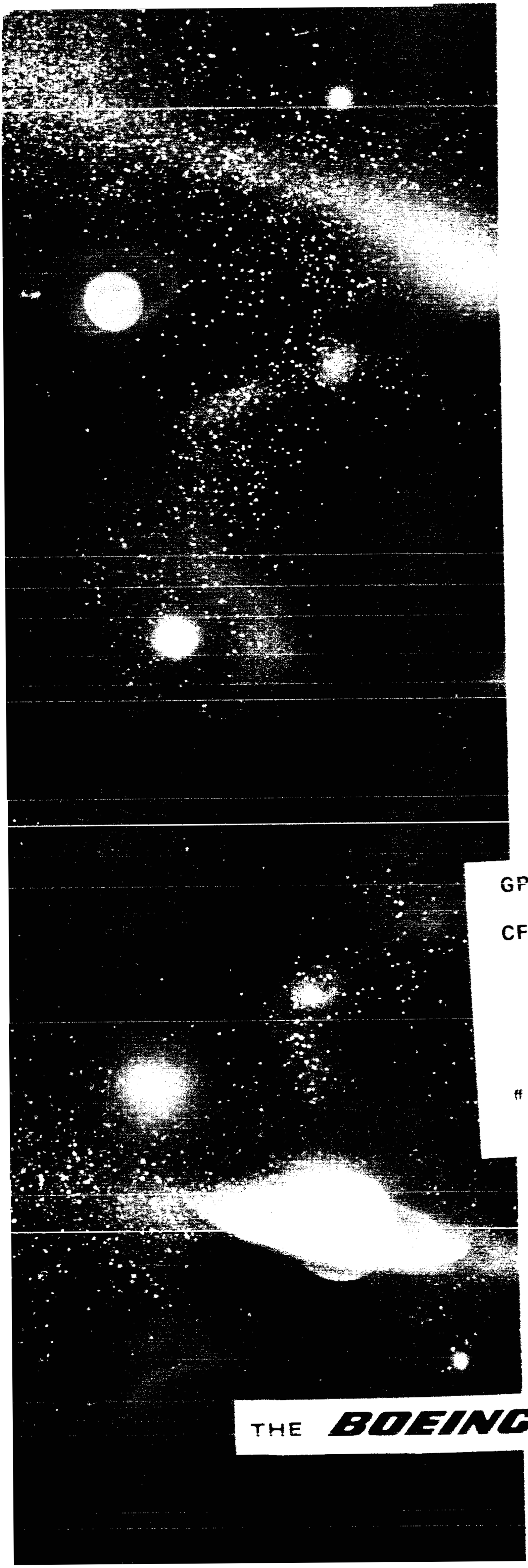

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AIRBORNE EVALUATION EQUIPMENT ADVANCED SYSTEMS CHECKOUT DESIGN

THE **BOEING** COMPANY ▪ SPACE DIVISION

D5-13288

IMPLEMENTATIONS GUIDELINES
AIRBORNE EVALUATION EQUIPMENT
ADVANCED SYSTEM CHECKOUT DESIGN

FINAL REPORT
PHASE B

JULY 29, 1966

CONTRACT NAS8-20240
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

THE BOEING COMPANY
LAUNCH SYSTEMS BRANCH
HUNTSVILLE, ALABAMA

ADVANCED SYSTEMS DESIGN STUDY

PERIOD OF PERFORMANCE: 29 JUNE 1965 - 29 JULY 1966

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ABSTRACT

This document presents the results of Phase B of Contract NAS8-20240, "Advanced Systems Checkout Design," related to Saturn S-IVB and Instrument Unit checkout requirements and guidelines for implementing these requirements on-board the respective stages.

KEY WORDS AND PHRASES

NAS8-20240
Advanced System Checkout Design
Airborne Evaluation Equipment
Launch Vehicle Checkout
On-Board Checkout
Integral Evaluation
Test and Checkout System
Launch Operations

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1.0 INTRODUCTION

The Advanced Systems Checkout Design study was established to determine those checkout functions which can and should be performed on-board the Saturn Instrument Unit (IU) and S-IVB stages; how those functions would be mechanized; the impact of these changes on the presently planned Saturn V GSE and program schedules; and to develop design guidelines or requirements for incorporating the on-board checkout features. The resulting equipment concept is referred to as the Airborne Evaluation Equipment (AEE) concept.

1.1 SCOPE

The present checkout method for the Saturn vehicle uses extensive support equipment, with test system access to vehicle systems through umbilical connections and the telemetry system. This equipment varies in type and configuration between the different test locations, thereby making test data correlation difficult.

With the Saturn V vehicle out of the developmental status, the test requirements can be more firmly established. The need for acquiring engineering data is reduced, thereby permitting a change in scope in vehicle testing. The advances being made in electronic packaging density and the reductions in circuit size and power consumption, make it feasible to perform this new scope of testing with a large share of the evaluation equipment located on the vehicle proper. Implementation of such a concept would also provide relief in correlating test results between test sites since the test equipment would travel with the vehicle. Additional benefits to be derived from such an implementation include: test equipment availability during the mission to perform in-flight checkout; permanence in test system/functional system connections; accumulation of parametric data for long-term trend prediction; and reduction in test set-up time at each test location.

This concept places new emphases on the interface between the vehicle and support equipment. With Airborne Evaluation Equipment, the bulk of the data reduction and evaluation can occur on the stages under the overall supervisory control of the support complex computer, then status and maintenance information is sent to the ground.

This concept will drastically reduce the number of umbilical interconnects and quantity of support equipment, making it easier and less costly to accommodate varying configurations of vehicles at checkout complexes.

The implementation of the AEE concept may be accomplished in degrees. The first step would place miniaturized test equipment on the stage, and the second step would re-design the stage subsystem to incorporate the test functions.

1.2 ORGANIZATION

The study was divided into two phases, A and B. Phase A was devoted to the development of the AEE concept and definition of the airborne evaluation equipment. Phase B required the generation of applicable guidelines for incorporating the AEE into a space vehicle system.

Phase A was concluded by a presentation given to the MSFC Quality and Reliability Assurance Laboratory on May 16, 1966. The presentation included discussions on: the S-IVB and Instrument Unit stages test equipment requirements; approaches to test equipment implementation, and function satisfying test equipment configurations. The test system described in Section 3 of this report and its capability to accomplish the requirements of the Airborne Evaluation Equipment concept was presented.

Boeing document D5-13257, "Requirements and Implementation - Airborne Evaluation Equipment," submitted informally to MSFC, reports the results of phase A of the study.

This document is the final report on Phase B of the ASCD study, and is concerned with implementing the AEE into the Saturn space vehicle system.

To provide an understanding and a reference for the implementation guidelines, this report presents a summary of the test equipment requirements leading to the development of the AEE system; a discussion of the S-IVB and Instrument Unit systems and tests; and the checkout flow required for each stage. The guidelines are presented for the construction and use of the AEE equipment. The last section identifies techniques for achieving complete isolation between the on-board test system and many of the stage functional systems.

2.0 AIRBORNE EVALUATION EQUIPMENT REQUIREMENTS

General requirements for the airborne evaluation equipment were identified in the contract statement of work. Additional requirements can be identified by the configuration, operation, and mission of the Saturn vehicle S-IVB and IU stages. These three areas were examined during Phase A of the study to identify any restraints imposed on airborne evaluation equipment. The results of these activities are summarized in the following paragraphs with a brief description of the stage systems requiring test and the physical test flow for each of the stages. This section provides a foundation for the on-board test system described in Section 3.

2.1 SYSTEM REQUIREMENTS

The general test system requirements are:

a. The system must be located on-board the vehicle;

b. The test system must be capable of testing each stage independently;

c. The test system must provide the capability to accomplish factory, prelaunch, countdown, and post-launch testing of the vehicle;

d. The test system must provide a high degree of confidence in the operational integrity of the vehicle at the conclusion of testing, and must provide fault isolation to a predetermined replaceable stage assembly;

e. The test system must provide a means for continuously monitoring critical stage parameters and provide control as necessary;

f. The test system must accommodate current stage test methods;

g. The test system must be compatible with computer supervision;

h. The test system must contain those capabilities and be sufficiently flexible to incorporate new test methods as they are developed;

i. The test system data formats must be compatible with those of the RCA 110A computer;

j. The test system must interface with a test conductor via the control computer;

2.1 (Continued)

k. The test system must be capable of accommodating the following test conductor manual capabilities:

1. The test conductor can initiate and stop tests,
2. The test conductor can interrupt tests,
3. The test conductor can enter emergency procedures,
4. The test conductor can manipulate the course of testing,
5. The test conductor can invent new test procedures where the preprogrammed sequences do not provide sufficient data.

2.2 S-IVB STAGE REQUIREMENTS

The functional systems of the S-IVB are:

a. The propulsion system;
b. The propellant and oxidizer system;
c. The pressurization system;
d. The flight control and hydraulic system;
e. The power distribution system;
f. The switch selector; and
g. The measurement system.

The remaining systems are for telemetry and range safety.

The S-IVB functional systems are basically mechanical, with replaceable assemblies consisting of valves, solenoids, etc., that contain one or two test points. Failures are based on the inability of these items to close or open as required, or because of a leak. These systems are controlled through the switch selector or umbilicals, using 28VDC relay logic.

Test practices within the systems consist basically of exercising the various relays and valves and verifying normal operation. This is generally accomplished by sequentially applying 28VDC to relays and control solenoids and monitoring 28VDC for normal operation. Other tests consist of applying nitrogen and helium under pressure to storage bottles, propellant tanks, regulators, control valves, and relief valves to check performance. Parameters to be measured are 28 or 0 VDC discrete signals and 0 to 5 VDC analog signals, the

2.2 (Continued)

latter being pressure and temperature monitors.

The flight control and hydraulic systems operate together to control the vehicle. The hydraulic system is tested by operating the auxiliary hydraulic pump and performing temperature, pressure, and leak tests. The flight control, thrust vector control system is checked by simulating Instrument Unit commands to the control actuators and monitoring servo actuator position. These commands are given to the servo actuator in steps from null position to full extension, to null, to full retraction, to null position. The S-IVB accelerometers are tested by a built-in check feature, wherein a DC current is applied to the torque coils in steps, and a DC output voltage is monitored for proper operation.

Electrical system testing applies external power to the stage and verifies buss voltages by operating buss control switching. Similar tests are performed using stage internal power.

The propellant utilization system, an electronic system, is tested by simulating LOX and LH_2 liquid levels and measuring output shaft position, a 0 to 5 VDC analog voltage.

The switch selector controls events aboard the vehicle. For testing, a parallel digital word properly coded is required for operation. Operation is verified by 28 VDC measurements. The flight measurement system is similarily checked. A parallel digital word is required to program high and low calibration signals to individual signal conditioners. Analog measurements verify proper calibration and operation. The S-IVB stage systems are distributed throughout the stage. Test access is provided through control distributers, power distributors, and telemetry junction boxes. All testing is sequential in manner. Test speed is dictated by relay and valve actuation times, and test levels provide fault isolation to a replaceable assembly. Sampling rates of 4 to 400 samples per second and responses of 2.4 to 400 Hz are employed.

In summary, a test system suitable for functional test of the S-IVB stage should be capable of the following:

a. Making system status determination by a logical evaluation of test parameters;
b. Controlling 28 VDC relays and solenoid valves;
c. Providing DC voltages of -lVDC, +1VDC, +5VDC, +10VDC, +28VDC, 0 to 1.2VDC;
d. Providing parallel digital messages using 0 and 28VDC logic levels;
e. Evaluating discrete voltage values of 0 VDC or 28 VDC;
f. Measuring and evaluating analog voltages from 0 to 56 VDC within 0.1;
g. Measuring and evaluating response time;

2.2 (Continued)

h. Controlling as a minimum, the following;

1. 195 discrete commands,
2. 148 discrete measurements,
3. 10 analog commands,
4. 249 analog measurements;

i. Controlling the following ground based supplies through the ground computer;

1. Ground power,
2. GN_2-0 to 4000 psi,
3. Helium-0 to 3100 psi,
4. Dry Air-2500 psi.

2.3 INSTRUMENT UNIT REQUIREMENTS

The major systems of the Instrument Unit (IU) are the power distribution system, cooling system, instrumentation system, guidance computer, and the guidance and control system. These systems are basically electronic or electrical requiring a number of test connections. Failure determinations are based on tolerance performance, usually a voltage measurement to preset limits.

Automatic testing of the systems is performed sequentially beginning with the power systems, networks, etc. Systems that are dependent on other systems are tested last in a building block approach to allow fault isolation.

In testing the power distribution system, external and internal power is applied to the IU systems through relays and switches. The required comands and measurements are 28 VDC discrete signals. Power supply buss voltages and regulators are monitored to within ±4 VDC of nominal.

The cooling subsystem tests consist of measuring coolant flow rate, pressures, and temperatures at various places in the Instrument Unit. These measurements are analog signals.

The network tests consist of verifying the operation of certain specific functions within the stage. Safety switches (set and reset), firing circuits (set and reset), switch selector operation, and power transfer are some of the tests. The test signals are 28 VDC discrete commands and discrete measurements.

The instrumentation system tests check the operation of the beacons and transponders and the command receiver. Measurements and 28 VDC discrete commands verify the application of primary power to these components. Analog measurements verify the operating condition of the components.

2.3 (Continued)

The first portion of the guidance computer tests is a manual inspection of the computer and data adapter, a manual check of the ground support equipment, and a check of the cooling system. The guidance computer tests are run in conjunction with the RCA 110A ground computer. Test results are displayed on ground consoles.

The guidance and control system can be divided into two separate subsystems, the navigation subsystem and the control subsystem. The navigation subsystem consists of the stable platform, accelerometer signal conditioner, platform electronics assembly, and the platform AC power supply. The control subsystem consists of the flight control computer, control signal processor, control accelerometers, and control rate gyros.

The navigation subsystem tests are performed in conjunction with the guidance computer, the RCA 110A ground computer, and a considerable quantity of ground support equipment required for allignment of the stable platform. Evaluation is accomplished by monitoring discrete and analog signals.

The control subsystem has a number of discrete commands and measurements to control and verify power on, flight switch point settings, etc. The majority of tests consist of applying analog voltages to the flight control computer and computing loop gains from various analog measurements.

The telemetry system is functionally tested by checking power output. All measurement channels are checked and calibrated. Telemetry tests are completed by checking the complete data link including the ground station and ground support equipment. The test signals are discrete commands and measurements such as power on and off, and analog measurements for RF power (incident and reflected).

The emergency detection system is tested by supplying simulated emergency signals and verifying that the system recognizes them by noting the output response. The signals are discrete commands and measurements. The simulated plug drop and overall tests can be described as a front to back test for the Instrument Unit. Power transfer, data flow, liftoff simulation are a few of the specific functions checked. In addition, a flight test simulation is performed in which all of the stage systems are involved. In the course of this test, a large majority of the stage test points, both analog and discrete, are involved.

All testing is sequential in manner. Test speed is dictated by component response times, and test levels provide fault isolation to a replaceable assembly. Sampling rates of four to 400 samples per seconds and responses of 2.4 to 400 Hz are employed.

2.3 (Continued)

In summary, a test system suitable for functional checkout of the Instrument Unit should be able to:

a. Measure and evaluate analog signals in the range of 0-26V and 0-2000 Hz;

b. Evaluate discrete signals of 0 VDC and 28 VDC;

c. Measure and evaluate response time;

d. Make system status determination by a logical evaluation of discrete or analog inputs or a combination of discrete and analog inputs;

e. Provide 28 VDC control signals (commands) capable of driving stage relays, switch selector, etc;

f. Accept an input word from the ground computer or the guidance computer;

g. Provide an output word to the guidance computer;

h. Provide analog stimuli (commands) to stage systems in the range of 0-26 V, 0-2000 Hz;

i. Control, as a minimum, the following

   1. 179 discrete commands,
   2. 190 discrete measurements,
   3. 20 analog commands,
   4. 176 analog measurements.

2.4 VEHICLE TEST PLANS

The S-IVB and IU vehicle stages are tested at several geographically remote locations, each of which must be accommodated by the on-board test system. The tests conducted at the various sites are described in this section.

2.4.1 S-IVB Stage Checkout

The S-IVB stage generic checkout flow is shown in Figure 1. The S-IVB stage is assembled at Douglas Space System Center in Huntington Beach, California. Prior to assembly, all purchased and manufactured parts, assemblies, end items, and subsystems are functionally tested. Following assembly, a manufacturing checkout consisting of pre-requisite tests, detail subsystem tests, and overall system tests is performed on the stage. Each of these tests must be accommodated by AEE system.

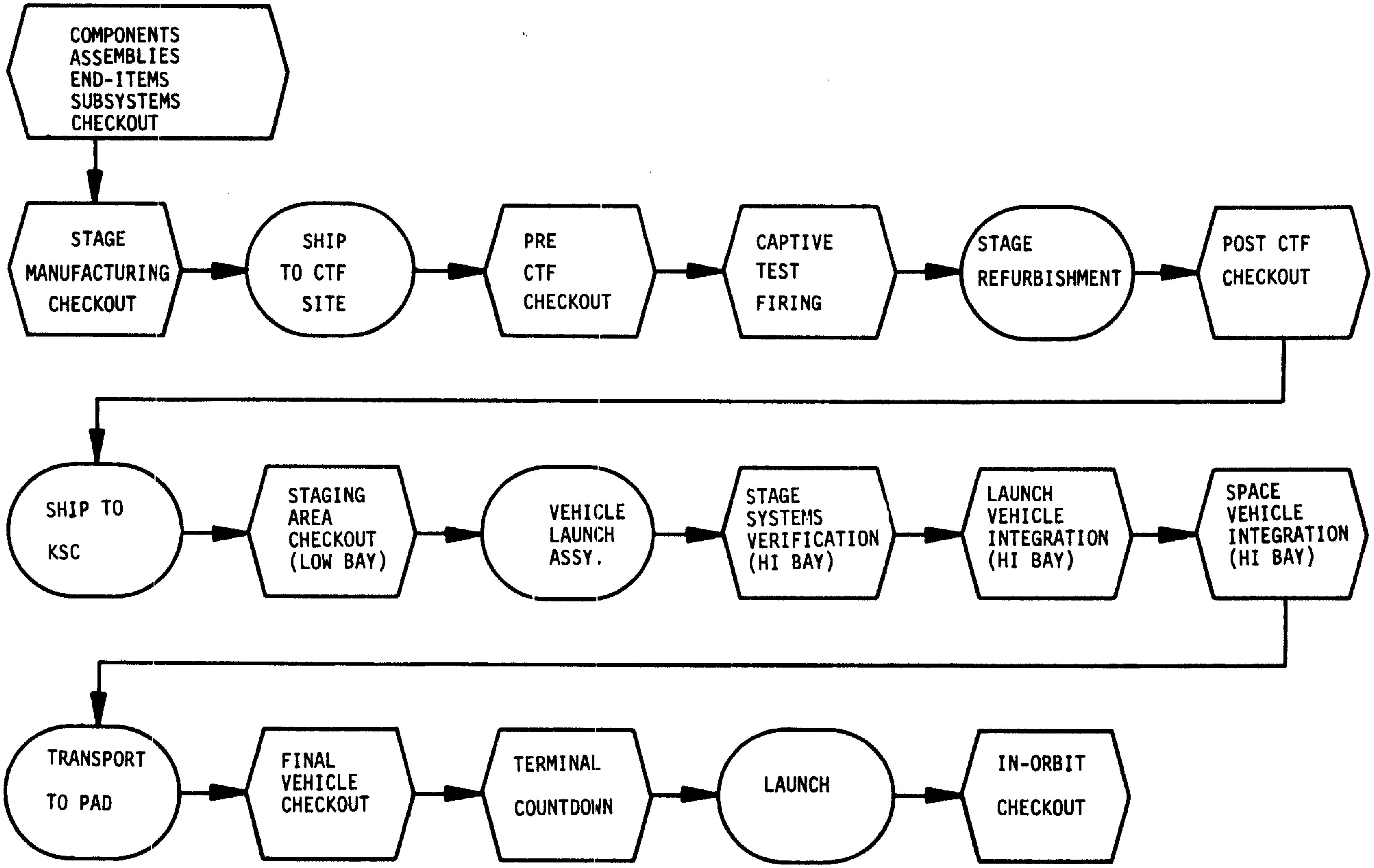


Figure 1: S-IVB CHECKOUT FLOW CHART

2.4.1 (Continued)

The prerequisite tests verify electrical continuity, the electrical system, the DDAS system, and the environmental control system prior to attempting subsystem tests that are dependent on these systems. The subsystem tests test and verify each vehicle system in turn, prior to the flight simulation tests. The overall system tests simulate prelaunch and flight conditions as closely as possible. The test begins with propellant loading simulation and continues through simulated J-2 engine 1st and 2nd burns. These tests are conducted twice, first with electrical umbilicals connected, then with umbilicals disconnected. A general purpose computer is used in conjunction with an IU substitute to program signals to the stage sequencer through the stage switch selector. Stage testing is controlled by the stage switch selector/sequencer combination.

Following successful completion of the factory tests, the stage is shipped to Sacramento for static firing, where pre-CTF checkout, captive test firing, and post-CTF checkout is performed. The CTF checkout is similar to the tests described above. During captive firing, the stage propulsion system and associated subsystems are tested under dynamic conditions, and the J-2 engine is rated against design specifications. Following successful completion of these tests, the stage is shipped to KSC for further testing and launch.

At KSC, the stage undergoes a receiving inspection and functional checkout in the low bay area of the VAB to assure readiness for assembly to the launch vehicle. Testing in the low bay is limited to those tests that normally cannot be accomplished in the high bay. This includes mechanical clearance checks and leak checks on the thrust chamber, engine, propellant tanks, and associated flanges.

Assembly and stage mating is accomplished in the high bay area of the VAB where a complete integrated system test, a simulated countdown, and mission test are conducted on the launch vehicle. The vehicle is then transported to the launch pad where the S-IVB stage, as part of the launch vehicle, undergoes final system verification, propellant loading, ordnance installation, countdown, and launch.

2.4.2 Instrument Unit Checkout

The Instrument Unit checkout flow is shown in Figure 2. The instrument Unit is assembled at the IBM Facility in Huntsville, Alabama. Prior to assembly, all of the various components are functionally tested.

Following assembly, the Instrument Unit undergoes a post manufacturing checkout.

A typical post manufacturing checkout starts with electrical continuity tests. Power distribution tests are run and verified. GN_2 leak tests and cooling subsystem tests complete the preliminary portion of the checkout sequence.

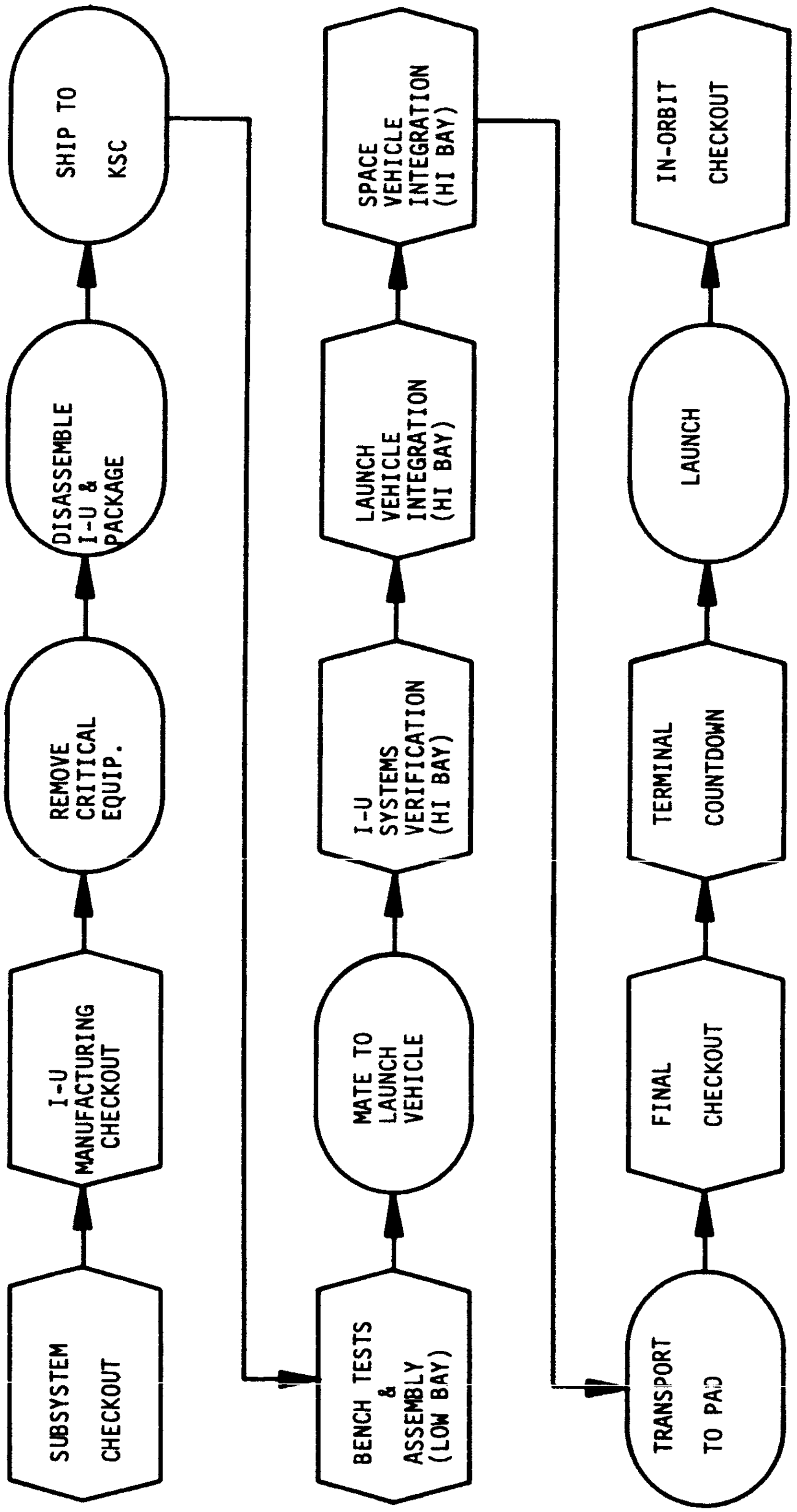


Figure 2: INSTRUMENT UNIT CHECKOUT FLOW CHART

2.4.2 (Continued)

Network tests are then performed which check the operation of such things as safety switches, power to various subsystems, etc. Next the instrumentation systems are tested followed by tests of the guidance computer, the guidance and control systems, the telemetry system (also calibrated), the environmental cooling system and the emergency detection system.

The final portion of the post manufacturing test and checkout sequence consists of a simulated plug drop and overall test. Power transfer tests, guidance and control tests, and DDAS tests are conducted. The final tests to be performed are simulated liftoff and flight tests with and without umbilicals.

Following acceptance of the Instrument Unit, certain critical items such as the guidance computer and data adaptor and the ST-124M platform are removed for separate shipment. The Instrument Unit is then shipped to KSC.

The Instrument Unit is re-assembled in the low bay area of the VAB. The guidance computer and data adaptor and the ST-124M platform are bench tested and installed. The Instrument Unit is then transported to the high bay area where it is mated to the vehicle.

The high bay area tests begin with electrical system interface tests and cooling system operational tests. The telemetry system is checked and calibrated. Next, the operation of various subsystems is verified. The final high bay checkout consists of malfunction sequence tests and a simulated flight test.

When the vehicle reaches the launch pad a pre-launch checkout is performed. The tape recorder system is tested. The safing systems and the EDS system are checked. The RF systems are tested and verified. During the countdown, final subsystems tests, destruct systems tests, power transfer tests, RF systems tests and critical status checks are performed. Just prior to launch a final guidance and control check is performed.

3.0 AIRBORNE EVALUATION EQUIPMENT FUNCTIONAL GUIDELINES

The on-board test system recommended for implementation of the airborne evaluation equipment concept, as it applies to the Saturn vehicle S-IVB and IU stages, is described in this section. Section 3.1 contains a functional description and Section 3.2 a suggested physical arrangement of the major elements of the recommended on-board system.

3.1 TEST SYSTEM FUNCTIONAL DESCRIPTION

A block diagram of the recommended system for the on-board testing of the S-IVB stage and Instrument Unit is shown in Figure 3. The major system elements are the ground and guidance computers, digital control unit, three program controllers, and the emergency monitor and control unit.

The recommended test system has three modes of operation: computer programmed, computer sequenced, and computer initiated. These modes allow independent operation of a program controller, complete remote control, or a combination of both.

In the computer programmed mode, program instruction is derived completely from the control computers (ground or guidance), permitting the generation of unforseen test instructions either by computation of failure trends or by manual innovation.

In the computer initiated mode, the computer programs only the initial test step of a block of tests. The remaining instructions for the entire block are prestored within a local programmer.

The computer sequenced mode consists of the computer programming only a single desired test step. The local programmer provides test instructions for that stop as in the computer initiated mode.

The system follows a testing program determined by the programming mode selected by the test conductor through the computer. In general, a test consists of a sequentially selected stimulus, a stimulus application point, the response test point, the mode of evaluation for the response, and the evaluation limits. After the test conditions are established, the program controller makes the test connections, waits for a programmed evaluation delay, if required, measures the response, and then evaluates the measured value by comparing it to programmed high and low limits to derive a go or no-go decision. Another feature allows the evaluation of several discrete signals simultaneously as desired. Both the measured value and the evaluation results are available to the control computer.

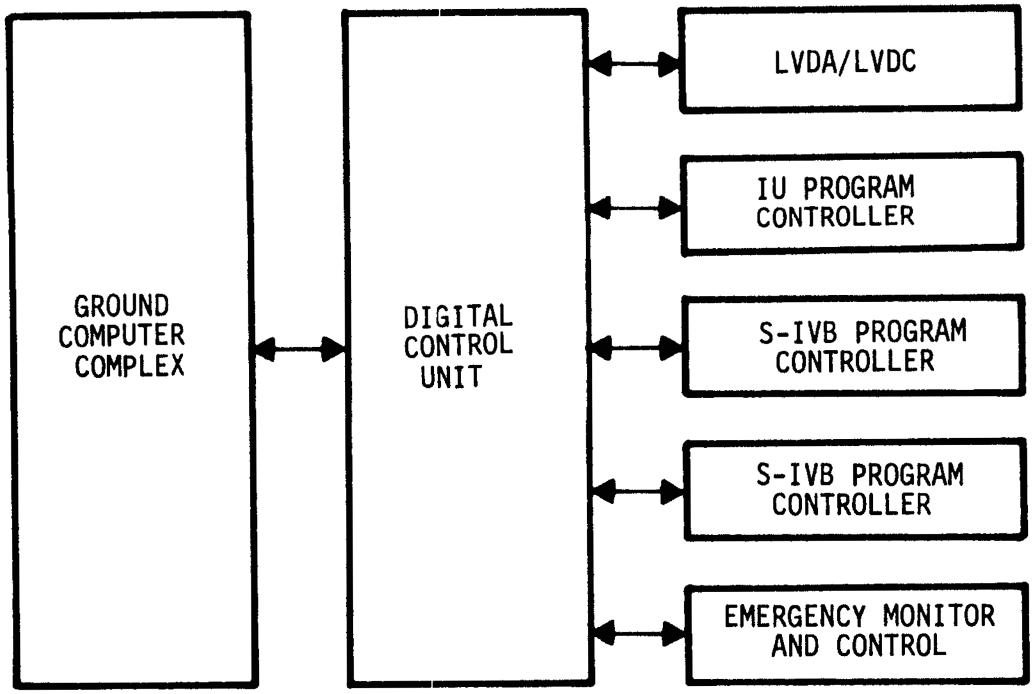


Figure 3: AEE FUNCTIONAL CONFIGURATION

3.1 (Continued)

The program controllers are automatic programmer-evaluators, utilizing locally stored instructions to perform stimuli selection, measurement and evaluation mode selection, and evaluation limits. This relieves the control computer memory of the thousands of detailed instructions that can be pre-determined by system specialists and allows its use,on a time sharing basis, for other functions such as data reduction, formatting for displays, and control of other support equipment. Each program controller is fully capable of performing a test or a group of tests, and evaluating the results. It acts under the control of the ground computer or guidance computer dependent on mission phase.

A functional diagram of a program controller is shown in Figure 4. Principal elements are the local programmer, control section, discrete sensors, response section, stimuli and switching.

The local programmer is a bulk storage device containing detailed test instructions. These instructions will control the sequential steps necessary in applying stimuli and evaluating the results of the equipment under test.

The control section provides for the correct routing of the instructions into its temporary storage device, the universal memory, a unique device which controls all functions within the program controller as shown in Figure 5. There can be a total of 23 memories working with a program controller. Seven memories set up the response section to evaluate incoming data. The remaining memories can be remotely located to control stimuli and discrete sensors within the subsystem under test. Loading, verification, and erasure control of the memories are accomplished completely in the program controller.

Analog measurement capability is provided through the use of an analog-to-frequency converter and counter. By utilizing an analog-to-frequency converter, both frequency and voltage measurements can be made by a single device. The measured data is evaluated by comparison with stored limits and the use of a binary structure in the counter places the data in a format readily acceptable by the control computer. The discrete sensor, consisting of programmable solid-state logic, is used for the evaluation of discrete signals in various combinations.

Solid state and relay switching is provided for the routing of response and stimuli signals, each switch matrix being controlled by a universal memory. Stimuli modules are provided, as necessary, to be used in a centralized location or within the unit to be tested, depending on the number of test points and their location.

The continuous monitor and control system shown in Figure 6 provides continuous monitor of selected parameters and initiates control signals in the event an out-of-tolerance condition develops. It can be used to continuously monitor and evaluate

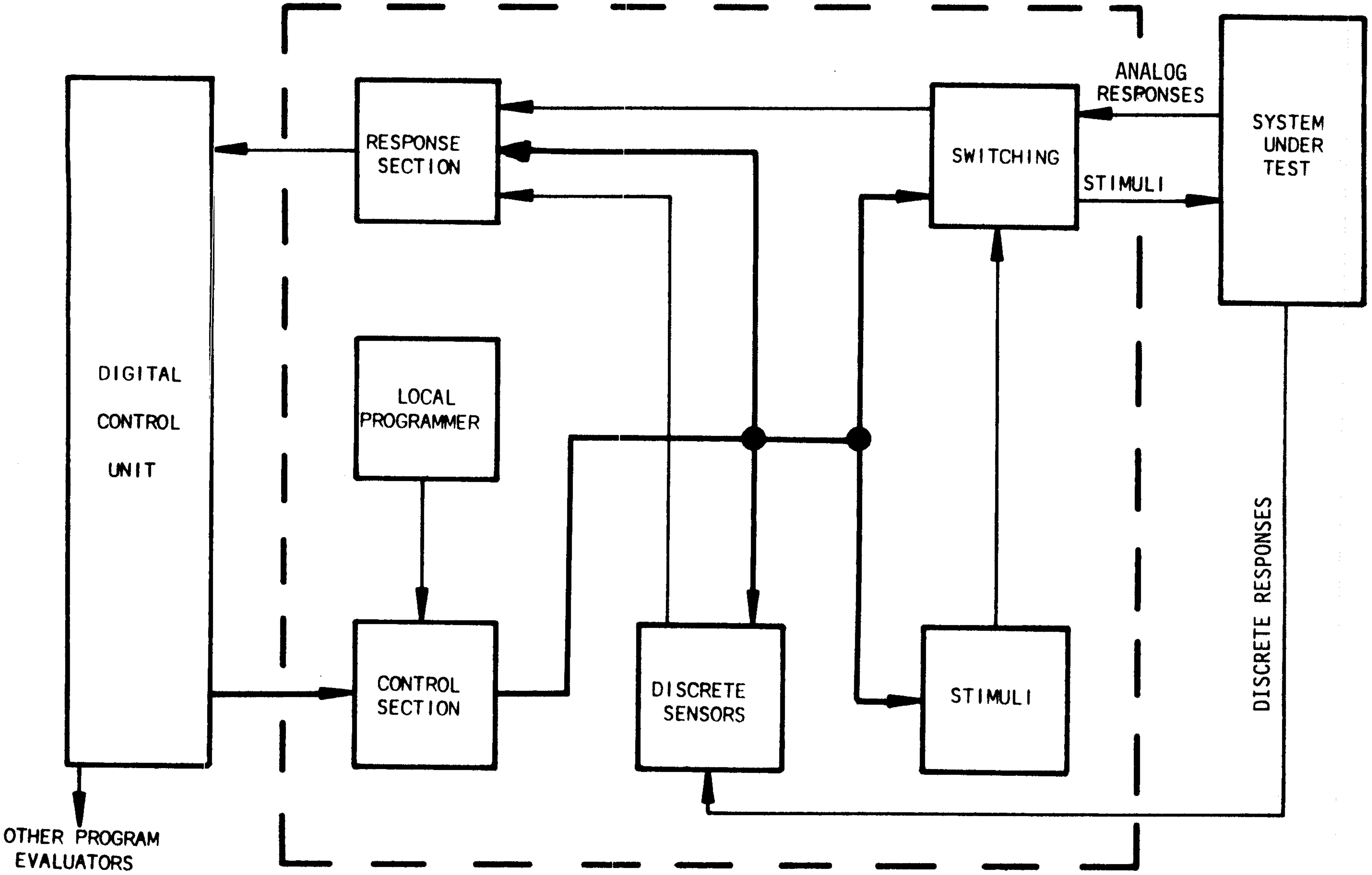


Figure 4: PROGRAM CONTROLLER

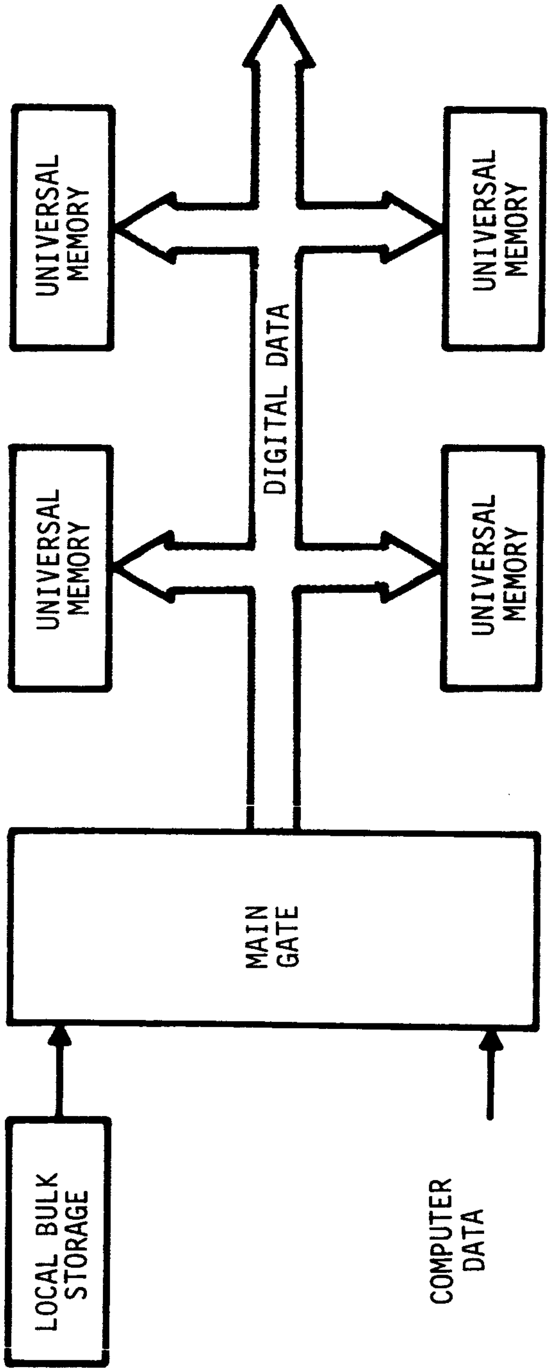


Figure 5: CONTROL SECTION DATA FLOW

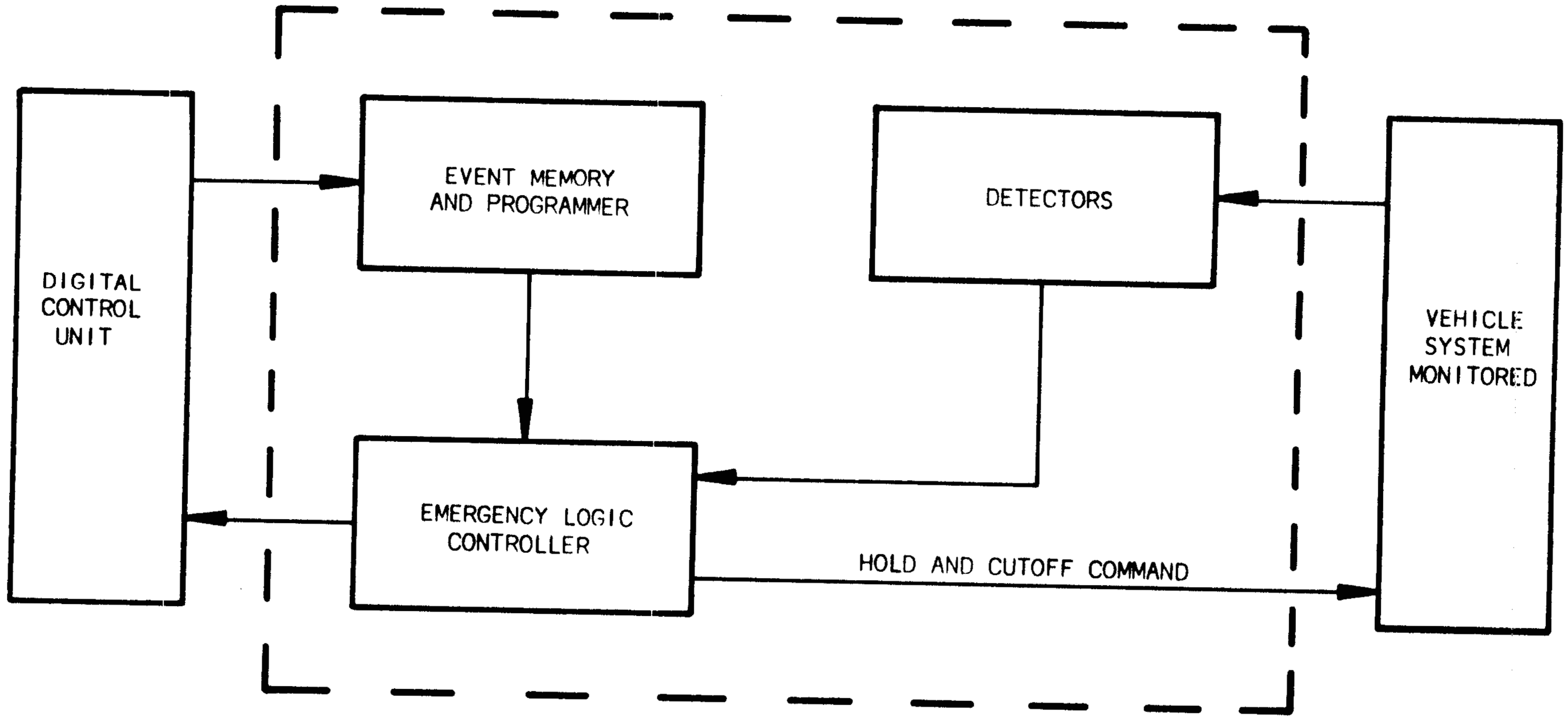


Figure 6: CONTINUOUS MONITOR AND CONTROL SYSTEM

3.1 (Continued)

any desired vehicle parameter. Principal elements of the system include the event memory and programmer, detectors, and the emergency logic controller. The system could be implemented by using either a multiplex scheme between the detectors and emergency logic or by hardwire connections.

Hardwire connections are recommended for the S-IVB and IU stages where few test points are involved and cable runs are short.

Each detector is designed to continuously evaluate a given parameter within present limits. If an out-of-tolerance condition occurs, it is sensed by the emergency logic controller. Depending on mission phase, the emergency logic controller performs a control action - such as engine shutdown-and/or notifies the control computer. Parameter masking is performed by the event memory and programmer acting on instructions from the control computer and serves to change the emergency logic as a function of mission phase.

The digital control unit serves as a switch for the routing of data between the control computers, program controller, and emergency equipment.

3.2 TEST SYSTEM PHYSICAL DESCRIPTION

The principal components of the test system are located on-board the S-IVB/IU stages as shown in Figure 7. The IU contains the guidance computer, digital control unit, one program controller, and the real time monitor and control system. The S-IVB stage contains two program controllers, one mounted forward and the other aft, to reduce the number of interconnect wires through the stage. The emergency monitoring equipment located in the S-IVB stage consists only of detectors with the emergency logic and event programmer in the IU.

A layout of the on-board test equipment is shown in Figure 8. The equipment mounted forward is located on the cold plates for environmental protection. The equipment mounted aft will require internal protection.

The program controller consists of two assemblies, the control and response section and the local programmer. The control and response section contains the necessary logic for performing the test program and the local programmer stores the test specifications and sequences for conducting the tests.

The response and control section utilizes integrated circuits and a small number of discrete components in order to attain minimum size, weight, and power consumption characteristics.

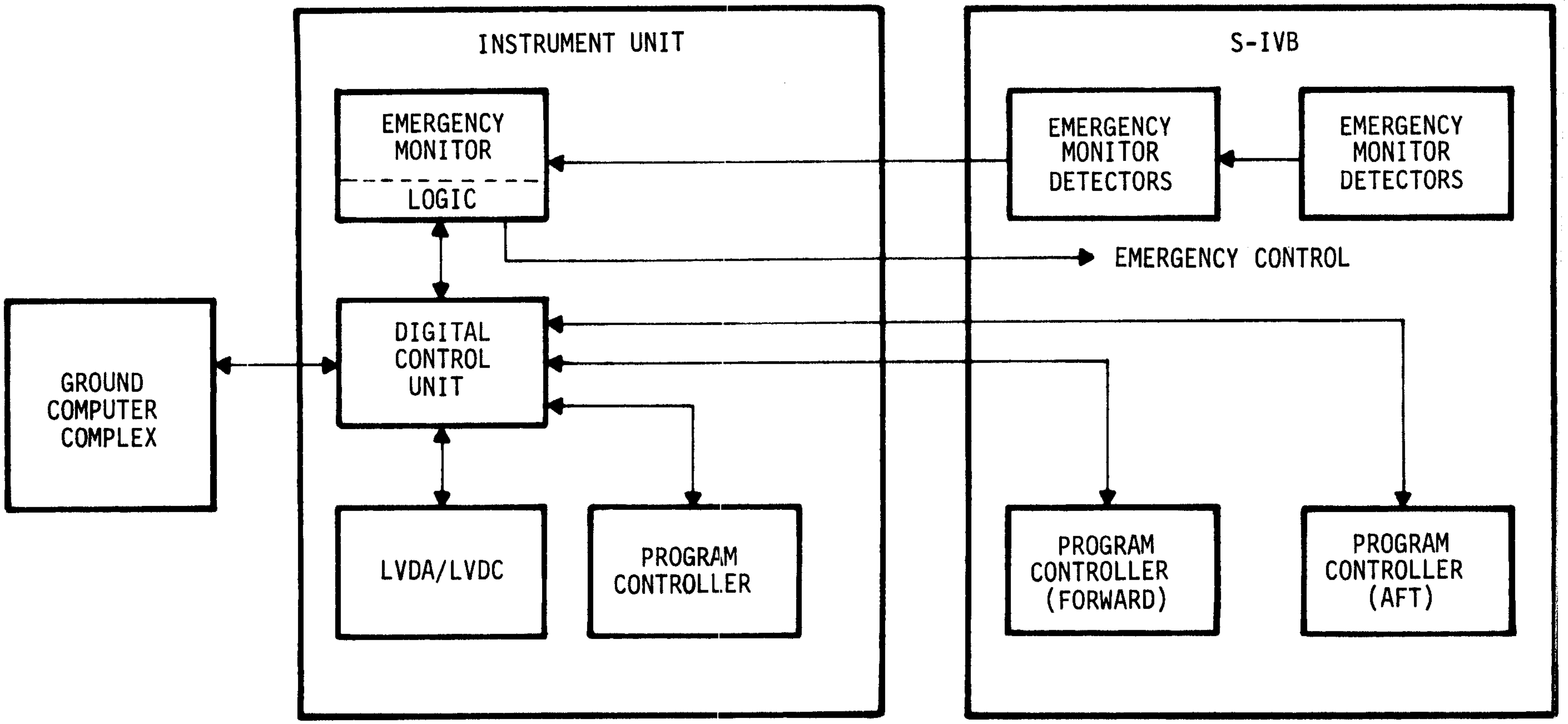


Figure 7: AEE COMPONENT LOCATION S-IVB LAUNCH VEHICLE

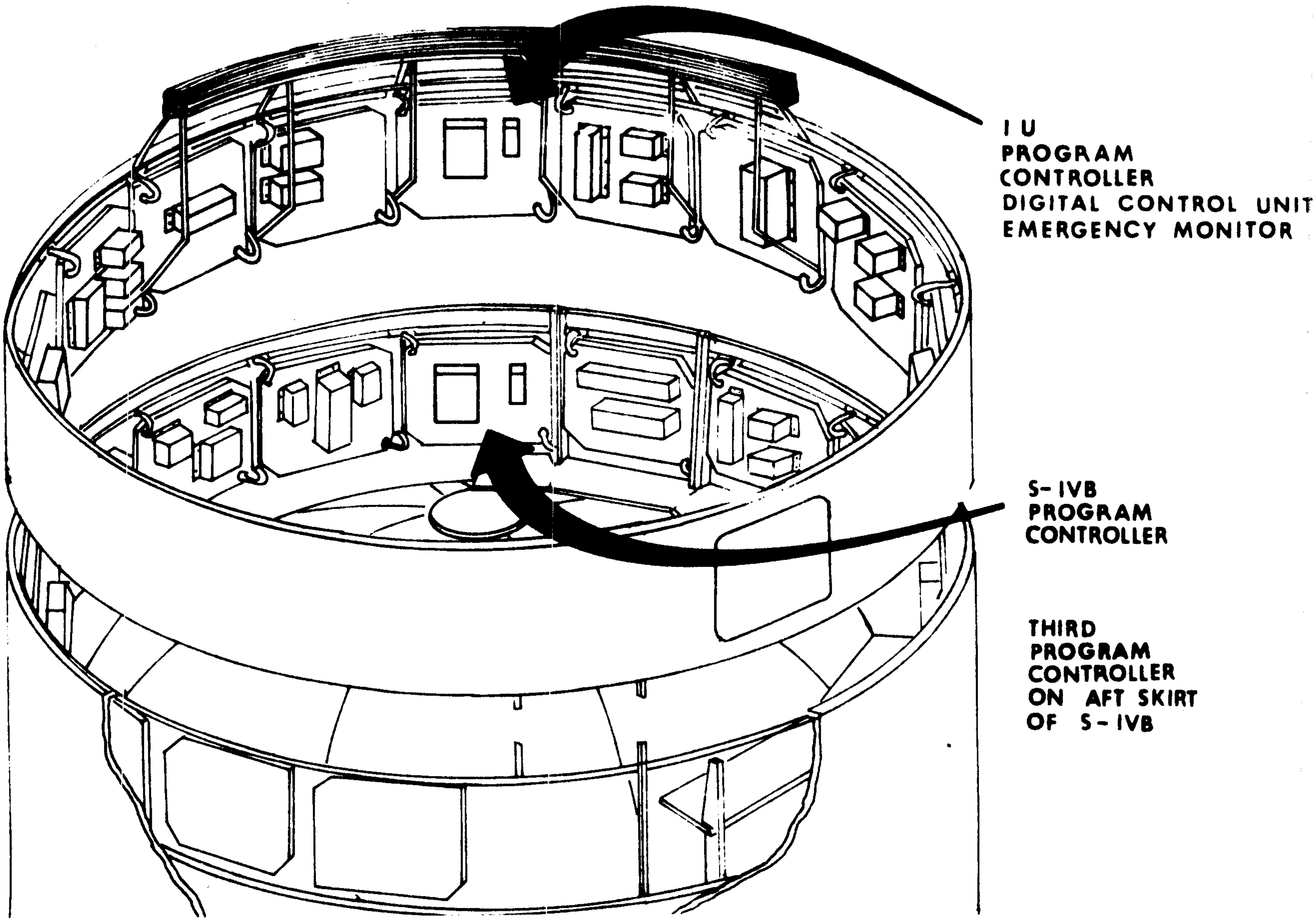


Figure 8: VEHICLE INCORPORATION — STAGE

3.2 (Continued)

Switching is accomplished utilizing relays for high level signals and field effect transistors (FET) for low level signals. The stimuli section contains provisions for providing 28 VDC for the actuation of relays and solenoids within the stage systems and a function generator for providing variable current levels from 0 to 28 VDC where required. The programmer-controller weighs about 53 pounds, consumes 54 watts average power, and requires 1,011 cubic inches of space.

The local programmer is a motor driven, magnetic tape storage device. This memory system provides controlled access to 10,000 twenty-four bit-words, plus a data available signal at output logic levels of 0.0 and +5.0 volts. Control and memory is provided by integrated circuits, discrete components and magnetic tape memory techniques. The weight of this unit is 7.06 pounds, power consumption is 8.3 watts average, and it required 285 cubic inches space.

The remaining components of the test system are the continuous monitor and control system and the digital control unit. These items are constructed utilizing solid state integrated circuits and discrete components. They each weigh 10 pounds, require 216 cubic inches space and consume 4.6 and 1.5 watts respectively.

Various elements of the test system may be distributed within stage functional systems where desirable or necessary. This distribution would probably consist of using universal memories in conjunction with switch units, stimuli, discrete sensors, and analog evaluators. Another example, Figure 9, shows a discrete sensor module within a stage power distributor assembly. The module monitors and evaluates discrete test signals on command from a program controller.

Figure 10 shows test system elements functionally connected to the IU control computer. For this application, switch units, digital sensors, stimuli and analog evaluator modules would be required. This approach, as shown on the figure required redesign of major vehicle components. Where this is undesirable or impractical, all test equipment would be centrally located.

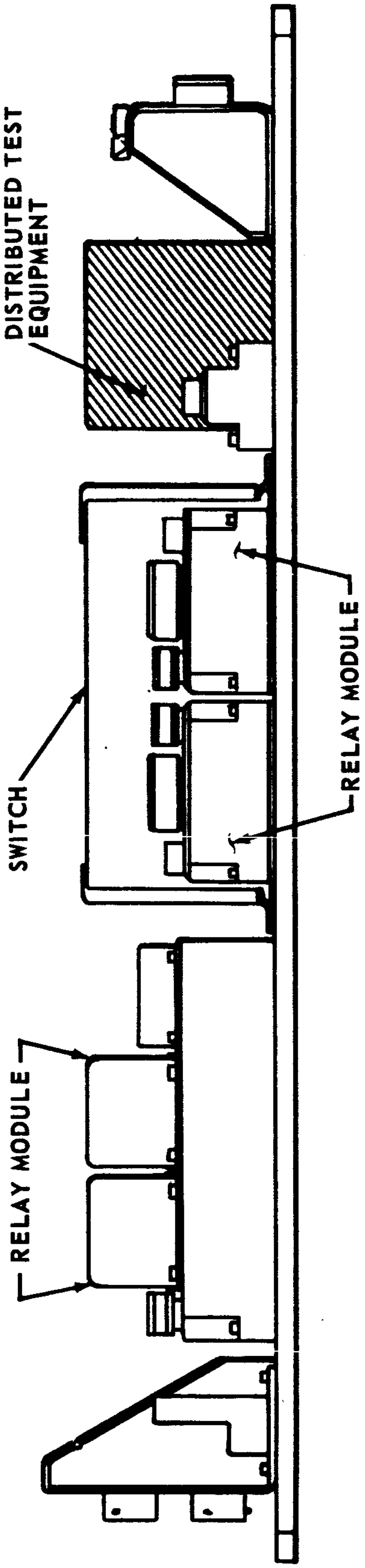


Figure 9: VEHICLE INCORPORATION — CHASSIS

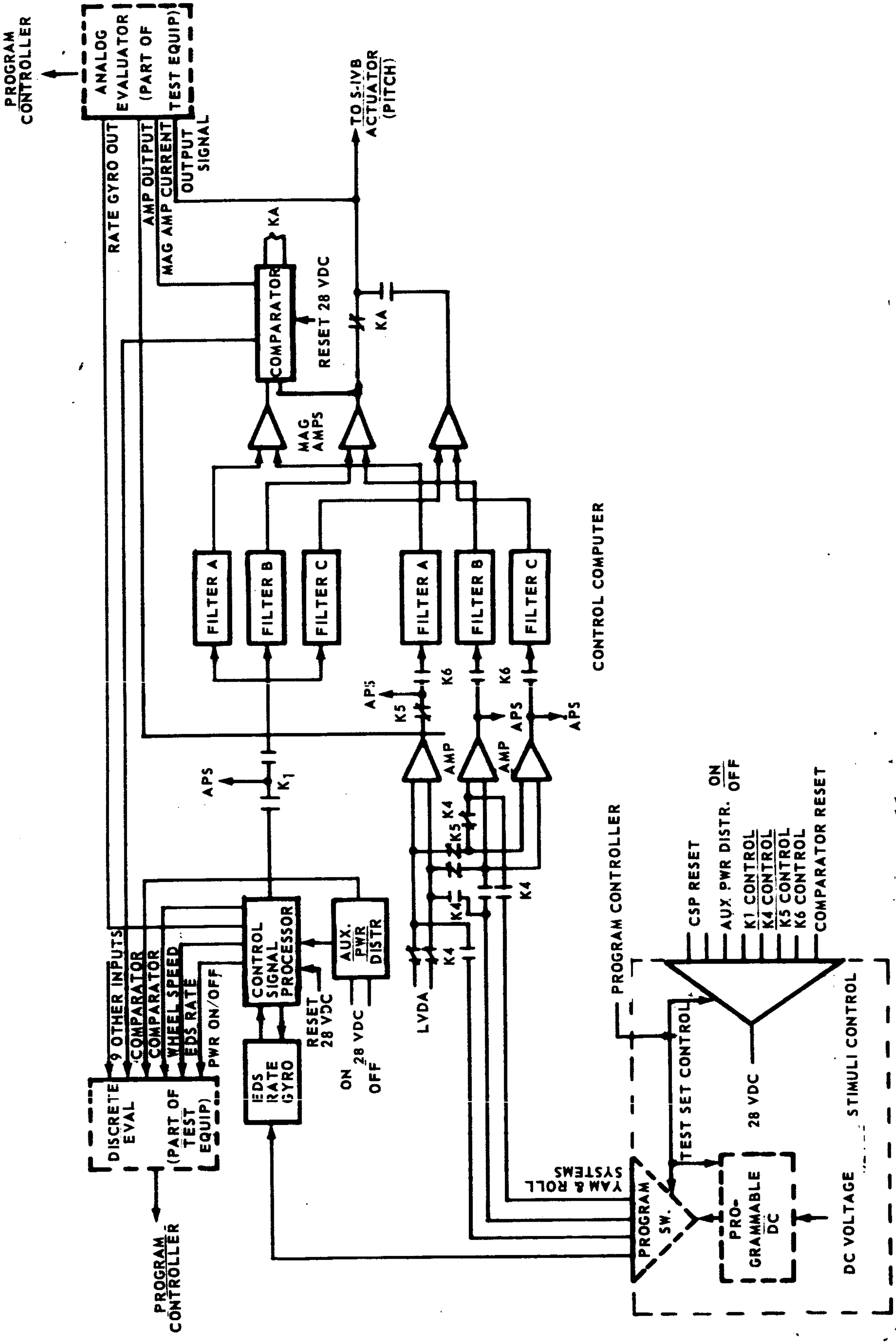


Figure 10: VEHICLE INCORPORATION — SYSTEM

4.0 IMPLEMENTATION GUIDELINES

For maximum system effectiveness the test function and specific test system configurations should be recognized and treated during the detailed design of functional systems. Thus the test or checkout system is developed concurrently with the functional system and advantages can be incorporated in both systems. However, test system requirements are not firmly established until the functional system design has been solidified. Implementation of the airborne evaluation equipment concept must recognize that the functional systems of the Saturn vehicle S-IVB and Instrument Unit stages are established. As a result the on-board test system recommended for implementation of the airborne evaluation equipment concept must adopt completely to the configuration of the vehicle stage systems.

The following guidelines therefore, are established in recognition of the constraints and are intended to identify some of the parameters required of the test system in meeting its objectives.

4.1 SYSTEM IMPLEMENTATION

Implementation of the AEE concept into vehicle stage systems involves a number of guidelines with respect to minor stage and system modifications. These include modifications to provide for computer control and supervision of the test operation; interface between the ground computer, digital control unit, and launch vehicle data adapter; mounting of components within the stages and systems; and routing of interconnect cables.

a. System Guidelines

1. The on-board test equipment will be capable of remote control by the ground computer complex and the launch vehicle digital computer.
2. The ground computer will provide the interface with the test conductor.
3. All test data, test step numbers, magnitudes, and results will be available to the control computers.
4. The test system will be capable of fault isolation to a replaceable component in a system or subsystem.

4.1 (Continued)

b. S-IVB Stage Guidelines

1. Two program controllers will be utilized for checkout, one mounted forward on the cold plates and one mounted aft. The aft mounted program controller will be environmentally protected.

2. The program controllers will be connected in parallel and interface with the digital control unit mounted in the Instrument Unit. This interface will provide control access to factory equipment for post assembly checkout when the IU is not available.

3. Current instrumentation will be utilized for checkout.

4. Analog test parameters will be routed through a programmable switch matrix for evaluation.

5. Discrete test parameters will be evaluated using the discrete sensor, allowing simultaneous evaluation of several parameters.

6. Programmable stimuli, 0 to 28 VDC at several discrete levels, will be required.

7. Ground service equipment required will be controlled by the ground computer.

8. Analog parameters selected for continuous monitor will be evaluated near their source by voltage limit detectors. Outputs from the detectors will be bi-level signals. Bi-level parameters selected will not require detectors for monitoring purposes. The majority of these points are located within power distributors and telemetry point distributors.

9. Parameters selected for continuous monitor will be routed via hardwire in a single cable to interface with emergency logic in the Instrument Unit. For factory test, external emergency logic will be provided to perform this function.

10. Provisions will be incorporated for automatic self test of all checkout equipment.

4.1 (Continued)

c. Instrument Unit Guidelines

1. One program controller - the digital control unit and the emergency monitor and control unit are required. They will be mounted on cold plates for environmental protection.

2. The digital control unit will provide the interface between ground computer, launch vehicle data adapter, emergency control system, and the program controllers.

3. Current instrumentation will be utilized for checkout.

4. Analog test parameters will be routed through a programmable switch matrix for evaluation.

5. Discrete test parameters will be evaluated using the discrete sensor, allowing simultaneous evaluation of several parameters.

6. Programmable stimuli, 0 to 28 VDC at several discrete levels, will be required.

7. Ground service equipment required for testing will be controlled by the ground computer.

8. Analog parameters selected for continuous monitor will be evaluated near their source by voltage limit detectors. Outputs from the detectors will be bi-level signals. Bi-level parameters selected will not require detectors for monitoring purposes. The majority of these points are located within power distributors and telemetry point distributors.

9. Parameters selected for continuous monitor will be routed via hardwire in a single cable to interface with emergency logic in the Instrument Unit.

10. Provisions will be incorporated for automatic self test of all checkout equipment.

4.2 SYSTEM PARAMETERS

During the design and development of the AEE system various parameters must be considered and incorporated. These parameters apply to the physical and functional capabilities of the system and to a large extent determine the worthiness of the system to fulfill its objectives.

4.2.1 Physical Parameters

Physical parameters of a system include size, weight, and power consumption characteristics. The test system, being on-board a launch vehicle, will require that these quantities be minimized. This can readily be accomplished by the utilization of microcircuits, miniaturized components, and high density packaging methods.

The proposed packaging approach for the AEE system is to use a cast aluminum chassis and planar subassemblies to provide structural integrity and conductive thermal paths for the discrete electronic and microelectronic parts. Chassis mounts will be on two inch centers as required by the standard IU thermal panels.

The planar assemblies, about 2 x 5 inches, will house the sub-miniature parts and microcircuitry being electrically interconnected by the etched copper clad circuit boards. These boards will have four or six layers of circuitry with parts mounted and directly interconnected to the proper layer by resistance pulse soldering through clearance holes in the surface layers.

The four or six layer boards have two copper planes which provide power and ground distribution to the assembly. These planes will also serve as conductive thermal paths for heat removal. The temperature differential between electronic parts and the board chassis mounting interface for a representative microelectronic board assembly of 48 networks with one watt power dissipation is 15 degree F. Polyurethance coating of the planar assemblies provides the thermal path for heat from the parts to the board and also the necessary mechanical support for the parts. The use of the planar assembly, as described, also allows trouble shooting and repairability of assemblies to the discrete part level.

Modular assemblies will be required for relay switching. Minimum size will be achieved by the use of solid state switches. These assemblies will mount directly to the chassis for mechanical protection and thermal dissipation. Wiring between all assemblies will be achieved by using small diameter wiring, AWG 26. Miniature circular connectors will be used to interface with other external assemblies.

The reliability of this system will be increased by the judicious breakdown of the system logic diagram to functional groups within a given assembly. This minimizes subsequent interwiring and simplifies functional testing and fault isolation within the system and subassemblies.

The packaging approach selected and described satisfies the physical and environmental requirements for equipment mounted in the IU and S-IVB forward section. The AEE unit which will be mounted in the aft end of the S-IVB will be the same basic unit; but it requires an interface mounting assembly which will provide a thermal shroud for environmental control.

4.2.2 Functional Parameters

Functional parameters involve the performance characteristics of a system. For test equipment these are, in part, determined by the system to be tested. The major parameters are discussed as follows:

a. Reliability - System reliability is the combination of the reliability of all parts of the system including equipment, human reliability, and the reliability of procedures.

Equipment reliability is basically a function of the state-of-the-art at the time the equipment is designed. The AEE equipment being a state-of-the-art item will have the advantages inherent in the use of microcircuits and new packaging methods, i.e., few interconnections and long operating life. Design techniques now allow improvements in equipment reliability over that obtainable in the past. Similar equipment, fabricated by The Boeing Company, has accumulated well over 7,000 hours under power life tests without a circuit failure.

Human reliability, relates to skill and numbers. The AEE system, being a fully automatic concept, requires few operating personnel, decreasing the possibility of human error.

Reliability of procedures relates to the quality of instructions manuals and equipment software or computer programs. This again is a function of the state-of-the-art at the time of inclusion.

b. Fault Isolation and Fault Prediction - Fault isolation and status determination is the primary responsibility of a test system. The level of fault isolation required is determined by the maintenance plan for the system to be tested. The AEE system uses the test points currently utilized within the Saturn V program assuring compliance with the maintenance plan.

The on-board system described has the capability of performing tests organized in a sequential manner as currently employed. The tests are preprogrammed and executed on command from the control computers. The tests would be programmed in a logical manner to isolate a fault in a replaceable vehicle assembly.

Status determination is accomplished following the successful completion of the test steps. This allows the same degree of confidence in the vehicle systems to perform their mission as currently achieved.

A degree of fault prediction is possible using the described test system. It can be accomplished by storing all test results from each test phase and performing a trend analysis. This is because identical test equipment is used for all test phases.

4.2.2 (Continued)

c. Test Capacity - It is estimated that a maximum of 500 tests will be performed by each program controller. This requires about 5,000 twenty-four-bit words. This can be accommodated in the recommended AEE magnetic tape memory system which has the following capabilities:

Slewing speed = 2,500 words/sec
Stepping speed = 800 words/sec
Packing density = 108 words/inch
Active tape length (5,000 words) = 46 inches

The memory has a maximum access time of two seconds and a random access time of about one-half second which is within the requirements for the system to be tested.

d. Measurement Capability - Measurement capability involves the quantity and magnitude of the signals to be measured. Within the S-IVB/IU stage system, the required quantities of measurements are:

1. S-IVB Stage
   a. Discrete signals - 262 points
   b. Analog signals - 257 points
2. IU Stage
   a. Discrete signals - 152 points
   b. Analog signals - 151 points

In the proposed AEE configuration discrete signals are evaluated by discrete sensors which check only for the presence of a signal. This allows a simplified approach in design since signal amplitude is not important for proper evaluation and several signals can be simultaneously evaluated.

Frequency and analog voltage levels are measured by the program controller. Voltage levels are converted to a frequency, counted, and compared to preset limits for evaluation. Frequencies require only counting and comparing.

Measurement accuracies of 0.1 percent and 0.5 percent for DC and AC voltages respectively can be obtained for the range of values encountered within the S-IVB/IU stages.

4.2.2 (Continued)

e. Flexibility - Flexibility is a characteristic that must be incorporated into launch systems test equipment. Flexibility will provide for increased test programs, different programs, different test routines, and expansion.

The proposed checkout system utilizes three on-board program controllers to perform the tests. These are controlled by a control computer and a test conductor. Each program controller contains pre-stored test routines for associated vehicle assemblies. These routines are programmed on magnetic tape.

The program controllers have three modes of operation, allowing independent operation, complete remote control or a combination of both.

Flexibility is inherent in design, the magnetic tapes can be changed or altered and the program can be up dated during test by the test conductor.

Another unique feature is that each functional element of a program controller is controlled by a universal memory. This memory is loaded either directly from the control computer or from magnetic tape, following verification. Therefore, more functional elements can be added to each program controller providing increased capabilities.

f. Self Maintenance Requirements - The test system must be capable of self evaluation to insure confidence in results. Self evaluation is accomplished by operating the test system in a test mode pre-programmed within the local programmer. The tests are based on a built-in frequency standard and voltage reference and are designed to exercise all test system components. The tests allow for fault isolation to a replaceable assembly. The frequency standard and voltage reference must be periodically calibrated using standard test equipment.

A typical self test routine is tabulated below. Described are system tests. In the event of an indicated system malfunction a subroutine for fault isolation would be initiated.

1. Check counter operation using frequency standard. Check for both noise immunity (no spurious counts) as well as standard frequencies. Comparator operation is also verified.

2. Check analog-to-digital converter and comparator using the voltage standard.

3. With previously verified input, program limits to produce comparator no-go. Program a comparator no-go with incorrect polarity and decimal point.

4.2.2 (Continued)

4. Measure all internal power supplies.

5. Check error indicators indicating improper programming (parity, equality etc.).

6. Check all evaluation modes including time interval, period, count, ratio, peak voltage, difference, sum, AC.

7. Check all stimuli systems.

g. Test Structure - The tests performed on the vehicle systems are derived from the prestored test specification and sequences within each program controller or directly on command from the control computer. These test specifications and sequences are arranged into test blocks, consisting of a group of tests on a particular vehicle system, and individual test steps within the system. Input data to the program controller is in the form of twenty-four-bit words. The first word will address a particular program controller, determine the mode of operation (computer programmed, computer sequenced or computer initiated) and contain the test number of the particular test desired in the local memory if either of the latter two modes are selected. If the computer programmed mode is selected, the following computer words will load various universal memories. Each universal memory will then be programmed to perform a particular test function, e.g., counter control, conditioner programming, stimuli control, response select, limit control, evaluation delay, discrete sensor, and switching.

Other word instructions are for control purposes. One is to generate a command in the response section in which test conditions have been established and to begin the measurement; another is used in conjunction with memory erasure to allow an iterate mode which will shorten test routines.

h. EMI Compatibility - During the design, fabrication, and installation of electronic test equipment, it is important that electromagnetic interference compatibility be maximized. To assure compatibility between the test system and the system to which it is linked, an EMC control plan is necessary. This control plan is a detailed program that outlines all of the specific tasks that must be accomplished. It will cover the period from the concept phase to the final activity of the program. Particular attention must be paid to applicable EMI specifications in that compliance to certain specifications such as MIL-I-6181D, MSFC-SPEC-279 and MIL-E-605 is necessary for effective EMI compatibility.

The AEE system, itself, should possess no E.I. problems. Being completely enclosed, only radiated high frequency energy can leak into the set. Since the test set operates at comparatively low frequencies, these difficulties are minimized. Therefore, the only problems involved will be due to incompatible interfaces. Incoming power will require filtering to minimize conducted interference.

4.2.2 (Continued)

The cable configuration is such that high and return lines would be as physically close as possible. Sensor configuration will determine if coax, twisted pair, or shielding is required. As an overall test to insure interface compatibility, the incoming cables will be checked to insure that the net current is zero.

i. Elimination of Wiring - An advantage in placing the test equipment on-board a launch vehicle is the reduction in the amount and length of interconnect wiring between the system under test and the test equipment. This not only reduces possible failures, but it also allows increased test accuracies since signal degradation is minimized.

The proposed AEE system provides both advantages. The AEE system, being an on-board test system, provides for the elimination of the umbilical connectors associated with checkout functions and by distributing components of the program controller into certain vehicle assemblies, allows the evaluation of vehicle parameters within these assemblies.

5.0 PASSIVE INSTRUMENTATION APPLICATIONS

Passive instrumentation techniques are defined as those techniques which will not impair, alter, or affect vehicle system operation. These techniques can be implemented by utilizing various secondary effects emanating from the electrical and mechanical systems and establishing the relationship between these effects and the functional parameters of interest.

The utilization of passive instrumentation and stimulation techniques were investigated by The Boeing Company under contract NAS8-20090, Passive Instrumentation and Stimuli Generation for Saturn IB Equipment Checkout. The results of which are contained in Document D5-13268 of the same title.

It was found that these methods can be effectively integrated into the AEE concept as the output of the passive devices are compatible with the AEE system, whereas the outputs require conditioning when used with ground checkout equipment on launch vehicles.

Some of the techniques investigated that are particularly applicable are discussed below.

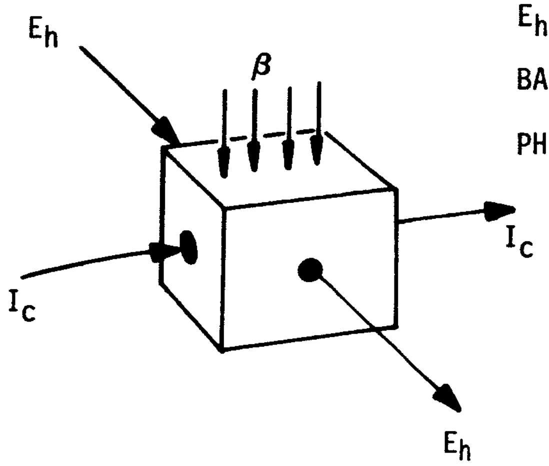
5.1 MAGNETIC AND ELECTRIC FIELD TECHNIQUES

The Hall effect device, the magneto-resistor, the RF monitoring equipment and the metal-oxide semiconductor field-effect transistor (MOS/FET) electrometer are the most promising sensing devices presently available. The Hall effect device, Figure 11, provides an excellent means for measuring a static or time varying magnetic fields, and can be applied to numerous subsystems within the launch vehicle. The device is a semiconductor which exhibits a linear output (E_h) as a function of the mutually perpendicular flux (β) and control current (I_c). These devices have a sensitivity, a good frequency response, and small physical characteristics, appropriate for the electromechanical devices found in the launch vehicles. One disadvantage of the Hall effect device is the control current requirement. However, the forward voltage drop through the device is small, permitting connection of many devices in series for operation from a standard power source.

Another promising device for measuring magnetic fields is the magnetoresistor, Figure 12. The magnetoresistor exhibits a variation in resistance as a function of magnetic flux density. As shown in the figure, this variation is sufficiently large to provide good resolution in measuring the magnetic field.

During experimental activities conducted by The Boeing Company, several relays, solenoid actuators and solenoid valves were instrumented with Hall-effect devides and magneto-resistors. Good results were obtained for determining: application of power to the coils; time of operation for the armature, indicating sticky contacts, both open and closed; and the degree of armature travel. In addition non-magnetic

β	.1 - 30k GAUSS
I_c	50 - 150 mA (@ APPROX. 200 mV)
E_h	10 V - 100 mV
BAND WIDTH	DC - 1 mHz
PHYSICAL	.5 x .25 x .03 inches
	.05 x .05 x .01 inches



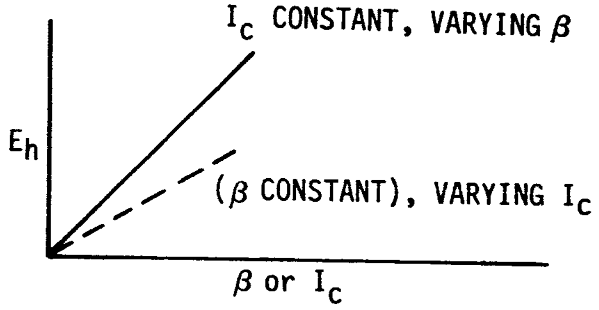
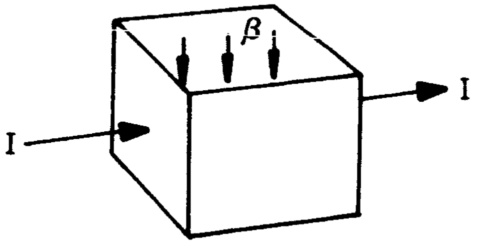
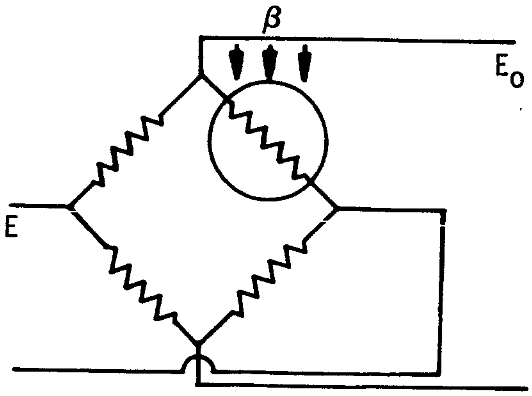


Figure 11: HALL EFFECT DEVICES



β	.1 - 30k GAUSS	
BAND WIDTH	DC - 1 mHz	
$\frac{\Delta R}{R_o}$	(I CONNECTIONS)	4%/KILOGAUSS

(INITIAL R_o 100 - 10,000 Ω)
PHYSICAL - SAME AS HALL-EFFECT DEVICE



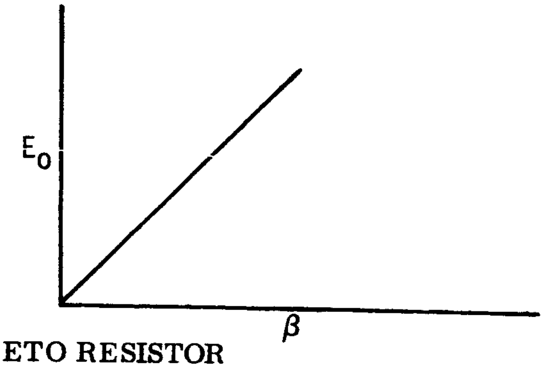


Figure 12: MAGNETO RESISTOR

5.1 (Continued)

devices such as motor shafts were seeded with magnets so that angular position and angular rate were monitored with Hall-effect probes.

Data was also obtained for modulators utilizing Hall-effect devices and magneto-resistor elements. Carrier suppression and linearity achieved were excellent. A flight control computer was successfully tested by stimulating the amplifiers with these modulators.

Incipient failures in electronic components are detectable by an increase in RF noise from the failing part. This noise is broadband, and is exhibited by resistors, semiconductors and electrical joints-contacts. The radiation is apparently due to an arcing mechanism in the component.

Hand-held probes, shown schematically in Figure 13, are commercially available and exhibit a sensitivity on the order of 5 to 40 db above ambient noise, permitting their use in isolation on a circuit board or with a component on the board. They are tuned to approximately 27 MHz to take advantage of low ambient noise.

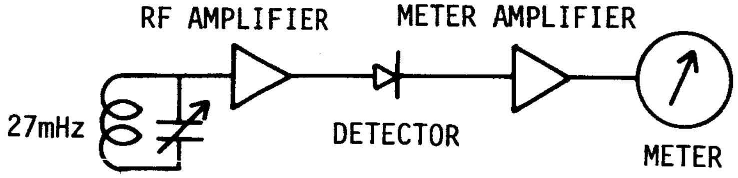


Figure 13: RF MONITORING

The metal-oxide semiconductor-field-effect transistor (MOS/FET) electrometer is a valuable device for measuring low voltages. Although the device requires hard-wire connection to the test point, it can be used without impairing, altering, or affecting the functional system operation. This is possible since the device makes use of the high gate-source resistance of the FET, thereby providing isolation in the order of 10^{12} ohms. The MOS/FET electrometer is shown in Figure 14.

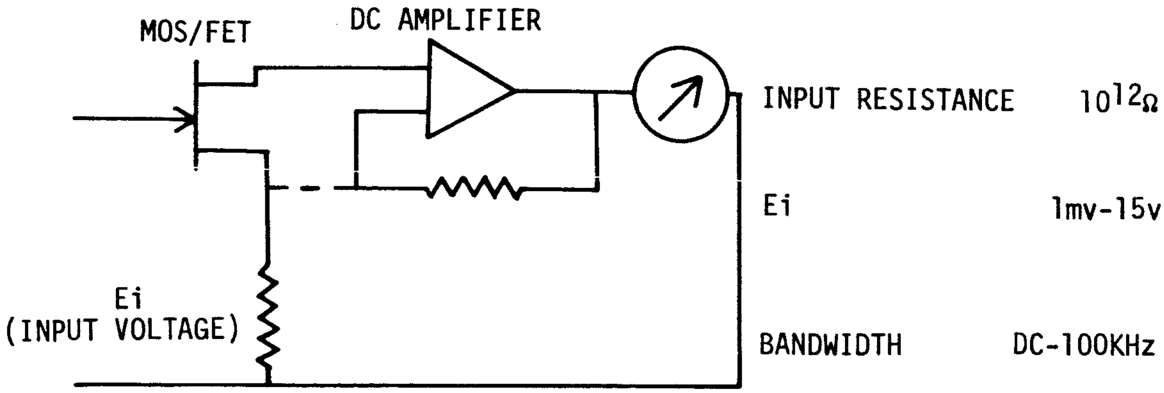


Figure 14: MOS/FET ELECTROMETER

5.2 INFRARED AND HEATING TECHNIQUES

The use of infrared and heat techniques is directly applicable to measuring temperature. Heat is a by-product or secondary effect of vehicle parameters such as: power dissipation, electrical and thermal quality of contacts, thermal profile of modules, friction, and flow rate. Photon and thermal sensors are applicable in this area.

Photon sensors are available operating to 14 microns and, with associated optical components, are compatible with fault isolation down to component parts on an etched circuit board. Figure 15 shows some typical responses for different detectors at various temperatures.

Thermal sensors of compact size are available as resistors, thermo-couples and semiconductors. These sensors are useful over a much wider temperature range than photon sensors. Their primary usefulness is in the measurement of average power levels, since their frequency response is limited by the physical heat sink characteristics of the sensor. They are normally used in direct contact with the source being measured, although they will respond to radiant energy.

The semiconductor sensor shown in Figure 16 is the so-called transistor thermometer. It possesses good linear characteristics over the range of -50 degrees C to 100 degrees C. In most cases no conditioning is necessary as the transistor amplification factor provides a high level output signal.

5.3 OPTICAL AND LUMINESCENT TECHNIQUES

Application of optical and luminescent techniques to passive instrumentation is primarily one of decoupling. By using semiconductor emitters and sensors, incandescent emitters, and enhancement techniques such as fiber optics, optical lens, reflective coatings and gratings, the optical and luminescent area can be made to yield meaningful data for the parameters of voltage, current, vibration, position, rate and temperature.

Shown schematically in Figure 17 are two applications of optoelectronics. In Figure 17 a photo diode has been installed as an additional component in a functional system. It serves as a light emitter and a photo diode sensor is used in the monitoring circuit. The same figure depicts an application of light-sensitive field-effect transistors (FotoFet) for switching the input to a system or subsystem and as a gain-changing switch for an operational amplifier.

5.4 MECHANICAL AND ACOUSTIC TECHNIQUES

Ultra-sonic techniques have been used to measure flow, with the transducers coupled directly to the fluid. They have also been used to measure flow with the transducers clamped to the outside of plastic tubing. Sufficient energy can be

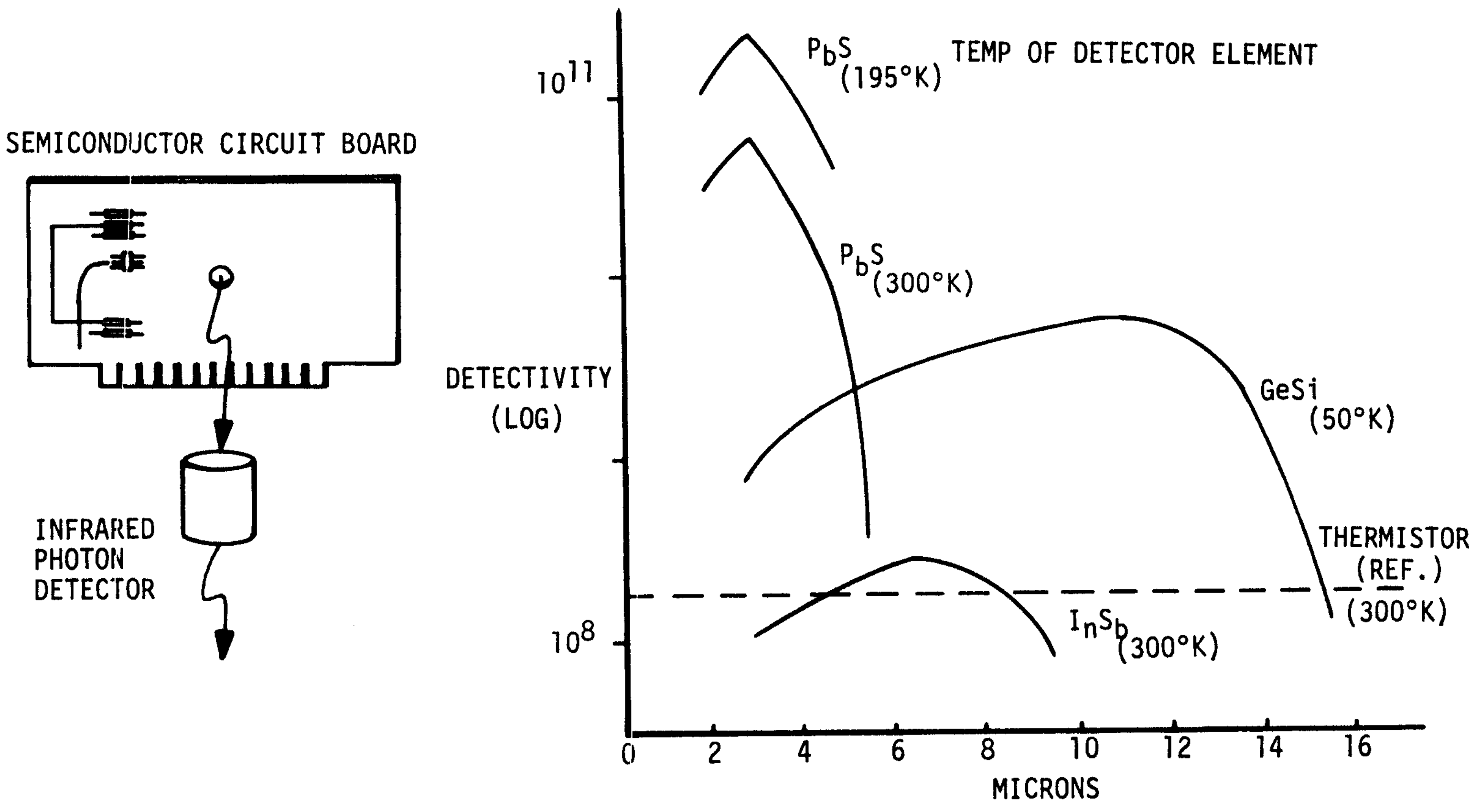
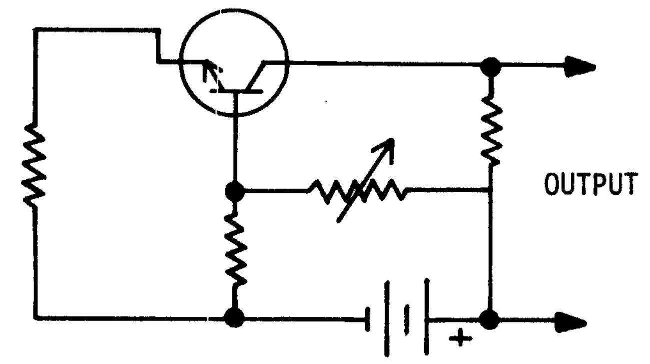
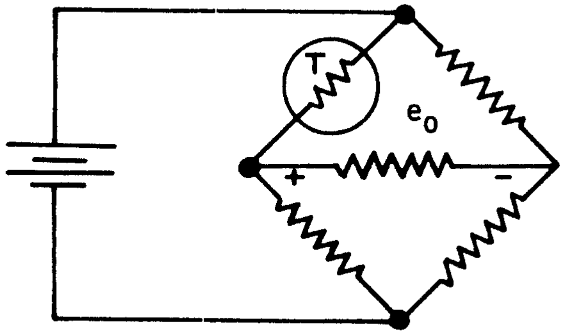


Figure 15: PHOTON SENSOR SENSITIVITIES



TRANSISTOR AS THERMAL SENSOR

ACCURACY —— ± 3%
RANGE —— -50°C to +100°C



THERMISTOR SENSOR IN WHEATSTONE BRIDGE CONFIG.

ACCURACY —— 1% to .02%

RANGE —— 74°C to 260°C

OTHER THERMAL SENSORS

RESISTORS RANGE	-260°C to 1000°C	ACCURACY 0.1%
THERMAL COUPLES RANGE	-420°C to 4500°C	ACCURACY 0.02 TO 1%
LIQUID CRYSTALS	- 20°C to 250°C	
TEMP-PLATE (PLASTIC INDICATOR)	38°C to 593°C	
TEMPLAQ (MATERIAL WITH SPECIFIC MELTING POINT)	38°C to 1370°C	

Figure 16: THERMAL CONDUCTION SENSORS

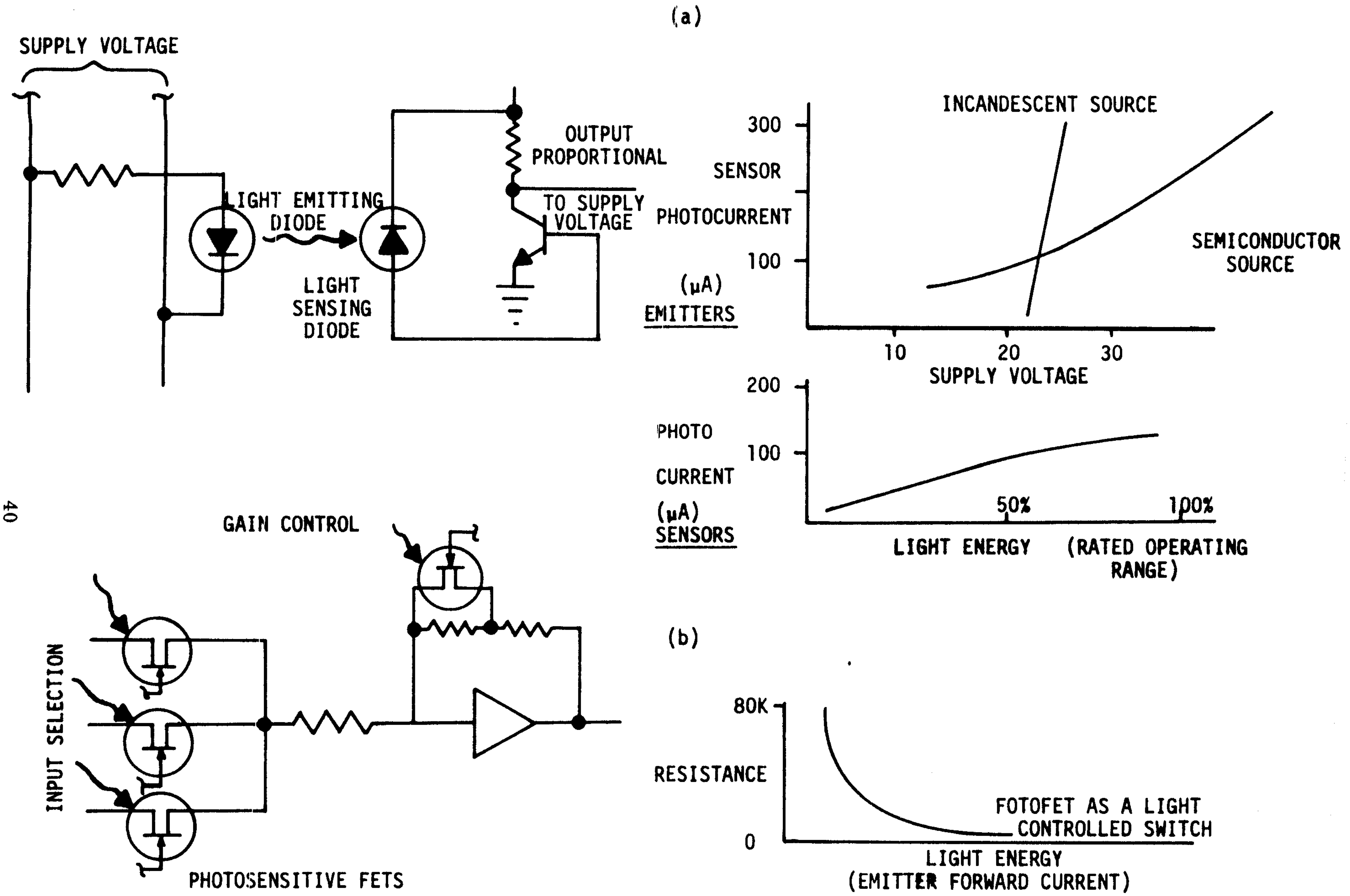


Figure 17: OPTOELECTRONICS

5.4 (Continued)

coupled through metal pipes to perform meaningful measurements of flow rate. The technique takes advantage of the differing propogation velocities in the pipe and the fluid. An ultra-sonic discontinuity in the pipe, normally provided by joints, elbows, valves, tees, etc., is required. Figure 18 shows the characteristics of this technique.

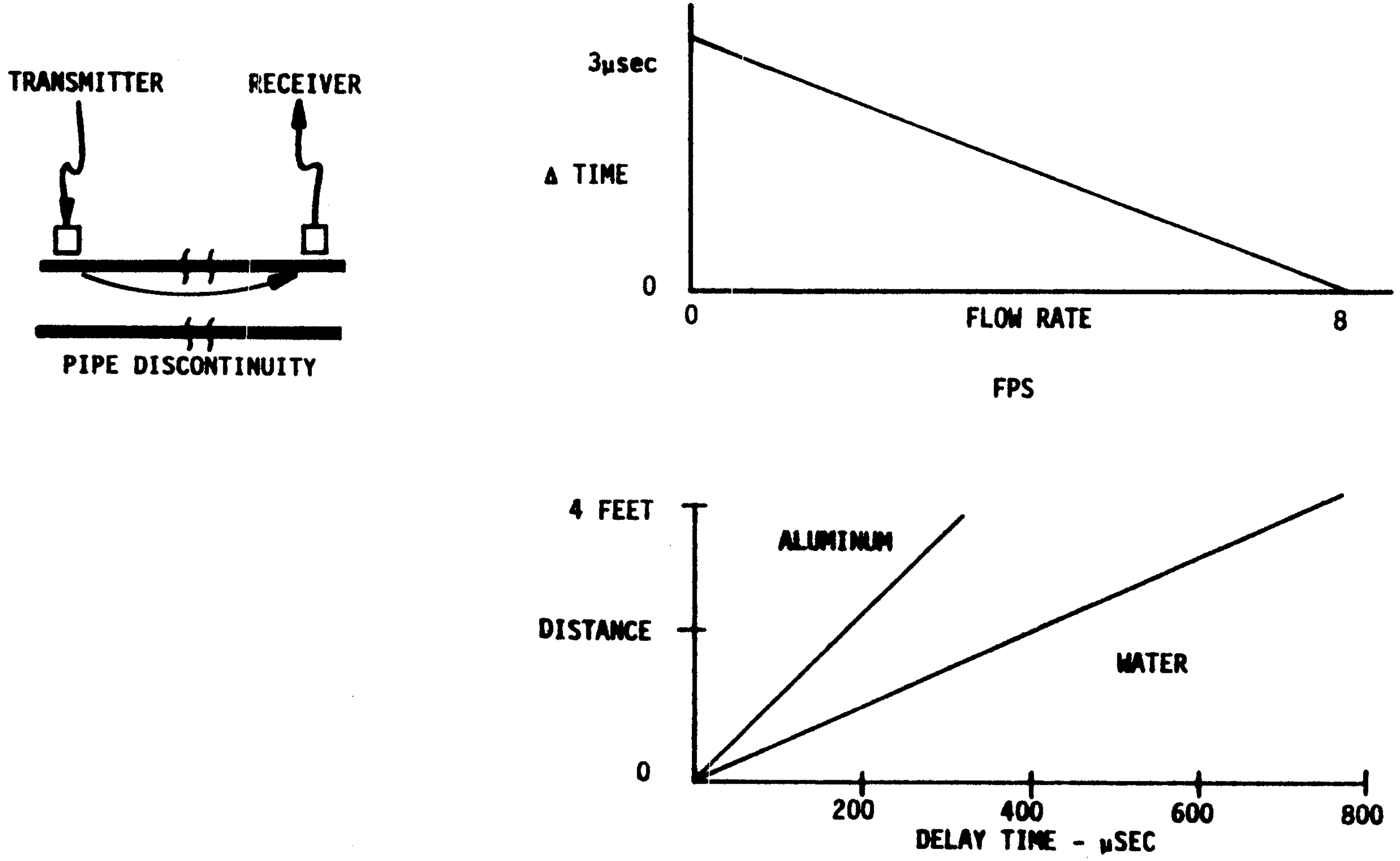


Figure 18: ULTRASONIC FLOWMETER

6.0 CONCLUSIONS AND RECOMMENDATIONS

In accomplishing the Advanced Systems Checkout Design Study certain conclusions relative to the airborne evaluation equipment concept were reached. Paramount among these is the conclusion that the AEE concept is feasible, realistic, effective, readily implementable, and representative of the type of activity required to achieve an acceptable overall systems effectiveness for the Saturn vehicle.

In addition to this general conclusion, the following specific conclusions were reached.

a. The proposed AEE system provides for the function satisfying test equipment to be located aboard a vehicle stage and, to a measure, integrated into the flight systems. This provides the following:

    1. Increased reliability due to evaluation being performed on the stage and utilization of solid state components.

    2. The use of the same equipment for all test phases including post launch.

    3. Accurate comparisons of test data.

    4. Deletion of umbilicals for test purposes.

b. The proposed AEE system utilizes test steps and routines similar to those currently employed thereby insuring fault isolation to a replaceable assembly and a high degree of confidence following a successful test.

c. The proposed AEE system includes provisions for positive control and assessment of vehicle emergency situations by the utilization of on-board fixed logic for catastrophic events, and computer control of other events.

d. The proposed AEE system allows vehicle implementation to proceed in degrees to assure operability prior to the deletion of current methods.

e. The proposed AEE system minimizes size, weight and power penalties by utilizing solid state discrete components and microcircuits.

As a result of the above conclusions, recommendations relative to continuation of the effort accomplished during the course of the study are presented as indicative of the effort necessary to achieve full implementation of the AEE concept. These recommendations represent a logical and timely effort, which, if carried out, will result in the early development of autonomous (in regard to the test and checkout function) stages for the Saturn vehicle.

6.0 (Continued)

It is recommended that a prototype on-board test system development program be initiated. This program should include development of prototype hardware and software in conformance with the guidelines of Section 4.0 of this report.

It is recommended that the prototype system both hardware and software elements be verified utilizing the systems development facility (SDF) currently in operation at the Marshall Space Flight Center.

REVISIONS

REV. SYM	DESCRIPTION	DATE	APPROVED