Memorandum

TO: See Addressees Through: Mr. Gagle, R-ASTR-BH

DATE: May 19, 1966

FROM: Chief, Guidance and Control Systems Analysis Branch, R-ASTR-NG

EC Smith/vjd/876-5912

SUBJECT: Control System Information for SA-203

1. Purpose: This memorandum presents the control system information for Saturn IB/203. (See Appendix 9 for references).

2. Definitions of Symbols: Definitions of symbols used in this memorandum are given in Appendix 1.

3. General Description: A general description of the guidance and control system and discussion of its operation are given in Appendix 2 with a general block diagram shown in Figure 1.

4. Control System Diagrams: Block diagrams of the control system dynamics are shown in Sheets 1, 2, 3, and 4 of Drawing 50M34204. These diagrams are intended to be mathematical descriptions of the control system for simulation purposes. Detailed diagrams of the control system are shown on Sheets 1, 2, and 3 of Drawing 50M34207.

5. Polarity Definitions: Vehicle polarity definitions are given in Drawing Number 50M35036.

6. Control System Equations: The essential equations which define the control system actuator motion, and resultant thrust position as a function of individual actuator motions are contained in Appendix 3. The auxiliary system equations are described in Appendix 7 with the aid of Figures 10 and Sheets 1 and 2, Drawing Number 50M34204.

Factors, Tolerances, and Characteristics: The scale factors, tolerances, and characteristics are tabulated in Appendix 4 for flight control, Appendix 5 for ESE, and servo characteristics are given on sheet 50M34027.

Compensation Networks: Typical 203 compensation networks in Sheet 4 of Drawing Number 50M34204.

System Redundancy: Appendix 8 contains information pertaining to the switching threshold and components being switched.

S. M. Seltzer

88 (August 1966)
APPENDIX 1

Definitions of Symbols

Commanded thrust direction (β command) in pitch, yaw, and roll respectively,

Commanded actuator motions for individual actuators.

Resultant position of thrust vector due to individual actuator motions.

Individual actuator motions,

Ratio of β actuator to β command,

Acceleration of actuator piston,

Velocity of actuator piston,

The minimum value of β error signal in degrees required to cause full flow in the servo hydraulic valve, (Applies to S-PB only).

Differential current output of the S-IB magnetic amplifiers of the control computer used to drive the H-1 engine servo.

Current output of the S-IVB magnetic amplifiers of the control computer used to drive the J-2 engine servo.

Vehicle angular acceleration in pitch, yaw, and roll, (deg/sec^2).

Vehicle attitude error in pitch, yaw, and roll respectively (sometimes referred to as Δp, Δy, and Δr).

Vehicle attitude rate in pitch, yaw, and roll respectively,

Vehicle lateral acceleration perpendicular to the vehicle longitudinal axis in pitch and yaw respectively.

Control computer attitude error gain,

Control system attitude error gain,

Control system attitude rate gain,

Control system accelerometer control gain,

Enclosure 1
APPENDIX I (Continued)

\[ K_p, K_y, K_r \]
\[ \dot{x}_i, \dot{y}_i, \dot{z}_i \]
\[ \Delta \dot{x}_i, \Delta \dot{y}_i, \Delta \dot{z}_i \]
\[ \chi_x, \chi_y, \chi_z \]
\[ \varepsilon_p, \varepsilon_{Y-R}, \varepsilon_{Y+R} \]
\[ \tau_f \]
\[ \dot{z}_p, \dot{z}(Y+R), \dot{z}(Y-R) \]
\[ E_c \]
\[ E_o \]
\[ K_f \]
\[ K_i \]
\[ K_o \]
\[ T_p, T_y, T_r \]
\[ T_f \]
\[ I_{p}, III_{p}, III_{II}, III_{IV}, III_{II}, III_{IV} \]
\[ T_1, T_2, T_3 \]
\[ T_3 + 1 \]

Digital computer attitude error gain constants in pitch, yaw, and roll respectively.
Inertial accelerations in the X, Y, and Z space-fixed directions, respectively,
Incremental inertial velocity outputs of the platform accelerometer encoders, corresponding respectively to the \( \dot{x}_i, \dot{y}_i, \dot{z}_i \).
Vehicle attitude commands in Euler angles calculated by the LVDC.
Spatial amplifier error command in pitch and yaw-roll mixed,
Spatial amplifier lag network time constant (seconds)
Engine functions of the APS system,
Cut-on level (volts) of spatial amplifier
Output of the spatial amplifier
Spatial amplifier lag network gain,
The amount of \( \beta \) in degrees caused by 1 ma of \( i_v \) input to the \( J=2 \) valves,
Spatial amplifier hysteresis network gain,
Resultant thrust of the APS system in the pitch, yaw, and roll axes respectively,
Time of flight in seconds,
Engine numbers of the APS system,

Time base #1: Initiated at liftoff,
Time base #2: Initiated by the actuation of the S-IB propellant level sensors.
Time base #3: Initiated by S-IB engine cutoff,
Time base #4: Initiated within the digital computer when S-IVB cutoff conditions are satisfied or forced by a discrete signal at a premature S-IVB engine cutoff.
Time of event: Command Flight Control Computer S-IVB burn mode on,

Enclosure 1£
APPENDIX 1 (Continued)

Time of event: **Command** Flight Control Computer S-IVB Burn **Mode** Off (Begin Coast Phase)

Current output of the spatial amplifiers of the control computer used to operate the attitude control engines.
APPENDIX 2

GENERAL DESCRIPTION OF THE GUIDANCE AND CONTROL SYSTEM FOR SATURN IB/203

1. General: The general operation of the guidance and control system for Saturn IB/203 is discussed with the aid of Figure 1.

2. Guidance System:

a. The purpose of the guidance system is to perform navigation evaluations, to issue discrete commands, to initiate certain guidance and control functions, and to steer the vehicle in a manner to satisfy mission requirements. This is accomplished by means of a guidance program compiled for a particular mission and stored in the Launch Vehicle Digital Computer (LVDC) memory. The LVDC is provided the input data prior to launch and throughout flight from which it determines the prescribed steering signals and discrete outputs. The inputs during the flight consist of inertial velocities and discretes, and the outputs consist of attitude commands and discretes.

b. The vehicle inertial accelerations are sensed by the accelerometers of the stabilized platform (ST-124M). The signals are sent to the Launch Vehicle Data Adapter (LVDA), processed by the LVDA and passed to the LVDC where they are utilized in guidance computations. The attitude signals are detected by the ST-124M platform gimbals, processed by the platform electronics, and sent to the crossover detectors (COD's) of the LVDA where they are further processed to obtain gimbal angles. Gimbal angles are then utilized by the LVDC to compute guidance and control commands.

c. The LVDC calculates the vehicle attitude commands in Euler angles \( (X, Y, Z) \) as a function of time during S-IB flight and as closed loop steering commands during S-IVB flight. These commanded angles are compared with the ST-124M gimbal angles \( (\theta_x, \theta_y, \theta_z) \) which represent the vehicle position. The \( X \)'s and \( \theta \)'s are differenced to obtain the attitude errors which are then transformed into the vehicle coordinate system, converted from digital to analog form, and issued to the control computer approximately 25 times per second as attitude error commands \( (\psi_x, \psi_y, \psi_z) \). The \( X \)'s are calculated approximately every 1.0 second for S-IB stage and every 1.8 seconds for S-IVB stage, and the \( \theta \)'s are sampled approximately 25 times a second.

3. Control System:

a. The control system maintains the vehicle attitude and reduces vehicle aerodynamic loading by detecting the vehicle attitude, attitude rate, and lateral accelerations, processing these data, and issuing commands to position the control engines or fire the Auxiliary Propulsion System (APS) engines.

b. The control computer analog inputs consist of the attitude error signals \( (\psi_x, \psi_y, \psi_z) \) from the LVDA, the attitude rate signals \( (\phi_x, \phi_y, \phi_z) \) from the control rate gyro and Control Signal Processor (CSP), the lateral acceleration signals \( (\gamma_x, \gamma_y, \gamma_z) \) from the control accelerometers, and the S-IB stage actuator positions \( (\beta_1, \beta_2, \beta_3, \beta_4) \) from potentiometers on these actuators. There are no inputs from the S-IVB stage actuators since these actuators have mechanical feedback to their respective valves. The control computer performs the logic switching, gain changing, and filtering of the input signals to control the effects of bending and sloshing on the control system, to control the effects of the sampling rate and quantization of the attitude error signals and to maintain proper control system stability. It then mixes Enclosure 2
the \( \psi, \phi, \) and \( \gamma \) signals to form the actuator position commands which are compared with the actuator positions on the S-IB stage to produce error signals \( (\Delta \psi_1, \Delta \psi_2, \Delta \phi_1, \Delta \phi_2, \Delta \gamma_1, \Delta \gamma_2) \) which are sent to the servovalves to position the actuators of the S-IB stage. To position the S-IVB engine, the input commands \( (\psi, \phi) \) form the actuator position commands which are issued to the servovalve as \( i \). These servos have mechanical feedback within the valves and actuators rather than electrical \( \beta \) feedback to the control computer.

\( c. \) Engines 1 through 4 on the S-PB stage are utilized for vehicle control. Pitch and roll signals are mixed on the four pitch actuators, and yaw and roll are mixed on the four yaw actuators to obtain the required engine gimbal angles \( (\beta_1, \beta_2, \beta_3, \beta_4) \) or thrust vector components, and resulting control torques. For the S-IVB stage, there is only one engine which is gimbaled in pitch and yaw. The pitch signals go to the pitch actuator and the yaw signals go to the yaw actuator to produce the required engine gimbal angles \( (\beta_1, \beta_2) \) or pitch and yaw thrust vector components. The roll signals are processed by the APS system to produce the required roll thrust vector components. Thus, the required pitch, yaw, and roll control torques are produced during the S-IVB powered phase. During the S-IVB coast phase, the APS system accepts \( \psi \) and \( \phi \) input commands, multiplies these signals by the proper gains, mixes the yaw and roll signals, and produces output signals from the spatial amplifier which are pseudo rate modulated. For example, for an input \( 0 ^\circ \leq \epsilon \leq 1^\circ \) \( (\epsilon_1=1^\circ) \), the spatial amplifier output is zero. For an input \( \epsilon_1 \leq \epsilon \leq \epsilon_2 \) \( (\epsilon_2=1.6^\circ) \), the spatial amplifier is full on. For an input \( \epsilon_1 \leq \epsilon \leq \epsilon_2 \) the spatial amplifier output is pulse width and pulse rate modulated, the width and rate depending on the input signal level. The output of the spatial amplifier drives the control relays which activate the solenoid-valves. These cause the hypergolic engines to ignite producing thrust in the required direction.

\( d. \) The control accelerometers are used only during the S-IB stage flight. There are two rate gyro cases: one using the emergency detection system (EDS) rate gyros and associated CSP, and another using the control rate gyros and their build-in demodulators. The control rate gyros can be utilized only on S-IB stage flight; however, the EDS rate gyro package and CSP may be utilized during any or all phases of flight. The EDS rate gyros will be used on the SA-283 flight. The attitude commands will come only from the Instrument Unit (IU) system (not the spacecraft) during the entire 203 flight.

\( e. \) It should be noted that on the Saturn IB vehicles the EVDC is an integral part of the control system, whereas the guidance computer (ASC-15) of Saturn I was not. This results in the attitude loop being digitized with the effects of quantization, sampling rate, and transport Bag being introduced in the attitude loop. Transport Bag is given in Sheet 3, Drawing Number 50M34204 and Figure 2.

\( f. \) It should be noted that \( a_0, a_1, \) and \( g_2 \) are calculated from the following equations:

\[
a_0 = \frac{\beta_E}{\psi} = \text{degrees of engine movement} \quad \text{for the S-IB stage and for}
\]

powered pitch and yaw of the S-IVB stage.

Enclosure 2
APPENDIX 2 (Continued)

\[ a_0 = \frac{e}{\psi K} = \text{degrees of spatial attitude command} \]
\[ \psi K \text{ degree of attitude error } \times \text{digital computer attitude gain factor} \]

for the S-IVB powered roll and pitch, yaw, and roll during the coast phase.

\[ a_1 = \frac{\beta_E}{\delta} = \text{degrees of engine movement} \]
\[ \delta \text{ degree per second of attitude rate} \]

for the S-PB stage and for powered pitch and yaw of the S-IVB stage,

\[ a_1 = \frac{e}{\phi} = \text{degrees of spatial attitude command} \]
\[ \phi \text{ degree per second of attitude rate} \]

for the S-IVB powered roll and pitch, yaw, and roll during the coast phase.

\[ g_2 = \frac{\beta_E}{\gamma} = \text{degree of engine movement} \]
\[ \gamma \text{ meter per second per second of lateral acceleration} \]

\( g_2 \) applies only to the S-IB stage, \( g_2 \) relays close at \( T_1 + 28\frac{1}{2} \) second and open at \( T_1 + 110\frac{1}{2} \) second.

The S-IB stage servo-valve is limited to full flow at 8 mA of \( \Delta_i \) by a mechanical stop which limits the travel of the valve spool. The valves were originally designed for 12 mA full flow.

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APPENDIX 3

CONTROL SYSTEM EQUATIONS (ACTUATOR SYSTEMS)

1. The control law for actuator systems is represented by the following equations which give the commanded thrust direction ($\beta$ command). Symbols used are defined in Appendix 1.

- **Pitch:**
  $$\beta_{pc} = a_{0p}\dot{\psi}_p + a_{1p}\dot{\psi}_p \cdot g_{2p}\gamma_p$$

- **Yaw:**
  $$\beta_{yc} = a_{0y}\dot{\psi}_y + a_{1y}\dot{\psi}_y \cdot g_{2y}\gamma_y$$

- **Roll:**
  $$\beta_{rc} = a_{0r}\dot{\psi}_r + a_{1r}\dot{\psi}_r$$

2. The following equations define the individual commanded actuator motions in terms of commanded thrust direction for the S-IB stage.

- $\beta_{p1c} = \beta_{pc} - \beta_{rc}/\sqrt{2}$
- $\beta_{p2c} = \beta_{pc} - \beta_{rc}/\sqrt{2}$
- $\beta_{p3c} = \beta_{pc} + \beta_{rc}/\sqrt{2}$
- $\beta_{p4c} = \beta_{pc} + \beta_{rc}/\sqrt{2}$
- $\beta_{y1c} = \beta_{yc} + \beta_{rc}/\sqrt{2}$
- $\beta_{y2c} = \beta_{yc} = \beta_{rc}/\sqrt{2}$
- $\beta_{y3c} = \beta_{yc} = \beta_{rc}/\sqrt{2}$
- $\beta_{y4c} = \beta_{yc} + \beta_{rc}/\sqrt{2}$

3. The following equations define the individual commanded actuator motions in terms of commanded thrust direction for the S-IVB stage.

- $\beta_{p1c} = \beta_{pc}$
- $\beta_{y1c} = \beta_{yc}$

4. The following equations represent the resultant thrust position as a function of the individual actuator motion for the S-IB stage.

Enclosure 3
5. The following equations represent the resultant thrust position as a function of the individual actuator motion for the S-IVB stage,

\[ \beta_p = \frac{1}{4} (\beta_{p1} + \beta_{p2} + \beta_{p3} + \beta_{p4}) \]
\[ \beta_y = \frac{1}{4} (\beta_{y1} + \beta_{y2} + \beta_{y3} + \beta_{y4}) \]
\[ \beta_r = \sqrt{2/8} (\beta_{y1} - \beta_{p1} - \beta_{y2} - \beta_{p2} - \beta_{y3} + \beta_{p3} + \beta_{y4} + \beta_{p4}) \]

6. The preceding equations are approximations which are valid only as frequency approaches zero since all hardware dynamics are neglected. Even at control frequency, use of these equations in control system studies may give erroneous results. It is suggested that bending mode filters and engine position servo dynamics be examined before any attempt is made to use the idealized equations given here. The degree of accuracy of a particular study depends upon these dynamics.
<table>
<thead>
<tr>
<th>Scale Factor &amp; Tolerance</th>
<th>Max. Range</th>
<th>Null</th>
<th>S-Nil Space</th>
<th>Tolerance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000000772 gtt/bit time</td>
<td>±0.625 deg.</td>
<td>±0.1 deg.</td>
<td>2x-10% Resolvers</td>
<td>±2% ±10% ±10%</td>
<td>1,13</td>
</tr>
<tr>
<td>0.000928 9 x 10^-10 bit</td>
<td>±180 degrees</td>
<td>±1.0 deg.</td>
<td>CROSS-OVER DETECTORS &amp; RECODER</td>
<td></td>
<td>1,13</td>
</tr>
<tr>
<td>backup</td>
<td>(21:1)</td>
<td>(21:1)</td>
<td>MINOR LOOP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W = 8.88/deg.</td>
<td>± 2% from 0 to 22.5°</td>
<td>± 15.3°</td>
<td>LADDERs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>± 3% = 0.25 to 15.8°</td>
<td>Quantization level is 0.06 deg. /bit</td>
<td></td>
<td>K w</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1%</td>
<td>3.0 v/deg</td>
<td>±30 cm</td>
<td>SCALING AMPLIFIER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td></td>
<td></td>
<td>FILTER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td></td>
<td></td>
<td></td>
<td>11,13</td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td></td>
<td></td>
<td>SERVO AMP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td></td>
<td></td>
<td>INPUT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2x</td>
<td></td>
<td></td>
<td>FEEDBACK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6 mm (± 0.0075 mm)</td>
<td></td>
<td></td>
<td>OUTPUT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5%</td>
<td>0.6 mm (± 0.0075 mm)</td>
<td></td>
<td>VALVE</td>
<td>OPEN LOOP SERVO</td>
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</tr>
<tr>
<td>1.5%</td>
<td></td>
<td></td>
<td>ACTUATOR</td>
<td></td>
<td>9,13</td>
</tr>
<tr>
<td>1.5%</td>
<td></td>
<td></td>
<td>ACTUATOR POTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.58 volts/deg.</td>
<td>± 3 deg.</td>
<td>178.2 cm. (± 0.006 deg.)</td>
<td>ACTUATOR POTS</td>
<td>CONT. TELL.</td>
<td></td>
</tr>
<tr>
<td>3x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6,13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CLOSED LOOP SERVO</td>
<td></td>
</tr>
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</table>
CONTROL SYSTEM SPECIFICATIONS
ATTITUDE RATE CHANNEL
(PITCH, YAW, AND ROLL)

<table>
<thead>
<tr>
<th>SCALE FACTOR &amp; TOLEANCE</th>
<th>MAX. RANGE</th>
<th>NULL</th>
<th>S-DB STAGE</th>
<th>TOLERANCE</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi = 4.5 \text{ v/deg./sec.}$</td>
<td>$\pm 10 \text{ deg./sec.}$</td>
<td>$\pm 953 \text{ mv}$ ($\pm 1.125%$)</td>
<td>$\phi$</td>
<td>$\pm 8%$</td>
<td>$\pm 13.5%$</td>
</tr>
<tr>
<td>1.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td>$\pm 0.6 \text{ ma}$ ($\pm 0.075^\circ$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5%</td>
<td>$\pm 12 \text{ ma}$</td>
<td>$\pm 0.6 \text{ ma}$ ($\pm 0.075^\circ$)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\dot{\phi} = 2.58 \text{ v/deg.}$</td>
<td>$\pm 8 \text{ deg.}$</td>
<td>$\pm 178.2 \text{ mv}$ ($\pm 0.069 \text{ deg}$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td></td>
<td></td>
<td></td>
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</table>

SUB-SYSTEM OR COMPONENT SPECIFICATION

ECLOSURE 46
### Appendix I

**Control System Specifications**

**Attitude Error Channel**

**Pitch and Yaw**

<table>
<thead>
<tr>
<th>Scale Factor &amp; Tolerance</th>
<th>Max. Range</th>
<th>Null</th>
<th>3-IVB Stage (Powers)</th>
<th>Tolerance</th>
<th>System Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>.00279 deg./bit</td>
<td>±5.625 deg.</td>
<td>±0.1 deg.</td>
<td>ST-12L Resolvers</td>
<td>±5% ±7%</td>
<td></td>
</tr>
<tr>
<td>Fine</td>
<td></td>
<td>Fine</td>
<td></td>
<td>±10%</td>
<td></td>
</tr>
<tr>
<td>.00999 deg./bit Backup</td>
<td>±180 deg.</td>
<td>±1.0 deg.</td>
<td>Cross-over Detectors</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Backup (2x1l)</td>
<td></td>
<td>Register</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>±15.3 deg.</td>
<td></td>
<td>Minor Loop</td>
<td>1.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>±25.3 deg.</td>
<td></td>
<td></td>
<td>1.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quantization level</td>
<td>is .06 deg./bit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>±30 mV (±.010)</td>
<td></td>
<td>Scaling Amplifier</td>
<td>2.13</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>FILTER</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>±1 mV.</td>
<td></td>
<td>SERVO AMPLIFIER</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>±.7 mV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>±.00364 deg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>±16.7 mV</td>
<td></td>
<td>VALUE</td>
<td>1.5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>±.1 mV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(±.112°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K_2 = 0.11/96 deg./mA.</td>
<td>±16.7 mV</td>
<td></td>
<td></td>
<td>1.5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>±.1 mV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(±.112°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.5%</td>
<td>±21 deg.</td>
<td></td>
<td>ACTUATOR</td>
<td>1.5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>±21 deg.</td>
<td></td>
<td>ACTUATOR POT</td>
<td>NOT USED FOR CONTROL</td>
<td></td>
</tr>
</tbody>
</table>

ENCLOSURE 4.
### Appendix 4

**Control System Specifications**  
**Attitude Rate Channel (Pitch and Yaw)**

<table>
<thead>
<tr>
<th>Scale Factor &amp; Tolerance</th>
<th>Max. Range</th>
<th>Null</th>
<th>3-IV Stage (Powered)</th>
<th>Tolerance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta = 4.5 \text{ v/deg./sec.}$</td>
<td>$\pm 10 \text{ deg./sec.}$</td>
<td>$\pm 58.3 \text{ mv}$ ($\pm 0.125 \text{ deg./sec}$)</td>
<td>$\phi$</td>
<td>$-2%$</td>
<td>$12,13$</td>
</tr>
</tbody>
</table>

**DES Rate Gyrob**

<table>
<thead>
<tr>
<th>1.5%</th>
</tr>
</thead>
</table>

**CSP**

| 3, 4, 6, 13 |

**Filter**

| 3, 4, 6, 13 |

| 1h |

| 12, 13 |

**Servo Amp**

| $i_x$ | $\pm 60 \text{ ma}$ | $\pm 0.7 \text{ ma}$ ($\pm 0.1 \text{ deg}$) |

**Valve**

| $k_I = 0.3 \text{ lb/s-sec/m}$ | $i_x$ | $\pm 6.7 \text{ ma}$ | $\pm 1 \text{ ma}$ ($\pm 0.1 \text{ deg}$) |

**Actuator**

| 1.5% |

| 3% |  

**Actuator Pot**

| Not used for control |

**Enclosure 45**
<table>
<thead>
<tr>
<th>SOLENOID VALVES</th>
<th>CONTROL RELAY</th>
<th>SPATIAL AMPLIFIER</th>
<th>SCALING AMPLIFIER</th>
<th>MOTOR</th>
<th>CROSS-OVER SWITCH</th>
<th>ENCODER</th>
<th>SCALE FACTOR</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 or ±20 Volts</td>
<td>+2.25 volts + 0.05 volts</td>
<td>+10 %</td>
<td>+10 %</td>
<td>21.3</td>
<td>21.3</td>
<td>21.3</td>
<td>± 5%</td>
<td>± 0.1 degree</td>
</tr>
</tbody>
</table>

** Specifications: **

- Minimum pull-in duration: 65 ms ± 2.0 ms
- Maximum pull-out duration: 250 ms ± 50 ms
- Threshold voltage: +1.28 V
- Pulse duration: 65 ms ± 2.0 ms
- Scale factor: ± 5% ± 0.1 degree

** Notes:**

- System must be powered on.
### Appendix 4

**Control System Specifications**

**Attitude Rate Channel**

(Pitch & Yaw - Coast)

(Roll - Powered or Coast)

<table>
<thead>
<tr>
<th>Sub-system or Component Specification</th>
<th>System Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale Factor &amp; Tolerance</td>
<td></td>
</tr>
<tr>
<td>Max. Range</td>
<td>Null</td>
</tr>
<tr>
<td>Gain = 5</td>
<td>30 mV (±0.001%)</td>
</tr>
<tr>
<td>Triggering threshold ± 0.9 ± 6%</td>
<td>Full on threshold ± 1.1 ± 10%</td>
</tr>
<tr>
<td>Minimum pulse duration 65ms ± 10%</td>
<td></td>
</tr>
<tr>
<td>0 or +28 volts ± 2 ± 3 ms delay</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

- 47
NOTES: 1. The gimbal angles (θ's) are sensed by means of two constant amplitude, constant frequency, phase-shifted signals from the gimbal angle resolvers. These signals are converted to a digital pulse count by the Crossover Detectors (COD's) in the LVDA. Complete error analysis due to quantization and hardware tolerances is discussed in IBM document 64-208-008 dated 24 December 1964.

2. The attitude error signal (ψ) is active at all times during flight unless overridden by a manual signal from the command service module (CSM) of the Apollo spacecraft which will not be possible until SA-204. The ψ signal to the control computer is the result of a D/A conversion in the LVDA and has a quantization level of 0.06 deg/bit. The change of this signal is limited by the flight program in the LVDC to a maximum value of 0.48 degree per sampling period of approximately 40 milliseconds.

3. Only one rate gyro package will be active throughout flight— the EDS rate gyro package.

4. The attitude rate signals are obtained from the rate gyro demodulator output.

5. Rate gyro nulls include zero off-set, hysteresis, mass unbalance, and temperature variation.

6. The attitude rate signals are obtained from the demodulator output of the control signal processor. Tolerances are the sum of the rate gyro and control signal processor tolerances and both units have pair/spare redundancy. The control signal processor provides signals to the EDS distributor from preset rate switches. The $\Delta_1$ and $\Delta_2$ switches are set for $\pm 5.0^\circ/s$ $\pm 5^\circ/s$ and the $\Delta_3$ is set for $\pm 20^\circ/s$ to $1.5^\circ/s$. Two of the three rate gyros in either the pitch, yaw or roll axis must exceed the preset value in order to issue an abort signal.

7. The control accelerometers are active only during S-IB flight. The lateral acceleration signals are obtained from the accelerometer signal conditioners.

8. Both the telemetry and control potentiometers are 5k ohms resistance. There is an individual 60 volt power supply for each control potentiometer and a common 5 volt supply for the eight telemetry potentiometers. The tolerance on the scale factor includes effects of pot loading. The B null is determined with the actuator mechanical locks in position. This value represents the null due to the pot and the mechanical locks. For a closed loop servo, the B null due to all control computer inputs at maximum gain with specified limits is determined to be 0.6 degrees at lift-off. This null neglects mechanical misalignments of stages and sensors.

9. The valve null shift is measured by the amount of $A_1$ or $B$ required to cancel it. For the S-IB stage, the valve was designed for 12 ma to cause full flow.

10. Same as note 9, except that the S-IVB valve was designed for 46.7 ma to cause full actuator extension or retraction.

Enclosure 4
APPENDIX 4 (Continued)

11. The magnetic summing amplifier saturates at approximately ±23 mA. The null shift is based on zero input to the control computer. This null shift may be represented by an equivalent $B$.

12. Same as Note 13, except the S-IVB magamp saturates at ±60 mA.

13. Control system unit output = nominal output value ± the gain tolerance ± the null shift.

14. See drawing 50M34204 sheet 4 for filter characteristics.

15. See drawing 50M34207 sheet 2 for valve and solenoid characteristics.

Enclosure 4
### APPENDIX 5

**TELEMETRY FUNCTIONS**

**ATTITUDE ERROR CHANNEL**

---

**SUBLIGHT OR COMPONENT SPECIFICATION**

<table>
<thead>
<tr>
<th>SCALE FACTOR &amp; VOLUME</th>
<th>MAX. RANGE</th>
<th>NULL</th>
<th>S-T STAGE</th>
<th>SYSTEM SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>±15 deg.</td>
<td>± 0.1 deg.</td>
<td>fine</td>
<td>± 1.0 deg</td>
<td>ST-12k RESISTORS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CROSS-OVER DETECTORS &amp; REGISTER</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MINOR LOOP</td>
</tr>
<tr>
<td>$\gamma = 0.5 \mu/d$</td>
<td>Gain ± 3.75</td>
<td>± 30 mv</td>
<td>$4_+01%$</td>
<td>LADDER</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SCALING AMPLIFIER</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FILTER</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OUTPUT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OPEN LOOP SERVO</td>
</tr>
<tr>
<td>$\gamma = 0.1 \mu/d$</td>
<td>Gain ± 0.6</td>
<td>± 0.6 mv</td>
<td>$0.075%$</td>
<td>FEEDBACK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OUTPUT</td>
</tr>
<tr>
<td>$\gamma = 0.2 \mu/d$</td>
<td>Gain ± 0.6</td>
<td>± 0.6 mv</td>
<td>$0.075%$</td>
<td>FEEDBACK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OUTPUT</td>
</tr>
<tr>
<td>$\gamma = 0.3 \mu/d$</td>
<td>Gain ± 0.6</td>
<td>± 0.6 mv</td>
<td>$0.075%$</td>
<td>FEEDBACK</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OUTPUT</td>
</tr>
</tbody>
</table>

---

**FOOTNOTES:**

1. $\gamma = 0.5 \mu/d$
2. $\gamma = 0.1 \mu/d$
3. $\gamma = 0.2 \mu/d$
4. $\gamma = 0.3 \mu/d$

---

**NOTES:**

- ST-12k RESISTORS
- CROSS-OVER DETECTORS & REGISTER
- MINOR LOOP
- SCALING AMPLIFIER
- FILTER
- OUTPUT
- OPEN LOOP SERVO
- FEEDBACK
- FEEDBACK
- FEEDBACK
- FEEDBACK
- FEEDBACK

---

**ENCLOSURE 9**
### Appendix 5

**Telemetry Functions**

**Accelerometer Channel**

**Pitch and Yaw**

<table>
<thead>
<tr>
<th>Sub-System or Component Specification</th>
<th>System Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scale Factor &amp; Tolerance</strong></td>
<td><strong>Max. Range</strong></td>
</tr>
<tr>
<td>$g = 1.0 \text{ v/m/s}^2$</td>
<td>$\pm 5 \text{ m/s}^2$</td>
</tr>
</tbody>
</table>

**Notes:**
- $g_2$: Gain = 6
- $h$: Feedback
- $s$: Output
- $e$: Error
- $\theta$: Angle
### Sub-System or Component Specification

<table>
<thead>
<tr>
<th>Scale Factor &amp; Tolerance</th>
<th>Gain, Range</th>
<th>Null</th>
<th>Signal Stage (Pumped)</th>
<th>Tolerance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>±15 deg.</td>
<td>±01 deg fine, ±10 deg backup</td>
<td>ST-124 RESOLVERS</td>
<td>±6% ±5% ±10%</td>
<td>1, 2, 3, 4, 5, 6, 7</td>
<td></td>
</tr>
<tr>
<td>2%</td>
<td>Gain = 3.75 ±30mV (±0.01%)</td>
<td>CROSS-OVER DETECTORS &amp; REGISTER</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0% deg</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1%</td>
<td>LADDERS</td>
<td>SCALING AMPLIFIER</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8 v/deg</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kx</td>
<td>FILTER</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.15% ma</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.02 v/ma</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±50 ma</td>
<td>SERVO AMPLIFIER</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±0.7 ma (±0.1%)</td>
<td>VALUE</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±6.7 ma (±0.1%)</td>
<td>ACTUATOR</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±1 ma (±0.1%)</td>
<td>ACTUATOR POT</td>
<td>15, 16, 17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±339 v/deg.</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±5%</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

- 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17
APPENDIX 5 (Continued)

SATURN IB/SA-203 TELEMETRY FUNCTIONS

1. Available on control computer connector Y-9 pins \( n \) and \( p \) for pitch, \( k \) and \( m \) for yaw, and \( l \) and \( j \) for roll,

2. Available on control computer connector J-9 pins \( u \) and \( v \) for pitch, \( s \) and \( t \) for yaw, and \( q \) and \( r \) for roll,

3. Available on control computer connector Y-9 pins \( v \) and \( z \) for pitch, and \( w \) and \( x \) for yaw,

4. Control system unit output = nominal output value \( \pm \) the gain tolerance \( \pm \) the null shift,

5. It should be noted that these measurements are made at the telemetry outputs of the flight control computer and not in the blockhouse.

6. On Enclosure 5 of this Appendix are the tolerances for measurements being made in the blockhouse,

7. When telemetry outputs are measured in the blockhouse, refer to Enclosure 5.

8. See drawing 50M34204 sheet 4 for filter characteristics.

9. See drawing 50M34207 sheet 2 for valve and solenoid characteristics.

Enclosure 5
NOTE: Measured Output = Theoretical output plus the larger of:

(a) ± 20% of the theoretical output or,
(b) ± 10% of the maximum range.

These tolerances include control and measuring system tolerance, bias, and noise effects.
### Saturn IB/SA-203 ESE Input Functions

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UNIT</th>
<th>RAMP GENERATOR SCALE FACTOR</th>
<th>MAXIMUM RANGE</th>
<th>TORQUER SCALE FACTOR</th>
<th>REMARKS (SEE NOTES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\psi$</td>
<td>Attitude Error</td>
<td>0.8 v/deg</td>
<td>$\pm 15.3$ deg</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>$\phi$</td>
<td>Attitude rate</td>
<td>4.5 v/deg</td>
<td>$\pm 10$ deg/s</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>$\dot{\phi}$</td>
<td>EDS rate gyro</td>
<td>None</td>
<td>$\pm 10$ deg/s</td>
<td>8 mafdegfs (160 ma max.)</td>
<td>P</td>
</tr>
<tr>
<td>$\ddot{y}$</td>
<td>Lateral acceleration input</td>
<td>1.0 v/meter/s²</td>
<td>$\pm 10$ m/s²</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>$\dddot{y}$</td>
<td>Control accelerometer</td>
<td>None</td>
<td>$\pm 10$ mfs²</td>
<td>17 ma/m/s² (170 ma max.)</td>
<td>2, 3</td>
</tr>
</tbody>
</table>

### Notes:

1. Resistance of torquing coils is 135 ±15 OHMS.
2. Resistance of torquing coils is 150 ±10 OHMS.
3. Accelerometers with serial numbers 1 through 9 have a torquer scale factor of 15 ma/meter/s².

Enclosure 6
APPENDIX 7

AUXILIARY PROPULSION SYSTEM (APS)

1. The control law for the APS system is represented by the following equations which give error command \( \varepsilon \) to the pseudo rate modulafor (spatial amplifier).

\[
\varepsilon_p = a_{op} \dot{\psi}_p + a_{1p} \dot{\phi}_p
\]

\[
\varepsilon_{Y-R} = a_{oy} \psi - a_{or} \dot{\psi}_r + a_{ly} \dot{\phi}_y - a_{lr} \dot{\phi}_r
\]

\[
\varepsilon_{Y+R} = a_{oy} \psi + a_{or} \dot{\psi}_r + a_{ly} \dot{\phi}_y + a_{lr} \dot{\phi}_r
\]

2. The following table illustrates the polarity of the signal required to cause each engine to fire.

<table>
<thead>
<tr>
<th>Error signal</th>
<th>Engine on</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. +( \varepsilon_p )</td>
<td>( I_p ) (+P)</td>
</tr>
<tr>
<td>2. -( \varepsilon_p )</td>
<td>( III_p ) (-P)</td>
</tr>
<tr>
<td>3. +( \varepsilon_{Y-R} )</td>
<td>( III_{II} ) (+Y, -R)</td>
</tr>
<tr>
<td>4. -( \varepsilon_{Y-R} )</td>
<td>( III_{IV} ) (-Y, +R)</td>
</tr>
<tr>
<td>5. +( \varepsilon_{Y+R} )</td>
<td>( I_{II} ) (+Y, +R)</td>
</tr>
<tr>
<td>6. -( \varepsilon_{Y+R} )</td>
<td>( I_{IV} ) (-Y, -R)</td>
</tr>
</tbody>
</table>

3. The following equations represent the "on-off-modulation" characteristics of the spatial amplifiers, where \( E_o \) is the spatial amplifier output and \( \varepsilon \) is the attitude command in degrees:

\[
\text{for } \varepsilon \leq |\pm 1^\circ| \Rightarrow E_o = 0
\]

\[
\text{for } |\varepsilon| \leq |\pm 1^\circ| \Rightarrow E_o = \text{minimum pulse width and frequency}
\]

\[
\text{for } |\pm 1^\circ| < \varepsilon < |\pm 1.6^\circ| \Rightarrow E_o = \text{pseudo rate modulated signal}
\]

\[
\text{for } \varepsilon \geq |\pm 1.6^\circ| \Rightarrow E_o = 28 \text{ constant}
\]

Enclosure 7
4. The above equations do not represent the dynamics of the spatial amplifier nor the rest of the auxiliary control system. However, they do describe the steady-state characteristics. The dynamic characteristics may be obtained from other references, if desired. An approximation is given in Sheet 1 and 2, Drawing Number 50M34204c.

5. Table 1 gives the angular accelerations for S-IVB burn and coast phases due to various engines firing.

6. Figure 7B and 7C are phase plane plots of S-IVB 203 pitch, yaw and roll deadbands. The maneuvering rate ledge for S-IVB 203 has been set at:

\[ \pm 0.30^\circ/s \] for pitch and yaw where \( T_f > T_4 + 5 \)
\[ \pm 0.50^\circ/s \] for roll where \( T_f > T_3 + 1 \)

7. Spatial amplifier tolerance
   a. \( \psi \) triggering threshold \[ \pm 0.8^\circ \pm 6\% \]
   b. \( \psi \) full on threshold \[ \pm 1.2^\circ \pm 6\% \]
   c. \( \phi \) triggering threshold \[ \pm 0.9^\circ \pm 6\% \]
   d. \( \phi \) full on threshold \[ \pm 1.4^\circ \pm 6\% \]
   e. Minimum pulse duration 65 ms \pm 10

8. Figures 8A, 8B, 9A, 9B, 10A, and 10B are curves for an ideal pseudo rate modulator (spatial amplifier).
   a. Figures 8A and 8B = Input signal (volts) versus switching frequency,
   b. Figures 9A and 9B = Input signal (volts) versus percent on time,
   c. Figures 10A and 10B = Input signal (volts) versus on-time pulse width,
### APPENDIX 7 (Continued)

**TABLE 1**

**SA-203 S-IVB AUXILIARY PROPULSION SYSTEM CHARACTERISTICS**

<table>
<thead>
<tr>
<th>MISSION PHASE</th>
<th>APS ENGINES FIRED</th>
<th>ANGULAR ACCELERATION = DEG/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-IVB BURN &amp; Tₚ = T₃ + 1</td>
<td>Iᵢ, IIᵢ, IIIᵢ, or IIIᵢV</td>
<td>* * 0.904</td>
</tr>
<tr>
<td>S-IVB BURN &amp; Tₚ = T₃ + 457</td>
<td>Iᵢ, IIᵢ, IIIᵢ, or IIIᵢV</td>
<td>* * 0.929</td>
</tr>
<tr>
<td>S-IVB COAST (Fuel Aft)</td>
<td>Iᵢ or IIIᵢ</td>
<td>0.125 * *</td>
</tr>
<tr>
<td></td>
<td>Iᵢ or IIIᵢV</td>
<td>0.013 0.120 0.929</td>
</tr>
<tr>
<td></td>
<td>IᵢV or IIIᵢ</td>
<td>0.013 0.120 0.929</td>
</tr>
<tr>
<td>S-IVB COAST (Fuel Fore)</td>
<td>Iᵢ of IIIᵢ</td>
<td>0.161 * *</td>
</tr>
<tr>
<td></td>
<td>Iᵢ or IIIᵢV</td>
<td>0.016 0.156 0.930</td>
</tr>
<tr>
<td></td>
<td>IᵢV or IIIᵢ</td>
<td>0.016 0.156 0.930</td>
</tr>
</tbody>
</table>

**NOTES:**

1. All φ's are for unmanned type mission.
2. φ's in table are for single engine firings.
3. φₚ during S-IVB burn does not include 230 ft-lb roll torque due to 9-2 swirl.
4. φ = \(\frac{NFDK}{\phi}\) deg/s² where
   
   \(N\) = number of engines firing
   
   \(F\) = thrust component = 150 lb \(\sin \) or \(\cos 6''\)
   
   \(d\) = moment arm in inches
   
   \(\phi = \text{mass moment of inertia} \ K_g = M = s^2\)
   
   \(K = \text{proportionality constant} = 0.66 \frac{1b-in}{kg\cdot m}\)
5. Symbol * indicates negligible accelerations,
6. CG off-set not considered,
7. The AFS engines during S-IVB burn are activated by ψ roll and φ roll inputs only,

Enclosure 7
APPENDIX 8

CONTROL SYSTEM REDUNDANCY

1. Platform Resolvers

   a. Each platform axis has two resolvers associated with it to provide backup modes of operation should one fail during flight.

   b. A fine (64:1) resolver system is used in the prime mode and a backup (2:1) system is used if three (3) unreasonable values occur in the fine resolver system during one computation cycle. The resolvers are read and checked once each minor loop (40 ms). If the difference between the Past reading and the new reading is $\geq 0.4^\circ$, the change is considered unreasonable.

2. Switch selector

   a. The reset, stage select, and read command relays, each, consist of two parallel relays (both coils and contacts) offering improved reliability.

   b. The switch selector register is protected from failure by allowing the code or its complement to operate the same output relay driver. The LVDC sends an 8-bit code to the selected register. The eight complement Pines are returned to the LVDC via the LVDA and the transmitted code is checked. In the event an error is detected, the register is reset and the complement code is transmitted.

   Using this code or complement-type operation allows the switch selector to work around an inoperative relay.

3. LVDA D/A convertor channels

   a. Channels A & B in conjunction with the reference channel provide redundancy for the attitude error (ψ) inputs to the control computer.

   b. Channel A is the prime channel. Channel "B" will be selected for use if the reference ladder output and the Channel "A" ladder output differ by an amount $\geq 0.117^\circ$ (0.094v) or when the LVDA output (sample & hold circuit) to the control computer and the reference ladder output differ by an amount 20.469" (0.375v). (Each channel consists of the ladder registers, ladder, sample & hold circuit and the selection circuits).

4. Control signal processor and EDS rate gyro's

   a. The EDS command E spare rate gyro's, with their demodulators, in conjunction with the EDS reference rate gyro's and its demodulator provide redundancy for the attitude rate (ψ) input to the control computer.

   b. The command gyro's and their demodulators are used until the outputs of the demodulators for the command and reference gyro's differ by an amount $>1.64^\circ/s \pm 0.222$ deg/s then the spare gyro's and their demodulators are selected for use.

Enclosure 8
APPENDIX 8 (Continued)

5.  50 ma servo amplifier channel (pitch or yaw)

   a. The 50 ma command and spare servo amplifier channels in conjunction with
the reference servo amplifier channel provide redundancy for S-IVB actuator control.

   b. The command servo amplifier is the prime channel. The spare amplifier
channel is used if the outputs of the reference and command amplifiers differ by an
amount >8 ma ±3%. The 50 ma servo amplifier channel consists of the servo, amplifier,
ψ and φ filters and the ψ scaling amplifiers.

6. Spatial amplifier channels (pitch or yaw/roll)

   a. The command and spare channels in conjunction with the reference channel
provide control computer attitude control (output) signal redundancy for the roll axis
during S-IVB burn phase and for pitch, and yaw/roll during coast phases,

   b. The command spatial amplifier channel is used until its output and the
output of the reference channel differ by an amount from forty per cent to sixty per
cent duty cycle then the spare channel output is selected for use. (See Sheet 2,
Drawing 50M34207; spatial amplifier channel consists of the spatial amplifiers and
the ψ and φ scaling amplifiers).

7. Control Relay Package

The control relay package design takes advantage of the quad redundant valves by
putting relay coils in parallel to control the series parallel valves. (refer to
Astrionics Systems Handbook dated Aug 1, 1965 and Sheet 2. Drawing 50M34207 for more
information on control relay package & valve redundancy).

Enclosure 8²
APPENDIX 9

REFERENCES


Report, "Hardware Description and Error Analysis of the Attitude Control System for the Saturn IB/V Vehicle," December 24, 1964, IBM Control No, 64-208-00081


Enclosure 9
$\alpha_0$ TOLERANCE IS $\pm 10\%$ OR $\pm 1$ SECOND AT THE SWITCH POINTS

Saturn IB/SA-203
Attitude Error Control Gains
First Stage Flight
Fig. 3

$\alpha_0$ (DEG/DEG)

ROLL GAIN

PITCH & YAW GAIN

$T_1 = LIFT-OFF$
$a_1$ TOLERANCE IS $\pm 10\%$ OR $\pm 1$ SECOND AT THE SWITC H POINTS.

Saturn IB/SA-203
Attitude Rate Control Gains
First Stage Flight
Fig. 4

<table>
<thead>
<tr>
<th>ROLL GAIN</th>
<th>$a_1$ (DEG/DEG/SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PITCH &amp; YAW GAIN</th>
<th>$a_1$ (DEG/DEG/SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

$T_i = LIFT-OFF$

FLIGHT TIME (SECONDS):

- $T_i$
- $T_i + 40$
- $T_i + 80$
- $T_i + 120$
- $T_i + 160$
$g_2$ TOLERANCE IS $\pm 10\%$ OR $\pm 1$ SECOND AT THE SWITCH POINTS

Saturn IB/SA-203
Lateral Acceleration Control Gain
First Stage Flight
Fig. 5

$g_2$ (DEG/METER/SEC$^2$)

$T_i$ = LIFT-OFF

FLIGHT TIME (SECONDS)
Tolerance is ±10% or ±1 second at the switch points.

Saturn IB/SA-203
Attitude Error Control Gains
Second Stage Flight
Fig. 6A

_roll gain

$T_{3+1} = \text{START S-IV B BURN}$

$T_{3+457} = T_4 = \text{S-IV B CUT-OFF}$

$T_{3+701} = \text{START COAST}$
FIG 7B

\[ \Phi \text{ DEG/SEC} \]

\[ T_4 + 5 = \text{SIVB CUTOFF} \]

MANEUVERING RATE LEDGE

MANEUVERING RATE LEDGE

ON ZONE

OFF ZONE

0.32 DEG/SEC

0.2 DEG/SEC

\[ \psi \text{ DEG} \]

PROGRAMMED \[ \psi \text{ LIMIT ON ZONE} \]

PITCH AND YAW AXIS

-1.0 DEG

-1.6 DEG

-1.5

-1.0

-0.5

0.0

0.5

1.0

1.5

2.0

2.5

3.0

3.5

4.0

APS PSEUDO-RATE MODULATOR CHARACTERISTICS

SA-203

\[ T_p > T_4 + 5 \]

4-12-64
FIG. 7C

\[ \phi \text{ DEG/SEC} \]

-0.5

ON ZONE

ZONE

OFF ZONE

0.32 DEG/SEC

0.2 DEG/SEC

\[ \psi \text{ DEG} \]

-4 -3 -2 -1

1 2 3 4

PROGAMMED \( \psi \) LIMIT

MODULATED ZONE

ON ZONE

ROLL AXIS

-1.5

-2.0

APS

PSEUDO-RATE MODULATOR

CHARACTERISTICS

SA-203

\[ \tau_p > \tau_{3+1} \]
Spatial Amplifier Pulse Output Frequency Versus \( v \) Input Voltage

Theoretical Curve
SPATIAL AMPLIFIER "ON TIME" VERSUS INPUT VOLTAGE

Theoretical Curve - - - - -
SPATIAL AMPLIFIER OUTPUT PULSE WIDTH VERSUS INPUT VOLTAGE

Theoretical Curve
SPATIAL AMPLIFIER OUTPUT PULSE WIDTH
VERSUS INPUT VOLTAGE

Theoretical Curve
*NOTES

1. \( K_1 \) and \( K_2 \) versus signal source

<table>
<thead>
<tr>
<th>( K_1 )</th>
<th>( K_2 )</th>
<th>Signal Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.75</td>
<td></td>
<td>IU LVDA</td>
</tr>
<tr>
<td>10.00</td>
<td></td>
<td>APOPHO SC</td>
</tr>
<tr>
<td>1.00</td>
<td></td>
<td>IU CSP (For ( K_2 = 1 ) The amplifier will be removed)</td>
</tr>
<tr>
<td>4.50</td>
<td></td>
<td>CONTROL RG</td>
</tr>
</tbody>
</table>

2. The EDS Rate Gyros will be used during the entire flight for SA-202 & 203.

3. Spacecraft control will not be utilized before Saturn IB Vehicle 206.

4. The control accelerometers are utilized only during S-IB flight. These filters will be active.

5. A telemetry signal available for \( \phi_R \) only.

6. This diagram does not include dynamics. Values in each block are steady-state values.

7. The 50 mA magamps and the spatial amplifiers have pair/spare redundancy. A 'no compare' signal will pick the relay and switch amplifiers.

8. The yaw and roll nozzles are canted 6°. The three nozzles of each module do not lie in the same plane.

9. The symbol indicates a telemetry signal available from the control computer at the indicated points.

10. The symbol \( \text{EDS} \) indicates rate switch outputs to the emergency detection system. These signals are not voted by the control signal processor and are not limited to the demodulator limit of \( \pm 90 \) degrees per second.

11. The symbol \( \text{EDS} \) indicates rate switch outputs to the emergency detection system.

12. The symbol \( \text{EDS} \) indicates rate switch outputs to the emergency detection system.

13. In S-IVB burn mode both \( Y, R \) spatial amplifiers fire simultaneously.

14. In S-IVB burn mode the yaw signal is inhibited from reaching the spatial amplifier.

15. Relay-Contacts \( B_1, B_2, B_3, \) and \( B_4 \) are activated by S-IVB burn DISCRETE FROM LVDA.
16. Megamp winding resistance is 22.64 ohms per 100 turns. The stage, channel, turns per winding, number of windings in series, total turns, and resistance that each filter output sees is tabulated below:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Channel</th>
<th>Turns per Winding</th>
<th>Number Windings in Series</th>
<th>Total Turns</th>
<th>Total Resistance (Ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-IB</td>
<td>( \psi_p )</td>
<td>424</td>
<td>4</td>
<td>1696</td>
<td>383.97</td>
</tr>
<tr>
<td></td>
<td>( \psi_y )</td>
<td>424</td>
<td>4</td>
<td>1696</td>
<td>383.97</td>
</tr>
<tr>
<td></td>
<td>( \psi_r )</td>
<td>50</td>
<td>8</td>
<td>400</td>
<td>90.56</td>
</tr>
<tr>
<td></td>
<td>( \phi_p )</td>
<td>200</td>
<td>4</td>
<td>800</td>
<td>181.12</td>
</tr>
<tr>
<td></td>
<td>( \phi_y )</td>
<td>200</td>
<td>4</td>
<td>800</td>
<td>181.12</td>
</tr>
<tr>
<td></td>
<td>( \phi_r )</td>
<td>200</td>
<td>8</td>
<td>1600</td>
<td>362.24</td>
</tr>
<tr>
<td></td>
<td>( \psi_p )</td>
<td>424</td>
<td>4</td>
<td>1696</td>
<td>383.97</td>
</tr>
<tr>
<td>S-IVB PWR</td>
<td>( \psi_y )</td>
<td>450</td>
<td>1</td>
<td>450</td>
<td>101.88</td>
</tr>
<tr>
<td></td>
<td>( \phi_p )</td>
<td>200</td>
<td>1</td>
<td>200</td>
<td>45.28</td>
</tr>
<tr>
<td></td>
<td>( \phi_y )</td>
<td>200</td>
<td>1</td>
<td>200</td>
<td>45.28</td>
</tr>
<tr>
<td>S-IVB APS</td>
<td>( \psi_p )</td>
<td>300</td>
<td>1</td>
<td>300</td>
<td>67.32</td>
</tr>
<tr>
<td></td>
<td>( \psi_y )</td>
<td>300</td>
<td>2</td>
<td>600</td>
<td>135.84</td>
</tr>
<tr>
<td></td>
<td>( \psi_r )</td>
<td>300</td>
<td>2</td>
<td>600</td>
<td>135.84</td>
</tr>
<tr>
<td></td>
<td>( \phi_p )</td>
<td>300</td>
<td>1</td>
<td>300</td>
<td>67.92</td>
</tr>
<tr>
<td></td>
<td>( \phi_r )</td>
<td>300</td>
<td>2</td>
<td>600</td>
<td>135.84</td>
</tr>
</tbody>
</table>

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NATIONAL AERONAUTICS
& SPACE ADMINISTRATION

ORIGINAL DATE
18 FEB 65

Saturn - IB
Control System
Detailed Diagram

MF: 503340207

SHEET 4 OF 4