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Memorandum

TO : See Addressees
Through: ~~Mr. Cagle, R-ASTR-BU~~ BHC 5/23/66

DATE : May 19, 1966

In reply refer to:
R-ASTR-NG-74-66
BCSmith/vjd/876-5942

4595

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

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 con- ... positive actuator motion, and resultant thrust position as a function ...idual actuator motions are contained in Appendix 3. The auxiliary ...on system equations are described in Appendix 7 with the aid of Figures ... 10 and Sheets 1 and 2, Drawing Number 50M34204.

...e Factors, Tolerances, and Characteristics: The scale factors, tolerances, ...r data are tabulated in Appendix 4 for flight control, Appendix 5 for ...y, Appendix 6 for ESE, and servo characteristics are given on sheet ...wing 50M34207.

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

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

S. M. Seltzer

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...88 (August 1960)

APPENDIX 1

Definitions of Symbols

β_{pc}, β_{yc}, β_{rc}	Commanded thrust direction (β command) in pitch, yaw, and roll respectively,
β_{p1c}, β_{p2c}, β_{p3c}, β_{p4c} β_{y1c}, β_{y2c}, β_{y3c}, β_{y4c}	Commanded actuator motions for individual actuators.
β_p, β_y, β_r	Resultant position of thrust vector due to individual actuator motions.
β_{p1}, β_{p2}, β_{p3}, β_{p4} β_{y1}, β_{y2}, β_{y3}, β_{y4}	Individual actuator motions,
β_A/β_C	Ratio of β actuator to β command,
$\ddot{\beta}$	Acceleration of actuator piston,
$\dot{\beta}$	Velocity of actuator piston,
C_x	The minimum value of β error signal in degrees required to cause full flow in the servo hydraulic valve, (Applies t~ S-PB only).
Δ_i	Differential current output of the S-IB magnetic amplifiers of the control computer used to drive the H-1 engine servo.
i_v	Current output of the S-IVB magnetic amplifiers of the control computer used to drive the J-2 engine servo,
$\ddot{\phi}_p$, $\ddot{\phi}_y$, $\ddot{\phi}_r$	Vehicle angular acceleration in pitch, yaw, and roll, (deg/sec^2).
ψ_p, ψ_y, ψ_r	Vehicle attitude error in pitch, yaw, and roll respectively (sometimes referred to as $\Delta\phi_p$, $\Delta\phi_y$, and $\Delta\phi_r$).
$\dot{\phi}_p$, $\dot{\phi}_y$, $\dot{\phi}_r$	Vehicle attitude rate in pitch, yaw, and roll respectively,
$\ddot{\gamma}_p$, $\ddot{\gamma}_y$	Vehicle lateral acceleration perpendicular to the vehicle longitudinal axis in pitch and yaw respectively,
a_o'	Control computer attitude error gain,
a_o	Control system attitude error gain,
a_1	Control system attitude rate gain.
g_2	Control system accelerometer control gain,

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K_p, K_y, K_r	Digital computer attitude error gain constants in pitch, yaw, and roll respectively,
$\ddot{X}_I$, $\ddot{Y}_I$, $\ddot{Z}_I$	Inertial accelerations in the X, Y, and Z space-fixed directions, respectively,
$\Delta\dot{X}_I$, $\Delta\dot{Y}_I$, $\Delta\dot{Z}_I$	Incremental inertial velocity outputs of the platform accelerometer encoders, corresponding respectively to the $\ddot{X}_I$, $\ddot{Y}_I$, $\ddot{Z}_I$
χ_x, χ_y, χ_z	Vehicle attitude commands in Euler angles calculated by the LVDC,
ε_p, ε_{Y-R}, ε_{Y+R}	Spatial amplifier error command in pitch and yaw-roll mixed,,
τ_f	Spatial amplifier lag network time constant (seconds)
$\pm p$, $\pm(Y+R)$, $\pm(Y-R)$	Engine functions of the APS system,
E_c	Cut-on level (volts) of spatial amplifier
E_o	Output of the spatial amplifier, 28 V return [illegible]
K_f	Spatial amplifier lag network gain,
K_i	The amount of β in degrees caused by 1 ma of i_v input to the J-2 valves,
K_o	Spatial amplifier hysteresis network gain,
T_p, T_y, T_r	Resultant thrust of the APS system in the pitch, yaw, and roll axes respectively,
T_f	Time of flight in seconds,
I_p, III_p, III_{II}, III_{IV}, I_{II}, I_{IV}	Engine numbers of the APS system,
T_1	Time base #1: Initiated at liftoff,
T_2	Time base #2: Initiated by the actuation of the S-IB propellant level sensors.
T_3	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.
$T_3 + 1$	Time of event: Command Flight Control Computer S-IVB burn mode on,,

$T_4 + 5$	Time of event: **Command** Flight Control Computer S–IVB Bum **Mode** Off (Begin Coast Phase)
V_i	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 acceferometers 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 (χ_x, χ_y, χ_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 (θ_x, θ_y, θ_z] which represent the vehicle pasition, The χ's and θ'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 (ψ_p, ψ_y, ψ_r). The χ's are calculated approximately every 1.0 second for S-IB stage and every 1.7 seconds for S-IVB stage, and the θ'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 (ψ_p, ψ_y, ψ_r) from the LVDA, the attitude rate signals ($\dot\phi_p$, $\dot\phi_y$, $\dot\phi_r$) from the control rate gyros and Control Signal Processor (CSP), the lateral acceleration signals ($\ddot\gamma_p$, $\ddot\gamma_y$) from the control accelerometers, and the S-IB stage actuator positions (β_{1p}, β_{2p}, β_{3p}, β_{4p}, β_{1y}, β_{2y}, β_{3y}, β_{4y}) 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

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the ψ, ϕ, and $\ddot{\gamma}$ signals to form the actuator position commands which are compared with the actuator positions on the S-IB stage to produce error signals (Δi_{1p}, Δi_{2p}, Δi_{3p}, Δi_{4p}, Δi_{1y}, Δi_{2y}, Δi_{3y}, Δi_{4y}) which are sent to the servovalves to position the actuators of the S-IB stage. To position the S-IVB engine, the input commands (ψ and $\dot{\phi}$) form the actuator position commands which are issued to the servovalve as i_v. These servos have mechanical feedback within the valves and actuators rather than electrical β feedback to the control computer.

c. Engines 1 through 4 on the S-IB 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 (β_p, β_y, β_r), or thrust vector components, and resulting control torques. For the S-IVB stage, there is only one engine which is gimballed 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 (β_p, β_y) 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 ψ and $\dot{\phi}$ 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 $0 \leq \varepsilon < \varepsilon_1$ ($\varepsilon_1 = 1°$), the spatial amplifier output is zero. For an input $\varepsilon \geq \varepsilon_2$ ($\varepsilon_2 = 1.6°$), the spatial amplifier is full on. For an input $\varepsilon_1 \leq \varepsilon < \varepsilon_2$ 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 assoicated 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-203 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 lag being introduced in the attitude loop. Transport lag 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:

$$a_0 = \frac{\beta_E}{\psi} = \frac{\text{degrees of engine movement}}{\text{degree of attitude error}}$$ for the S-IB stage and for powered pitch and yaw of the S-IVB stage.

$$a_0 = \frac{\varepsilon}{\psi K} = \frac{\text{degrees of spatial attitude command}}{\text{degree of attitude error x digital computer attitude gain factor}}$$

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

$$a_1 = \frac{\beta_E}{\dot{\theta}} = \frac{\text{degrees of engine movement}}{\text{degree per second of attitude rate}}$$

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

$$a_1 = \frac{E}{\dot{\phi}} = \frac{\text{degrees of spatial attitude command}}{\text{degree per second of attitude rate}}$$

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

$$g_2 = \frac{\beta_E}{\ddot{\gamma}} - \frac{\text{degree of engine movement}}{\text{meter per second per second of lateral acceleration}}$$

g_2 applies only to the S-IB stage, g_2 relays close at T_1 + 28±1 second and open at T_1 + 110±1 second.

g. The S-IB stage servo-valve is limited to full flow at 8 ma of Δ_i by a mechanical stop which limits the travel of the valve spool. The valves were originally designed for 12 ma full flow.

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 (β command), Symbols used are defined in Appendix 1,

Pitch: $$\beta_{pc} = a_{op}\psi_p + a_{1p}\dot{\phi}_p + g_{2p}\ddot{\gamma}_p$$

Yaw: $$\beta_{yc} = a_{oy}\psi_y + a_{1y}\dot{\phi}_y + g_{2y}\ddot{\gamma}_y$$

Roll: $$\beta_{rc} = a_{or}\psi_r + a_{1r}\dot{\phi}_r$$

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,

$$\beta_p = 1/4\ (\beta_{p1} + \beta_{p2} + \beta_{p3} + \beta_{p4})$$

$$\beta_y = 1/4\ (\beta_{y1} + \beta_{y2} + \beta_{y3} + \beta_{y4})$$

$$\beta_r = \sqrt{2}/8\ (\beta_{y1} - \beta_{p1} - \beta_{y2} - \beta_{p2} - \beta_{y3} + \beta_{p3} + \beta_{y4} + \beta_{p4})$$

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

$$\beta_p = \beta_p$$

$$\beta_y = \beta_y$$

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,

APPENDIX 4

CONTROL SYSTEM SPECIFICATIONS
ATTITUDE ERROR CHANNEL
(PITCH, YAW, AND ROLL)

SUB-SYSTEM OR COMPONENT SPECIFICATION — SYSTEM SPECIFICATION

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IB STAGE	TOLERANCE	NOTES
0.00279 °/bit fine 0.08929 °/bit backup	±5.625 deg. fine (64:1) ±180 degrees backup (2:1)	±0.1 deg. fine ±1.0 deg. backup	Θ ST-124 RESOLVERS	±5% ±10% α_o ±10%	1,13
			CROSS-OVER DETECTORS & REGISTER		1,13
			MINOR LOOP		
ψ = .8v/deg. ± 2% from 0 to ±2.5° ± 4% " ±2.5° to ±15.3° Quantization level is .06deg./bit	± 15.3 deg.		LADDERS $K\psi$		
1% 3.0 v/deg	GAIN=3.75	±30 mv (±.01°)	SCALING AMPLIFIER T		
1%			FILTER		
1%			SERVO AMP INPUT		11,13
1%			FEED-BACK β_{fb}		
		0.6 ma (± 0.075°)			
2%			OUTPUT		
1.5%	±12ma.	0.6 ma (± 0.075°)	VALVE	OPEN LOOP SERVO	9,13
1.5%			ACTUATOR		
β = 2.58 volts/deg. 3%	± 8 deg.	± 178.2mv. (±.069deg.)	ACTUATOR POTS CONT. TELE.	CLOSED LOOP SERVO	8,13

APPENDIX 4

CONTROL SYSTEM SPECIFICATIONS
ATTITUDE RATE CHANNEL
(PITCH, YAW, AND ROLL)

SUB-SYSTEM OR COMPONENT SPECIFICATION — SYSTEM SPECIFICATION

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IB STAGE	TOLERANCE	NOTES
$\dot{\phi}$ = 4.5 v/deg./sec. 8%	± 10 deg./sec	± 563 mv (± .125 °/s)	ϕ EDS RATE GYROS	± 8% ±13.5% a_1 ± 10%	3,4,6,13
			CSP $\dot{\phi}$ (T)		3,4,6,13
1.5%			FILTER		4
1%			SERVO AMP INPUT		
1%		± 0.6 ma (±0.075°)	FEED-BACK		
2%			β_{fb} OUTPUT		11,13
1.5%	± 12 ma.	±0.6 ma (±0.075°)	VALVE	OPEN LOOP SERVO	9,13
1.5%			ACTUATOR		
β=2.58 v/deg. 3%	± 8 deg.	± 178.2 mv. (±.069 deg)	ACTUATOR POTS CONT. TELE. (T)	CLOSED LOOP SERVO	8,13

ENCLOSURE 4[2]

APPENDIX 4

CONTROL SYSTEM SPECIFICATIONS
ACCELEROMETER CHANNEL
(PITCH AND YAW)

SUB-SYSTEM OR COMPONENT SPECIFICATION				SYSTEM SPECIFICATION	
SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IB STAGE	TOLERANCE	NOTES
$\ddot{\gamma}$ = 1.0 v/m/s^2 ± 6%	± 10 m/s^2	± 80 mv (± .08 m/s^2)	$\ddot{\gamma}$ CONTROL ACCELEROMETER & DEMOD (T)	±6% ±14% g_2 ±10%	
3%			CONTROL ATTENUATION TIMER		
1%	g_2 Gain = 6		SCALING AMPLIFIER & FILTER		7,8,13
1% 1% 2%		±0.6ma (± 0.075°)	SERVO AMP: INPUT, FEED-BACK, E_{fb}, OUTPUT		11,13
1.5%	± 12 ma	± 0.6ma (± 0.075°)	VALVE	OPEN LOOP SERVO	9,13
1.5%			ACTUATOR		
β= 2.58 v/deg. 3%	± 8 deg.	± 178.2 mv (±.069 deg.	ACTUATOR POTS CONT. TELE. (T)	CLOSED LOOP SERVO	8,13

CONTROL SYSTEM SPECIFICATIONS
ATTITUDE ERROR CHANNEL
(PITCH AND YAW)

SUB-SYSTEM OR COMPONENT SPECIFICATION — SYSTEM SPECIFICATION

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IVB STAGE (POWERED)	TOLERANCE	NOTES
.00279 deg./bit Fine .08929 deg./bit Backup	± 5.625 deg. Fine (64:1) ± 180 deg. Backup (2:1)	± 0.1 deg. Fine ± 1.0 deg. Backup	⊖ ST-124 RESOLVERS	± 5% ± 7% a_0 ± 10%	1,13
			CROSS-OVER DETECTORS & REGISTER		1,13
			MINOR LOOP		
ψ = .8v/deg. 2% from 0° to ± 2.5° ± 4% " ±2.5°-±15.3° Quantization level is .06deg./bit	± 15.3 deg.		LADDERS		
1% 3.0v/deg	Gain = 3.75	± 30 mv. (± .01°)	$K\psi$ SCALING AMPLIFIER		2,13
1%			FILTER		14
1%	± 60 ma.	± 0.7 ma. ±0.1049 deg	SERVO AMPLIFIER		
K_i = 0.1496 deg./ma. 1.5%	± 46.7 ma.	± 1 ma. (±.14°)	i_v VALVE		
1.5%			ACTUATOR		
5%		(±.21 deg.)	ACTUATOR POT	NOT USED FOR CONTROL	

ENCLOSURE 4

APPENDIX 4

CONTROL SYSTEM SPECIFICATIONS
ATTITUDE RATE CHANNEL
(PITCH AND YAW)

SUB-SYSTEM OR COMPONENT SPECIFICATION

SYSTEM SPECIFICATION

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IV STAGE (POWERED)	TOLERANCE	NOTES
$\dot{\phi}$ = 4.5 v/deg./sec. 8%	± 10 deg./sec.	± 563 mv (± .125°/s)	$\dot{\phi}$ EDS RATE GYROS	a_1 +8% 10.5% +10%	3,4,6,13
			CSP		3,4,6,13
1.5%			$\dot{\phi}$ (T) FILTER		14
1%	± 60 ma	± 0,7 ma (±0.1049 deg)	SERVO AMP i_v (T)		12,13
K_i=0.1496 /ma 1.5%	± 46.7 ma	± 1 ma (± .14°)	VALVE		
1.5%			ACTUATOR		
5%		(±.21 deg.)	ACTUATOR POT	NOT USED FOR CONTROL	

APPENDIX 4

CONTROL SYSTEM SPECIFICATIONS

ATTITUDE ERROR CHANNEL
(PITCH & YAW- COAST)
(ROLL- POWERED OR COAST)

SUB-SYSTEM OR COMPONENT SPECIFICATION — SYSTEM SPECIFICATION

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IVB STAGE	TOLERANCE	NOTES
.00279 deg./bit fine .08929 deg./bit backup	± 5.625 deg. fine (64:1) ± 180 deg. backup (2:1)	± 0.1 deg. fine ± 1.0 deg. backup	θ ST-124 RESOLVER	± 5% ± 10% α_o ± 10%	1,13
			CROSS-OVER DETECTORS & REGISTER		1,13
			MINOR LOOP		
ψ = .8v/deg. ± 2% from 0 to ± 2.5 ± 4% " ± 2.5 to ± 15.3 Quantization level is .06 deg. /bit	± 15.3 deg.		LADDERS $K\psi$		
1%	Gain = 3.75	± 30 mv. (± .01°)	SCALING AMPLIFIER		2,13
Triggering Threshold = ± 0.8v ± 6% Full on Threshold = ± 1.28v ± 6% Minimum Pulse Duration = 65ms ±10%		± 10 mv.	T SPATIAL AMPLIFIER V_i T	triggering threshold ±0.8v ± 10% full on, threshold ±1.28v± 10% Minimum pulse duration 65ms ± 10%	
0 or + 28 volts ± 2 volts 3 ms. delay			CONTROL RELAY PACKAGE	Same as the spatial amplifier	
			T SOLENOIDS & VALVES		15

APPENDIX 4

CONTROL SYSTEM SPECIFICATIONS
ATTITUDE RATE CHANNEL
(PITCH & YAW – COAST)
(ROLL – POWERED OR COAST)

SUB-SYSTEM OR COMPONENT SPECIFICATION — SYSTEM SPECIFICATION

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IVB	TOLERANCE	NOTES
0 = 4.5 v/deg./sec. 8%		± 563 mv (± .125°/s)	$\dot{\phi}$ EDS RATE GYROS	+ 8% ±11% a_1 ±10%	3,4,6,13
			CSP $\dot{\phi}$		3,4,6,13
1%	Gain = 5	± 30 mv (± .0013°/s)	SCALING AMPLIFIER		2,13
Triggering Threshold =±.9v± 6% Full on Threshold =±1.44v± 6% Minimum Pulse Duration = 65ms ± 10%		± 10 mv	SPATIAL AMPLIFIER V_i	triggering threshold ± 0.9v ± 10% full on threshold ± 1.44v ± 10% Minimum pulse duration 65ms ± 10%	
0 or +28 volts ± 2 v 3 ms delay			CONTROL RELAY PACKAGE	Same as the spatial amplifier	
			SOLENOIDS & VALVES		15

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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 64-208-008H 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 $\dot{\phi}_p$ and $\dot{\phi}_y$ switches are set for $\pm 5.0°/s \pm .5°/s$ and the $\dot{\phi}_r$ is set for $\pm 20°/s \pm 1.5°/s$. Two of the three rate gyros in either the pitch, yaw or roll axis must exceed the nreset 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 fram 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 β 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 Poop servo, the β 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 Δ_i or β required to cancel it, For the S-IB stage, the valve was designed for 12 ma to cause full flow,

P0, Same as note 9, except that the S-IVB valve was designed for 46.7 ma to cause full actuator extension or retraction,

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 β.

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.

APPENDIX 5

TELEMETRY FUNCTIONS
ATTITUDE ERROR CHANNEL
(PITCH, YAW, AND ROLL)

SUB-SYSTEM OR COMPONENT SPECIFICATION | **SYSTEM SPECIFICATION**

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IB STAGE	TOLERANCE	NOTES
	±15 deg.	± 0.1 deg fine ± 1.0 deg backup	Θ ST-124 RESOLVERS	±5% ±11% α_o ±10%	
			CROSS-OVER DETECTORS & REGISTER		
			MINOR LOOP		
ψ = 0.8v/deg (± 4%)			LADDERS $K\Psi$		
1% 3.0v/deg	Gain = 3.75	± 30 mv. (±.01°)	SCALING AMPLIFIER (T)		1,4,7
1.0%			FILTER		8
1%			SERVO AMP INPUT		
1%			FEED-BACK β_{fb}		4,5,7
3% Ai = 0.1v/ma		± 0.6 ma (± 0.075°)	OUTPUT (T)		
	± 14 ma	± 0.6 ma (±0.075°)	VALVE	OPEN LOOP SERVO	4
1.5%			ACTUATOR		
0.212 v/deg. ±5%	± 8 deg.	± 14.63 mv (±.069°)	ACTUATOR POTS CONT. TELE. (T)	CLOSED LOOP SERVO	4,5,7

APPENDIX 5

TELEMETRY FUNCTIONS
ATTITUDE RATE CHANNEL
(PITCH, YAW, AND ROLL)

SUB-SYSTEM OR COMPONENT SPECIFICATION				SYSTEM SPECIFICATION	
SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IB STAGE	TOLERANCE	NOTES
$\dot{\phi}$ = 4.5 v/deg/sec ± 12 %	± 10 deg/sec	± 563 mv (±.125 °/sec)	ϕ → EDS RATE GYROS	± 12% ± 18.5% ±10% a_1	
			CSP → $\dot{\phi}$ (T)		7
1.5%			FILTER		8
1%			SERVO AMP: INPUT		
1%		± 0.6 ma (± 0.075°)	FEED-BACK		4,5,7
3%			OUTPUT (T) β_{fb}		
Δi = 0.1 v/deg					
	± 14 ma	± 0.6ma (±0.075°)	VALVE	OPEN LOOP SERVO	4
1.5%			ACTUATOR		
0.212 v/deg ±5%	± 8 deg.	± 14.63 mv (±.069°)	ACTUATOR POTS CONT. TELE. (T)	CLOSED LOOP SERVO	4,5,7

APPENDIX 5

TELEMETRY FUNCTIONS
ACCELEROMETER CHANNEL
(PITCH AND YAW)

SUB-SYSTEM OR COMPONENT SPECIFICATION | **SYSTEM SPECIFICATION**

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IB STAGE	TOLERANCE	NOTES
$\ddot{\delta}$ = 1.0 v/m/s² ± 9%	± 5 m/s²	± 80 mv (±.08 m/s²)	$\ddot{\delta}$ CONTROL ACCELEROMETER & DEMOD $\ddot{\delta}$ (T)	± 9% ±18% g_2 ±10%	3,4,7
3%			CONTROL ATTENUATION TIMER		
1%	g_2 Gain = 6		SCALING AMPLIFIER & FILTER		8
1% / 1% / 3% / Δi = 0.1 v/ deg		0.6 ma (± 0.075°)	SERVO AMP: INPUT, FEED-BACK, OUTPUT (T)		4,5,7
	± 14 ma	±0.6 ma (±0.075°)	VALVE	OPEN LOOP SERVO	4
1.5%			ACTUATOR		
.212 v/deg. ± 5%	± 8 deg	± 14.63 mv (±.069 deg)	ACTUATOR POTS CONT. TELE. (T)	CLOSED LOOP SERVO	4,5,7

APPENDIX 5

TELEMETRY FUNCTIONS
ATTITUDE ERROR CHANNEL
(PITCH AND YAW)

SUB-SYSTEM OR COMPONENT SPECIFICATION

SYSTEM SPECIFICATION

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IVB STAGE (POWERED)	TOLERANCE	NOTES
[illegible]	± 15 deg.	± 0.1 deg fine ± 1.0 deg backup	Θ ST-124 RESOLVERS	±6% ±9% α_o ±10%	
			CROSS-OVER DETECTORS & REGISTER		
			MINOR LOOP		
0.8 v/deg 4%			LADDERS $K\psi$		
2% 3.0v/deg	Gain = 3.75	± 30mv (±.01°)	SCALING AMPLIFIER (T)		7
1%			FILTER		8
i_v = .02 v/ma 2%	± 50 ma	± 0.7 ma (± 0.1049°)	SERVO AMPLIFIER i_v (T)		4,5,7
K_i = 0.1496 °/ma 1.5 %	± 46.7 ma	± 1 ma (±0.14°)	VALVE		
1.5%			ACTUATOR		
β = .339 v/deg. ± 5%	± 7 deg.	± 52.25 mv (±.154 deg)	ACTUATOR POT (T)		4,5,7

APPENDIX 5

TELEMETRY FUNCTIONS
ATTITUDE RATE CHANNEL
(PITCH AND YAW)

SUB-SYSTEM OR COMPONENT SPECIFICATION | SYSTEM SPECIFICATION

SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IV STAGE (POWERED)	TOLERANCE	NOTES
$\dot{\phi}$ = 4.5 v/deg/sec ± 12%	± 10 deg/sec	± 563 mv (±.125 °/sec)	$\dot{\phi}$ EDS RATE GYROS	± 12% ±15.5% α_1 ±10%	
			CSP		7
1.5%			$\dot{\phi}$ (T) FILTER		8
i_v = .02 v/ma 2%	± 50 ma	± 0.7 ma (±0.1049°)	SERVO AMP		
K_i = 0.1496 °/ma 1.5%	± 46.7 ma	± 1 ma (±.14°)	i_v (T) VALVE		7 4,5
1.5%			ACTUATOR		
0.339 v/deg ±5%	± 7 deg	± 52.25mv (±.154 °)	ACTUATOR POT (T)		4,5,7

APPENDIX 5

TELEMETRY FUNCTIONS
ATTITUDE ERROR CHANNEL
(PITCH & YAW- COAST)
(ROLL- POWERED OR COAST)

SUB-SYSTEM OR COMPONENT SPECIFICATION				SYSTEM SPECIFICATION	
SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IB STAGE	TOLERANCE	NOTES
	± 15 deg.	± 0.1 deg. fine ± 1.0 deg. backup *	Θ ST-124 RESOLVER	±6% ±10% ±10%	
			CROSS-OVER DETECTORS & REGISTER		
			MINOR LOOP		
0.8 v/deg 4%			LADDERS KΨ		
2% 3.0 v/deg	Gain = 3.75	+ 30 mv. (*.01 °)	SCALING AMPLIFIER		7
triggering = ±0.8v threshold ±6% full on = ±1.28v threshold ±6% Minimum pulse duration = 65ms ± 15%		± 10 mv	T SPATIAL AMPLIFIER Vi T	triggering threshold ±0.8v ±10% full on threshold ±1.28v±10% Minimum pulse duration 65ms ± 15%	4,5 7
0 or + 28 volts ± 2 volts 3 ms delay			CONTROL RELAY PACKAGE	Same as the spatial amplifier	7
			T SOLENOIDS & VALVES		9

TELEMETRY FUNCTIONS
ATTITUDE RATE CHANNEL
(PITCH & YAW - COAST)
(ROLL-POWERED OR COAST)

SUB-SYSTEM OR COMPONENT SPECIFICATION				SYSTEM SPECIFICATION	
SCALE FACTOR & TOLERANCE	MAX. RANGE	NULL	S-IVB	TOLERANCE	NOTES
$\dot{\phi}$ = 4.5 v/deg/sec ± 12%	± 10 deg/sec	± 563 mv (±.125 deg/s)	$\dot{\phi}$ EDS RATE GYROS	±12% ±10% a ±10%	
			CSP $\dot{\phi}$ T		7
1%	Gain = 5	± 30 mv. (±.00133°/s)	SCALING AMPLIFIER		
triggering threshold -9.9 v ±6% full on threshold =±1.44v ± 4% Minimum pulse duration 65ms ± 15%		± 10 mv	SPATIAL AMPLIFIER V_i T	triggering threshold ±0.9v ± 10% full on threshold ±1.44v ± 10% Minimum pulse duration 65ms ± 15%	4, 7
0 or + 28 volts ± 2 volts 3 ms delay			CONTROL RELAY PACKAGE T	Same as spatial amplifier	7
			SOLENOIDS & VALVES		9

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 i 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 y and z for pitch, and w and x for yaw,

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

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

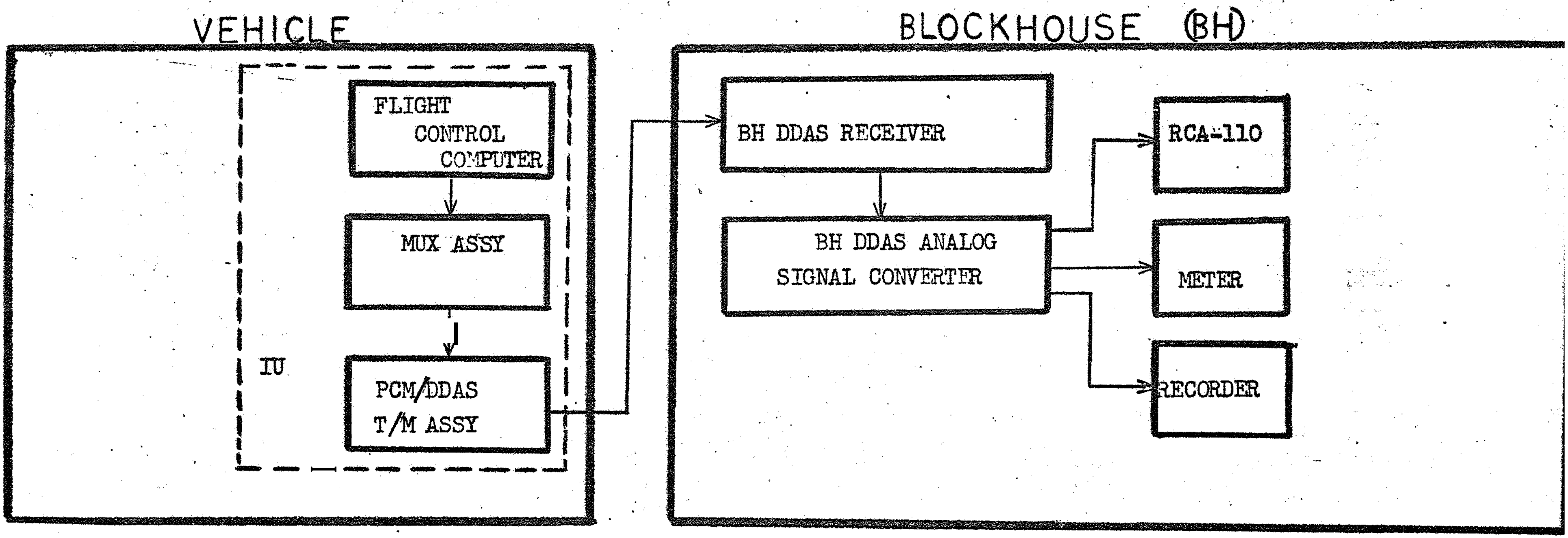
6, On Enclosure 5[8] of this Appendix are the tolerances for measurements being made in the blockhouse,

7, When telemetry outputs are measured in the blockhouse, refer to enclosure 5[9].

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

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

FLIGHT CONTROL SYSTEM MEASUREMENT BLOCK DIAGRAM



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.

APPENDIX 6

SATURN IB/SA-203 ESE INPUT FUNCTIONS

PARAMETER	UNIT	RAMP GENERATOR SCALE FACTOR	MAXIMUM RANGE	TORQUER SCALE FACTOR	REMARKS (SEE NOTES)
ψ	Attitude Error substitute input to control computer	0.8 v/deg	±15.3 deg	None	
$\dot{\phi}$	Attitude rate substitute input to control computer	4.5 v/deg	±10 deg/s	None	
$\dot{\phi}$	EDS rate gyro	None	±10 deg/s	8 ma/deg/s (160 ma max.)	P
$\ddot{Y}$	Lateral acceleration substitute input to control computer	1.0 v/meter/s^2	±10 m/s^2	None	
$\ddot{Y}$	Control accelerometer	None	±10 m/s2	17 ma/m/s2 (170 ma max.)	2,3

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/s^2.

Enclosure 6

AUXILIARY PROPULSION SYSTEM (APS)

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

Pitch: $\varepsilon_p = a_{op}\psi_p + a_{1p}\dot{\phi}_p$

Yaw - Roll Mixed;

$$\varepsilon_{Y-R} = a_{oy}\psi_y - a_{or}\psi_r + a_{1y}\dot{\phi}_y - a_{1r}\dot{\phi}_r$$

$$\varepsilon_{Y+R} = a_{oy}\psi_y + a_{or}\psi_r + a_{1y}\dot{\phi}_y + a_{1r}\dot{\phi}_r$$

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

Error signal	Engine on
1. $+\varepsilon_p$	I_p (+P)
2. $-\varepsilon_p$	III_p (-P)
3. $+\varepsilon_{Y-R}$	III_{II} (+Y, -R)
4. $-\varepsilon_{Y-R}$	III_{IV} (-Y, +R)
5. $+\varepsilon_{Y+R}$	I_{II} (+Y, +R)
6. $-\varepsilon_{Y+R}$	I_{IV} (-Y, -R)

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

for $\varepsilon < |\pm 1°|$, $E_o = 0$

for $\varepsilon = |\pm 1°|$, E_o = minimum pulse width and frequency,

for $|\pm 1°| < \varepsilon < |\pm 1.6°|$, E_o = pseudo rate modulated signal,

for $\varepsilon \geq \pm 1.6°|$, $E_o = 28_v$ constant

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 50M34204.

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:

$\pm 0.30°/s$ for pitch and yaw where $T_f > T_4 + 5$

$\pm 0.50°/s$ for roll where $T_f > T_3 + 1$

7. Spatial amplifier tolerance

a, ψ triggering threshold $\begin{matrix}\pm 0.8v \\ \pm 1°\end{matrix}$ $\pm$ 6%

b. ψ full on threshold $\begin{matrix}\pm 1.28v \\ \pm 1.6°\end{matrix}$ $\pm$6%

c. $\dot{\phi}$ triggering threshold $\begin{matrix}\pm 0.9v \\ \pm 0.2°/s\end{matrix}$ $\pm$6%

d. $\dot{\phi}$ full on threshold $\begin{matrix}\pm 1.44v \\ \pm 0.32°/s\end{matrix}$ $\pm$ 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 88 and 8B - Input signal (volts) versus switching frequency,

b. Figures 98 and 9B - Input signal (volts) versus percent on time,

e, 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

MISSION PHASE	APS ENGINES FIRED	ANGULAR ACCELERATION = DEG/s^2 PITCH	YAW	ROLL
S-IVB BURN $T_f = T_3 + 1$	I_{II}, I_{IV}, III_{II}, or III_{IV}	*	*	0.904
S-IVB BURN $T_f = T_3 + 457$	I_{II}, I_{IV}, III_{II}, or III_{IV}	*	*	0,929
S-IVB COAST [Fuel Aft)	I_P or III_p	0,125	*	*
	I_{II} or III_{IV}	0.013	0.120	0,929
	I_{IV} or III_{II}	0,013	0,120	0.929
S-IVB COAST (Fuel Fore)	I_P or III_p	0.161	*	*
	I_{II} or III_{IV}	0.016	0,156	0.930
	I_{IV} or III_{II}	0.016	0,156	0,930

NOTES: 1. All $\ddot{\phi}$'s are for unmanned type mission,

2. $\ddot{\phi}$'s in table are for single engine firings.

3, $\ddot{\phi}_R$ during S-IVB burn does not include 230 ft-lb roll torque due to 9-2 swirl,

4. $\ddot{\phi} = \frac{NFdK}{\Phi}$ deg/s^2 where

N = number of engines firing

F = thrust component = 150 lb X sin or cos 6"

d = moment arm in inches

Φ = mass moment of inertia in $K_g - M - s^2$

K = proportionality constant = $0.66 \frac{lb-in}{Kg-M}$

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 $\dot{\phi}$ roll inputs only,

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 ≥0.4°, 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 sperate 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 cheeked, 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 referenee 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 mount ≥0.117° (0.094v) or when the LVDA outnut (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 E hold multiplier, sample & hold circuit and the selection circuits).

4. Control signal processor and EDS rate gyros.

a. The EDS command E spare rate gyros, with their demodulators, in conjunction with the EDS referenee **rate** gyros and its demodulator provide redundancy for the attitude **rate** ($\dot{\phi}$) input to the control computer,

b. The **command** gyros and their demodulators are used until the outputs of the demodulators for the command and reference gyros differ by an amount >1.64°/s ±0.222 deg/s then the spare gyros and their demodulators are selected for use,

Enclosure 8

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 referenee 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 spatials 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).

APPENDIX 9

REFERENCES

Memo, "Status of Saturn IB/201 Control Computer Design," December 2, 1964, R-ASTR-NF-368-64

Memo, "Saturn I - Block PI Control System Block Diagram, Scale Factors and Steady-State Equations," February 13, 1963, M-ASTR-N-171

Memo, "Steady-State Equations for Saturn V Control System During Powered Flight Phase," May 14, 1964, R-ASTR-NG-10

Report, "Hardware Description and Error Analysis of the Attitude Control System for the Saturn IB/V Vehicle," December 24, 1964, IBM Control No, 64-208-0008I-l

Memo, "The Linear Equations and Nonlinear Models for Saturn IB Thrust Vector Control System," March 19, 1965, R-ASTR-NFM-128-65

Astrionics Systems Handbook, "Saturn Launch Vehicles," August 1, 1965

Memo, "Flight Sequence for SA-203," March 7, 1966 R-ASTR-EAA

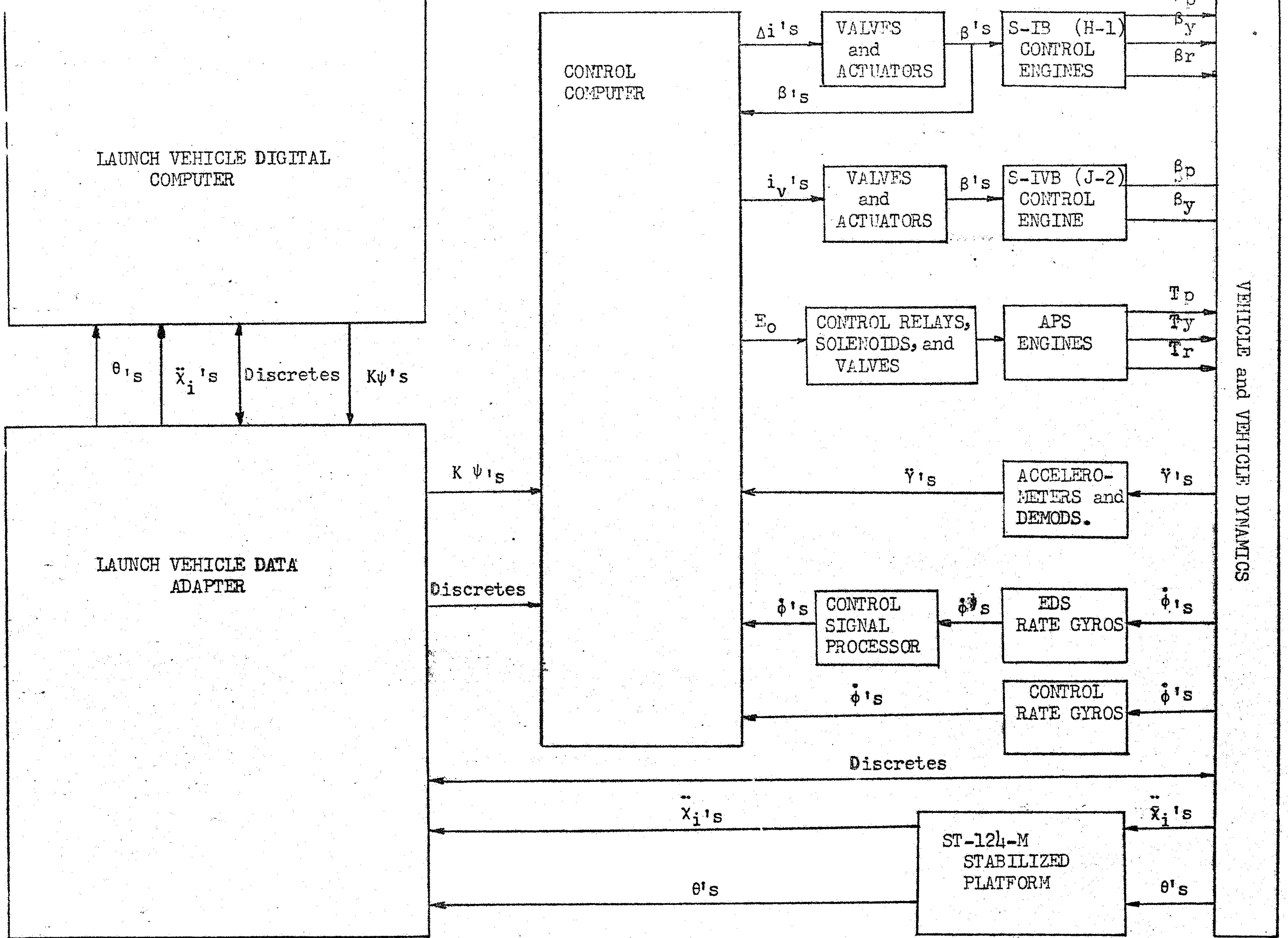
Memo, "Saturn V/S-IU Guidance & Control Information,'* September 22, 1965 R-ASTR-NG-92-65

Memo, "Control Gains and Shaping Networks for Saturn SA-283, S-HB and S-IVB Stages," July 15, 1965 R-ASTR-F-65-110

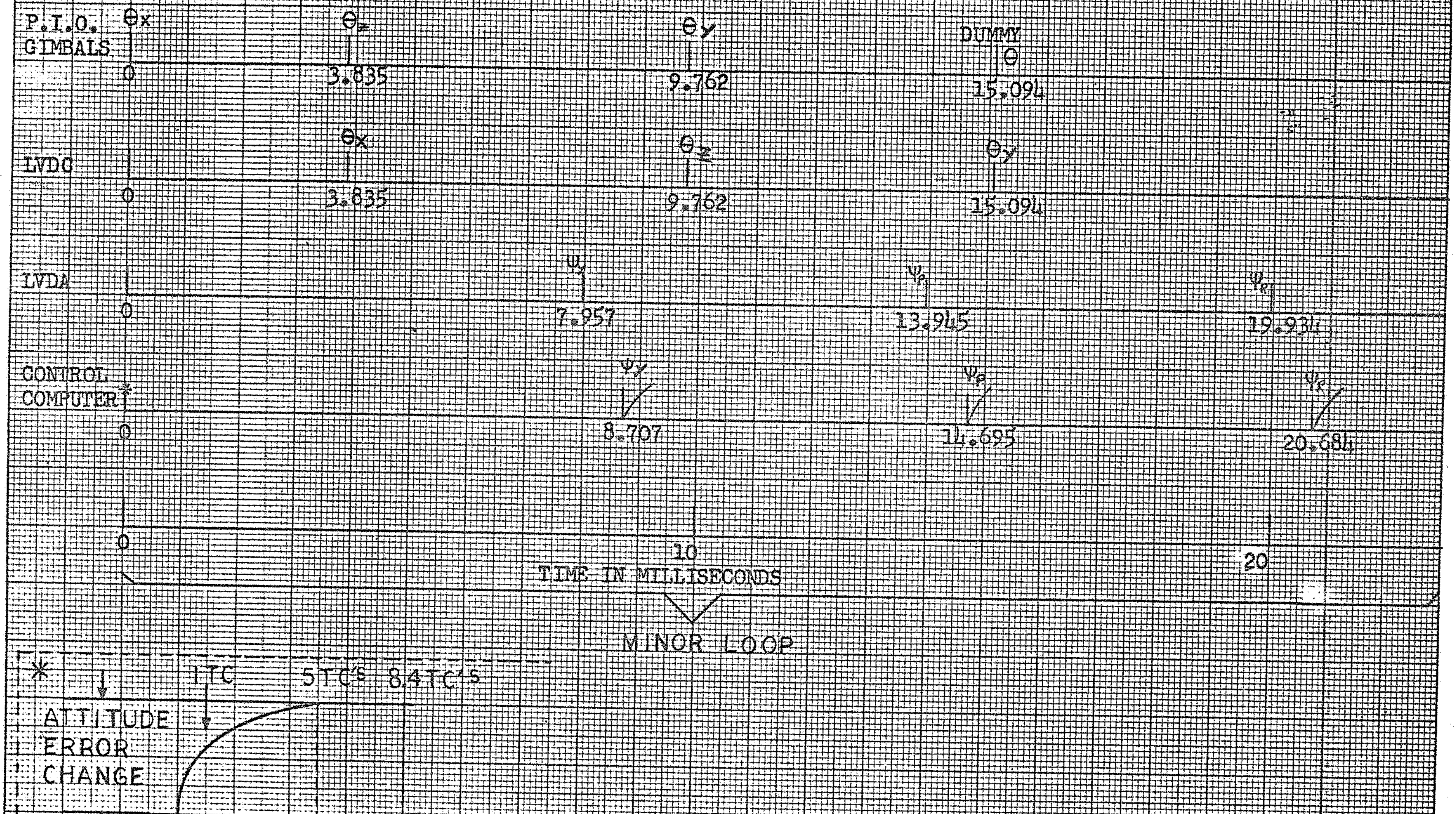
Memo, "Control System Tolerances," August 13, 1965 R-ASTR-NFE-208-65

Memo, "Control System Specifications for SA-202 and SA-203," R-ASTR-NFS-161-66, May 17, 1966

FIGURE 1. GUIDANCE AND CONTROL SYSTEM GENERAL DIAGRAM



TRANSPORT DELAY FROM GIMBAL P.I.O. TO CONTROL COMPUTER INPUT



LVDA OUTPUT HOLD CAPACITOR TC=0.15ms.
CONTROL COMPUTER INPUT FOLLOWS THE CHARGE OF THE HOLD CAPACITOR.
8.4 TC IS MINIMUM CHARGE TIME ON CAPACITOR DUE TO LVDG PROGRAM.

A MINOR LOOP STARTS EVERY 40 MILLISECONDS IF NO ERRORS OR INTERRUPTS OCCUR.

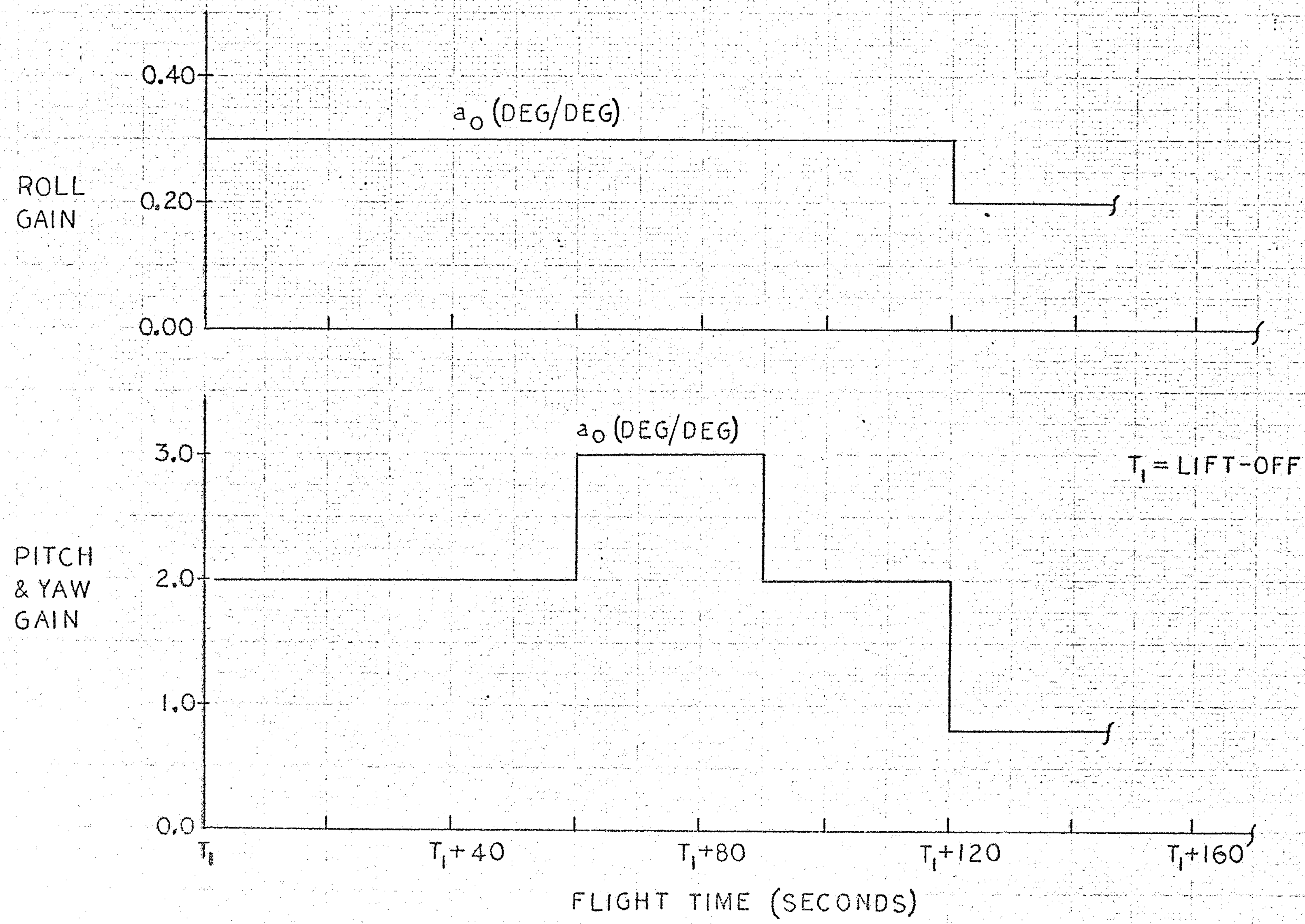
ALL TIMES ARE INPUT TIMES.

FIG. 2

5-11-66

a_o TOLERANCE IS $\pm$ 10% OR $\pm$ 1 SECOND AT THE SWITCH POINTS

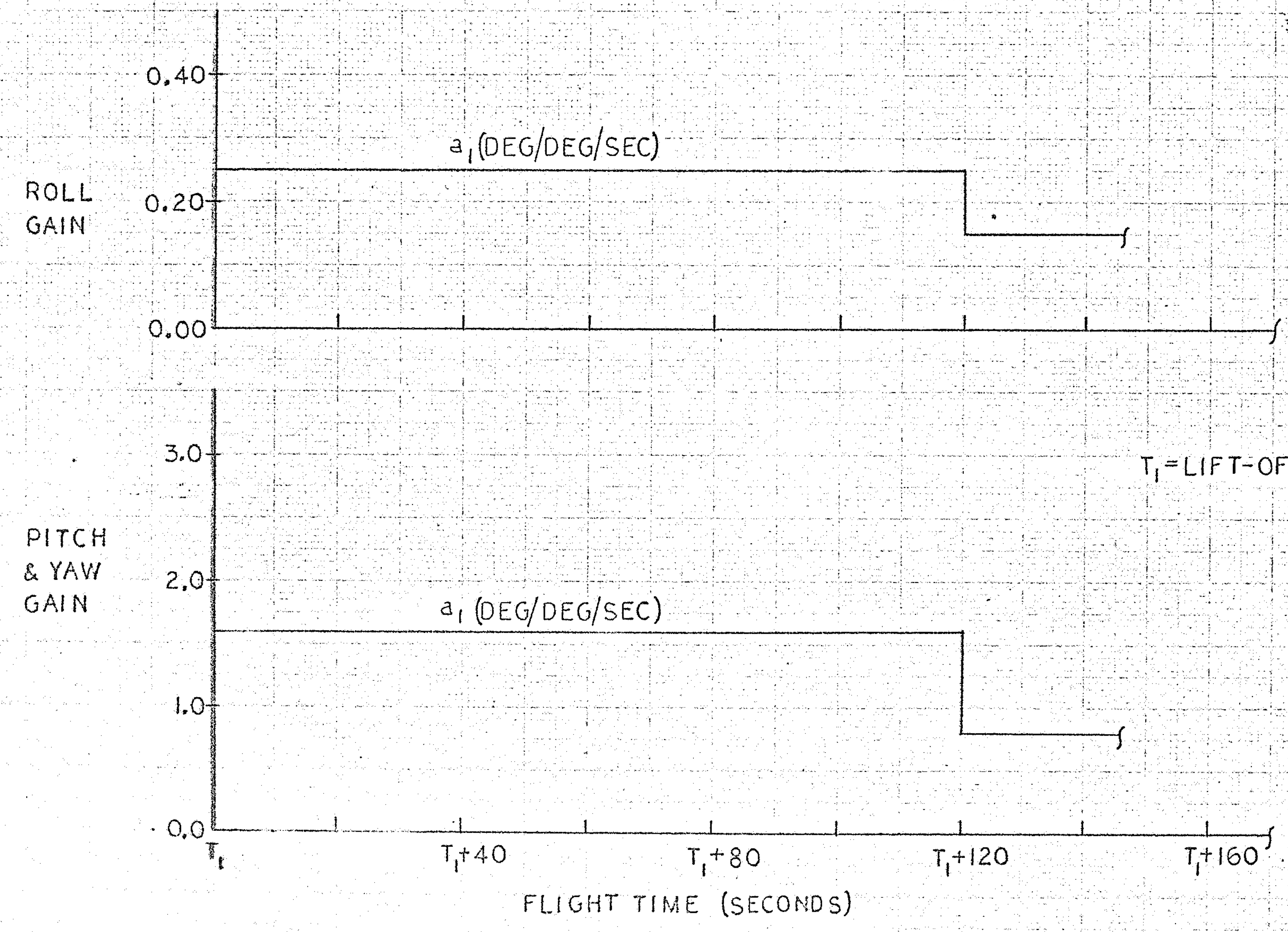
Saturn IB/SA-203
Attitude Error Control Gains
First Stage Flight
Fig. 3



1-31-66

a_1 TOLERANCE IS ±10% OR ±1 SECOND AT THE SWITCH POINTS

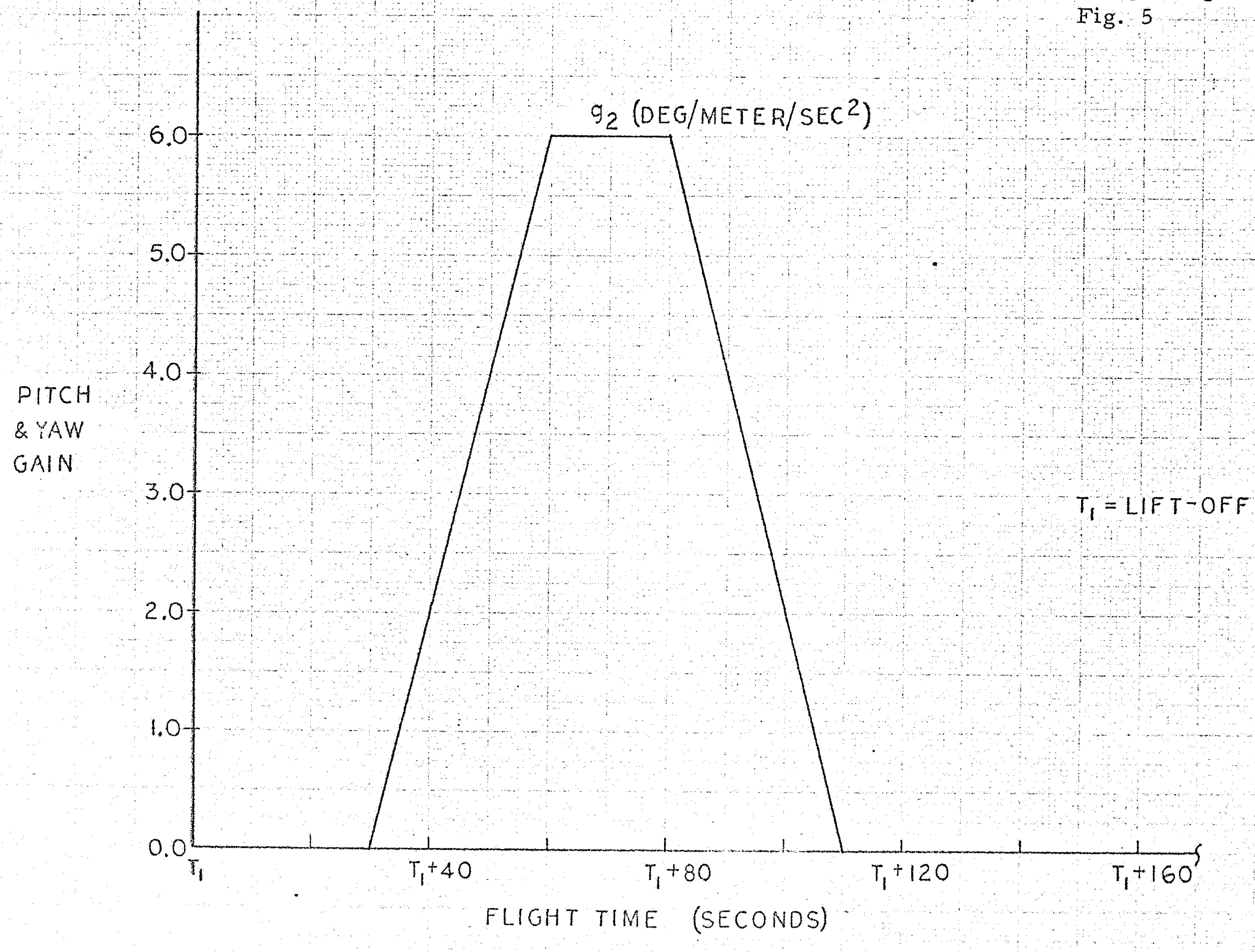
Saturn IB/SA-203
Attitude Rate Control Gains
First Stage Flight
Fig. 4



E.b.d.
1-31-66

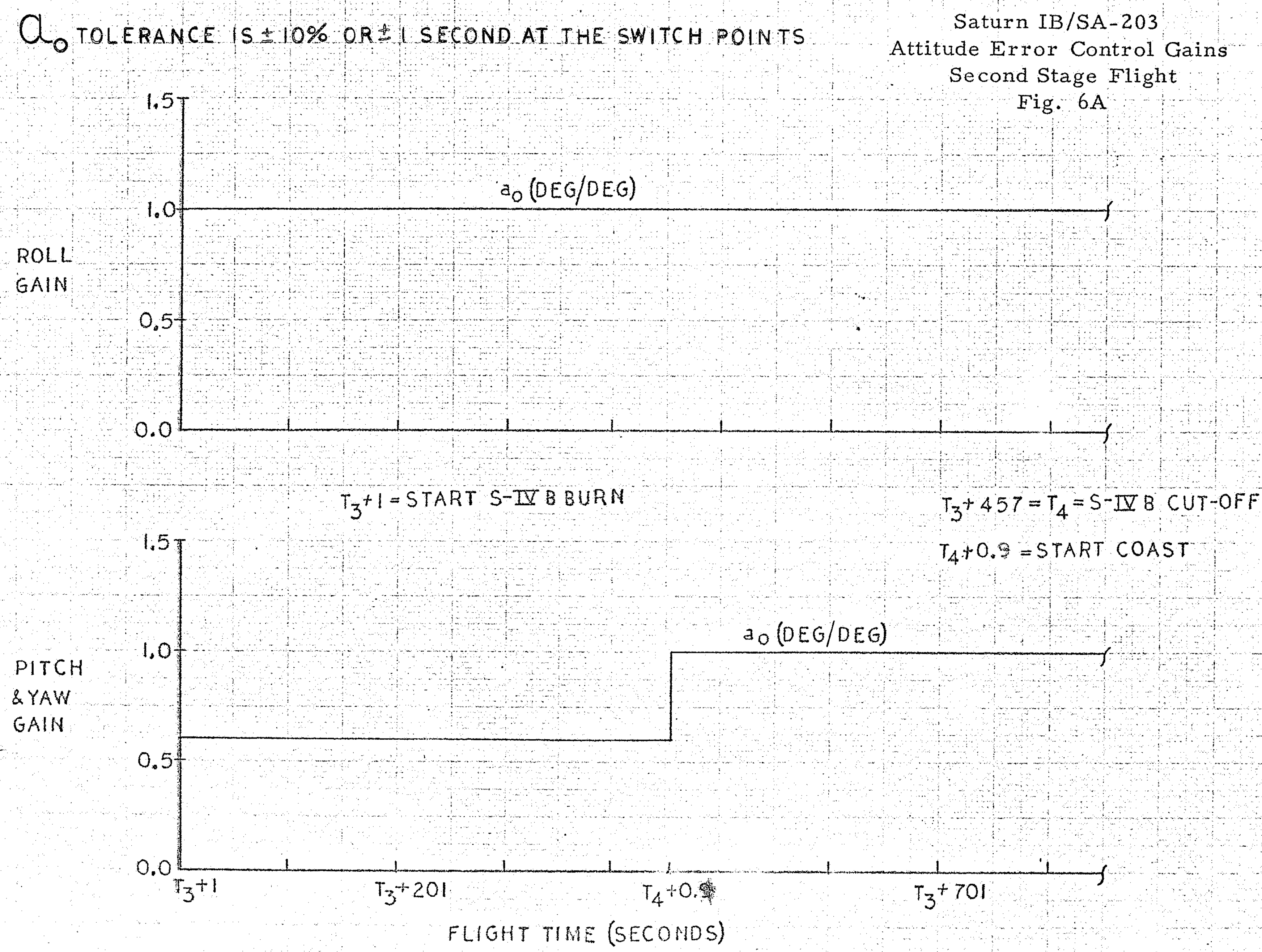
Saturn IB/SA-203
Lateral Acceleration Control Gain
First Stage Flight
Fig. 5

g_2 TOLERANCE IS ± 10% OR ± 1 SECOND AT THE SWITCH POINTS



E.L.S.
1-31-66

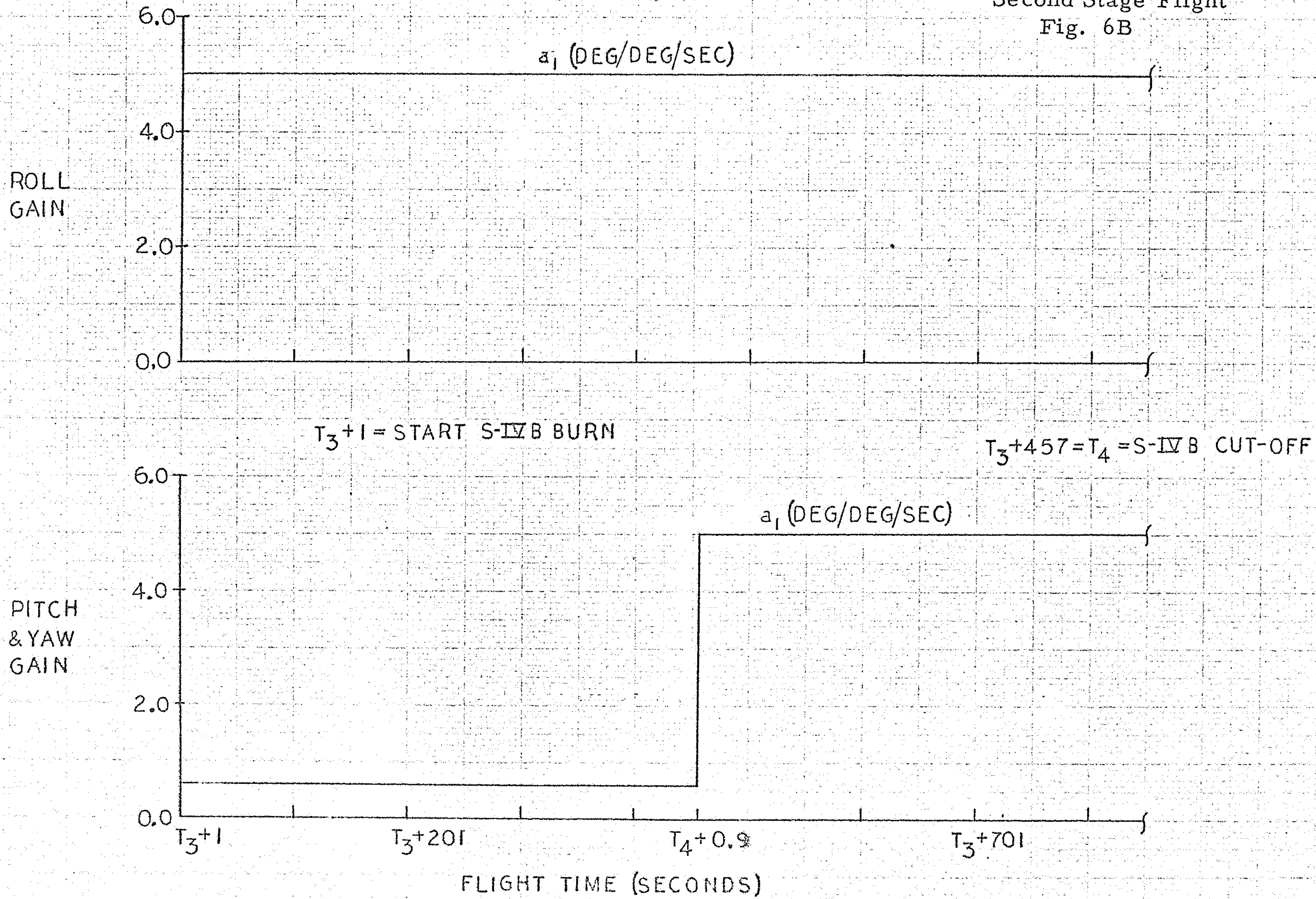
Saturn IB/SA-203
Attitude Error Control Gains
Second Stage Flight
Fig. 6A



E.L.L.
1-31-66

a_1 TOLERANCE IS ± 10% OR ± 1 SECOND AT THE SWITCH POINTS

Saturn IB/SA-203
Attitude Rate Control Gains
Second Stage Flight
Fig. 6B



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FLIGHT CONTROL COMPUTER APS CONTROL

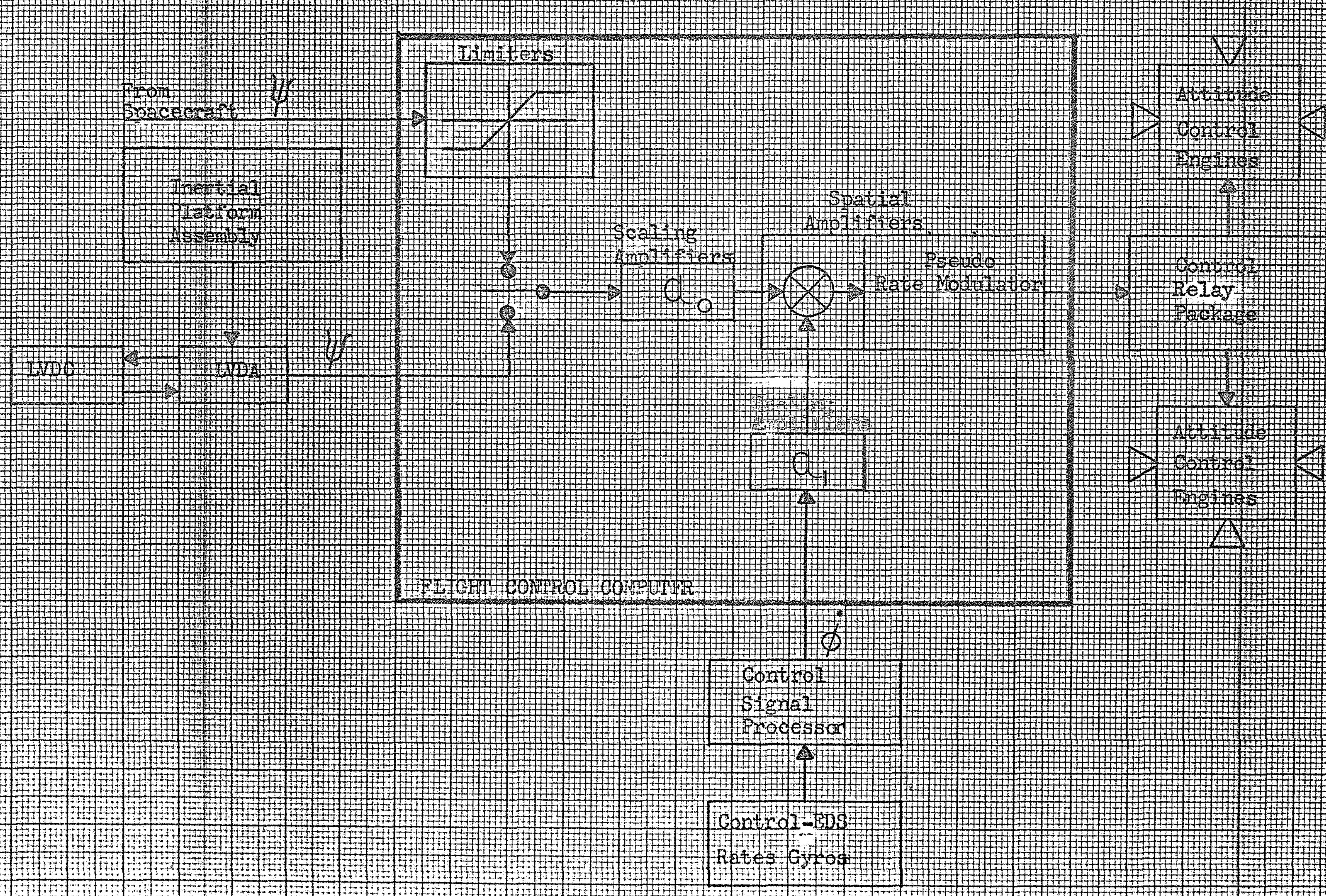


FIG. 7A

E.C.S.

FIG 7B

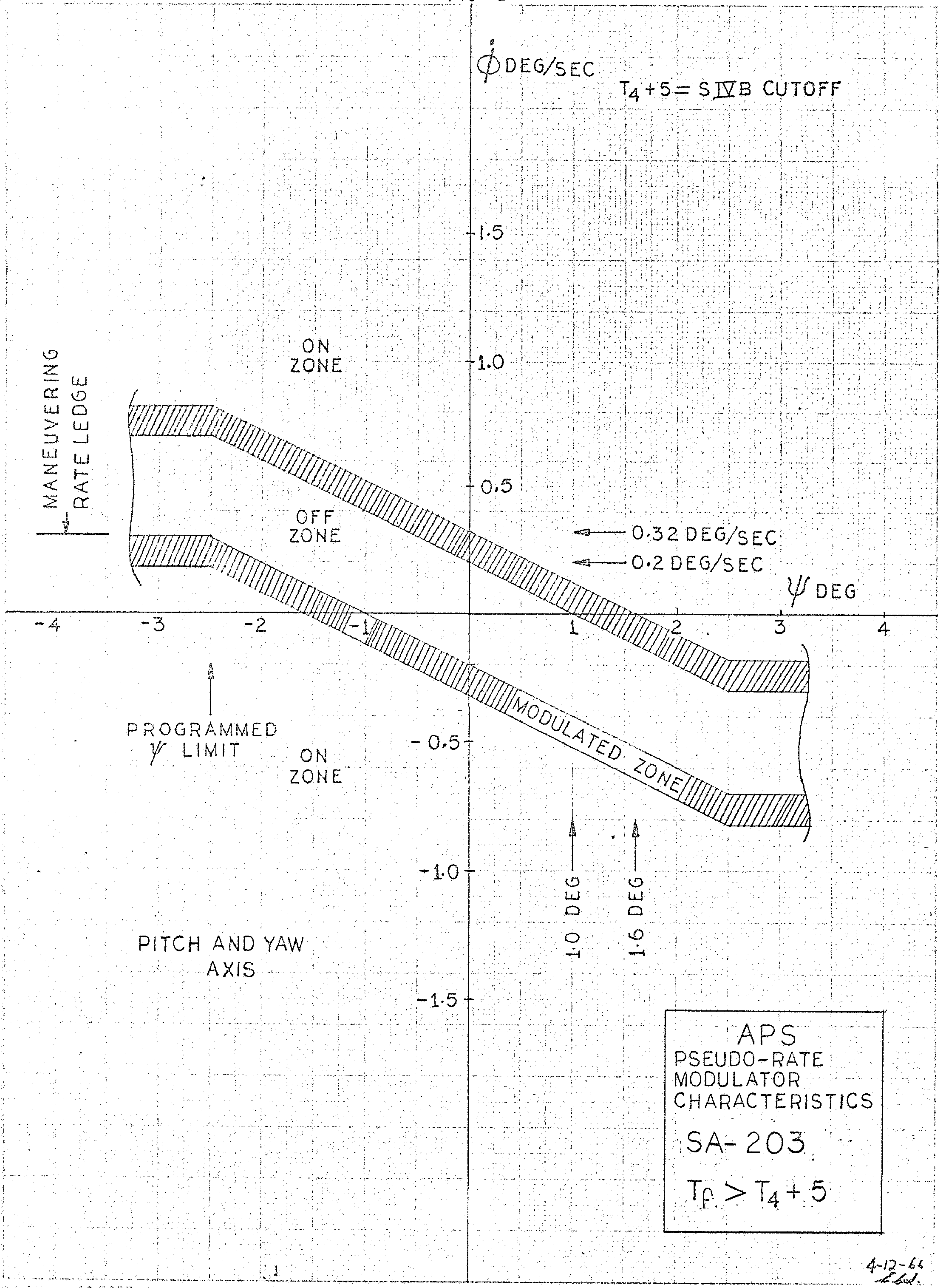
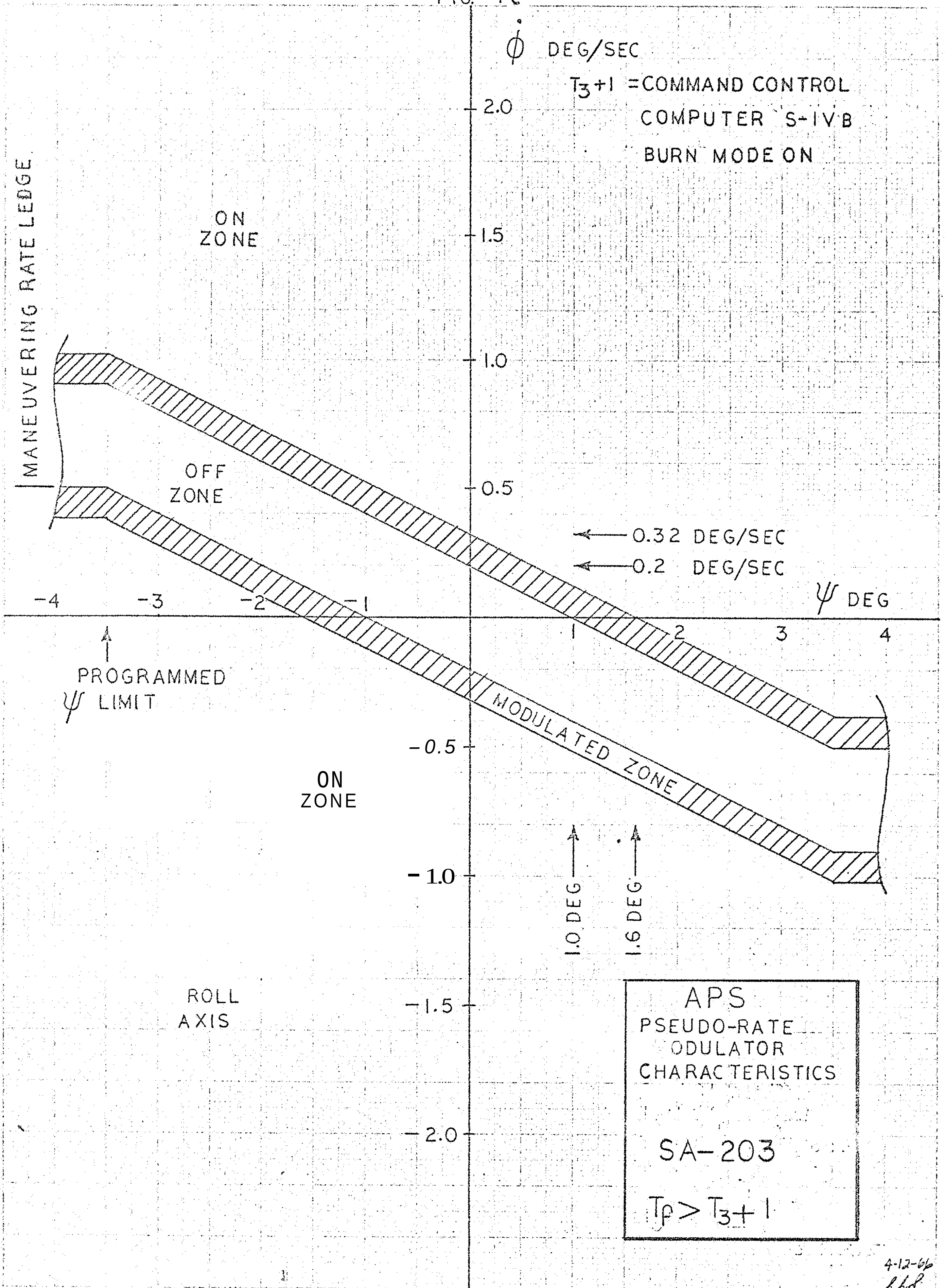

$\dot{\phi}$ DEG/SEC
$T_4 + 5 =$ S IVB CUTOFF
1.5
1.0
0.5
-0.5
-1.0
-1.5
-4
-3
-2
-1
1
2
3
4
ψ DEG
ON ZONE
OFF ZONE
ON ZONE
MANEUVERING RATE LEDGE
0.32 DEG/SEC
0.2 DEG/SEC
MODULATED ZONE
PROGRAMMED ψ LIMIT
1.0 DEG
1.6 DEG
PITCH AND YAW AXIS
APS
PSEUDO-RATE
MODULATOR
CHARACTERISTICS
SA-203
$T_f > T_4 + 5$
4-12-66

FIG. 7C



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KEUFFEL & ESSER CO.

FIG 8A

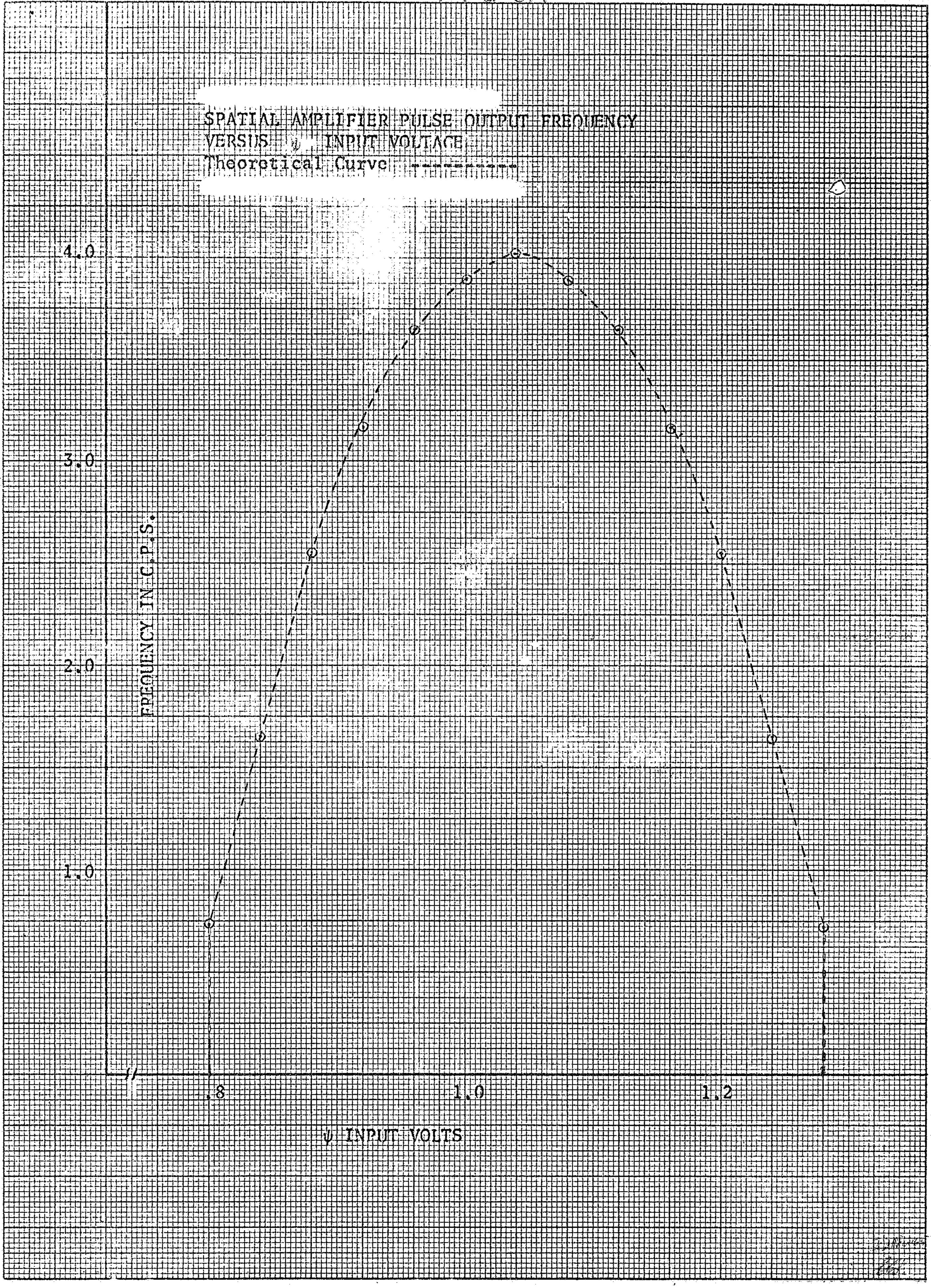

SPATIAL AMPLIFIER PULSE OUTPUT FREQUENCY
VERSUS ψ INPUT VOLTAGE
Theoretical Curve ----------
FREQUENCY IN C.P.S.
4.0
3.0
2.0
1.0
.8
1.0
1.2
ψ INPUT VOLTS

FIG 8B

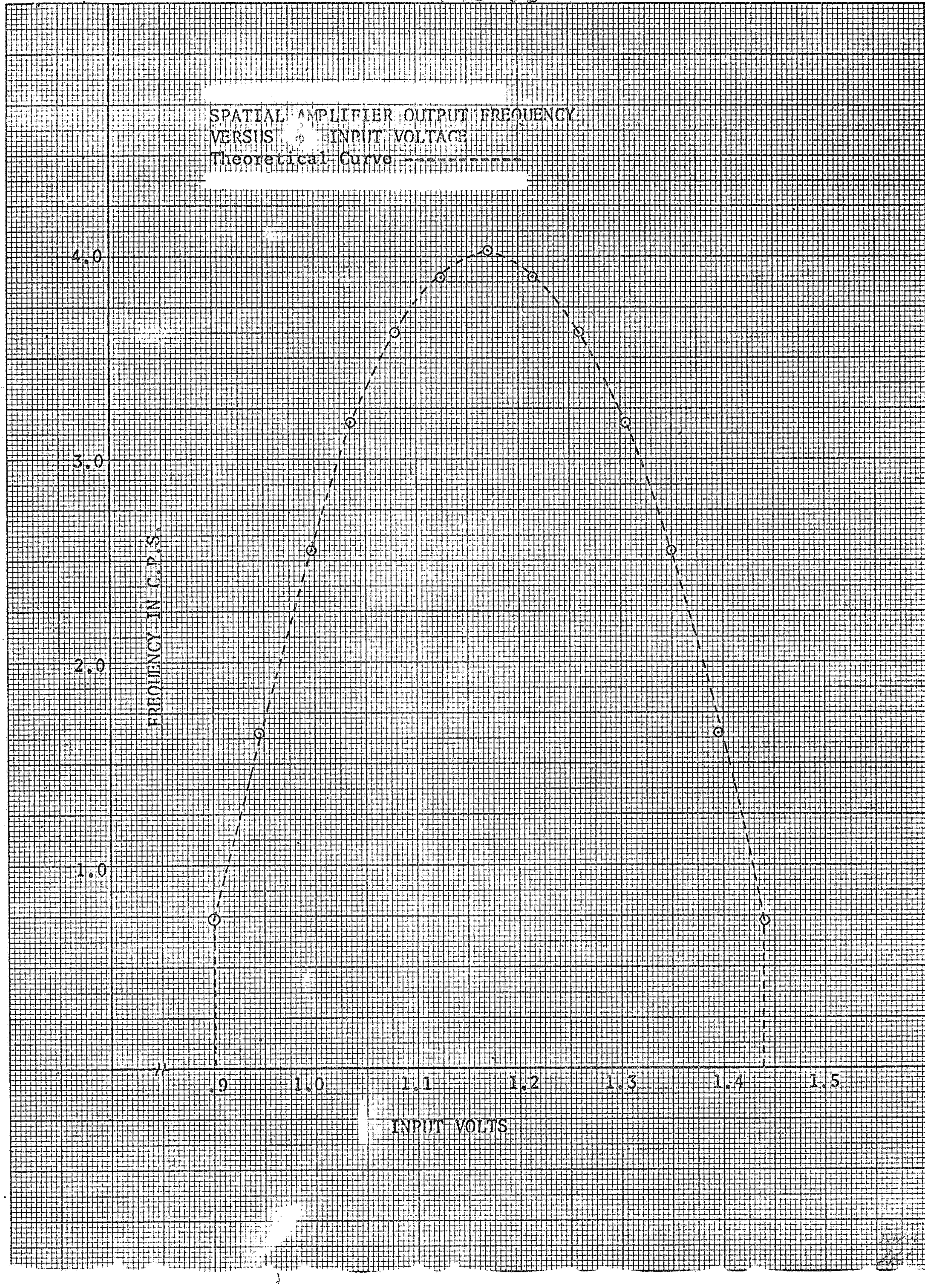
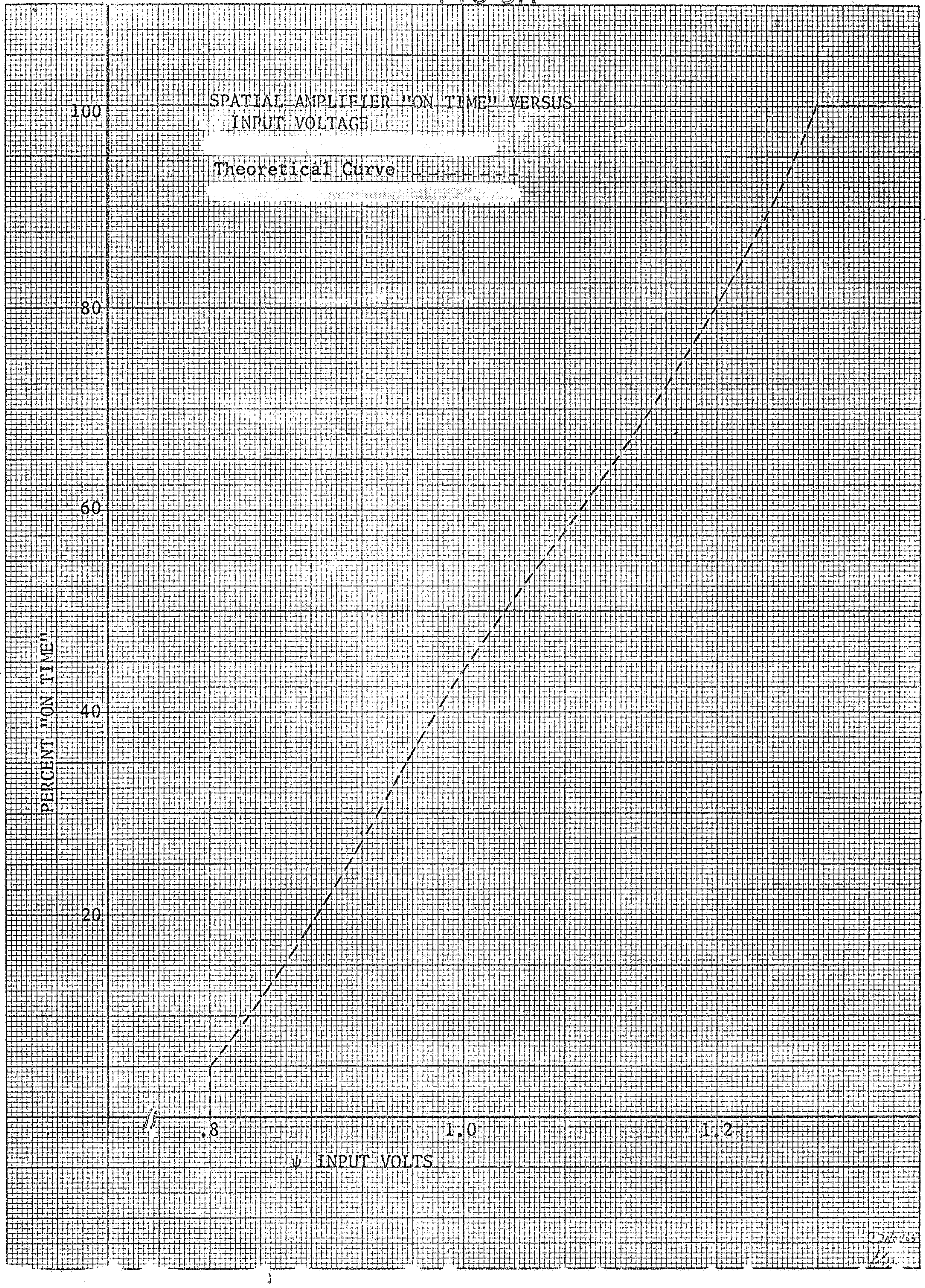

SPATIAL AMPLIFIER OUTPUT FREQUENCY
VERSUS INPUT VOLTAGE
Theoretical Curve
4.0
3.0
2.0
1.0
FREQUENCY IN C.P.S.
.9
1.0
1.1
1.2
1.3
1.4
1.5
INPUT VOLTS

FIG 9A



SPATIAL AMPLIFIER "ON TIME" VERSUS
INPUT VOLTAGE
Theoretical Curve
PERCENT "ON TIME"
100
80
60
40
20
.8
1.0
1.2
ψ INPUT VOLTS

FIG 9B

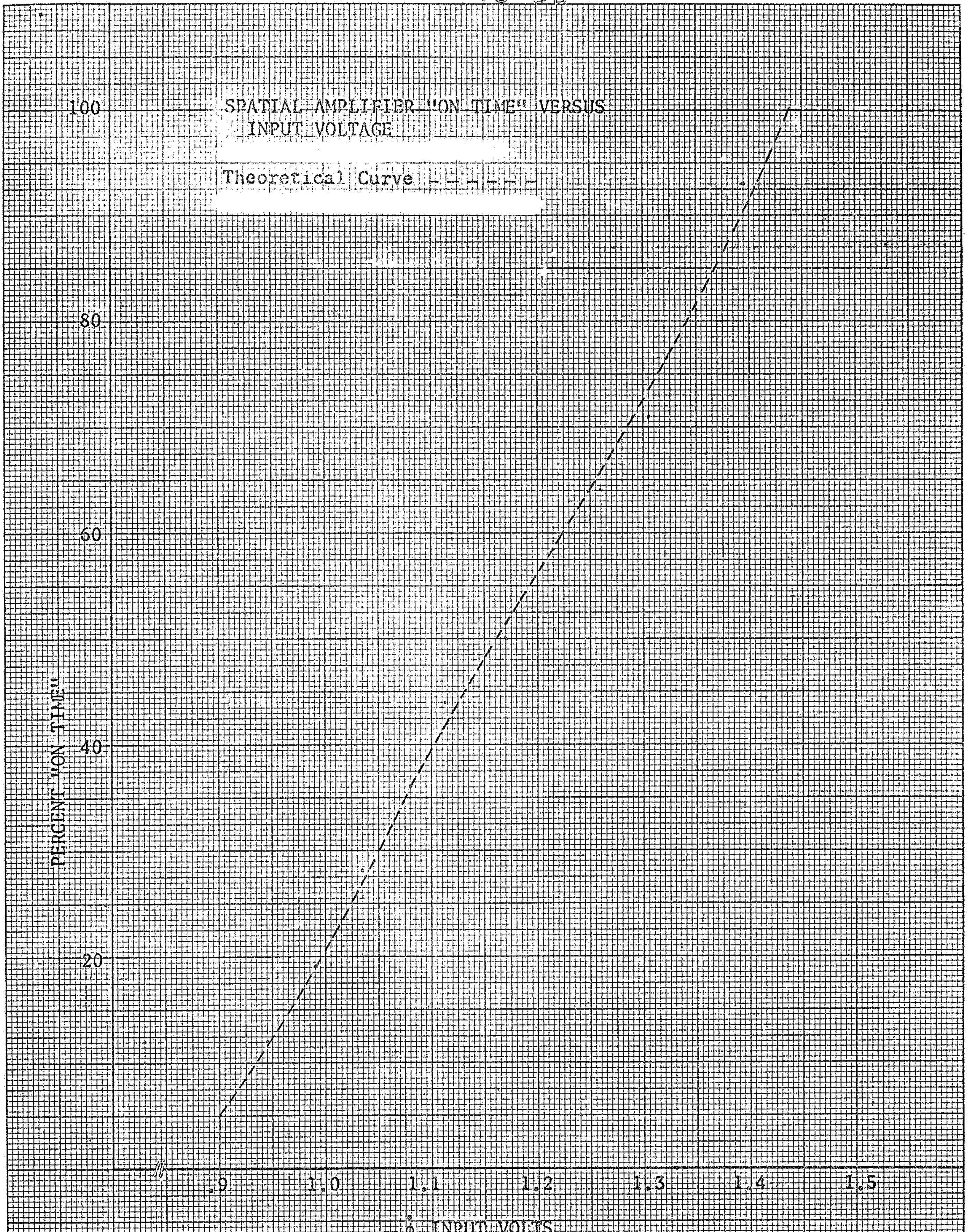

SPATIAL AMPLIFIER "ON TIME" VERSUS
INPUT VOLTAGE
Theoretical Curve - - - - - -
100
80
60
40
20
PERCENT "ON TIME"
.9
1.0
1.1
1.2
1.3
1.4
1.5
ϕ INPUT VOLTS

FIG 10A

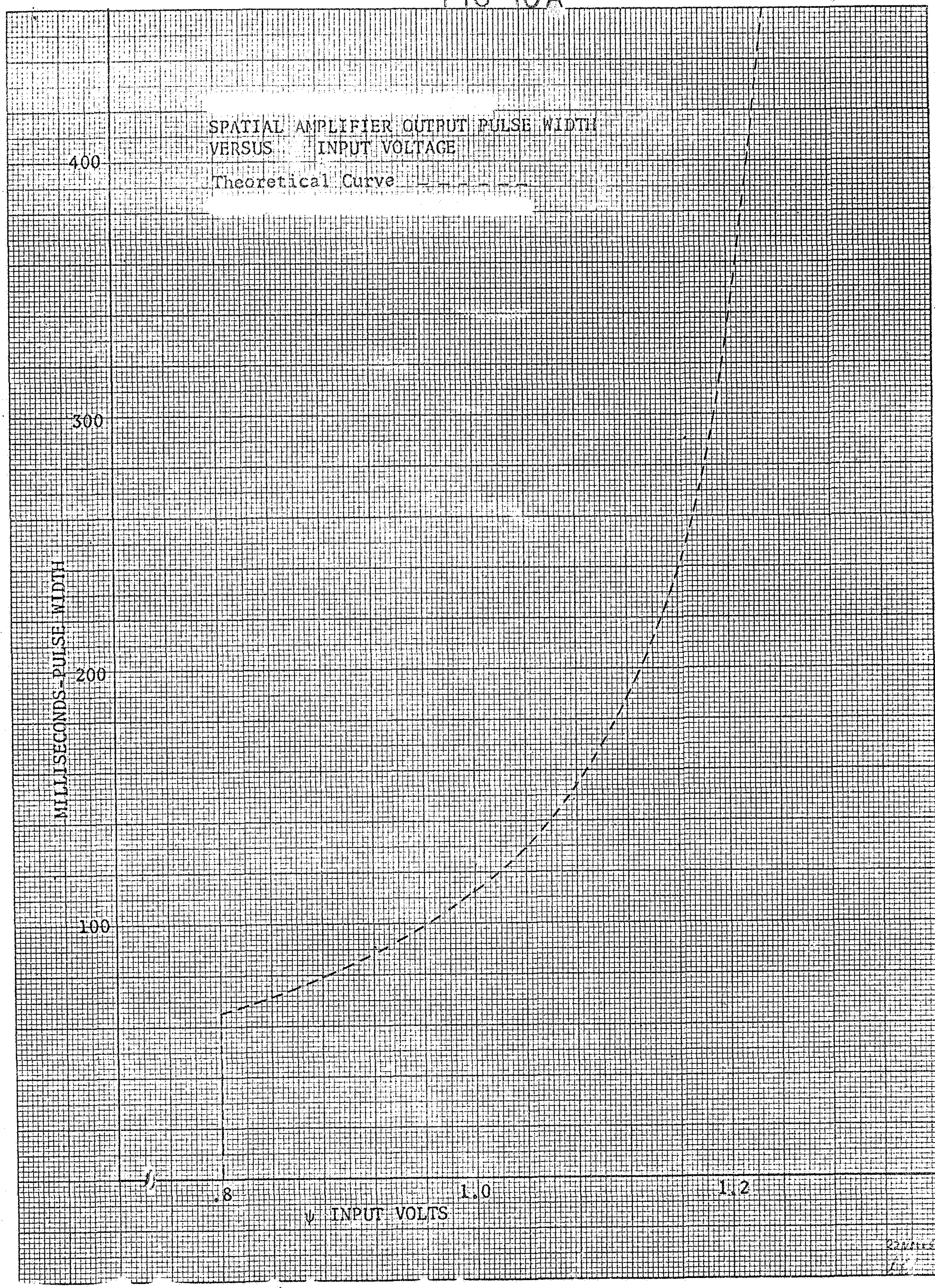
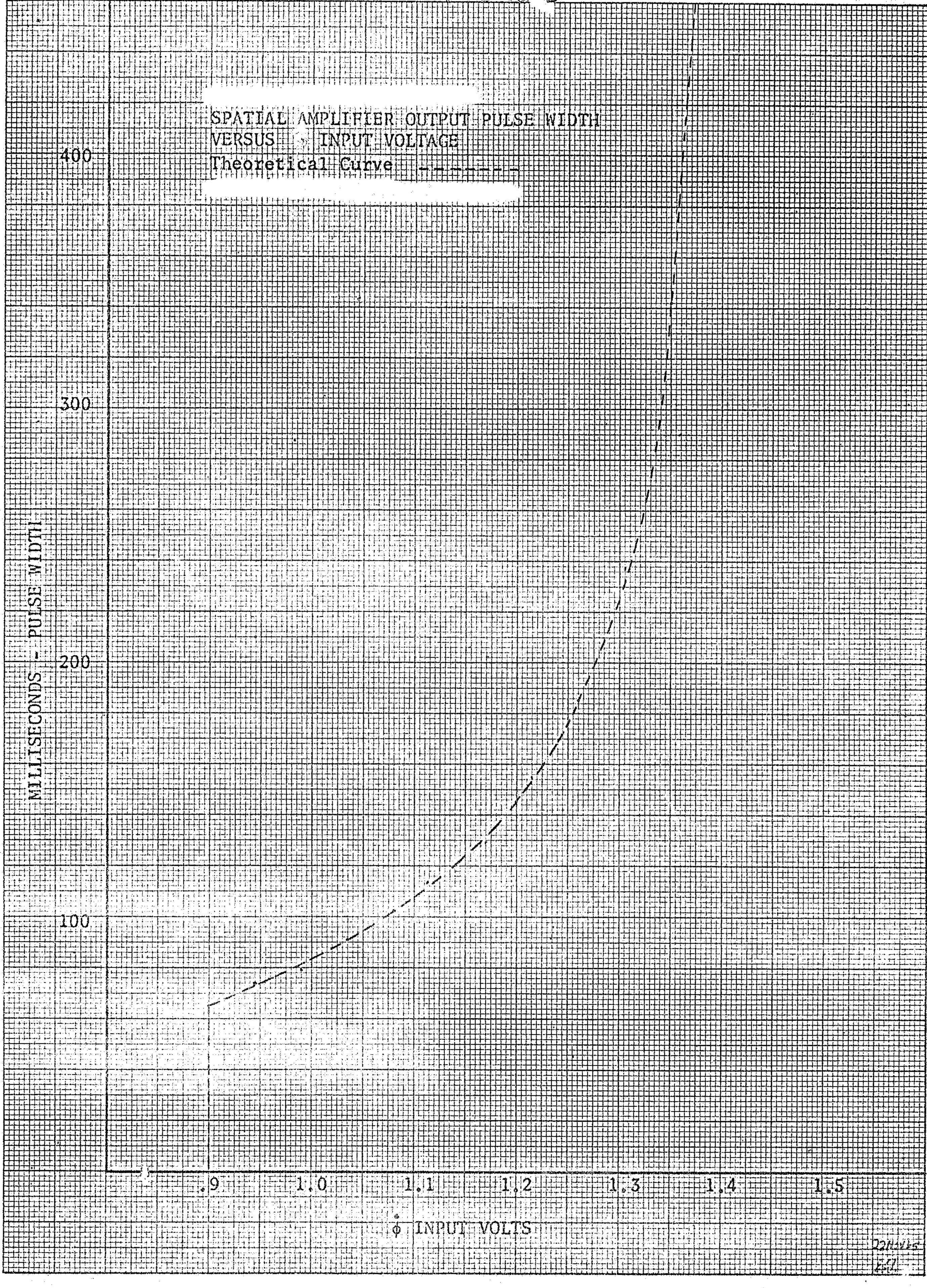
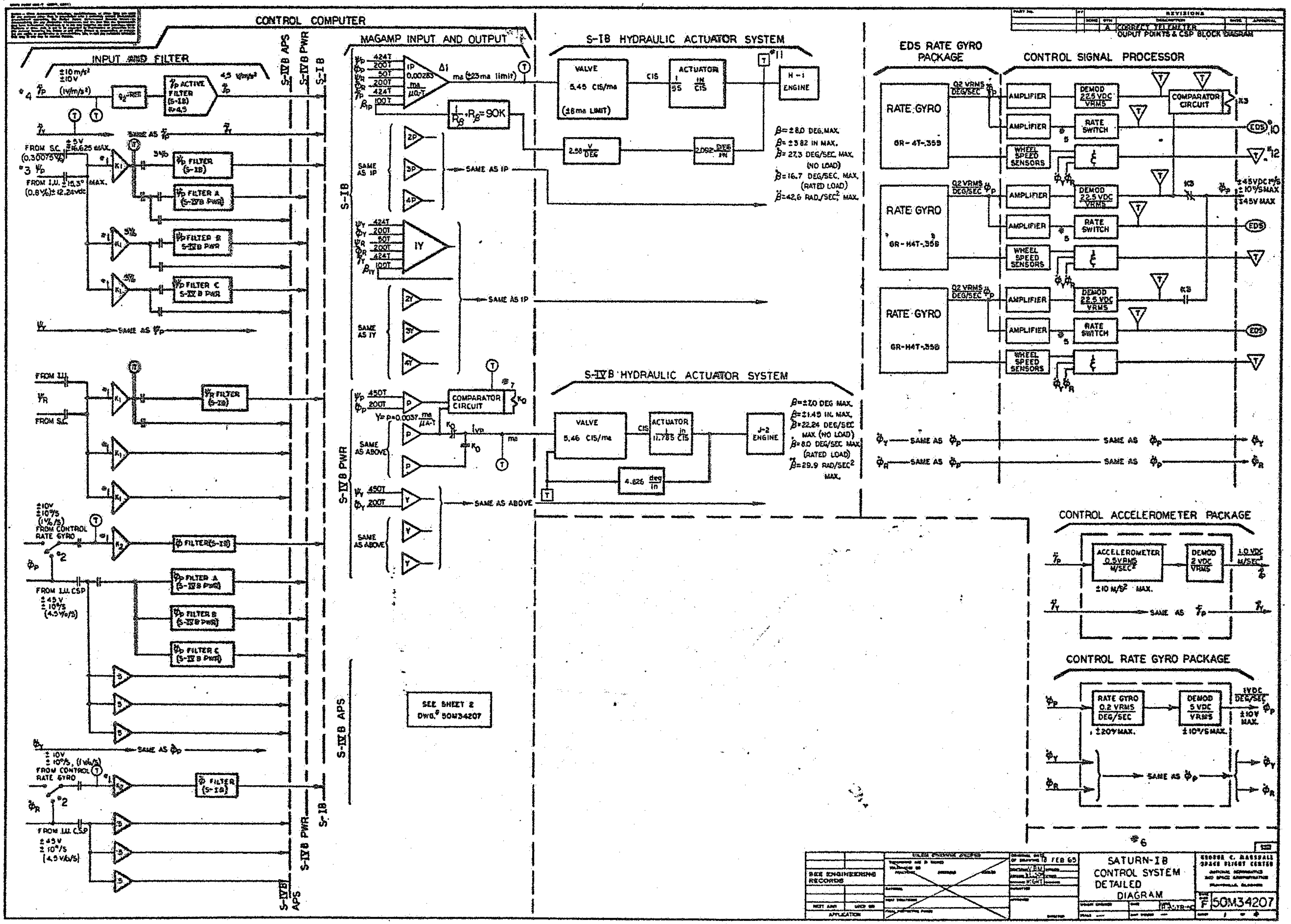
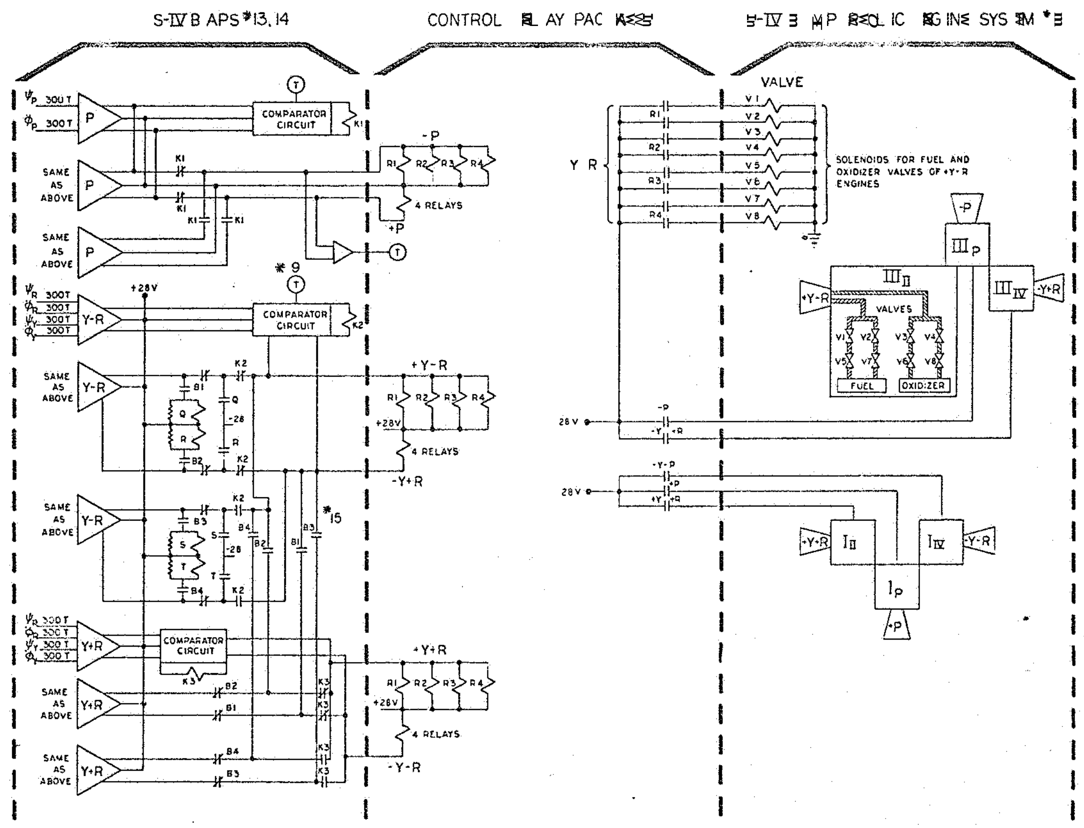

SPATIAL AMPLIFIER OUTPUT PULSE WIDTH
VERSUS INPUT VOLTAGE
Theoretical Curve - - - - - -
400
300
200
100
MILLISECONDS-PULSE WIDTH
.8
1.0
1.2
INPUT VOLTS

FIG 10 B


SPATIAL AMPLIFIER OUTPUT PULSE WIDTH
VERSUS INPUT VOLTAGE
Theoretical Curve --------
400
300
200
100
MILLISECONDS - PULSE WIDT
.9
1.0
1.1
1.2
1.3
1.4
1.5
ϕ INPUT VOLTS


CONTROL COMPUTER
INPUT AND FILTER
MAGAMP INPUT AND OUTPUT
S-IB HYDRAULIC ACTUATOR SYSTEM
S-IVB HYDRAULIC ACTUATOR SYSTEM
EDS RATE GYRO PACKAGE
CONTROL SIGNAL PROCESSOR
CONTROL ACCELEROMETER PACKAGE
CONTROL RATE GYRO PACKAGE
RATE GYRO
AMPLIFIER
RATE SWITCH
WHEEL SPEED SENSORS
DEMOD 22.5 VDC VRMS
COMPARATOR CIRCUIT
VALVE
ACTUATOR
H-1 ENGINE
J-2 ENGINE
SAME AS IP
SAME AS IY
SAME AS ABOVE
SEE SHEET 2 DWG. 50M34207
S-IB
S-IVB PWR
S-IVB APS
CORRECT TELEMETER OUPUT POINTS & CSP BLOCK DIAGRAM
SATURN-IB CONTROL SYSTEM DETAILED DIAGRAM
GEORGE C. MARSHALL SPACE FLIGHT CENTER
50M34207



SEE ENGINEERING RECORDS

ORIGINAL DATE OF DRAWING 7 FEB 66

SATURN-IB CONTROL SYSTEM DETAILED DIAGRAM

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

F 50M34207

SHEET 2 OF 4

A

*NOTES

1, K_1 and K_2 versus signal source

K_1	K_2	Signal Source
3.75	∞	IU LVDA
10.00		APOLLO SC
-	1.00	IU CSP (For $K_2 = 1$ The amplifier will be removed)
	4.50	CONTROL RG

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 $\dot{\phi}_R$ 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 (T) indicates a telemetry signal available from the control computer at the indicated points,,

10, The symbol (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 ± PO degrees per second,

11. The symbol $\boxed{T}$ indicates a telemetry signal available from the actuators,

12, The symbol ▽T indicates a telemetry signal available Prom the control signal processor,

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.

ORIGINAL DATE 18 FEB 65	Saturn-IB Control System Detailed Diagram	GEORGE C. MARSHALL SPACE FLIGHT CENTER NATIONAL AERONAUTICS & SPACE ADMINISTRATION
DFMN	CHK Smith, E.C.	
ENGR Hight, H.H.	ENGR	
SYM	DESCRIP	DATE
REVISIONS		
A	50M34207	sheet 3 of 4

16. Magamp 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:

Stage	Channel	Turns per Winding	Number Windings in Series	Total Turns	Total Resistance (Ohms)
	β	100	1	100	22.64
S-IB	ψ_p	424	4	1696	383.97
	ψ_y	424	4	1696	383.97
	ψ_r	50	8	400	90.56
	$\dot{\phi}_p$	200	4	800	181.12
	$\dot{\phi}_y$	200	4	800	181.12
	$\dot{\phi}_r$	200	8	1600	362.24
	$\ddot{\gamma}_p$	424	4	1696	383.97
	$\ddot{\gamma}_y$	424	4	1696	383.97
S-IVB PWR	ψ_p	450	1	450	101.88
	ψ_y	450	1	450	101.88
	$\dot{\phi}_p$	200	1	200	45.28
	$\dot{\phi}_y$	200	1	200	45.28
S-IVB APS	ψ_p	300	1	300	67.32
	ψ_y	300	2	600	135.84
	ψ_r	300	2	600	135.84
	ϕ_p	300	1	300	67.92
	6,	300	2	600	135.84
	$\dot{\phi}_r$	300	2	600	135.84

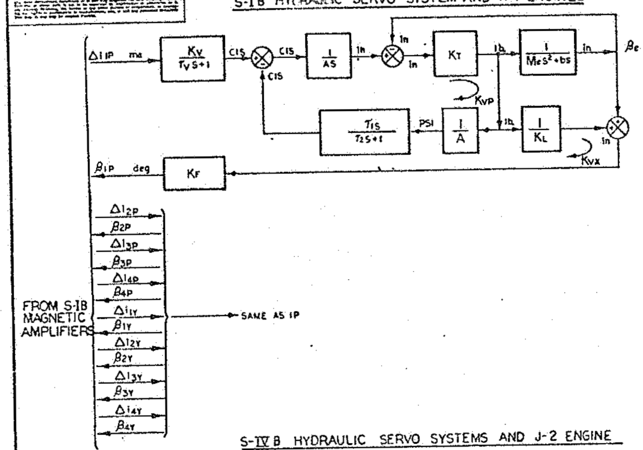
ORIGINAL DATE 18 FEB 65
DFMN
CHK Barton
ENGR Hight
ENGR
SYM DESCRIP DATE
MF REVISIONS

Saturn - IB
Control System
Detailed Diagram

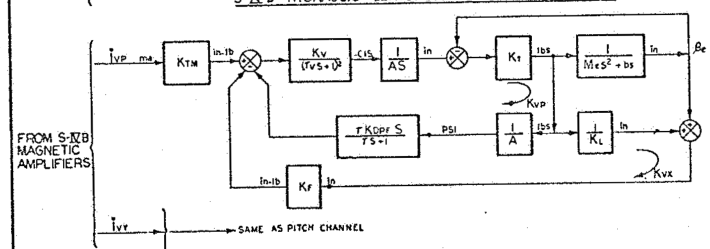
GEORGE C. MARSHALL
SPACE FLIGHT CENTER
NATIONAL AERONAUTICS
& SPACE ADMINISTRATION

A 50M34207

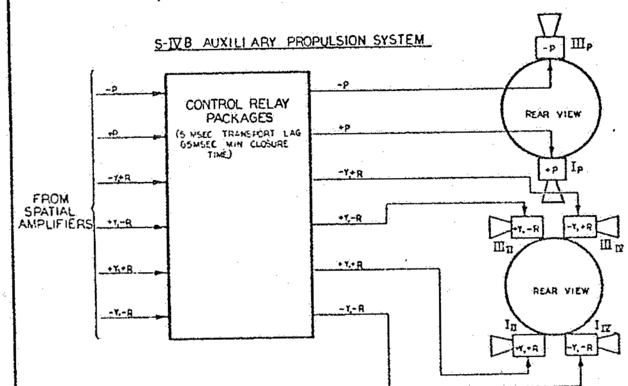
S-IB HYDRAULIC SERVO SYSTEM AND H-1 ENGINES



S-IVB HYDRAULIC SERVO SYSTEMS AND J-2 ENGINE



S-IVB AUXILIARY PROPULSION SYSTEM



S-IB SYSTEM PARAMETERS

K_V — 5.45 CIS/ma.
τ_V — 3.18×10^{-3} Sec.
A — 5.0 in²
K_T — 57,910 lb/in
K_L — 66,800 lb/in
M_e — 16.1 lb-Sec²/in
b — 103.0 lb-Sec/in
τ_1 — 0.956×10^{-3} Sec.
τ_2 — 0.796×10^{-4} Sec.
K_F — 2.092 deg/in
K_{VP} — 27.80 Sec⁻¹
K_{VX} — 20.75 Sec⁻¹
C_X — 1.5 deg

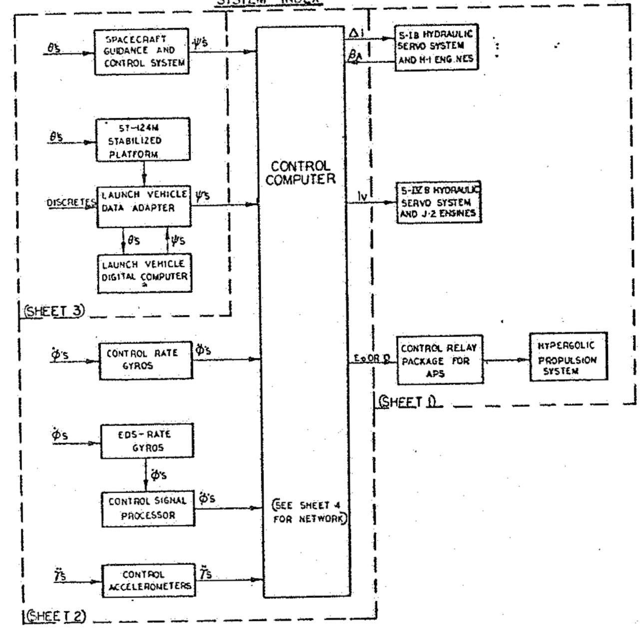
LIMITS: ACTUATOR MOTION: ±3.82 in OR 8 deg
VALVE FLOW: 45.12 CIS OR 8 ma.
MAGAMP OUTPUT: 16 ma.

S-IVB SYSTEM PARAMETERS

K_{TM} — 0.033 in-lb/ma
K_V — 149.5 CIS/in-lb
τ_V — 3.18×10^{-3} Sec
A — 11.78 in²
K_T — 202,400 lb/in
K_L — 236,600 lb/in
M_e — 120.0 lb-Sec²/in
b — 595.0 lb Sec/in
τ — .08 Sec
K_{DPF} — 10×10^{-3} in-lb/PSI
K_F — 1.129 in-lb/in
K_{VP} — 21.8 Sec⁻¹
K_{VX} — 14.25 Sec⁻¹

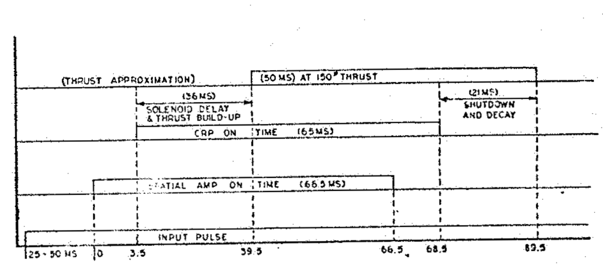
LIMITS: ACTUATOR MOTION: ±1.45 in. OR ±7 deg
VALVE FLOW: 53.9 CIS
MAGAMP OUTPUT: 60 ma.

SYSTEM INDEX



ESTIMATED RELAY, SOLENOID, AND THRUST CHARACTERISTICS

FOR SIMULATION OF AUXILIARY PROPULSION SYSTEM



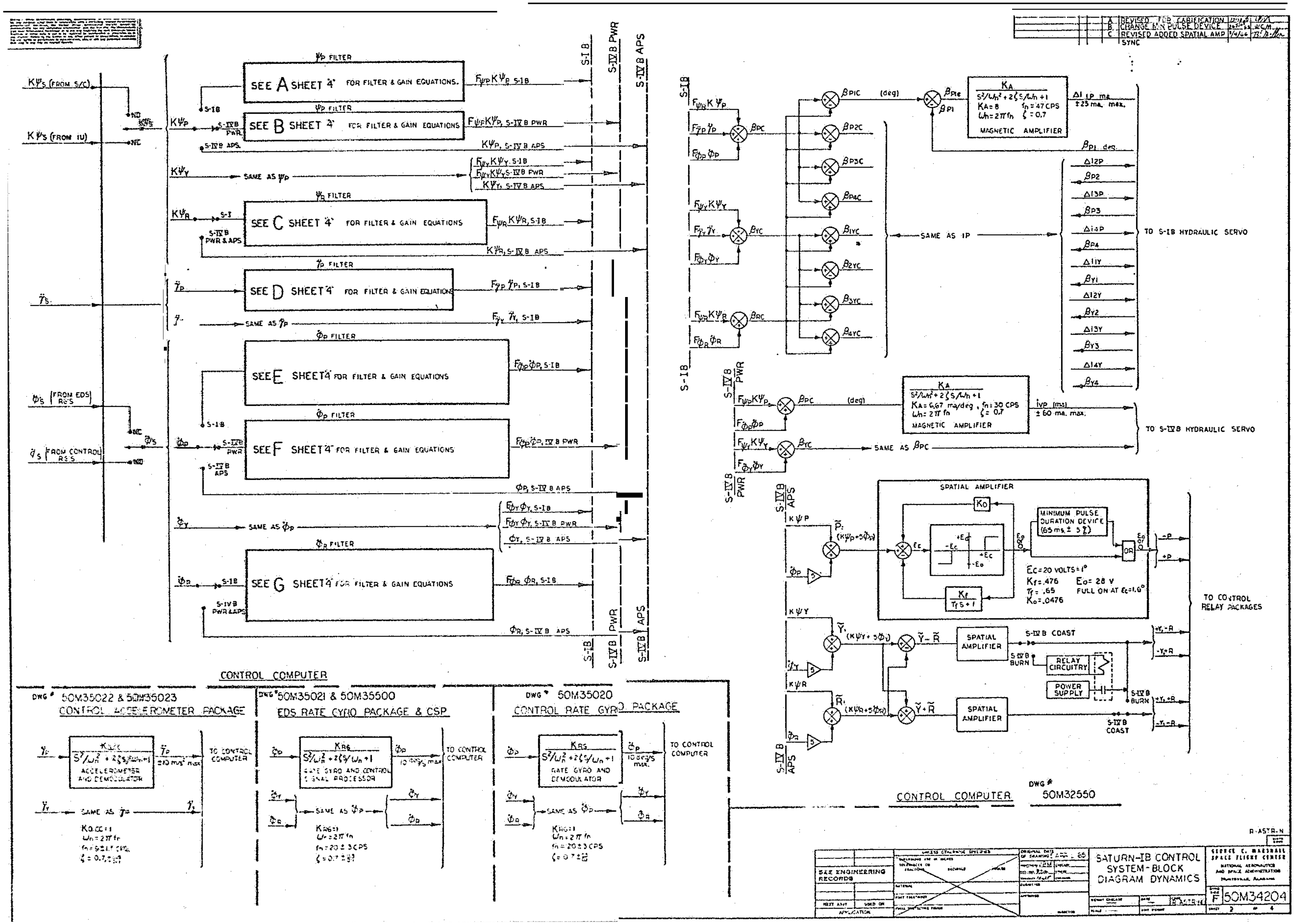
NOTES:
1. THE 25-50 MS DELAY BETWEEN THE INPUT STEP AND THE SPATIAL AMP ON TIME DEPENDS UPON THE VOLTAGE LEVEL PRIOR TO THE INPUT STEP

REVISIONS
A REVISED IDENTIFYING TITLES
B CHANGE MIN IMPULSE DEVICE

SATURN-IB CONTROL SYSTEM-BLOCK DIAGRAM DYNAMICS

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

F 50M34204


SEE A SHEET 4 FOR FILTER & GAIN EQUATIONS.
SEE B SHEET 4 FOR FILTER & GAIN EQUATIONS
SEE C SHEET 4 FOR FILTER & GAIN EQUATIONS
SEE D SHEET 4 FOR FILTER & GAIN EQUATIONS
SEE E SHEET 4 FOR FILTER & GAIN EQUATIONS
SEE F SHEET 4 FOR FILTER & GAIN EQUATIONS
SEE G SHEET 4 FOR FILTER & GAIN EQUATIONS
S-IB
S-IVB PWR
S-IVB APS
SAME AS IP
TO S-IB HYDRAULIC SERVO
TO S-IVB HYDRAULIC SERVO
MAGNETIC AMPLIFIER
SPATIAL AMPLIFIER
MINIMUM PULSE DURATION DEVICE (65 ms ± 5%)
RELAY CIRCUITRY
POWER SUPPLY
TO CONTROL RELAY PACKAGES
CONTROL COMPUTER
DWG # 50M35022 & 50M35023
CONTROL ACCELEROMETER PACKAGE
DWG # 50M35021 & 50M35500
EDS RATE GYRO PACKAGE & CSP
DWG # 50M35020
CONTROL RATE GYRO PACKAGE
TO CONTROL COMPUTER
CONTROL COMPUTER
DWG # 50M32550
A REVISED FOR CABIFICATION
B CHANGE MIN PULSE DEVICE
C REVISED ADDED SPATIAL AMP
SATURN-IB CONTROL SYSTEM-BLOCK DIAGRAM DYNAMICS
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA
F 50M34204
R-ASTR-N

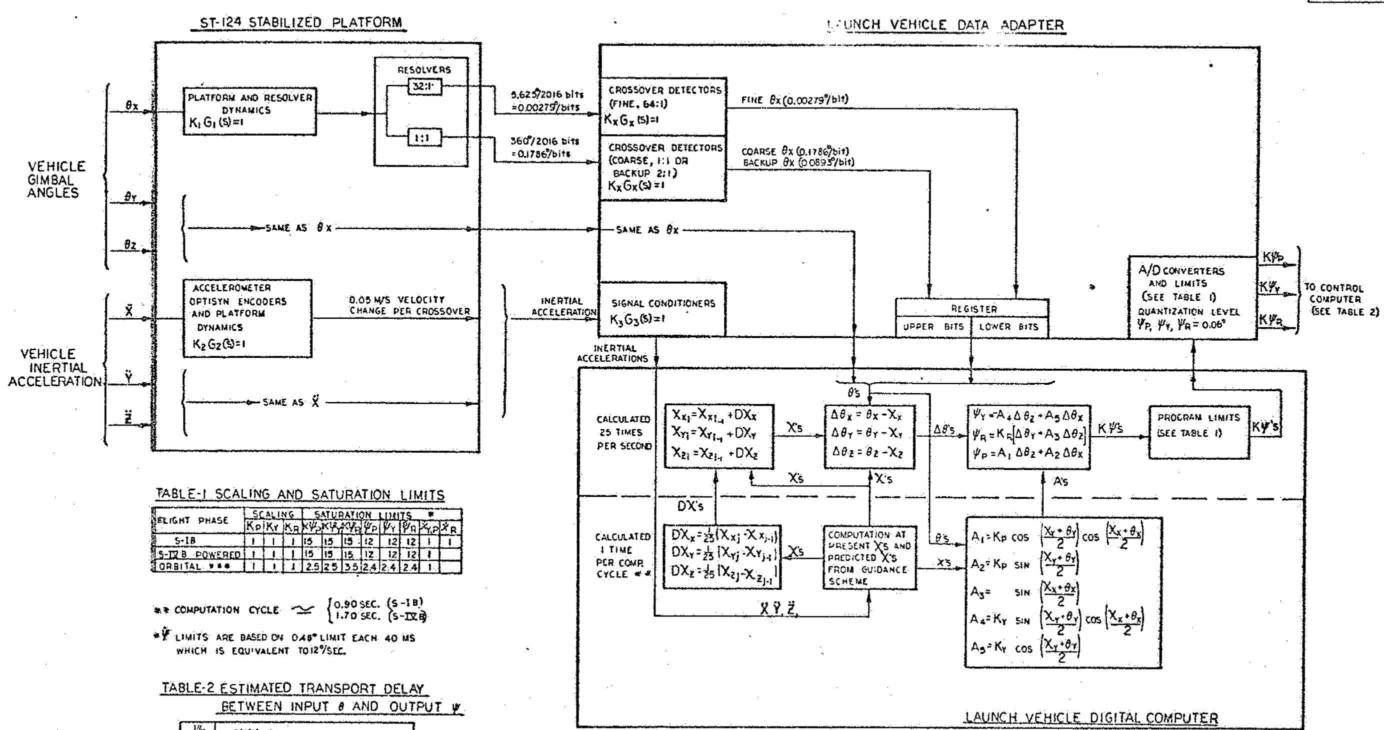


TABLE-1 SCALING AND SATURATION LIMITS

FLIGHT PHASE	SCALING			SATURATION LIMITS *							
	K_P	K_Y	K_R	$K\psi_P$	$K\psi_Y$	$K\psi_R$	ψ_P	ψ_Y	ψ_R	$\dot{X}_{Y,P}$	$\dot{X}_R$
S-IB	1	1	1	15	15	15	12	12	12	1	1
S-IVB POWERED	1	1	1	15	15	15	12	12	12	1	
ORBITAL ***	1	1	1	2.5	2.5	3.5	2.4	2.4	2.4	1	

** COMPUTATION CYCLE ≃ {0.90 SEC. (S-IB); 1.70 SEC. (S-IVB)}

*$\dot{\psi}$ LIMITS ARE BASED ON 0.48° LIMIT EACH 40 MS WHICH IS EQUIVALENT TO 12°/SEC.

TABLE-2 ESTIMATED TRANSPORT DELAY BETWEEN INPUT θ AND OUTPUT ψ

ψ_P	14.44 MS
ψ_Y	8.62 MS
ψ_R	20.02 MS

REVISIONS

SEE ENGINEERING RECORDS

SATURN-IB CONTROL SYSTEM-BLOCK DIAGRAM DYNAMICS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

R-ASTR-NG

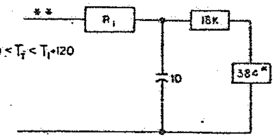
F 50M34204

A	REVISED & REDRAWN TO SUPERSEDE 6APR 65 DWG

★A S-IB

$F\psi_P \frac{a_0}{B_1S+1}$ WHERE $\begin{cases} a_0 = .2 & B_1 = .165600 \quad R_1 = 207.08K \quad T_1<T_f<T_1+60;\ T_1+90<T_f<T_1+120 \\ a_0 = .3 & B_1 = .158400 \quad R_1 = 132K \quad T_1+60<T_f<T_1+90 \\ a_0 = .8 & B_1 = .1742 \quad R_1 = 545K \quad T_1+120<T_f<B.O. \end{cases}$

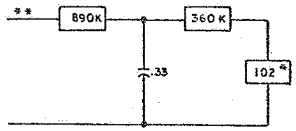
$\psi_{P,Y}$



★B S-IVB

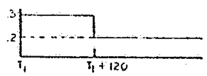
$F\psi_P = \frac{a_0}{0.845860\times10^{-1}S+1}$; WHERE $a_0 = 0.6$ FOR $T_3+1<T_f<T_4$

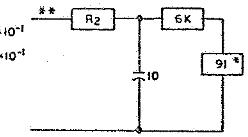
$\psi_{P,Y}$



★C S-IB

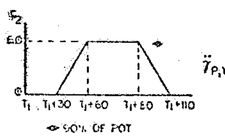
$F\psi_R = \frac{a_0}{B_1S+1}$ WHERE $\begin{cases} a_0 = .3 \quad R_2 = 244K \quad T_1<T_f<T_1+120 \quad B_1 = .5956\times10^{-1} \\ a_0 = .2 \quad R_2 = 369K \quad T_1+120<T_f<B.O. \quad B_1 = .5904\times10^{-1} \end{cases}$



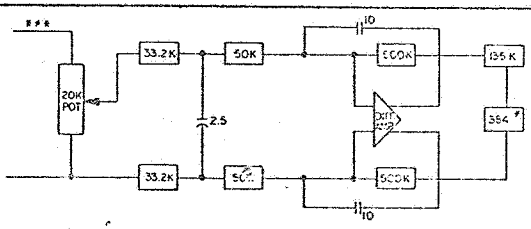


★D S-IB

$\ddot{\gamma}_P \quad \frac{a_2}{.5S^2+.6S+1}$ WHERE,



$\ddot{\gamma}_{P,Y}$



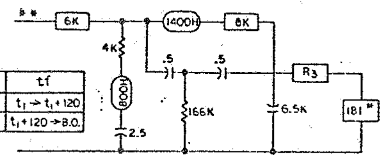
$\ddot{\gamma}_{P,Y}$

★E S-IB

$F\dot{\phi}_P = \frac{(.116200\times10^{-5}S^5 + .124500\times10^{-5}S^4 + .393420\times10^{-3}S^3 + .39920\times10^{-2}S^2 + .176000S)a_1}{B_6S^6 + B_5S^5 + B_4S^4 + B_3S^3 + B_2S^2 + B_1S + 1}$; WHERE

$\dot{\phi}_{P,Y}$

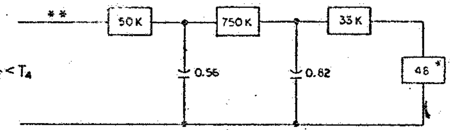
a_1	B_1	B_2	B_3	B_4	B_5	B_6	R3	tf
1.6	.291511	$.327621\times10^{-1}$	$.255972\times10^{-2}$	$.985078\times10^{-4}$	$.301594\times10^{-5}$	$.420716\times10^{-8}$	183K	$t_1 \rightarrow t_1+120$
.8	.291711	$.330726\times10^{-1}$	$.261856\times10^{-2}$	$.905792\times10^{-4}$	$.312936\times10^{-5}$	$.436802\times10^{-6}$	384K	$t_1+120 \rightarrow$ B.O.



★F S-IVB

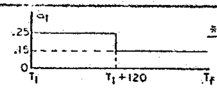
$F\dot{\phi}_P = \frac{a_1}{0.66218\times10^{-3}S^2 + 0.52507\times10^{-1}S+1}$; WHERE $a_1 = .6$ FOR $T_3+1<T_f<T_4$

$\dot{\phi}_{P,Y}$



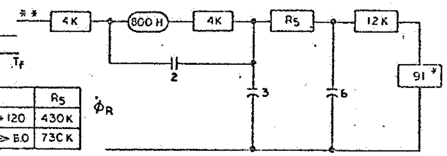
★G S-IB

$F\dot{\phi}_R = \frac{(.16000\times10^{-2}S^2 + .8000\times10^{-2}S)a_1}{B_4S^4 + B_3S^3 + B_2S^2 + B_1S + 1}$



a_1	B_1	B_2	B_3	B_4	T_f	R_5
.25	0.103340	0.637212×10^{-2}	0.301667×10^{-3}	0.132096×10^{-5}	$T_1 \rightarrow T_1+120$	430K
.15	0.103616	0.638327×10^{-2}	0.306657×10^{-3}	0.134554×10^{-5}	$T_1+120 \rightarrow$ B.O.	730K

$\dot{\phi}_R$



NOTES:
- * MAGAMP RESISTANCE.
- ** OUTPUT IMPEDANCE OF DRIVING CIRCUIT IS LESS THAN 10 OHMS.
- *** OUTPUT IMPEDANCE OF DRIVING CIRCUIT IS LESS THAN 500 OHMS.
- ◯ CHOKE (HENRYS)
- ▭ RESISTANCE (OHMS)
- —|(— CAPACITANCE (MICROFARADS)
- ★ SEE SHEET 2 OF 4

SEE ENGINEERING RECORDS	
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED

ORIGINAL DATE OF DRAWING 8 DEC 65

EFFECTIVE ON SA-203

SATURN IB CONTROL SYSTEM — BLOCK DIAGRAM DYNAMICS

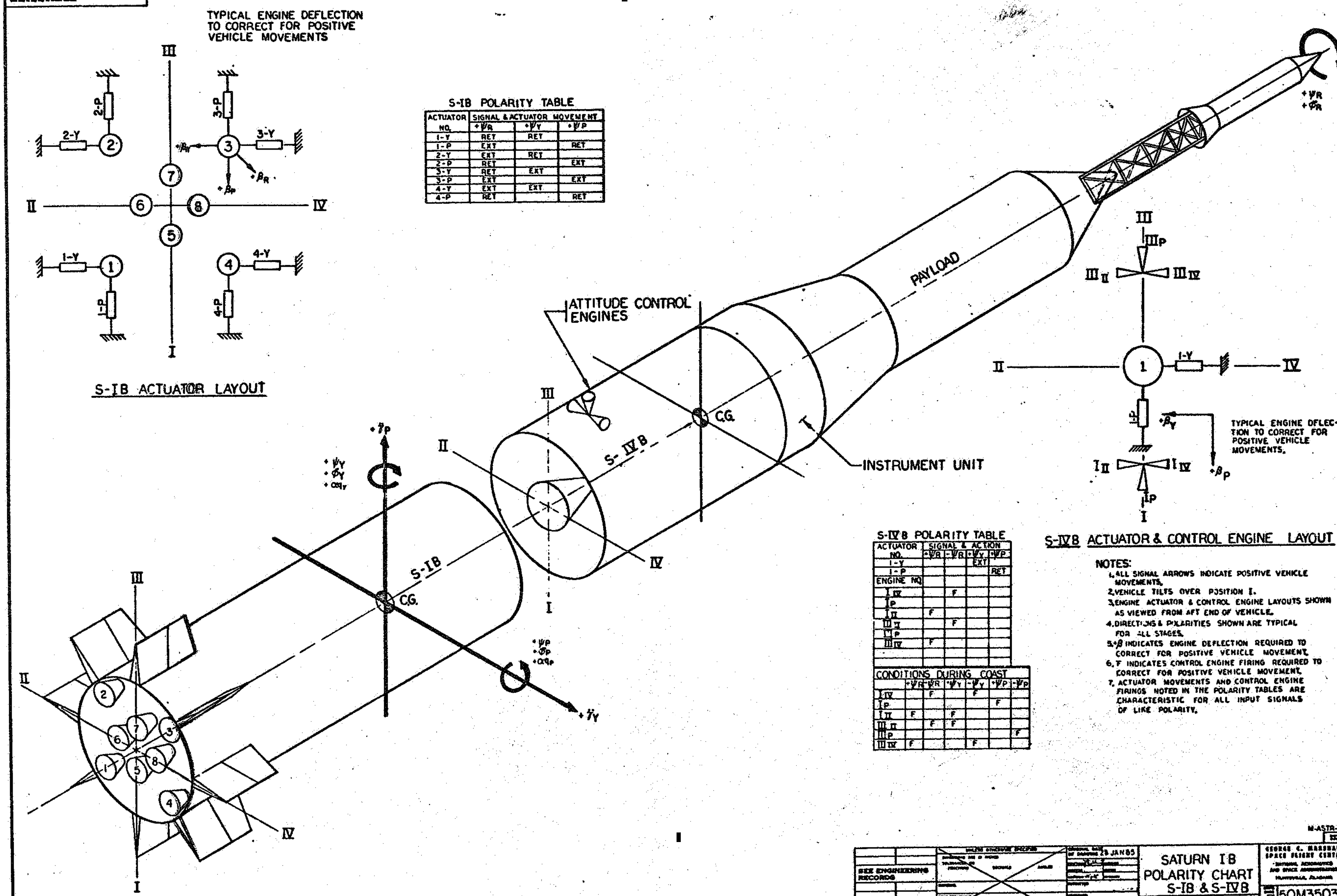
GEORGE C. MARSHALL SPACE FLIGHT CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

HUNTSVILLE, ALABAMA

F 5C17420

TYPICAL ENGINE DEFLECTION TO CORRECT FOR POSITIVE VEHICLE MOVEMENTS



S-IB ACTUATOR LAYOUT

S-IB POLARITY TABLE

ACTUATOR NO.	SIGNAL & ACTUATOR MOVEMENT $+\psi_R$	$+\psi_Y$	$+\psi_P$
1-Y	RET	RET	
1-P	EXT		RET
2-Y	EXT	RET	
2-P	RET		EXT
3-Y	RET	EXT	
3-P	EXT		EXT
4-Y	EXT	EXT	
4-P	RET		RET

S-IVB POLARITY TABLE

ACTUATOR NO.	SIGNAL & ACTION $+\psi_R$	$-\psi_R$	$+\psi_Y$	$+\psi_P$
1-Y			EXT	
1-P				RET
ENGINE NO.				
I IV		F		
I P				
I II	F			
III II		F		
III P				
III IV	F			

CONDITIONS DURING COAST	$+\psi_R$	$-\psi_R$	$+\psi_Y$	$-\psi_Y$	$+\psi_P$	$-\psi_P$
I IV		F		F		
I P					F	
I II	F		F			
III II		F	F			
III P						F
III IV	F			F		

S-IVB ACTUATOR & CONTROL ENGINE LAYOUT

NOTES:

1. ALL SIGNAL ARROWS INDICATE POSITIVE VEHICLE MOVEMENTS.
2. VEHICLE TILTS OVER POSITION I.
3. ENGINE ACTUATOR & CONTROL ENGINE LAYOUTS SHOWN AS VIEWED FROM AFT END OF VEHICLE.
4. DIRECTIONS & POLARITIES SHOWN ARE TYPICAL FOR ALL STAGES.
5. $+\beta$ INDICATES ENGINE DEFLECTION REQUIRED TO CORRECT FOR POSITIVE VEHICLE MOVEMENT.
6. F INDICATES CONTROL ENGINE FIRING REQUIRED TO CORRECT FOR POSITIVE VEHICLE MOVEMENT.
7. ACTUATOR MOVEMENTS AND CONTROL ENGINE FIRINGS NOTED IN THE POLARITY TABLES ARE CHARACTERISTIC FOR ALL INPUT SIGNALS OF LIKE POLARITY.

M-ASTR-N

SEE ENGINEERING RECORDS

APPLICATION

28 JAN 65

SATURN IB
POLARITY CHART
S-IB & S-IVB

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

F 50M35036

1 OF 1