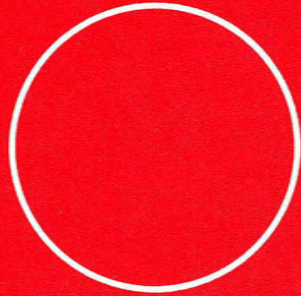
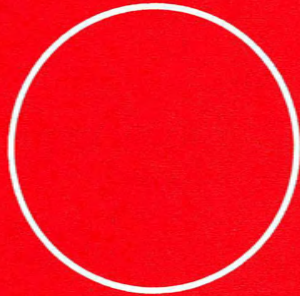
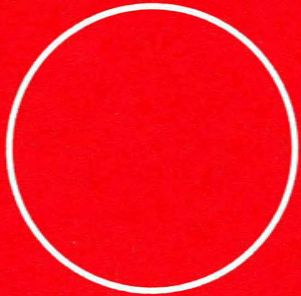
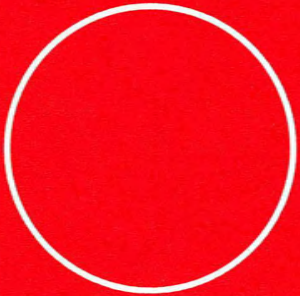
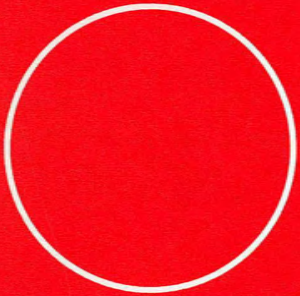
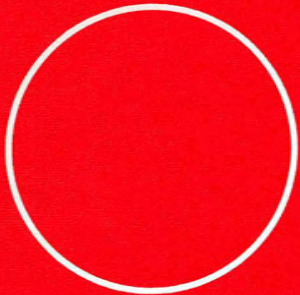
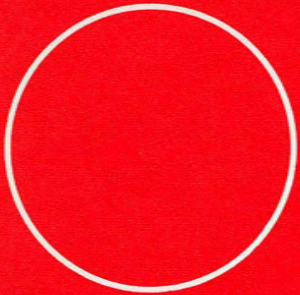


Instrument Unit Systems Description



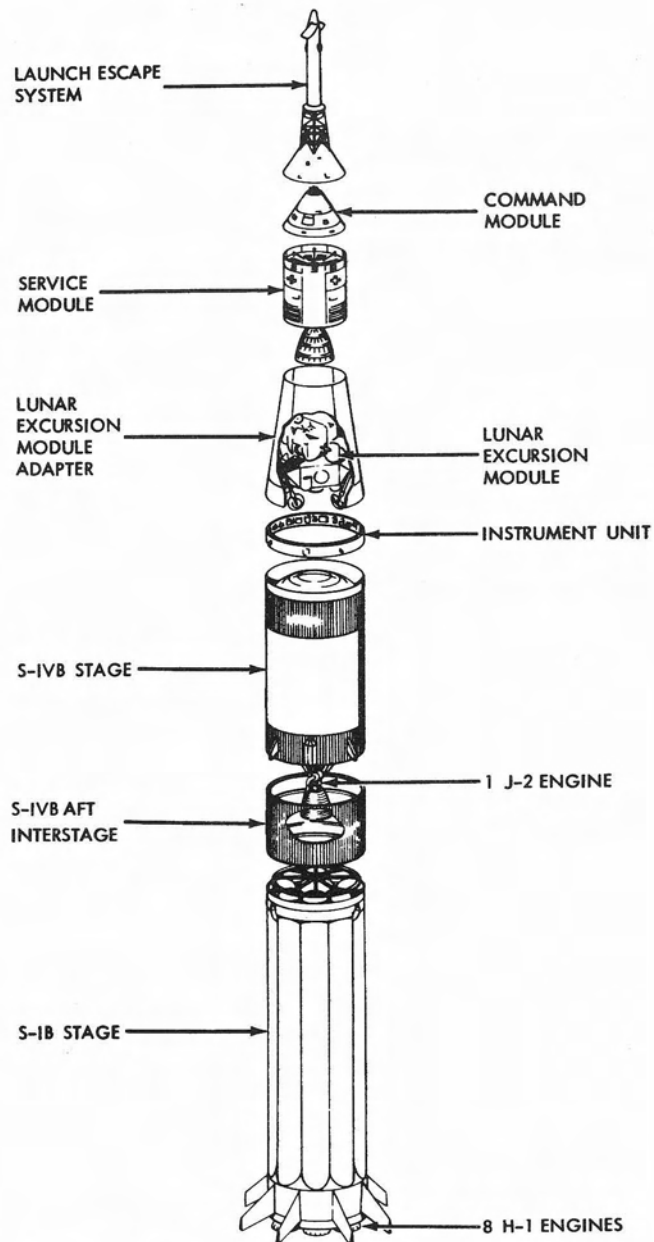
IBM

Preface

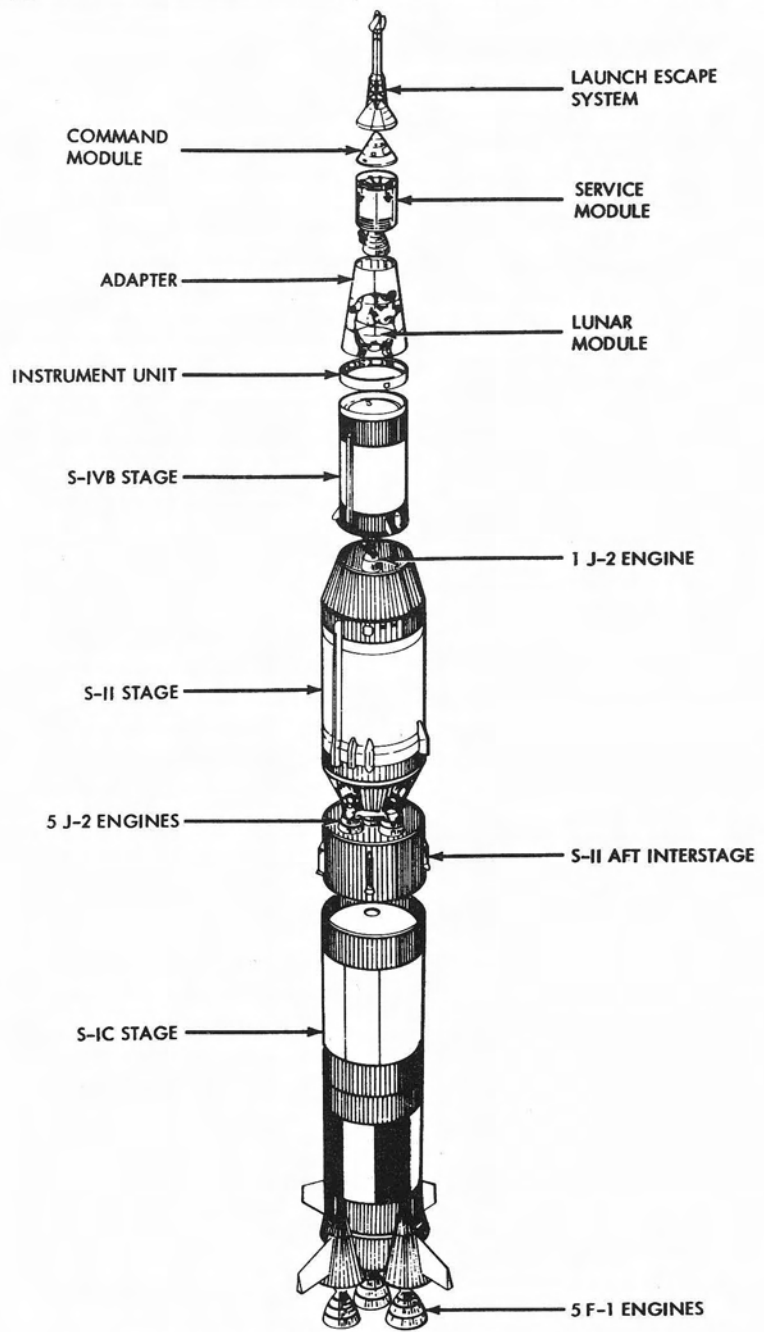
As you know, IBM has the responsibility of assembling the Instrument Units to be used in the Saturn/Apollo Missions. In effect, it is our job to see that the payloads receive proper guidance during the initial part of Saturn/Apollo missions. The Instrument Unit may appear as a rather small part of a very large vehicle, but this small size is by no means a scale of its importance. In fact, the Instrument Unit is considered the "brain" or "nerve center" of the vehicle.

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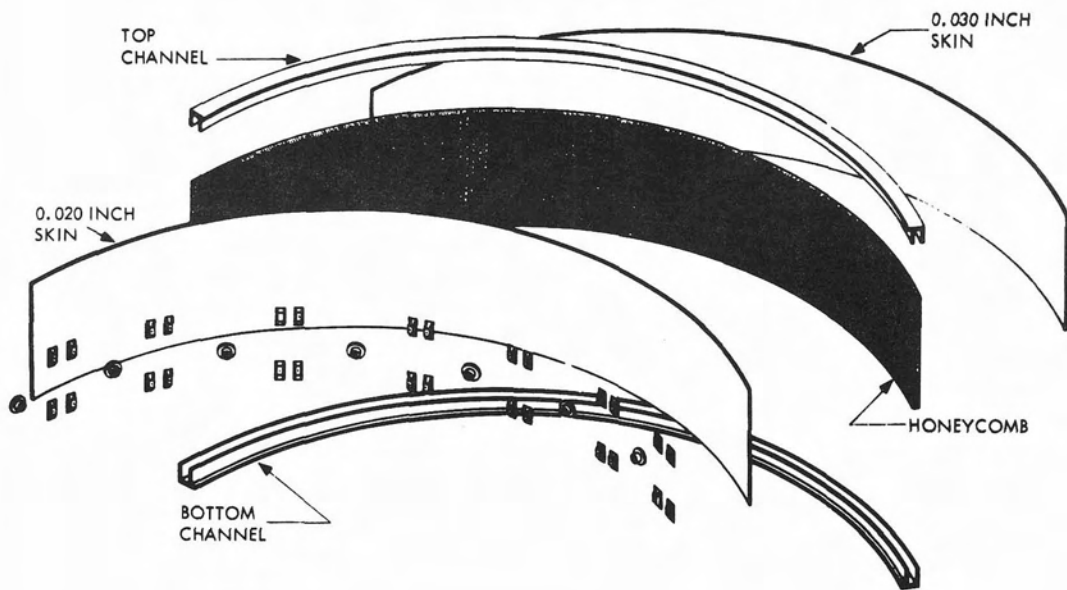
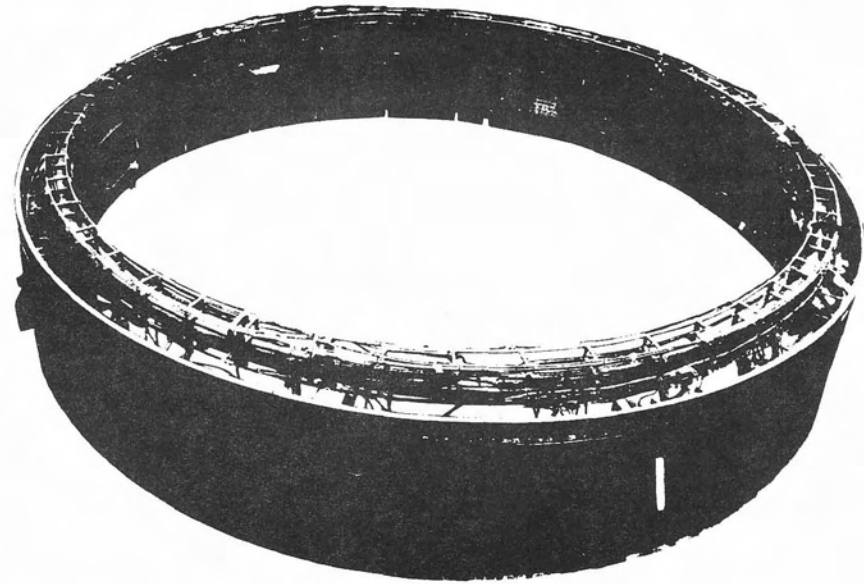
Upgraded Saturn I Vehicle



Apollo-Saturn V Vehicle

Introduction

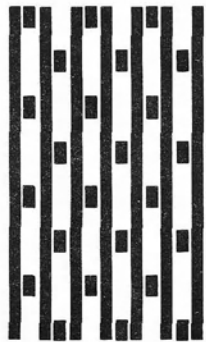
The Instrument Unit for The Uprated Saturn I and Saturn V vehicles is a ring 21.6 feet in diameter, and three feet in height. On the flight-ready Saturn vehicle, it is located on top of the S-IVB Stage. Mounted on its inner surface is the guidance and control equipment which will guide the vehicle from liftoff into a parking orbit around the earth, and from that orbit into a lunar trajectory. Also mounted on the inner surface are the measuring and communications equipment which monitor and transmit to earth information concerning the environment and performance of the vehicle.



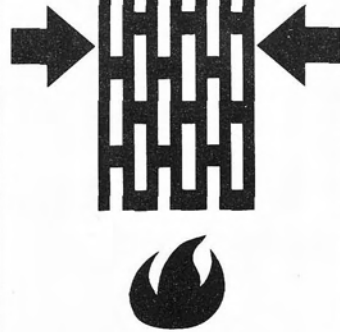
Structural Subsystem

The Structural Subsystem provides the mounting support for the Instrument Unit electronic equipment and is, in addition, a load-carrying structural element of the complete Saturn booster. The thrust generated during first stage burn is transmitted to the payload through the Instrument Unit structure, and in addition to withstanding the resulting tremendous forces of thrust and vehicle maneuver, the structure must support approximately 3500 pounds of equipment mounted internally. The required strength is achieved at a minimum weight penalty by using an aluminum alloy honeycomb inner core bonded to inner and outer skins of sheet aluminum. The complete structure weighs approxi-

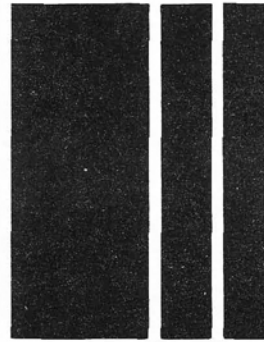
mately 450 pounds, and is fabricated in three 120 degree segments. During assembly of the Instrument Unit, the segments are joined by splice plates bolted to the segment at both the inner and outer surfaces. This results in a structurally solid ring which can be easily separated again into its three segments if necessary for packaging and shipping.



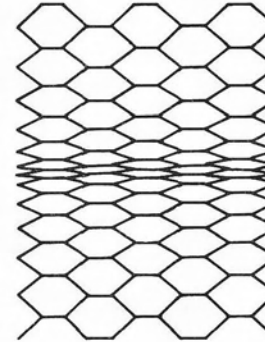
The aluminum alloy honeycomb core of the structure is made by piling thin sheets of foil on top of one another. Adhesive is laid in long strips between the sheets.



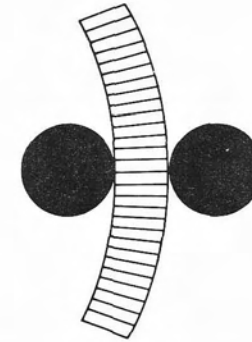
The sheets are then bonded using a combination of heat and pressure.



Individual stacks having the desired thickness are sliced from the large bonded pile.



When each stack is pulled apart slightly, the result is a structure of hexagonal cells.



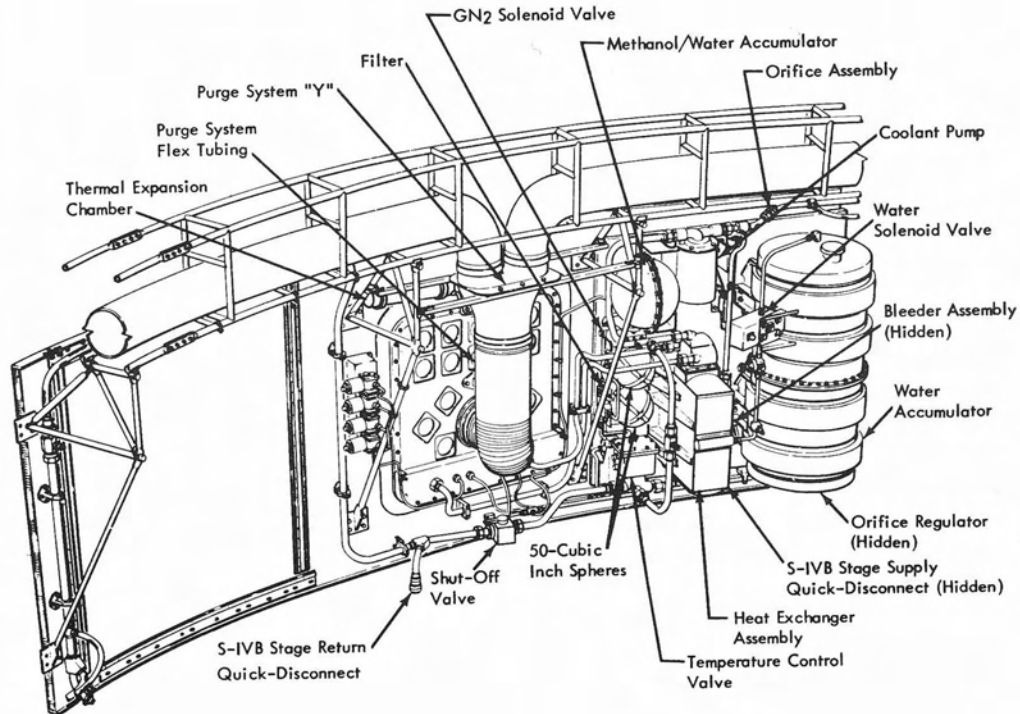
Now the honeycomb core is rolled to give it a curved shape.

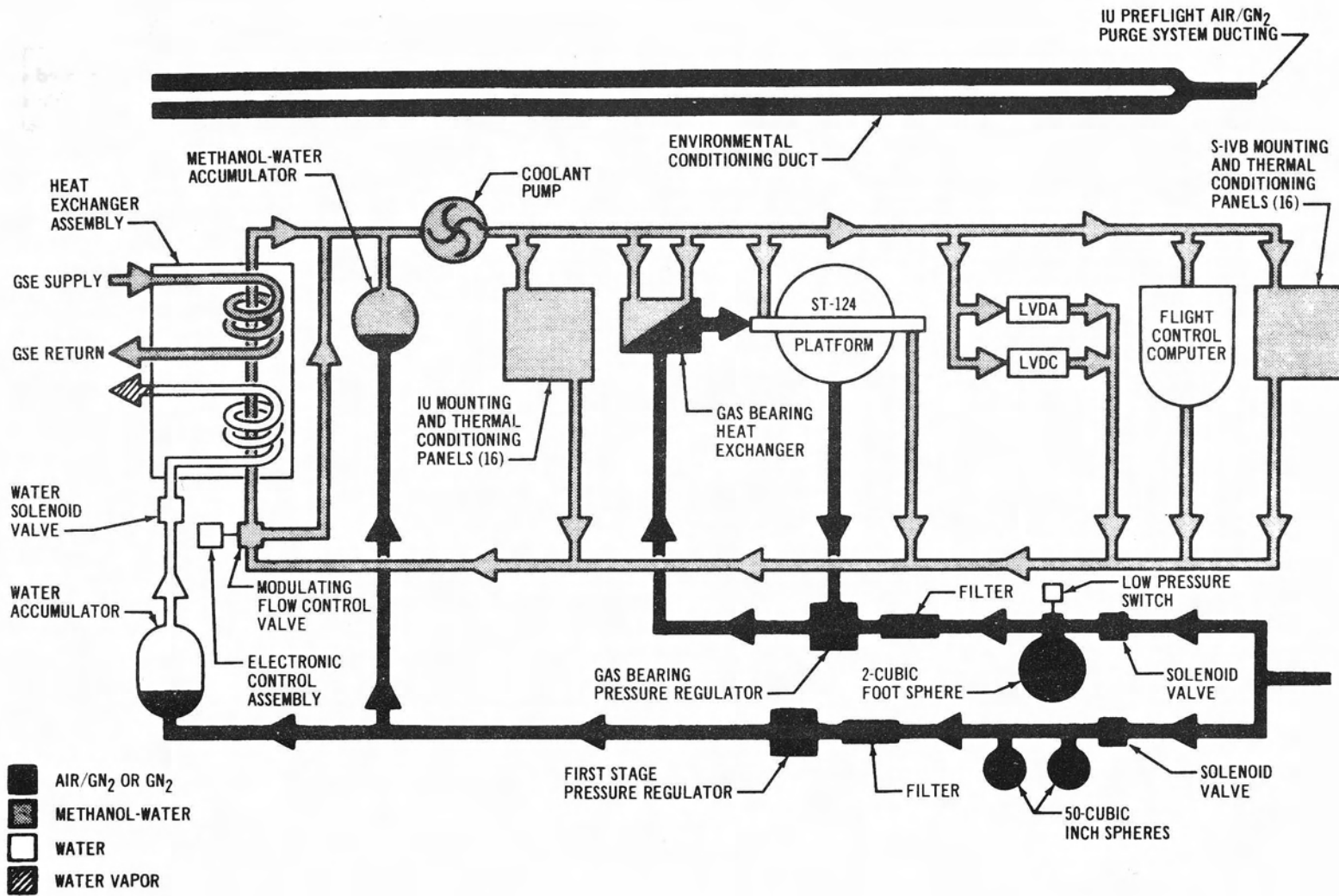
Environmental Control Subsystem

The Environmental Control Subsystem (ECS) maintains acceptable operating conditions for the Instrument Unit components during preflight and flight operations. The ECS is composed of the Thermal Conditioning System (TCS), Gas Bearing Supply System (GBS) and the Preflight Air/GN₂ Purge System.

The ECS performs the following three functions:

- Thermal Conditioning System - The Thermal Conditioning System cools the astronics equipment during pre-launch and flight by maintaining the temperature at $59^{\circ}\text{F} \pm 1^{\circ}$.
- Gas Bearing Supply System - The Gas Bearing Supply System furnishes gaseous nitrogen (GN₂) at a regulated temperature and pressure for the Gas Bearings in the ST-124M Inertial Platform.
- Preflight Air/GN₂ Purging System - The Purging System maintains a controlled inert environment in the Instrument Unit and S-IVB upper compartment by furnishing a temperature and pressure regulated supply of filtered air/GN₂.





Environmental Control Block Diagram

Electrical Subsystem

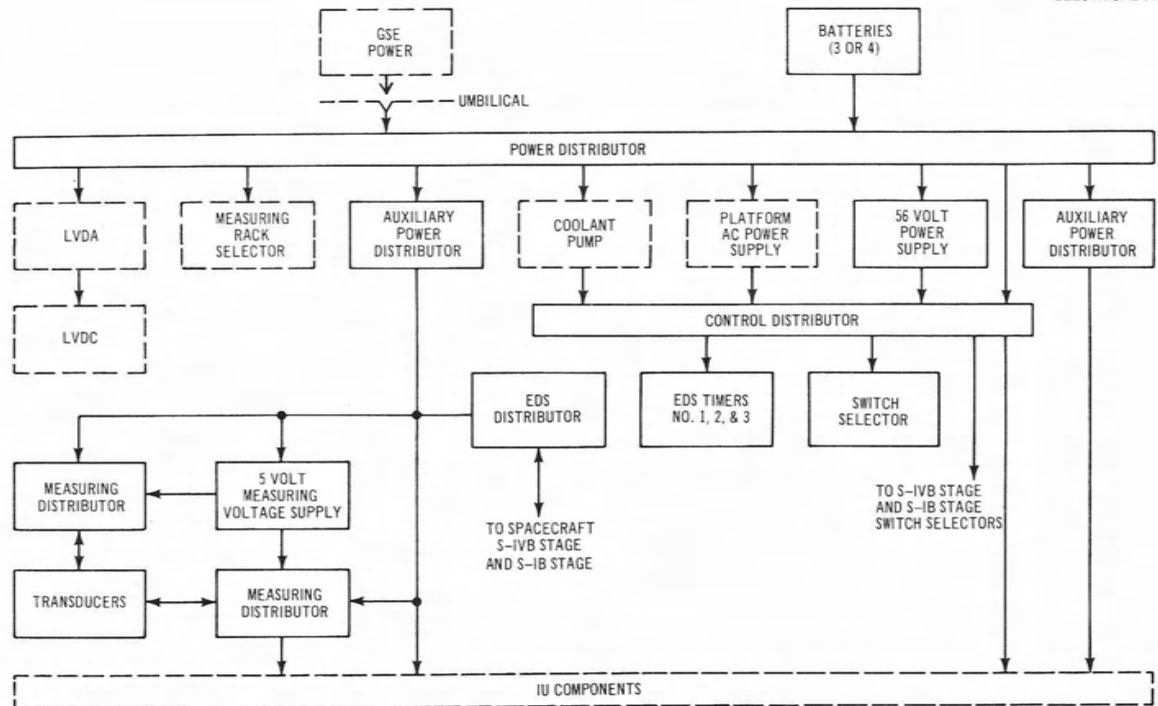
The electrical power for operation of all systems located within the IU is furnished by batteries. These batteries contain silver-zinc cells with potassium hydroxide electrolyte. Each battery supplies 28 VDC and can deliver 35 amperes for 10 hours.

Distribution of the power is accomplished through the Power Distributor and Auxiliary Power Distributor which act as junction boxes and switching points.

Most cabling within the Instrument Unit is supported on a cable rack. With the advancement in the field of flat printed wiring, some cables connect directly between components and are not attached to the support rack.

AC voltages are supplied on a subsystem level by the use of solid state DC to AC converters.

NOTE: DASHED LINES INDICATE COMPONENTS THAT ARE NOT A PART OF THE ELECTRICAL SYSTEM

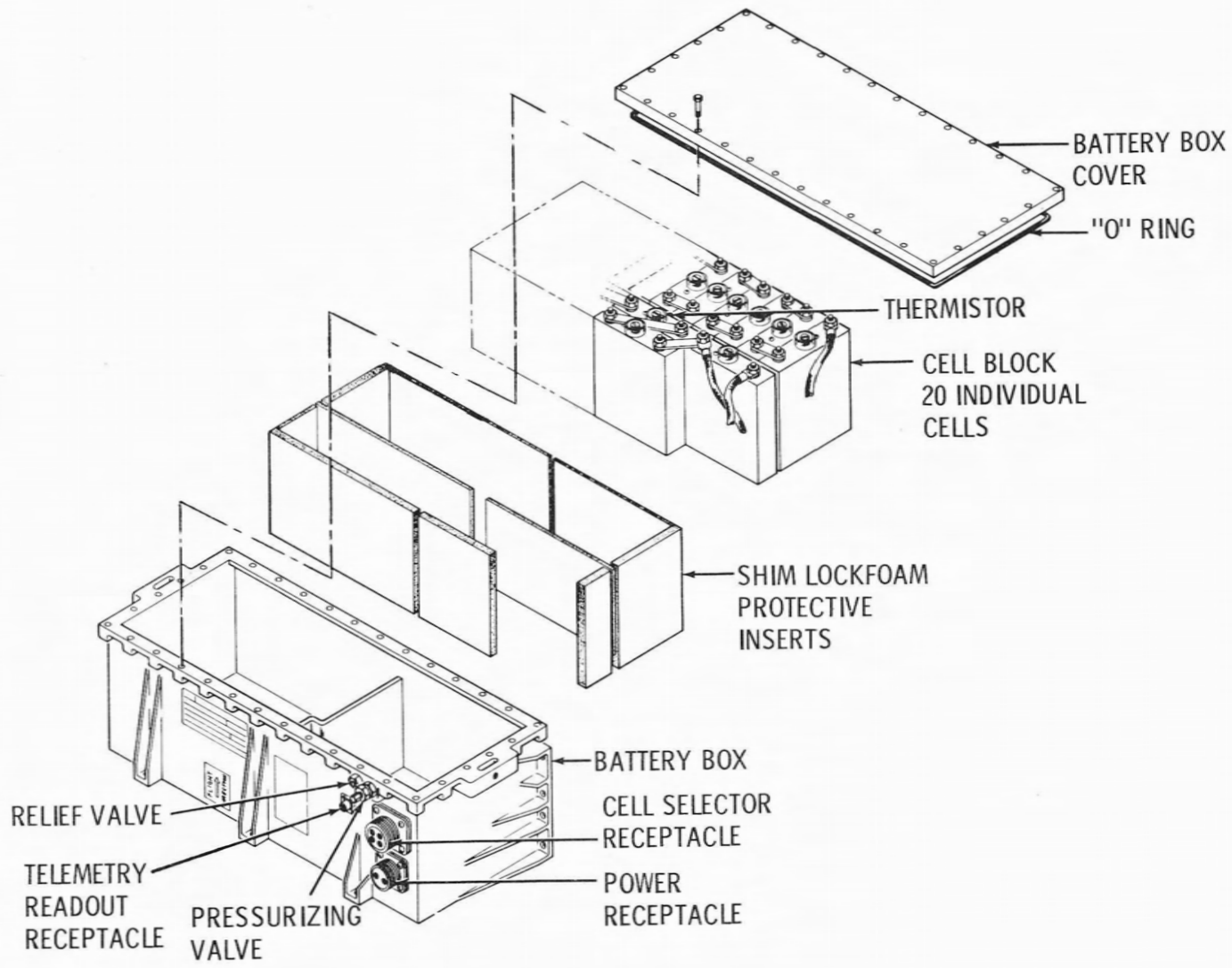


Battery Power Block Diagram

BATTERY CHARACTERISTICS

<u>Item</u>	<u>Description</u>
Battery Type	MAP 4240 - Dry charged
Cells	
Number	20 (with provisions for selecting 18 or 19 cells if required)
Nominal voltage per cell	1.5 VDC
Material	Alkaline silver-zinc
Electrolyte	Potassium hydroxide (KOH)
Output	
Voltage	+28 ± 2 VDC
Current	35 amperes for a 10-hour load period (if used within 72 hours after activation)
Measurements available	Current output Internal temperature

<u>Item</u>	<u>Description</u>
Cooling System	Cold plate
Ambient Temperature Range	+10°C to +48.9°C (+50°F to +120°F) for proper operation
Heat Transfer Characteristics	
Dissipation	0.07 W/cm ² (0.47 W/in. ²)
Surface area	2074 cm ² (321.4 in. ²)
Total dissipation	150 watts
Physical Characteristics	
Activated weight	75 kg (165 pounds)
Dimensions	
Length	65.5 cm (25.4 in.)
Width	26.9 cm (10.6 in.)
Depth	23.1 cm (9.1 in.)
Volume	40,164 cm ³ (2,450 in. ³)

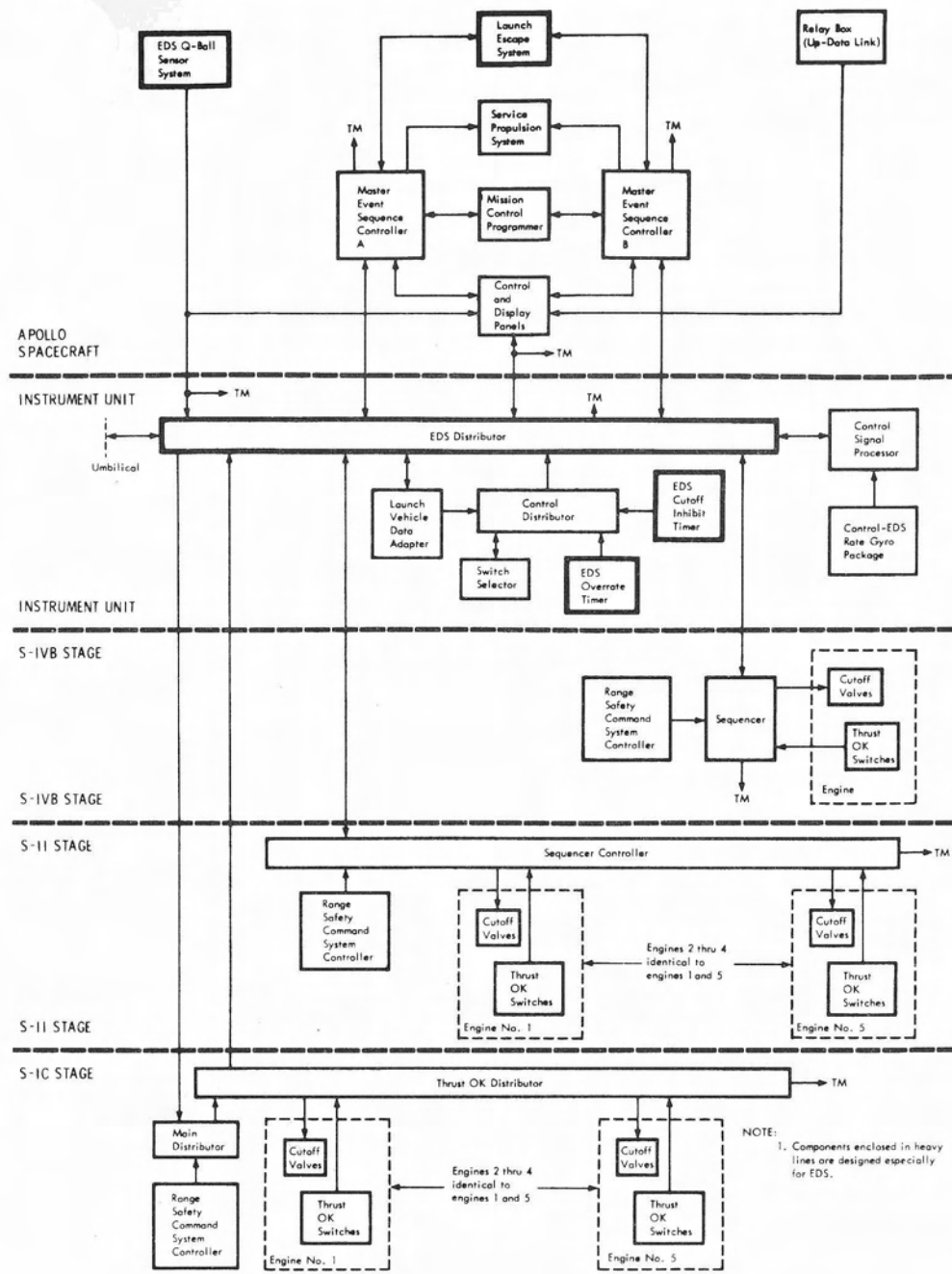


Basic Battery Components

Emergency Detection System

The purpose of the Emergency Detection System (EDS) is to sense and act upon onboard emergency situations arising during Saturn-boosted phases of Apollo-Saturn space flights. Protection of the Apollo crew against failure of the Saturn vehicle is the prime function of the EDS. However, for protection of personnel at the launch area, certain portions of EDS are deactivated until a short interval after liftoff. This deactivation period prevents EDS cutoff of all engines which would result in the vehicle falling back upon the launch area.

The EDS reacts to emergency situations in one of two ways, depending upon the seriousness of the emergency. If the EDS senses an emergency that will lead to rapid vehicle breakup, the EDS automatically initiates an abort sequence for the safety of the Apollo crew. If, however, the emergency is of such nature that the crew has time to evaluate the effects of the emergency, the EDS furnishes only visual indications of the specific emergency present. The crew then makes the decision of whether or not to manually initiate an abort sequence. Once initiated, either automatically by the EDS or manually by the crew, the abort sequence is completed automatically.



Uprated Saturn I EDS

Guidance and Control Subsystem

The problem of directing a ballistic missile or space vehicle, to accomplish a given mission, is customarily discussed in terms of three separate functions: navigation, guidance, and control. The boundaries between these three areas are to some extent arbitrary and conventional. The three terms, navigation, guidance, and control, are used according to the following definitions:

- Navigation is the determination of position and velocity of the vehicle from measurements made onboard the vehicle
- Guidance is the computation of maneuvers necessary to achieve the desired end conditions of a trajectory (e.g., an insertion into orbit).
- Control is the execution of the maneuver (determined from the guidance scheme) by controlling the proper hardware.

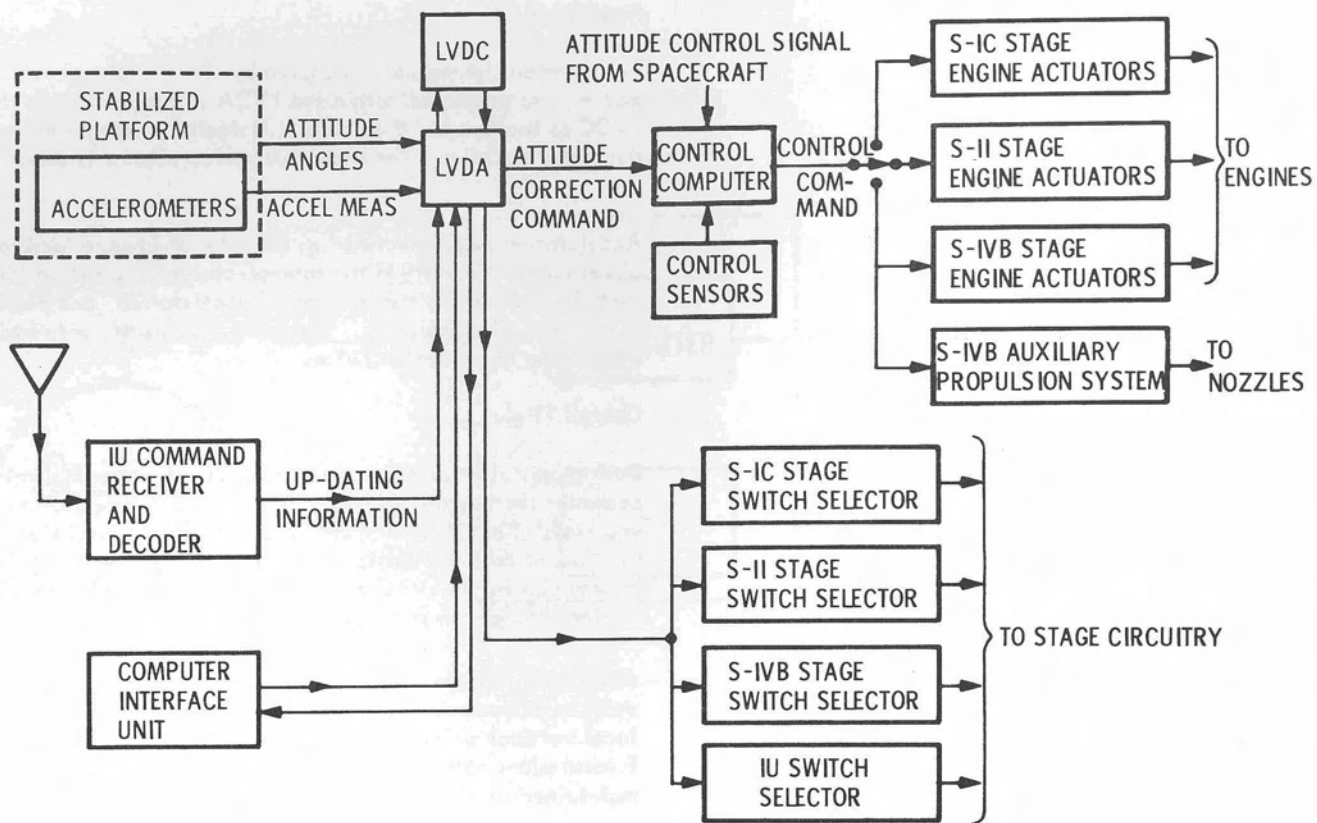
Consider the block diagram of the overall Saturn V guidance and control subsystem. (This diagram is also true for The Up-rated Saturn I Vehicle if the S-II Stage Switch Selector and engine actuator blocks are omitted.) The three-gimbal stabilized platform (ST-124M) provides a space-fixed coordinate reference frame for attitude control and for navigation (acceleration) measurements. Three accelerometers, mounted on the gyro-stabilized inner gimbal of the platform, measure the three components of velocity resulting from vehicle propulsion. The accelerometer measurements are sent through the LVDA to the LVDC. In the computer, the accelerometer measurements are combined with the computed gravitational acceleration to obtain velocity and position of the vehicle.

The LVDA is the input/output device for the LVDC. It performs the necessary processing of signals to make these signals acceptable to the computer.

According to the guidance scheme (programmed into the computer), the maneuver required to achieve the desired end conditions is determined by the LVDC. The instantaneous position and velocity of the vehicle are used as inputs. The result is the required thrust direction (guidance command) and the time of engine cutoff.

Control of the launch vehicle can be divided into attitude control and discrete control functions. For attitude control, the instantaneous attitude of the vehicle is compared with the desired vehicle attitude (computed according to the guidance scheme). This comparison is performed in the LVDC. Attitude correction signals are derived from the difference between the existing attitude angles (gimbal angles) and the desired attitude angles. In the Flight Control Computer, these attitude correction signals are combined with signals from control sensors to generate the control command for the engine actuators. The required thrust direction is obtained by gimbaling the engines in the propelling stage and thus changing the thrust direction of the vehicle. Since the S-IVB Stage has only one engine, an auxiliary propulsion system is used for roll control during powered flight. The auxiliary propulsion system provides complete attitude control during coast flight of the S-IVB/IU Stage.

Guidance information stored in the LVDC (e.g., position, velocity) can be updated through the IU command system by data transmission from ground stations. The IU command system provides the general capability of changing or inserting information in the LVDC.



Saturn Guidance and Control Subsystem Block Diagram

Navigation Scheme

Powered Flight

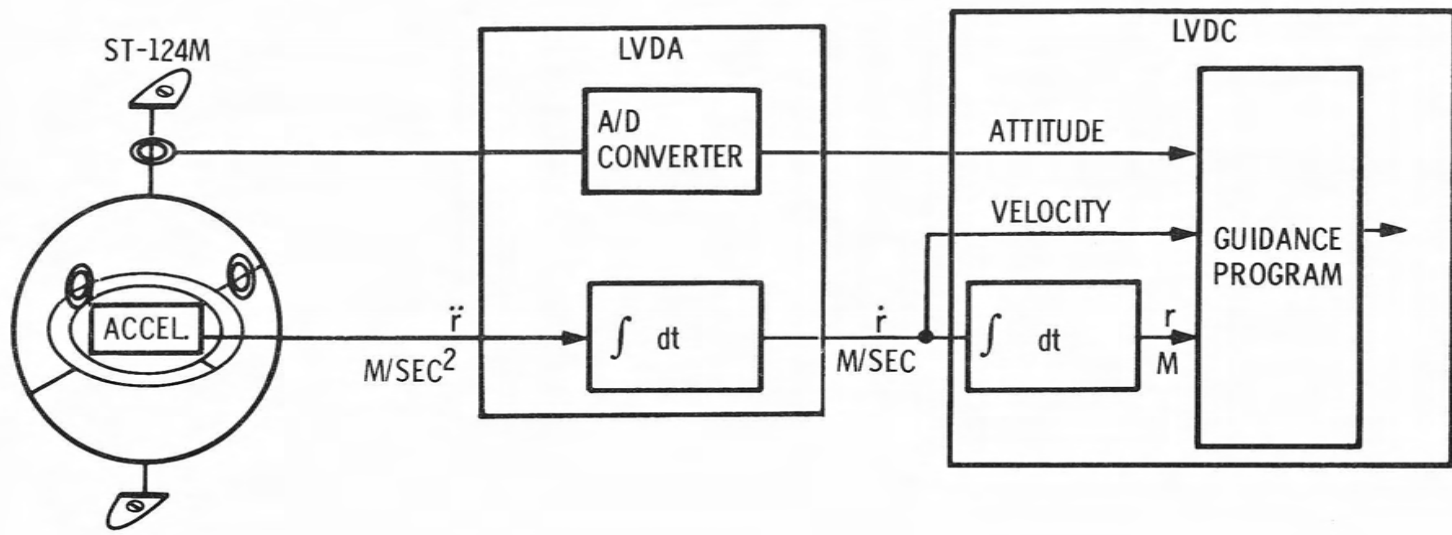
The acceleration values, measured by the Platform accelerometers, are processed within the LVDA and forwarded to the LVDC as increments of velocity. Velocity is integrated to determine position. The basic navigation scheme is shown.

Acceleration may be defined as the rate-of-change (derivative) of velocity. Velocity is the rate-of-change of position (distance). Velocity is the integral of acceleration, and position is the integral of velocity. Therefore, position is obtained by integrating acceleration twice.

Orbital Flight

During orbital coast flight, the navigational program continually computes the vehicle position, velocity, and acceleration from equations of motion which are based on vehicle conditions at the time of orbital insertion. In orbit, navigation and guidance information in the LVDC can be updated by digital data transmission through the radio command system.

Additional navigational computations are used in maintaining vehicle attitude during orbit. These computations establish a local vertical which is used as a reference for attitude control. Present plans call for the attitude of the vehicle roll axis to be maintained at 90 degrees with respect to the local vertical.



Navigation Scheme

Guidance Computations

The guidance function of the launch vehicle is accomplished by computing the necessary flight maneuvers to meet the desired end conditions of the flight (e.g., inserting the payload into earth orbit). Guidance computations are performed within the LVDC by programmed guidance equations which use navigation data and mission requirements as their inputs. These computations are actually a logical progression of computed formulas which have a guidance command as their solution. After the desired attitude has been determined by the "best path" program, the guidance computations might be reduced into the following equation: $\chi - \theta = \psi$

where:

χ is the desired attitude

θ is the vehicle attitude

ψ is the attitude error command

$$\begin{array}{ccccc}
 \chi & & \theta & & \psi \\
 \text{CHI} & & \text{THETA} & & \text{PSI} \\
 & - & & = & \\
 \text{DESIRED} & & \text{ACTUAL} & & \text{ATTITUDE} \\
 \text{ATTITUDE} & \text{MINUS} & \text{ATTITUDE} & = & \text{ERROR}
 \end{array}$$

χ FOUND BY GUIDANCE PROGRAM

- A. TIME TILT
- B. ITERATIVE GUIDANCE
- C. ORBITAL GUIDANCE

θ MEASURED WITH DUAL SPEED RESOLVERS ON ST-124M GIMBAL PIVOTS

ψ DETERMINED 25 TIMES/SEC BY GUIDANCE COMPUTER

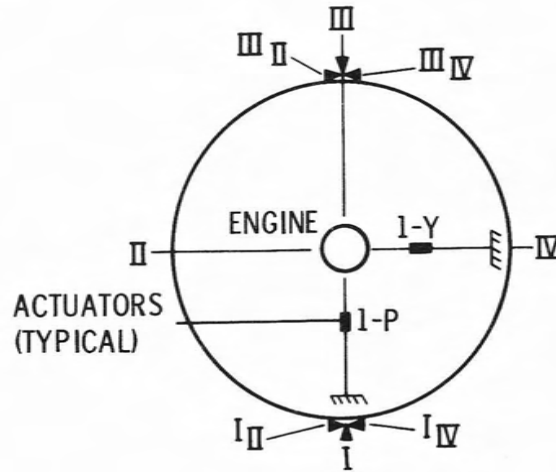
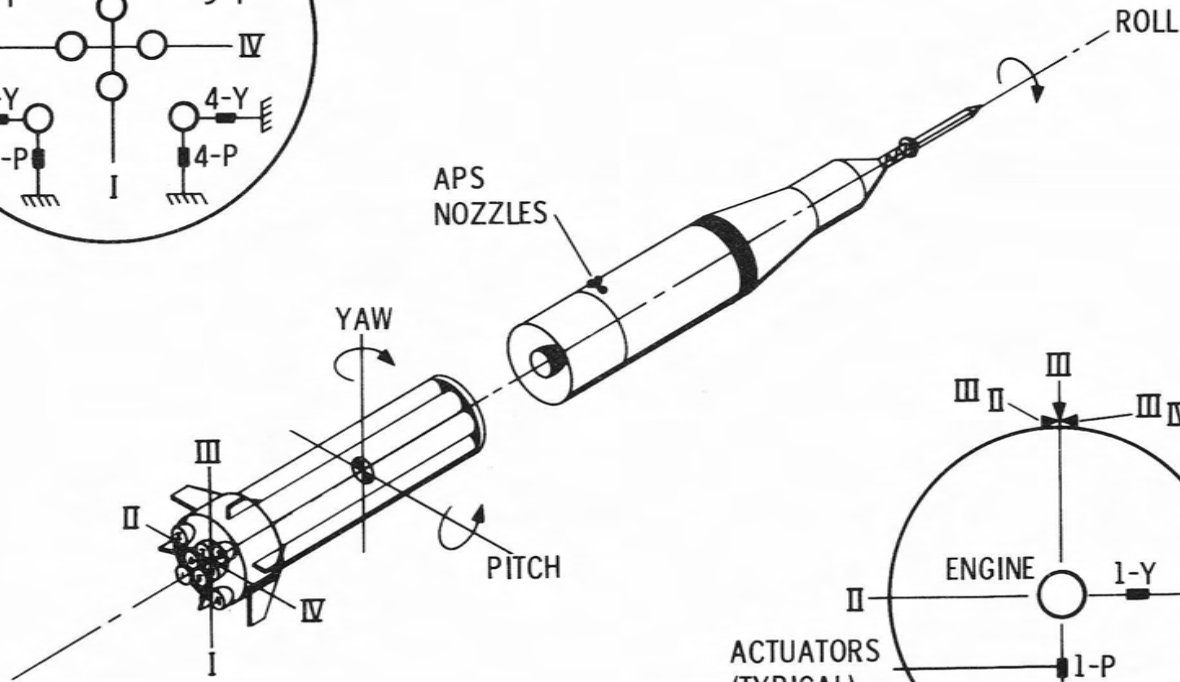
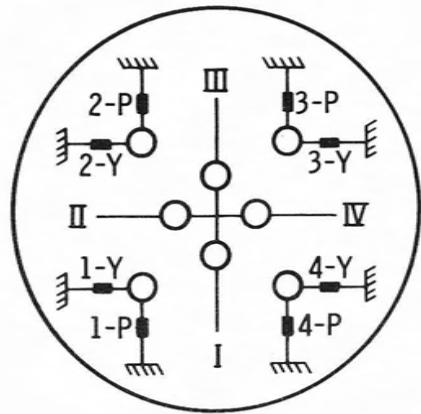
The Updated Saturn I Control Subsystem

The Control Subsystem is designed to maintain and control vehicle attitude by forming the steering commands to be used by the controlling engines of the active stage.

Attitude control of the Saturn Launch Vehicle may be divided into two parts, powered (burn) flight control and coast flight control. Powered flight consists of the two stages of propulsion necessary to carry the last stage (S-IVB Stage) and payload into orbit. Coast flight consists of maneuvering the payload and last stage to maintain a predetermined orbital attitude.

Vehicle attitude is achieved by gimbaling the four outboard engines of the S-IB Stage during first-stage burn. These control engines are actually moved about their mounting axes by piston-like hydraulic actuators.

During the powered phase of the S-IVB Stage flight, yaw and pitch maneuvers are accomplished by gimbaling its single propulsion engine. Roll maneuvers, which cannot be executed with a single engine, are controlled by an Auxiliary Propulsion System (APS). The APS consists of two relay packages and six thrust nozzles. These nozzles are arranged in two groups of three as shown in the cross sectional view of the S-IVB Stage. The ON-OFF thrust action of the nozzles produces the desired thrust direction. The APS is used exclusively during the coast flight phase of the S-IVB Stage since the main engine is turned OFF. All three maneuvers (pitch, roll, and yaw) are executed by the APS nozzle configuration during this coast period.



Upated Saturn I Control

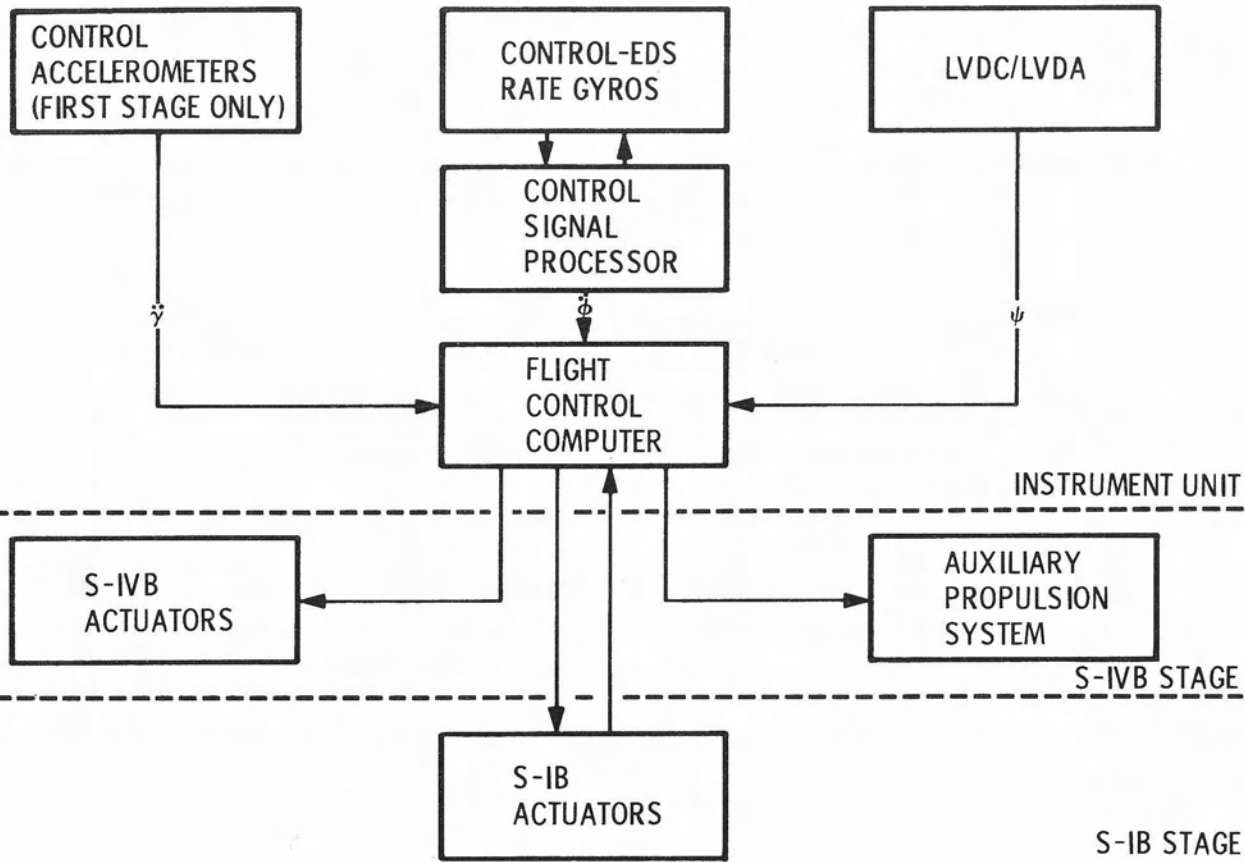
Control Subsystem Operation

The Flight Control Computer, which is the heart of the Control Subsystem, accepts signals from three sources:

- Attitude error signals (ψ) from the LVDC/LVDA Guidance System.
- Attitude angular rate signals ($\dot{\phi}$) from Control-EDS Rate Gyros.
- Lateral acceleration signals (\ddot{y}) from Control Accelerometers.

The Flight Control Computer uses the angular rate to modify the attitude error signals to conform to vehicle limits. These command limits are needed to maintain the rate of vehicle maneuver and motion within safe limits during all phases of the flight.

Because of high aerodynamic loading pressures and jet-stream winds encountered during first-stage burn, lateral acceleration measurements are also used in forming the engine attitude command signals. In the subsequent burn and coast phases of the flight, lateral acceleration is disregarded.



Upated Saturn I Control Subsystem (Block Diagram)

ST-124 M Inertial Platform Assembly

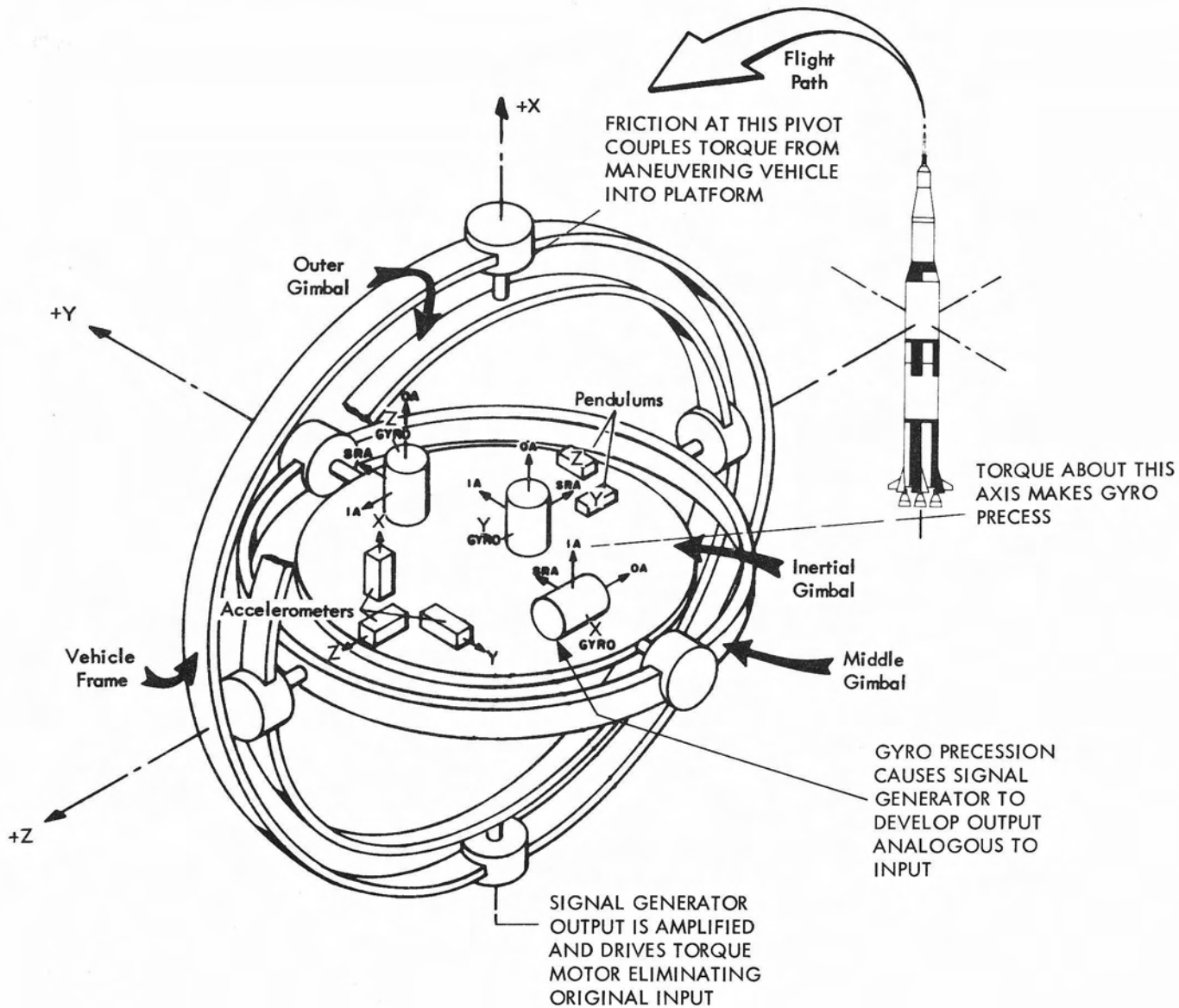
The Inertial Platform Assembly, used in The Uprated Saturn I and V Vehicles, can take either of two configurations. These two configurations are designated ST-124M3 and ST-124M4 and are three- and four-gimbal systems, respectively. In the basic design of the Inertial Platform, the outer, middle, and inertial gimbals are identical in both models. The ST-124M4 has a fourth, or redundant, gimbal and a larger base structure; it also requires a different mounting frame. The IU intercabling and wiring for these two systems are identical.

The gimbal configuration of the ST-124M4 offers unlimited freedom about all three inertial reference axes, while the ST-124M3 is limited to ± 45 degrees about its Z axis (vehicle yaw at launch). For the Apollo mission, the ST-124M3 configuration is used.

The gimbal system allows the inertial gimbal rotational freedom. Three single-degree-of-freedom gyroscopes have their input axes aligned along an orthogonal inertial coordinate system X_I , Y_I , and Z_I of the inertial gimbal. The signal generator, which is fixed to the output axis of the gyro, generates electrical signals proportional to torque disturbances. These signals are transmitted through the servoelectronics which terminate in the gimbal pivot servotorque motors. The servoloops maintain the inner gimbal rotationally-fixed in inertial space.

The inner gimbal has three pendulous integrating gyro accelerometers oriented along the inertial coordinates X_I , Y_I , and Z_I . Each accelerometer measuring head contains a pendulous single-degree-of-freedom gyro; the rotation of the measuring head is a measure of acceleration along the input axis of the accelerometer.

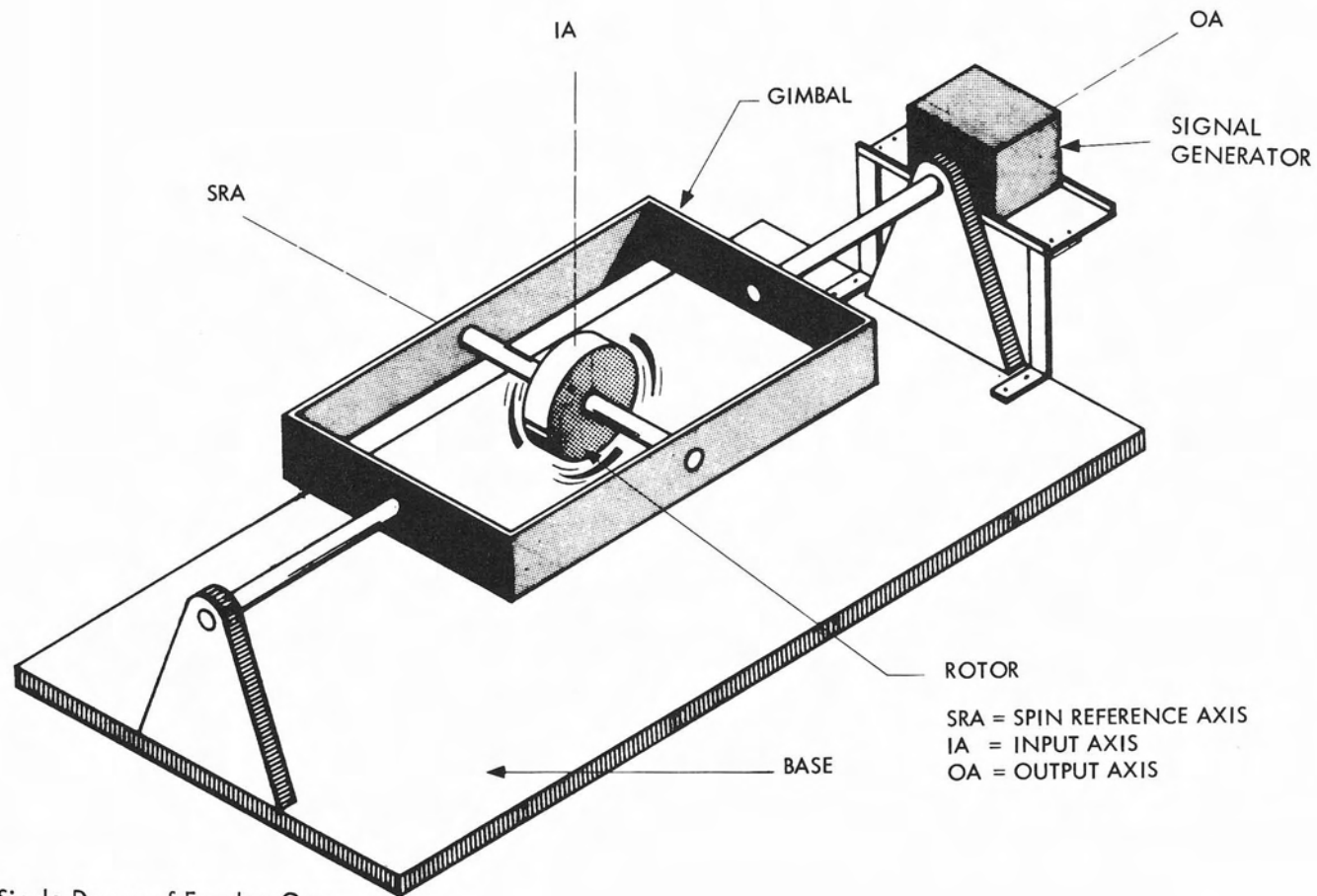
Vehicle attitude is measured with respect to the Inertial Platform using dual speed (32:1) resolvers located at the gimbal pivot points. The outputs of these angle encoders are converted into a digital count in the LVDA.



Platform Stabilization

Integrating Gyro

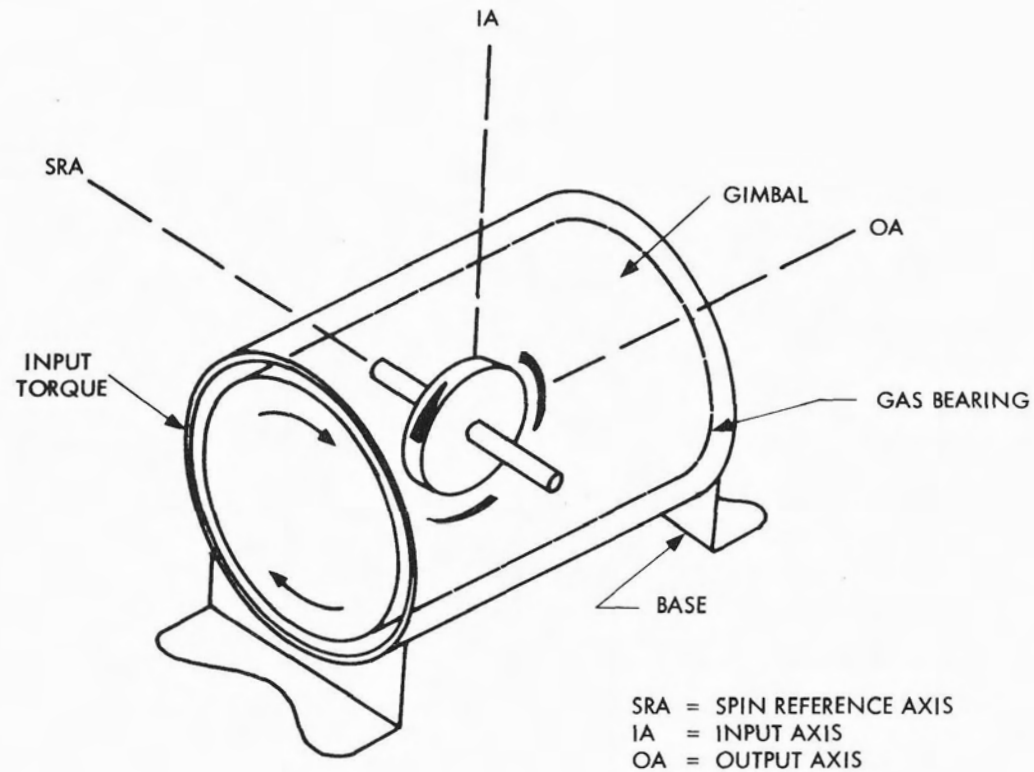
A single-degree of freedom gyro consists of a gyro rotor and a single gimbal. When this gimbal is mounted to a base through an unrestrained coupling, the gyro is called an integrating gyro. Such a gyro will respond to torque about its input axis (IA) by precessing about its output axis (OA). A single-degree-of-freedom gyro is often used to position a signal generator, thus converting torque to an electrical analog signal.



Single Degree of Freedom Gyro

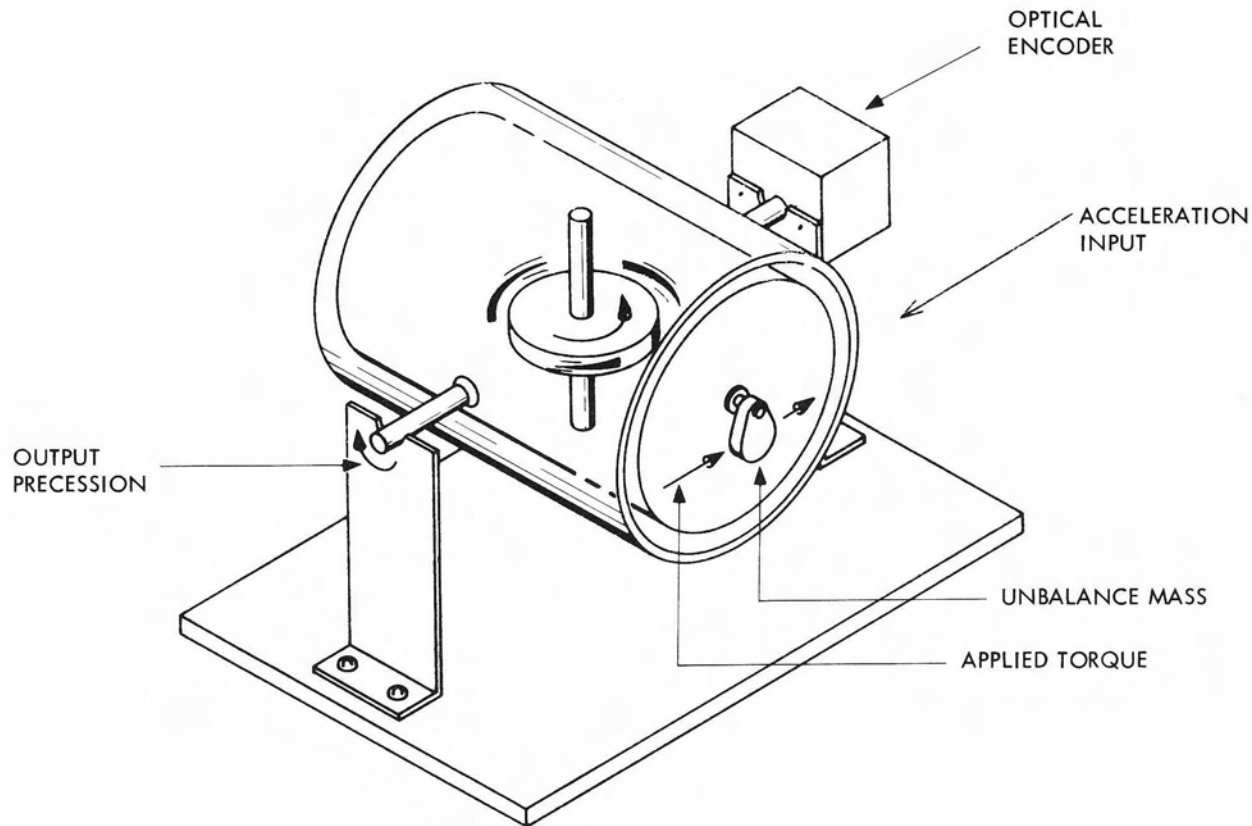
Stabilization Gyro

The ST-124M Stabilizing Gyro has a sealed cylinder as its single gimbal. This gimbal rides on a cushion of flowing nitrogen gas and is therefore unrestrained. A shorted turn signal generator becomes unbalanced by the precession of the inner cylinder and generates an electrical output proportional to the gyro's input torque.



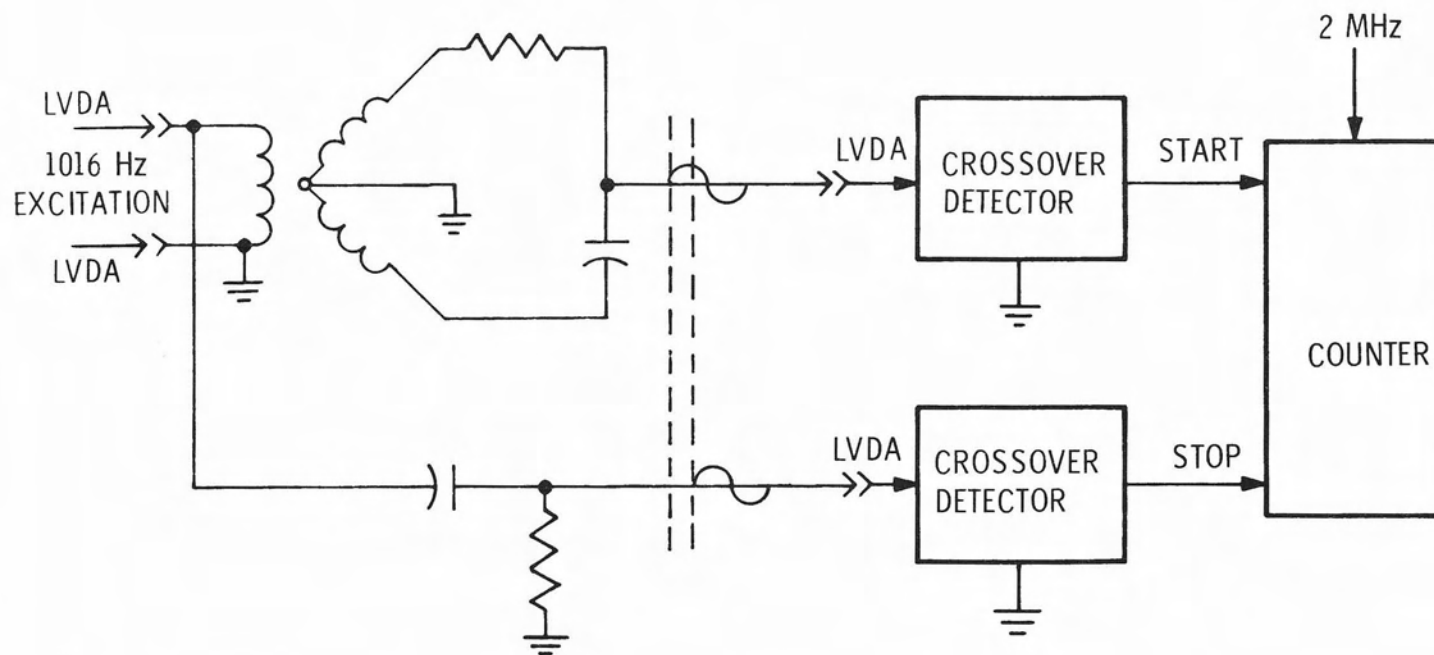
AB 3-K8 Accelerometer

The AB3-K8 Accelerometer is used to convert dynamic acceleration to a precession about its output axis. An optical encoder monitors this precession and sends this signal to the LVDA. An unbalanced mass mounted on the inner cylinder of the accelerometer behaves like a pendulum when exposed to acceleration. The pendulum applies an input torque on the gyro resulting in output precession.



Attitude Measurements

Vehicle attitude is measured with respect to the Inertial Platform using dual speed resolvers mounted at the gimbal pivot points. These resolvers and their associated R-C networks shift the phase of the input excitation voltage. The amount of phase shift is proportional to the mechanical angle about the pivot point. Crossover detectors and a digital counter in the LVDA convert the phase shift to a digital count.



Attitude Resolver Network

Launch Vehicle Digital Computer and Launch Vehicle Data Adapter System (LVDC/LVDA)

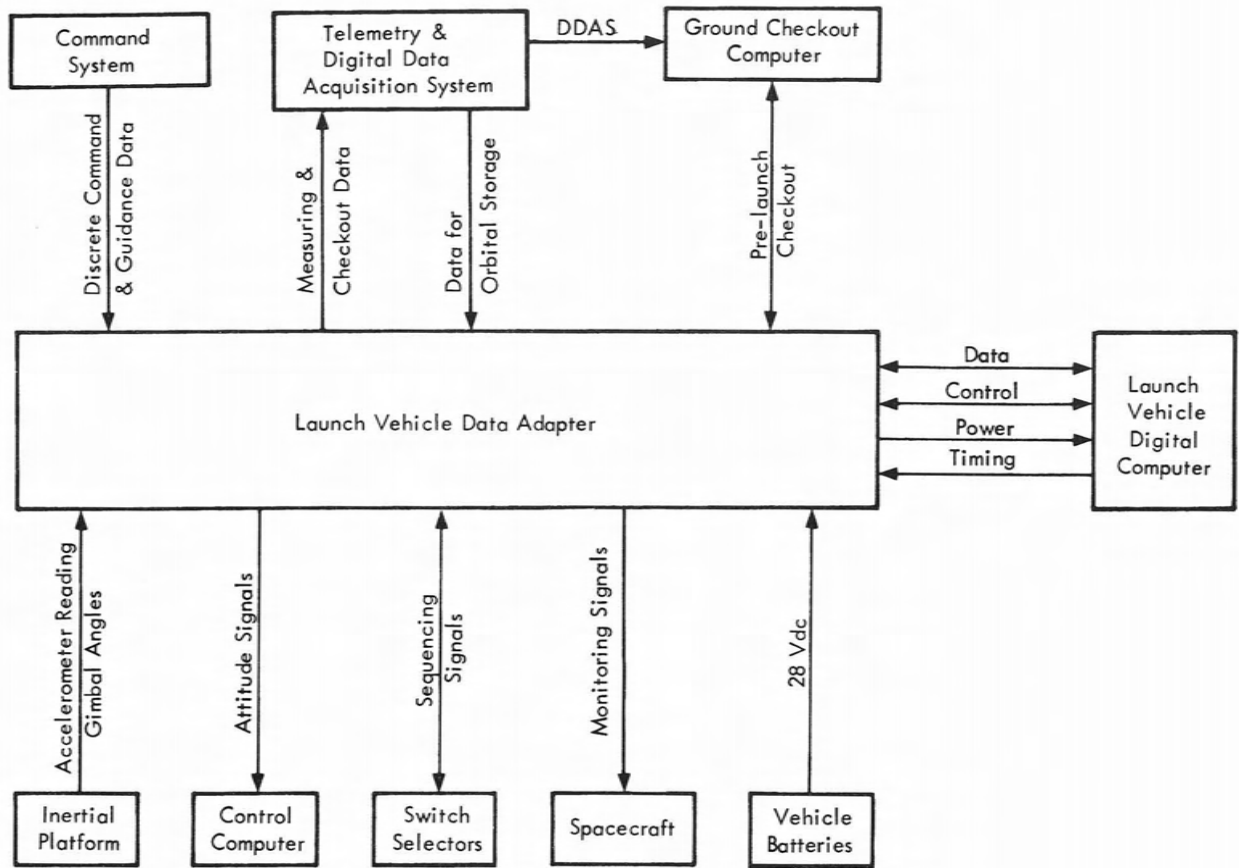
The LVDC and LVDA comprise a modern electronic digital computer system. The LVDC is a relatively high-speed computer with the LVDA serving as its Input/Output (I/O) device. Any signal to or from the computer is routed through the LVDA. The LVDA serves as central equipment for interconnection and signal flow between the various systems in the Instrument Unit.

The LVDC/LVDA are involved in the following main operations:

- Prelaunch checkout
- Navigation and Guidance Computations
- Vehicle sequencing
- Orbital checkout

The LVDC is a general purpose computer which processes data under control of a stored program. The computer uses fixed-point, two's complement arithmetic. Data is processed serially in two arithmetic sections which can, if desired, operate concurrently. Addition, Subtraction, and logical extractions are performed in one arithmetic section while multiplication and division are performed in the other.

The LVDA is the input/output device for the LVDC and the central station for signal flow in the Saturn Astrionics System. The LVDA transforms input and output signals to a form that is compatible with the characteristics of the receiving equipment, controls the data flow in the IU, performs certain simple computation and logical operations on data, and provides temporary storage of data.



Signal Flow Between LVDC/LVDA and Associated Equipment

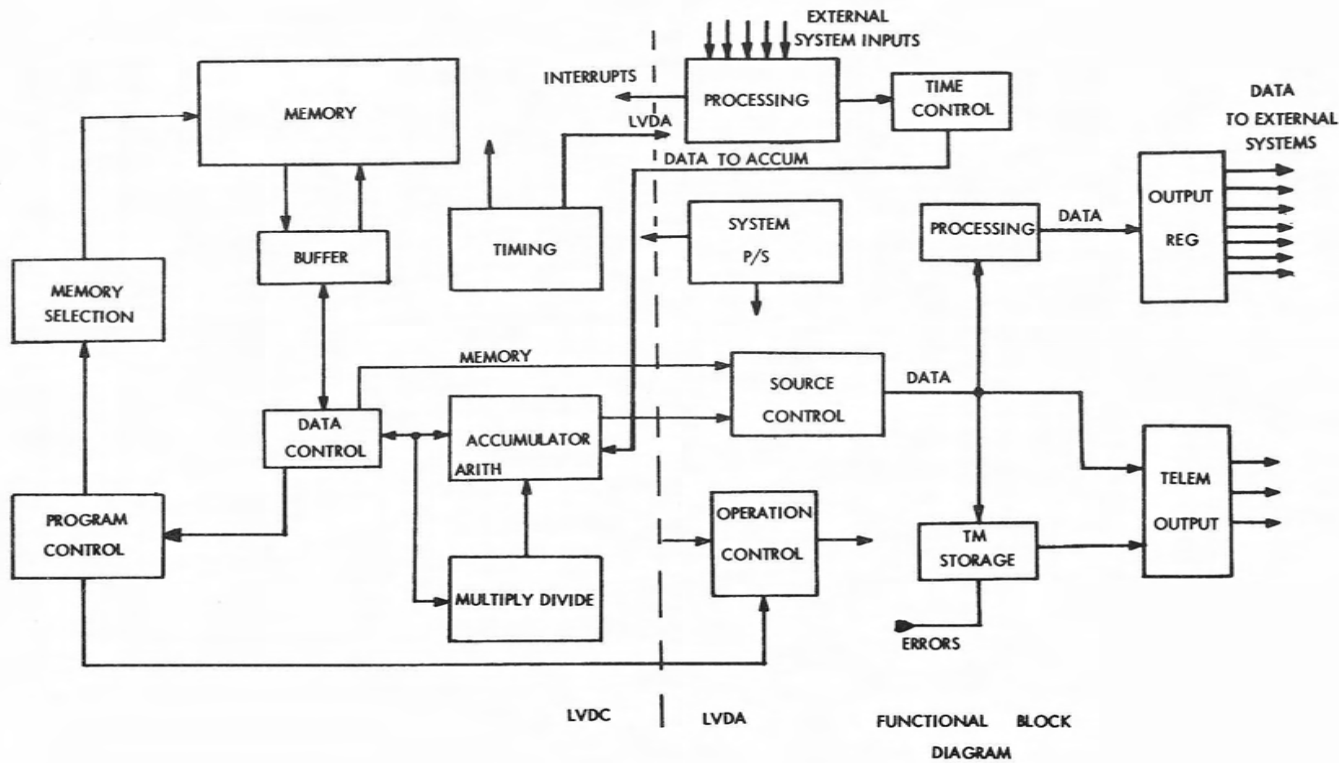
Launch Vehicle Digital Computer Characteristics

Item	Description
Type	Binary, serial, general purpose, stored program.
Accuracy	Add, Subtract and Multiply: 2 ⁻²⁶ ; Divide: 2 ⁻²⁴ .
Speed	512,000 bits per second serial; Add: 82 usec; Multiply: 328 usec; Divide: 656 usec.
Memory	Ferrite core, random access, 4,096 locations of 28 bits each memory; self-contained memory modules.
Arithmetic	Fixed Point, 2's complement.
Programming	18 instruction codes consisting of 10 arithmetic instructions, 6 program control instructions, 1 input/output instruction, and 1 store instruction.
Electronics	Current-switching diode logic (positive), micro-miniature packaging.
Word Make-Up	Data word: Sign +25 magnitude bits; Instruction word: 4 operation code +9 operand address bits.
Timing	4-clock system, clock repetition rate: 2.048 MHz; bit time: 1.953 microseconds; phase time: 14 bit times; computer cycle: 3 phase times.
Input/Output	Program controlled, serial.

Launch Vehicle Data Adapter Characteristics

Item	Description
Computer input-output rate	512 kHz serial
Power supplies	6 duplexed regulated DC Supplies 2 AC resolver power supplies
Switch Selector	8-bit Switch Selector input 15-bit Switch Selector output
Discretes	7 interrupt inputs from the IU 13 discrete outputs 32 discrete inputs
Buffer register	26 bits
Tab register	8 bits
Mode register	6 bits
Digital-to-analog converter	8 bits plus sign, 2.5 millisecond operation, three attitude commands, and two spare outputs
Analog-to-digital converter	Equivalent of 17 bits from a 2-speed resolver
Platform	4 two-speed gimbal angle resolver inputs
Spares	10 single-speed resolver inputs
Delay lines	3 four-channel delay lines for normal operations 1 four-channel delay line for telemetry operations (DOM)

Item	Description
Telemetry	
Command Receiver	14 bits for input data
Data Transmitter	38 data and identification bits plus validity bit and parity bit
Computer Interface Unit	15 bits address plus a data request bit for output data 10 bits for input data plus data ready interrupt
Output to launch computer	41 data and identification bits for output data plus discrete outputs
Input from RCA-110 Ground Control Computer	14 bits for input data plus interrupt
Number of components (estimated)	38,000 silicon semiconductors, cermet resistors, and other special components
Reliability	0.99 probability of success for 250 hours of operation; uses TMR logic, duplex special circuits, duplex power supplies
Packaging	125 electronic page assemblies, plus special electronic assemblies
Weight	80 kilograms (214 pounds)
Volume	0.1 cubic meter (3.6 cubic feet)
Power (without computer)	320 watts



Functional Block Diagram

Definition of Mnemonic

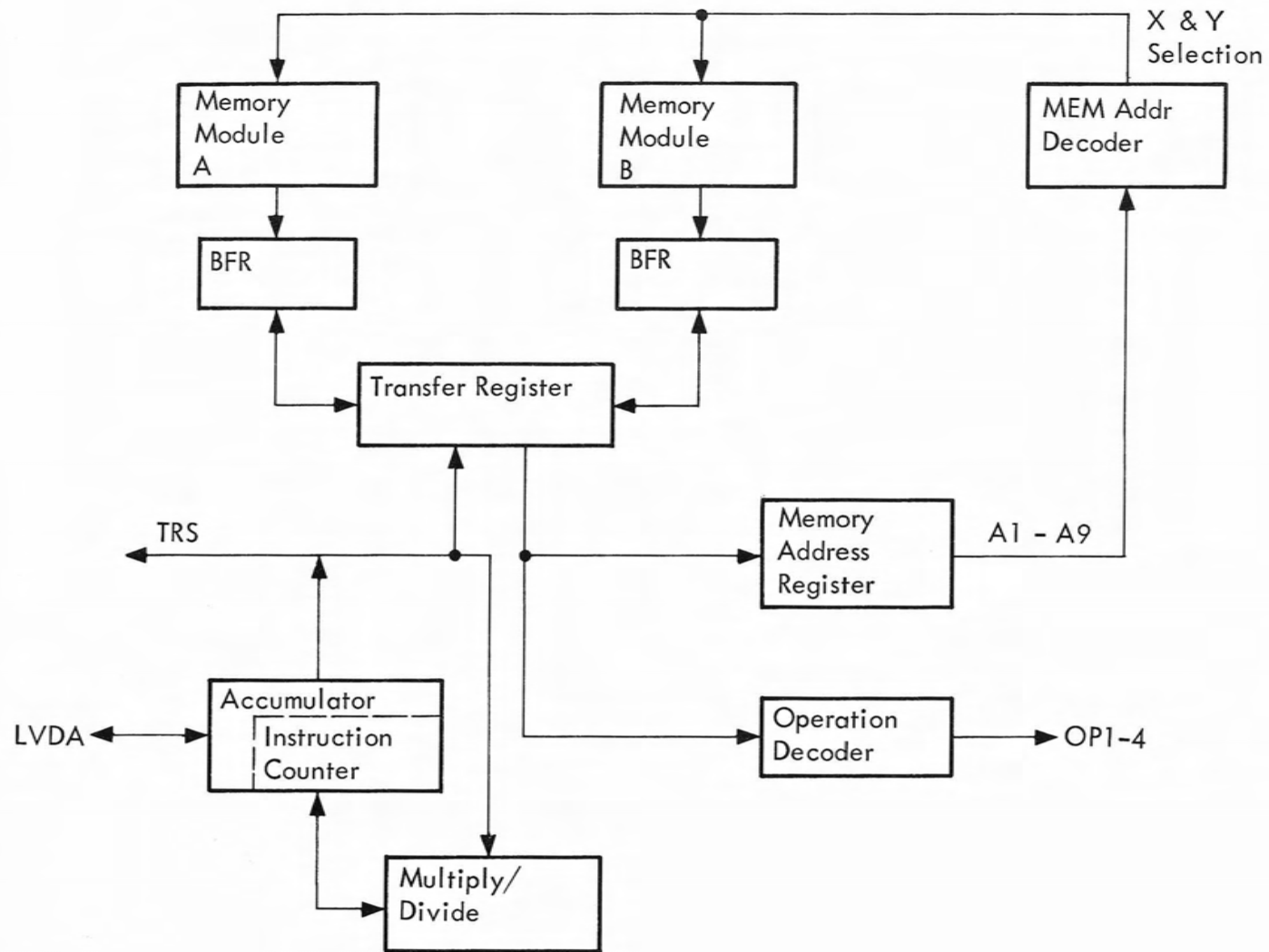
Item	Definition
HOP	- Initializes the Computer Operation
MPY	- Multiply
SUB	- Subtract
DIV	- Divide
TNZ	- Transfer (if accumulator) Not Zero
MPH	- Multiply (and) Hold
AND	- And
ADD	- Add
TRA	- Transfer (unconditionally)
XOR	- Exclusive or
PIO	- Process Input-Output
STO	- Store the accumulator
TMI	- Transfer (if accumulator) is minus
RSU	- Reverse subtract
SHF	- Shift accumulator
CDS	- Change Data Sector (similar to HOP)
EXM	- Execute Modified Instruction
CLA	- Clear and Add

Instruction Complement

Operation Code	Machine Cycles	Mnemonic	Description *
00	1	HOP	Specifies next instruction
01	4	MPY	$A \times M \rightarrow PQ$ register
02	1	SUB	$A - M \rightarrow A$
03	8	DIV	$A \div M \rightarrow PQ$ register
04	1	TNZ	If A is not zero, operand address specifies next instruction
05	5	MPH	$A \times M \rightarrow PQ$ register and A
06	1	AND	A AND'd with M \rightarrow A
07	1	ADD	$A + M \rightarrow A$
10	1	TRA	Operand address specifies next instruction
11	1	XOR	A XOR'd with M \rightarrow A
12	1	PIO	LVDC/LVDA input-output
13	1	STO	$A \rightarrow M$, A is unchanged
14	1	TMI	If A is minus, operand address specifies next instruction
15	1	RSU	$M - A \rightarrow A$
16 · A9 · $\overline{A8}$ · A1	1	SHF	Shift A one place to right
16 · A9 · $\overline{A8}$ · A2	1	SHF	Shift A two places to right
16 · A9 · $\overline{A8}$ · A5	1	SHF	Shift A one place to left
16 · A9 · $\overline{A8}$ · A6	1	SHF	Shift A two places to left
16 · A9 · $\overline{A8}$ · $\overline{A6}$ · $\overline{A5}$ · $\overline{A2}$ · $\overline{A1}$	1		Zero A
16 · A9 · $\overline{A8}$ · A7	1		Test memory (error latches)
16 · A9 · $\overline{A8}$ · A4	1		Test memory (timing)
16 · A9 · $\overline{A8}$ · A3	1		Test memory (parity)
16 · $\overline{A9}$	1	CDS	Change memory data selections
16 · A9 · A8	1 Plus	EXM	One machine cycle plus instruction from memory
17	1	CLA	$M \rightarrow A$

***Symbol Explanations**

A Accumulator
M Contents of specified memory address
 \rightarrow Arrow indicates direction of data movement



Computer Basic Block Diagram

Flight Program

The Flight Program is defined as a set of instructions which controls the LVDC operation from seconds before liftoff until the end of the mission. These instructions are stored in the LVDC memory system.

The LVDC Flight Program may be divided into two main parts: the Major Loop and the Minor Loop. The Major Loop contains the navigation and guidance calculations, timekeeping, and all other repetitive functions which do not occur within the Minor Loop. The Minor Loop contains the control system computations and accelerometer sampling routine.

Several subroutines or secondary functions are also available to the main program. They are utilized at specific times within the Main Loop or at certain phases of the flight. (e.g., boost navigation computations.) In addition, an interrupt routine permits interruption of the normal program operation to free the LVDC for priority work. These interrupt operations may occur at any time within the program. Actually, the Minor Loop is an interrupt operation which will occur at 40 millisecond intervals. (i.e., every 40 milliseconds, the main program is interrupted while accelerometer sampling and control system routines are processed.)

A programmed telemetry feature is also provided as a method of monitoring LVDC and LVDA operations. The telemetry routine transmits specified information and data to the ground by way of the Instrument Unit telemetry equipment.

The execution time for any given Major Loop, complete with Minor Loop computations and interrupts, is not fixed. The various modes of the Major Loop and the uncertainties of interrupt processing make the cycle time unpredictable (several interrupts may occur within one cycle of the Major Loop while the very next cycle may have only a few interrupts). The longest program cycle should always be less than 1 second in duration.

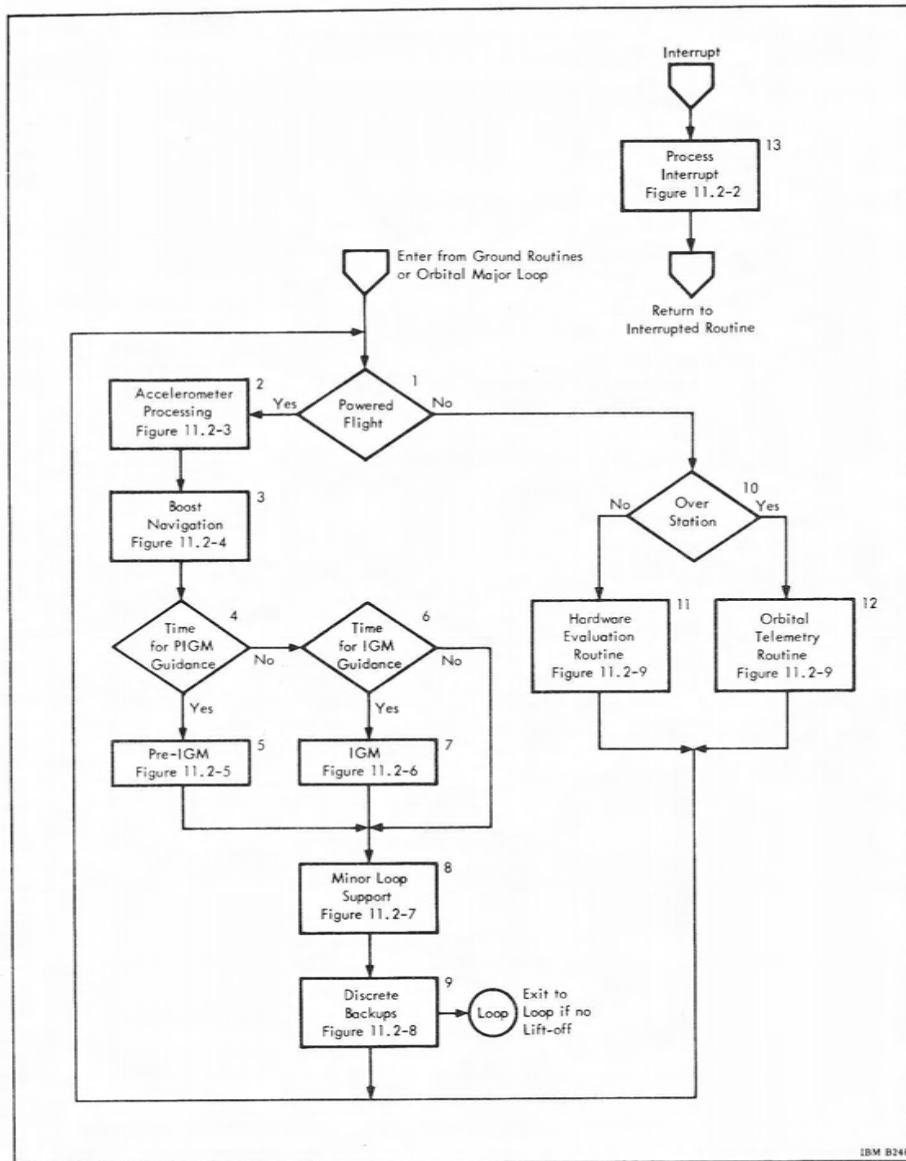


Figure 11.2-1 Major Loop

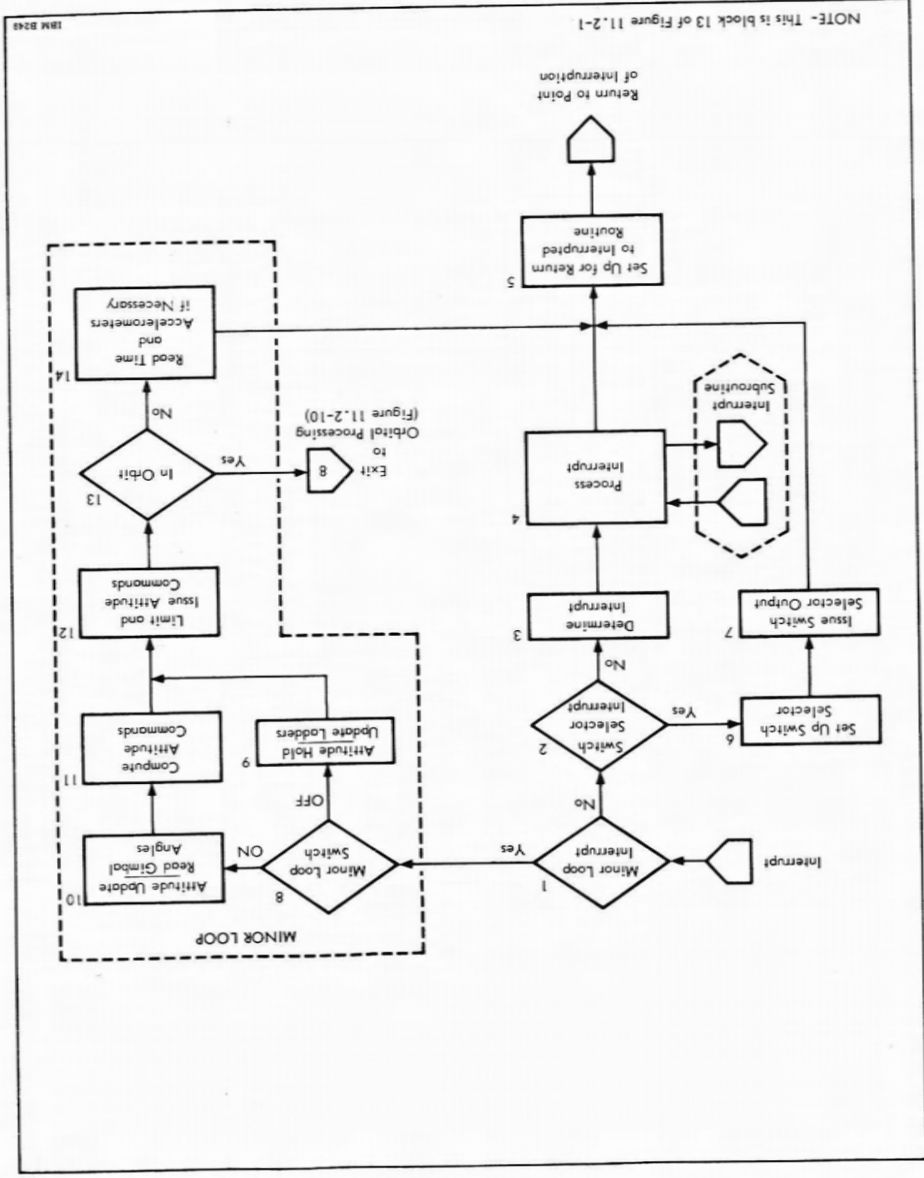


Figure 11.2-2 Interrupt and Minor Loop Processing

Astrionics System
Section 11.2

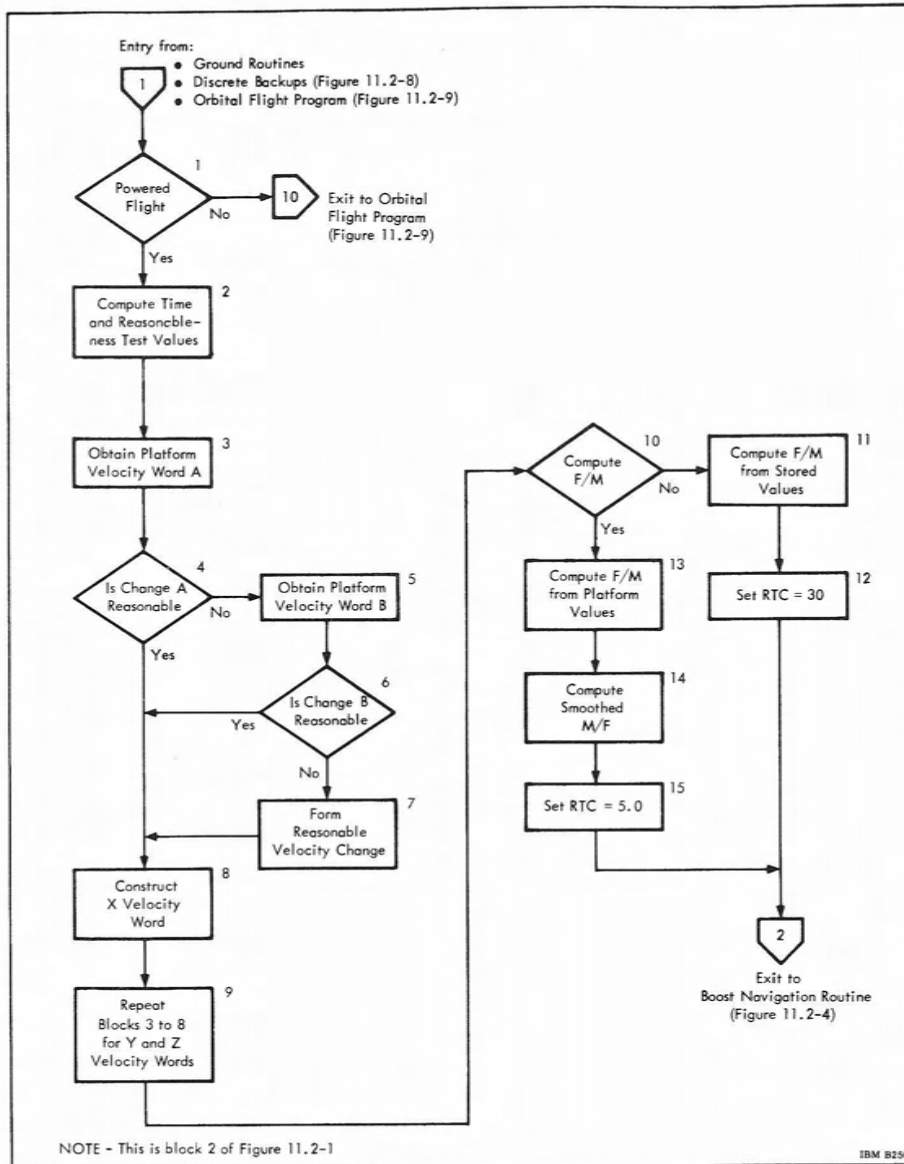


Figure 11.2-3 Accelerometer Processing

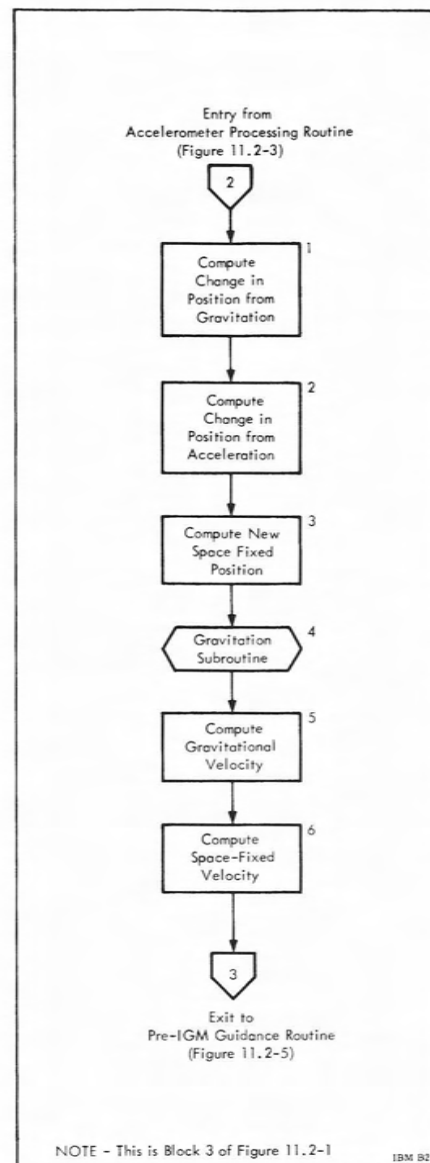


Figure 11.2-4 Boost Navigation

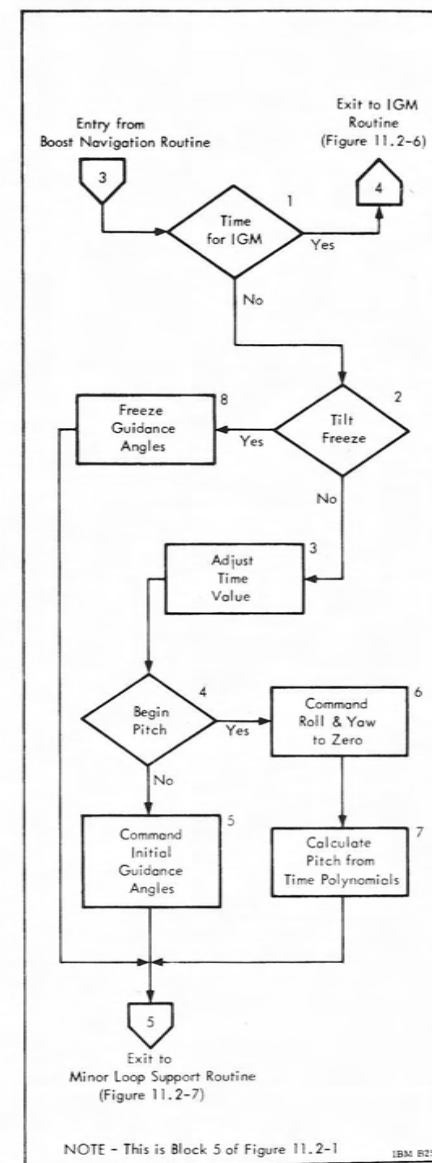


Figure 11.2-5 Pre-IGM Guidance

Changed 15 August 1966

Astrionics System
Section 11.2

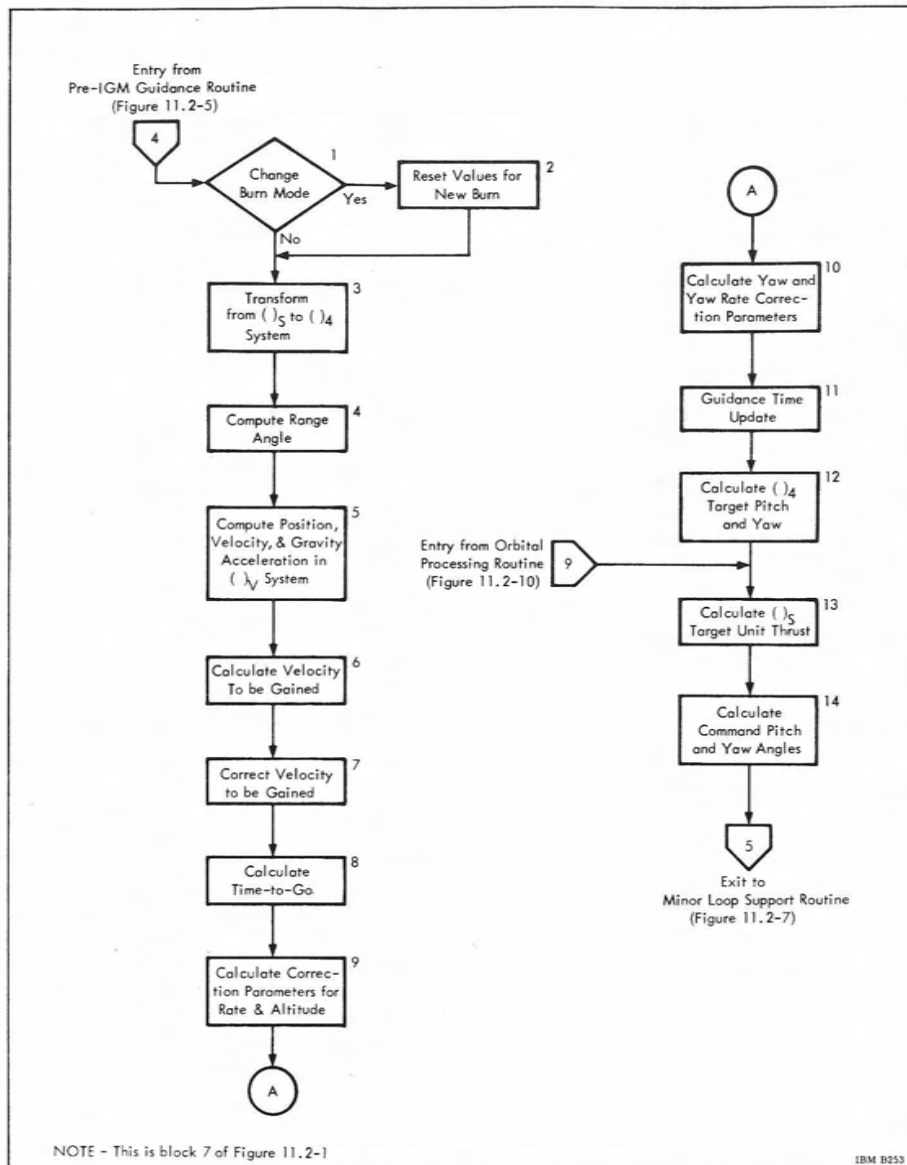


Figure 11.2-6 IGM Flow Diagram

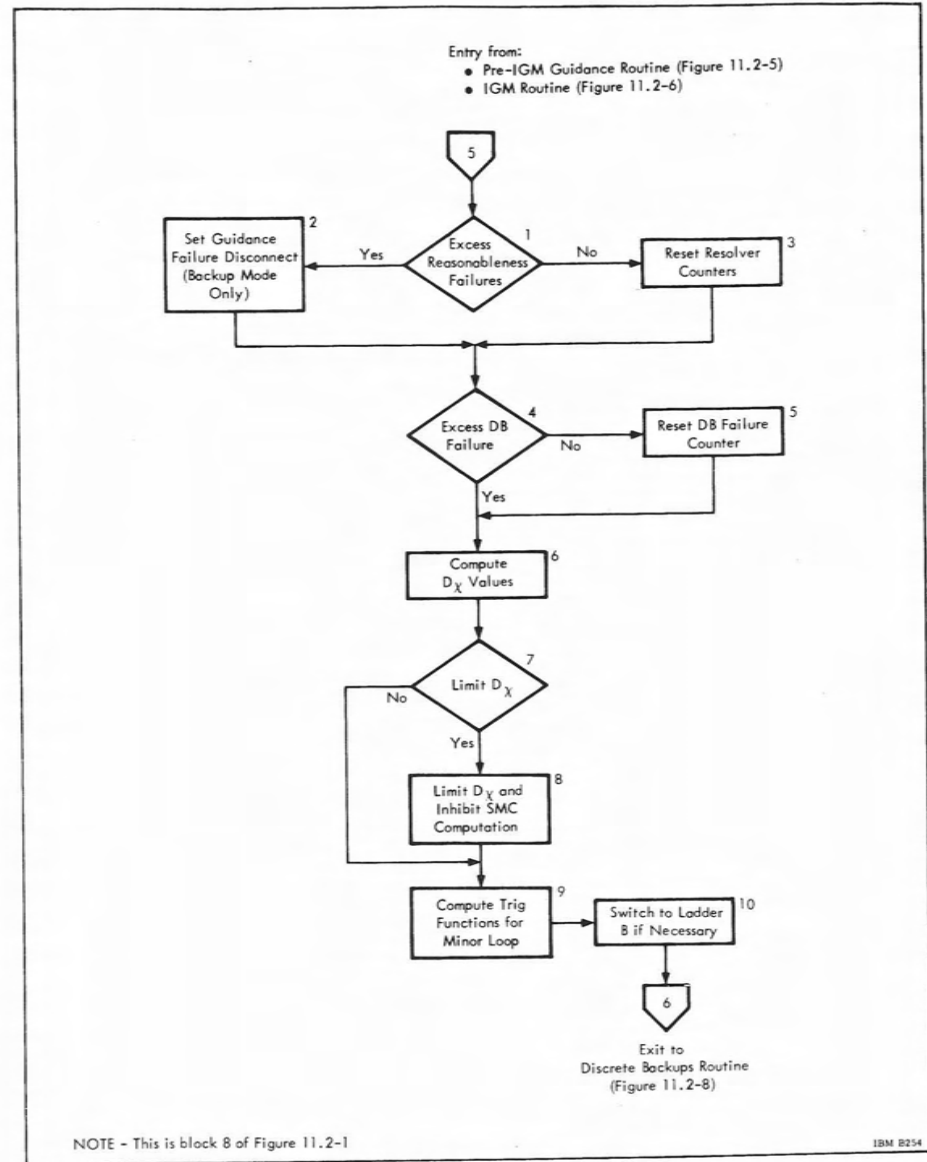


Figure 11.2-7 Minor Loop Support

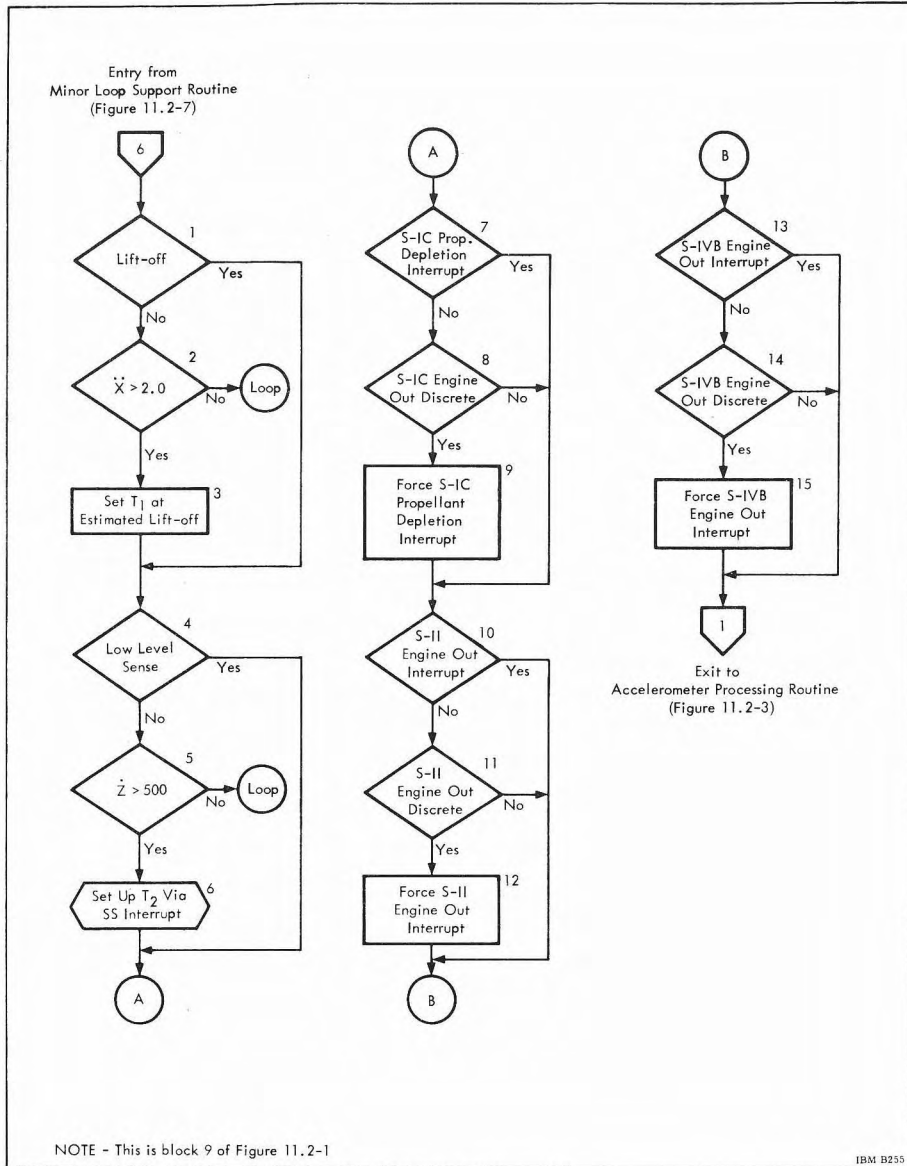


Figure 11.2-8 Discrete Backups

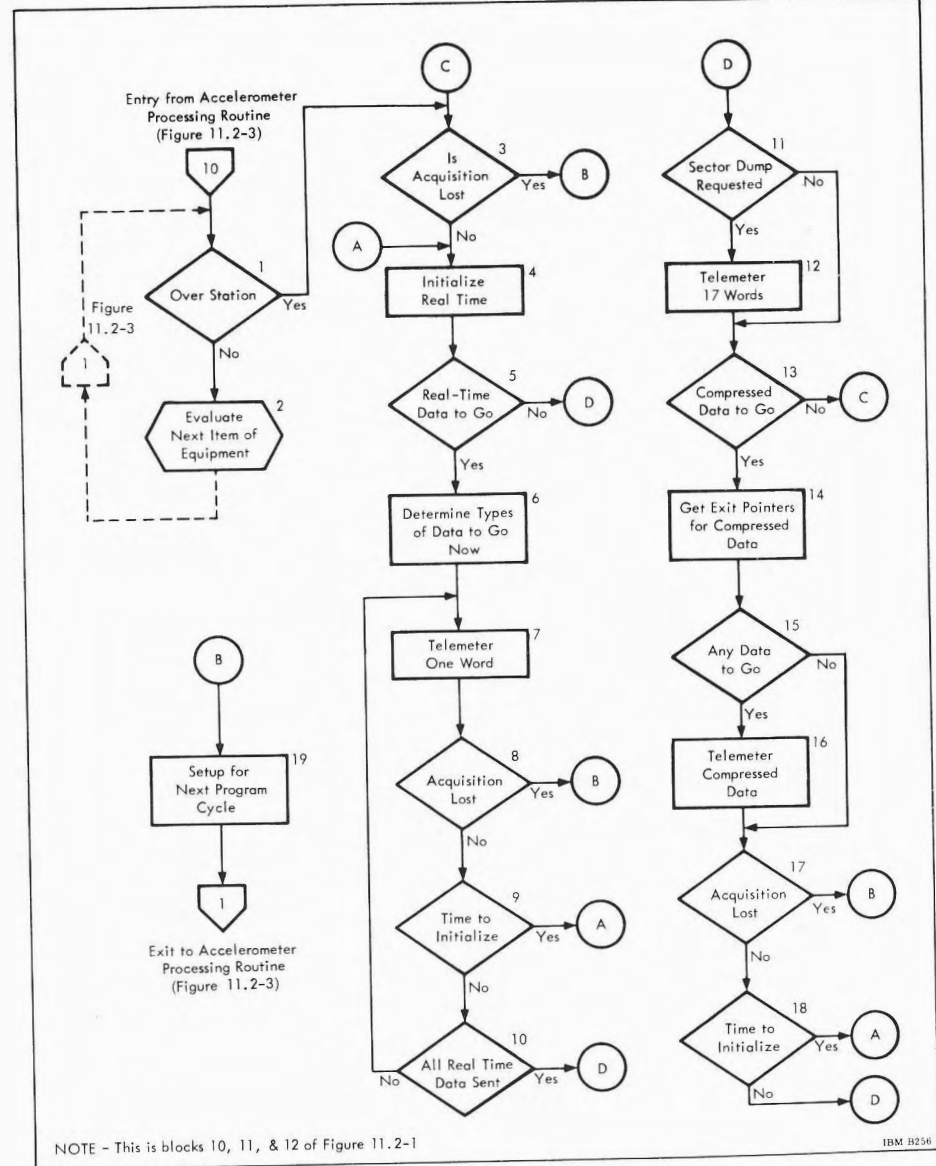


Figure 11.2-9 Orbital Flight Program

Astrionics System
Section 11.2

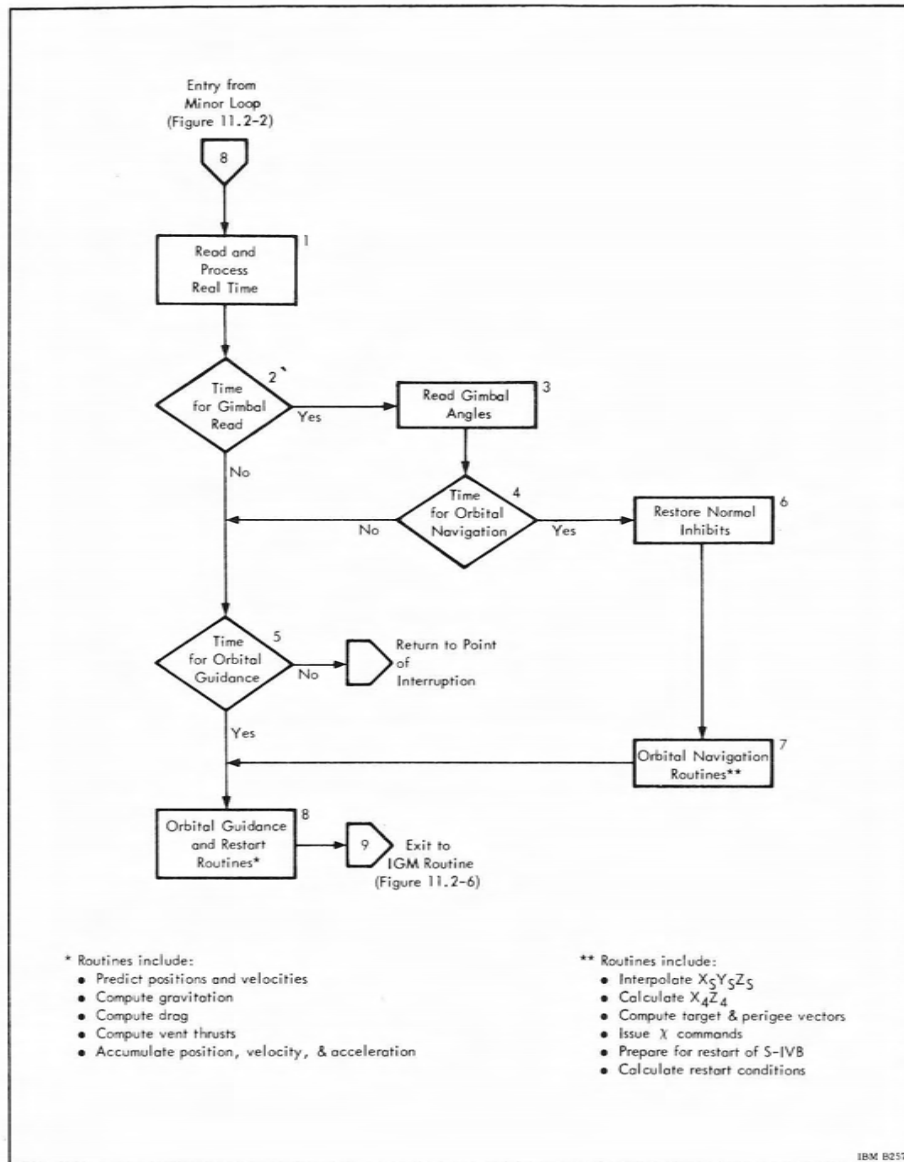


Figure 11.2-10 Orbital Processing

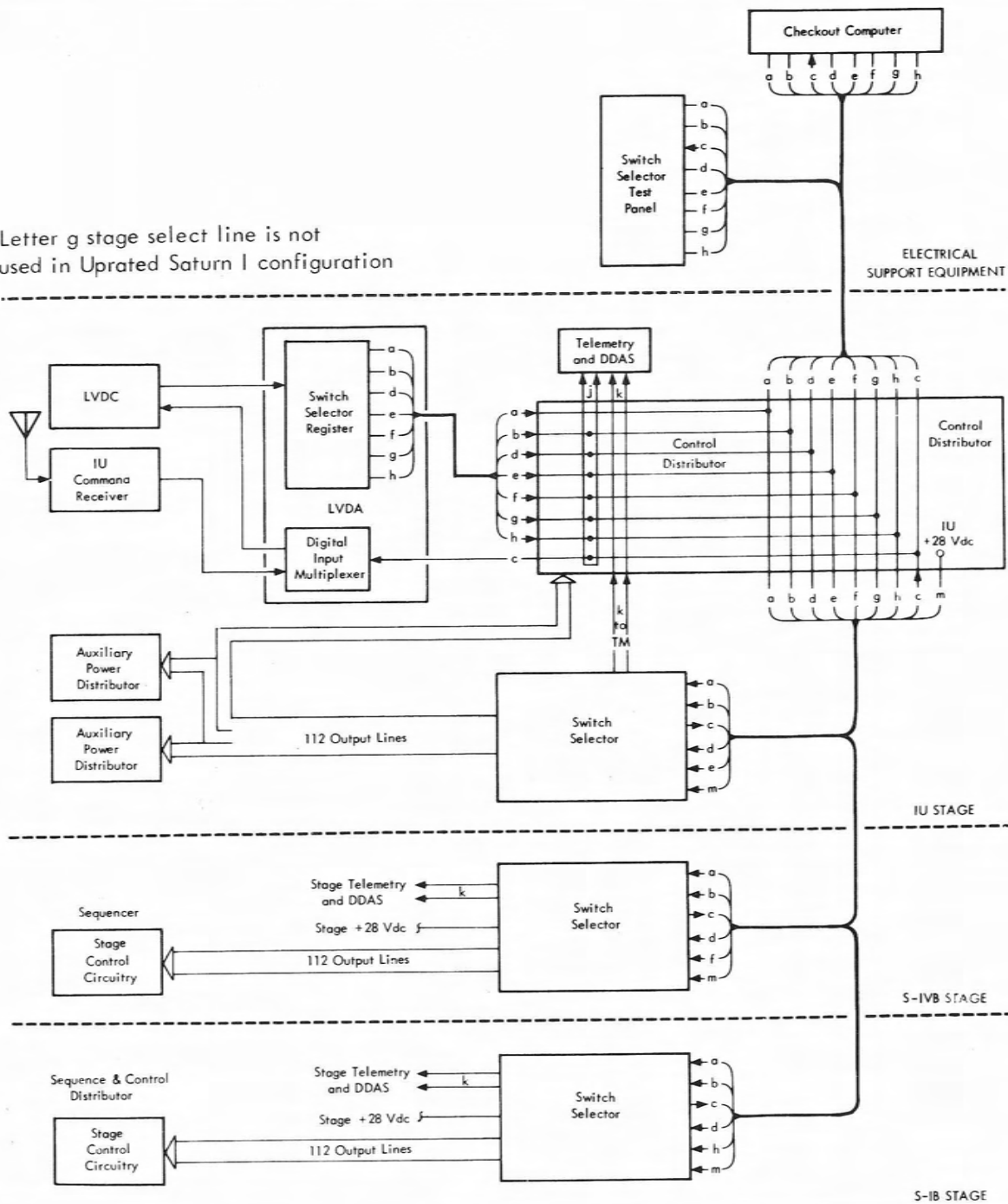
Sequencing System

The Switch Selector is a combination solid state and electro-mechanical component which provides interstage mode and sequence control between the Launch Vehicle Digital Computer/Launch Vehicle Data Adapter (LVDC/LVDA) and the stage distributors. One Switch Selector is located in each stage and in the Instrument Unit of the Saturn Launch Vehicles.

By utilizing a digital coding-decoding technique, each Switch Selector can activate, one at a time, 112 different circuits in the stage in which it is located. Coding of the flight sequence commands and the decoding of these commands by the stage Switch Selectors has the following advantages: the number of interface lines between stages is reduced; flexibility of the system with respect to timing and sequencing is increased; and the discrete output circuitry of the LVDC/LVDA is conserved.

Commands for flight sequence control are generated in the LVDC according to a stored program. These commands are transferred through the LVDA to the Switch Selector of the corresponding vehicle stage. Examples of flight sequence control are engine ignition, cutoff, and stage separation. The Switch Selector in the addressed stage activates the necessary circuit to perform the commanded function.

Letter g stage select line is not used in Uprated Saturn I configuration

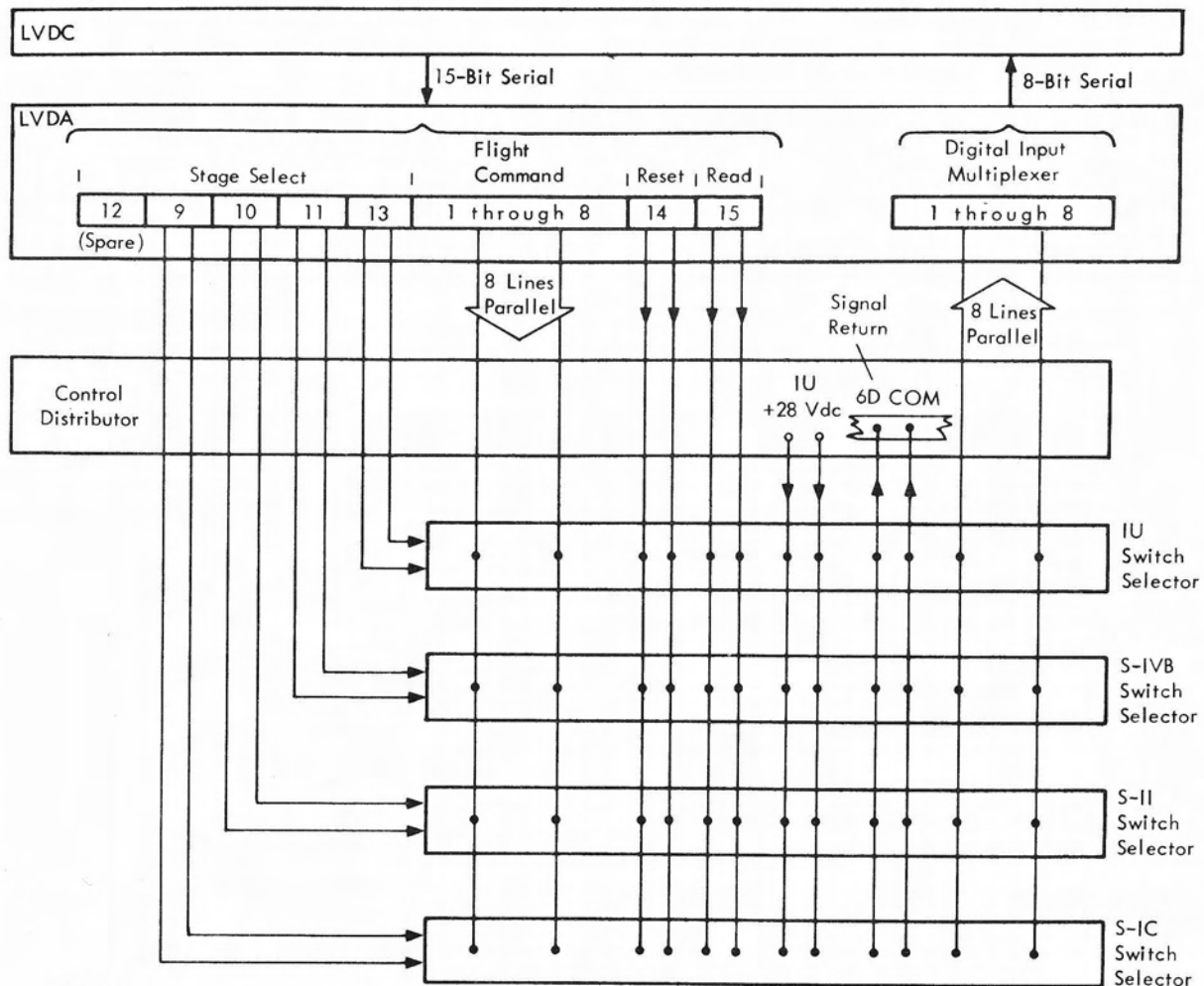


- Notes:
- Signal return lines from the Switch Selectors to the Control Distributor are not shown in this Figure.
 - The letters used to label interstage connections between units are not actual pin or cable connectors. The letter code is denoted below:
- a = 8-digit address (8 lines)
 - b = Force reset (register) (1 line + 1 redundant line)
 - c = Register verification (8 lines)
 - d = Read command (1 line + 1 redundant line)
 - e =
 - f = } Stage select lines
 - g = } (1 line + 1 redundant line)
 - h =
 - j = b, c, d, e, f, g, and h to IU telemetry
 - k = Register test } To stage telemetry
 - l = Zero indicate } (1 line each)
 - m = Sw Sel output
 - m = +28 Vdc from the Instrument Unit

Uprated Saturn I Switch Selector Configuration Block Diagram

Switch Selector Processing

- The 8 verify lines are sampled to ensure that all stage select relays have been reset, thereby ensuring an unwanted stage is not selected. Zero voltage on all lines indicates that this condition exists. The presence of Instrument Unit + 28 VDC on the verify lines indicates that the verify lines are enabled because a stage Switch Selector is not reset. Having detected this situation, the LVDC commands a "force reset" and then rechecks the verify lines.
- The LVDC inserts the 8-bit flight command into the LVDA switch selector register. At the same time, a stage select command is sent to the appropriate Switch Selector. Application of the stage select command completes the signal return path for the input relays and allows the 8-bit command to be stored in the Switch Selector input relays.
- The verification lines are sampled to determine if the command transfer was correct.
- If the verification is correct, the LVDC sends a read command to the Switch Selector; activating it, and causing the proper output to occur.
- If the verification is not correct, the LVDC initiates a reset command to prepare the Switch Selector to receive the complement of the original command.
- After the forced reset is completed, the LVDC loads the stage select command, and the complement of the previously sent command, into the LVDA switch selector register.
- Neglecting the verification information that occurs after the complement command is inserted, the LVDC initiates a read command which produces an output from the selected switch selector channel. The read command also energizes the automatic reset circuitry which returns the Switch Selector to the reset condition to prepare it for a new cycle.



Notes:

1. 22 lines between each Switch Selector and LVDA.
2. 26 lines between all Switch Selectors and LVDA (Uprated Saturn I) (3 Switch Selectors).
3. 28 lines between all Switch Selectors and LVDA (Saturn V) (4 Switch Selectors).
4. 30 lines (maximum number) available to Switch Selectors from LVDA (5 Switch Selectors).
5. 4 lines (IU + 28 Vdc and signal return) to all Switch Selectors from Control Distributor (Uprated Saturn I and V).

LVDC - Switch Selector Interconnection Diagram

Control System

The attitude control requirement of the Saturn Launch Vehicle can be divided into attitude control during powered flight and attitude control during coast flight. Attitude control and stabilization during powered flight are accomplished by swiveling of the propulsion engines to control thrust vector direction. During coast flight (in orbit and after translunar injection), attitude control is provided by the auxiliary propulsion system of the S-IVB Stage. This auxiliary propulsion system is used also during powered flight of the S-IVB Stage for roll control which cannot be achieved with the single engine of the S-IVB Stage.

Control of the launch vehicle during ascent into earth orbit can be divided into two phases. During first-stage powered flight, the vehicle traverses the dense portion of the atmosphere. Large side forces (resulting from aerodynamic flow and wind) can act on the vehicle. Maneuvers during this flight phase are limited because of structural constraints. Structural loads from aerodynamic forces are kept within a tolerable range by controlling the vehicle to achieve a minimum angle of attack. The basic control scheme is an attitude/attitude-rate scheme.

The control law for the thrust vector deflection angle (β) is:

$$\beta = a_0 \psi + a_1 \dot{\phi} + g_2 \ddot{\gamma} \quad (\text{Up-rated Saturn I})$$

$$\beta = a_0 \psi + a_1 \dot{\phi} \quad (\text{Saturn V})$$

Where a_0 and a_1 are gain factors, ψ and $\dot{\phi}$ are attitude error angle and attitude angular rate respectively, $\ddot{\gamma}$ is the lateral acceleration measured by the accelerometers with its sensitive axis perpendicular to the vehicle longitudinal axis, and g_2 is the corresponding gain factor. The attitude error angle (ψ) is obtained from the LVDC/LVDA, the attitude rate ($\dot{\phi}$) from the rate gyros, and the lateral acceleration ($\ddot{\gamma}$) from control accelerometers.

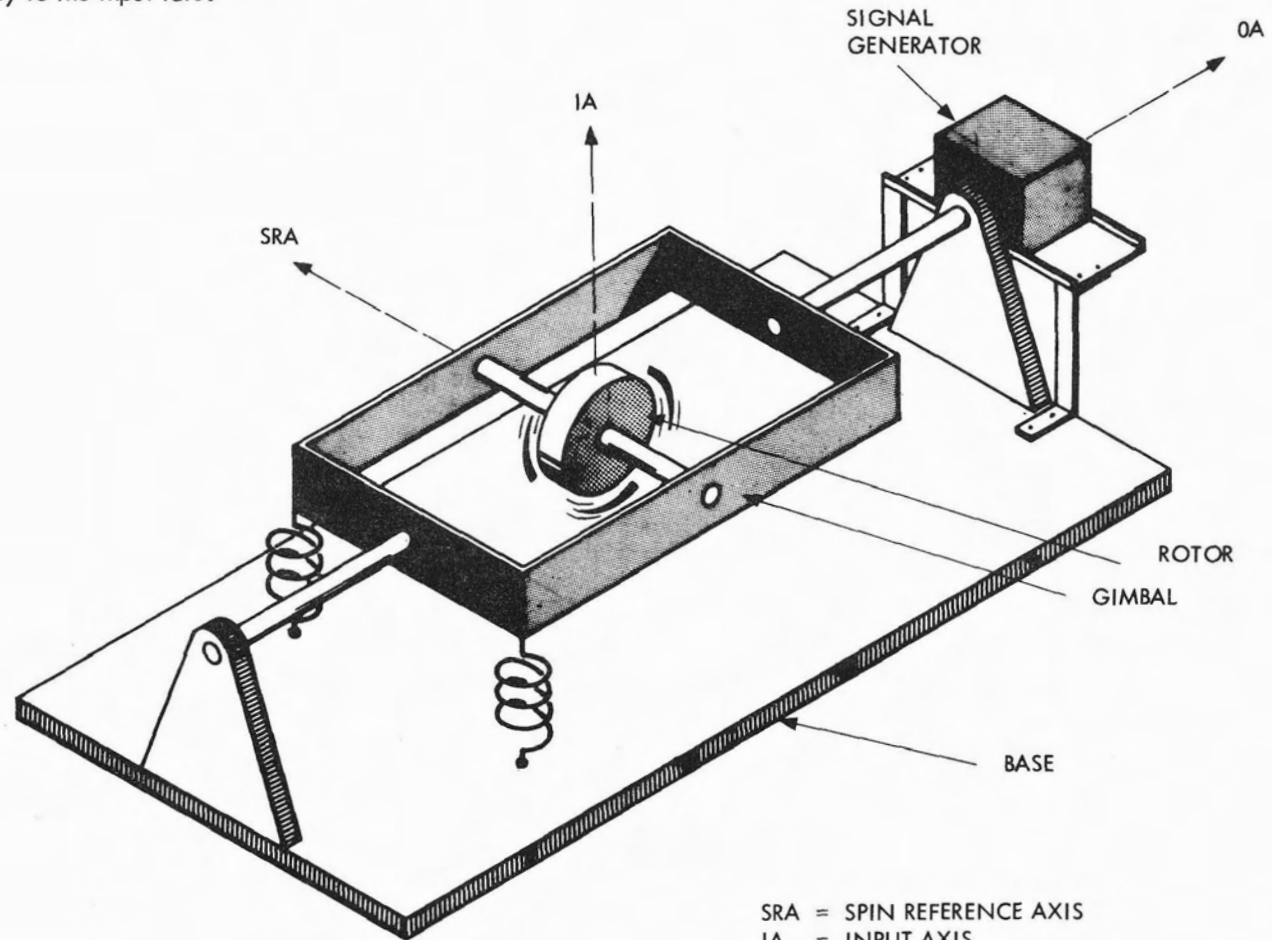
The lateral acceleration control is used during first-stage propulsion to reduce structural loads from aerodynamic forces and to provide drift-minimum control.

Input Channel	Symbol	Gain* Factor	Signal Sources
Lateral Acceleration			
Pitch	$\ddot{\gamma}_P$	} g_2	Saturn IB Control Accelerometers
Yaw	$\ddot{\gamma}_Y$		
Angular Rate			
Pitch	$\dot{\phi}_P$	} a_1	Control-EDS Rate Gyros
Yaw	$\dot{\phi}_Y$		
Roll	$\dot{\phi}_R$		
Attitude Error			
Pitch	ψ_P	} a_0	LVDA/LVDC or Spacecraft
Yaw	ψ_Y		
Roll	ψ_R		
<p>*Time-varying functions that determine which of the three terms of the control equation will be dominant. The control equation is defined as: $\beta_c = a_0 \psi + a_1 \dot{\phi} (+ g_2 \ddot{\gamma}$ for Saturn IB)</p>			

Input Signals to the Flight Control Computer

Rate Gyro

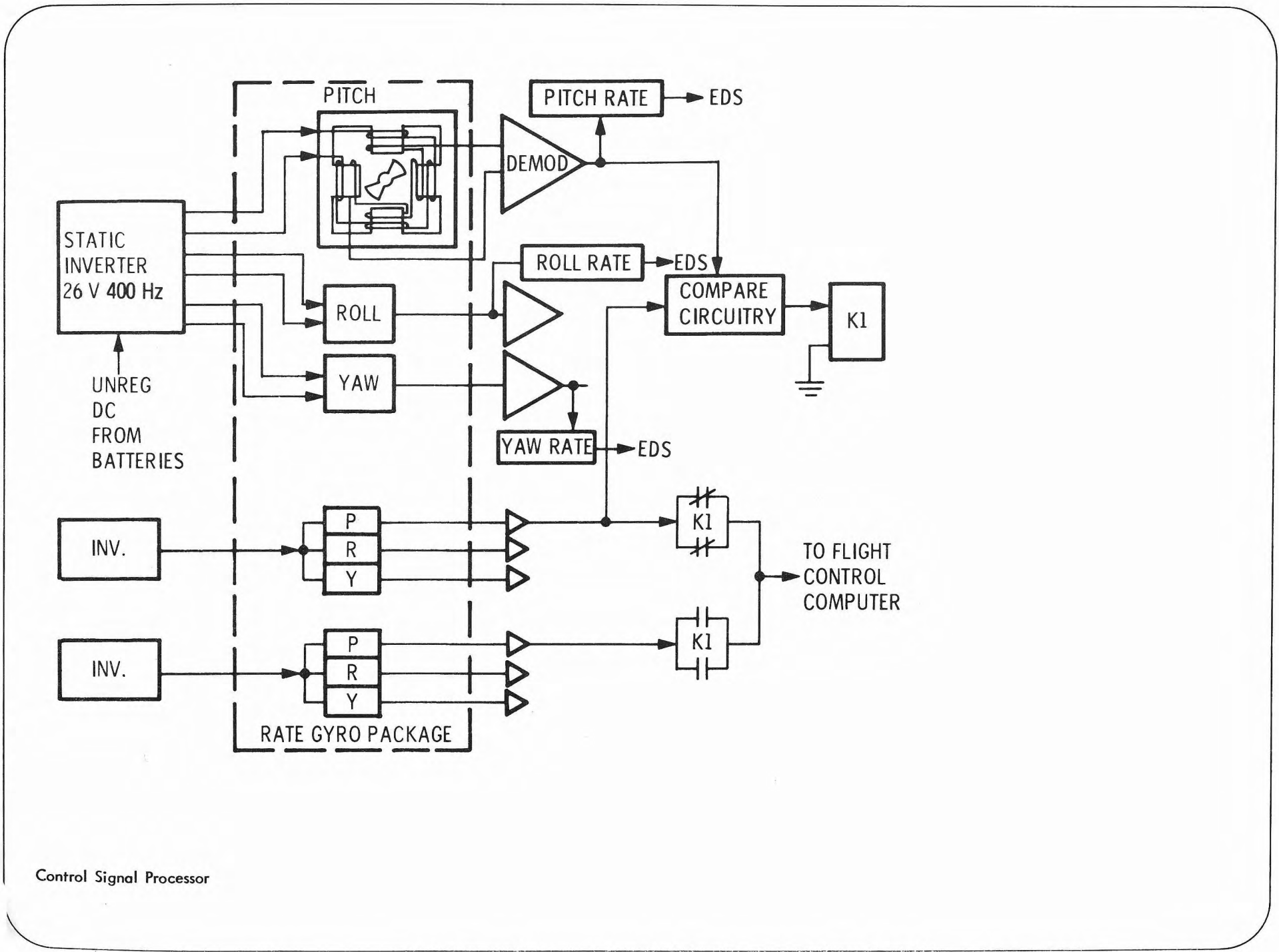
A single degree of freedom gyro which is restrained by spring torque is classified as a rate gyro. In this configuration, the gyro responds to angular rate about its input axis by developing torque about its output axis. The output torque working into a torsion bar or coil spring allows the gimbal to displace proportionally to the input rate.



SRA = SPIN REFERENCE AXIS
IA = INPUT AXIS
OA = OUTPUT AXIS

Control Signal Processor

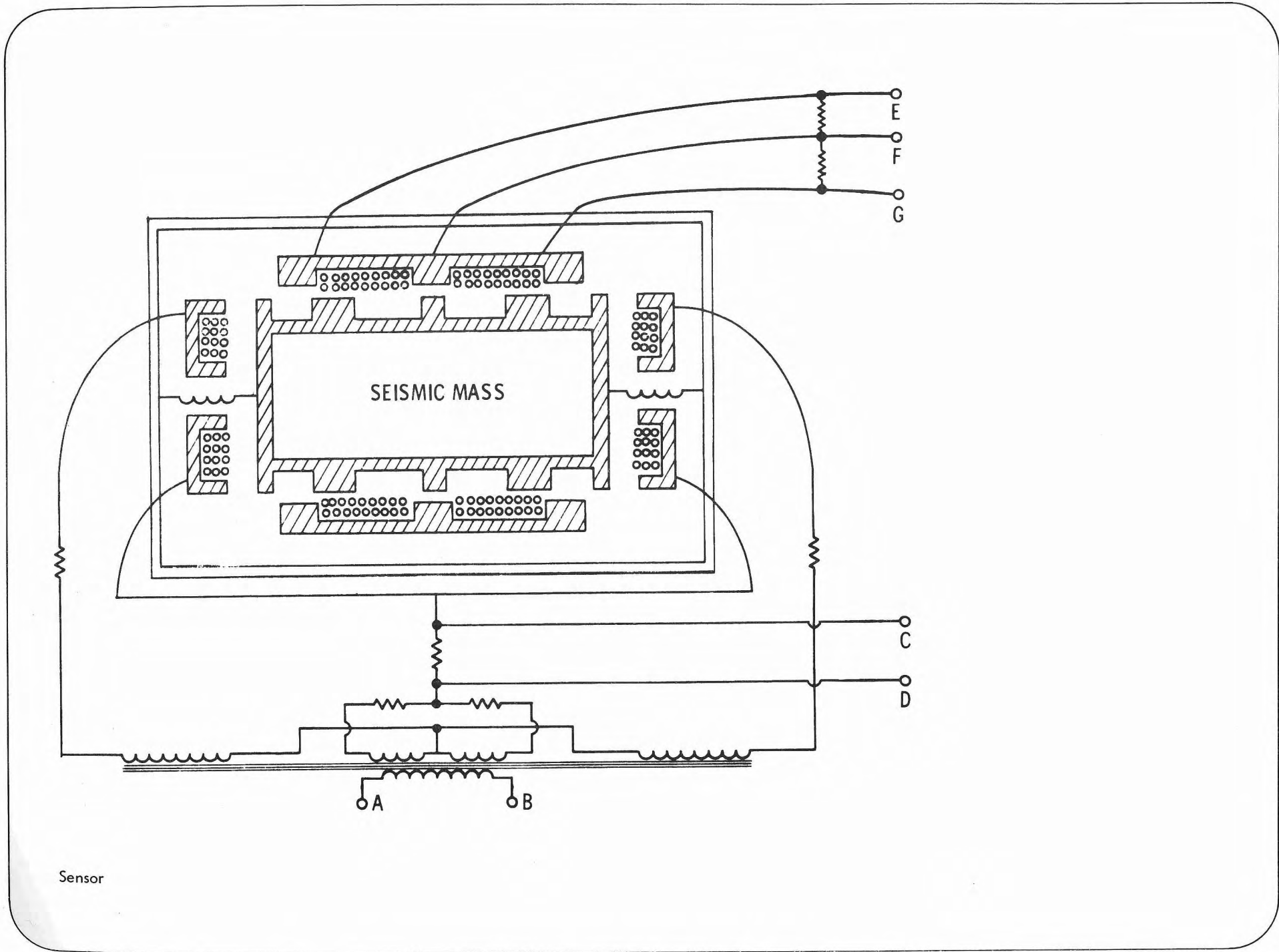
The Control Signal Processor serves as a power source, demodulator, comparator, and distributor for the Control/EDS Rate Gyros. Demodulators convert AC outputs of the gyros to DC signals. These DC signals are compared to determine if a malfunction has occurred. If a malfunction has occurred, the spare signal channel will be used. Rate switches signal the Emergency Detection System when excessive rates of maneuver are experienced.



Control Signal Processor

Measuring Lateral Acceleration

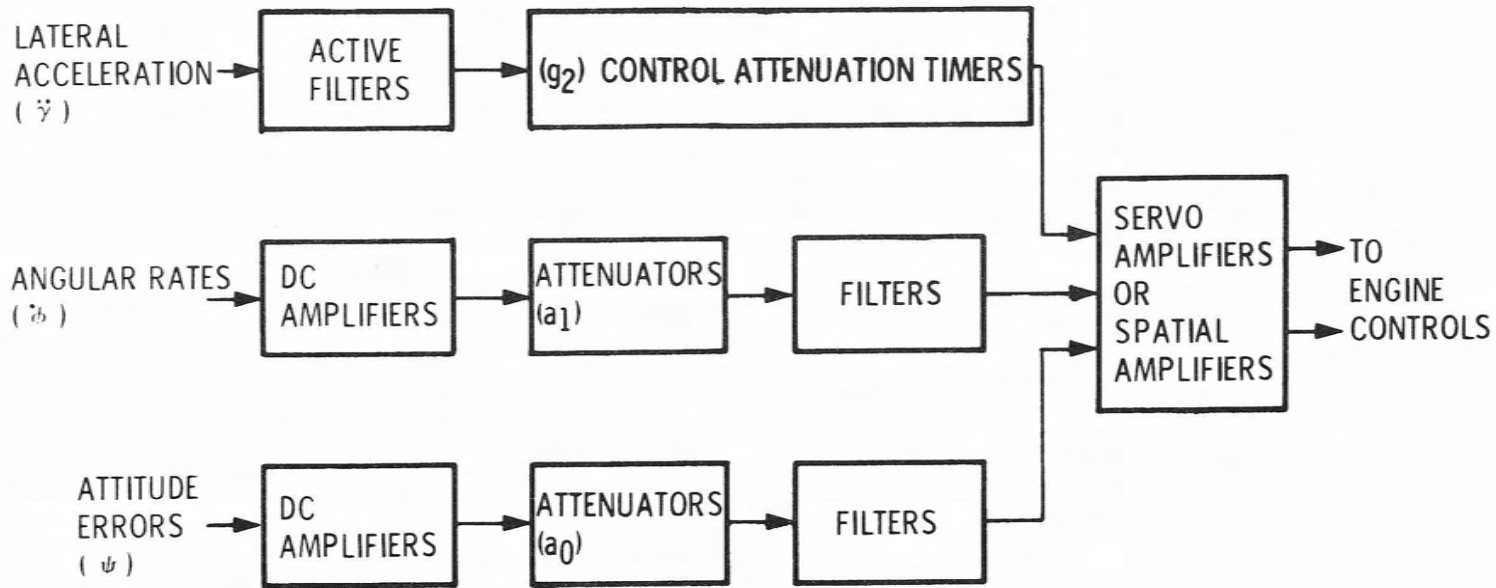
Lateral acceleration is sensed using a seismic mass which is floated in a viscous silicon fluid. Acceleration in the longitudinal axis of the sensor causes the mass to shift within the case. Iron core material of this mass unbalances current in the sensing windings. The difference in current between these windings develops an output voltage.



Sensor

Flight Control Computer - General

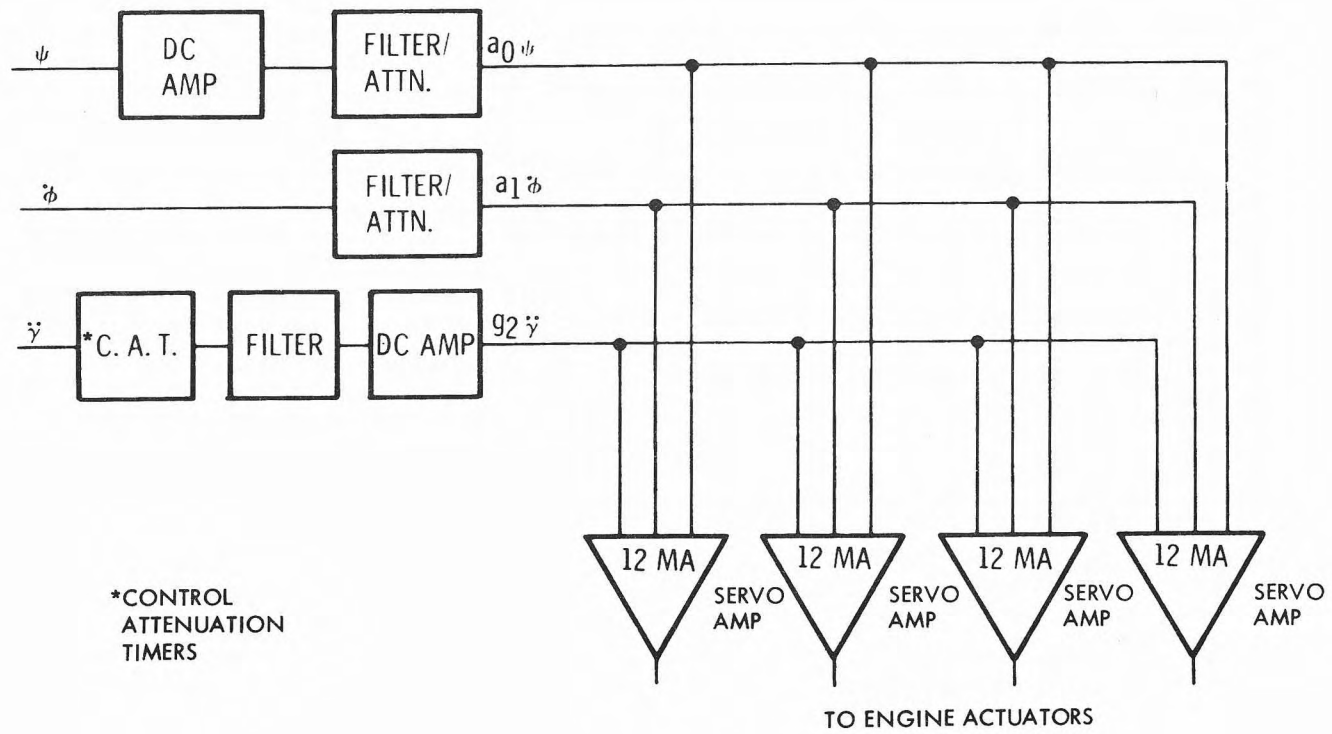
Each of the input variables to the Flight Control Computer must be multiplied by a coefficient which has been determined from simulated flight dynamics. The multiplication is accomplished using DC amplifiers and attenuators. Servo amplifiers develop analog gimbaling commands by summing the three inputs. Spatial amplifiers develop discrete commands to the auxiliary propulsion system.



Flight Control Computer (Simplified Block Diagram)

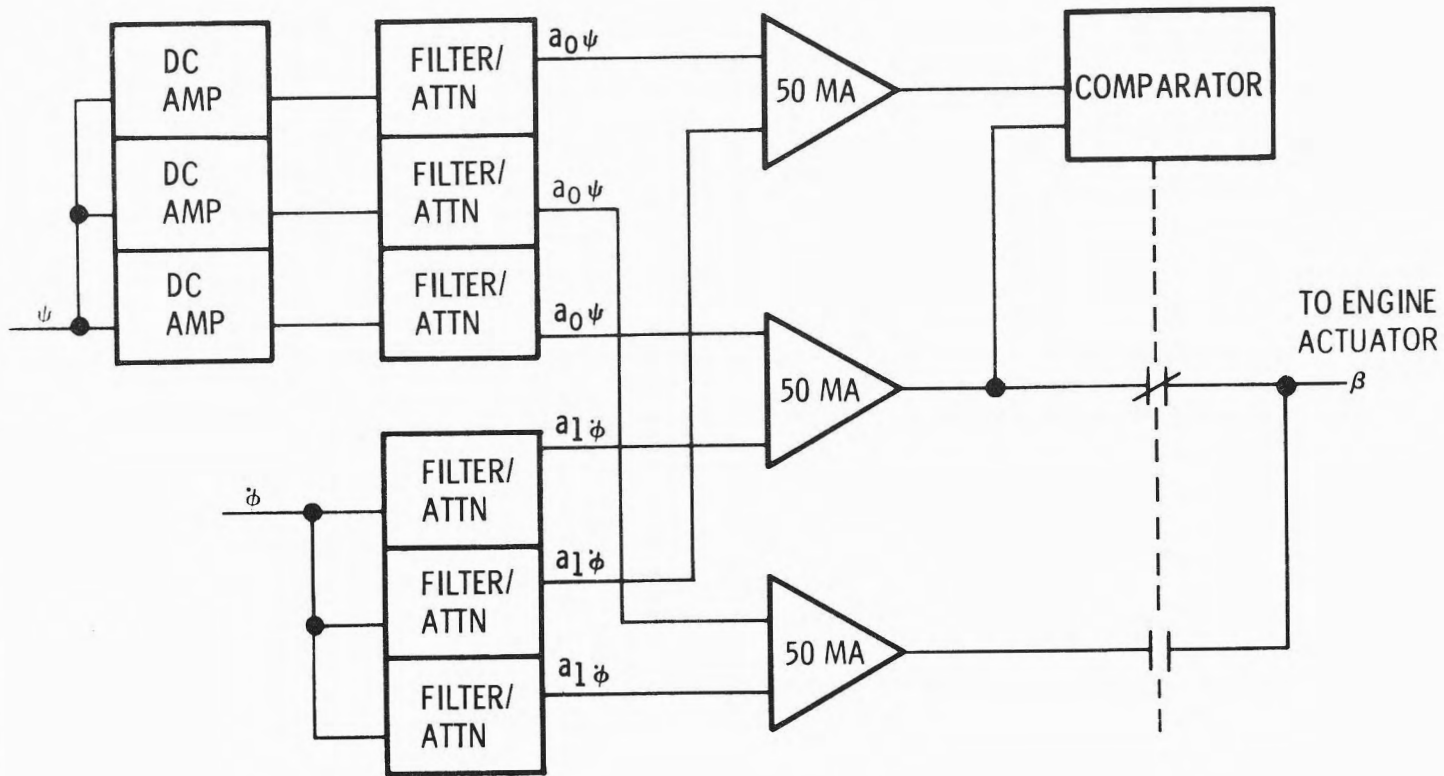
Flight Control Computer - S-IB Burn

The circuit configuration of the Flight Control Computer is dictated by the hardware requirements of the powered stage. The S-IB Stage has four gimballed engines; each is controlled by two hydraulic actuators, one for yaw control and one for pitch control. Twelve milliamps of input to one of these actuators results in maximum deflection of the engine in that axis.



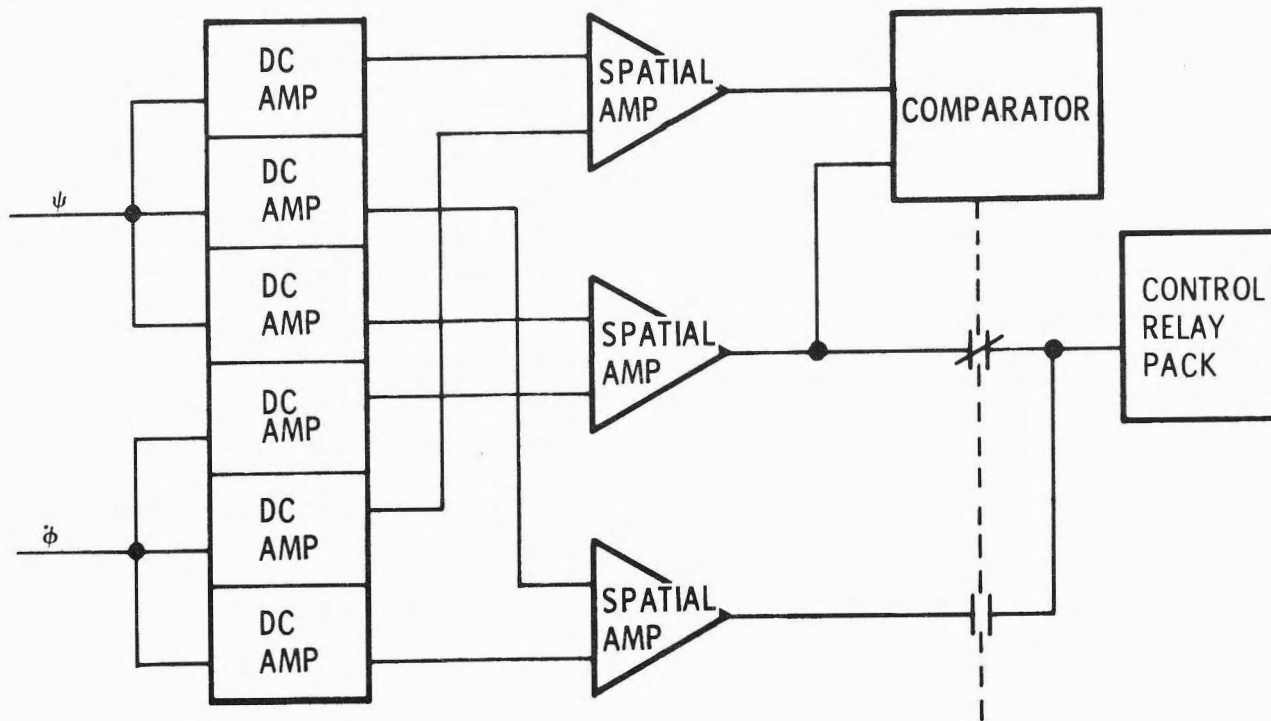
Flight Control Computer - S-IVB Burn

The S-IVB Stage is powered by a single engine having only one yaw actuator and one pitch actuator. To assure high reliability, the Flight Control Computer develops the command in three identical (redundant) channels. Comparator circuitry selects the channel to be used.



Flight Control Computer-Coast

To maintain the desired attitude during the coast phase (also during S-IVB Burn for roll), Auxiliary Propulsion System nozzles are fired as required. This requires the Flight Control Computer to have a discrete (engine ON/engine OFF) capability. This capability is accomplished using Spatial Amplifiers. When the sum of the inputs to this amplifier exceeds a given "threshold", an "ON" signal is generated to fire the proper nozzle.

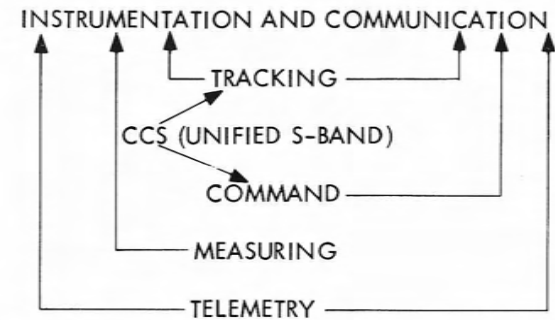


Flight Control Computer - Coast

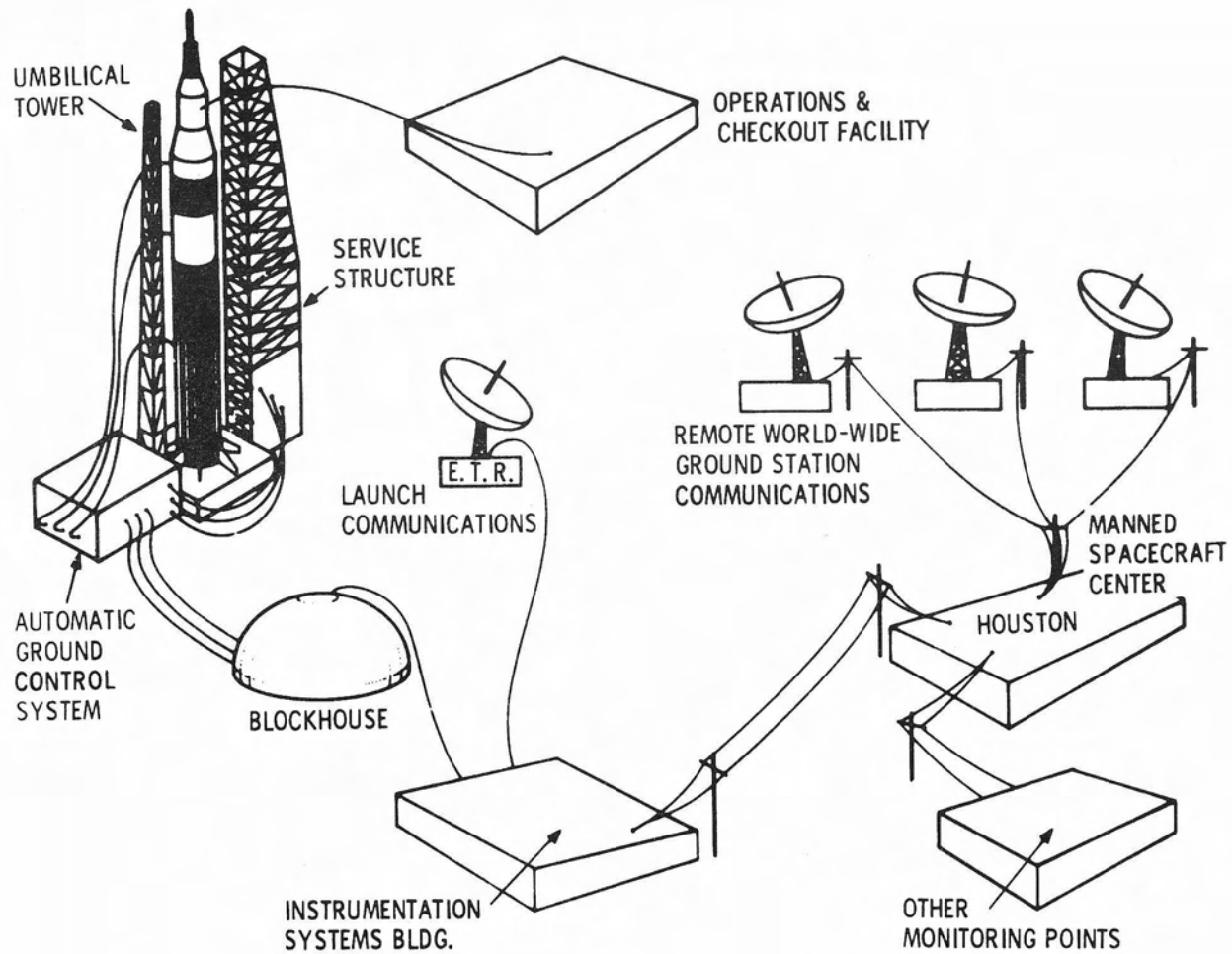
Instrumentation and Communications

The Instrument Unit is capable of navigating, guiding, and controlling the Saturn vehicle; however, there still exists a primary need for monitoring on-board functions from Earth stations. Since primary control of the Saturn mission rests on the shoulders of the KSC, remote site, and MSC personnel.

The functions involved in monitoring and communicating with the vehicle can be grouped according to the following table.



- **Measuring Functions** Monitoring or measuring parameters on board the vehicle.
- **Tracking Functions** Monitoring or measuring the location of the vehicle in flight by communicating with the vehicle.
- **Telemetry Functions** Transferring on-board parameters from the vehicle to Earth stations.
- **Command Functions** Transferring information from Earth to the vehicle.



Instrumentation and Communications Network

Measuring and Telemetry

For monitoring physical parameters, it is necessary to use sensing devices (transducers) to reduce the physical quantity to electrical intelligence. Conditions already in acceptable electrical form will allow direct pick-off of the quantity. Since various electrical forms will be picked off, they must be conditioned to values acceptable to the telemetry equipment. This signal conditioning is performed in measuring racks.

The quantity and variety of monitored conditions are great, thus it is necessary to integrate these measurements into limited transmitting paths. This is accomplished by the telemetry functions of time and frequency sharing techniques. Various combinations of the following multiplexing techniques are employed:

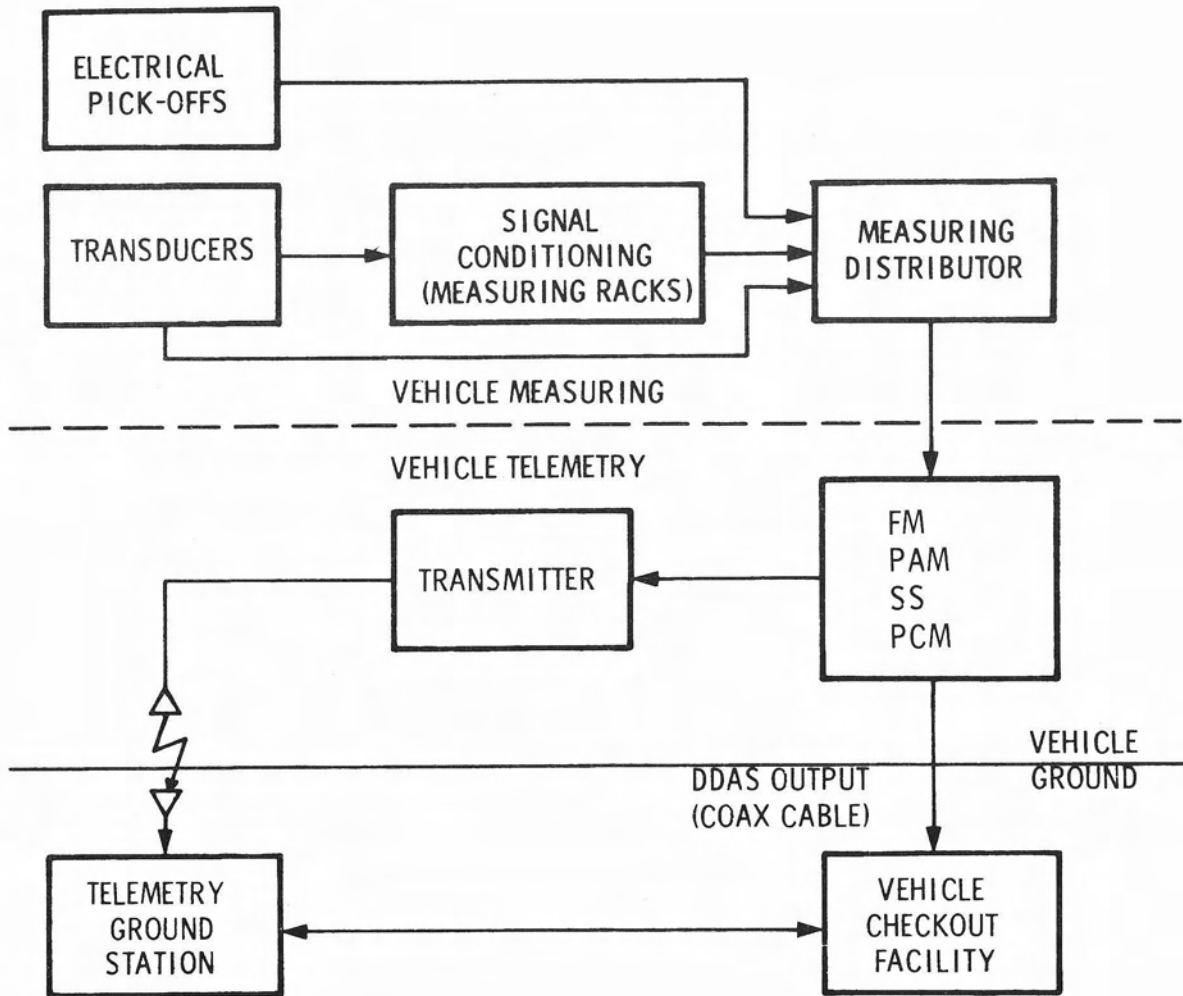
- Frequency Modulation
- Pulse Amplitude Modulation
- Single Sideband Modulation
- Pulse Code Modulation

The following two methods are utilized for transferring intelligence from the vehicle to an accessible location:

- 1 Vehicle on pad → hardwire through umbilical cords
- 2 Vehicle in flight → transmitted through space

At the Earth stations, the received intelligence is:

- 1 Used for vehicle checkout
- 2 Reduced for real time evaluation
- 3 Used to verify commands
- 4 Recorded for future use



Vehicle Measuring System

Measuring

Transducer

Generally, transducers change energy from one form to another. In measuring techniques, they are used as electromechanical measuring instruments which contain sensing devices for converting mechanical and environmental quantities into electrical signals. Evaluation of vehicle performance and inflight monitoring requires the measurement of a large variety of physical quantities onboard the vehicle. Therefore, many different types of transducers are used. Some typical transducers and the corresponding measurements are listed below.

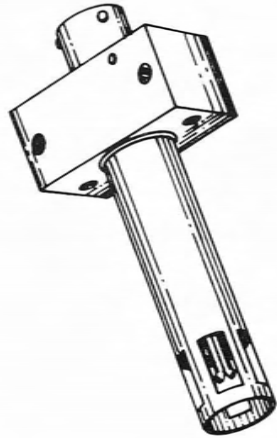
<u>Parameter</u>	<u>Transducer</u>
● Vibration	Piezoelectric Accelerometer
● Acoustic energy	Piezoelectric Microphone
● Pressure	Bellows and Bourdin Tube Pressure Gauges
● Temperature	Thermistors and Resistance Thermometers
● Flow Rate	Turbine Flowmeters
● Acceleration	Force Balance Accelerometer
● Position	Potentiometers

Signal Conditioning

The signal conditioning system takes the measured signal and converts it to a signal that is acceptable to telemetry. The signal may be a raw electrical signal from the vehicle or it may be the output from a transducer. Certain transducers have output signals which do not require signal conditioning. The signals are then fed directly to the Measuring Distributor. The following lists transducers located in the Instrument Unit in relation to the type of signal conditioning required.

<u>Transducer</u>	<u>Type of Signal Conditioner</u>
Piezoelectric Accelerometer	AC Amplifiers
Piezoelectric Microphone	AC Amplifiers
Pressure Gauges	None
Temperature Transducers	DC Amplifiers
Flowmeters	Frequency-to-DC Converters
Force Balance Accelerometers	Servo Accelerometer Units

One analog measurement needing signal conditioning, that is not listed, is the direct pick-off of the 400 Hz output of the excitation source for the platform gyro motors. This requires the use of a signal conditioning module called a Frequency Measuring Adaptor.



THERMISTOR



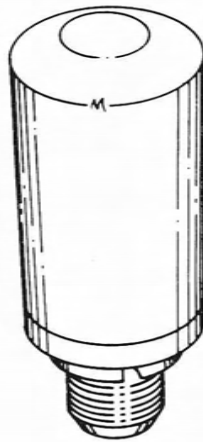
RESISTANCE THERMOMETER



RESISTANCE THERMOMETER



PRESSURE SENSOR

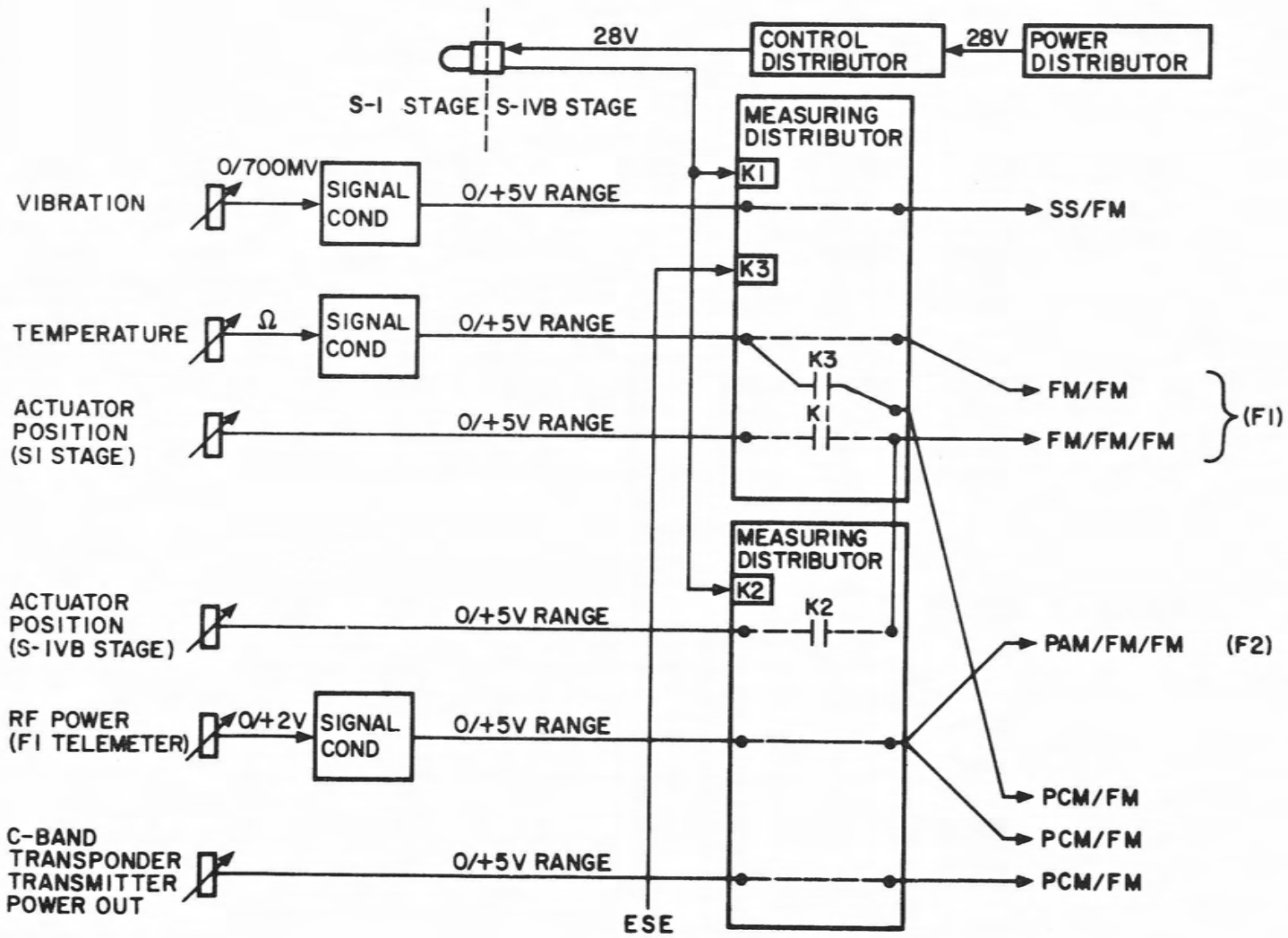


RATE GYRO PACKAGE

Distribution

In the routing of the various measurements to the proper telemetry equipment, flexibility is needed in assignment of paths. To provide this flexibility, measurements are routed through measuring distributors. The distributors provide the following three types of signal routings:

- Hardwire patching
- Pre-flight relay switching
- Inter-stage relay switching



Examples of Measurement Routing

Telemetry

The primary responsibility of telemetry is to integrate as many measurements as possible onto the least amount of transmitting frequencies and retain the accuracies of the measurements. This can be referred to as adding efficiency to the information transfer path from the vehicle to earth.

Frequency Sharing

The frequency sharing techniques used within the Instrument Unit are Single Side Band (S1 path), Frequency Modulation (F1 and F2 paths), and Frequency Modulated-Frequency Modulation (F1 and F2 paths).

Time Sharing

The time sharing (sampling) techniques used within the Instrument Unit are Slow-Speed Multiplexing, Pulse Amplitude Modulation, and Pulse Code Modulation (P1 path).

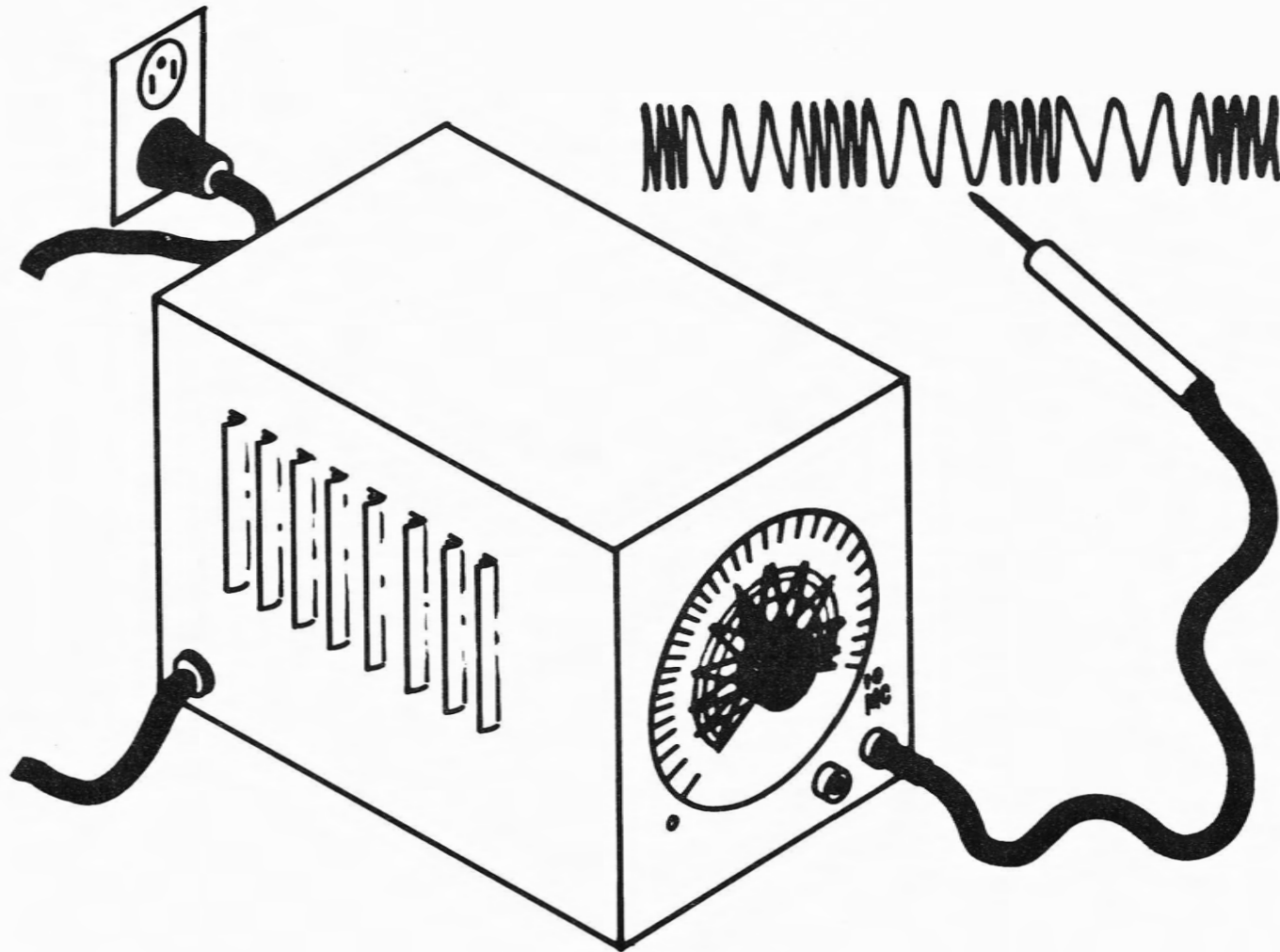
When all these various outputs are channeled to the transmitters, the voltage-controlled transmitting oscillator provides another frequency modulation step to the techniques. The results are referred to as SS/FM, FM/FM/FM, FM/FM, PAM/FM/FM, and PCM/FM.

Slow Speed Multiplexer

The purpose of the Model 245 Slow Speed Multiplexer is to time-share up to 80 high-frequency measurements. The measurement capacity of the telemetry equipment is increased by this method. The inputs may come from transducers, signal conditioners, or other sources. These inputs are multiplexed into 17 output channels which may be sent to the S1, F1, or F2 Telemeters.

S1 Single Sideband Telemeter

The S1 Single Sideband Telemeter provides 17 modulation channels of wide-frequency-band data to a FM transmitter. Measurements data is routed through 15 of these bands while the other two are used for synchronizing signals. The channels are spaced in a manner to produce a nominal band-spread to the transmitter while retaining high frequency response. The single sideband modulation method is used to improve the measurement handling capacity of the transmitter. The 17 modulation channels of the Single Sideband Telemeter are summed and applied to the voltage control oscillator of the S1 transmitter.

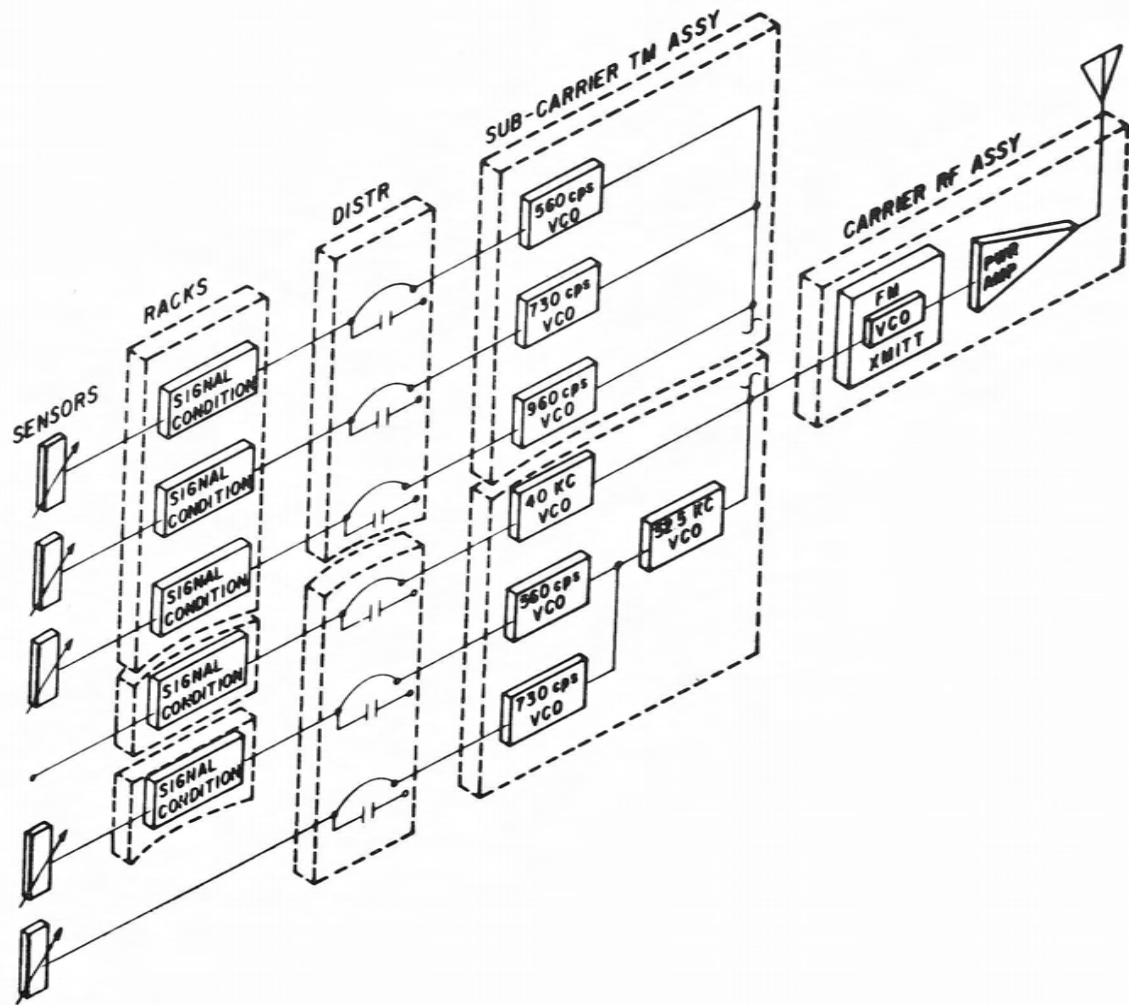


Frequency and Amplitude Retention

FM/FM Telemetry

The FM/FM accepts individual and multiplexed (PAM and slow-speed) analog measurements and transforms them into individual frequency information outputs, mixed into a single output. This method of modulation is also called frequency multiplexing. Several voltage controlled oscillators (subcarrier oscillators) are used, with one analog measurement or one multiplexed pulse train modulating each one.

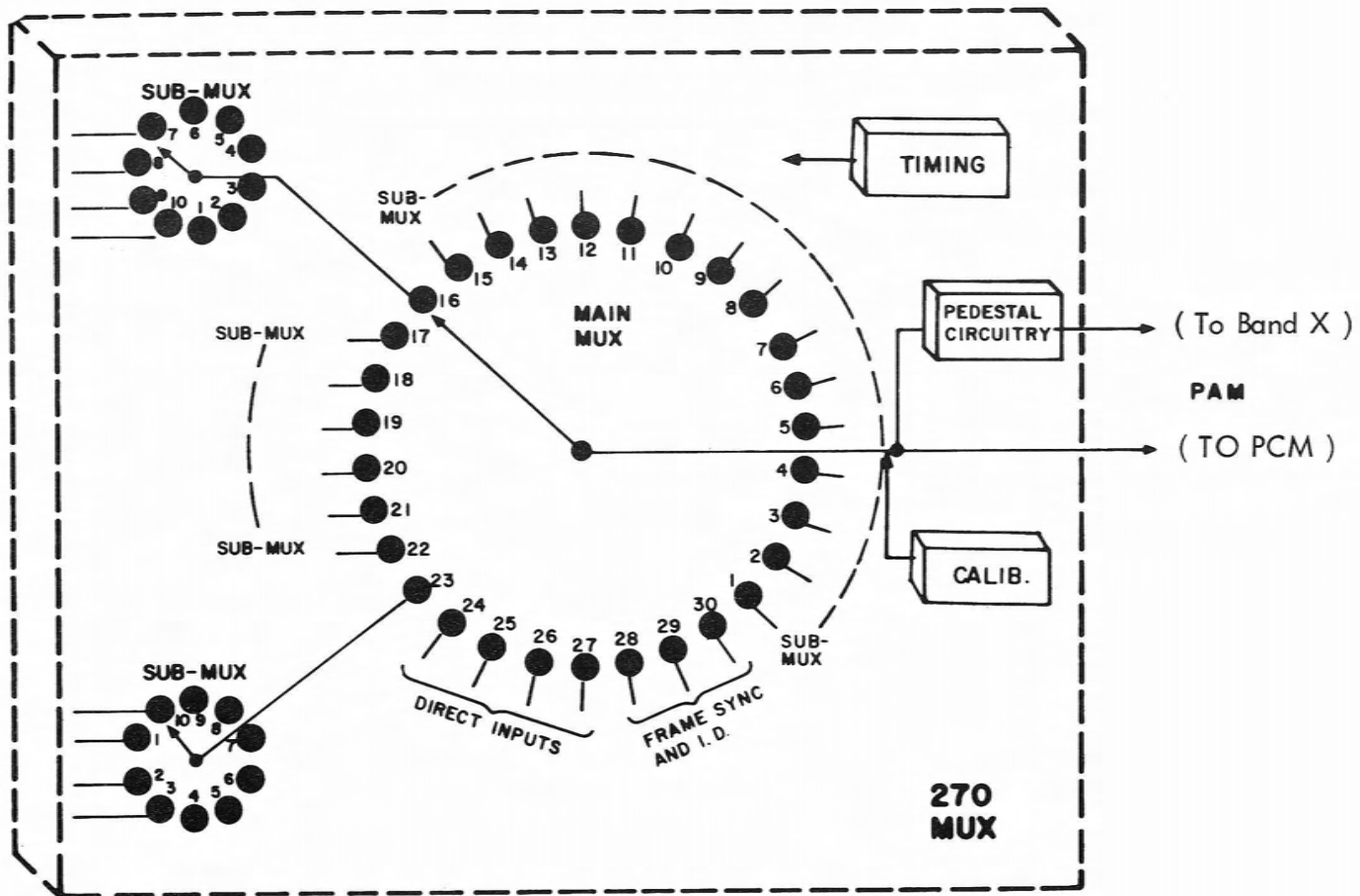
To increase measurement handling capacity, the mixed outputs of several low-frequency subcarrier oscillators are used as inputs to one high-frequency oscillator thus freeing the same low frequencies for use by other low frequency subcarrier oscillators. These frequency-modulated signals are then mixed and amplified for output to an FM transmitter.



FM/FM and FM/FM/FM

Model 270 Multiplexer

The Model 270 Multiplexer is a time division multiplexer that sequentially monitors many analog input signals, and produces two parallel repeating pulse trains, with each pulse being a sample of an input signal (PAM). The input signals are pre-conditioned to a range of 0 VDC to 5 VDC. The sampling rate is governed by sync signals from the PCM/DDAS tele-meter.



PCM/DDAS Telemeter

The Pulse Code Modulation/Digital Data Acquisition (System) (PCM/DDAS) is an encoder-multiplexer assembly that will accept and time-integrate PAM analog signals, discrete signals, and digital signals into a single output. The single output is furnished to other components in three different forms. The PCM/DDAS Telemeter is the key component for telemetry synchronization. The PCM/DDAS houses the master clock.

The three forms of the PCM/DDAS Telemeter output are:

- A serial, digital pulse train that is sent to an FM transmitter for broadcast to ground receiving stations.
- A series of parallel, digital 10-bit groups that is sent to the Computer Interface Unit for transfer to Guidance and Control.
- A 600 kHz FM carrier, modulated by the serial pulse train, that is sent to the ground Electrical Support Equipment by way of the umbilical.

Remote Digital Multiplexer

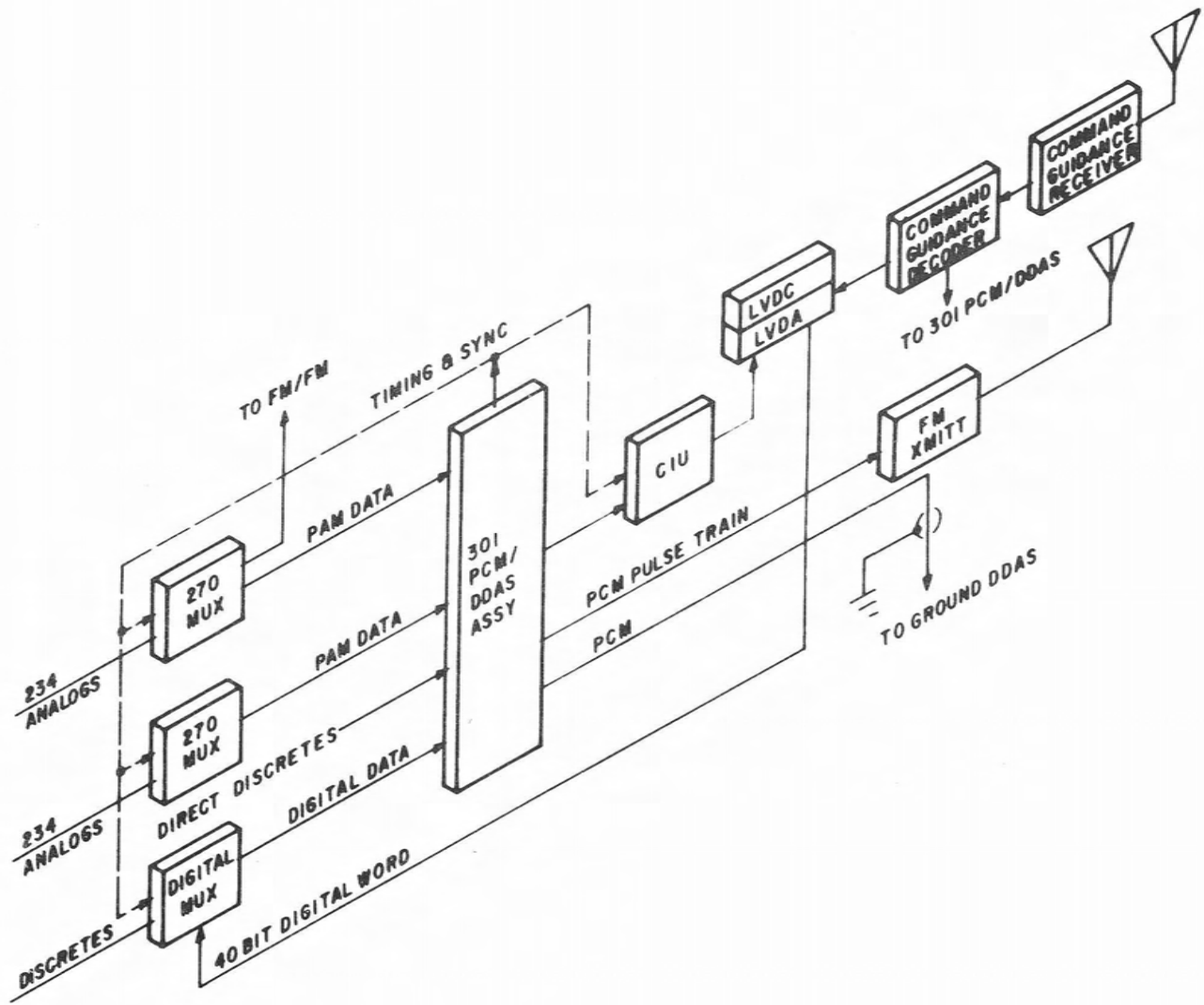
The Model 410 Remote Digital Multiplexer (RDM) accepts up to 100 bits of digital data, or up to 100 individual discretes or a combination of the two and temporarily stores them as ten 10-bit digital words. The words are sent in a repeating sequence to the PCM/DDAS Telemeter. The unit is pre-programmed to determine the order of monitoring the inputs and the order of sending the words to the PCM/DDAS Telemeter. The unit is synchronized with the PCM/DDAS Telemeter to cause the output words to appear at the instant the PCM/DDAS Telemeter is programmed to accept them.

Computer Interface Unit

The Model 501 Computer Interface Unit (CIU) assists in the transfer of telemetry data to the LVDA/LVDC for storage. All instrumentation data from the PCM/DDAS Telemeter is furnished to the CIU and on request from the LVDA/LVDC selected words of this data are transferred to the LVDA/LVDC for storage.

Calibration

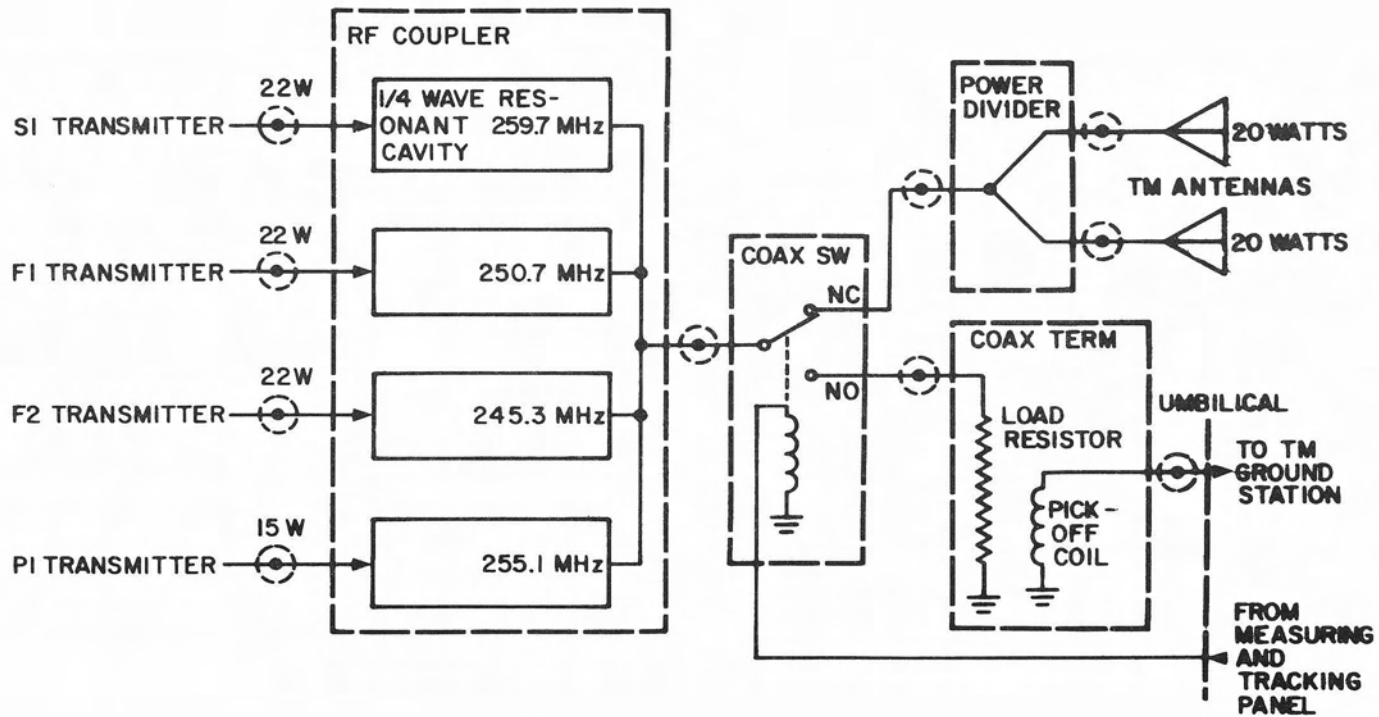
Several portions of telemetry are equipped with circuits that permit calibration signals to be applied. These calibrations signals are applied both prior to launch and during flight. At the receiving stations, the normal broadcast data is compared to the calibrated broadcast data to determine system accuracy.



Pulse Code Modulation

RF Transmission Components

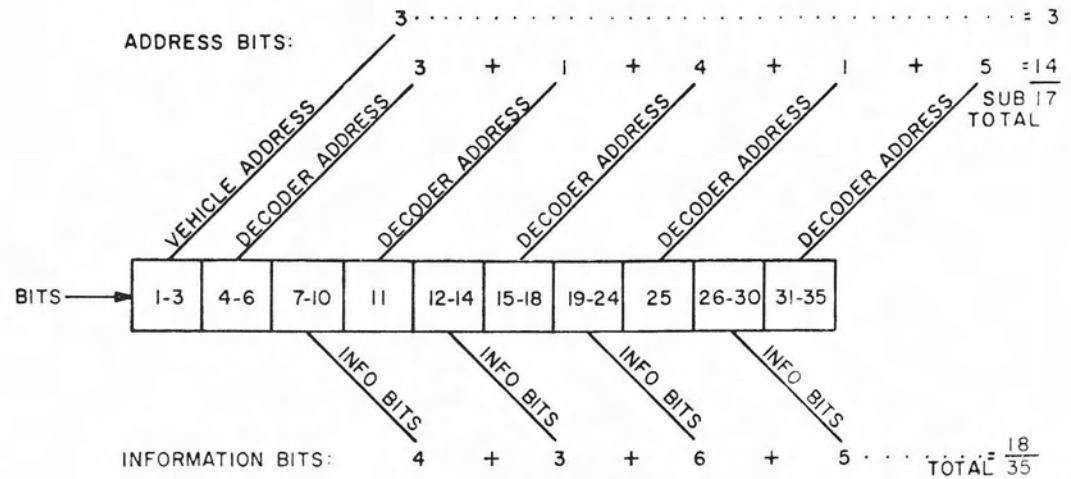
The RF transmission components transfer the carrier signals from the four telemetry transmitters to ground receiving stations. The signals may be radiated through antennas or carried by coaxial cable through the umbilical. The components are the RF Coupler, Coaxial Switch, Coaxial Termination, Power Divider, and two Telemetry Antennas.



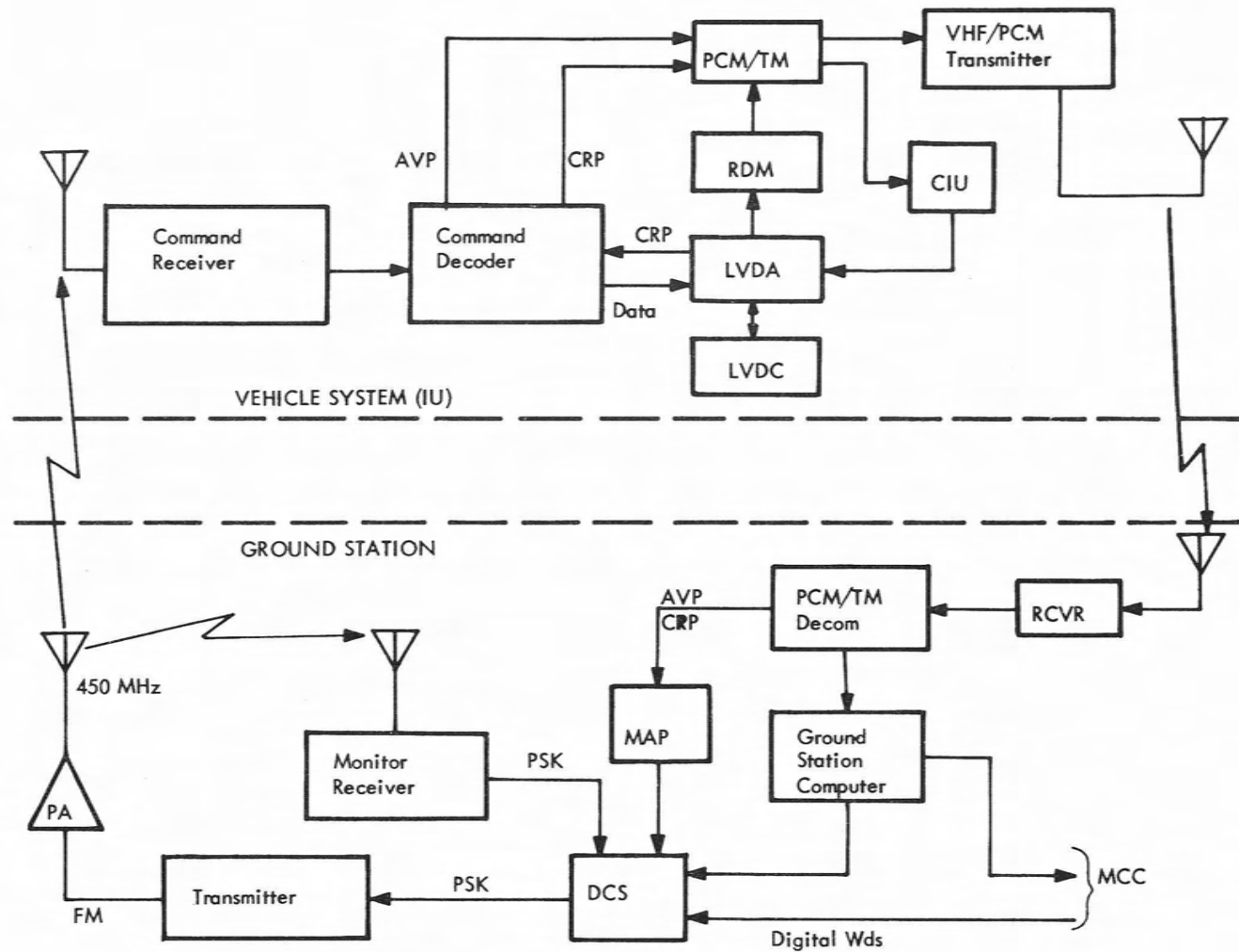
RF Transmission Components Functional Diagram

Command

The purpose of the Saturn Instrument Unit Command Function is to provide a radio frequency/digital data transmission link from various Manned Space Flight Network stations to the on-board Launch Vehicle Digital Computer (LVDC). The LVDC uses the transmitted data to update the mission guidance parameters or to perform certain orbital (S-IVB/IU) checkout functions. The command function will be used to update guidance information or to command certain vehicle functions such as stage selector switch operations, review of data in certain locations of the Launch Vehicle Digital Computer memory, and out-of-sequence telemetering of S-IVB pressures, temperatures, etc., for orbital checkout. In every case access to these functions is through the Launch Vehicle Digital Computer.



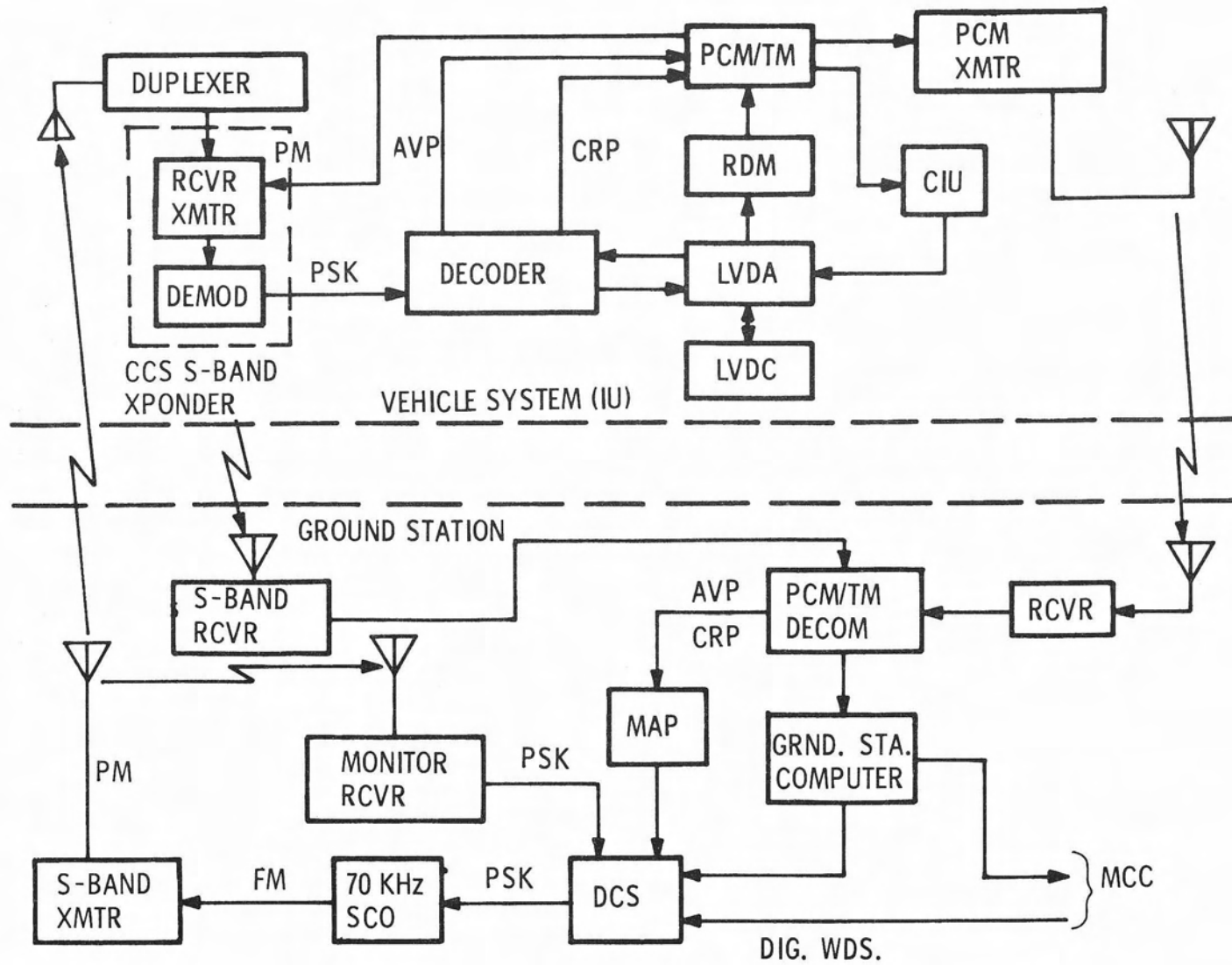
Command Word in IU Command



Command and Communications

The IU Command and Communication (CCS) is a phase-coherent receiver-transmitter capable of establishing a communication link between the Unified S-Band (USB) ground stations and the Instrument Unit of the Saturn V Launch Vehicle. Specifically, the CCS will:

- Receive and demodulate command up-data for the guidance computer in the Instrument Unit
- Transmit pulse code-modulated (PCM) mission control measurements originating in the S-IVB and the Instrument Unit to the USB ground stations for processing
- Retransmit the range code that is received from the USB ground stations for tracking purposes.



Tracking

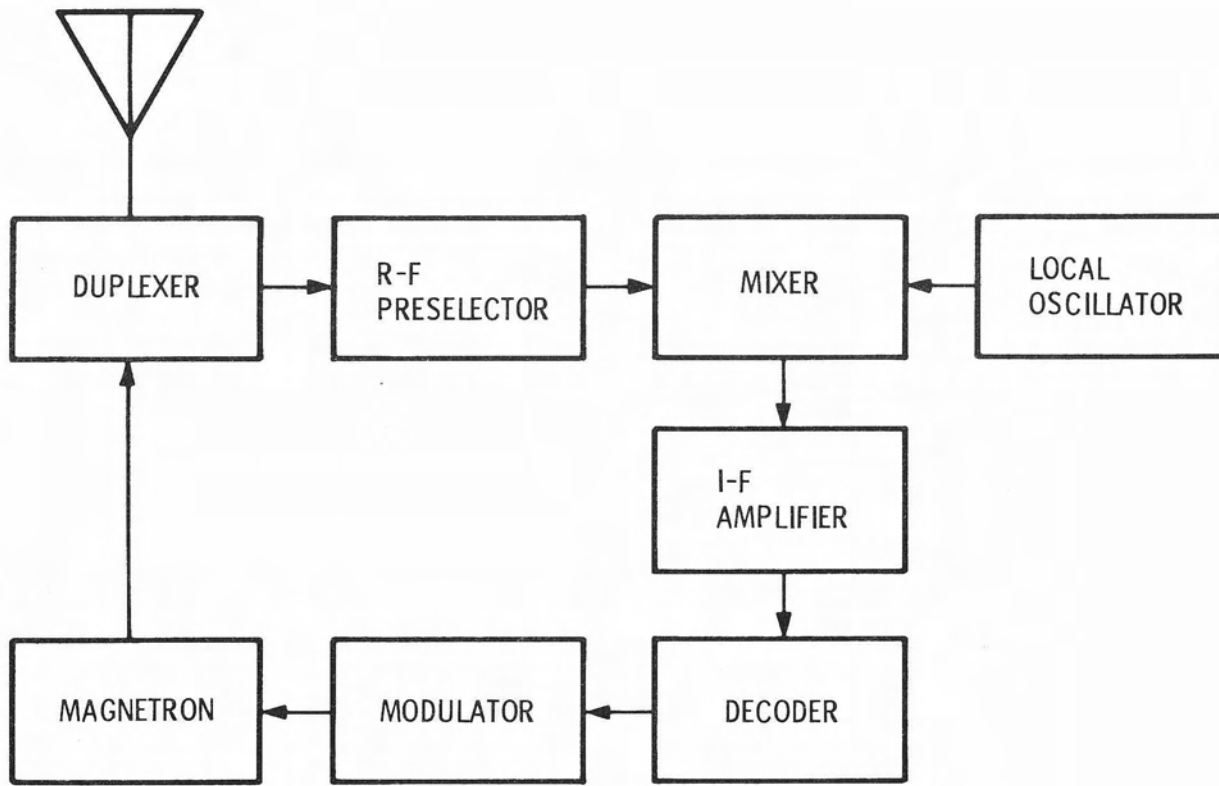
The Saturn Vehicle is tracked for the following three principal reasons:

- To evaluate the vehicle's Guidance and Control Subsystem.
- To perform guidance corrections after the primary inertial injection.
- To ensure range safety.

Several tracking systems are used to determine the vehicle trajectory during powered ascent and orbital flight. Redundant tracking data provides the best possible trajectory information and increased mission reliability. The Instrument Unit equipment includes the AZUSA Tracking System and the C-Band Tracking System.

C-Band Radar Transponder (Model SST-135C)

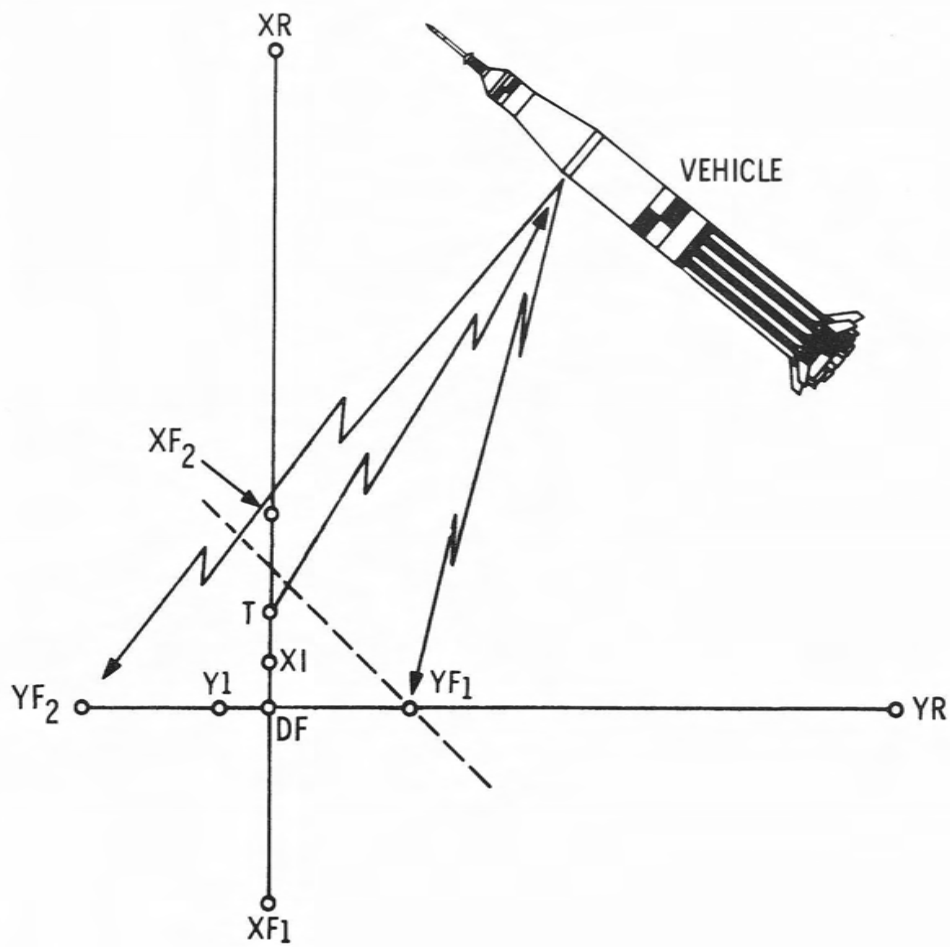
The function of the Saturn Instrument Unit C-Band Radar Transponder is to extend the tracking range of the AN/FPS-16 Tracking Radar and similar C-Band tracking ground radar stations. The transponder receives coded (dual) pulse or single pulse interrogations from ground stations and transmits a single pulse reply in the same frequency band (5000 MHz to 5900 MHz). A common antenna is used for receiving and transmitting. Interrogation pulses are directed from the antenna to the receiver, and reply pulses are directed from the transmitter to the antenna. The preselector attenuates all radio frequency signals outside the receiving band. The mixer and local oscillator converts the interrogation signal to an intermediate frequency of 50 MHz. The receiver utilizes a linear-logarithmic intermediate frequency amplifier for transponder delay stability, large input signal dynamic range capability, and short recovery time. A decoder is employed for decoding a 1 or 2 pulse interrogation code and to trigger the modulator if the code is within acceptance limits. A pulsed magnetron functions as the transponder transmitter.



C-Band Transponder Block Diagram

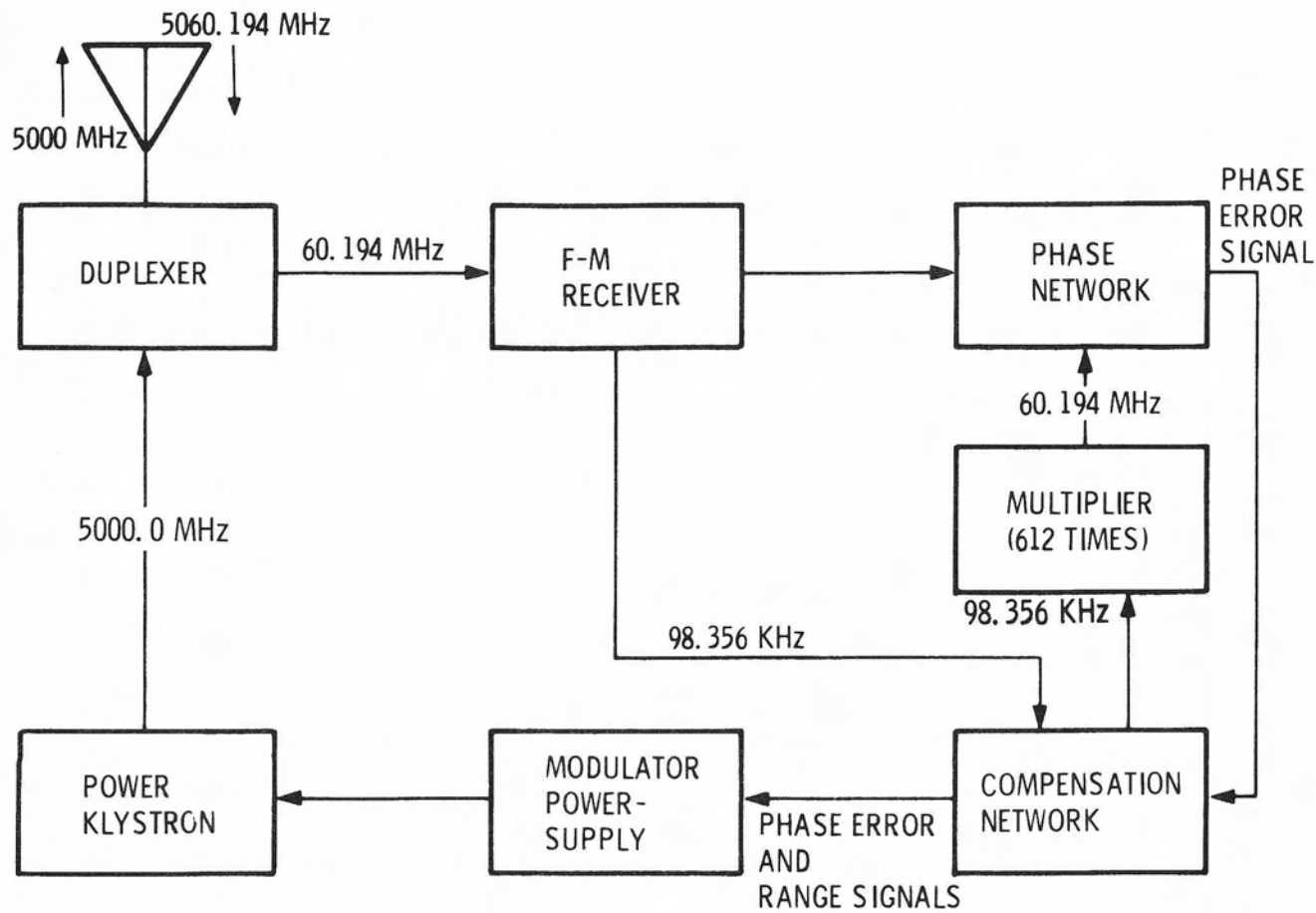
AZUSA Type C Transponder

The AZUSA Type C Transponder, an integral part of the AZUSA tracking equipment, is designed for installation in the Instrument Unit of the Saturn Vehicle. AZUSA is a high-precision, trajectory-measuring equipment consisting of a single ground station and a transponder. The equipment determines position by measuring slant range and direction cosine values from the ground station to the vehicle borne transponder. These values are measured by continuous phase comparison between signals transmitted to and received from the vehicle transponder. Ground station receiving antennas are arranged along two mutually perpendicular coordinate axes. The path lengths from the transponder to each antenna differ, thus reply signals arrive at separate antennas out of phase. By applying basic principles of geometry, the phase differences of the carrier can be used to obtain two direction cosines with respect to base-lines collinear with the X and Y coordinate axes. By modulating the carriers and measuring total phase delay of the modulation frequencies over the propagation path length, the system determines slant range.



Azusa Antenna Baselines

The AZUSA Type C Transponder contains a Frequency Modulation receiver and a 5000-MHz klystron power oscillator. The klystron frequency is controlled by automatic frequency and phase loops. The high-gain automatic-frequency-control loop modulates the klystron with the received range modulation and controls the output frequency to follow the incoming carrier with a constant 60.194-MHz offset. The automatic-phase-control loop provides a coherent carrier by phase-locking the offset to a multiple (612 times) of the 98.356-KHz fine-range modulation. The Type C Transponder is a solid-state device except for the klystron power oscillator. The transponder has a minimum receiver sensitivity of -90 dbm and a minimum power output of 2.5 watts into a 50 ohm load. The AZUSA Type C Transponder draws 125 watts, including blower power, from a 28 VDC supply.



Azusa Type C Transponder Simplified Block Diagram

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IBM



Apollo/Saturn Team