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SATURN V VEHICLE ELECTRONICS

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ABSTRACT

Saturn V Vehicle Electronics

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This presentation is a review of the electrical and electronics systems of the Saturn V launch vehicle. Since airborne and ground electronics cannot be separated as a system, this presentation will touch upon both the airborne and ground checkout equipment. Certain airborne electronic items are singled out in order to elaborate upon the application of computers for checkout and launch. This review covers in a broad sense such airborne electronics as the control computer, the measuring telemetry and RF systems, the switch selector, the digital command receiver and the remote automatic calibration system. The ground support equipment electronics covered include such equipment as the data link, computer system and display systems. The importance of software in the Saturn V program is stressed by the application of a standard program language through the use of acceptance test or launch language (ATOLL).

SATURN V LAUNCH VEHICLE ELECTRONICS

OUTLINE OF PRESENTATION

A. INTRODUCTION

1. Launch Vehicle Description Breakdown into Stages
2. Role of Instrument Unit for Launch Vehicle from Systems View Point
3. Combination of Electrical Ground Support Equipment with The Vehicle into One Overall System
4. Typical Launchsite Operation
5. Description of Major Electronic Systems

B. VEHICLE ELECTRONICS

1. Switch Selector
2. Digital Command Receiver
3. Exploding Bridge Wire System
4. Measuring, Telemetry, R-F Systems
5. Remote Automatic Calibration System

C. GROUND SUPPORT EQUIPMENT ELECTRONICS

1. General Layout and Function of GSE Electronics
2. Data Link
3. Computer System
4. Display System

D. SOFT WARE

1. Programming Effort
2. Standardization of Programming Language
3. Acceptance Test or Launch Language (ATOLL)

E. CONCLUSION

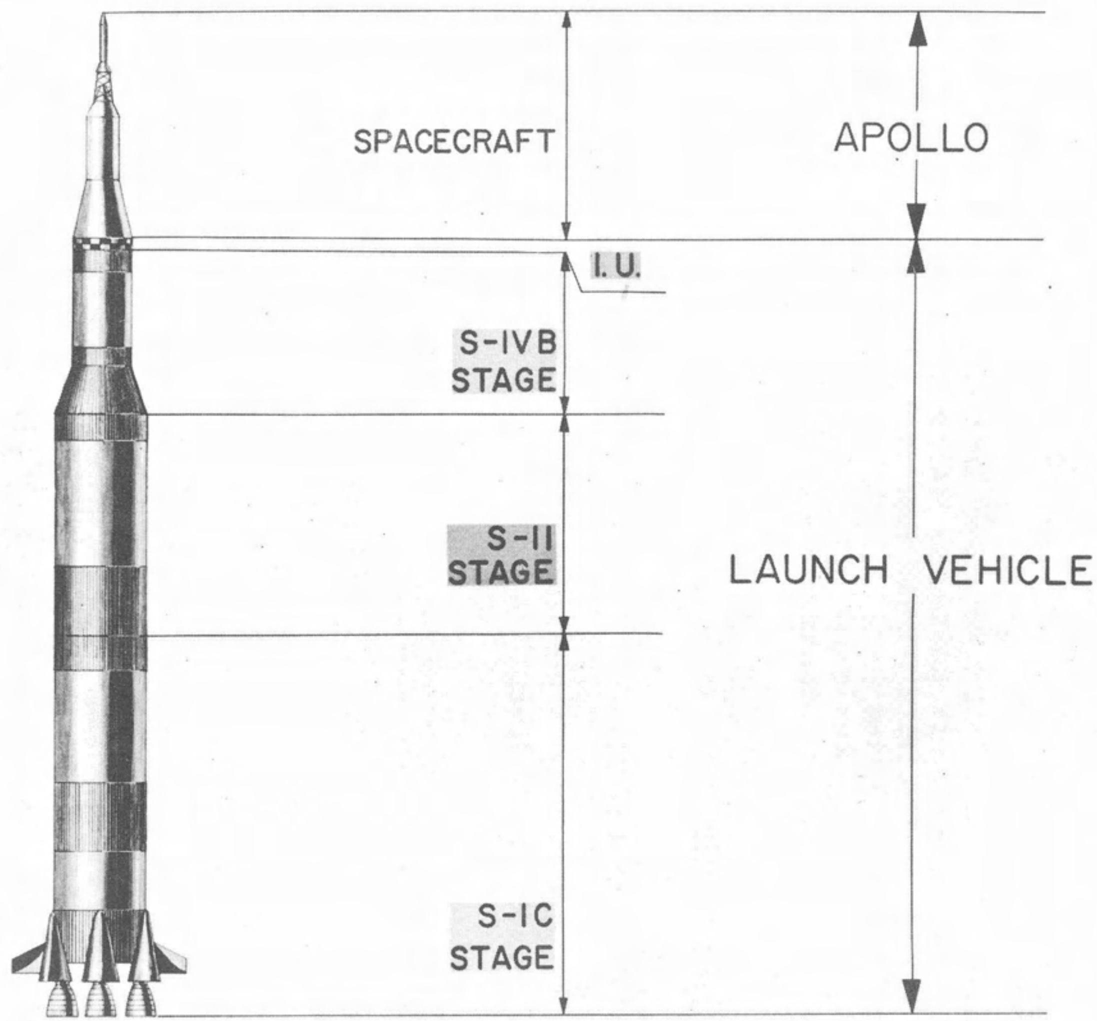

FIGURE I. SATURN V CONFIGURATION

SATURN V LAUNCH VEHICLE ELECTRONICS

A. INTRODUCTION

A discussion of electronics with respect to the Saturn V Launch Vehicle should include some consideration of the launch vehicle configuration as illustrated in Figure 1. The Saturn V Launch Vehicle, consists of the three propulsion stages and the instrument unit employed to lift, propell, guide and control the Saturn-Apollo from liftoff through the injection phase of its mission. The first stage, S-IC, built by the Boeing Company, the second stage, S-II, built by North American Aviation, and the third stage, S-IVB, built by the Douglas Aircraft Corporation. The instrument unit is presently being designed by MSFC, with the help of IBM who will manufacture all Saturn V instrument units.

The S-IC, S-II and S-IVB Stage are purposely called propulsion stages, neither of which is entirely operational within itself from a mission standpoint; they all must operate in conjunction with the instrument unit. The instrument unit is identified as the electronic stage of the launch vehicle. It contains the launch vehicle guidance system, provides control data to the stages, and furnishes all sequencing and timing functions to the stages; therefore, it must follow an overall scheme for the entire launch vehicle system.

This discussion cannot isolate the airborne electronics of the launch vehicle, since the electrical checkout and launch equipment is a part of the entire system. Very early in the Saturn program it was decided:

> To use a ground computer system in conjunction with the airborne digital computer.
>
> To use these computers as major system components for controlling stage and launch vehicle checkout.
>
> To computer control or automate stage and launch vehicle checkout.
>
> That individual stage checkout equipment would not be employed at the launch site, since we did not want separate computer systems for each stage, and from a system standpoint, the stages lose their identity after assembly into the total launch vehicle; therefore, one set of checkout equipment is provided for the assembled vehicle at the launch site. This equipment is systems oriented, such as propulsion, control, networks, etcetera, and is not stage oriented. The launch site and preflight-inflight checkout requirements are the main factors used in deciding the exact equipment to be used.

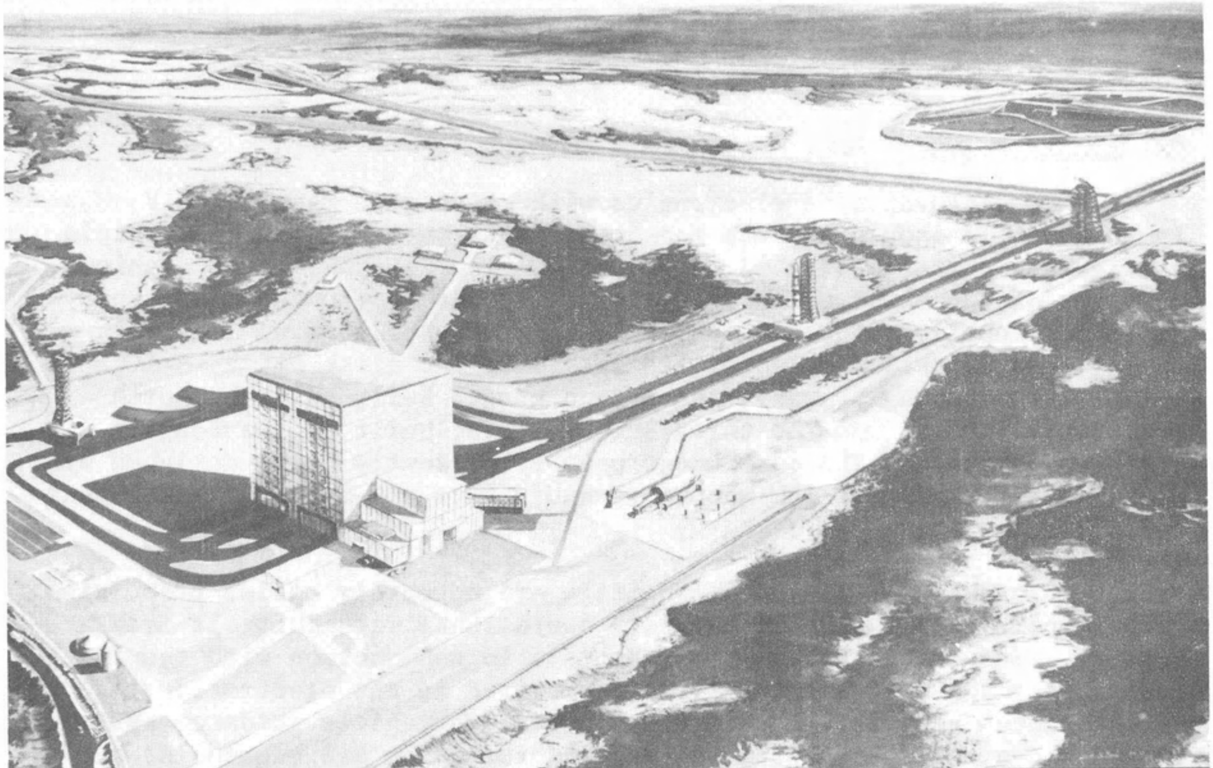

FIGURE 2. SATURN LAUNCH COMPLEX-39

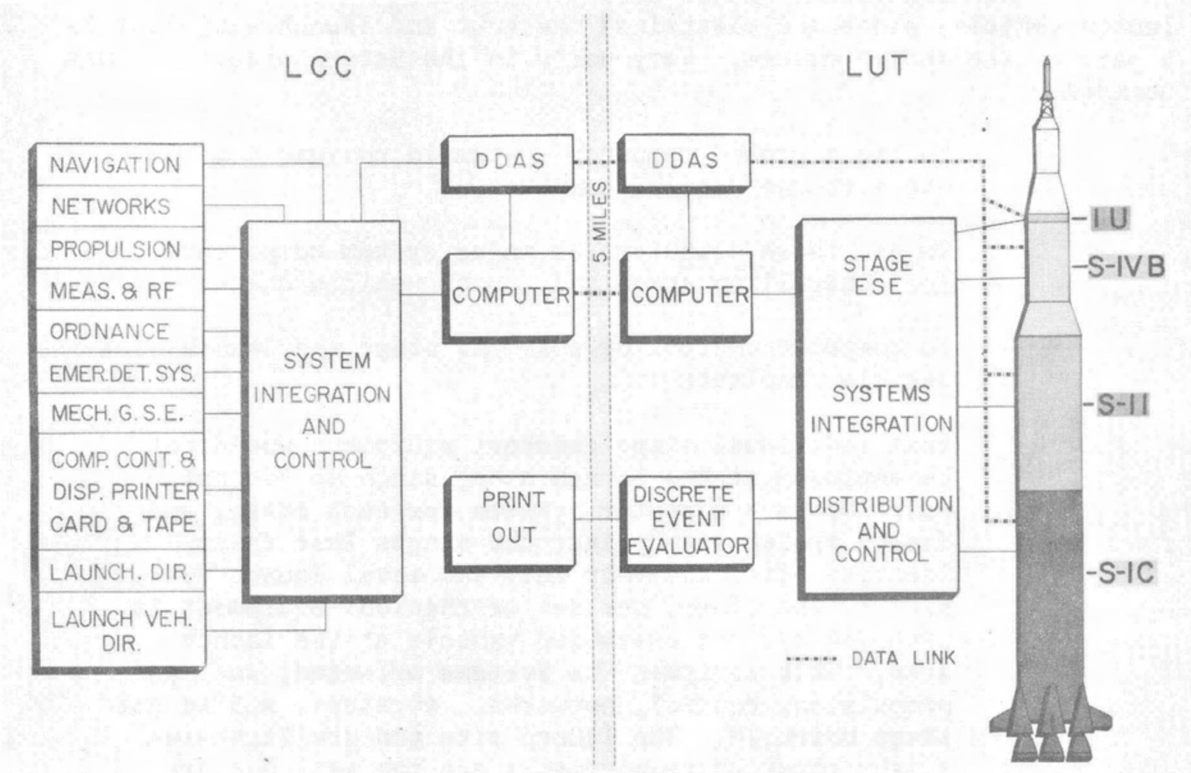

FIGURE 3. LAUNCH COMPLEX 39 ESE BLOCK DIAGRAM

Saturn V does not use new designs throughout. Actually the Saturn I and IB Vehicles are the test beds for most of the electronics used in the Saturn V Program.

Figure 2 gives you an idea of the Saturn V launch complex layout and for better understanding of the discussion to follow, it seems appropriate to briefly describe its operation. The vehicle will be assembled in the vertical assembly building and completely checked out there. Each stage is verified separately and then the combination of all stages with the instrument unit will be checked out as one system. This is done prior to moving the entire system from the vertical assembly building to the launch pad which are several miles apart. During transfer of the launch vehicle to the pad no umbilical connections are broken between the launch umbilical tower and the stages.

The functional interconnect diagram shown in figure 3 presents a typical Saturn V launch site with only the major areas of functional operations shown. The central item of equipment in the system is the computer. Two computers operate in conjunction with each other but are separated by several miles between the launcher/umbilical tower (LUT) on the pad and the launch control center (LCC) in the vertical assembly building. Data is transmitted between both computers via coaxial data links. In conjunction with the computer system, we make full use of a digital data acquisition system providing preflight telemetry in the proper format to be used by the computer system.

A remote automatic calibration system is utilized to provide a fast means by which to address the many stage measurements to be calibrated. As mentioned before, the launch site checkout equipment is not stage oriented but is systems oriented, consequently, operation and monitor stations are provided for such systems as:

Navigation
Networks
Propulsion
Measuring & RF
Ordnance
Emergency Detection
Mechanical Ground Support

A control system and cathode ray display employing the computer, provides the operators of the above mentioned systems with both the status of the system under test and a means of controlling the tests or altering a program when it becomes necessary. The Launch Vehicle Test Director and the Overall Launch Director is also provided with this control and display system as an aid for decision making and status monitoring.

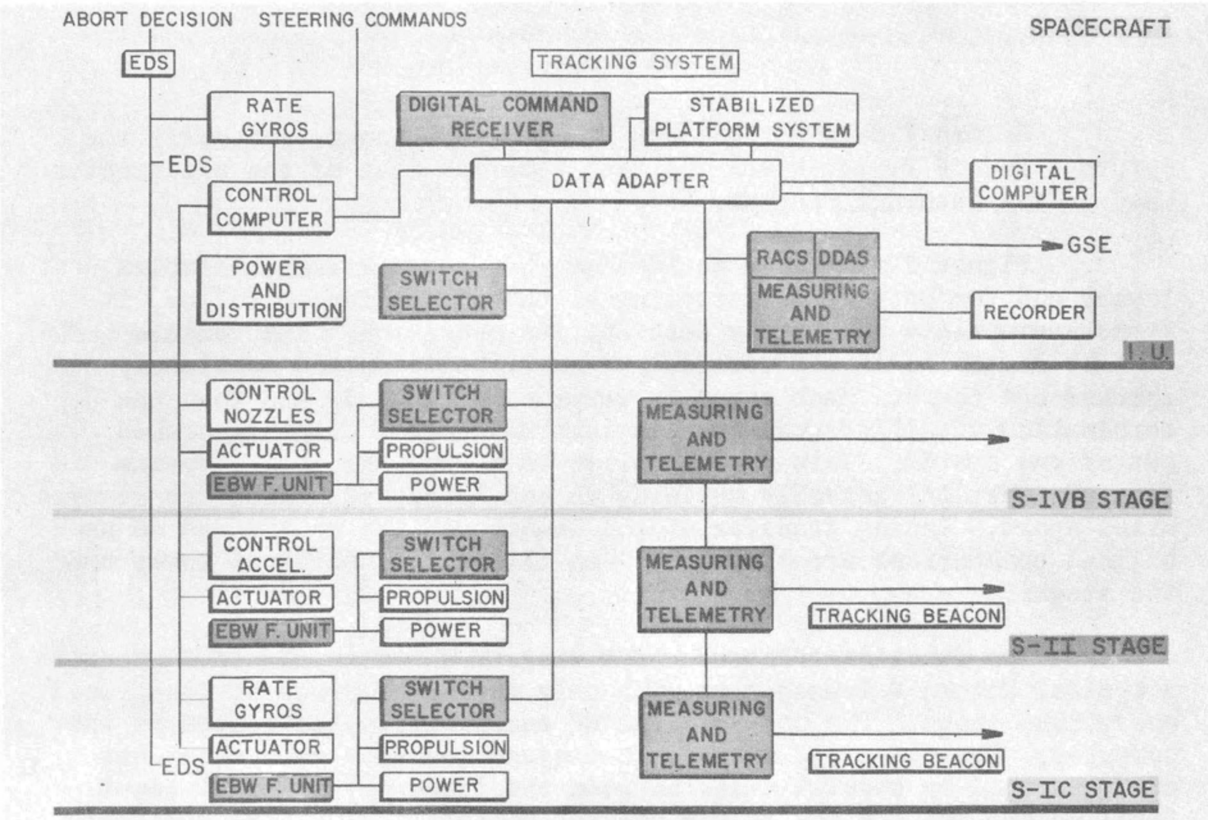

FIGURE 4. SATURN V ELECTRONICS

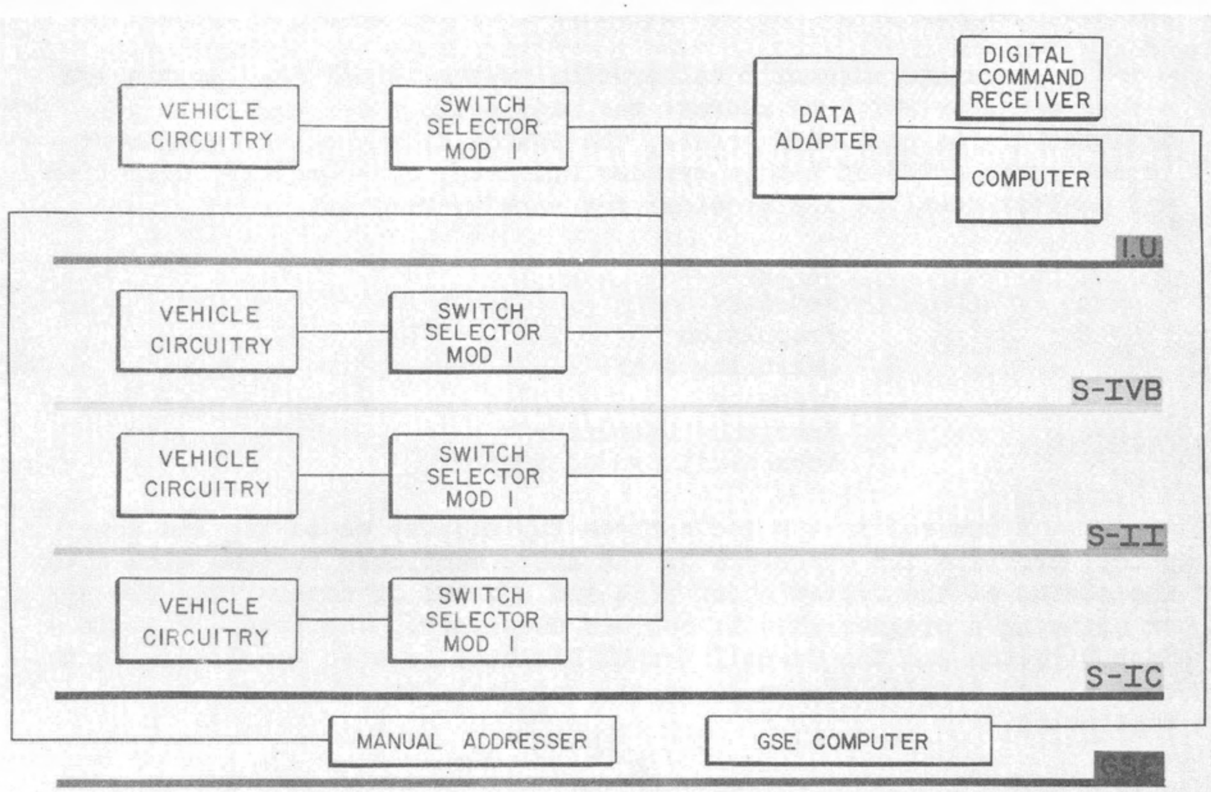

FIGURE 5. SWITCH SELECTOR SCHEME

B. VEHICLE ELECTRONICS

Time does not permit a description of all the electronic elements in the Saturn V launch vehicle; therefore, this presentation will be limited to the electronic packages indicated in color on the chart (Figure 4).

1. Switch Selector

A switch selector is located in each of the stages and the instrument unit. Based on the decision, mentioned earlier, the airborne digital guidance computer will be used on every flight. At the same time, it was also decided to utilize this computer for other functions. Since the entire Saturn V timing system derives from the airborne computer, a switch selector was developed to insure compatibility between the computer and the stages. The switch selector is basically a series of low power switches; the input of which is individually selected and controlled by a coded signal from the computer. The switch selector decodes internally from an 8-bit word and furnishes an output from one of the 112 function relay driver outputs. The block diagram shown as figure 5 depicts its utilization in all stages. The computer is programmed to control the vehicle circuits by addressing the switch selectors in the respective stages. During flight, a digital command receiver can be employed to address the computer which inturn addresses the stage switch selectors. This system permits command of an in flight vehicle from the ground through the command receiver-computer link. Through this link, the switch selector may be addressed from the ground either manually or automatically using the ground computer system.

2. Digital Command Receiver

The digital command receiver mentioned in connection with the switch selector is another electronic item of special importance as an aid to orbital checkout. The digital command receiver will play a vital role during the Saturn V missions again utilizing the airborne digital computer. As part of its mission Saturn V will place the Apollo Spacecraft affixed to the S-IVB stage and the instrument unit into earth orbit. Due to the requirements of the Apollo Spacecraft guidance system, from one to three orbits are necessary with this combination of spacecraft, S-IVB Stage and instrument unit. During these orbits the S-IVB stage and instrument unit will be conducting a number of electrical, electro-mechanical and electronic operations; some of which must be controlled by radio command from the ground to the airborne digital computer in the instrument unit. The radio command "up-link" performing this communication task is called the Saturn V IU command.

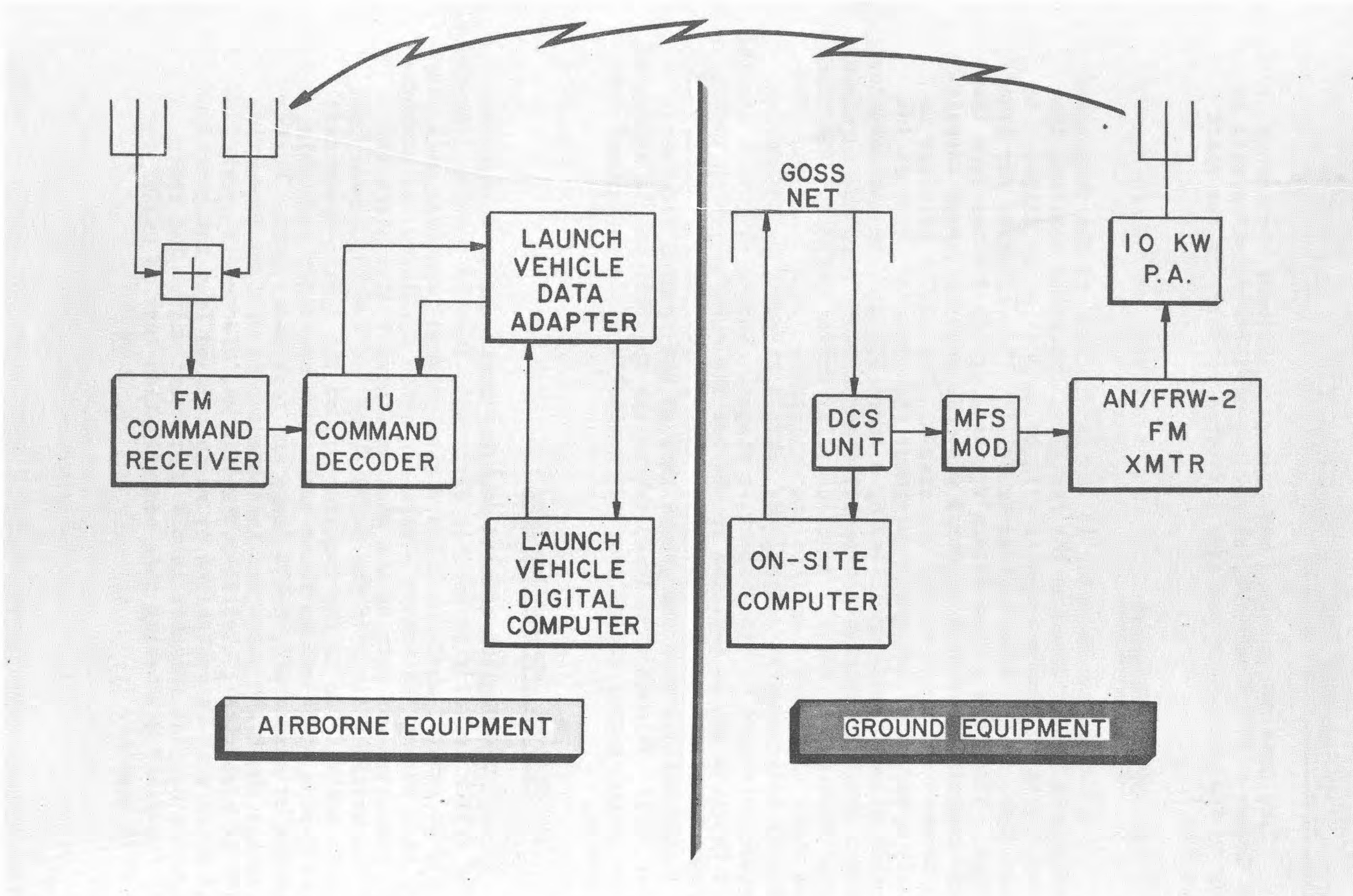

FIGURE 6. IU COMMAND UP-LINK, SIMPLIFIED BLOCK DIAGRAM

The block diagram (Figure 6) shows the FM command receiver with its antenna connected to the instrument unit command decoder. This decoder is connected through the data adapter to the airborne digital computer.

The ground computer is connected to the ground operational support system (GOSS) network for data up-dating and gives commands through the coding and modulating unit to the transmitter which sends correction or command signals to the orbiting equipment. Another function of the digital command system during the Saturn V missions may be a command or commands (undefined as yet) at the time of the service module docking maneuver. This will occur about 15,000 N. miles from earth.

What are the requirements for such a command system? The function of the system is to accurately and reliably receive information from the ground digital coding unit, transmit this information to the vehicle and present it to the vehicle digital computer.

The entire system must be reliable over the 15,000 N. miles (slant-range) to the orbiting vehicle.

This system must utilize existing ground operational support system (GOSS) network equipment and be compatible with the AN/FRW-2 transmitter.

The system must exhibit a very low probability of presenting erroneous information to the computer.

The command format chosen uses a word length output of 35 bits (175 sub-bits). The 35 bits are divided into:

a. Vehicle Address

b. Launch Vehicle Data Adapter Control

c. Synchronization

d. Interrupt

e. Priority Interrupt

f. Mode

To assure correctness of the received versus the transmittal command, an automatic verification mode is employed utilizing onboard PCM telemetry before commands enter the computer storage.

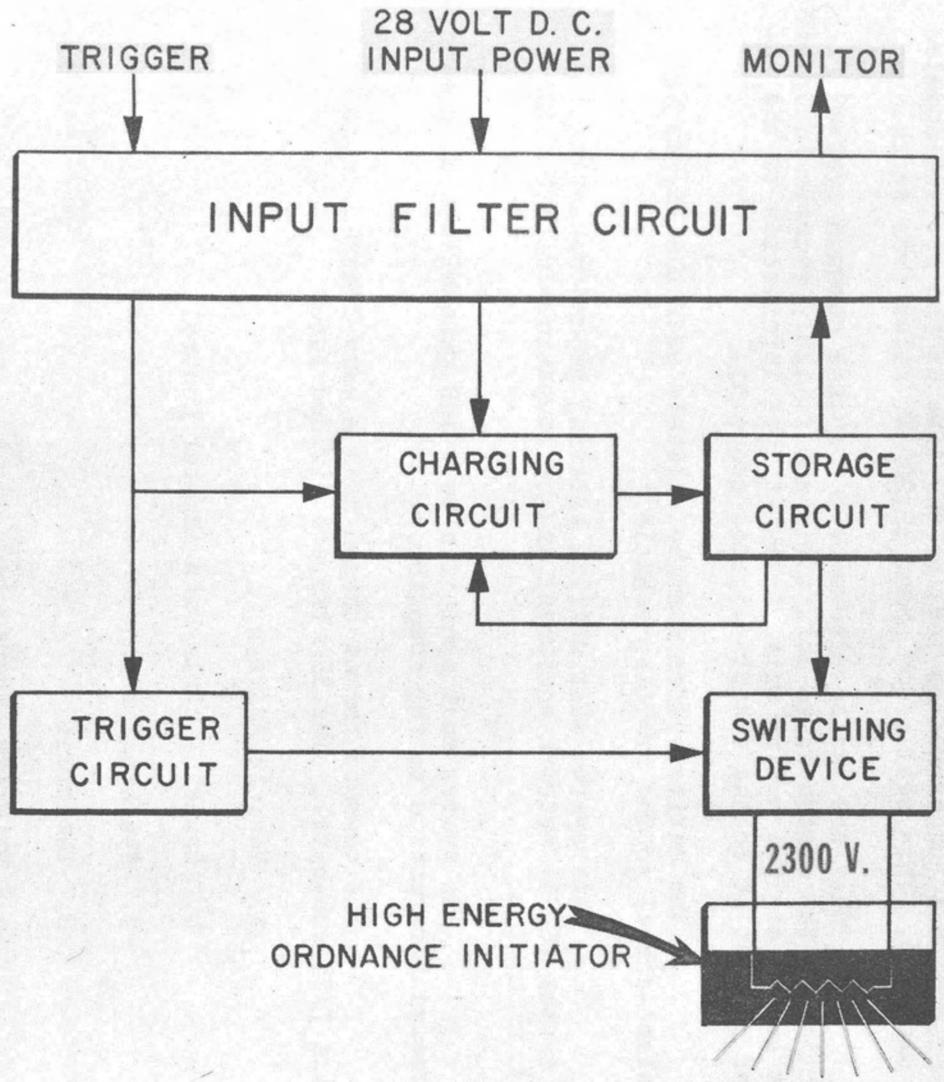

FIGURE 7. EXPLODING BRIDGE WIRE SYSTEM

3. Exploding Bridgewire System

The Exploding Bridgewire (EBW) System is another area of electronic equipment design pursued in the early Saturn Program which will be used exclusively on the Saturn V vehicle. The EBW system includes the electronics needed to fire the vehicle ordnance items. The exploding bridgewire system, not actually a new system, was designed and is used in Saturn for launch vehicle destruct, for retro and ullage rocket ignition, ullage rocket jettison, and for stage separation. A total of 18 firing units are employed throughout the Saturn V launch vehicle. As stated before, the exploding bridgewire system is not new but the problem of delivering high power - short duration pulses is unique to Saturn because of the long transmission lines. Figure 7 illustrates the major components of the exploding bridgewire system. The exploding bridgewire firing unit is a standard component of the entire vehicle system and is used on all stages alike. In principal, the firing unit receives 28 volts DC and converts it into a 2,300 volt DC charge which is stored in a one microfarad capacitor. The EBW firing unit provides a trigger to discharge this stored energy in a short duration pulse into a relative insensitive explosive detonator or initiator. The advantages of the exploding bridgewire system over the standard 28 volt ordnance systems are:

1. Less sensitive to physical environment, temperature, shock, etc.

2. Simplification or elimination of safety and arming devices.

3. Less sensitive to electrical stresses such as radio frequency fields, stray currents, cross talk, or transients.

4. Provides for the use of less sensitive explosives for detonators or initiators.

The electronics discussed thus far are directly connected with the functional operation of the Saturn V launch vehicle. Other major uses of electronics in the vehicle are in the areas of measuring, telemetry and RF.

4. Measuring, Telemetry & RF

Relative to the measuring program for the Saturn V launch vehicle, it must be kept in mind that we are concerned with a research and development program, and considerable data must be evaluated before we can call the launch vehicle operational. It is through the measuring systems that the data is obtained to make these evaluations.

STAGE	TELEMETRY SYSTEM	NO. OF RF LINKS	CHANNELS AVAILABLE	TRANSMITTER FREQUENCY	TRANSMITTER POWER, WATTS
I.U.	FM/FM SS/FM PCM/FM	2 1 1	500	225-260 MHZ	20
S-IVB	FM/FM SS/FM PCM/FM	3 1 1	1,000	225-260 MHZ	20
S-II	FM/FM SS/FM PCM/FM	3 2 1	1,000	225-260 MHZ	20
S-IC	FM/FM SS/FM PCM/FM	3 2 1	1,000	225-260 MHZ	20

FIGURE 8. TELEMETRY SYSTEMS IN THE VARIOUS SATURN V VEHICLE STAGES

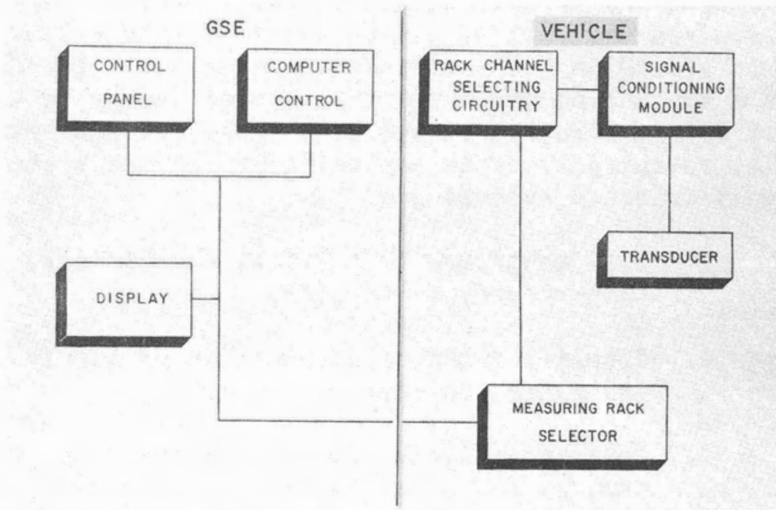

FIGURE 10. RACS SIMPLIFIED BLOCK DIAGRAM

SYSTEM	S-IC	S-II	S-IVB	I. U.
MISTRAM		●		
ODOP	●			
AZUSA - GLOTRAC				●
C-BAND RADAR				●
RADAR ALTIMETER				●
MINITRACK				●
TV	●		●	
GUIDANCE COMMAND				●
RANGE SAFETY COMMAND	●	●	●	

FIGURE 9. SATURN V RF SYSTEMS

Measuring devices such as transducers are used in the Saturn V Program and have one general function which is to sense conditions and report these conditions by an electrical output. During most of these measurements, the transducer output is sampled at appropriate intervals and routed to a telemetry channel. There are more than 2000 measurements made throughout the entire Saturn V launch vehicle. An appropriate combination of three basic telemetry techniques is used in Saturn V to provide the required transmission capacity and characteristics. These are FM/FM, SS/FM, and PCM/FM. Each of these systems has characteristics appropriate to handle specific categories of data. In combination they form an efficient, reliable and flexible data gathering system. The tabulation in figure 8 outlines the use of the different telemetry systems in Saturn V launch vehicle. Shown by stages are the telemetry systems, number of RF links, channels available, transmitter frequencies and transmitter power. It is presently anticipated that 21 RF links will be employed by the Saturn V launch vehicle. In addition to the telemetry requirements, RF systems are employed for other needs of the vehicle. These RF systems are listed in figure 9, and include Mistram, ODOP, AZUSA - Glotrac, C-Band Radar, Radar Altimeter, Minitrack, Television, Guidance Command and Range Safety Command.

5. Remote Automatic Calibration System

The tremendous size of the measuring program made it necessary to find a quick way to calibrate the 2000 or more transducers for an immediate analysis of the entire measuring program prior to vehicle liftoff. To implement the quick calibration, a remote automatic calibration system is being developed. Figure 10 shows a simplified block diagram of the ground support equipment tied in with the vehicle measurements. Using the ground control panel, selection is made of: the measuring rack to be addressed in the vehicle, the telemeter channel, and the calibration mode. Since the ground computer can and usually addresses the vehicle as pre-programmed, manual operation from the control panel will be used only for certain special addresses to a specific transducer.

The vehicle has the equipment required for measuring rack and channel selection, and the equipment for signal conditioning through which the channel calibration level is selected, the transducer to be addressed and calibrated. The remote automatic calibration system enables the test engineer to determine the status of the entire instrumentation network. The system provides the ability to command any instrumentation point that requires signal conditioning from a "run" to a "high" or "low" calibration condition. This system, as indicated before, can be operated manually or automatically through the ground checkout computer.

The use of a binary coded signal, decoded in the vehicle, allows a large number of points to be controlled by using only a few address wires. This saves time during instrumentation checkout, allows checkout just before launch which was not possible before, and allows for calibration of instrumentation required during launch countdown which should occur just prior to computer evaluation. Last minute calibration allows for flight adjustment which will result in increased accuracy and confidence.

Another significant use of the telemetry systems is for pre-launch vehicle monitoring. Pre-launch vehicle monitoring functions are integrated into the vehicle stage telemetry design in such a way that no significant increase in telemetry hardware is needed. This pre-launch monitoring is performed by equipment used also for inflight stage monitoring; therefore, no vehicle assemblies can be specifically identified as a digital data acquisition system. For convenience, the vehicle stage telemetry system will be referred to as the DDAS output.

The digital data acquisition system output of the vehicle is referred to in conjunction with the telemetry system because power is supplied to the portions of the vehicle such as telemetry multiplexers, PCM/DDAS assemblies, etc. for pre-launch monitoring. The DDAS may then serve as a utility link any time data is needed from the stage, including stage preparation and checkout.

C. GROUND SUPPORT EQUIPMENT ELECTRONICS

1. General Layout and Function of GSE Electronics

The major item of ground support equipment to be discussed is the computer system used for launch site checkout and launch. Some of the typical functions the computer system must perform are: Systems test, evaluation and monitoring of:

a. Flight Guidance Computer and Signal Processor

b. Stabilized Platform

c. Control Computer

d. Azimuth Positioning System

e. Flight Telemetry System

f. Inverter and Power System

g. Emergency Detection System

h. Radar Altimeter

i. Remote Automatic Calibration System

j. Ground Equipment Test Set

k. Stage Interface Test Set

l. Countdown Clock

m. Stage Electrical System

The Saturn V ground computer system consists of two computers. One on the launch - umbilical tower (LUT) and one in the launch control center (LCC).

2. Data Link

Serving as a life line between both these computers is the data link which terminates at each computer complex and each link terminal is serviced by an input data channel of the operational computer. The purpose of the data link is to provide programmable communications between the two computer systems which may be as much as 7 miles apart. Two types of information may be transferred over the data link between the computers:

a. Data relating the experimental results of programs.

b. Commands in the form of request for tests and acknowledgement of the command that tests be run, or that data be transferred.

The most significant system parameters are:

a. Commands are fully duplexed.

b. Data words are half duplexed.

c. Information is transmitted serially by computer word with complete error checking of each word.

d. Distance between terminals may range from 1500 ft. to seven miles.

e. Nominal effective information carrying capacity is 133,000 bits/second.

f. Gross transmission rate with redundant bits of 250,000 bits/second.

g. Output rate of the transmitting link is determined by the receiving system.

h. Each terminal has simulating circuitry that can be used for self checking purposes in a disconnect mode.

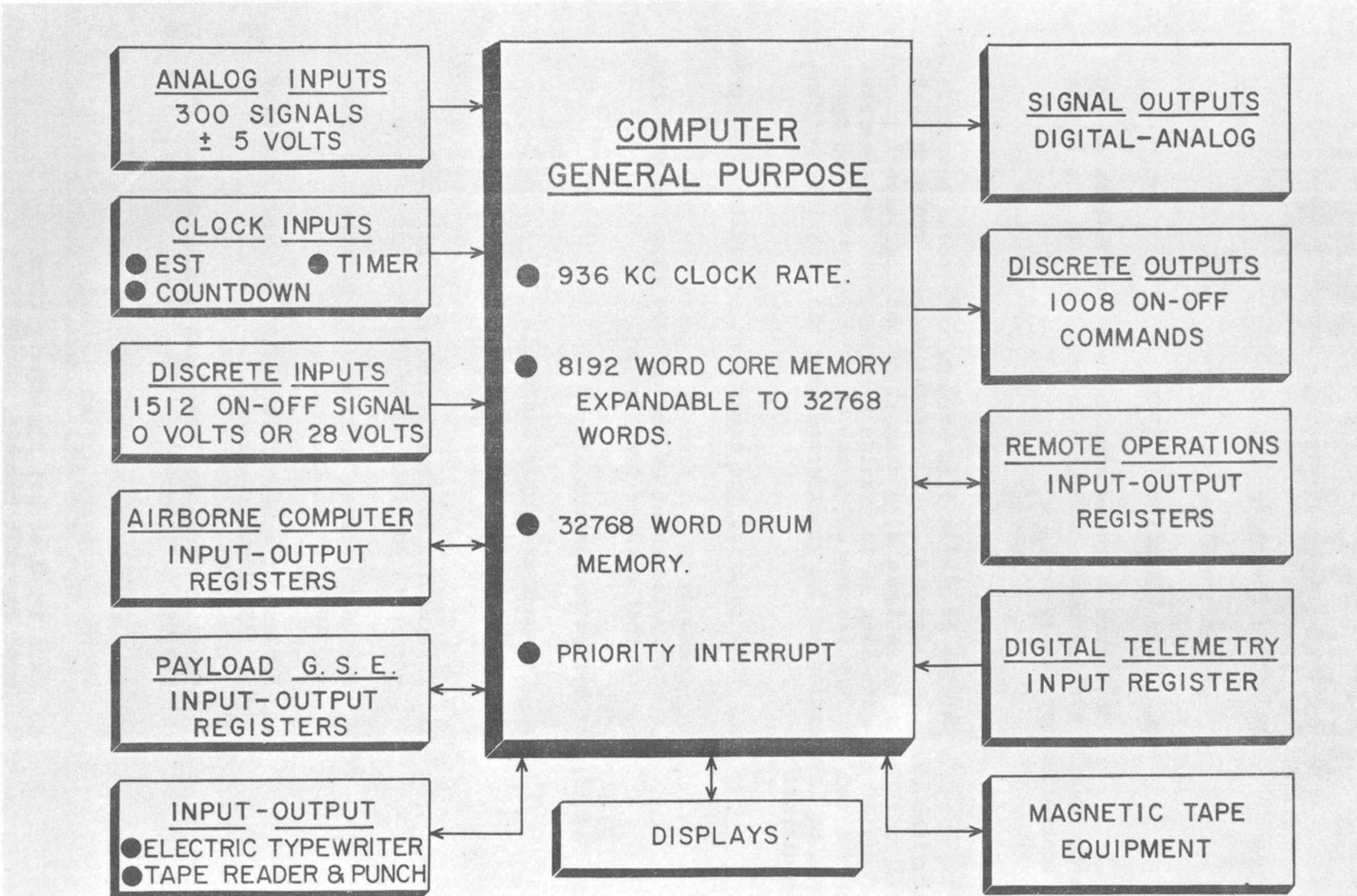

FIGURE 11. SATURN V COMPUTER COMPLEX BLOCK DIAGRAM

3. <u>Computer System</u>

Each computer is a general purpose digital computer with internally stored programs, employing process control, and designed specifically for real-time control in industrial application. The computer system's mode of operation is parallel transmission, serial arithmetic; its logic is single address; its word structure is 9 bit instruction, 3 bit address modifier and 12 bit address field; and it has 24 bits data. The computer has six index registers, 15 bits each. It has a magnetic core memory storage of 32,786 words. Access to the 32,786 word memory is accomplished through the utilization of an index register for purposes of address modification. The computer clock rate is 936 KC. The computer has a drum memory of 32,786 words with a priority interrupt possibility.

Figure 11 is a block diagram outlining what the computer can do. Shown on the left of figure 11 are the 300 analog inputs; clock inputs presented in eastern standard time, timer inputs and countdown clock connections; discrete inputs, airborne computer input-output registers and input-output registers of the payload or spacecraft ground support equipment.

Shown on the right of figure 11 are the digital outputs, digital-analog, discrete outputs, 1008 on-off commands, remote operations input-output registers and digital telemetry input registers. Input-outputs may be recorded by electric typewriter, magnetic tape or punch tape. Data storage may be accomplished by connecting the magnetic tape equipment. A further connection is made to the display system operating in conjunction with the computer.

4. <u>Display System</u>

Operator displays associated with the Saturn V launch vehicle program can be divided into three groups: Those that receive the data primarily from DDAS, those that receive data from the computer to operate control and display consoles and those that receive safing data via hardwire.

The Saturn operational checkout computer utilizes an internally stored program and therefore has an inherent ability to accumulate large volumes of data in a very short time. Evaluation of this data is contingent upon the methods employed to display and communicate this data to the test engineer. Means are provided to facilitate rapid evaluation of test data to determine correlations and to support trend analysis, malfunction and timing of events. To achieve the degree of control and monitoring capability that is required by the test operator, it was necessary to provide a display system composed of many individual consoles, opposed to one central display. With this type of display and its associate panel, experimentation was undertaken to (1) determine the extent of automation, (2) methods to improve man/machine relationships and (3) the development of techniques for remote station control of the operational computer. The most economical approaches were of considerable importance in making these determinations.

The Saturn V display system will consist of several equipment racks which will contain the central storage, logic, and the distribution equipment capable of driving up to 20 cathode ray tube (C.R.T.) display consoles. The present plan calls for 10 to 12 C.R.T. Consoles in the Launch Control Center (LCC). This display system will be a refresh type, thereby having the ability to display a page of data indefinately. The tube will have the ability to display any combination of 62 characters including all standard alpha numeric as well as additional special characters. The communication links between the computer system and display will utilize a six bit code for characters and a nine bit code for graphic presentation. The speed at which information can be accepted for display will be approximately 250,000 characters per second. A keyboard, for input and control of information to the computer, includes all characters available for display by the tube. Additional controls are available for: power-on-off, cursors enable control, intensity and contrast control, selective data erase, manual erase, display selection and hard copy control; to name a number of the more important controls.

The display system is one of the principal methods for operator on-line communications with the computer system. It provides a means to request data from the computer, display the data in tabular or graphic form and allow a qualified operator to edit or correct the data for insertion into the computer for processing. Each operational area will be furnished at least one display console. Computer attention is attained through external, automatic priority interrupt. Priority assignment of consoles is accomplished by internal program priority methods. The test conductor and several other display areas can look in on any other display presentation at their discretion.

From the few examples presented thus far, it is obvious that something else is needed besides the hardware of the Saturn V system; this, of course, being the Software program.

D. SOFTWARE

1. Programming

The software of the Saturn V is a big item and must be established well within the schedule. Conceptual design, development and control of computer programming for space vehicle operation have resulted in very broad problems during the last two years. Systems engineers and computer programmers have observed the conceptual developments with misunderstandings and loosely defined parameters. Even after the methods of conveying ideas are understood, seldom are two individuals in agreement as to exactly the best approach. This lack of conceptual agreement actually created an environment from which a more stable and expedient concept has evolved.

2. Standardization of Programming Language

The Saturn V program has adopted a standard, test oriented programming language to which all Stage Contractors and MSFC adhere. This standard programming language is specifically oriented toward automatic checkout and launch testing of stages and vehicles. The acronym "ATOLL" (Acceptance test or launch language) is used to express the standard programming language. ATOLL was developed to serve the following needs:

a. Provide a language for use in automatic checkout and launch testing of a stage or vehicle completely independent from locality considerations.

b. To utilize the knowledge of the launch vehicle test engineer for automatic checkout and testing.

c. To establish criteria for the development of a single document to satisfy the following needs:

(1) Serve as a detailed test procedure, when automatic checkout and launch testing is conducted.

(2) Serve as a test program for input into the automatic checkout and launch test system.

(3) Serve as a test review and evaluation document for plant representatives or Project staffs.

(4) Serve as a checklist for government inspection teams, verifying contractor performance of automatic tests.

What are the criteria for such a standard programming language?

a. It must be close enough to standard test nomenclature to be easily taught and used.

b. It must be capable of expressing a simple test function.

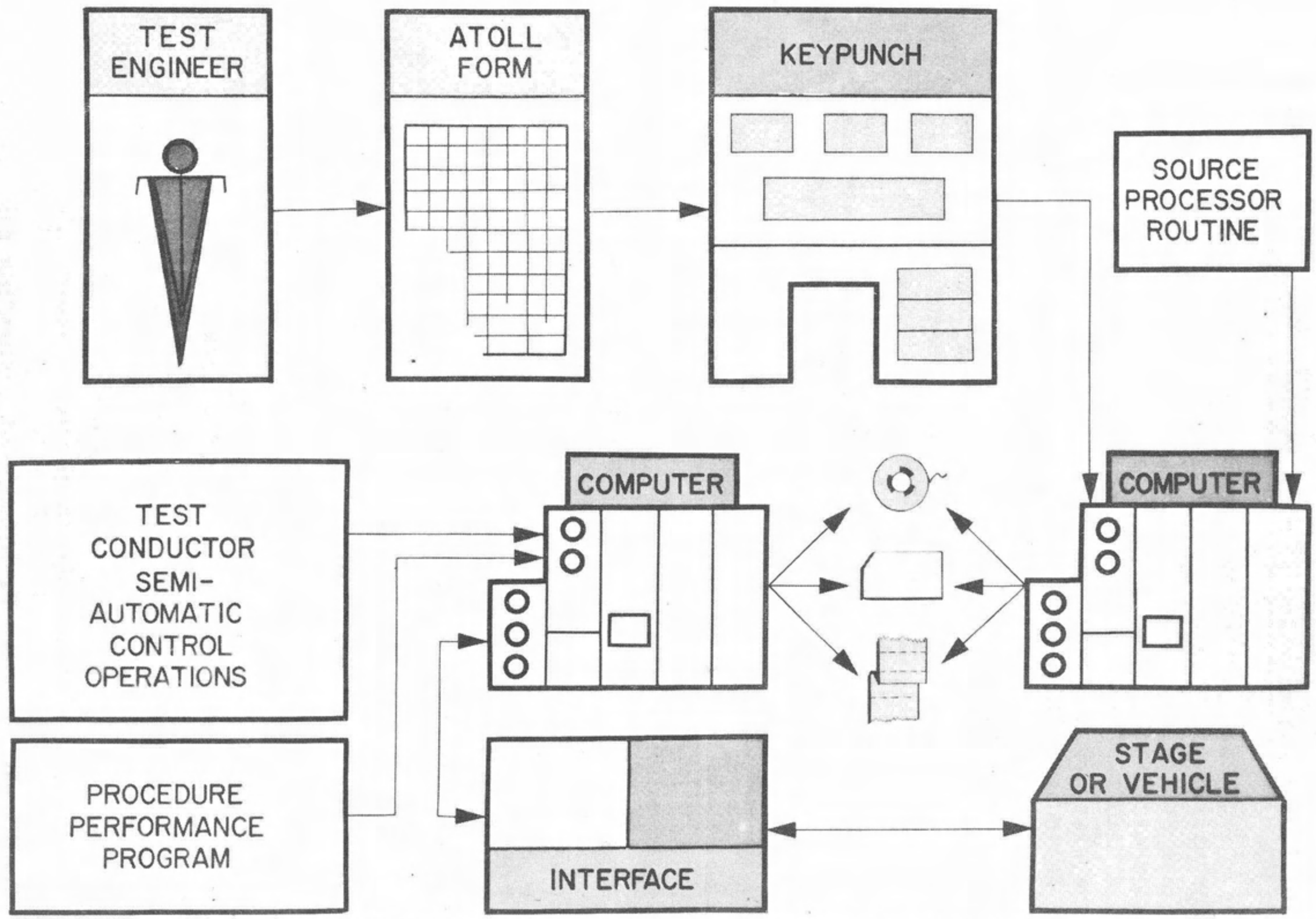

FIGURE 12. ATOLL-LANGUAGE SYSTEM FLOW CHART

c. It must be flexible enough to permit test engineers to easily group a series of simple test functions into a comprehensive test procedure expressing more complex test functions.

d. The format must be directly translatable into necessary computer operating instructions required to perform the indicated functions or tests.

e. It must conform with the general philosophy of automatic checkout and testing.

3. Acceptance Test or Launch Language (ATOLL)

Figure 12 shows the ATOLL system. Initially, the test engineer writes an English language test program and translates it into the ATOLL format. From this format, the program is transferred to a punch card. Through source process routines, translators, compilers, the machine program is established and will be available on magnetic tape, punch card or print outs. With this machine program, the checkout computer will be loaded to address the launch vehicle through the proper interface. The test conductor can operate the program through semi-automatic controls, or address the computer through executive routines to rearrange the programs as needed. Using ATOLL, the programs or portions of the programs created by the stage contractor needed for stage checkout can be taken and utilized for overall vehicle checkout at the launch site. The various sub-routines written in ATOLL can be used and assembled in the proper sequence for the launch site, and the executive routines can be written to combine the sub-routines into the proper launch sequence.

E. CONCLUSION

To draw a conclusion from the few examples described, one must agree that the Saturn V launch vehicle relies heavily upon its electronic equipment. These electronic systems must be trusted and the success of the Saturn V program depends upon them. It is not a question as to wheather the equipment works during a particular test, but it must work repeatedly with the same accuracy and at a level of confidence during all test, checkouts and launches.

Simple design, extreme reliability, redundancy where necessary in critical circuits and extreme quality control to harden the confidence we place in the electronics of Saturn V. These are the main parameters that must be kept in mind to make Saturn V successful.