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GEORGE C. MARSHAL

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SATURN IB/V ASTRIONICS SYSTEM

By

S. M. Seltzer

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ABSTRACT

A brief, semi-technical, functional description of the astrionics systems for the Saturn IB and V launch vehicles is presented. The astrionics equipment consists of the vehicle guidance, control, and instrumentation systems. The adaptive guidance mode and the manner in which the mission is to take place are also briefly described.

The Saturn IB and V vehicles will use almost identical astrionics systems; minor differences may be caused by the reflection upon the astrionics system of two or three stages or by the assigned mission.

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SUMMARY

A brief, semi-technical, functional description of the astrionics systems for the Saturn IB and V launch vehicles is presented. The astrionics equipment consists of the vehicle guidance, control, and instrumentation systems. The adaptive guidance mode and the manner in which the mission is to take place are also briefly described.

The Saturn IB and V vehicles will use almost identical astrionics systems; minor differences may be caused by the reflection upon the astrionics system of two or three stages or by the assigned mission.

I. INTRODUCTION

The Saturn IB/V astrionics system will provide the Saturn IB and V launch vehicles with guidance, control, and instrumentation. Any differences in the astrionics system for these two vehicles will be minor and will be caused by the reflection upon the astrionics system of the two (Saturn IB) or three (Saturn V) stages comprising the launch vehicle. In general, the Saturn IB/V astrionics system is an advanced development of the present Saturn I astrionics system. The major portion of the astrionics equipment is located in the Instrument Unit (IU), shown in FIGURE 1. This unit is a right geometric cylinder, 36 inches in height, 260 inches in diameter, and of honeycomb structure. It consists of three, approximately 120° segments. All of the components within this structure are located on the inner periphery and mounted on cold plates that are cooled by convective fluid (flowing through tubes). This fluid conducts generated heat away from the components. A typical R&D Instrument Unit layout is shown in FIGURE 2.

As in the case of Saturn I, one integrated astrionics system serves the entire Saturn IB or V launch vehicle. FIGURE 3 is a block

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diagram describing the astronics system. The block diagram is organized into five blocks, from top to bottom, representing the Apollo spacecraft, the Saturn Instrument Unit, the S-IVB stage (found on both the Saturn IB and Saturn V launch vehicles), the S-II stage (found only on the Saturn V), and the S-IC stage (found only on the Saturn V; the Saturn IB's first stage is designated as the S-IB stage and is strongly similar to the Saturn I's S-I stage).

II. DATA ADAPTER

A glance at the block diagram shows that nearly all components of the astronics system ultimately furnish outputs to, or receive inputs from, the data adapter.

a. Computer-Associated Circuits. The data adapter contains certain computer-associated circuits, such as the power supplies for both the digital computer and the data adapter itself. It contains a real time clock which is used by the digital computer in performing its guidance functions. Also contained within the data adapter are priority interrupt circuits to alert the computer to occurrences within the system.

b. Attitude Command System. The shaft angle readout scheme, which is employed to read platform gimbals angles, consists of a two-speed resolver device. Its scale factor and speed ratio are arranged so that either the coarse or the fine output may be used by the system. Thus a failure in the coarse system readout, which would be detected by a standard reasonableness test conducted within the data adapter, will result in a fine winding being read exclusively. Conversely, failure in the fine system readout would result in the coarse readout being used (with some degree of accuracy degradation). In case of either type of failure, the system will continue to function, yielding a high probability of success. This analog to digital conversion is accomplished before the attitude angles are provided to the digital computer. Specifically, it converts analog gimbal angles received from the stabilized platform into digital signals. The data adapter also converts digital error signals (that is, the steering error signals that go to the analog control computer) into analog signals for control computer use.

c. Horizon Sensor Interface. The data adapter provides an interface with the horizon sensors, converting their analog angle outputs into digital signals. This is performed by time-sharing the equipment that is used with the attitude command system previously described. This same equipment gives the astronics system a certain degree of mission growth potential by providing the system with additional orbital operation capability.

d. Vehicle Discrettes. The data adapter receives vehicle discrettes from the digital computer and coded signals from the IU command system. It conditions these inputs and forwards coded signals, or commands, to the switch selectors that are found in the Instrument Unit and in each stage of the vehicle. The data adapter also furnishes miscellaneous discrettes as they are needed and receives discrettes as they are generated.

e. Miscellaneous Functions. During prelaunch operations, the data adapter forms an interface with the launch computer system (the ground computer system at the launch site). Prior to launch, the data adapter receives command receiver system words and requests and receives digital data acquisition system (DDAS) information for orbital checkout verification (the DDAS system is a major portion of the PCM system). The data adapter contains a register and a code (or buffer) to hold computer PCM words; it also conditions all telemetry data as required.

III. DIGITAL COMPUTER

Working closely with the data adapter is the digital computer, utilizing a duplex memory and triple redundant control logic.

a. Computations. The digital computer determines the desired vehicle heading from time data received from the data adapter clock and from accelerometer data received from the stabilized platform. It transforms this heading into the platform coordinate system so that desired attitude may be compared with actual attitude as determined by the platform gimbal angles. The result of this comparison is then forwarded, in vehicle-fixed coordinates, through the data adapter to the control computer. In addition, the digital computer computes vehicle discrete commands, required engine cutoffs, and S-IVB stage's engine reignition command to inject into the translunar trajectory.

b. Orbital Operations. The digital computer conducts the orbital checkout of the space vehicle, receiving implementing commands and any necessary supplementary data from the command receiver system (forwarded by the data adapter). This information originates at the ground remote sites, or the Integrated Mission Control Center at Houston, and is in addition to the checkout programs that are stored in the computer for automatic checkout. The computer then provides a "go/no-go" indication to the spacecraft and to the ground remote sites via PCM telemetry. The digital computer also performs certain orbital operational tasks other than orbital checkout, such as updating the guidance functions (by comparing them with ground-computed functions received via the command receiver), performing attitude control functions during orbital operations, etc.

c. Miscellaneous. The digital computer is used in the emergency detection system (EDS) as required. As mentioned in the data adapter discussion, the digital computer possesses a priority interrupt capability, which allows flexibility in handling large amounts of varying types of data. It has been designed to include the capacity to perform additional missions beyond the Apollo mission which is primarily being described here.

Having reviewed the data adapter and the digital computer, the question arises as to why are there two separate pieces of equipment-- a data adapter and a digital computer--rather than one combined component? There are several reasons for this. The primary reason lies in design philosophy. It was decided at the outset of the development to place items that would remain unchanged from mission to mission in the digital computer and to place items that are dependent on the particular mission to be flown and are to be changed from one mission to the next in the data adapter. Thus, most of the interface circuitry finds itself within the data adapter. A second benefit is a better structural mounting capability in the Instrument Unit.

IV. STABILIZED PLATFORM SYSTEM

The ST-124M stabilized platform system will be a three or four-gimbal platform, inertially stabilized in space by three, mutually orthogonal, gas-bearing gyroscopes. The choice of the number of gimbals will depend on the mission prescribed for each particular flight; i. e., design flexibility permits a choice to be made at a later date. This flexibility is insured by providing the ability to add a fourth gimbal with a "kit installation." The inner gimbal is the pitch gimbal, the middle gimbal is the yaw gimbal, and the third gimbal is the roll gimbal. This gimbal arrangement is the same as that used by the Apollo platform. When a four-gimbal configuration is used, the fourth (outer) gimbal is a redundant yaw gimbal. Mounted on the inertial gimbal of the ST-124 are three, mutually perpendicular, gas-bearing gyroscopes for inertial stabilization; three, mutually perpendicular, gas-bearing, pendulous integrating, gyroscopic accelerometers that furnish velocity information to the data adapter (as already described); and three, gas-bearing pendulums for platform erection. As described previously, platform gimbal angles are furnished to the data adapter for subsequent vehicle attitude determination. Platform accelerometer outputs are read by redundant incremental encoders and summed in the registers of the data adapter.

V. CONTROL SYSTEM

The analog control computer normally receives analog control commands from the digital computer through the data adapter. These commands are steering error signals resulting from comparing the actual vehicle attitude (determined by the stable platform's gimbal angles) and the desired attitude (determined by the digital computer).

A package of triple-redundant rate gyros is mounted in the Instrument Unit, and a package of non-redundant rate gyros is located in the first stage; their purpose is to provide attitude rate information to the control computer. Rate information from these packages is also furnished to the emergency detection system (EDS). A pair of body-fixed accelerometers is mounted in the S-II stage of the Saturn V, or in the Instrument Unit of the Saturn IB, to provide lateral acceleration signals to the control computer so that angle-of-attack control can be used during first stage burning.

The control computer mixes the angular error signals from the data adapter with the angular rate signals from the rate gyros and with the lateral acceleration signals from the control accelerometers. It performs necessary filtering and then selects the proper engine gimbal actuators for thrust vector and attitude control. For the S-IVB stage, which has a single engine, proper control nozzles must be utilized in addition to the engine actuators. These control nozzles are six small nozzles located around the periphery of the S-IVB to change the attitude in roll during main engine burning and to change the attitude in pitch, yaw, and roll during coast when the S-IVB engine is not burning.

During the earth orbital coast phase, four infrared horizon sensors, each of which has a 90° field of scan, may be used to provide angular information to the data adapter which converts the analog signals into digital form and forwards them to the digital computer. There, the angles are processed to determine the local earth vertical. Digital error signals are determined and sent to the data adapter for conversion into analog error signals which are then forwarded to the control computer. When these signals are nulled (by altering the vehicle's attitude with the S-IVB control nozzles), the longitudinal axis of the vehicle will remain perpendicular to the local earth vertical.

There are times when the astronaut, located in the Apollo spacecraft, must alter the attitude of the space vehicle while in earth orbit; specifically when he realigns the Apollo stabilized platform and when he performs landmark identification or horizon photometry. He performs this attitude control by commanding (called "steering commands" on Fig. 3) the control computer to bring about the desired attitude change. After he has completed his sightings, the astronaut permits the control computer to return to its normal mode of automatic operation.

VI. SWITCH SELECTORS

A digital switch selector is located in the Instrument Unit and in each stage for initiating sequence functions, which originate in the digital computer and are forwarded through the data adapter. The stage switch selectors act as communication links between the digital computer-data adapter and stage equipment which is to be controlled by the digital computer. Switch selector operation, both on the ground and in flight, is accomplished via a digital coded command sent to the particular switch selector desired. Before the received coded command is actually executed, an "echo-check" is sent back to the digital computer to verify that the command received is the same as the command that was originally transmitted.

VII. EMERGENCY DETECTION SYSTEM

Sufficient onboard instrumentation is carried to detect emergency conditions in time either to automatically abort the mission (where time is short) or to notify the astronauts (where time exists) of the condition so that they may decide whether to abort the mission.

VIII. TELEMETRY

FIGURE 4 portrays the telemetry and RF equipment to be used on Saturn IB. While Saturn IB is portrayed, the information shown applies almost identically to Saturn V (S-II stage instrumentation will be nearly identical to S-IB equipment). The Instrument Unit and each stage will have their own telemetry. In general, three types of telemetry are planned for use in the Saturn IB and V launch vehicles. PAM/FM/FM will be used for telemetering data that are neither digital nor have a wide bandwidth requirement. Single sideband/FM telemetry is used where measurements having wide bandwidth characteristics, such as vibration measurements, must be transmitted. This telemetry system consists of equipment in which the telemetry information modulates the FM carrier with a single sideband AM subcarrier. The bandwidth efficiency of the single sideband FM is approximately ten times that of a standard FM/FM. PCM/FM will be used to transmit digital data. Since PCM requires digitized (or quantized) information, it lends itself very nicely to transmitting existing digital data over a PCM/FM system. It also has the capability of converting analog data to a digital form. For operational telemetry, it is planned to use only PCM.

IX. RF SYSTEMS

a. IU Command System. The IU command system provides a means of transmitting digitally encoded commands from the ground, via an RF carrier, to a command receiver in the Instrument Unit. The command information is sent through the data adapter to the digital computer where it is stored. Prior to actual execution, all data or commands that have been received through the IU command system (and stored in the computer) are transmitted via PCM to a ground station where they are compared with the original messages. If the comparison is satisfactory, a message verifying this fact is transmitted to the digital computer (via the command system). After receipt of this verification signal, the stored command is implemented at the appropriate time by the computer.

b. Radar Altimeter. A radar altimeter is used at high altitudes to supplement data from other tracking systems to improve the accuracy of tracking. The system utilizes a crystal oscillator and a counter to determine the travel time of a single, emitted radar pulse which is transmitted from the vehicle to the earth and reflected. The measured travel time is digitally encoded and telemetered to the ground.

c. Tape Recorder. The tape recorder will record information generated when the vehicle is not in communication with ground stations, transmitting this information when the vehicle is in communication with the ground stations.

d. MISTRAM. The missile trajectory measurement system (MISTRAM) consists of a MISTRAM transponder (located in the Saturn V S-II stage or the Saturn IB Instrument Unit) and a ground station complex. Range measurements are determined from the phase shift between the transmitted signal and the signal received by the receiving antenna at the ground station. Vehicle position in space is determined from phase shift measurements between spaced antennas at the ground station (yielding range differences). Finally, vehicle velocity is determined from measurements of rates of change of range and range differences.

e. C-Band Radar. A C-band radar transponder, located in the Instrument Unit, is used by radar ground stations to measure range, azimuth, and elevation so that position can be determined. The transponder is compatible with an improved AN/FPS-16 system and will mate with the Apollo ground net radar stations during earth orbit.

f. AZUSA. The AZUSA system consists of a ground station and an onboard transponder, located in the Instrument Unit. This system measures slant range and direction from the ground station to the vehicle by measuring phase delay and phase differences. From this information, vehicle position and velocity are determined. The AZUSA transponder will be used with the Glo-Track system (the global tracking system being installed by the U. S. Air Force).

g. ODOP. ODOP is an offset doppler system whose transponder will be located in the first stage. It will determine position from measured velocity information, acquiring data during the critical first portion of the flight. This system is similar to the better known UDOP with the following exceptions: UDOP merely doubles the uplink frequency of 450 MHz, whereas ODOP receives the uplink frequency at 890 MHz and then shifts (or offsets) it to 960 MHz. This higher operating frequency yields better accuracy because of less ionospheric interference at that frequency.

h. AROD. The airborne range and orbit determination system (AROD) is presently being developed. It is, in essence, a doppler and range tracking system with the following exceptions: usually doppler transmitters and receivers are located on the ground and the transponder is located in the vehicle. In AROD, the reverse is the case. The transmitter and receiver are onboard the vehicle, while the transponders are located at various locations on the earth. If the development proves successful, an onboard tracking system will result, thus permitting the rapid onboard determination of the vehicle's position and velocity. This will be accomplished by measuring the doppler frequency shift to determine vehicle velocity and the phase delay of a wave, transmitted from the vehicle to several ground transponders and returned, to determine vehicle position.

i. Miscellaneous. Each stage will contain a separate range safety command system which, during early flights, will consist of an audio-tone system. Later, it is planned that each stage will contain a digital system with a coded circuit highly resistant to countermeasures. A television system will be located in the first stage (and perhaps in other stages) to provide real time visual recording of the performance of a particular portion of the vehicle system. Finally, a Minitrack transmitter is carried in the Instrument Unit to allow continuous tracking of the orbiting vehicle (to meet the orbital debris requirements).

X. POWER

Two 2-kW fuel cells will furnish power to the Instrument Unit during flight. These fuel cells will use hydrogen and oxygen (carried in spherical tanks). Their long life and weight saving features were the primary reasons for their use in lieu of more conventional battery-supplied power. Each stage will have its own power supply.

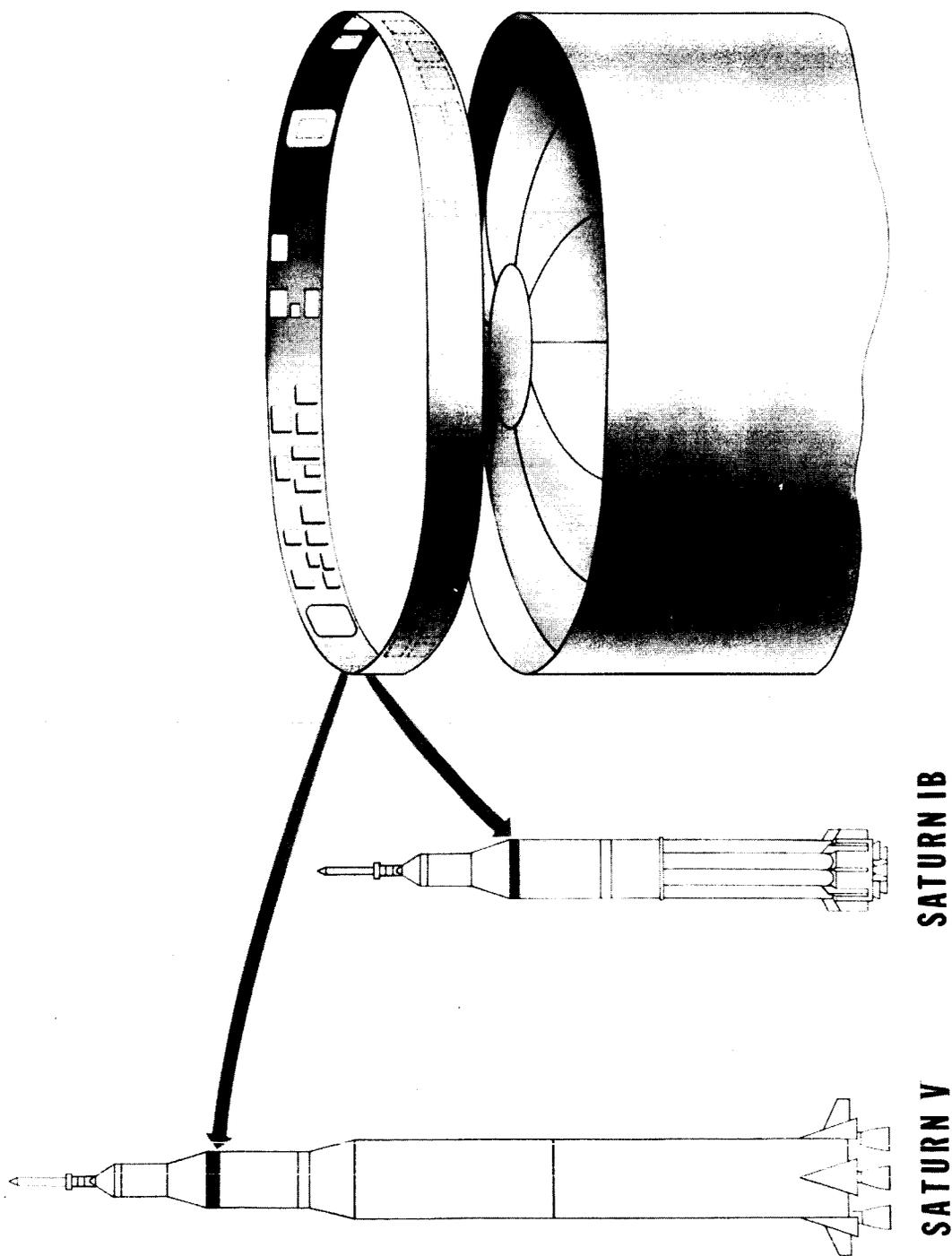
XI. UTILIZATION OF ASTRIONICS EQUIPMENT

The foregoing has been a description of the astrionics hardware and each item's functions. The following will briefly cover the use of this equipment and a brief description of the adaptive guidance mode. Before the vehicle is sent to the launch site, it is necessary to determine what the orbital plane is going to be during the anticipated possible days of launch. Then, the volume of trajectories that will enable the vehicle to be fired into this orbital plane is calculated. This is a volume of

trajectories, rather than a single trajectory, for several reasons. First, to achieve the most optimum possible steering, the calculus of variations is used to obtain a deck of trajectories or a group of trajectories. These trajectories are perturbed from the nominal by allowing the variables to differ from the nominal by the greatest amount that might be expected. By taking these perturbations into account, as well as variable time of launch, a volume of trajectories is obtained for any given launch window. Later, at the launch site at Cape Canaveral, the stable platform is erected just before the launch window begins; however, it is not released inertially. At the moment the launch window begins, a reference coordinate system is established which is the coordinate system that the stable platform would lie in if the vehicle were fired at that time. Of course, it is improbable that a launch will actually take place at that precise moment. From this time on, the platform is held inertially-fixed (leveled to the local vertical), except that it is rotated in azimuth continually during the launch window so that it will always point at the most desirable launch azimuth to remain in the orbital plane (or remain as close to the orbital plane as possible). At the time the vehicle is launched, the stable platform is released and held inertially. It is now oriented in what is called the measuring coordinate system. The measurements from the stable platform in the measuring coordinate system are continually compared with the results from the equations that were inserted in the digital computer in reference coordinate system form. A transformation matrix that is computed by the ground computer just before launch is required to get all quantities into the same coordinate system. Immediately after launch, the launch vehicle is rolled about its longitudinal axis so that it will fly at the correct azimuth, i. e., the azimuth that was determined by the platform when it had completed its azimuth torquing and was released before launch.

After the vehicle is rolled to the proper azimuth, it is then pitched at a predetermined pitch rate during first stage burning. This is predetermined as a program to stay within the bounds of the structural limits of the vehicle. After first stage burning is completed, the adaptive guidance mode is used through second stage burning and, in the case of the Saturn V, for part of the third stage (S-IVB) burning. Then, when the adaptive guidance mode determines it is time to shut down the engine because the vehicle is about to achieve the desired orbit, engine cutoff is performed from the digital computer. The space vehicle will perform one to three orbits, depending on how long the astronauts need to align and checkout their own guidance systems. At the proper time, the Saturn Instrument Unit's equipment determines when reignition of the third stage must take place to inject the vehicle into a translunar trajectory. At that time the third stage (S-IVB stage) reignites and injects the space vehicle into the desired translunar trajectory, at which time the S-IVB engine is shut down for the last time. The space vehicle is now on a coasting translunar trajectory. The Instrument Unit is required to hold the attitude of a portion of the space vehicle fixed while a rather intricate mating maneuver between the

S-IVB/Instrument Unit/Lunar Excursion Module combination and the Command Module/Service Module combination is performed. After this attitude stabilization has been performed, the Instrument Unit and the S-IVB are disengaged from the Apollo capsule, and the small attitude control rockets on the S-IVB are reignited to move the S-IVB and Instrument Unit away from the path of the spacecraft (to preclude the possibility of a collision later). At this time the task of the astronics system is essentially completed.



SATURN IB

SATURN V

FIGURE 1. SATURN IB/V INSTRUMENT UNIT

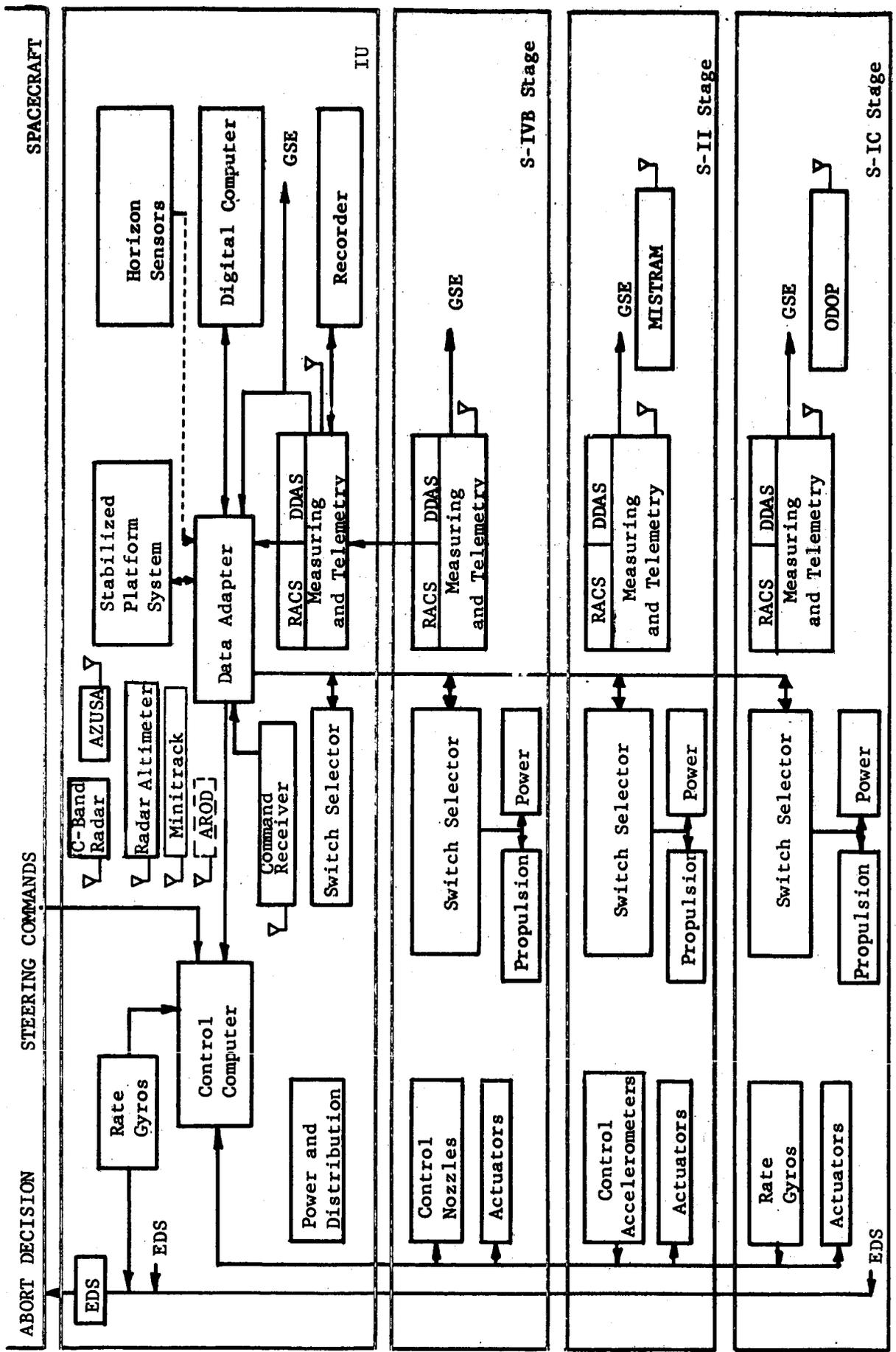


FIGURE 3. BLOCK DIAGRAM OF SATURN V ASTRIONICS SYSTEM.

TELEMETRY AND RF SYSTEMS

Apollo

IU

- 2-PAM/FM/FM
- 1-PCM/FM
- 1-SS/FM
- IU Command System
- Radar Altimeter
- Tape Recorder
- MISTRAM
- Minitrack
- RADAR, C-BAND
- AZUSA
- AROD

IU

S-IVB

- 3-PAM/FM/FM
- 1-PCM/FM
- 1-SS/FM
- Range Safety Command System

S-IVB

S-IB

- 2-PAM/FM/FM
- 1-PCM/FM
- 1-SS/FM
- ODOP
- Range Safety Command System
- Television

S-IB

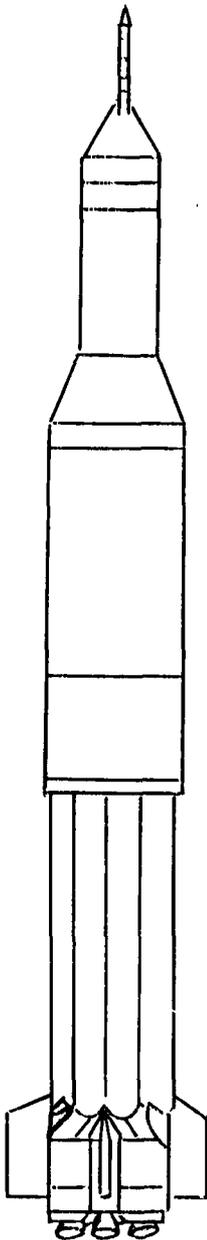


FIGURE 4. SATURN IB (R&D) INSTRUMENTATION SYSTEMS.

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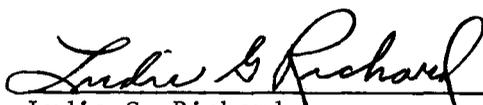
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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.



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Director, Astrionics Laboratory

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