X1.4
X1.17 April, 1967

SOME COMPUTER APPLICATIONS IN SATURN STAGE CHECKOUT

Max E. Rosenthal
Vehicle Systems Checkout Division
Quality & Reliability Assurance Laboratory
George C. Marshall Space Flight Center
Huntsville, Alabama

Summary

The paper discusses a number of interesting applications of digital computers in the checkout of individual Saturn stages and in the prelaunch checkout of the complete Saturn vehicle. It discusses the concepts of automation in Saturn checkout, the unique two-computer mode of operation at the launch site and the operation of the high speed data link connecting the two computers. Also discussed are the functions of the computer while propellants are loaded automatically on one of the stages; the functions of the display computer in the newest and largest Saturn display system, and operations and utilization of the Digital Events Evaluator, the main r   ding device utilized during stage checkout.

Introduction

The assurance of proper operation of the Saturn launch vehicle from the instant of liftoff until its final seperation from the payload is the goal of the Saturn checkout program. The size and complexity of the Saturn vehicle has made the utilization of computers a necessity for many of the functions that are required during both the checkout of individual stages and of the complete launch vehicle.

This paper does not attempt to discuss the multitude of uses that are made of computers in the Saturn program that could easily be the topic of a symposium itself, rather it presents a few of the more interesting applications of computers in the checkout of Saturn stages.

General Hardware Description

Each assembled stage of the Saturn launch vehicle is individually tested using automatic Ground Support Equipment (GSE) under control of a computer. The stage under test is controlled or stimulated, and responses from the stage are acquired and evaluated. The computer can pro- most of the control and stimulation almost ctly to the stage but obviously it cannot generate RF, pneumatic and hydraulic functions. These functions, therefore, are generated by hardware external to the computer but under control of the computer.

Stimuli are presented to the stage over hardwire through umbilical connections or via RF links. Resultant stage responses are transmitted back to the GSE through umbilical connections, test plug connections and RF links. These responses are made available to the computer either directly or through a data acquisition system, for evaluation and determination of Go/No-Go conditions.

Overall control of the computer and test operations is maintained from a test conductor's console which contains a cathode ray tube display system. In addition to the cathode ray tube display, stage and GSE functions and responses are displayed locally at the stimulus or function generating equipment. Data received by the data acquisition system is recorded for later strip-out on analog recorders. Other analog recorders are hardwired directly to certain critical functions which must be monitored at all times. To supplement the checkout computer in monitoring discrete events, a Digital Events Evaluator (DEE) is used to continually scan a multitude of stage and GSE discrete data and record all changes and the time at which they occurred.

The four areas of computer applications that will be discussed in this paper are: (1) the checkout computer at the launch site, (2) the display system, (3) the DEE, and (4) automatic propellant loading. Each of these applications of computers represents not what can be done but what is being done in the field of automatic checkout.

The Checkout Computer at the Launch Site

Figure 1 is a general block diagram of the checkout equipment at the Saturn V launch complex. The checkout equipment is divided into two major areas: the Launch Control Complex (LCC), which is in the blockhouse, and the Launch Umbilical Tower (LUT), which is mounted on a crawler-transporter and travels with the vehicle from the Vertical Assembly Building to the launch pad. The distance between the two sets of equipment is about 3 miles. Note that there is a checkout computer in each of the two major areas, one in the LCC and one in the LUT.

Checkout Computer

The checkout computer employed for Saturn V checkout at the launch site is the RCA-110A computer. It is an improved version of an earlier RCA computer employed for Saturn I testing. The 110A has a 32,768 word high speed magnetic core memory and the same size drum memory. The computer is capable of sending out 1,008 discrete output signals; 72 analog output signals; and can receive 1,512 discrete inputs and 300 analog inputs.

The two computers employed for checkout and launch operations operate in series such that inputs to one computer result in outputs being generated in the other computer. The LCC computer is the main controlling computer.

Modes of Operation

The checkout computer at the launch site is utilized in one of two modes of operation; either in the semi-automatic mode, or the fully automatic mode of operation.

Semi-Automatic Mode. The semi-automatic mode of checkout is presently the normal mode of operation at the launch site. Briefly, the mode operates as follows: a command is initiated either by activating a switch on one of the electrical support equipment panels in the LCC or through the display system keyboard. This stimulus is received by the LCC checkout computer which initiates a signal that is transmitted via the data link to the LUT computer. This computer, in turn, furnishes a command to the stage via the support equipment in the LUT. Responses to the stage flow in the reverse direction. Note that while the initial action was completely manual, i.e., activating a switch, and only one function was performed, both checkout computers were involved in the action. Thus, we have termed this semi-automatic operation, as opposed to pure manual operation where no computer is involved.

To get a better understanding of the semi-automatic mode of operation, figure 2 has been included. This figure shows only the equipment directly involved in the command and response loop.

To initiate a stage function, the operator places the Stage Function Command switch to the "on" position. This causes a 28 volt signal to be received on Computer Input B. The computer executive program compares this input to a stored table and determines that Computer Output B in the LUT computer should be turned on. The computer program then initiates the appropriate commands to the data link which in turn transfers the commands to the LUT computer at a rate of 133K bits/sec. The LUT computer receives the commands from the data link, decodes the commands and turns Computer Output B on. A 28 volt signal is sent to relay K_1 in the LUT electrical support equipment. This in turn energizes the stage function relay. The relay upon becoming energized returns a signal back to the LUT support equipment energizing relay K_2 and causing Computer Input C in the LUT computer to receive a 28 volt signal. The LUT computer executive program, upon recognizing that Computer Input C is on, compares this information to a stored table and determines that Computer Output C in the LCC computer should be energized. The LUT computer issues the appropriate commands to the data link and the LCC computer, upon receiving and decoding the command, turns on Computer Output C energizing a Stage Function On indication on the LCC support equipment panel.

Automatic Mode. In the automatic mode of operation, the stage function switches are left in the "AUTO" position. To generate the same function, a stored program within the LCC computer would execute the appropriate commands to the data link which in turn would command the LUT computer to energize Computer Output B. All other events would occur as in the preceding sequences. It should also be noted that even if an automatic program is being executed, any change in a panel switch will cause a corresponding change in a computer input or output. Thus, at any time while the computer is controlling the test, a function may be turned on or off by activating the appropriate switch on the electrical support equipment panels.

Data Link

The equipment that makes the two computer modes of operation possible is the high speed data link. The data link provides programmable communications between two RCA-110A control computers over distances of up to 7 miles. There is a data link terminal for each computer, one designated as the local station and one the remote station; each has the capability of simultaneously transmitting and receiving information.

The data link transmits two classes of information:

(1) Data - which can be individual test results or complete test routines.

(2) Commands - which can be requests and acknowledgements that data be transferred or routines be run, etc.

Data link operation is such that the computer data and command words are received at the local station, the words are modified by adding parity bits, transmission acknowledgement bits and sequence and destination bits so that the original 25 bit computer word now becomes a 45 bit data link word. The local station converts this data link word into a modified diphase signal and transmits it to the remote station. The transmitted word is retained by the local station until notified by the remote station that reception was good. At the remote station the signal is reconverted to a computer word and the added bits stripped out.

When the computer is not supplying data or command words, test words are transmitted back and forth between data link terminals. If a received word is unacceptable, a request for retransmission is generated. After three rejections of a word, it is assumed that the remote station is not synchronized to the local station and sync patterns are transmitted between the stations until they are in phase again.

Display System

The advent of automatic checkout, with its increased speed of operations and added complexity, generated a requirement for an interface between the test engineer and the automation systems. The functions of the interface equipment are to provide the test engineer with a means for both determining the status of the test and for controlling the test activities.

The first display system was developed for the Saturn I program and has been somewhat improved for the uprated Saturn I program. This display system consists of two display cabinets, housing the power supplies and logic circuits that act as an interface between the checkout computer and the display system, and two to six display consoles, housing the keyboard, cathode ray display tube and the circuits required to transform the digital data into meaningful display information. The Saturn I display system depends on the checkout computer for timing operations and memory storage.

The increased complexity of prelaunch checkout and launch operations for the Saturn V vehicle coupled with the resulting increased difficulty in maintaining close control over the test operations, e[illegible]nced the utilization of a display system as th[illegible]ontrolling point for checkout operations. However, the requirement for an increased number of display consoles imposed too great a demand on the checkout computer's time and memory. Thus, a second generation display system containing its own computer was developed for the Saturn V program. A block diagram of the Saturn V display system is shown in figure 3.

General Description

The Saturn V Display System interfaces with the Saturn V automatic checkout system and establishes a communications link or interface between systems test personnel and the vehicle under test, providing real-time monitoring, command and emergency control capability. Data transfer between the Saturn V checkout computer and the display system is via an input-output data channel located in the computer. In operation, the display console operator can initiate a checkout procedure and real-time operation of the checkout computer provides digital data reflecting the requested test information. The display system converts this data into either an alphanumeric or graphic display on a CRT screen. The operator can evaluate the displayed test data with information at hand, or if desired, he can select reference material from slide bank storage. Closed circuit television inputs from cameras monitoring stage or ground equipment complement these capabilities enabling an operator to gain a complete and comprehensive picture of checkout progress. If a permanent record of any displayed data is desired, the operator can command a hard copy to be made.

Display Computer

The most important feature of the display system is the display computer. The utilization of a seperate computer allows for the expansion of the display system to perform functions in a time frame not permissable utilizing the existing checkout computer's memory and timing capability.

The display computer is a DDP-224 general purpose digital computer capable of various types of processing including real-time information and scientific data. The computer characteristics include a 24 bit word, synchronous operations, internally stored programs, with indexing and indirect addressing features. Most of the computers have a 24,000 word magnetic core memory which is expandable up to 32,000 words. The display computer processes all command and edit functions requested by the display consoles, handles all communications to the checkout computer controlling the Saturn V checkout, and in addition, processes all input data received from the checkout computer for use within the display system.

Typewriter and Paper Tape Unit

The typewriter is used to communicate with the display computer. It can be used as an output device providing a printout of data from the display computer, or as an input device, applying binary-coded decimal signals representing manually selected characters to the display computer. The paper tape unit is also used to communicate with the display computer. When used as an input device, punched paper tapes containing programs or data may be read into the computer using the tape reader. When used as an output device, punched paper tapes of data read out of the computer may be made.

Additional Display Units

The central logic unit provides buffering between the various units of the system, and controls the processing and distribution of data within the system. Incoming and outgoing data is reformatted and processed according to the origin and destination of the data and the type of data involved. Storage of digital data is provided by the central logic unit control, and status signals are processed and distributed to other units of the system.

By use of the display consoles the system engineer can monitor, or manually over-ride, the automatic checkout program. The display console contains a 21 inch cathode ray tube, a 64 character stroke generator, a vector generator, a keyboard control panel, a display buffer and power supplies. Up to 20 display consoles can be employed in the display system.

The hard copy unit can supply a permanent record of an alphanumeric or slide display on a 8 by 11 inch sheet of paper within 5 to 35 seconds after being requested to do so. The data presented on the display console is reproduced on a cathode ray tube in the copier unit. The reproduced data is then copied by a combination of photographic and electrostatic processes to provide the copies of the selected data.

The television distribution unit provides means of switching, controlling, and monitoring the system television video signals. The television transmission unit converts selected pages of data (digital and/or slide video), as presented at the display consoles, into 525-line video signals for transmission over closed circuit television transmission lines.

The slide transmission unit contains 256 reference slides which can be selected by the console operator. The slide images are transmitted from the slide bank to the console via 945 line high resolution TV.

Test Operations

The function of the display system is to act as the interface between the test engineer and the automation system. When automatic checkout was introduced to the Saturn program, the interface between the test engineer and the computer was a simple switch panel and a programmer. The switch panel was utilized to change the status of the computer discrete inputs and outputs and the programmer stood by the checkout computer ready to make changes in the computer program as requested by the test conductor.

From this crude beginning we have progressed to the utilization of a display system as the interface between the man and the automation system. Now, the test conductor controls all test operations from the display console. He initiates the test to be performed through the display keyboard and continually monitors the progress of the test through the information displayed on the CRT. If a No-Go or out-of-tolerance condition is detected during the test, the computer transfers to a "control" mode of operation and a list of over 20 different test options are displayed for the test conductor on the display console. The test conductor selects one of the options and the display system gives him a more complete description of the selected option. For example, the test conductor may wish to repeat the portion of the test just executed, he may wish to scan all of the computer discrete output lines that are on, he may wish to change the state of a discrete output or accept the error information as correct, or simply hold in the present configuration while troubleshooting is accomplished. He can select the desired option by typing in the option number on the display keyboard. The computer will then execute the selected option and inform the test conductor of the results, via the display system.

Above all, the display system allows for the full utilization of the test engineer's experience and capabilities since he can now act as an extension of the automation system. This utilization of man in the automatic checkout system is of great value because unlike data processing, where the computer can out perform the man in almost every category, the test engineer can perform functions and make many decisions, using the computer, considerably better than the computer can by itself.

Digital Events Evaluator

The introduction of automation to Saturn checkout presented a number of problems in the field of data recording and evaluation. The first computers utilized in checkout were capable of recognizing changes in only those input lines that they were programmed to monitor. Even in the improved computers in use today, the computer, while recognizing all unpredicted changes occurring on its input lines, cannot always immediately notify the test conductor of these changes if it is busy performing some test sequence. To alleviate this problem and at the same time to perform with more accuracy than before, a number of functions such as maintaining records of all discrete events occurring during checkout, maintaining time and cycle records on key components, and determining the time each event takes place, the Digital Events Evaluator was introduced.

The DEE is a sensitive, high-speed discrete event recorder and analyzer that is built around a standard general purpose digital computer capable of handling a variety of data-reduction and data-correlation problems. It has the capability of monitoring and evaluating up to 4,320 individual discrete input events.

Operation

The major function of the DEE is to monitor and evaluate the individual discrete events that occur during stage checkout. Nearly all the input li furnishing discrete inputs to the computer are also monitored by the DEE.

The operation of the DEE can best be described through the use of the block diagram of figure 4.

Input lines to the DEE are divided into groups of 24 inputs per group. The DEE being illustrated here has 180 groups for a total of 4,320 inputs. The voltage on the input lines may vary from +50 vdc to -50 vdc without harming the input circuit components. In order to ensure that random noise is not recorded as an input, input filters are employed to reject pulses of less than 0.5 milliseconds. Any pulse greater than 2.0 milliseconds duration will be passed by the input filters.

The DEE goes through three cycles for each operation: Scan, Process and Output.

Scan. During the Scan cycle, the DEE begins scanning the status of each line of the first group and proceeds until all of the groups have been scanned. While the status of any group of input lines is being presented to one side of the comparator, the results of the previous scan of the same group of lines is being presented to the oth ıalf of the comparator. The information abou the previous cycle is retrieved from the previous scan cycle memory. Each input line is normally scanned every 2 milliseconds. If the present logic state of each input line of the group being scanned is the same as the logic state during the previous scan, no action is required. However, if the status of any line in a group has changed, a "digital event" has occurred and action is required by the DEE to properly evaluate the event.

Process. During the Process cycle, if a digital event has been detected, a signal is sent from the comparator to the computer. This signal forces the computer to store four words each containing information about the event. The four words contain information about:

(1) The time the event was detected.

(2) The number of the line on which the event occurred.

(3) The present status of all 24 lines in the group being scanned.

(4) The previous status of the lines in the group.

The present status of the group is sent to the previous scan cycle memory in preparation for the next cycle. All of the information is then sent to the output buffer.

Output. During the Output cycle data stored in the output buffer is converted to a format that permits the output data to be displayed on the appropriate output device. All output information will be either listed locally on the teletype or remotely on one of the line printers. Data may also be recorded on magnetic tape or punched paper tape. The output devices may either be specified locally through the teletype keyboard or remotely on the operator control panel.

The printout obtained from the DEE during checkout lists each output in the order of its occurrence. The printout lists the identification number of the event and if it is "on" or "off". The time each event occurs is expressed in seconds and milliseconds, and is referenced to the last minute.

Utilization

The record maintained by the DEE is evaluated after each test to ensure that no unexpected events occurred during testing. Previously, hundreds of channels of events were recorded on a wet-ink recorder and had to be evaluated by the test personnel. Now the test results and the original test program can be placed in the DEE, evaluated and a print-out of every unpredicted event and every out-of-sequence event obtained.

In addition to providing its normal print-out of discrete events as they occur, the DEE is capable of performing special output functions. If, for example, during a scanning cycle, the operator wishes to know the status of all input lines, he may exercise the "On Demand Print" option. When this command is given, all lines which are "on" will be typed out. If events in a given test are expected to occur in a specific sequence, the operator may elect to use the Sequence Scan option. This option has two sub-options. Using the first suboption, every event which takes place is printed with the out-of-sequence events indicated by an asterisk. Utilizing the second suboption, only the out-of-sequence events are printed by the typewriter. The time information furnished by the DEE about every event permits a precise determination of the elapsed time between various stimuli or between stimulus and response. It is used to provide running time and operating cycle information on certain critical stage components. The DEE record is processed off-line to extract the time and cycle information which is accumulated for the purpose of assuring that the design life of critical stage components has not been exceeded.

Automatic Propellant Loading

The subject of automatic propellant loading is of considerable interest since it represents automation's entry into an area that has heretofore been the exclusive domain of manual checkout equipment. The precise control and monitoring of numerous test points required during the loading of highly volatile fuels has always been performed by employing a large number of test personnel each with his own sector of operations to monitor and control. The system to be described is the first automatic propellant loading system utilized in the Saturn program and is employed by the Douglas Aircraft Company at their S-IVB static firing facility. The system employs a computer to keep track of the loading operations and to control the loading and detanking of propellants.

System Components

The block diagram of figure 5 shows the major components of the automatic propellant loading system.

Computer. The computer employed for automatic propellant loading and stage checkout is the CDC-924A. It contains a main computer cabinet; operator's console, including a display panel, controls and paper tape punch and reader; a magnetic tape station; a typewriter and a high speed line printer. The computer employs a 24 bit word format, has a magnetic core storage of 16,000 words and is expandable to 32,000 words. A representative program cycle time is 5.3 microseconds with an access time of 1.8 microseconds.

Computer Interface Unit (CIU). The CIU allows the general purpose computer to be employed for the specific purpose of propellant loading. The CIU controls all inputs to and outputs from the computer, it converts the computer's parallel output into a serial format and provides data buffering and addressing.

Safety Item Monitor. The Safety Item Monitor scans up to 100 discrete and 50 analog responses of a critical nature during propellant loading. The monitor is a programmable digital device that will interrupt the computer program if an out-of-tolerance condition is detected on one of its input lines.

Other Components. The propellant control consoles are manual consoles that can control testing operations under certain conditions to be discussed shortly. The major utilization of these consoles occur during emergency operations, troubleshooting and for display of information. The stimuli signal conditioner converts the computer word into a discrete command while the response signal conditioner performs the reverse function. The auxiliary signal distribution unit contains the logic circuits for selecting manual or automatic mode of operation and the latching relays that control the pneumatics and propellant loading. The gas heat exchanger receives gaseous hydrogen and helium and provides cold helium gas for filling the LOX tank pressurization bottles and cold hydrogen gas for filling the engine turbine start bottle.

Automatic pneumatic console A serves to receive, regulate, and control the distribution of ambient helium gas to meet the stage propulsion system requirements for propellant loading, propellant purging, and propellant unloading. All flow control valves and system bleed valves are controlled remotely and automatically by signals from the computer. Critical pressures within the console are sensed by pressure transducers and monitored by the computer. Automatic pneumatic console B provides gaseous nitrogen and ambient and cold gaseous hydrogen and helium for pressurization and propellant loading operations during static firing.

The LOX valve complex receives LOX from a facility storage source and controls the flow to the stage LOX tank to achieve the requirements for LOX filling. The function of the liquid hydrogen (LH_2) valve complex is to receive LH_2 from a facility storage source and control the flow to the stage LH_2 tank and the gas heat exchanger. The DDAS ground station receives RF signals from the stage and converts them into analog and discrete signals for presentation to the computer.

Operating Concept

The operating concept for propellant loading is that the automation system only be utilized. The manual mode of operation is to be employed only for emergency venting or unloading, or troubleshooting, but the prime mode of operation is in the automatic mode under computer control.

Computer Operation. The computer operation is such that it monitors the lox level automatically through the onboard propellant utilization system. While propellants are being loaded, the computer scans critical vehicle parameters such as tank pressures, bus voltages and currents, valve positions, etc. If a malfunction is detected during this scan, the computer will automatically execute a loading termination routine. The routine will close the main fill valves to stop loading process. It will also inform the test conductor via the line printer of the cause of the loading interrupt. The test conductor will then make a decision as to the course of action to be followed. He can cancel the loading and unload propellants, or take corrective action to cure the problem and continue loading. Either course of action will be conducted automatically through use of a propellant unloading routine or a loading re-entry routine.

Depending on the criticality of the malfunction, the computer is programmed to do one of several things:

(1) Automatically safe and shutdown the vehicle. As an example, if tank overpressurization is detected, it would be automatically vented and the stage safed.

(2) Print out out-of-tolerance conditions to the test conductor and then "hold" until the test conductor decides to resume.

(3) Set a flag indicating a noncritical out-of-tolerance condition. These flags will be typed out at the end of a sequence for the test conductor's information.

Typical Signal Flow. To get a better understanding of the computer's role and the flow of test operations, stimuli and response circuits for the operation of the main LOX fill valve are shown in figures 6 and 7. The flow of a typical command will be traced through these circuits to enable the reader to obtain a clearer picture of the system operation and computer control.

Stimuli Circuit. Figure 6 shows a simplified version of the stimuli circuit for the main LOX fill valve. To open the valve requires that 28 volts be applied to the valve solenoid. The latching relay in the auxiliary distribution unit (ADU) must be "set", i.e., 28 volts applied to the "open" side of the relay.

The flow of operations is as follows: The computer through the computer interface unit initiates commands to the stimuli conditioner to send out a discrete signal on line "0". The command goes to the ADU where it must first pass through the manual-automatic interlock relay contacts. The contacts are in the state shown when automatic testing is being performed and in the opposite position when manual testing is being performed. If the signal passes through this interlock circuit it immediately goes to both the response signal conditioner and the latching relay. The signal that goes to the response signal conditioner is checked by the computer to ensure that the correct relay is to be activated. If the computer determines that the incorrect relay is being energized, it will immediately remove the command sent out from the stimuli signal conditioner. The signal can be removed from the ADU before the latching relay has had a chance to react. This scheme of signal generation and checking by the computer is known as "echo-checking".

If the correct signal has been sent out, the latching relay will be "set" and 28 volts will be applied to the solenoid of the main LOX fill valve. Note the commands to the solenoid is also sent to the response signal conditioner for monitoring by the computer.

Response Circuit. Figure 7 shows the response circuit for the commands just initiated. In the LOX Valve Complex, the main LOX fill valve has been driven open and the wiper arms will be in the position shown. The "open" signal will be sent through the ADU to a patch panel where the signal branches, one indication going to the manual propellant control console and the other indication going to the response signal conditioner where it is monitored by the computer.

While information is being sent over hardwire from the LOX Valve Complex to the computer, LOX level information is being sent via RF link from the stage to the DDAS Ground Station where all key information is displayed on strip charts. From the DDAS Ground Station the information is sent to the computer and to the manual consoles where a digital readout displays the data as requested.

One interesting automatic test operation is the self-check operation. The ADU in figure 7 indicates the presence of self-check relays, K_1 and K_2. Should the computer fail to receive an expected input, the "open" signal, for example, it will energize the appropriate self-check, K_2, causing a 28 volt signal to be applied at point A. If the computer receives this signal it informs the test personnel that the original signal was "lost" between the LOX Valve Complex and point A in the ADU. If the computer does not receive this self-check signal, it informs the test personnel that the original signal was "lost" between point A in the ADU and the computer. The problem can be isolated to one-half of the equipment and a considerable amount of troubleshooting time can be saved.

Manual Control. Although propellant loading is accomplished automatically, the system is designed to enable the test personnel to assume manual control in the event of an emergency condition or in case there is a need to troubleshoot the system. There are two ways manual control can be obtained.

(1) If an unsafe condition exists which requires immediate action, and for some reason the computer fails to detect it, the testing personnel can activate an "emergency stop" switch located on each console. This initiates an emergency shutdown routine and enables the manual control switches allowing the test personnel to assume full manual control.

(2) At times during loading, manual control may be desired for conditions that are not of an emergency nature. To permit this, the test conductor has a master manual control switch which can enable the individual manual control switches on each console. This will permit manual operation under the control of the test conductor.

Conclusions

While a considerable number of advancements have been made in the field of automatic checkout in the past few years, it is quite apparent that we have just begun to realize the potential applications for automation in the testing of large, complex systems. During the next decade advances in the field of automatic checkout should occur in three major areas.

First, there will be refinements in the techniques employed in testing electronic systems, these will include greater efficiency of computer time through improved programming techniques. In addition, improvements in dis-man-system interface.

Second, development of automatic checkout for nonelectronic systems should move rapidly ahead with indirect sensing coming of age. The spur in this development should be the development of a nuclear stage, since the static firing of such a stage will require a considerable amount of remote testing and automatic control of nonelectronic systems.

The third area of development will be in on-board checkout systems. Long duration space flights which will require maintenance and repair of the space systems by the astronauts will stimulate the development of automatic checkout systems that are an integral part of the flight equipment.

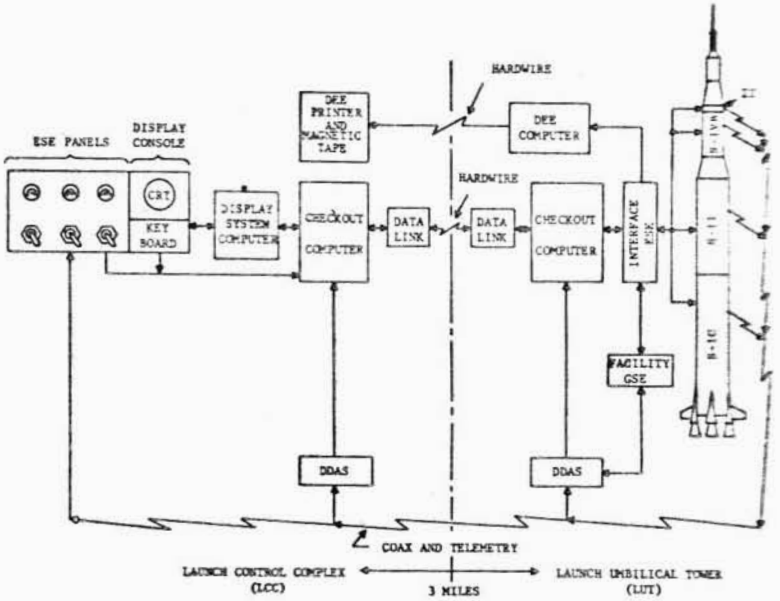

Figure 1
SATURN V LAUNCH COMPLEX

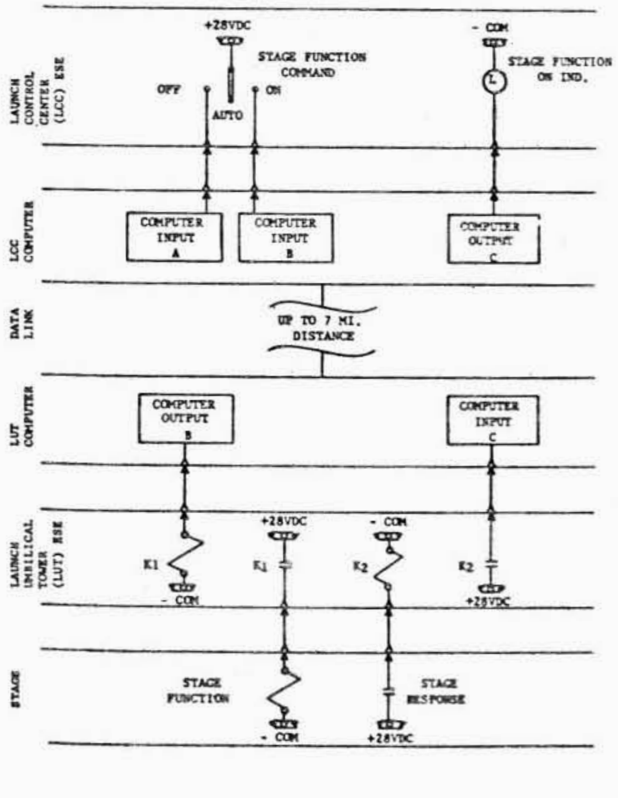

Figure 2
TYPICAL CONTROL AND RESPONSE CIRCUIT

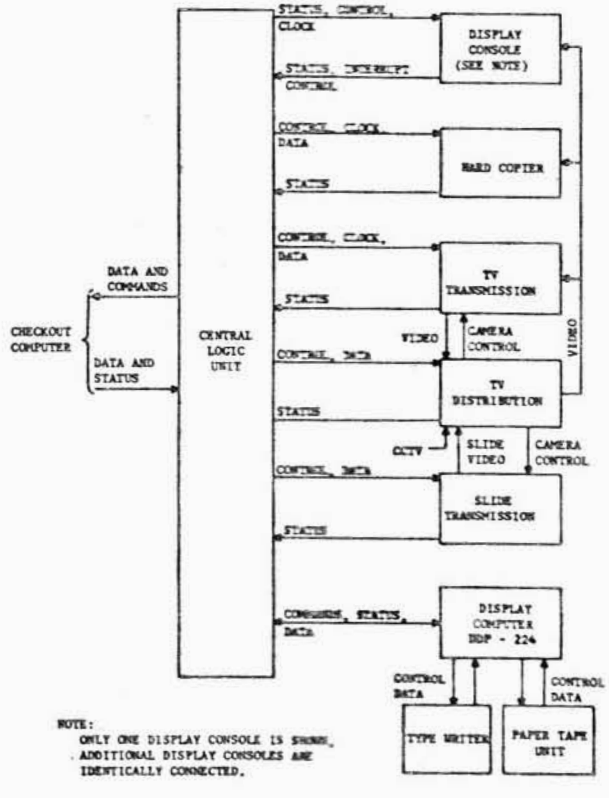

Figure 3
Display System

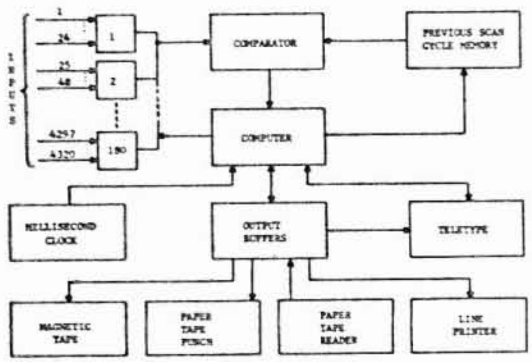

Figure 4. Digital Events Evaluator

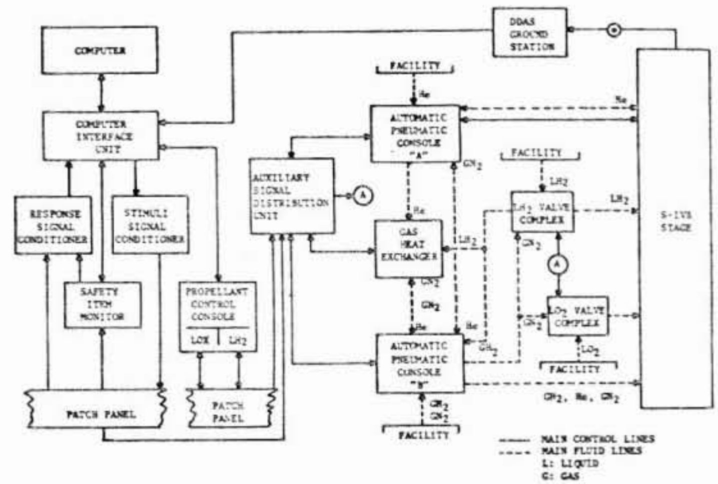

Figure 5
Automatic Propellant Loading System

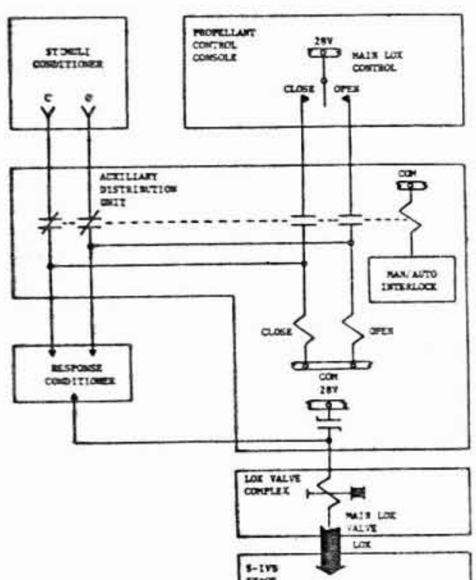

Figure 6. Stimuli Circuit

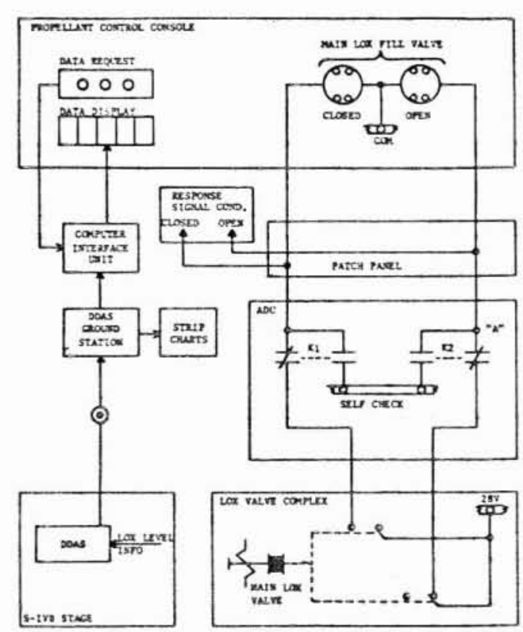

Figure 7. RESPONSE CIRCUIT