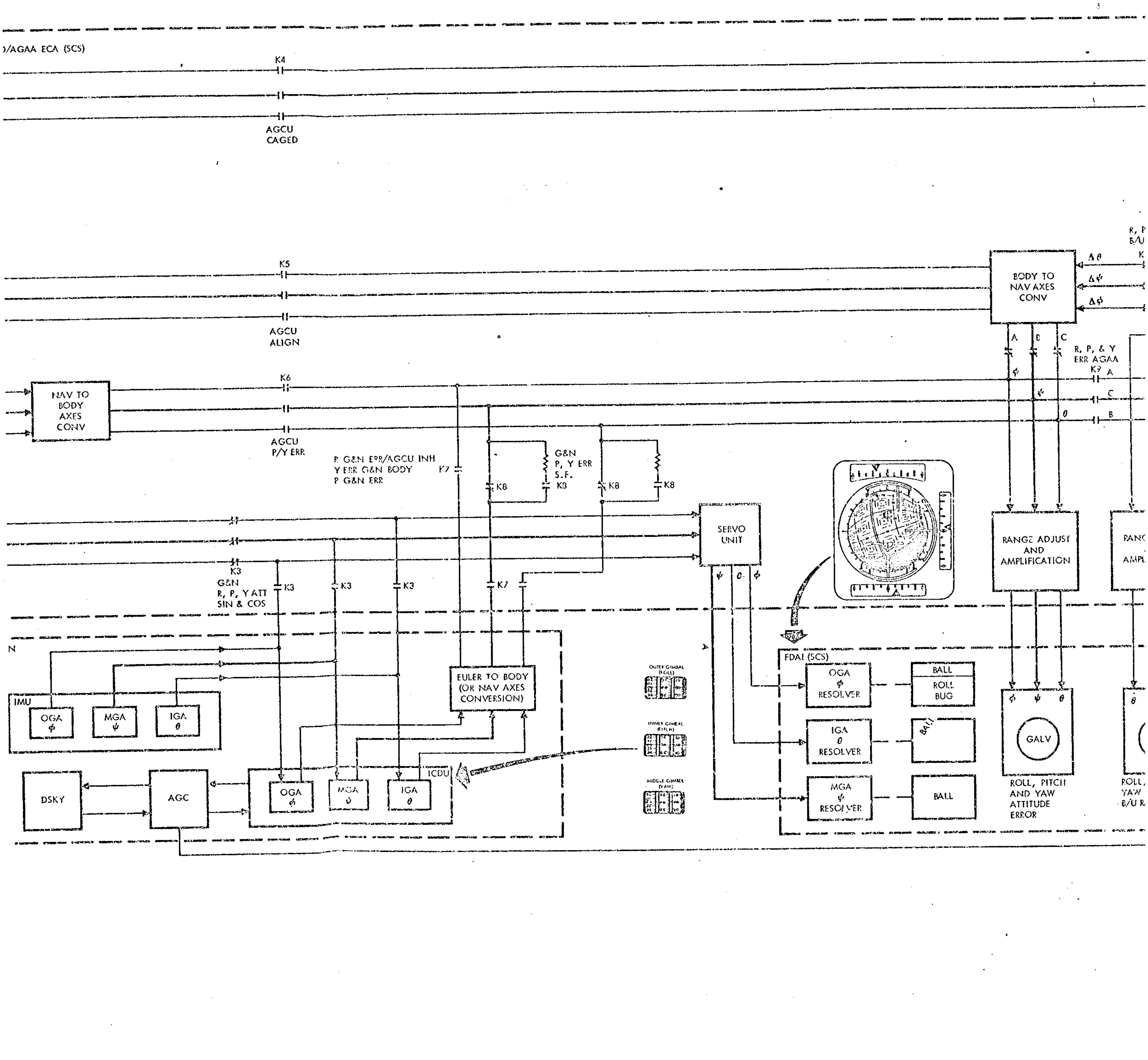
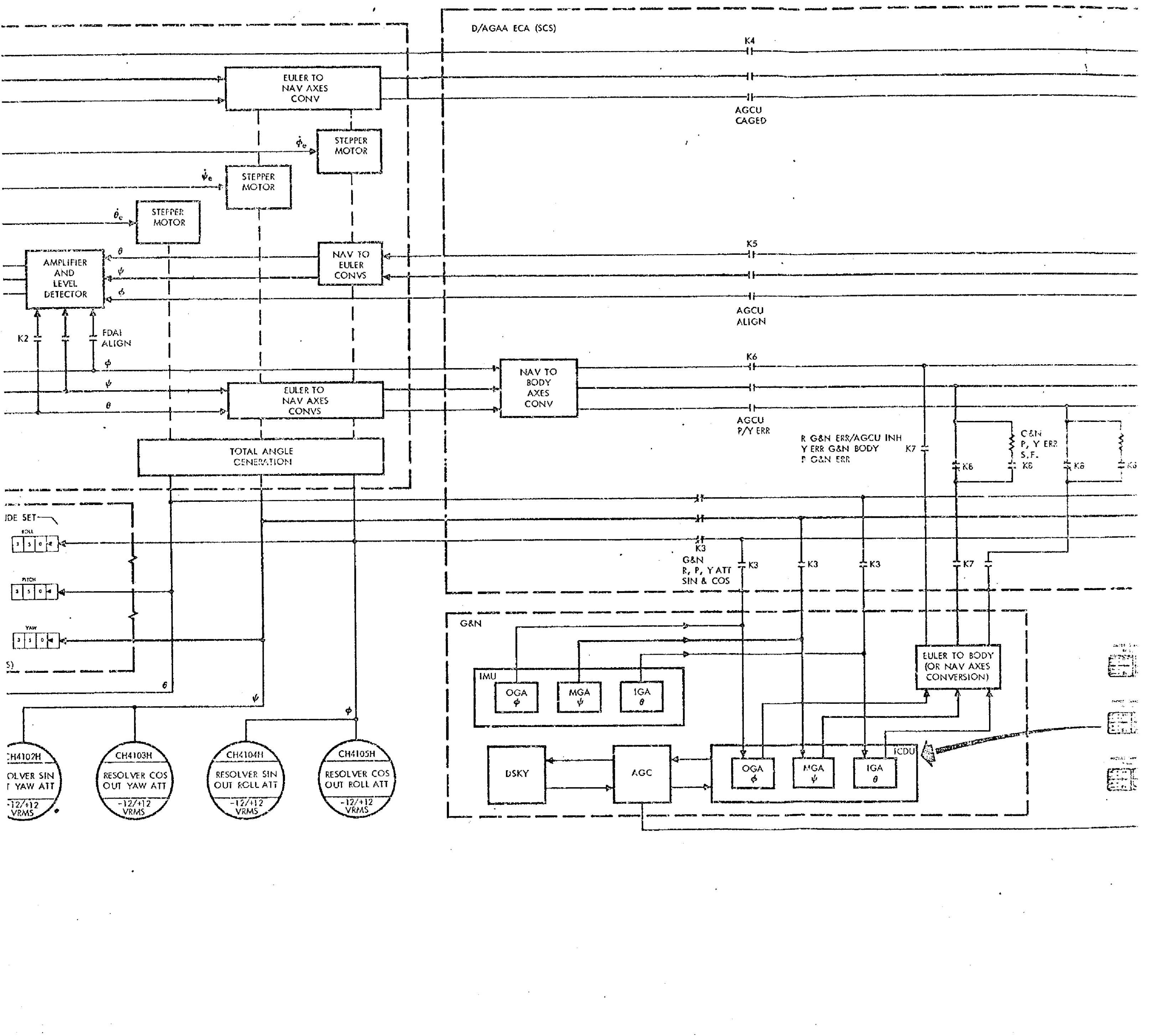
Figure 2.3-4. SCS Functional Flow Diagram (Sheet 1 of 4)



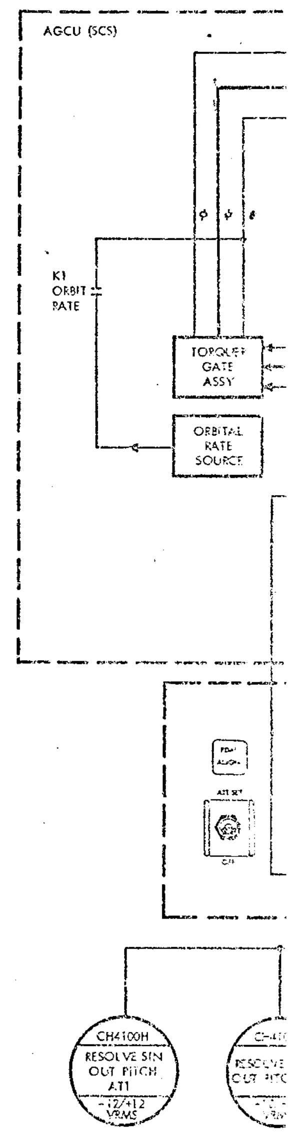
AGAA (SCS)
BMAG φ
BMAG ψ
BMAG θ
NAV TO BODY AXES CONV
GYRO TORQUER AMPLIFIERS
K4
AGCU CAGED
K10
K12
K12 R, P, Y RATE
RGA (SCS)
RATE GYRO φ
RATE GYRO ψ
RATE GYRO θ
CH2026V
COMBINED RATE GYRO SMRD
0/+5 VDC
PRE-AMPLIFIERS
K12A
K12C
K12B
ROLL
PITCH
RGA RATES TO ACS ROLL AND PITCH CHANNELS
G&N ATTITUDE ERRORS TO ACS ROLL AND PITCH CHANNELS
BMAG ATTITUDE ERRORS OR B/U RATES TO ACS ROLL AND PITCH CHANNELS
5 VAC 400 CPS SELF TEST
K13
R&Y/P RT SF
K11A
K11B
K11 MTVC RT OUT
MTVC PITCH RATES TO PITCH TVC CHANNEL
G&N ATTITU
BMAG ATTITUDE ERRORS O
G&N THRUST ON/OFF SIGNAL (PULSE TRAIN) TO S



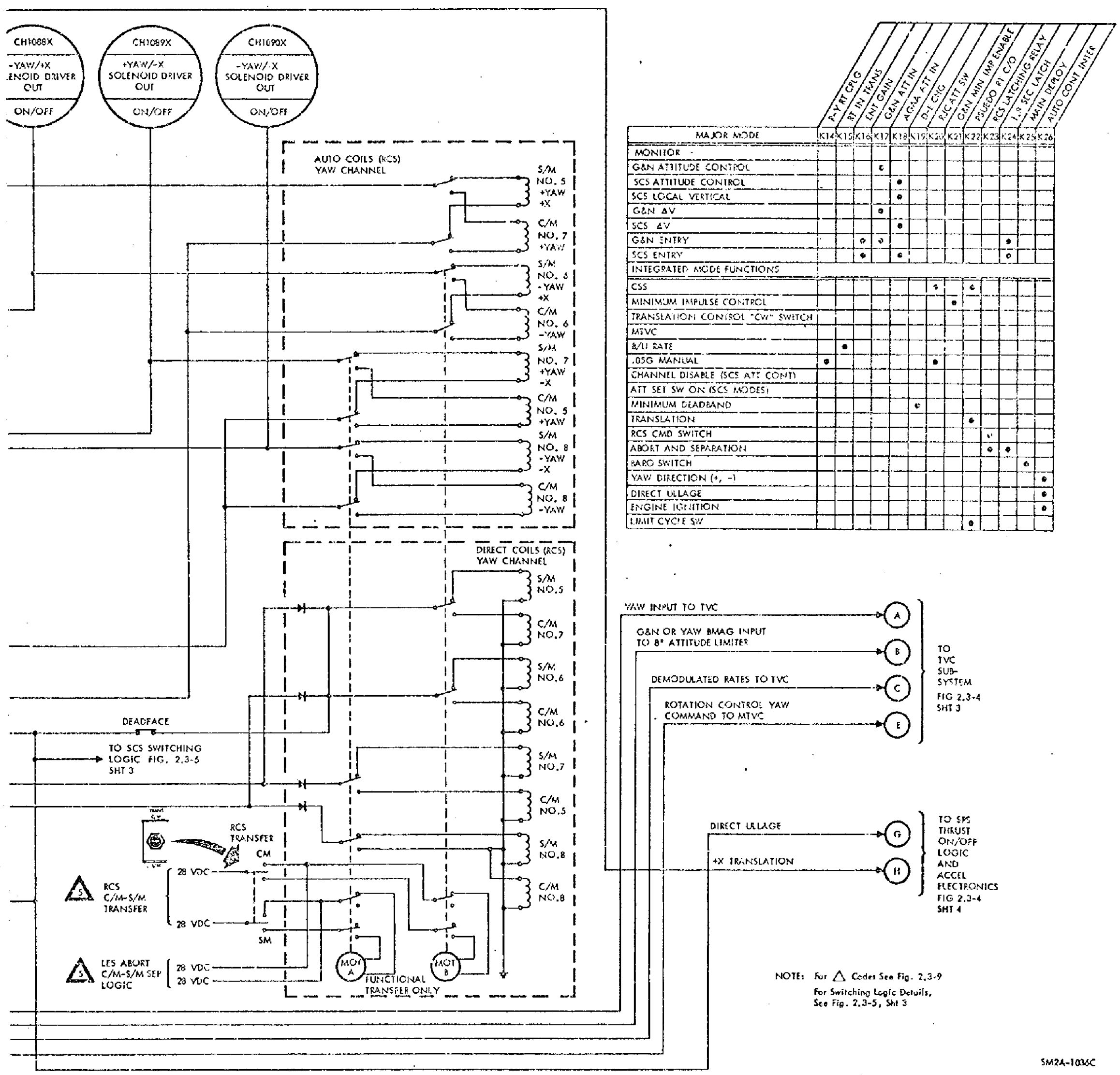
)/AGAA ECA (SCS)
K4
AGCU
CAGED
K5
AGCU
ALIGN
NAV TO
BODY
AXES
CONV
K6
AGCU
P/Y ERR
P G&N ERR/AGCU INH
Y ERR G&N BODY
P G&N ERR
K7
G&N
P, Y ERR
S.F.
K8
K3
G&N
R, P, Y ATT
SIN & COS
SERVO
UNIT
BODY TO
NAV AXES
CONV
R, P, & Y
ERR AGAA
K9
RANGE ADJUST
AND
AMPLIFICATION
IMU
OGA
MGA
IGA
EULER TO BODY
(OR NAV AXES
CONVERSION)
DSKY
AGC
ICDU
FDAI (SCS)
OGA
RESOLVER
IGA
RESOLVER
MGA
RESOLVER
BALL
ROLL
BUG
BALL
GALV
ROLL, PITCH
AND YAW
ATTITUDE
ERROR



D/AGAA ECA (SCS)
K4
EULER TO NAV AXES CONV
AGCU CAGED
STEPPER MOTOR
STEPPER MOTOR
STEPPER MOTOR
AMPLIFIER AND LEVEL DETECTOR
NAV TO EULER CONVS
K5
AGCU ALIGN
K2
FDAI ALIGN
NAV TO BODY AXES CONV
K6
EULER TO NAV AXES CONVS
AGCU P/Y ERR
R G&N ERR/AGCU INH
Y ERR G&N BODY
P G&N ERR
K7
K6
K8
G&N P, Y ERR S.F.
TOTAL ANGLE GENERATION
K3
G&N R, P, Y ATT SIN & COS
G&N
EULER TO BODY (OR NAV AXES CONVERSION)
IMU
OGA
MGA
IGA
DSKY
AGC
ICDU
CH4102H
CH4103H
RESOLVER COS OUT YAW ATT
-12/+12 VRMS
CH4104H
RESOLVER SIN OUT ROLL ATT
-12/+12 VRMS
CH4105H
RESOLVER COS OUT ROLL ATT
-12/+12 VRMS

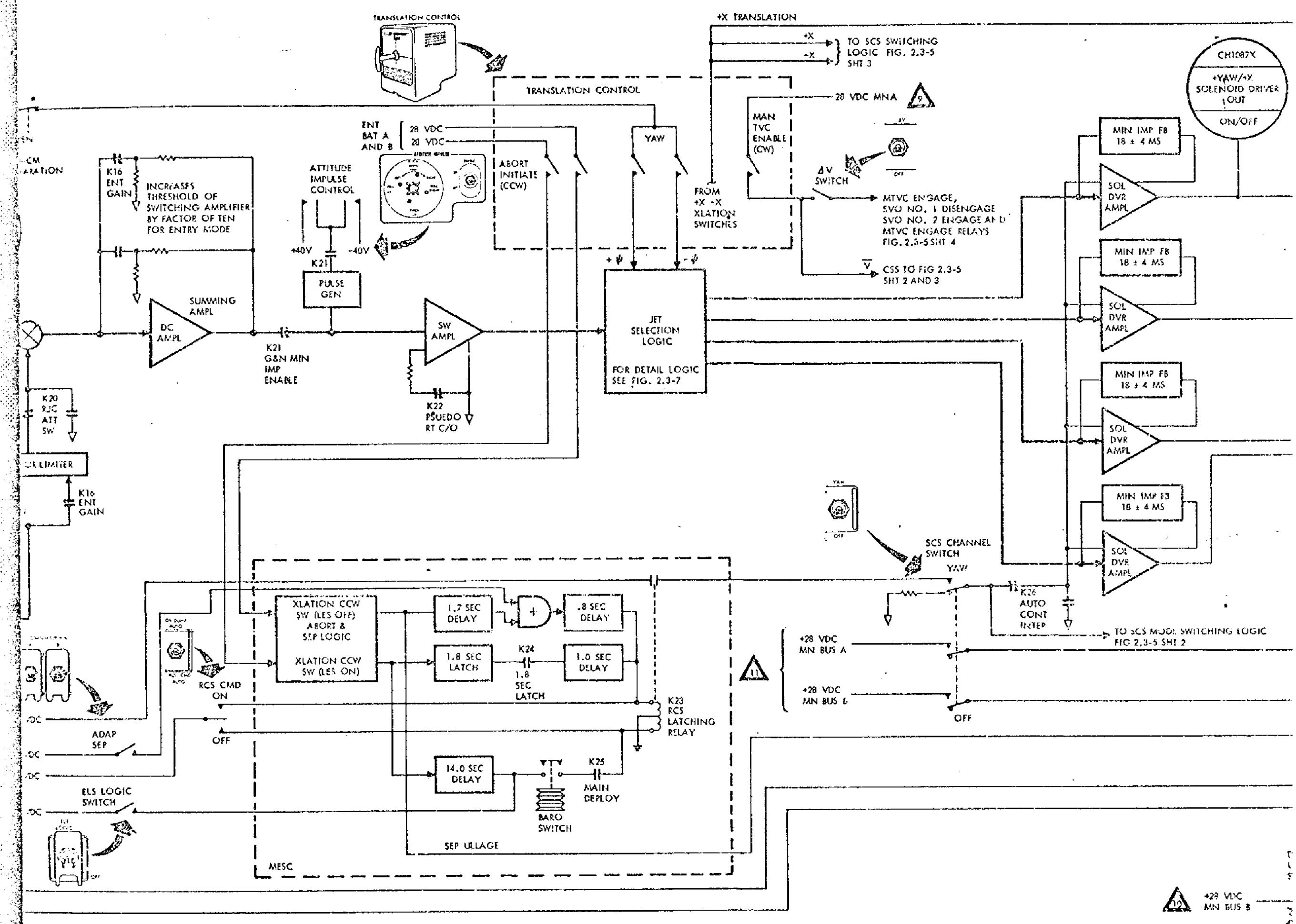


AGCU (SCS)
K1
ORBIT
RATE
TORQUER
GATE
ASSY
ORBITAL
RATE
SOURCE
CH4100H
RESOLVE SIN
OUT PITCH
AT1
-12/+12
VRMS

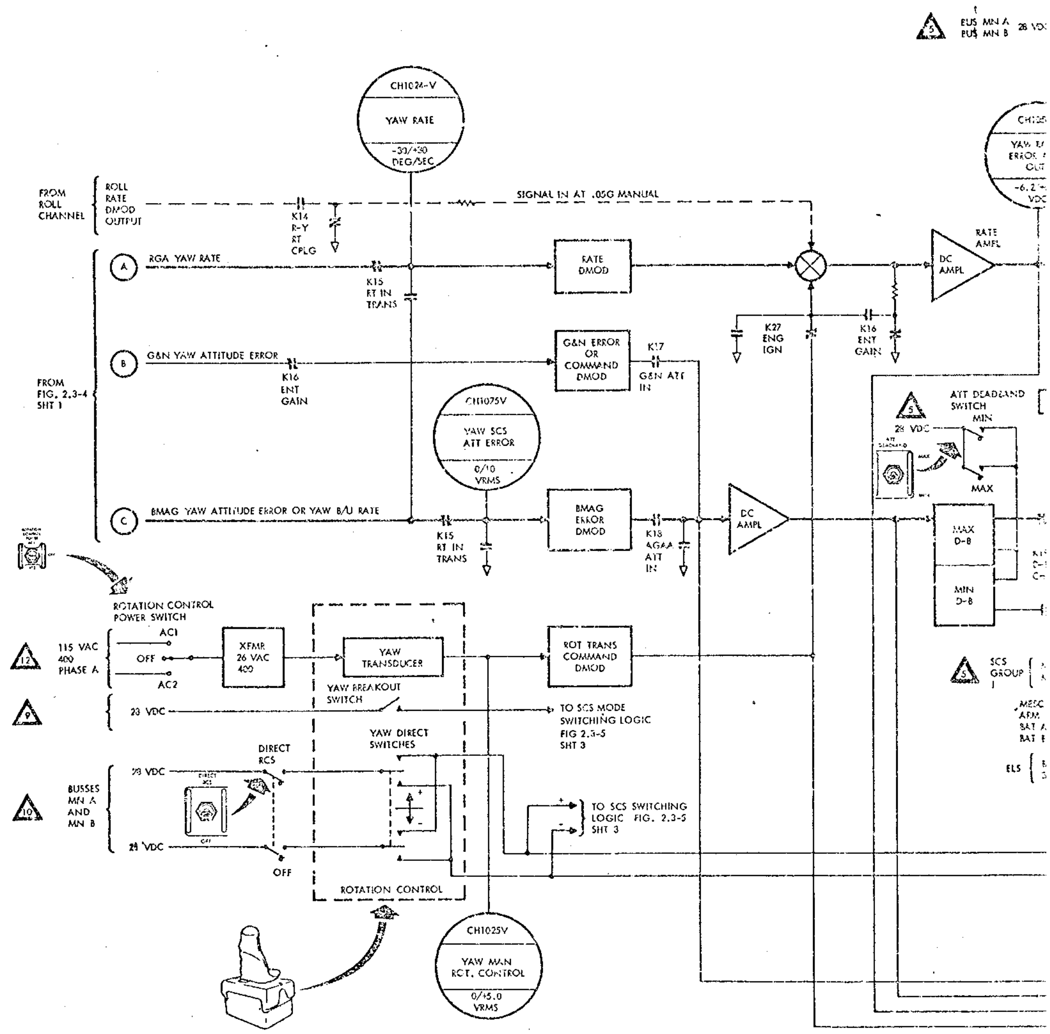


MAJOR MODE	K14 P-Y RT CPLG	K15 RT IN TRANS	K16 ENT GAIN	K17 G&N ATT IN	K18 AGAA ATT IN	K19 D-L CHG	K20 RJC ATT SW	K21 G&N MIN IMP ENABLE	K22 PSUEDO RT C/O	K23 RCS LATCHING RELAY	K24 1.8 SEC LATCH	K25 MAIN DEPLOY	K26 AUTO CONT INTER
MONITOR													
G&N ATTITUDE CONTROL				•									
SCS ATTITUDE CONTROL					•								
SCS LOCAL VERTICAL					•								
G&N ΔV				•									
SCS ΔV					•								
G&N ENTRY			•	•							•		
SCS ENTRY			•		•						•		
INTEGRATED MODE FUNCTIONS													
CSS							•		•				
MINIMUM IMPULSE CONTROL								•					
TRANSLATION CONTROL "CW" SWITCH													
MTVC													
B/U RATE		•											
.05G MANUAL	•						•						
CHANNEL DISABLE (SCS ATT CONT)													
ATT SET SW ON (SCS MODES)													
MINIMUM DEADBAND						•							
TRANSLATION									•				
RCS CMD SWITCH										•			
ABORT AND SEPARATION										•	•		
BARO SWITCH												•	
YAW DIRECTION (+, -)													•
DIRECT ULLAGE													•
ENGINE IGNITION													•
LIMIT CYCLE SW									•				

Figure 2.3-4. SCS Functional Flow Diagram (Sheet 2 of 4)



ATTITUDE CONTROL SUBSYSTEM



CH1024-V
YAW RATE
-33/+30 DEG/SEC
FROM ROLL CHANNEL
ROLL RATE DMOD OUTPUT
K14 R-Y RT CPLG
SIGNAL IN AT .05G MANUAL
RGA YAW RATE
K15 RT IN TRANS
RATE DMOD
RATE AMPL
DC AMPL
K27 ENG IGN
K16 ENT GAIN
G&N YAW ATTITUDE ERROR
G&N ERROR OR COMMAND DMOD
K17 G&N ATT IN
FROM FIG. 2.3-4 SHT 1
CH1075V
YAW SCS ATT ERROR
0/10 VRMS
BMAG YAW ATTITUDE ERROR OR YAW B/U RATE
BMAG ERROR DMOD
K18 AGAA ATT IN
ATT DEADBAND SWITCH
MIN
MAX
28 VDC
MAX D-B
MIN D-B
ROTATION CONTROL POWER SWITCH
115 VAC 400 PHASE A
AC1
OFF
AC2
XFMR 26 VAC 400
YAW TRANSDUCER
ROT TRANS COMMAND DMOD
YAW BREAKOUT SWITCH
28 VDC
TO SCS MODE SWITCHING LOGIC FIG 2.3-5 SHT 3
DIRECT RCS
YAW DIRECT SWITCHES
BUSSES MN A AND MN B
TO SCS SWITCHING LOGIC FIG. 2.3-5 SHT 3
OFF
ROTATION CONTROL
CH1025V
YAW MAN ROT. CONTROL
0/+5.0 VRMS
SCS GROUP 1
ELS

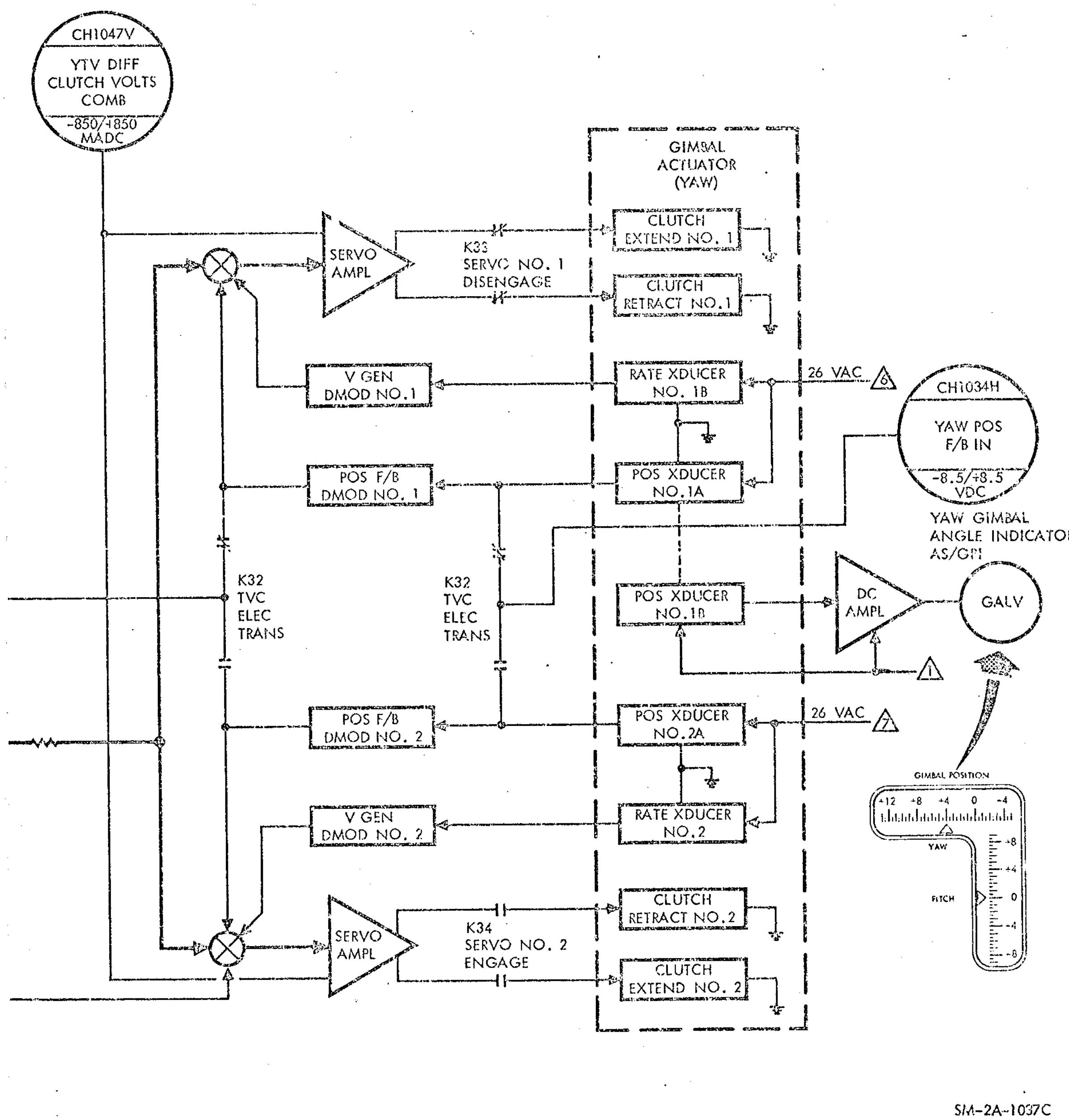
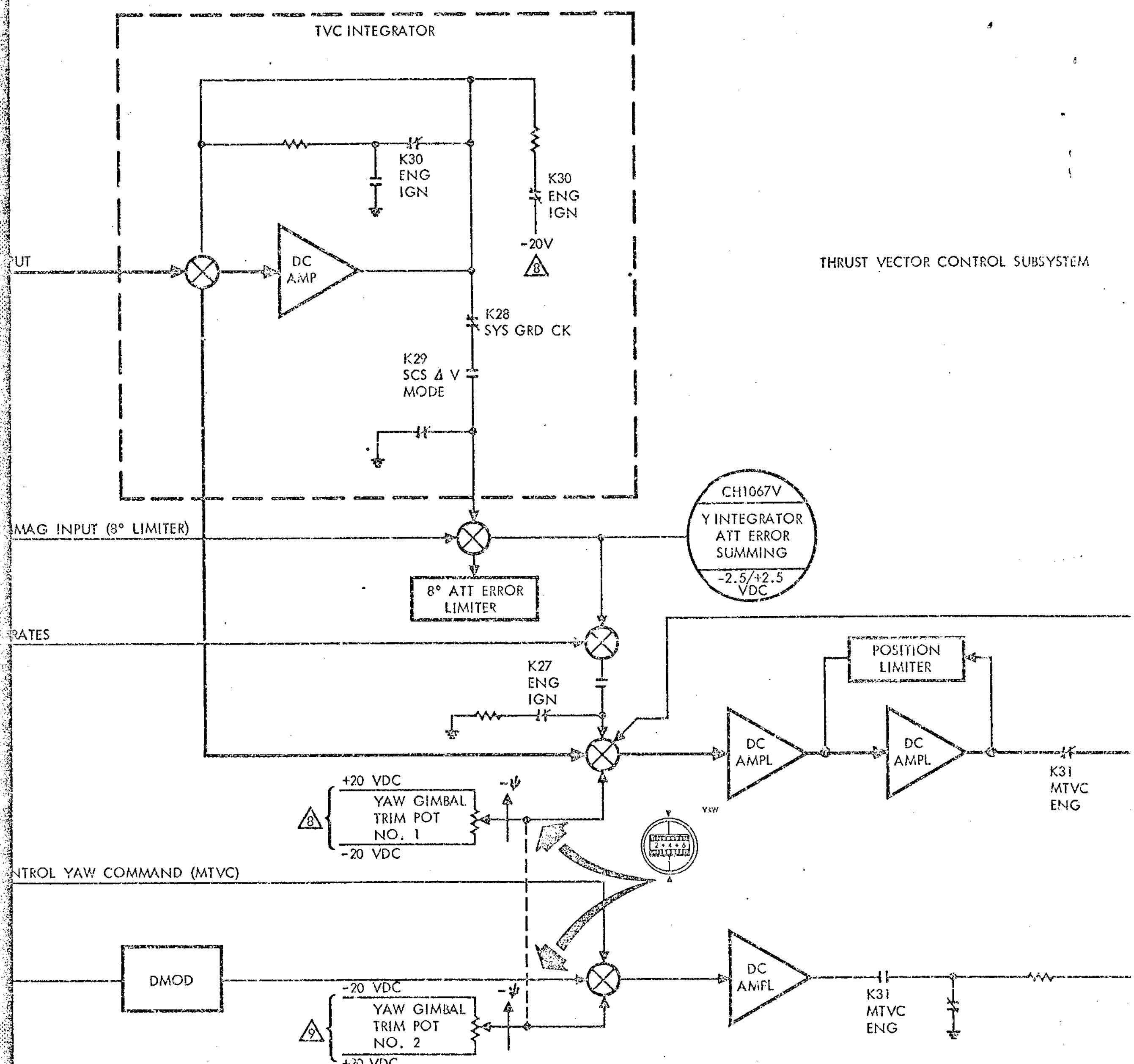


Figure 2.3-4. SCS Functional Flow Diagram (Sheet 3 of 4)

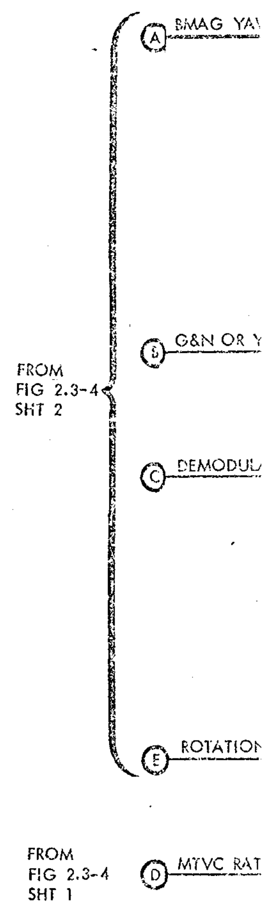


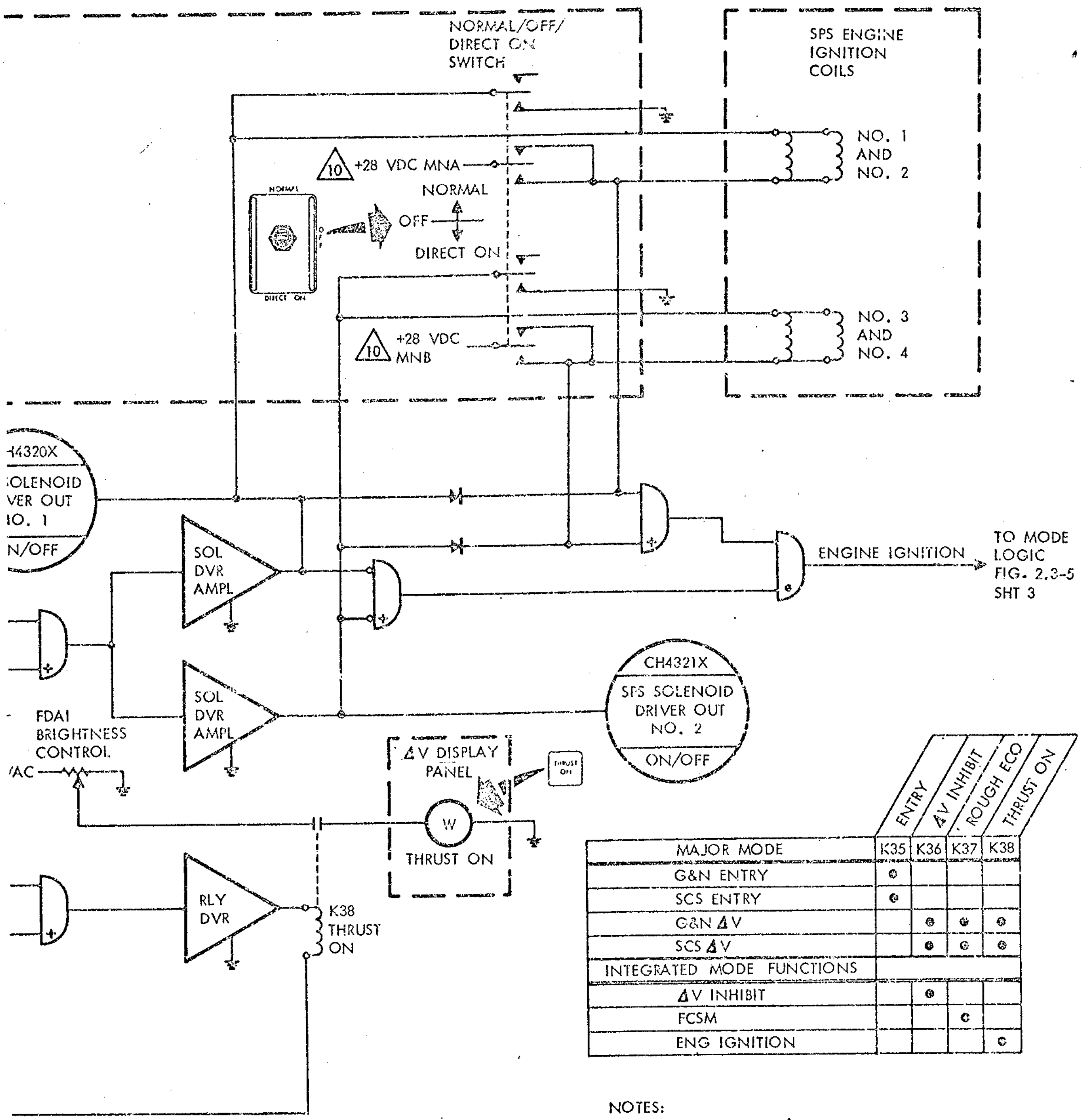
THRUST VECTOR CONTROL SUBSYSTEM

MAJOR MODE	K27 ENG IGN	K28 SYS GRD CK	K29 SCS ΔV MODE	K30 ENGINE IGN	K31 MTVC ENGAGE	K32 TVC ELEC TRANS	K33 SERVO NO. 1 DISENGAGE	K34 SERVO NO. 2 ENGAGE
SCS ΔV			●					
INTEGRATED MODE FUNCTIONS								
ENGINE IGNITION	●			●				
SYSTEM GRD CHECK		●						
MTVC ENGAGE					●		●	●
TVC MONITOR						●	●	●
TVC NO. 1 OFF						●	●	●

NOTE:

1. For Switching Logic Details, See Figure 2.3-5, Shts 3 & 4
2. For Δ Codes, See Figure 2.3-9





MAJOR MODE	K35	K36	K37	K38
G&N ENTRY	●			
SCS ENTRY	●			
G&N ΔV		●	●	●
SCS ΔV		●	●	●
INTEGRATED MODE FUNCTIONS				
ΔV INHIBIT		●		
FCSM			●	
ENG IGNITION				●

SPS THRUST ON/OFF LOGIC AND ACCELEROMETER ELECTRONICS

NOTES:

1. For Delta Codes △ See Fig. 2.3-9.
2. For Switching Logic Details, See Fig. 2.3-5, Sht 4.

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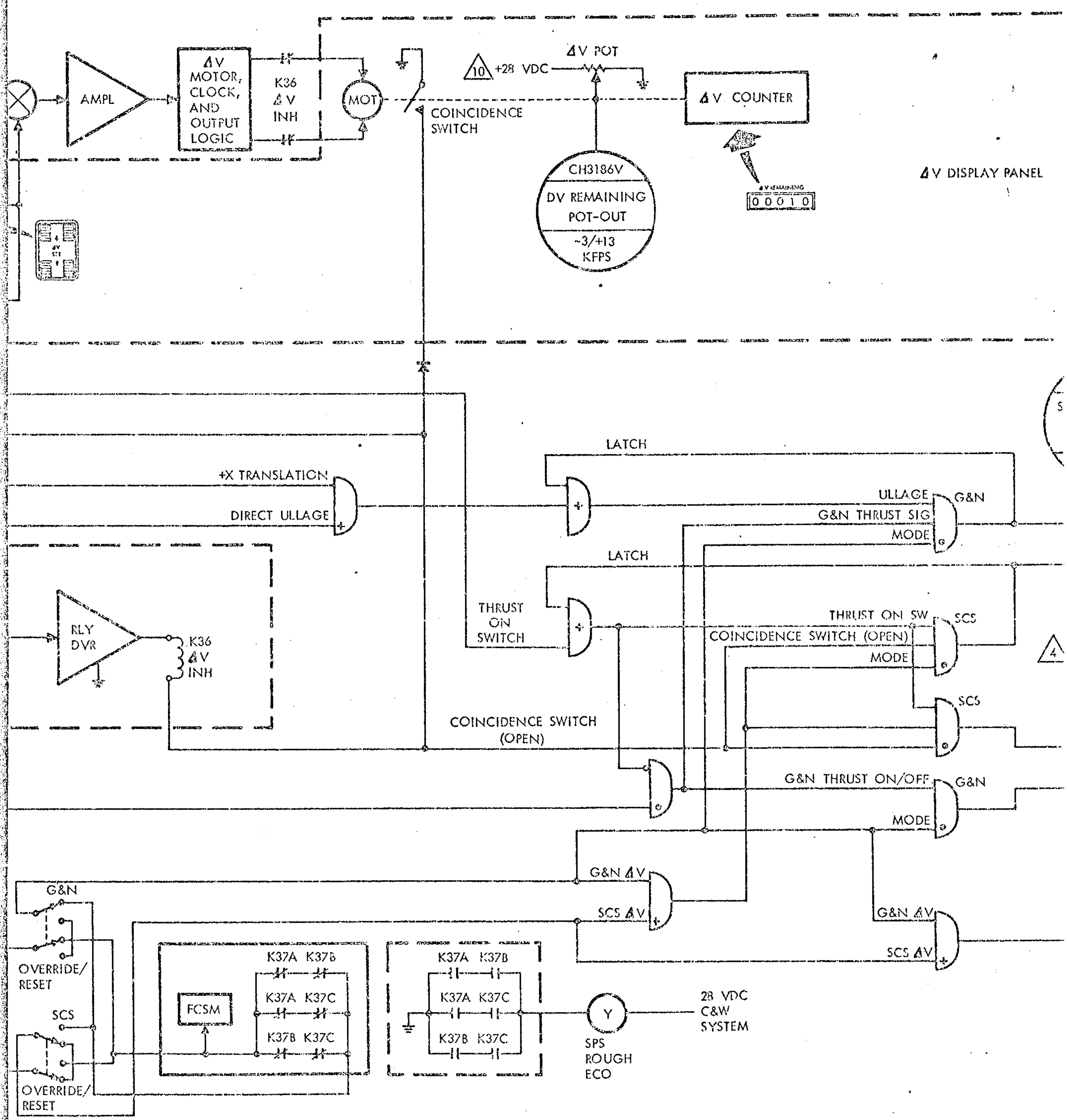
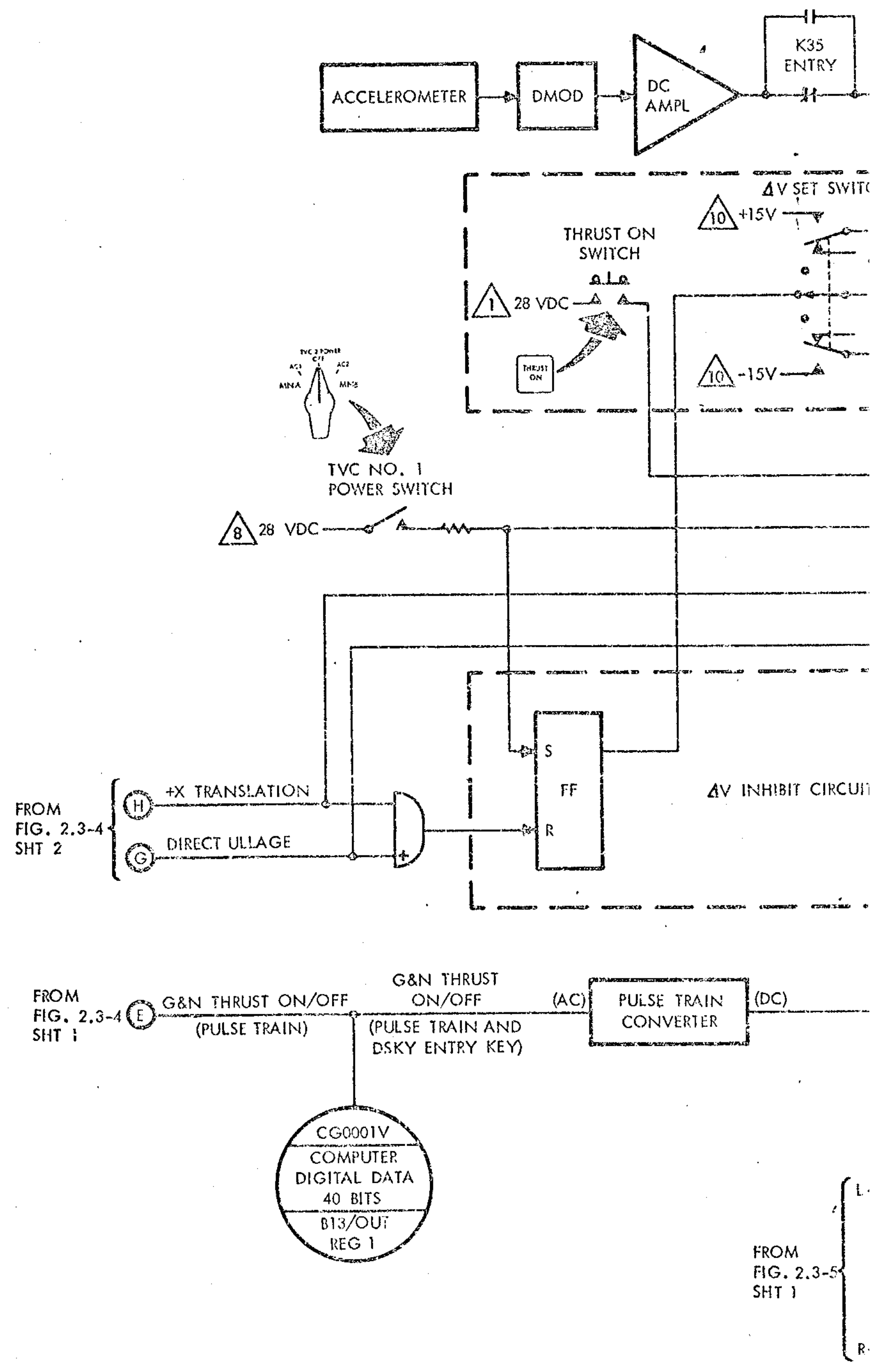
Figure 2.3-4. SCS Functional Flow Diagram (Sheet 4 of 4)



AMPL
ΔV MOTOR, CLOCK, AND OUTPUT LOGIC
K36 ΔV INH
MOT
COINCIDENCE SWITCH
+28 VDC
ΔV POT
ΔV COUNTER
CH3186V
DV REMAINING POT-OUT
-3/+13 KFPS
ΔV DISPLAY PANEL
0 0 0 1 0
LATCH
+X TRANSLATION
DIRECT ULLAGE
ULLAGE
G&N
G&N THRUST SIG
MODE
RLY DVR
K36 ΔV INH
THRUST ON SWITCH
THRUST ON SW
SCS
COINCIDENCE SWITCH (OPEN)
G&N THRUST ON/OFF
G&N ΔV
SCS ΔV
OVERRIDE/ RESET
FCSM
K37A K37B
K37A K37C
K37B K37C
SPS ROUGH ECO
28 VDC C&W SYSTEM



K35
ENTRY
ACCELEROMETER
DMOD
DC
AMPL
ΔV SET SWIT
+15V
THRUST ON
SWITCH
28 VDC
-15V
TVC NO. 1
POWER SWITCH
28 VDC
S
FF
R
ΔV INHIBIT CIRCUI
FROM
FIG. 2.3-4
SHT 2
+X TRANSLATION
DIRECT ULLAGE
FROM
FIG. 2.3-4
SHT 1
G&N THRUST ON/OFF
(PULSE TRAIN)
G&N THRUST
ON/OFF
(PULSE TRAIN AND
DSKY ENTRY KEY)
(AC)
PULSE TRAIN
CONVERTER
(DC)
CG0001V
COMPUTER
DIGITAL DATA
40 BITS
B13/OUT
REG 1
FROM
FIG. 2.3-5
SHT 1

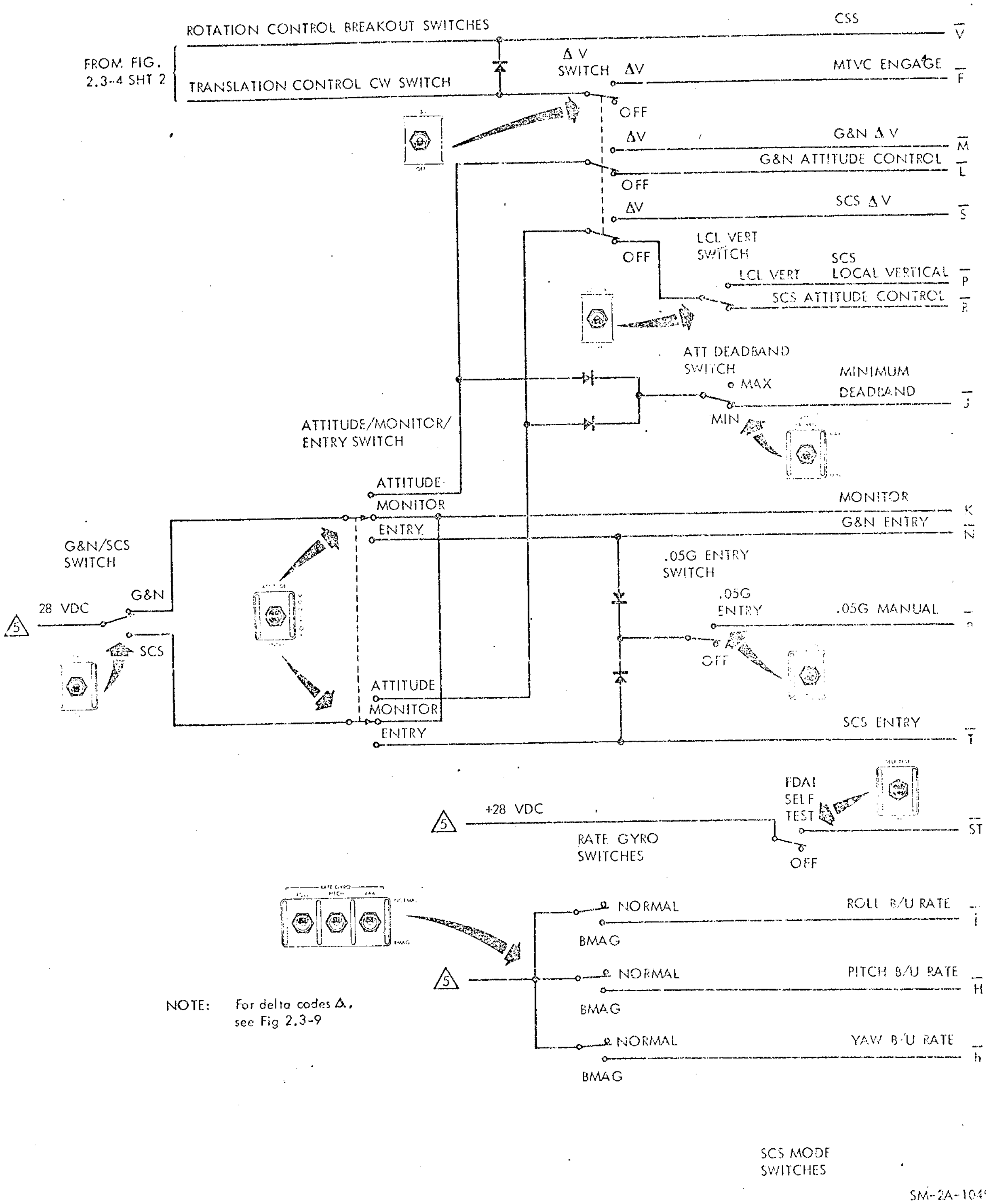


Figure 2.3-5. SCS Switching Logic (Sheet 1 of 4)

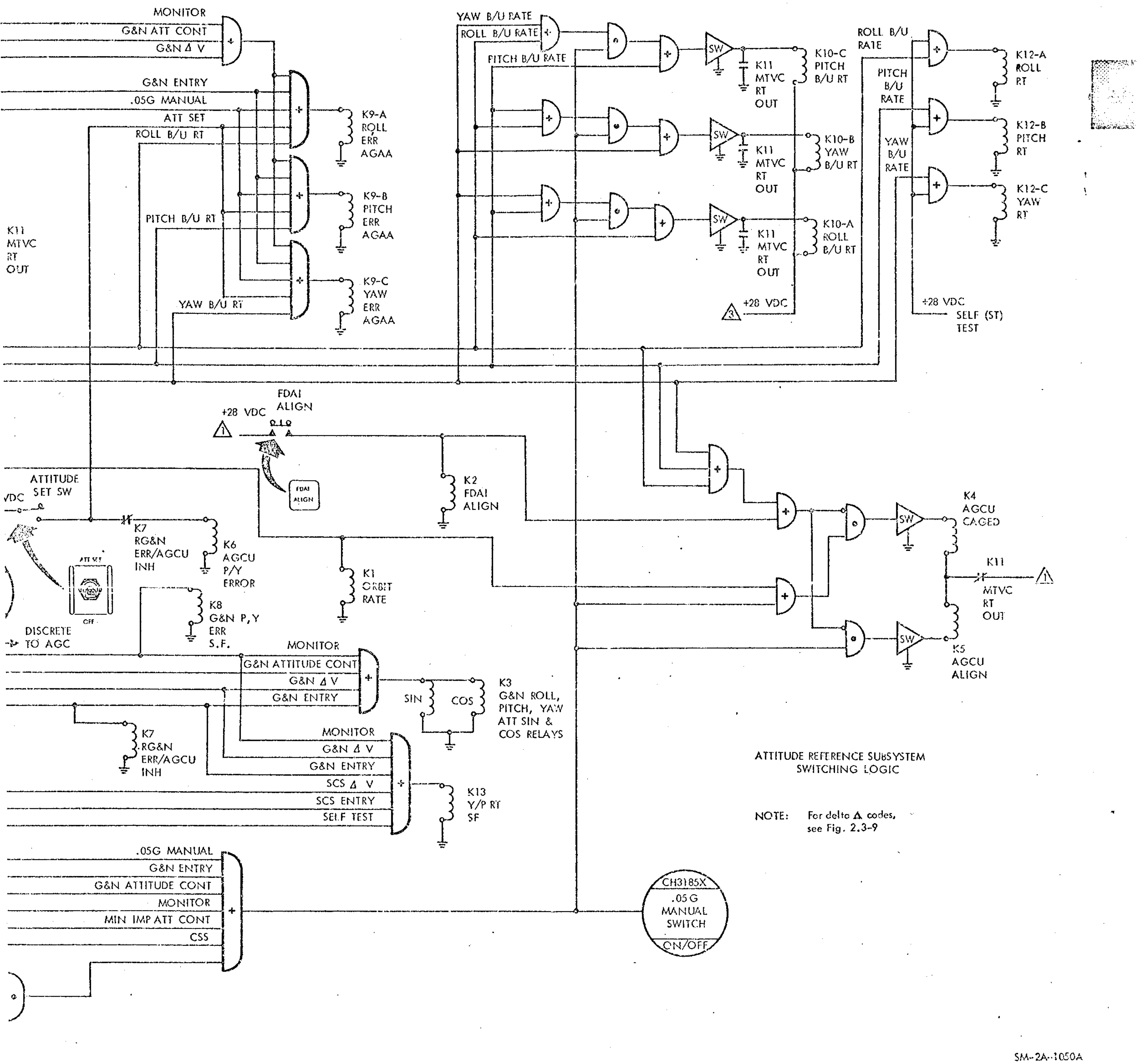
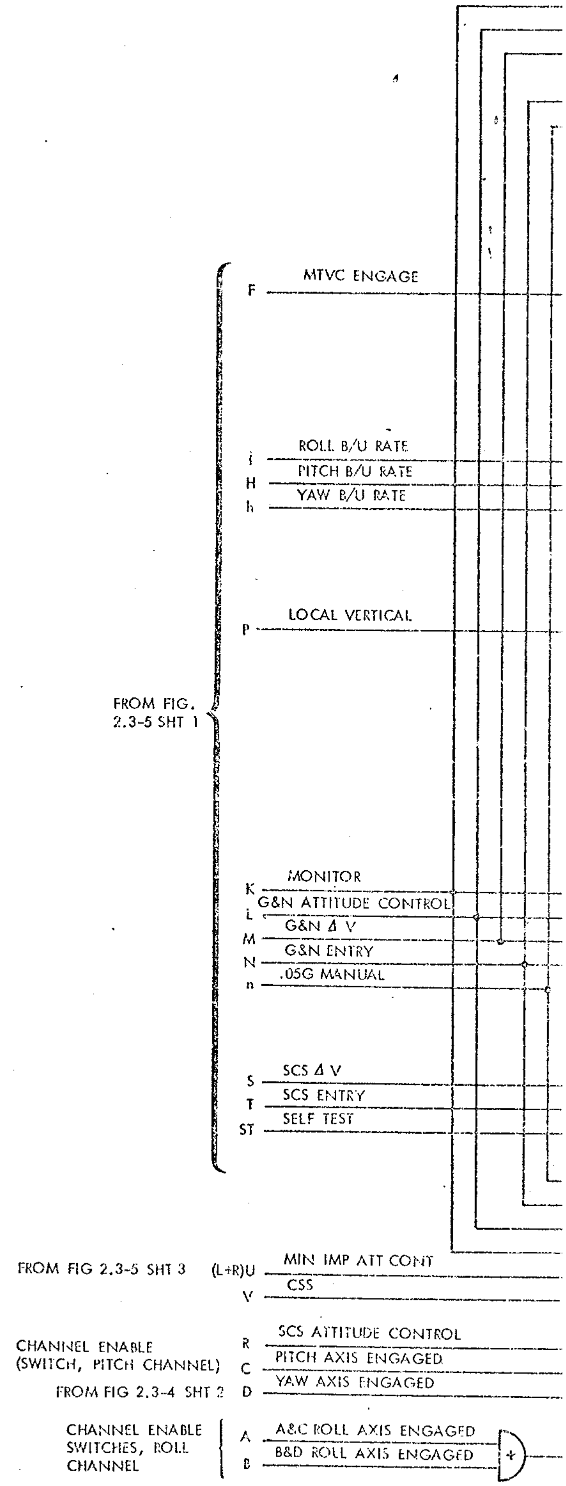


Figure 2.3-5. SCS Switching Logic (Sheet 2 of 4)


MTVC ENGAGE
F
ROLL B/U RATE
PITCH B/U RATE
YAW B/U RATE
i
H
h
LOCAL VERTICAL
P
FROM FIG.
2.3-5 SHT 1
MONITOR
G&N ATTITUDE CONTROL
G&N Δ V
G&N ENTRY
.05G MANUAL
K
L
M
N
n
SCS Δ V
SCS ENTRY
SELF TEST
S
T
ST
FROM FIG 2.3-5 SHT 3
(L+R)U
V
MIN IMP ATT CONT
CSS
CHANNEL ENABLE
(SWITCH, PITCH CHANNEL)
FROM FIG 2.3-4 SHT 2
R
C
D
SCS ATTITUDE CONTROL
PITCH AXIS ENGAGED
YAW AXIS ENGAGED
CHANNEL ENABLE
SWITCHES, ROLL
CHANNEL
A
B
A&C ROLL AXIS ENGAGED
B&D ROLL AXIS ENGAGED
+

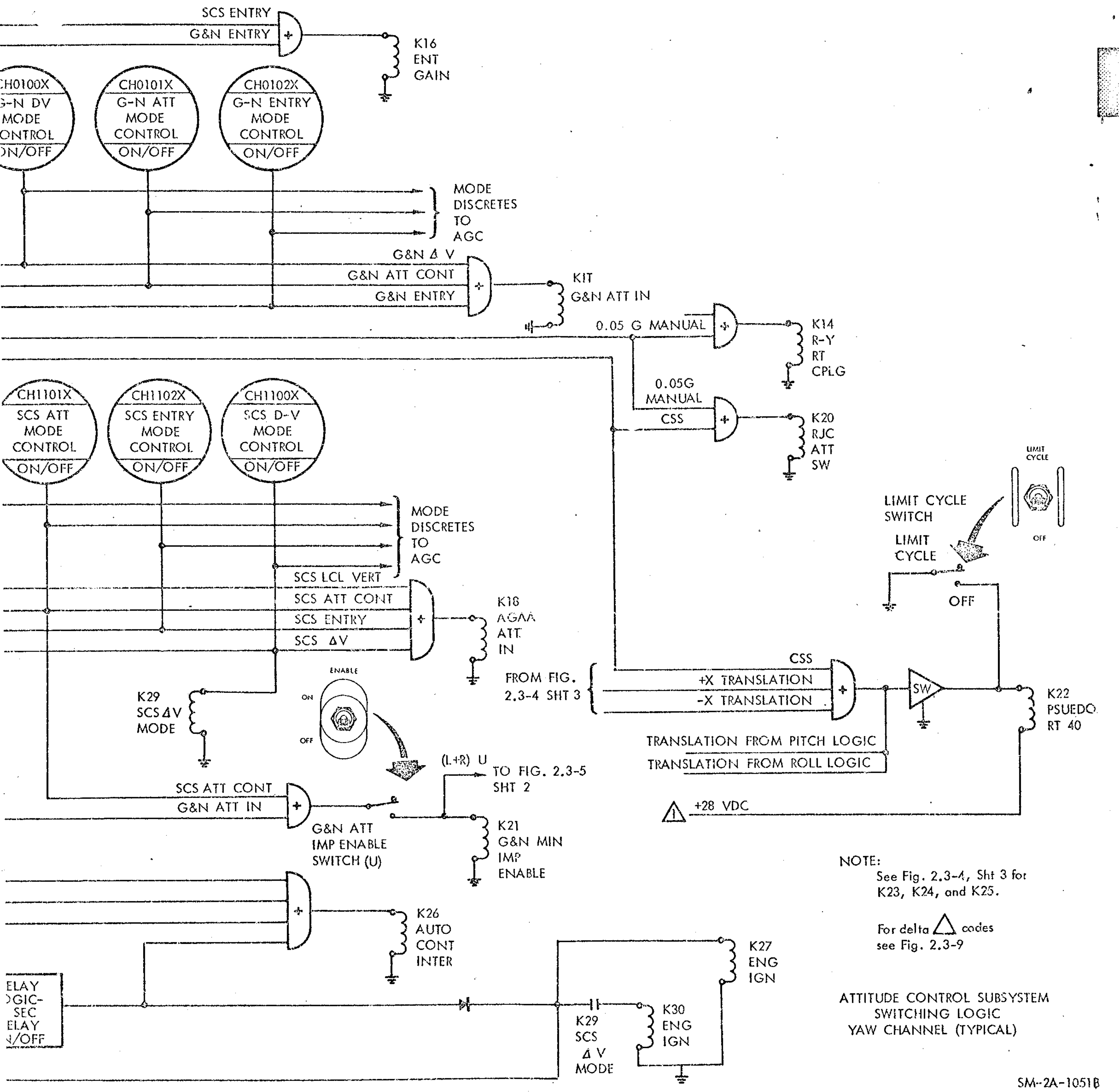
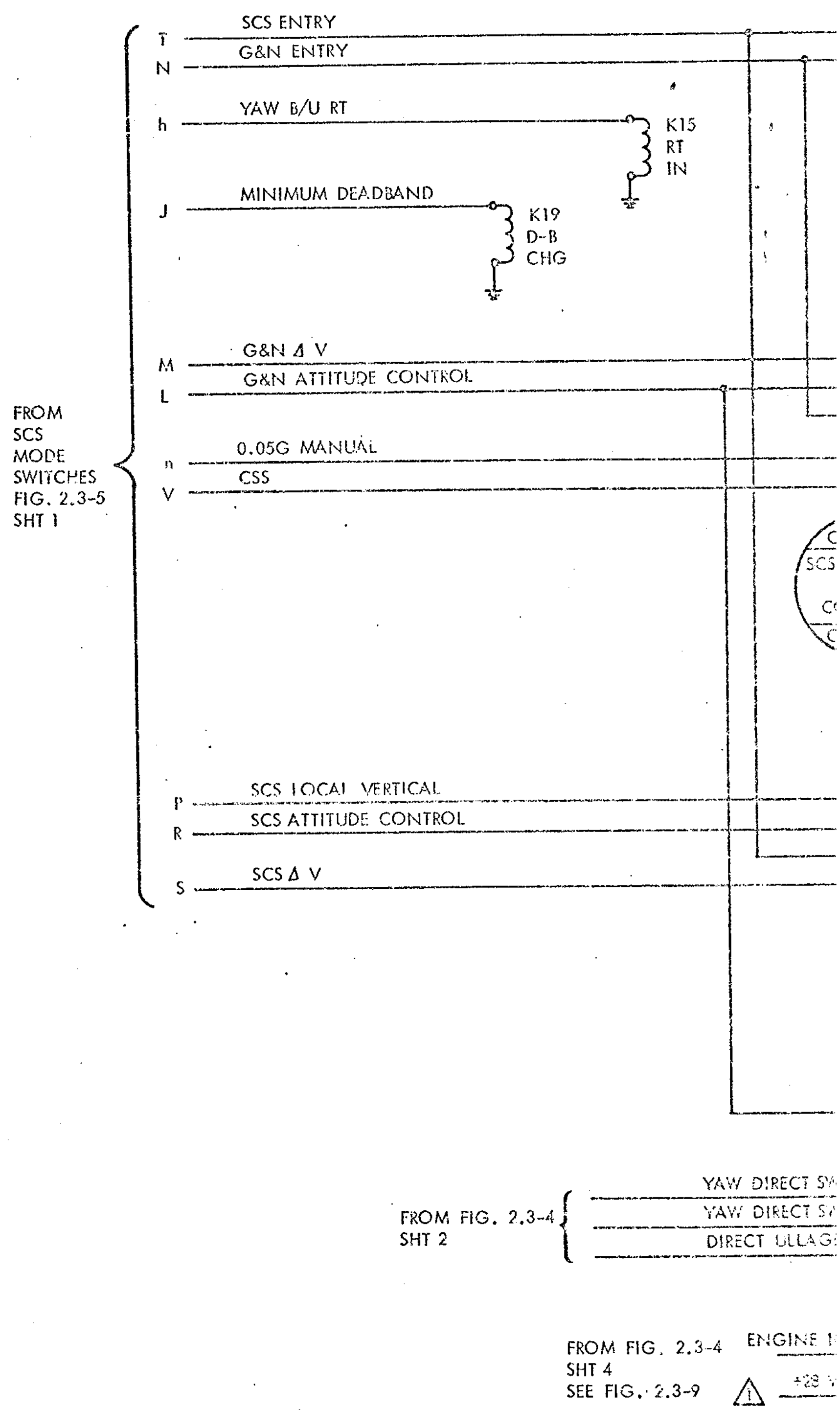


Figure 2.3-5. SCS Switching Logic (Sheet 3 of 4)



SCS ENTRY
G&N ENTRY
YAW B/U RT
K15
RT
IN
MINIMUM DEADBAND
K19
D-B
CHG
G&N Δ V
G&N ATTITUDE CONTROL
FROM
SCS
MODE
SWITCHES
FIG. 2.3-5
SHT 1
0.05G MANUAL
CSS
SCS LOCAL VERTICAL
SCS ATTITUDE CONTROL
SCS Δ V
T
N
h
J
M
L
n
V
P
R
S
FROM FIG. 2.3-4
SHT 2
FROM FIG. 2.3-4
SHT 4
SEE FIG. 2.3-9

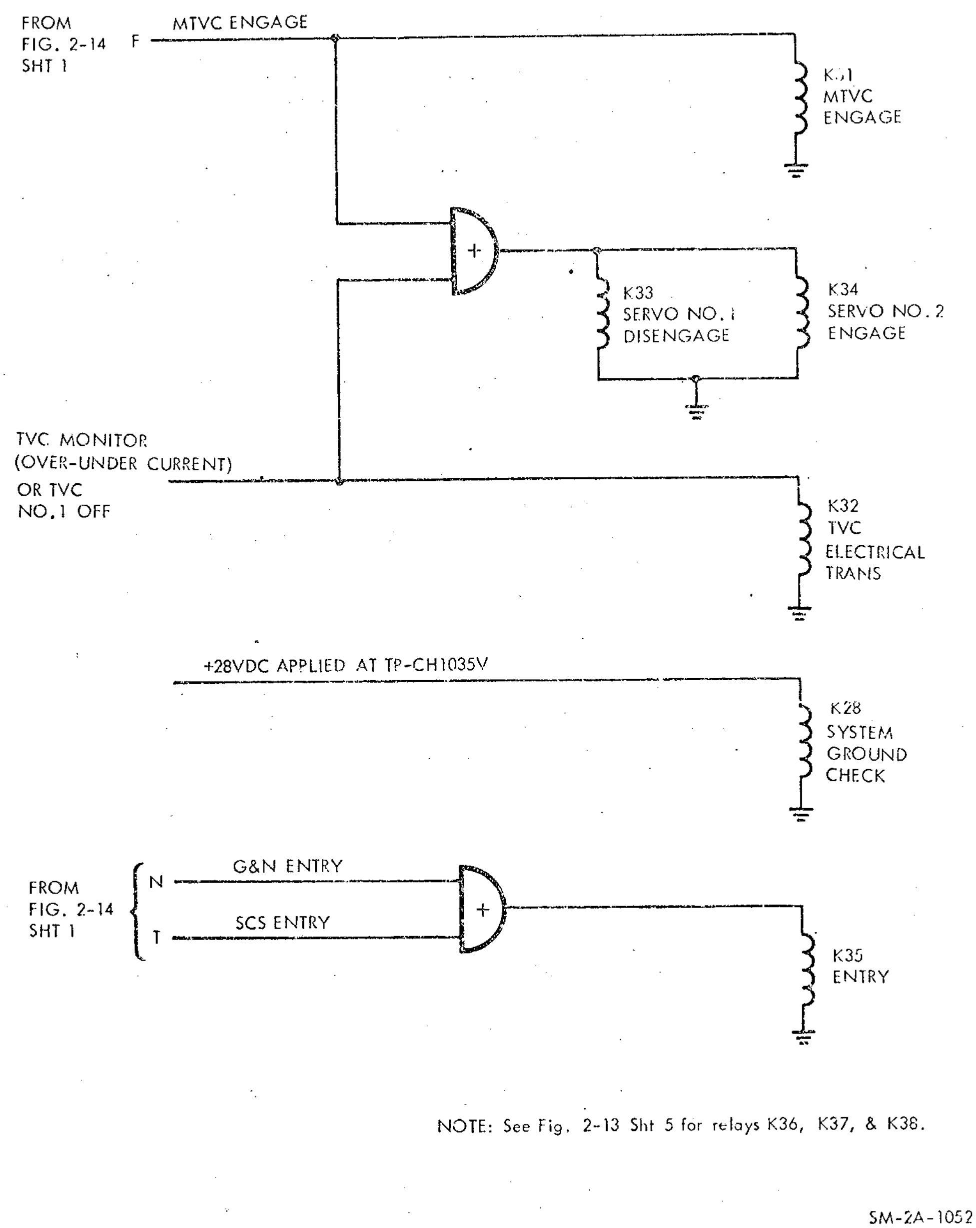


Figure 2.3-5. SCS Switching Logic (Sheet 4 of 4)

Inertial reference data may also be received by the astronauts via the MSFN voice link for AGC updating and/or for IMU alignment. With the computer subsystem in the G&N loop, automatic maneuvers and/or G&N-controlled velocity changes are possible.

The FDAI receives total attitude and attitude error information from the G&N system. The FDAI indicates S/C total attitude (S/C reference attitude) and attitude error. Total attitude represents the gimbal angles of the IMU; and attitude error is the difference between the IMU gimbal angles and the desired attitude. The desired attitude is obtained by maneuvering the S/C either manually or automatically in the directions that null out the indicated errors. This establishes S/C attitude to the desired inertial reference. The FDAI also displays rotational rates obtained from the SCS rate gyros. The SCS rate gyros supply rate information for all G&N and SCS control and display functions.

In G&N modes, the FDAI ball is continuously controlled by signals from the IMU gimbal angle resolvers. In SCS modes, the ball is controlled by the AGCU total angle resolvers. AGCU signals are applied to the ball only during manually initiated attitude changes (assuming none of the BMAGs are rate caged) and in the SCS entry mode after 0.05 G switching. At all other times, the ball remains stationary. The ball is always driven with reference to the IMU axes with the AGCU providing the conversion for the BMAGS from body axes to IMU axes.

Attitude Reference/SCS. If the IMU cannot be used for attitude reference, a backup or strapdown attitude reference comprised of assemblies contained within the SCS will provide inertial attitude reference. The strapdown reference is mechanized within the following:

- Attitude Gyro Accelerometer Assembly (AGAA)

  Contains the body-mounted attitude gyros (BMAGS), X-axis accelerometer, and self-contained electronics. Provides attitude error signals for the attitude control subsystem, AGCU, and FDAI. The BMAGS are also a source for backup rate signals, if required.

- Rate Gyro Assembly (RGA)

  Provides angular rate signals to the attitude control (ACS) subsystems and to the FDAI.

- Attitude Set/Gimbal Position Indicator (AS/GPI)

  The AS section provides a capability to set in desired reference attitudes and align the ARS to those attitudes. The GPI section allows the astronauts to manually position the SPS engine gimbals to a trim position prior to a delta V maneuver.

- Display/Attitude Gyro Accelerometer Assembly Electronic Control Assembly (D/AGAAECA)

  AGAA section: Contains electronics required to operate the BMAGS and to interface with the AGCU

  DECA section: Provides the interface electronics between all sensors and corresponding displays

- Auxiliary Electronic Control Assembly (AECA)

  AGCU section: Performs the mathematical computations and contains the transformation matrices required to display attitude and attitude errors of the S/C. The AGCU is the primary control device for the SCS ARS.

  The remainder of the AECA contains circuitry for the SPS engine thrust ON/OFF control function.

- Flight Director Attitude Indicator (FDAI)

  The FDAI (figure 2.3-12) provides the visual displays for S/C attitude; included is total attitude readout (FDAI ball) gimbaled in three axes: roll, pitch, and yaw.

  Pitch and yaw total attitude is read from either the body axes index (ν) or the navigation axes index (©). The indices are fixed to the instrument faceplate. Roll is indicated by a roll bug (indicator needle driven by the roll gimbal through a gear mechanism). Roll attitude is read by comparing the roll bug position with reference to a scaled bezel ring about the instrument periphery.

  Attitude errors are indicated by three fly-to needles.

  Angular rates are indicated by three fly-to needles.

  A + roll rate or + roll error will cause those needles to deflect left. A - roll rate or - roll error will cause the needles to deflect right.

  A + pitch rate or + pitch error will cause those needles to deflect down. A - pitch rate or - pitch error will cause the needles to deflect up.

  The yaw rate and error needles deflect in the same directions as the roll needles.

  To correct the error, the S/C is automatically or manually rotated in the direction of needle deflection.

The SCS attitude reference subsystem is mechanized such that it is used primarily for monitoring S/C attitude. Consequently, automatic maneuvering is not possible when SCS modes of operation are selected. However, by using the FDAI as a monitor and by proper selection of controls, precision manual maneuvers can be performed.

The subsystem, acting as a strapdown reference, will supply all of the attitude data normally available from the IMU. These data are subsequently applied to the FDAI for presentation of S/C attitude. The IMU is a three-gimbal platform and therefore will achieve a gimbal lock condition. The middle and outer gimbals become parallel and the output is not predictable. The AGCU has a similar function which creates an effective gimbal lock. This occurs in both systems for a 90-degree yaw displacement with respect to the navigation base. The FDAI and yaw attitude set control provides markings that will serve as a warning prior to achieving a gimbal-lock condition.

Basically, the body-mounted attitude gyros (BMAGS), attitude gyro coupling unit (AGCU), and the FDAI are the primary inertial sensing, computing, and display elements of the strapdown system. Attitude errors in roll, pitch, and yaw body axes are sensed by the body-mounted attitude gyros. The error signals are conditioned and subsequently directed to the FDAI for display of total attitude and attitude error. The major part of the conditioning takes place in the AGCU which provides signal inputs to the FDAI comparable to that of the IMU.

The AGCU section of the auxiliary electronic control assembly is the primary control or computing device for the SCS attitude reference subsystem. It performs most of the inertial reference computations and performs the mathematical conversions and transformations required to display total attitude and attitude error. The attitude gyro torquing loop, that the AGCU electromechanical elements are a part of, perform the following:

- Generate a pulse train that is equivalent to the total change in S/C attitude
- Provide two-directional control of resolver shaft angles
- Provide torquing current for the attitude gyros
- Provide forward and reverse conversion of gyro and attitude set error signals to appropriate axes representation for FDAI display, and for gyro torquing.

The SCS rate gyros sense vehicle angular velocity, and supply angular rate signals to the system for rate stabilization and to the FDAI rate indicators. The proper selection of switches will place the BMAGS in a backup-rate condition, and provide rate signals to the FDAI rate indicators. Whenever manual thrust vector control is selected, the BMAGS will automatically be placed in the backup-rate condition.

Attitude Reference Control. After a maneuver or a series of maneuvers, the S/C attitude (body axes) is, each time, different with respect to the inertial reference frame. Therefore, the requirement exists for a method of resolving the rotations about the different body axes, and establish a relationship between the body axes and the axes of the fixed reference frame. This relationship is established through an Euler angle transformation process obtained from either the IMU (stable element) or the strapdown attitude reference subsystem. The Euler angle, then, is the resolved difference between the S/C body axes coordinates and the coordinate's of the fixed inertial reference. The Euler angle attitude of the S/C, as displayed on the FDAI, is with respect to the coordinates of the fixed reference frame.

The conversion from body axes to Euler angle readout on the FDAI, basically, consists of a forward transformation and a reverse transformation. (See figure 2.3-3.) The forward transformation is essentially body-to-navigation axes conversion, then navigation axes-to-Euler angle transformation by resolvers in the AGCU. The resolvers and gimbal servos in the FDAI position the total attitude displays, resulting from the Euler errors. The reverse transformation is essentially Euler angle-to-navigation axes transformation by resolvers in the AGCU, then navigation-to-body axes conversion for signal application to the attitude gyro torquing amplifiers. After amplification, the signals are demodulated and applied to the gyro torquing coils which torque the gyros to null the original error.

After initial alignment to the IMU reference, the BMAG/AGCU loop is opened by relay action and further positioning of the FDAI ball is prevented. However, if the rotation control, for example, is displaced, the loop will be closed and the FDAI ball will follow S/C motion until the control is neutralized. The BMAG/AGCU loop will open and the ball will again be stationary. If in G&N mode, the FDAI ball is always coupled to represent and follow IMU gimbal angles.

<u>Attitude Errors</u>. The FDAI attitude error indicators represent the difference between actual S/C attitude and the inertial reference. The error is referenced to the S/C body axes in all modes of operation, except for G&N entry mode.

Signals that position the attitude error indicator of the FDAI come from three possible sources. (See figures 2.3-3 and 2.3-4.) In SCS modes, either the BMAGS or the AGCU provide body axes error signals to the error indicator meter movements. AGCU signals are applied when ATT SET is selected on the attitude set section of the AS/GPI. This applies the body axes equivalent of the difference between the attitude set resolver shaft and the AGCU resolver shaft.

When ATT SET is not selected, the outputs of the three BMAGS are applied to the attitude error meter movements of the FDAI. Whether from the BMAGS or the AGCU, the error signals are directed to the meter movements through scaling, range adjust, demodulator, and amplifier circuits. The following chart provides mode versus full-scale error indications as read on the FDAI.

Mode	Roll	Pitch	Yaw
Monitor	±25°	±15°	±15°
SCS and G&N Entry	±25°	±5°	±5°
All other modes	±5°	±5°	±5°

When G&N modes are selected, the error signals are directed to the FDAI via the inertial coupling display units (CDUs) and the attitude reference conversion circuitry. The roll and yaw channel signals are referenced to either the navigation base axes or the S/C body axes. Conversion in the pitch channel is not required. The capability to reference the roll and yaw channel signals to either the navigation base of S/C body axes is required to facilitate roll and yaw channel cross-coupling control. This is required when G&N entry maneuvers are performed; in which case, reference is to the navigation base axes.

Rates. The following chart provides mode versus full-scale rate indications as read on the FDAI.

Modes	Roll	Pitch	Yaw
Monitor SCS Entry G&N Entry	±25°/sec	±5°/sec	±5°/sec
SCS LCL Vert or SCS ATT Cont or G&N ATT Cont	±1°/sec	±1°/sec	±1°/sec
SCS and G&N V	±5°/sec	±5°/sec	±5°/sec

SCS Attitude Reference Alignment. Alignment of the attitude reference subsystem is performed by comparing the outputs of the total attitude set resolvers in the AGCU with the attitude set resolvers of the AS/GPI. The attitude set resolver shaft can be positioned by using the attitude set dials (thumbwheels) on the front of the AS/GPI. The dials indicate Euler angle of the attitude set resolver shaft, and the output of the resolver is the Euler angle difference between the attitude set resolvers and the total attitude resolvers in the AGCU.

When the FDAI ALIGN switch on the AS/GPI panel is pressed, the AGCU resolvers will align to the attitude set resolvers. Euler-to-navigation axes transformation, and navigation axes-to-body axes conversion takes place for the FDAI attitude error display functions. In SCS control modes, the attitudes indicated on the attitude set dials will be indicated on the FDAI with respect to the navigation axes symbol and the roll index.

2.3.2.3.2 Attitude Control Subsystem.

The attitude control subsystem (ACS) (figures 2.3-4 and 2.3-5), essentially, provides the means for controlling spacecraft motion. Control is either manual or automatic when using controlled inputs from the G&N system. Spacecraft motion, other than drift, is initiated through the use of the S/M RCS jets prior to C/M-S/M separation. After separation (entry), the C/M RCS jets are used. An attitude control logic chart is presented in figure 2.3-6.

There are four types of controls that the ACS contends with which to satisfy mission requirements. (See figures 2.3-4 and 2.3-7.) These are rotation, translation, attitude hold, and rate damping only. Rotational motion is required to establish navigational sightings with the G&N optics subsystem telescope and sextant for S/C alignment prior to a velocity change for TVC functions, for antenna orientation, for T/C transmission and reception, and for lift vector control (roll control plus pitch and yaw rate stabilization) during entry.

Translation control for the AS204A mission is required for the ullage function prior to SPS engine ignition.

Holding attitude (attitude hold) to a fixed reference (established by the ARS) is necessary for navigational sightings, preparing for a velocity change and ullage maneuvers. After establishing attitude hold, the S/C motion involved is the amount of drift that the S/C is allowed to rotate about its axes. The drift is limited to a selectable minimum or maximum deadband about all three axes.

Rate damping only provides rate stabilization during entry or in the event of an abort prior to launch escape system (LES) jettison. The motions involved here are the finite firings of the RCS jets when rotational rates exceed certain limits. The RCS jet firings will decrease the rates to within predetermined limits. The rates are limited to 0.2 degree/sec for all modes, except SCS and G&N entry modes when the rates are increased to 2 degrees/second.

The ACS includes the roll, pitch, and yaw electronic control assemblies (ECAs), the delta V indicator, attitude impulse section of the G&N optics control panel and, in addition, utilizes all of the physical elements and functions of the attitude reference subsystem.

S/M RCS ENGINES

ROLL QUAD & C/M SYSTEM		QUAD A				QUAD B				QUAD C				QUAD D			
ENGINE NO.		2	3	13	16	7	6	9	12	1	4	14	15	8	5	10	11
ROTATION	PITCH UP		●							●							
	PITCH DOWN	●									●						
	YAW RIGHT					●									●		
	YAW LEFT						●							●			
	ROLL RIGHT			●				●					●				●
	ROLL LEFT				●				●			●				●	
TRANSLATION	+X	●					●			●					●		
	-X		●			●					●			●			
	+Y			●								●					
	-Y				●								●				
	+Z							●								●	
	-Z								●								●
SCS CIRCUIT BREAKERS*		MN A	MN B	MN A		MN A	MN B	MN A		MN A	MN B	MN B		MN A	MN B	MN B	
		PITCH		A&C ROLL		YAW		B&D ROLL		PITCH		A&C ROLL		YAW		B&D ROLL	
SCS CHANNEL PITCH AND YAW SWITCHES		PITCH		A&C ROLL		YAW		B&D ROLL		PITCH		A&C ROLL		YAW		B&D ROLL	

C/M RCS ENGINES

ROLL QUAD & C/M SYSTEM		SYSTEM A						SYSTEM B					
ENGINE NO.		1	2	5	8	9	12	3	4	6	7	10	11
ROTATION	PITCH UP	●						●					
	PITCH DOWN		●						●				
	YAW RIGHT			●							●		
	YAW LEFT				●					●			
	ROLL RIGHT					●							●
	ROLL LEFT						●					●	
TRANSLATION	+X, -X, +Y, -Y, +Z, -Z	TRANSLATION MANEUVERS NOT APPLICABLE TO C/M RCS											
SCS CIRCUIT BREAKERS*		MN A		MN A		MN A		MN B		MN B		MN B	
		PITCH		YAW		B&D ROLL		PITCH		YAW		B&D ROLL	
SCS CHANNEL PITCH AND YAW SWITCHES		PITCH		YAW		B&D ROLL		PITCH		YAW		B&D ROLL	

* CIRCUIT BREAKER TABULATION IS APPLICABLE TO RCS ENGINES AUTOMATIC COIL OPERATION ONLY. FOR MANUAL DIRECT COIL OPERATION, POWER IS APPLIED FROM SCS DIRECT CONT CIRCUIT BREAKERS MN A OR MN B BY ACTUATION OF THE PILOTS OR CO-PILOTS HAND CONTROLLER, RESPECTIVELY.

NOTES:

1. Combinations of translation and rotation maneuvers requiring the simultaneous firing of identical S/M RCS engines is prohibited by jet selection logic circuit design.
2. Minimum impulse operation is accomplished in the roll axis by two engines only. Remaining engines are disabled by setting the A&C ROLL CHANNEL switch to OFF and pulling one B&D ROLL circuit breaker; or setting the B&D ROLL CHANNEL switch to OFF and pulling one A&C ROLL circuit breaker.
3. Fuel conservation and/or consumption balance between quads may be accomplished by using applicable SCS CHANNEL switches and circuit breakers to select single-engine operation in each direction.

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Figure 2.3-6. SCS Attitude Control Logic Chart

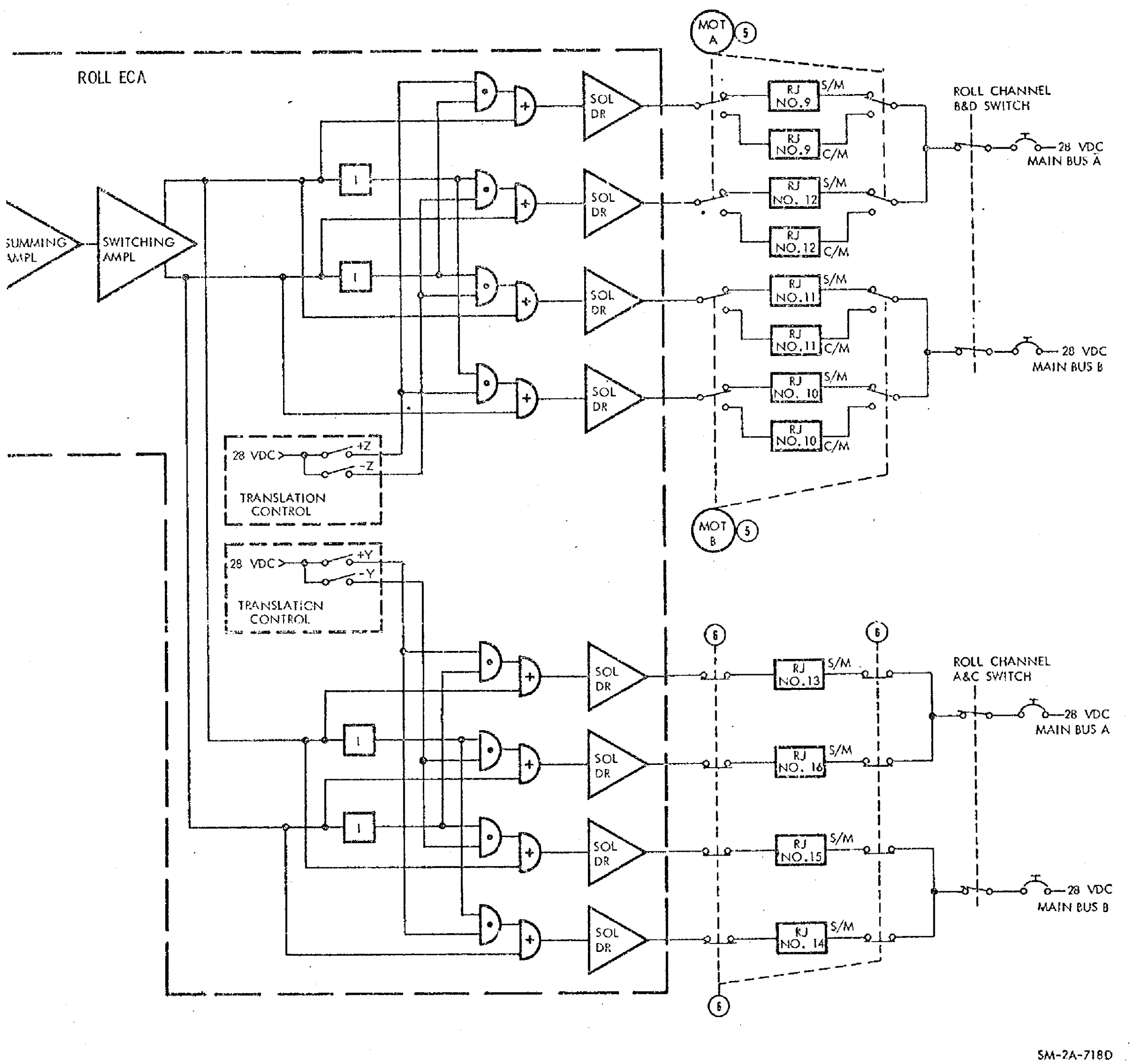
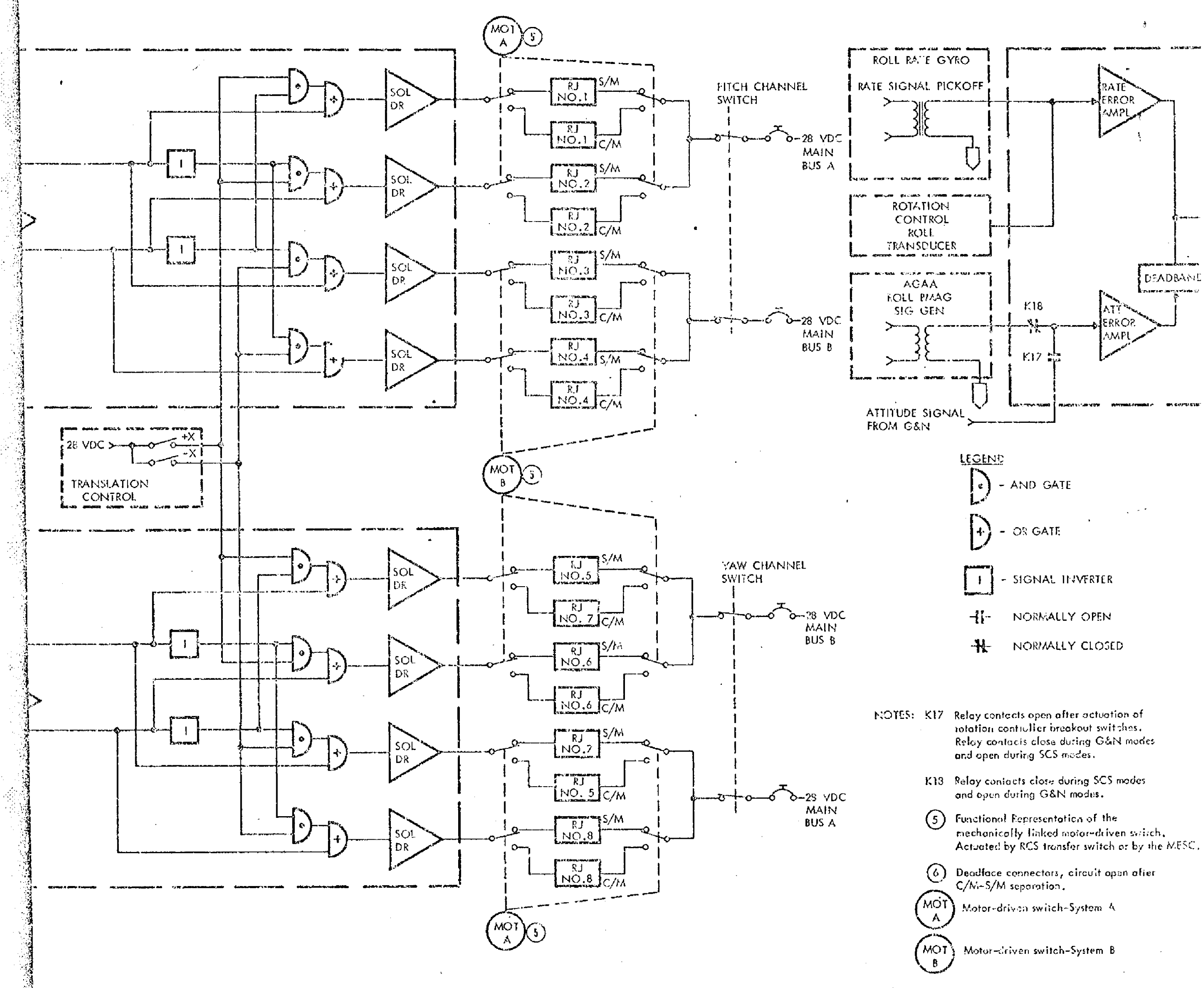
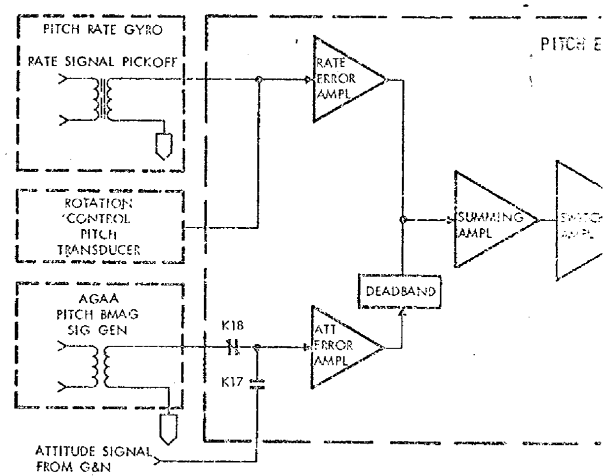
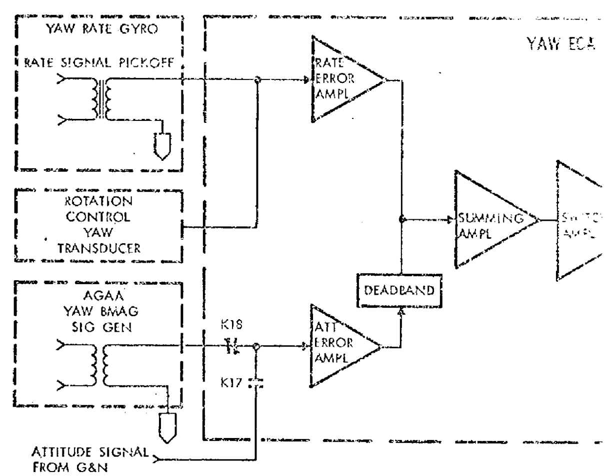


Figure 2.3-7. Jet Selection Logic Functional Flow Diagram


MOT A (5)
RJ NO.1 S/M
RJ NO.1 C/M
RJ NO.2 S/M
RJ NO.2 C/M
RJ NO.3 S/M
RJ NO.3 C/M
RJ NO.4 S/M
RJ NO.4 C/M
SOL DR
PITCH CHANNEL SWITCH
28 VDC MAIN BUS A
28 VDC MAIN BUS B
ROLL RATE GYRO
RATE SIGNAL PICKOFF
ROTATION CONTROL ROLL TRANSDUCER
AGAA ROLL PMAG SIG GEN
K18
K17
RATE ERROR AMPL
ATT ERROR AMPL
DEADBAND
ATTITUDE SIGNAL FROM G&N
28 VDC
+X
-X
TRANSLATION CONTROL
MOT B (5)
RJ NO.5 S/M
RJ NO.7 C/M
RJ NO.6 S/M
RJ NO.6 C/M
RJ NO.7 S/M
RJ NO.5 C/M
RJ NO.8 S/M
RJ NO.8 C/M
YAW CHANNEL SWITCH
28 VDC MAIN BUS B
28 VDC MAIN BUS A
MOT A (5)
LEGEND
- AND GATE
- OR GATE
- SIGNAL INVERTER
NORMALLY OPEN
NORMALLY CLOSED
NOTES: K17 Relay contacts open after actuation of rotation controller breakout switches. Relay contacts close during G&N modes and open during SCS modes.
K18 Relay contacts close during SCS modes and open during G&N modes.
(5) Functional Representation of the mechanically linked motor-driven switch. Actuated by RCS transfer switch or by the MESC.
(6) Deadface connectors, circuit open after C/M-S/M separation.
MOT A Motor-driven switch-System A
MOT B Motor-driven switch-System B



PITCH RATE GYRO
RATE SIGNAL PICKOFF
ROTATION CONTROL PITCH TRANSDUCER
AGAA PITCH BMAG SIG GEN
K18
K17
ATTITUDE SIGNAL FROM G&N
RATE ERROR AMPL
ATT ERROR AMPL
DEADBAND
SUMMING AMPL



YAW RATE GYRO
RATE SIGNAL PICKOFF
ROTATION CONTROL YAW TRANSDUCER
AGAA YAW BMAG SIG GEN
K18
K17
ATTITUDE SIGNAL FROM G&N
RATE ERROR AMPL
ATT ERROR AMPL
DEADBAND
SUMMING AMPL
YAW ECA

The attitude control subsystem electronics is contained within the roll, pitch, and yaw ECAs. The ECAs accept the manual and automatic inputs, conditions them, and directs on-off electrical command signals through jet selection logic to appropriate automatic (normal) coils of the RCS jets. The output of the jet selection logic will be either a time-modulated signal or a steady-state +20-vdc signal.

There are basically two types of inputs to the attitude control subsystem: manual and inertial sensor (AGAA, RGA, IMU). Manual inputs are provided by the rotation and translation controls, switches on the SCS control panel, attitude impulse switch on the attitude impulse section of the G&N optics control panel, and the direct ullage switch on the delta V display panel. These controls can be used for manual ullage maneuvers or as a backup during automatic delta V functions. The attitude impulse switch commands inputs to the ACS and subsequently to the RCS jets for small angular accelerations.

The inertial sensor inputs are provided by the AGAA, RGA, and the IMU via the G&N system. The AGAA (BMAG) and rate gyros (RGA) inputs are used for attitude hold, rate stabilization, and manual rotation control. The IMU inputs provide G&N attitude hold and command rate signals for manual or automatic rotational maneuvers.

Rotation Maneuvers. Rotation maneuvers can be performed by using four different types of manual controls or automatically by using the G&N computer subsystem. Manual rotation maneuvers are accomplished by using the rotation control, commonly called control stick steering (CSS), direct or emergency control which is a function of the rotation control, attitude impulse control, and positioning of the inertial CDUs. Automatic maneuvers result from astronaut inputs to the AGC via the DSKY. The AGC, according to computer program, automatically positions the CDUs and will command S/C motion to the programmed attitude.

Normal CSS is a proportional manual function and is available at any time in all operational modes. The maximum CSS proportional rates that can be commanded are as follows:

- 19 degrees per second (roll axis) entry mode
- 5 degrees per second (pitch and yaw axes) entry mode
- 0.79 degree per second (all axes) all other modes.

Even though CSS commands greater rates, the SCS electronics will limit the rates to those values given. Proportional control is obtained by using the rate gyro output to cancel the output of a transducer within the rotation control. CSS proportional commands are always directed to the automatic solenoid coils of the RCS engines.

When the rotation control (stick) is displaced, a transducer within the stick will command a rotation proportional to the amount of stick displacement. The rotational rates are limited to predetermined values, depending on the operational mode.

When in SCS attitude control mode and as the stick is displaced approximately 2.5 degrees from neutral, breakout switches within the stick close causing the BMAG and the AGCU to become closed loop. It also inhibits BMAG error signals to the SCS electronics. As the S/C rotates, the AGCU applies torquing current to the BMAG torquer coils. The gyros, then, are torqued at a rate proportional to the magnitude of BMAG error, keeping attitude error at approximately zero. Thus, the AGCU will follow S/C motion and establish a new attitude reference when the stick is returned to neutral.

When in G&N attitude control mode, a G&N SYNC switch must be energized to enable the attitude hold function when the control stick is returned to neutral. The G&N sync function provides IMU/CDU closed loop operation which keeps attitude errors at approximately zero during the maneuver. Consequently, the S/C will hold the new attitude when the stick is returned to neutral. If G&N sync is not enabled, the S/C will return to the attitude established before stick displacement.

NOTE For the AS204A mission the G&N SYNC switch will remain OFF for the entire mission.

The computer program will control the actual maneuver rate, but the SCS will limit the maximum. The maximum non-entry maneuver rate is 10°/second and entry maneuver rate is 17°/second in all axes.

Direct rotation control is a nonproportional function whereby initiated commands are applied directly to the RCS direct coils. To accomplish direct rotation, the DIRECT RCS/OFF switch (MDC-8) is set to DIRECT RCS; the SCS-CHANNEL switches (MDC-8) are set to OFF; if high rates are to be maintained, and the control stick is rotated about the desired axis or axes to hardstops. Just prior to engaging the hardstops, a switch closes and applies a direct command to the RCS direct coils. Rate feedback is not used to cancel stick movement. The breakout switches, however, close the BMAG/AGCU loop, and attitude error output to the SCS electronics is inhibited. With proper control and switch configuration, direct control is available at any time.

The attitude impulse control (G&N optics control panel) provides the capability for commanding low-rotational rates about all three axes. Attitude impulse control is available only in SCS or G&N attitude control modes and is used primarily for precise attitude maneuvers during navigational or star sighting periods. After the control is enabled and displaced, a switch closure in the control and an RC network combination generate one pulse, which is applied to the RCS jet selection logic. One pulse is generated for each attitude impulse switch closure (control displacement). It is not a proportional control and attitude hold is not available when the control is returned to neutral. When the control is enabled, relay action removes all rate, attitude error, and rotation control inputs to the SCS electronics.

Automatic positioning of the CDUs is accomplished by using the DSKY. This method of control is primarily used during G&N entry.

Translation Maneuvers. There are three methods of initiating translation maneuvers: normal translations, using the translation control; direct ullage, using the direct ullage button on the delta V control panel; and separation ullage, using the translation control.

Translation commands are not proportional; operation is through switch closure only and is available during all modes of operation prior to C/M-S/M separation. During normal translation, switch closures within the translation control provide commands to the jet selection logic which fire the appropriate jets for the desired direction of translation. The commands are directed to the automatic RCS engine coils. A primary function of normal translation is the ullage maneuver, which is necessary in preparation for a velocity change. Ullage maneuvers require translation along the +X-axis.

Direct ullage is accomplished by using the DIRECT ULLAGE pushbutton on the delta V control panel. When pressed, switch closures command the appropriate direct RCS coils to initiate translation along the +X-axis. Direct ullage is available at any time prior to C/M-S/M separation. Upon C/M-S/M separation, the direct ullage function to the C/M pitch and yaw direct coils is inhibited by deadfacing. It is primarily a backup operation in the event of normal translation failure. Ullage will continue as long as the DIRECT ULLAGE pushbutton is pressed.

The separation ullage function requires a CCW rotation of the translation control into a detent position. Ullage commands are directed to the direct RCS coils. The separation ullage maneuver is performed when SPS aborts are necessary or when S-IVB separation is required. If the LES has been jettisoned, the signal from the translation control in CCW detent will command the sequential events control system (SECS) to sequence the separation ullage and consequent separation from the S-IVB. If the LES is attached to the S/C, the same command will initiate a LES abort.

In G&N and SCS modes, a clockwise rotation of the translation control into a detent generates a CSS logic signal that inhibits attitude gyro signals from the SCS electronics, and provides BMAG/AGCU closed loop operation. It also initiates manual thrust vector control (MTVC).

The CW rotation enables capability for manual roll control by the rotation controller during G&N entry. This is normally an automatic function of the G&N system and entry program.

Attitude Hold. Attitude hold is a capability of the ACS to hold S/C attitude within selected deadband limits of a fixed reference attitude. The deadband (amount S/C is allowed to drift either side of reference attitude) is selected by setting the ATT DEADBAND switch on MDC8 to either MAX or MIN. In the G&N or SCS entry modes, however, the deadband will be maximum regardless of deadband switch position.

The ACS accomplishes attitude hold by inputting summed attitude error and rate gyro signals to the jet selection logic, which will turn on appropriate jets to keep the S/C within the selected deadband. The attitude error signal is conditioned by a deadband circuit and rate limiter before it is summed at the input of a summing amplifier with the rate gyro signal. When the summed input to the amplifier is greater than its threshold, the amplifier will cause a switching amplifier to pulse the jet selection logic. The lower the angular rates, the closer the S/C is allowed to drift to the deadband limits. As angular rates increase, the summed error/rate signal increases in magnitude proportionate to time. Therefore, the sooner the threshold of the summing amplifier is reached, the sooner the jets will fire, damping the oscillation.

A limit cycle switch on MDC8 can be used to provide time modulated pulses to the jet selection logic. Limit cycle is primarily used for fuel conservation purposes. The limit cycle switch enables a psuedo rate feed-back circuit at the output of the switching amplifier previously discussed. The psuedo rate, and consequently the time-modulated pulses, is a function of signal magnitude at the switching amplifier input. For large signal inputs, the output pulses will cause the RCS jets to pulse at a higher frequency and for longer periods. As the error decreases, the pulse widths and frequency decrease proportionately until the error is nulled.

The psuedo rate loop is normally used at all times (limit cycle on) when an inertial attitude is being maintained.

Attitude hold is available at all times in three axes, except during monitor mode and SCS entry mode after the 0.05 G switching. During G&N entry after 0.05 G switching, roll attitude hold is still enabled. Yaw and pitch attitude hold is inhibited.

Rate Damping Only. In addition to attitude control and maneuvering capabilities, the ACS provides a rate damping only capability. Although rate damping is a normal function during attitude control modes, rate damping can be used to limit S/C rotational rates (rate stabilization) when attitude hold is not being used. Normally, when S/C rotational rates exceed 0.2 degree per second in any axis, the rate gyros or the BMAG in backup rate sense the angular accelerations. The signals, conditioned via the roll, pitch, and yaw ECAs and through jet selection logic, are applied to applicable RCS engines to keep the S/C rates within the 0.2-degree-per-second rate deadband. If in SCS or G&N entry mode, the rate deadband is increased to 2 degrees per second. Rate stabilization, in addition to the attitude control functions, is available when any of the following conditions exist:

- Selection of monitor mode after S-IVB separation
- Selection of monitor mode for LES aborts
- Clockwise rotation of translation control after S-IVB separation
- SCS entry mode after 0.05 G switching
- G&N entry mode after 0.05 G switching (pitch and yaw axes only).

2.3.2.3.3 Thrust Vector Control Subsystem.

The purpose of the thrust vector control (TVC) subsystem (figures 2.3-4 and 2.3-5) is to align or position the gimbaled SPS engine to a trim position prior to SPS thrusting and maintain this trim during the acceleration period. The S/C experiences a changing center of gravity (c.g.) caused by the consumption of fuel and oxidizer during acceleration. The TVC subsystem maintains the SPS engine thrust vector through the c.g. and holds S/C attitude so that the thrust vector will remain in the desired direction. This compensates for undesirable forces that affect S/C stability because of the shifting c.g. Thrust vector control, in addition to the TVC subsystem, utilizes the functions of the G&N system, the propulsion systems, and the SCS attitude reference and attitude control subsystems.

The TVC subsystem essentially controls the SPS engine gimbals, and consequently the thrust vector, by energizing the gimbal actuators; one for pitch and one for yaw.

The normal method for controlling thrust is through the G&N delta V mode. This provides the most accurate control. The accelerometers on the IMU stable element and the AGC provide steering commands to the SPS engine gimbals and continuous trajectory corrections to compensate for undesired accelerations. The AGC also compensates for the near-body orbital and gravity affects on the S/C. So, the actual versus required velocity change will result in a curved trajectory.

Normally, both G&N delta V and SCS delta V modes operate by driving No. 1 and No. 2 servo electronics. If a failure occurs in No. 1, an automatic switchover to drive No. 2 servo electronics and No. 2 gimbal motor will occur. Or, No. 2 will drive if No. 1 is switched off or if manual thrust vector control is initiated.

A manual method of thrust vector control is provided to control the position of the SPS engine gimbal. When operating manually, inputs from the rotation control, translation control, and the BMAGs are directed to redundant servo electronics No. 2 and the No. 2 gimbal actuator motor. The nominal authority from either rotation controller is ±6 degrees of SPS gimbal engine deflection.

The gimbal position display section of the AS/GPI panel, the delta V display, SCS control panel, rotation control, translation control, and the SPS switches on MDC-3 are the principle controls and displays associated with TVC. They provide the capability for control and monitoring of system performance.

Thrust Vector Control. When G&N delta V mode is selected, automatic thrust on-off, attitude, and steering commands initiate in the G&N system. However, before the ullage maneuver and thrust-on, the gimbal position trim control thumbwheels on the AS/GPI are used to position the engine gimbals. The engine position is verified on the AS/GPI visual display. The gimbals are aligned such that, at the moment of thrust-on, the thrust vector will be through the S/C c.g. This is necessary before any delta V to prevent undesirable rotational movements about the c.g. when thrusting begins.

In addition to initial positioning of the gimbals, the amount of acceleration required for the velocity change less tailoff is set into the delta V remaining counter on the delta V display. This allows the crew a method of monitoring delta V remaining and, when in SCS ΔV mode, provides automatic thrust-off capability. A coincidence switch in the delta V display will, by inhibiting the thrust on logic, automatically terminate thrust when the ΔV remaining counter indicates zero. The accelerometer in the AGAA senses +X acceleration, and supplies acceleration signals to timing and output logic which subsequently drives the delta V remaining potentiometer to zero. The accelerometer thrushold is 1×10^{-4} g, but the ΔV counter will only step once for each 0.25 ft/sec velocity change.

NOTE It is possible, but not recommended, to have SPS engine ignition without ullaging when in SCS ΔV mode.

Prior to SPS ignition, the G&N system inputs attitude error information to the ACS to hold the S/C at a constant attitude in all three axes. Attitude errors from the G&N system and rate information from the SCS rate gyros are also applied to the SPS gimbal servo loops. Upon engine ignition, the combined attitude error and rate gyro inputs, conditioned by the servo electronics, reposition the gimbals as necessary to rotate the S/C to compensate for c.g. shift. The gimbal position is also modified by steering commands from the AGC so that the thrust vector will point in the right direction for the curved trajectory.

The BMAG/AGCU loop remains open and follows IMU changes so that the SCS will have the same inertial reference in the event a switchover to SCS delta V mode is necessary.

Normally, G&N delta V mode utilizes the primary gimbal servo and actuator motor No. 1. If the gimbal motor switches on MDC-3 are activated, a TVC monitor signal generator (over-undercurrent sensor) in the actuator will sense a failure of motor No. 1. If motor No. 1 fails, the sensor will automatically cause a switchover to motor No. 2 in the actuator. Since the No. 2 servo electronics are driven simultaneously with No. 1, an interruption during the velocity change will not occur. Motor No. 2 also contains a TVC monitor signal generator, but is not used. In the event of motor No. 2 failure, causing an excessive current drain on the d-c bus, a 70-ampere circuit breaker in the line will disconnect the motor from the d-c supply bus. Motor No. 2 has no switchover or warning light capability.

In SCS delta V mode, the gimbal servo loops function the same as in G&N delta V mode. Attitude error information, however, is derived from the BMAGS. The rate loop is identical, unless in backup rate condition. SCS delta V will not function if the BMAGS are required for backup rate because of the loss of attitude error information.

SCS delta V keeps the thrust vector through the c. g. by first comparing the trim position commands set by the gimbal position thumbwheels and the position transducer feedback signals. The difference, combined with attitude error information from the BMAGs, conditions the servo electronics to energize the actuator clutches.

Except for mode selection and thrust-on requirements, the same prerequisites for thrust-on, and the control and display functions are the same as for G&N delta V. The SCS system does not provide automatic thrust-on. A thrust-on switch on the delta V display provides the thrust-on command for SCS delta V mode. Thrust-off, however, is automatic by closing of the coincidence switch. A NORMAL-OFF-DIRECT-ON switch on the delta V display is also provided for manual thrust-on and serves as a manual backup for all automatic thrust-off commands.

If the translation controller cannot be used for the ullage maneuver prior to thrust-on, a DIRECT ULLAGE switch on the delta V display provides a manual backup to initiate ullage.

A manual delta V can be performed, providing a delta V mode has been selected and the translation control is rotated CW into detent. This removes all normal inputs into the TVC servo loops, allows commanded inputs from the rotation control, and rate data from the BMAGs in backup-rate condition, into the redundant No. 2 servo electronics and motor No. 2 of the gimbal actuators. This provides rate-stabilized manual control of the thrust vector. Thrust-on is initiated by the momentary thrust-on switch located on the delta V display.

The rotation control must be held to a given displacement to control the gimbals about the initial trim position established by the settings of the AS/GPI. The GPI provides the only indication of the position of the gimbal angles with respect to the S/C body axes.

2.3.3 FLIGHT CONTROL PROFILES.

There are three basic flight control profiles associated with mission AS204A. These include powered flight, coasting flight, and entry. Within these profiles, various modes of operation are established either within the atmosphere or in earth orbital environment. Because of the division of powered flight, i.e., ascent and earth orbital environment, the description is divided as follows:

- Ascent (including aborts)
- Coasting flight (earth orbital)
- Powered flight (earth orbital)
- Entry (nonpowered atmospheric flight).

As the various operational modes are discussed, reference will be made to figures 2.3-4, 2.3-5, and 2.3-6. A typical control channel yaw is shown in figure 2.3-4, sheet 2; therefore, differences not typical to the yaw channel will be clarified.

It should be noted that relays in figures 2.3-4, 2.3-5, and 2.3-7 are not relays of the actual system by number. However, the relay nomenclature is system oriented and may be cross-referenced by using the following chart.

Fig. 2.3-4, 2.3-5, 2.3-7 Relays	Function	SCS System Relay
K1	ORBIT RATE	24A14K3
K2	FDAI ALIGN	24A14K1
		24A14K2
K3	G&N ROLL, PITCH, YAW	22A16A3K4
	ATT SIN AND COS	22A16A3K6
		22A17A3K4
		22A17A3K6
		22A18A3K4
		22A18A3K6
K4	AGCU CAGED	22A8K1
		22A8K2
		22A8K4
		22A8K5
K5	AGCU ALIGN	22A8K6
		22A8K7

Fig. 2.3-4, 2.3-5, 2.3-7 Relays	Function	SCS System Relay
K6	AGCU P/Y ERROR	21A3K2
K7	R G&N ERR/AGCU INH	22A3K3
	G&N P ERR	20A3K3
	Y ERR G&N BODY	21A3K3
K8	G&N P, Y, ERR S.F.	22A20A3K1
		22A21A3K1
K9	ROLL, PITCH, YAW ERR AGAA	22A20A3K4
		22A21A3K4
	MONITOR + G&N ΔV + G&N ATT CONTR + G&N ENTRY +.05G MANUAL + AS + YAW B/U RATE	22A23A3K2
K10	ROLL, PITCH, YAW, B/U RATE	22A9K1
		22A9K2
		22A13K1
		22A13K2
		22A11K1
		22A11K2
K11	MTVC RT OUT	22A9K3
		22A11K3
		22A12K3
K12	ROLL, PITCH, YAW RATE	22A23A3
		22A20A3
		22A21A3K
K13	Y/P RT SF	22A22A3
K14	R-Y RT CPLG	23A11K2
K15	RT IN TRANS	23A19K1
		23A19K1
		19A26K1
K16	ENT GAIN	23A15K1
		23A15K2
		23A17K2
K17	G&N ATT IN	23A19K2
K18	AGAA ATT IN	23A19K3
K19	D-B CHG	23A15K3
K20	RJC ATT SW	23A11K1
K21	G&N MIN IMP ENABLE	23A13K
K22	PSUEDO RT CO	23A13K
K23	RCS LATCHING RELAY ARMED (JET DVRS ENABLED) SAFE (JET DVRS DISABLED)	MESC Z19
K24	1.8 SEC LATCH	MESC Z8

Fig. 2.3-4, 2.3-5, 2.3-7 Relays	Function	SCS System Relay
K25	MAIN DEPLOY	MESC Z12
K26	AUTO CONT INTER	23A11K3
K27	ENG IGN	23A21K2
K28	SYS GRD CK	23A21K3
K29	SCS ΔV MODE	23A21K1
K30	ENG IGN	23A27K1
K31	MTVC ENGAGE	23A18K2
K32	TVC ELEC TRANS	23A25K1
K33	SERVO NO. 1 DISENGAGE	23A14K1
K34	SERVO NO. 2 ENGAGE	23A18K1
K35	ENTRY	22A8K8
K36	ΔV INH	22A21A3K6
K38	THRUST ON LAMP	22A20A3K6

2.3.3.1 Ascent.

During the ascent phase, capability exists for monitoring boost vehicle stability. The SCS is in a monitor mode with all subsystems active, but supplies no active commands for control purposes for the first 61 seconds of flight. After 61 seconds, if aborts are required, the SCS will be used to supply signals for S/C stabilization and control.

2.3.3.1.1 Monitor Mode.

The monitor mode provides the capability of monitoring deviations from programmed launch vehicle attitude prior to S-IB separation and CSM attitude after S-IVB separation. The S-IVB utilizes a different guidance technique and monitoring C/M instruments relative to S-IVB operation provides no useful purpose. Monitor mode also provides rate stabilization, when required, any time during the mission.

Normal Ascent. At time of launch, RCS latching relays in the SECS system will be open to inhibit commands to the RCS jets. Relays K4 and K5 will be closed, providing BMAG/AGCU closed loop. The FDAI will be following IMU gimbal angle changes. The motor-driven switch 5 (figure 2.3-7) is set to the S/M position when the REACTON CONTROL SYS—TRANS C/M-S/M switch on MDC-16 is set to S/M.

Total attitude and attitude error signals from the IMU and inertial CDU (figure 2.3-4, sheet 1) are applied to the FDAI through relays K3, K7, and K8, respectively. Attitude error signals represent deviations from the trajectory for the first stage booster only. The SCS rate gyros apply attitude rates to the SCS electronics directly and to the FDAI via relay K12.

The X-axis accelerometer will be active, but its output will be used only if an abort delta V is required. The TVC subsystem is activated to hold the SPS engine thrust vector through the c.g. in the event of an SPS abort, and to keep the nozzle centered and stationary within the adapter. The SPS engine gimbals are aligned to null offset (pitch +0.4 degrees and yaw +3.6 degrees) prior to launch. Quiecsent current on the gimbal motor clutches maintains these angles during ascent.

LES Abort. If an LES abort is initiated (61 seconds or more after lift-off) requiring SCS operation, the SCS is enabled one second after LES ignition. The SCS is enabled by the arming of the RCS latching relays in the SECS, and the S/M-C/M transfer switch will be driven to the C/M position. The RCS latching relay will open by the operation of a barometric switch at approximately 24,000 feet during descent and will disable active commands to the C/M RCS. Besides rate stabilization, specific command inputs to the SCS above 24,000 feet will depend on altitude and other factors.

SPS Abort. An SPS abort would be initiated after the LES jettison. The translation control is rotated CCW into detent and the switch closure will cause the MESC to command a +X translation (separation ullage) via the direct coils of the S/M RCS. The direct coils are activated through the RCS transfer switch.

Before separation from the S-IVB, a delta V mode must be selected. For an SPS abort, alignment of the SPS engine gimbals is not required since they were preset prior to launch and no propellant has been consumed. At separation, an abort can be made into earth orbit or to a downrange landing site.

2.3.3.2 Coasting Flight (Earth Orbital).

The coasting flight profile ranges from a free-drift configuration (no control) to monitor mode (passive) to attitude hold (active control). The following paragraphs describe the various modes relative to the earth orbital environment.

2.3.3.2.1 G&N Attitude Control.

G&N attitude control will provide inertially stabilized attitude by utilizing the attitude reference and attitude control subsystems. Attitude data is obtained from the inertially referenced IMU. Relays K4 and K5 provide BMAG/AGCU closed loop so that if SCS attitude control is selected, the AGCU will have the same reference as the IMU for control and display purposes.

Attitude errors from the inertial CDU through relays K7 and K8 are applied to the FDAI and SCS electronics for attitude error display, and to provide attitude corrections. The errors from the CDU are the difference between the IMU gimbal angles and the commanded output of the AGC. Total attitude from the IMU is applied to the FDAI via relay K3. The attitude rates from the SCS rate gyro and relay K12 will drive the FDAI rate indicator at a scale range of ±1 degree/second.

The maximum deadband limit is normally set for G&N attitude control. If navigation sightings are required, the minimum deadband may be selected. The G&N system and SCS attitude control subsystem will maintain attitude within the selected deadband limits.

Maneuvering. Automatic maneuvers may be executed by inserting commands into the AGC via the DSKY. The S/C will automatically maneuver to the computer-commanded attitude. The SCS will follow the attitude error signal inputs from the CDU in response to AGC inputs for maneuvering to the commanded attitude. Manual maneuvers can be commanded with or without attitude hold.

In G&N mode, relay K18 (figure 2.3-7) is open. Relay K17 is closed. Relay K18 inhibits BMAG inputs and allows G&N attitude error signals into the jet selection logic for the attitude hold function. When the rotation control is displaced, the breakout switches open K17, inhibiting G&N signals and allowing proportional command (rotation control plus rate gyro) signals into the jet selection logic. When the control is returned to neutral, relay K17 closes and the G&N attitude hold function is restored, provided G&N sync is active.

Translation in all axes can be commanded by the translation control. As shown in figure 2.3-5, switch closures within the control apply command signals directly to the jet selection logic and, subsequently, to the auto RCS coils. Attitude hold is a normal function when translations are initiated, using the translation control.

The direct ullage switch on the delta V display is a backup for +X translations. When this switch is activated, the signal is applied directly to the RCS direct coils. Attitude hold is not a function of direct ullage.

Attitude impulse control (panel 105, LEB) is a manual control capability for G&N and SCS attitude control modes only. Each displacement of the attitude impulse control (figure 2.13-4, sheet 3) provides an output attitude impulse command to two RCS engines for a duration of 18±4 ms. The pulses command body angular rates of approximately 3 arc min/sec.

2.3.3.2.2 G&N Local Vertical.

The G&N local vertical mode is an extension of G&N attitude control. The purpose of this mode of operation is to accurately maintain the S/C X-axis at a fixed angle with respect to the local vertical (relative to the earth surface) while maintaining the S/C Y-axis normal to the orbital plane. The G&N local vertical mode is an AGC-commanded function. A computer program (not available for AS204A mission) is called by the astronaut by DSKY entry. After IMU alignment, with the S/C X-axis in the direction of the desired orbital path, the computer program provides an orbit rate source to command torquing of the IMU at a rate that will maintain the local vertical attitude. This mode may be used to make navigational sightings of earth landmarks by keeping the G&N optics within the area of the earth surface.

2.3.3.2.3 SCS Attitude Control.

SCS attitude control mode will hold the S/C at an inertial-referenced attitude and will limit S/C drift to the selected deadband limits, normally, ±5 degrees in earth orbit. If SCS attitude control is selected after a G&N attitude control function, the attitude reference subsystem is aligned to the IMU (BMAG/AGCU closed loop). If not, an FDAI/AGCU align function is required.

When SCS attitude control is selected, G&N inputs are removed from the FDAI and SCS electronics. The following relay contacts (figure 2.3-4, sheet 2) are activated to supply SCS-generated commands for display and control purposes.

- Relay K4 open—FDAI ball stationary
- Relay K12—Applies body rates to FDAI
- Relay K3 closed to AGCU—Applies attitude errors to FDAI
- Relay K11B—Applies attitude errors to SCS electronics

FDAI/AGCU Align. If the AGCU has not been aligned to the IMU or if a new attitude reference is desired while in SCS attitude control mode, the astronaut will determine S/C attitude from star sightings or from the MSFN. Inertial angles are dialed into the AS/GPI with the ATTITUDE SET dials and the FDAI ALIGN pushbutton is pressed. Relay K2 closes and the AGCU and FDAI ball will drive to the selected attitude.

Manual Maneuvers. After AGCU reference has been established, the S/C can be maneuvered to the desired attitude reference by flying out the errors, using CSS. The ATT SET/OFF switch is activated, relay K23 is activated, the RCS latching relays are closed to the S/M RCS, relays K6 and K9 close, and K20 will open. Attitude error, equal to the difference between ATTITUDE SET dial position and AGCU resolver shaft position, is then applied to the FDAI from the AGCU through K6. Attitude error from the BMAG is removed from the FDAI when K9 activates. When the rotation control is moved out of detent, CSS commands are applied through the ACS to the jet selection logic and auto coils of the RCS engines. At the same time, relays K4 and K5 close providing BMAG/AGCU closed loop. The BMAGs follow S/C rotation and repositions the FDAI ball. When the rotation control is returned to neutral, the BMAG/AGCU loop is opened, relays K4 and K5 open, and the new attitude will hold within the selected deadband.

When the ATT SET/OFF switch is OFF, relays K6 and K9 de-energize and attitude error signals from the BMAGs are now applied to the FDAI and ACS. If further attitude changes are desired, they can be accomplished by using CSS. The BMAG/AGCU loop will be closed, and opened when the rotation control is returned to neutral. The attitude error needles will indicate the difference between the AGCU and the S/C attitude. The error needles are fly-to needles and will be at full scale if the error is greater than 5 degrees. To fly out the error, the astronaut must fly-to the needles or use the FDAI ball markings until the needles come off full scale, and then fly-to the needle to null the remaining error.

Free Drift. Free drift is normally used during extended periods of time when power and RCS propellant conservation is desired. Free drift can be established in either attitude control mode by placing the SCS CHANNEL switches to OFF, inhibiting all command signals to the RCS auto coils. With an SCS attitude mode selected and an SCS CHANNEL switch to OFF (PITCH or YAW or A&C ROLL and B&D ROLL), relay action closes the BMAG/AGCU loop and updates the ARS while drifting. However, if one BMAG is placed in backup rate and a channel switch is off, relay action rate cages the remaining BMAGs and opens the BMAG/AGCU loop, thus, preventing the ARS from being updated.

2.3.3.2.4 SCS Local Vertical.

SCS local vertical mode is an extension of SCS attitude control. Its purpose is to maintain S/C attitude with respect to the local vertical. When the LCL VERT/OFF switch on MDC-8 is set to LCL VERT, relay K1 energizes and an orbit rate source with a preset level is applied to the BMAG/AGCU servo loop. At present, the preset level established for the orbit rate source is most accurate for a 100-n mi circular orbit and will maintain the attitude reference system at the local vertical with torque rates of 246 degrees/hour, or 4.1 degrees/minute. It will maintain an approximate attitude when the AGCU is aligned to represent S/C attitude when the S/C XZ plane is parallel to the orbital plane at the time LCL VERT is selected. All three RCS channels must be enabled for the local vertical mode. Modifications of the local vertical attitude can be made using CSS. The translation control is also active and available during this mode of operation

2.3.3.3 Powered Flight (Earth Orbital).

Powered flight includes those modes that provide the capability for velocity changes using the SPS engine. Included in the following discussion are the G&N delta V, SCS delta V, and the manual delta V modes.

2.3.3.3.1 G&N Delta V.

G&N delta V mode is the normal method for velocity changes. Prior to engine ignition, however, G&N attitude control mode must be established.

System relays apply the following (G&N/SCS switch on MDC-8 set to G&N and ATTITUDE/MONITOR/ENTRY switch set to ATTITUDE (figure 2.3-5, sheet 1)):

- Relay K7 and K8—Attitude error from CDUs to FDAI
- Relay K9—Attitude error from CDUs to SCS electronics
- Relay K3—Total attitude from IMU to FDAI ball
- Body rates to FDAI and SCS electronics
- RCS latching relay in MESC closed to RCS system

The FCSM-SCS-RESET/OVERRIDE and G&N-RESET/OVERRIDE switches on MDC-2 may be set to SCS and G&N positions. These switches provide an automatic monitoring of SPS engine combustion performance. If rough combustion occurs, the SPS ROUGH ECO warning light on MDC-10 will light and engine thrust will terminate. A restart can be made by resetting the FCSM switches and then setting them back to SCS and G&N. Or, the monitor can be bypassed by setting the FCSM switches to RESET/OVERRIDE.

Attitude information from the IMU is displayed on the FDAI ball. Attitude errors from the CDUs are also applied to the FDAI (±5-degree scale) and are used by the SCS to control attitude in response to AGC commands. Rotational rates are displayed by the FDAI rate indicators with a scale range of ±5 degrees/second. The computer-controlled velocity change will be monitored on the delta V display. The required velocity less tailoff will be set into the delta V display by the ΔV SET switch, using velocity information obtained from the G&N system or MSFN. Minimum deadband is set on MDC-8, the gimbal motor switches, and the inject pre-valve switches on MDC-3 are activated. The SPS gimbal trim angles are determined, set into the AS/GPI by the gimbal position thumbwheels, and gimbal position verified on the GPI. The NORMAL/OFF/DIRECT switch on the delta V display is set to normal.

Approximately 15 seconds prior to ignition, after the digital event timer (MDC-5 and 8) has been set for countdown, the astronaut will command a +X ullage using the translation control. At T = 0, the AGC will command a signal through the thrust on-off logic and enable the solenoid drivers of the TVC subsystem. The solenoid drivers will then activate the SPS engine ignition coils and SPS thrusting will occur. The lamp portion of the THRUST ON switch on the delta V display will light, verifying the automatic computer command.

System delay (AUTO CONT INTER) logic will terminate the RCS ullage approximately one second after SPS ignition. The computer will command pitch and yaw attitude of the SPS gimbals via the TVC to control the thrust vector. Roll commands will be applied to the roll RCS during the maneuver.

When the delta V remaining counter indicates zero, thrusting will terminate and the THRUST ON light will go out. The NORMAL/OFF/DIRECT ON switch will be set to OFF and the SPS motor switches, inject pre-valves, and the TVC electronics will be de-activated. Approximately one second after thrust terminates, pitch and yaw control is transferred back to the SCS for the attitude control function.

If a malfunction occurs during the maneuver, a switchover to SCS delta V will allow continuation of the velocity change. If there is no response from the translation control at ullage initiation, the DIRECT ULLAGE pushbutton on the delta V display may be used for the ullage maneuver prior to ignition of the SPS engine. Also, if automatic thrust-on does not occur at T = 0, the THRUST ON pushbutton on the delta V display will provide engine ignition.

2.3.3.3.2 SCS Delta V.

SCS delta V mode is a primary backup for the G&N delta V. Preliminary to engine ignition, SCS attitude control is established by setting the G&N/SCS switch on MDC-8 to SCS. After SPS engine ignition, the SCS uses S/M RCS roll jets to maintain roll attitude and applies commands to the SPS engine gimbals to control the thrust vector. Relays in figure 2.3-4 apply the following (RCS latching relay in the SECS is closed to the S/M RCS throughout the maneuver):

- Relays K9 and K10—Attitude errors from BMAGs to FDAI
- Relay K11B—Attitude errors from BMAGs to SCS electronics
- Relays K4 and K5 open—FDAI ball stationary
- Body rates to FDAI and SCS electronics (RGA).

The control and display activation process that was performed for the G&N delta V will be performed for SCS delta V. The major differences are as follows:

- Control of attitude and the thrust vector is through the SCS.
- At T = 0, ignition is initiated manually by pressing the THRUST ON pushbutton on the delta V display.
- Thrust is terminated automatically when the ΔV remaining counter (delta V pot.) indicates zero.

As in the G&N delta V mode, if the required command responses to not occur, the same backup controls can be used to perform the delta V.

In SCS delta V mode, if engine ignition does not occur when the THRUST ON switch is pressed, the NORMAL/OFF/DIRECT ON switch can be set to DIRECT ON. This applies a command signal directly to the SPS engine ignition coils and will initiate thrusting. The NORMAL/OFF/DIRECT ON switch must be set to OFF to terminate engine thrust.

2.3.3.3.3 Manual Delta V (MTVC).

A manual delta V will be performed only as a backup to a G&N or SCS delta V. Manual thrust vector control is initiated by a CW rotation of the translation control into detent. At this time, relays K4 and K5 will close, providing rate caging of all three BMAGs; and relays K10 and K11B will open removing rate gyro outputs from the FDAI and SCS electronics. The rate-caged BMAGs through relay and K12 will switch BMAG backup-rate signals into the SCS electronics.

In the G&N and SCS delta V modes, TVC servo electronics No. 1 and SPS gimbal drive motor No. 1 was used. When MTVC is initiated, relays K32, K33, and K34 activate. This closes the servo loop for commanding SPS gimbal drive motor No. 2.

Gimbal trim commands are applied through relay K31. When the rotation control is moved out of detent, pitch and yaw commands are applied to motor No. 2 through relay K31 and gimbal position feedback is through relay K32.

The summation of backup rate and proportional CSS commands into the TVC provides a rate-damped manual control of the engine gimbals. The astronaut must keep the rotation control at a given displacement to keep the thrust vector through the c.g. and to fly the correct trajectory.

If CW switches of the translation control are engaged while in G&N delta V, G&N attitude control, or G&N entry mode, attitude errors are not removed from the FDAI. This allows the astronaut to monitor and, if necessary, fly a G&N programmed maneuver using CSS.

2.3.3.4 Entry.

The entry profile consists of the various methods of controlling the S/C for the entry phase of the mission. The entry mode is normally selected after S/M-C/M separation. At separation, the motor-driven RCS transfer switches are closed to the C/M RCS.

2.3.3.4.1 G&N Entry.

G&N manual mode is the primary method of control for entry into the atmosphere for the AS204A mission. Automatic entry may be used in lieu of G&N manual mode.

G&N Manual. This is normally a backup for the G&N entry automatic mode. The translation control is rotated CW into detent. This removes inertial CDU attitude errors from the SCS electronics. Normally, the astronauts will call up the entry program via the DSKY shortly after S/M-C/M separation.

The entry angle, required pullout angle, and other required entry data is presented on the computer displays. The astronaut can manually perform a controlled g-level entry by using CSS to fly out the commanded attitude errors displayed on the FDAI. The BMAG/AGCU has been closed loop for backup reference in case switchover is necessary.

After .05 g, aerodynamic forces build up sufficiently to stabilize the S/C in the pitch and yaw axes. At this time, CSS will be effective in the roll channel only. The SCS will rate-damp the pitch and yaw channels, and the astronauts will have steering capability by using roll CSS to control the lift vector.

Automatic Entry. The FDAI rate display scale range changes to ±25 degrees/second in roll, and ±5 degrees/second in pitch and yaw. Deadband is maximum. The rate deadband is ±2 degrees/sec.

Prior to .05 G switching, attitude error from the inertial CDUs is applied to the FDAI error indicator through relays K7 and K8, and to the SCS electronics through relay K9. The RGA applies rate gyro body rates to the FDAI and SCS electronics. Relay K3 applies total attitude to the FDAI ball.

At .05 g, the .05 G ENTRY/OFF switch on MDC-8 is set to .05 G ENTRY. The SCS pitch and yaw channels perform rate stabilization only. The roll channel is still subject to computer-controlled roll commands. The AGC will fly the S/C according to a pre-established entry program.

2.3.3.4.2 SCS Entry.

The SCS entry mode is a primary backup to G&N entry mode. When selected, total attitude information to the FDAI is supplied throughout the entry. Prior to .05 g, the BMAGs apply attitude errors to the FDAI and SCS electronics through relays K3 and K9. After .05 g, relays K3 and K9 remove attitude errors from the FDAI and SCS electronics. Relays K4 and K5 close, providing BMAG/AGCU closed loop. For the remainder of entry, attitude errors are not displayed. There is no attitude hold capability. The rate gyros, however, provide rate signals for rate stabilization. The SCS electronics increase rates to a 2-degree/second rate deadband. The FDAI displays total attitude. The astronauts will initiate the necessary commands using CSS to fly a controlled g-level entry. After aerodynamics stability in pitch and yaw, steering capability will be in the roll channel only.

If, after .05 g, it is necessary to place a BMAG in backup rate, only the BMAG selected by the rate gyro select switch will have its inputs in the SCS for rate stabilization. When backup rate is selected, relays K9, K10, K12, and K15 activate, providing backup rate to the FDAI and SCS electronics. Loss of FDAI ball reference will occur. Relay K12 removes rate gyro output from the FDAI and SCS electronics. The astronauts will control the lift vector with the CSS roll channel. If they wish to decrease the g level, they will roll the S/C to keep the lift vector up. If they wish to increase the g level, they will roll the S/C so that the lift vector is down.

2.3.4 MAJOR COMPONENT/SUBSYSTEM DESCRIPTION.

The SCS consists of the following major components:

- Rate gyro assembly (RGA)
- Attitude gyro accelerometer assembly (AGAA)
- Pitch electronic control assembly (pitch ECA)
- Roll electronic control assembly (roll ECA)
- Yaw electronic control assembly (yaw ECA)
- Auxiliary electronic control assembly (aux ECA)
- Display and attitude gyro accelerometer assembly electronic control assembly (DISPLAY-AGAA ECA)
- Rotation control
- Translation control
- Flight director attitude indicator (FDAI)
- Attitude set/gimbal position indicator (AS/GPI)
- Velocity change indicator (ΔV display).

2.3.4.1 Rate Gyro Assembly.

The rate gyro assembly contains three identical rate gyros, mounted orthogonally along the spacecraft body axes, and associated gyro electronics. No provision is made for heaters or temperature control of the gyros. Each gyro is a single-axis unit, with the input axis determined by the gyro mounting fixture. Self-test capabilities are provided by torquing coils which enable the gyro to be displaced at a known rate and by spin motor rotation detection circuits which allow monitoring of the gyro spin motor speed. All self-test circuits are completely isolated from operational circuits to prevent a failure in the former from affecting gyro operation. The gyro outputs are used by the SCS as primary damping or stabilization signals and, in addition, as negative feedback to null rotational control commands and provide a proportional maneuver rate capability. The rate gyros also provide an indication on the FDAI of the rate-of-attitude change in pitch, roll, and yaw axes. An attitude change about any of the axes results in an output signal which is representative of the rate of displacement.

Each miniature rate gyro assembly consists of a spin motor, damping system, gimbal assembly, quadrilever spring, and self-check circuitry. The gyro spin motor is a 400-cps 3-phase synchronous hysteresis motor powered by 26 volts ac. The maximum time allowed for the gyro to come up to operating speed is 17 seconds. Damping is accomplished by positive displacement of the damping fluid through temperature-controlled orifices. The quadrilever spring provides the torsional restraint required by the gyro, together with radial support for the gimbal assembly. Some important rate gyro characteristics are as follows:

Full-scale range	30°/sec
Input range (to limit stop)	30°/sec
Maximum rate without damage	600°/sec

2.3.4.2 Attitude Gyro Accelerometer Assembly.

The attitude gyro accelerometer assembly contains three body-mounted attitude gyros (BMAGs) and an accelerometer. Electronic control circuits for the gyros and accelerometer are contained in the display and attitude gyro accelerometer assembly electronic control assembly.

2.3.4.2.1 Body-Mounted Attitude Gyros.

The three BMAGs are identical units, mounted orthogonally along the spacecraft body axes, to sense attitude displacement along the pitch, roll, and yaw axes. Each gyro is a single-axis unit, with the input axis determined by the physical mounting in the S/C. A spin motor detection circuit is included in each gyro to allow monitoring of gyro spin motor speed. This will be telemetered data only.

The BMAGs provide information denoting the angular displacement of the spacecraft from a preset attitude. They are initially set to a specific space-stabilized orientation; thereafter, any displacement from this initial setting results in output signals which are representative of the amount of angular displacement. The output signals are used to produce attitude error signals for an attitude-hold mode or for display on the flight director attitude indicator. The outputs may also be applied to the attitude gyro coupler unit (AGCU) for attitude change storage and for conversion to inertial measurement unit (IMU) axes. IMU axes differ from the spacecraft body axes. The AGCU and BMAGs are used as a substitute or backup inertial reference unit for the IMU during the periods when the IMU is