2 copies

NASA TECHNICAL MEMORANDUM

NASA TM X-53590

March 16, 1967

NASA TM X-53590

REPORT ON DIGITAL COMPUTERS USED IN AUTOMATIC CHECKOUT

by B. Funderburk
Quality and Reliability Assurance Laboratory

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

TECHNICAL MEMORANDUM TM X-53590

REPORT ON DIGITAL COMPUTERS USED IN AUTOMATIC CHECKOUT

By

B. Funderburk

George C. Marshall Space Flight Center

Huntsville, Alabama

ABSTRACT

The uses for digital computers are many and varied. The most common applications of these devices have been in the business and scientific computation world, but it is not uncommon to find them being used in apparel design, newspaper publication, and medical research. Another application which has evolved in the past few years is that of testing large space vehicles. This report describes 12 computer systems and their use in the various phases of space vehicle checkout.

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

TECHNICAL MEMORANDUM TM X-53590

REPORT ON DIGITAL COMPUTERS USED IN AUTOMATIC CHECKOUT

By

B. Funderburk

COMPUTER SYSTEMS SECTION
VEHICLE SYSTEMS INTEGRATION BRANCH
VEHICLE SYSTEMS CHECKOUT DIVISION
QUALITY AND RELIABILITY ASSURANCE LABORATORY

TABLE OF CONTENTS

Section		Page
	SUMMARY	1
I	INTRODUCTION	2
	A. Repetitious Operations	3
	B. Applications of Special Languages	4
II	INTERIM INSTRUMENTATION AND TELEMETRY SYSTEM	6
	A. General Description	6
	B. Hardware System Theory	6
	C. Software System Theory	9
	D. Systems Evaluation	12
III	PACKARD BELL SATURN I AUTOMATIC CHECKOUT SYSTEM	14
	A. General Description	14
	B. Hardware System Theory	14
	C. Networks Test Station	19
	D. Instrumentation and Telemetry Test Station	23
	E. Vehicle Test Station	27
	F. Electrical Test Station (Cable Analyzer)	30
	G. Software System Theory	33
	H. Systems Evaluation	35
IV	RCA-110 GROUND COMPUTER SYSTEM	37
	A. General Description	37
	B. Hardware System Theory	39
	C. Software System Theory	43
	D. Systems Evaluation	47
V	DIGITAL EVENTS EVALUATOR (DEE-3)	49
	A. General Description	49
	B. Hardware System Theory	51
	C. Software System Theory	52
	D. Systems Evaluation	54

TABLE OF CONTENTS (Continued)

Section		Page
VI	DIGITAL COMPUTER CONTROLLED TRAINING DEVICE (TRAINER)	55
	A. General Description	57
	B. Hardware System Theory	57
	C. Software System Theory	64
	D. Systems Evaluation	67
VII	VEHICLE INSTRUMENTATION SIMULATOR (VIS)	63
	A. General Description	65
	B. Hardware System Theory	67
	C. Software System Theory	69
	D. Systems Evaluation	81
VIII	TELEMETRY DIGITIZING SYSTEM (TDS)	83
	A. General Description	83
	B. Hardware System Theory	85
	C. Software System Theory	88
	D. Systems Evaluation	90
IX	GENERAL ELECTRIC GE-215 SUPPORT COMPUTER SYSTEM	91
	A. General Description	93
	B. Hardware System Theory	93
	C. Software System Theory	93
	D. Systems Evaluation	96
X	GENERAL ELECTRIC GE-235 SUPPORT COMPUTER SYSTEM	98
	A. General Description	98
	B. Hardware System Theory	101
	C. Software System Theory	101
	D. Systems Evaluation	102

TABLE OF CONTENTS (Continued)

Section		Page
XI	INSTRUMENTATION DATA TEST STATION (IDTS)	104
	A. General Description	104
	B. Hardware System Theory	110
	C. Software System Theory	113
	D. Systems Evaluation	117
XII	SATURN V, S-IC CHECKOUT SYSTEM (RCA-110A)	119
	A. General Description	119
	B. Hardware System Theory	122
	C. Software System Theory	126
	D. Systems Evaluation	133
XIII	ADVANCES TEST AND CHECKOUT METHODS EVALUATION DEVELOPMENT (ATCOMED) COMPUTER SYSTEM	135
	A. General Description	135
	B. Hardware System Theory	137
	C. Software System Theory	142
	D. Systems Evaluation	145

LIST OF ILLUSTRATIONS

Figure		Page
1	Computer and Peripheral Equipment	7
2	Remote Test Station	7
3	Interim Instrumentation and Telemetry System Block Diagram	8
4	Onboard Measuring System Block Diagram	10
5	Remote Indicator Unit (RIU)	11
6	Central Computer Complex	15
7	Automatic Checkout System Block Diagram	15
8	Instruction Word Format	16
9	Test Station Operator's Console	18
10	Networks Test Station	20
11	Networks Test Station Block Diagram	20
12	Instrumentation and Telemetry Test Station	24
13	Instrumentation and Telemetry Test Station Block Diagram	24
14	Vehicle Test Station	28
15	Vehicle Test Station Block Diagram	28
16	Electrical Test Station (Cable Analyzer)	31
17	Saturn I Instrument Unit Checkout System	38
18	Saturn I Instrument Unit Checkout System Block Diagram	38
19	Numeric Data Word	41
20	Alphanumeric Data Word	42
21	Instruction Word	42
22	ATOLL Programming System Block Diagram	44
23	Digital Events Evaluator (DEE-3)	50
24	DEE-3 Programming System Functional Block Diagram	53

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
25	Digital Computer Controlled Training Device (TRAINER)	56
26	Trainer Functional Block Diagram	58
27	Interface Equipment	60
28	Simulation Equipment	62
29	Simulation Modules	62
30	Vehicle Instrumentation Simulator (VIS)	70
31	Vehicle Instrumentation Simulator Block Diagram	72
32	Telemetry Digitizing System	84
33	Telemetry Digitizing System Block Diagram	84
34	General Electric GE-215 Support Computer System	92
35	GE-215 Computer System Block Diagram	94
36	General Electric GE-235 Support Computer System	99
37	GE-235 Computer System Block Diagram	100
38	Instrumentation Data Test Station (IDTS)	105
39	Instrumentation Data Test Station (IDTS) Block Diagram	106
40	System Control Unit (SCU)	107
41	Remote Selector Indicator Unit (RSIU)	108
42	System Interface Unit Block Diagram	111
43	RCA-110A Computer System	120
44	RCA-110A Computer System Block Diagram	121
45	Cathode-Ray Display Unit	123
46	ATCOMED Facility	136
47	ATCOMED Automatic Checkout Complex	138
48	ATCOMED ATOLL Functional Operation	143

LIST OF TABLES

Table		Page
1	GE-215 Computer Features	93
2	GE-215 Computer Utilization Summary	97
3	GE-235 Computer Hardware Statistics	98
4	GE-235 Computer Utilization Summary	103
5	IODC Assignments	124
6	Analog Output Characteristics	124
7	Analog Input Characteristics	125
8	Peripheral Equipment	125

TECHNICAL MEMORANDUM TM X-53590

REPORT ON DIGITAL COMPUTERS USED IN AUTOMATIC CHECKOUT

By

B. Funderburk

SUMMARY

The application of digital computers to the testing of large space vehicles began as a research and development program in the Quality and Reliability Assurance Laboratory in 1961. The first application proved to be a success in many of the checkout areas on the Saturn I first stage and established a foundation on which more advanced systems have been built.

Since the first automatic checkout system was used, more than a dozen digital computer systems have been developed to meet the increasing requirements of space vehicle testing in the Quality and Reliability Assurance Laboratory alone. Those systems have been used in many different facets of checkout ranging from training and simulation to data reduction and checkout itself.

This report describes 12 digital computer systems that have been used by the Quality and Reliability Assurance Laboratory. Included is a description of the hardware and software and an evaluation of each system.

SECTION I. INTRODUCTION

The Quality and Reliability Assurance Laboratory incorporated the first digital computer system to be significantly used in the automatic testing and checkout of a space vehicle. Subsequently, computers have been used by the Laboratory and the Marshall Space Flight Center in all phases of space vehicle development. In this Laboratory, all the computers have been an important part of the vehicle testing operations. They have been used as the controlling element of automated testing, support for the test computers, monitors during tests, vehicle simulators, training aids, and tools for developing new testing techniques.

One interesting observation that can be made from reviewing the uses of the digital computer in the Laboratory is the use of small computers (under $75, 000 cost) in real-time systems. With the introduction of micrologic circuitry, high speed memory, and optimized logic, it is becoming economically feasible to substitute a computer for the previously used special purpose hardware. The Vehicle Instrumentation Simulator (VIS) and Telemetry Digitizing System (TDS) are good examples of where it is obviously more economical and practical to use a small general purpose computer. This should not be a policy accepted with undue caution, however. Some problems and pitfalls can befall the unsuspecting user of systems which incorporate small computers. Normally,the system (e.g. the VIS) includes a "canned" program developed by the builder of the hardware and if the hardware functions do not change, the canned program will not need changing. If the hardware function does change, the canned program will also have to be changed and a programming group will be required to make these changes. Another problem exists in that the computer generally comes with a minimum of input-output peripheral equipment. This can be serious if the computer program has to be changed and reassembled. The peripheral equipment will generally include only a mechanical paper-tape reader/punch and a typewriter. Using this type of equipment can require several hours to assemble a program.

In many of the systems described in this document, the computer has essentially lost its identity by becoming an integral part of a real-time system designed to perform a real function on real hardware. As such, the justifications which would normally be used to procure and retain a computer are not valid in the cases of checkout and real-time operations. The utilization of the computer in terms of the number of hours a day it is used is meaningless and serves no useful purpose. It may be hard to understand why these computers cannot be utilized for other general purposes during idle time, but after analyzing the systems of which the computers are a part, it is obvious that the mechanics of using the system for two completely different functions on a scheduled basis is complex. Many of the systems are a part of or connected into, multimillion dollar hardware facilities, where the misuse of the system could result in the loss of man-hours and equipment and also endanger the well-being of the personnel involved. These computer systems are therefore classified as dedicated systems and cannot be made available for general use.

Although it appears that the computer has become commonplace in almost every phase of checkout, the use of these computers should not be misunderstood. The computer has not been used solely for the sake of automation. The Packard Bell system could be classified as experimental, but it was apparent that soon after the Packard Bell Saturn Automatic Checkout System was installed, there were definite advantages to be gained in certain areas of vehicle testing by the use of computers. The areas in which automation can be applied are basically identified as those involving repetitious operations or the application of special languages. Areas of testing where computers are of no advantage are avoided.

A. REPETITIOUS OPERATIONS

Digital computers are best suited to solve problems of a repetitive nature. A "noncheckout" example would be calculating the payroll of 10,000 employees, month after month. In this example, the same small program could be used for each employee and the only required changes would be the data, i.e., employee's name, base pay, hours worked, deductions, etc. The same applies to checkout; those checkout operations requiring repeated calculations, with only changes of data, stage after stage, will normally lend themselves to automation.

One of the most obvious applications in the Saturn I series was in the Instrumentation and Telemetry Systems. Many areas even within this one category were applicable, such as the Universal Measuring Adapter (UMA) Calibration. The Universal Measuring Adapter Calibration area contained more than 300 items to be verified and calibrated. Only one program was used in this example to verify one of the items and with only data changes, each item could be verified by the same program. In almost every case where the computer has been used for checkout, this has been true. Other test areas containing many similar items to be tested with only slight changes in data required to go from one item to another are:

1.	AC Heaters Test	-	Thirty heaters to be cycled three times
2.	Pressure Switches Test	-	Many switches to be tested
3.	Engine Gimbaling	-	Four engines, each gimbaled several times in several directions
4.	Pressure Test	-	Many pressure transducers to be tested

B. APPLICATION OF SPECIAL LANGUAGES

As previously stated, the computer is best suited to solve problems of a repetitive nature. To do otherwise is normally a waste of computer resources. The computer may be used, however, to advantage in areas where a scheme may be devised to develop computer programs simply and changes to the programs can be made quickly. Of course, this is a goal for all programming areas but such schemes are often difficult to develop to allow for this ease of software generation. One area of checkout in which this technique can be applied is that of electrical networks. In this area, the functions to be performed on the various electrical systems can be grouped, i.e., closing and opening relays, reading voltages, sensing discrete status, etc. In addition, these grouped functions occur in sequential order, i.e., the execution of one function depends upon the satisfactory completion of the previous function.

A language was developed that would allow computer programs for the electrical networks tests to be developed quickly, as compared to developing the UMA Calibration program. And, since the computer program that was developed for one stage was essentially a table of data, changes could be incorporated easily and the program used for succeeding Saturn stages.

The electrical networks area was therefore an area that was conducive to automation; not because it contained repetitious operations for the computer to perform, but through a simplified language, the programs could be developed in a relatively short period of time and changes could be incorporated in the program with minimum effort.

SECTION II. INTERIM INSTRUMENTATION AND TELEMETRY SYSTEM

The Interim Instrumentation and Telemetry System was the first hardware utilized with Saturn vehicle testing which incorporated a digital computer as the controlling element of the system. This system was delivered in 1961 as a result of the contract with the Packard Bell Computer Corporation. Although the contract with Packard Bell Computer Corporation was for the Saturn I Automatic Checkout System (section III), the decision was made to deliver a portion of the equipment early. The purpose of the early delivery of this system was to allow Quality and Reliability Assurance Laboratory personnel to become familiar with the technique and operations of automatic checkout prior to the delivery of the Packard Bell Saturn I Automatic Checkout System described in section III.

A. GENERAL DESCRIPTION

The Interim Instrumentation and Telemetry System consisted of the computer and peripheral equipment and the instrumentation and telemetry interface equipment. The system was delivered installed in eight specially designed equipment racks as a single unit. The system was later divided into two operational areas (computer and peripheral equipment and the remote test station) for reasons such as organizational structure and operational feasibility. The separation of the equipment provided practical experience in operating a computer complex with remote test stations but presented problems with data transmission due to the original design as a single unit. Figure 1 pictures the computer and peripheral equipment,and figure 2 pictures the remote test station.

B. HARDWARE SYSTEM THEORY

A block diagram of the Interim Instrumentation and Telemetry System is shown in figure 3. The system is shown functionally as two units (computer with peripheral equipment and a remote test station). The computer utilized in the system was the Packard Bell PB-250 digital computer. The PB-250 is a completely solid-state, general purpose, binary, digital computer. The storage medium is a group of nickel steel magnetostrictive delay lines. The basic memory of the computer contains 10 delay lines each capable of storing 256 words of information.

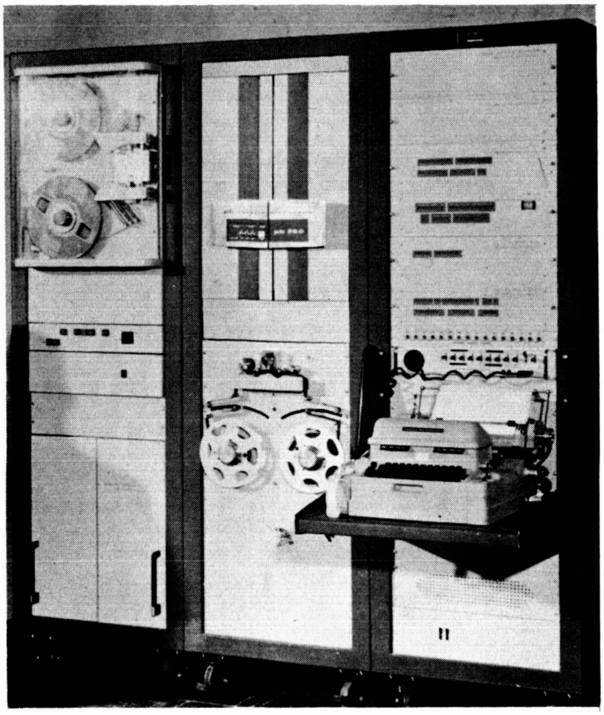

Figure 1. Computer and Peripheral Equipment

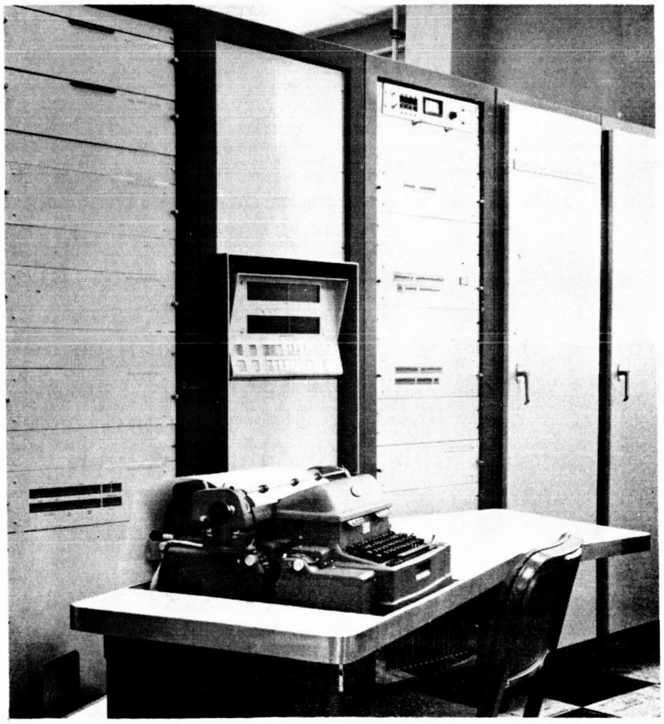

Figure 2. Remote Test Station

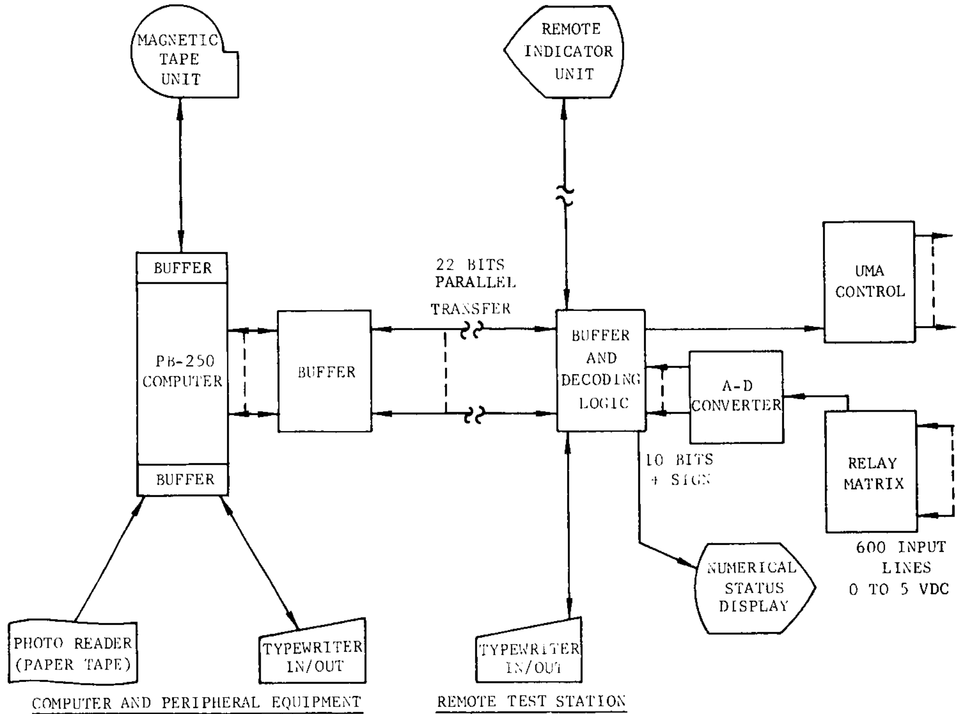

Figure 3. Interim Instrumentation and Telemetry System Block Diagram

However, additional delay lines were purchased and the total memory capacity was expanded to 10,000 storage locations. Each storage location consists of 21 bits which can represent either an instruction to the computer or a data word consisting of 21 bits plus sign. One word time in the computer is 12 microseconds. The time required to add two numbers together including the time of decoding the instruction and locating the number in the operand address can be as little as 24 microseconds. However, to obtain this speed the computer program must be optimized, i.e., data must be stored in the proper memory locations. Otherwise, an addition of two numbers may take as much as 3 milliseconds. Multiplication, division, and square root operation require approximately 250 microseconds for execution.

A modified Dynatronics photoelectric paper-tape reader was used for reading computer programs and data into the computer memory. The reading speed of the paper-tape reader was 300 characters per second.

A modified Friden flexowriter was used as the input-output controlling device by an operator. The flexowriter consisted of a standard typewriter keyboard, plus a mechanical paper-tape reader and a mechanical paper-tape punch. The flexowriter was capable of reading paper-tape at the rate of 10 characters per second and punching paper-tape at the rate of 15 characters per second under computer control. The computer was capable of interrogating the typewriter keyboard and the typewriter reader. The computer could therefore be programmed to interpret information being typed on the flexowriter keyboard by an operator. Responses to the operator's instructions and the printing out of test data results could be accomplished on the typewriter.

A modified Potter magnetic-tape unit was connected to the PB-250 computer. The magnetic-tape unit was a low density 200 BPI unit.

Commands could be issued by the computer to the remote test station through a computer buffer. Commands would be found in the computer memory and transferred 22 bits at a time to the buffer. Output of the computer buffer was transmitted over 22 parallel lines to the buffer and decoding logic in the Remote Test Station. Decoding and execution of the 22 bits of information received in the test station were similar to the operation described in section III. Information collected in the Remote Test Station could be transmitted back 22 bits at a time to the computer buffer over separate parallel lines.

The Remote Test Station consisted of the buffer and decoding logic, a flexowriter input/output device, numerical status display, remote indicator unit, a-d converter, relay matrix, universal measuring adapter (UMA) control unit, etc. Various output controlling signals could be sent to the S-I stage and responses being sent back from the stage could be sampled and read by the various measuring devices in the test station.

C. SOFTWARE SYSTEM THEORY

An executive routine as such was not utilized in the PB-250 computer. A utility package was utilized for certain control and program loading operations. In addition, a high-speed photoelectric reader program was utilized in loading computer programs in the high-speed memory. The octal utility package allowed the operator to perform certain transfer functions, print out locations of memory, store single words into memory, and begin the execution of programs that had been stored in memory.

Some of the test routines would contain several segments which would perform various operations in the Remote Test Station. These segments were called up by a small executive included in the routine upon instruction received from the flexowriter. Test routines included the UMA calibration program, telemetry discriminator test, telemetry subcarrier oscillator test, and telemetry identification test.

To illustrate the type of test performed by the system, the UMA calibration program will be discussed in some detail. Figure 4 illustrates a simplified block diagram of the onboard measuring and telemetry system. The UMA is simply a signal conditioning device which receives the output of a sensor and conditions the signal to a 0 to 5 volt level for input to the subcarrier oscillators. Each of the UMA's controlled by the UMA program could be adjusted manually by introducing a calibration voltage to the input of the amplifier in place of the sensor input. By adjusting the amplifier,the output could be calibrated to a predicted value. The UMA calibration program would apply the calibration stimulus to the input of the UMA and would read the output level and signal the operator onboard the stage through the remote indicator unit (RIU) figure 5, as to the high or low condition of the output. Through repeated sampling of the output of the UMA and the adjusting of the calibration potentiometer

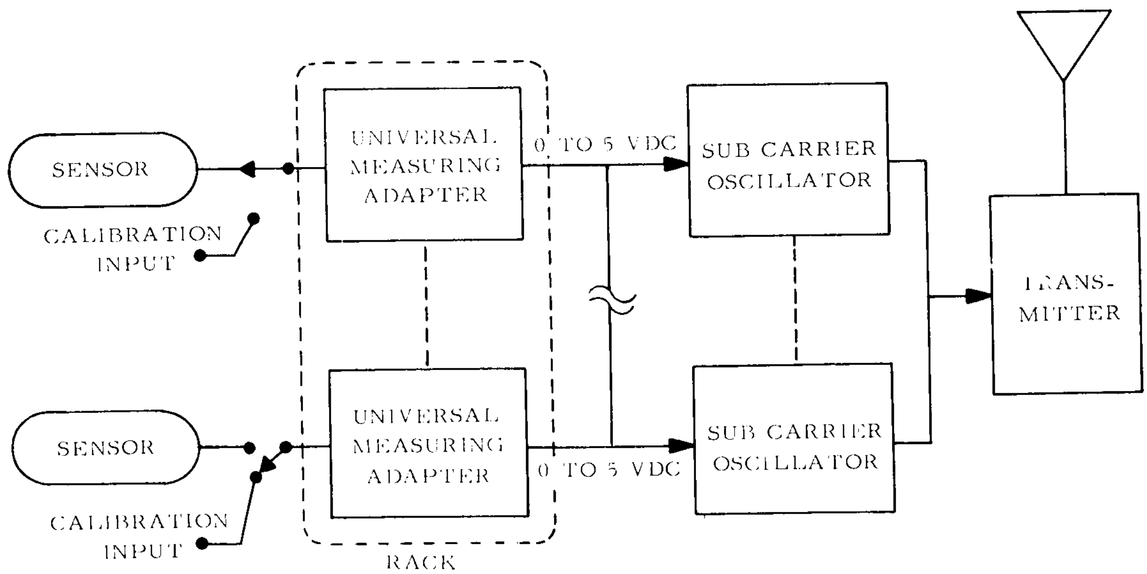

Figure 4. Onboard Measuring System Block Diagram

on the amplifier, the test engineer was able to calibrate the UMA. Upon completing the calibration of one UMA, the test engineer would signal the computer by depressing a test complete button on the remote indicator unit. The computer program would then step to another UMA and display to the test engineer the location of the next UMA to be calibrated. Each UMA was calibrated at two different points on its characteristic curve. The test engineer had the capability of selecting the point at which he was going to calibrate and was able to alternate back and forth between the high and low calibrate points by depressing a step button on the remote indicator unit. After the test engineer had attempted to calibrate each of the UMA's, the computer would printout on the flexowriter those measurements which were out of tolerance (no-go conditions). Analysis of the malfunctioning UMA's could then be performed by the engineering personnel and action taken to repair or replace the defective parts. The UMA's could then be recalibrated. The computer operator had the option of being able to look at the output of each UMA prior to the calibration exercise. This procedure would provide the engineering personnel with a list of those measurements which were out of tolerance and would have to be calibrated.

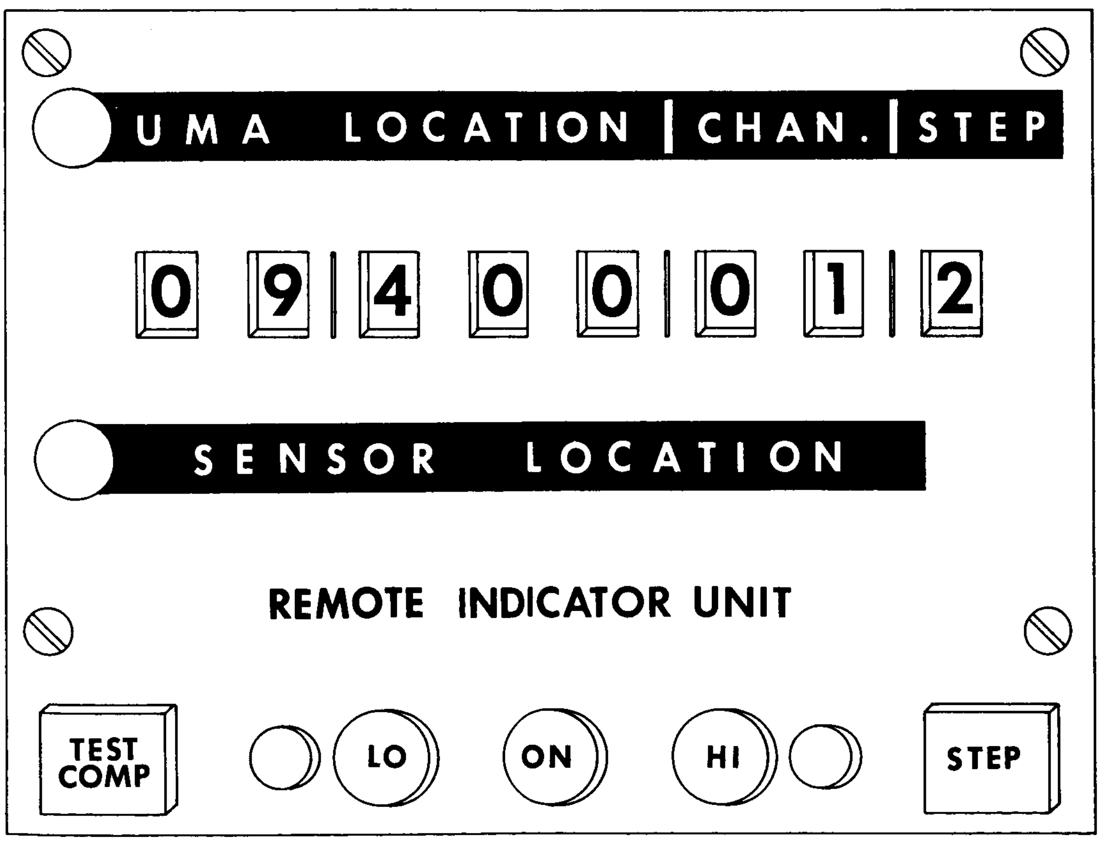

Figure 5. Remote Indicator Unit (RIU)

The Vehicle Test Station which was to be a part of the Saturn I Automatic Checkout System was developed and completed early and as a result was delivered for use with the interim computer system. Communication with this test station was similar to that of the Instrumentation Test Station with the exception of the information being transferred in serial rather than in parallel. Only one test station could be connected to the interim computer at one time. This required disconnecting the computer buffer for one test station and connecting the computer buffer for the other test station. The Vehicle Test Station was to be an integral part of the Saturn I Automatic Checkout System and will be discussed in detail with that system in section III of this document.

D. SYSTEMS EVALUATION

The Interim Instrumentation and Telemetry System provided valuable training and experience for test personnel and programming personnel in advance of the delivery of the automatic checkout system. There were many problems involved in getting the equipment into an operational status as it was the first application of computer controlled automatic checkout and because of the new and complex electronic designs involved.

The magnetic-tape unit in the computer complex was unreliable and the complexity required in programming and operation of the tape unit made it impractical to use. The fact that only one tape unit existed added to the inefficiency of the computer operation. The computer system itself was input/output bound, i.e., it was very difficult to get programs and data into the computer and get test results data printed out.

Most of the programs executed in the computer complex of the interim station contained large tables of data. These tables of data were contained on separate tapes and read in with the program at execution time. Much of the data changed in value up to the last minute prior to the running of a test. Considerable difficulty was encountered in updating this data as it was contained on punch paper-tape. The programs,however, were designed to accept last minute changes entered on the keyboard of the flexowriter and relieved this situation to some extent.

Printout of test results was a long and tedious operation. Many of the factors that have been mentioned were later to lead to a partial justification for a purchase of an off-line support computer system.

With the delivery of the Saturn I Automatic Checkout System, the Interim Computer Complex was converted into a programming support operation and an off-line data and program debugging system.

Another problem encountered with the interim system was the lack of sufficient displays of information and data being processed by the computer.

Because of the recirculating type of memory in the computer, programming was necessarily more difficult. In order to obtain the speeds required for fast sampling rates and various other timing requirements, the computer programs had to be optimized for data access in the computer memory. This was a tedious operation and required more time for program development than normally would be required for a random access memory type computer. Changes being made to the computer program would often upset the optimized portions of the program and would increase the difficulty even more.

With the separation of the test station from the computer complex, a communications problem existed between the operating personnel. However, this was somewhat alleviated by the installation of special voice communications equipment.

Much of a computer program could be debugged in the computer complex. However, when the portion of the program involved with testing had to be debugged, the programmer had to perform these operations in the test station area. This generated the requirements of having a utility program developed which would operate from the flexowriter located in the remote test station area and provide the programmer with a means of communicating with the computer directly. Here again, the lack of displays in the test station area hindered program debugging operations.

SECTION III. PACKARD BELL SATURN I AUTOMATIC CHECKOUT SYSTEM

As test operations increased and vehicles became more complex, a more sophisticated checkout system was required to handle the increasing number of tests, calibrations, and measurements. Automation was the best known solution to the problem and the digital computer proved the best means by which to control and evaluate the testing operations.

The basic philosophy leading to an automatic test concept was increased confidence in system reliability and at the same time, a decrease in final vehicle checkout time, if possible. In order to develop and implement a satisfactory checkout system, automated checkout concepts had to be integrated into the final verification tests performed on each stage at the manufacturer's plant. To establish guidelines for these operations, the Quality and Reliability Assurance Laboratory undertook an automated checkout program in July of 1960 which included design, development, and procurement of the operational hardware necessary to accomplish automated final tests on the first stage of the Saturn I, Block II, S-I vehicles. The goal was to achieve a checkout system with all practical steps carried out by automatic equipment. Packard Bell Electronics was selected to design and build the checkout hardware. Figure 6 illustrates the Central Computer Complex of the completed Automatic Checkout System.

A. GENERAL DESCRIPTION

The most attractive feature of the technical approach suggested by Packard Bell was the method of communicating with remote test stations via digital links. A multiple computer complex, centrally located, was proposed which would permit one slave computer to perform tests in one area, while a second slave computer performed tests in another area, each completely independent of the other. However, the master-slave relation could be used where two or more test stations were to be operated in a composite test.

B. HARDWARE SYSTEM THEORY

The automatic checkout system for the Saturn S-I stage basically consists of a Central Computer Complex and four remotely located test stations. Modular design allows expansion of the system to a total of ten computers in the central complex and 32 remote test stations. Figure 7 is a block diagram of the system function.

Figure 6. Central Computer Complex

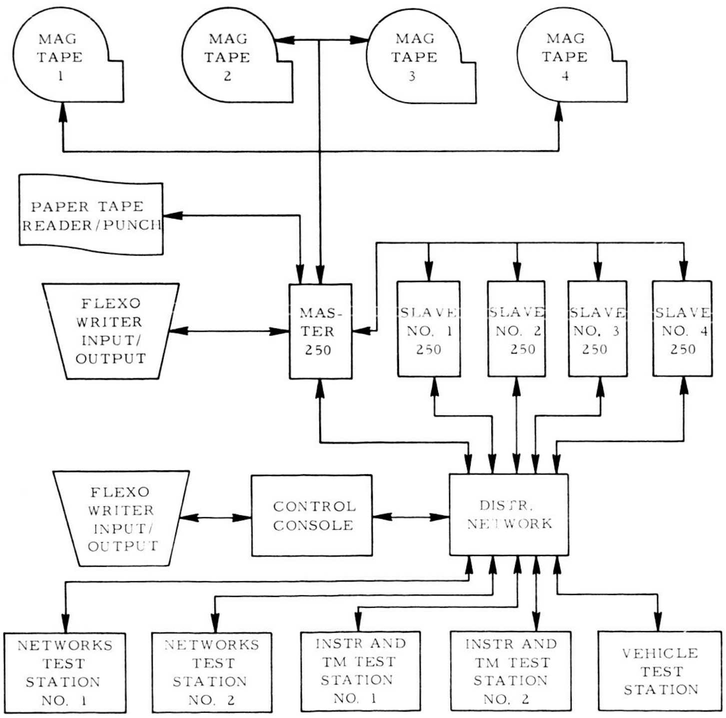

Figure 7. Automatic Checkout System Block Diagram

1. Central Computer Complex. The Central Computer Complex consists of three Packard Bell PB-250 computers with memory extension units, three magnetic-tape handlers with a control unit, a high-speed paper-tape reader/punch, and an operator's console. The operator's console is electrically connected as a remote station.

Each computer is a general purpose, fixed point, fractional, binary, digital computer. The memory consists of magnetostrictive delay lines 256 words long. The computers have a memory of 10,000 words each and can be expanded in increments of 256 words to a total of 15,888 words. Maximum access to any word in memory is 3.072 milliseconds and a word time is 12 microseconds. Each word in the computer is 24 bits long. Only 22 of the bits are accessible to the programmer, the other 2 being parity and guard bits used by the computer.

2. Test Station. Each test station can be considered as a computer which receives its instructions one at a time from the Central Computer Complex. The instructions are sent to the test stations as 22 bit words. Each word is interpreted as having an address, command, and data field as shown in figure 8.

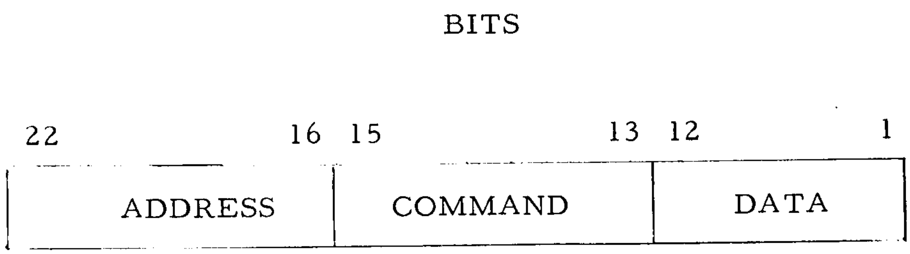

Figure 8. Instruction Word Format

The test station interprets the address portion of the word to mean a particular unit within the station, i.e., analog to digital converter, stimuli generator, relay matrix, etc. The command portion designates an operation to be performed by the test station. The data portion is used to designate which relay is to be actuated in the relay matrix, what signal is to be applied by the stimuli generator, etc.

Some instructions require that information be sent back to the Central Computer Complex after they are executed in the test stations. Such an instruction would be an analog to digital conversion. After the conversion has been made, the digital value would be read back to the Central Complex; up to 22 bits of information can be transferred back.

Each test station is designed to perform certain checkout operations on the S-I stage. The tests performed by the station are determined by the sequence and content of the instructions sent to the test station. In turn, the sequence and content of these instructions are determined by other instructions given to a computer in the Central Computer Complex.

The original design of the Saturn I Automatic Checkout System included 11 test stations as follows:

1. Instrumentation and Telemetry System
2. Instrumentation and Telemetry Components
3. Guidance and Control System
4. Guidance and Control Components
5. RF System
6. Networks Test
7. Electrical Test Number 1
8. Electrical Test Number 2
9. Vehicle Test
10. Mechanical Assembly Test
11. Mechanical Components Test

For reasons of economy, combination of functions, design techniques, etc., the number of test stations was reduced to the following four:

1. Instrumentation and Telemetry Test Station
2. Networks Test Station
3. Vehicle Test Station
4. Electrical Test Station

A Guidance and Control Test Station was fabricated and installed for use with the RCA-110 Ground Computer System and development of an RF Systems Test Station was made inhouse. Neither of the stations was used in first stage checkout operations.

Because each of the four test stations used with the Saturn Automatic Checkout System are complex in themselves, each will be discussed in detail separately. However, portions of each test station are exactly the same. These common areas consist of the Test Station Operator's Console (figure 9), test station buffer, and flexowriter. The decoding logic for each station was different because of the varying functions to be performed in each test area.

The test station is operated either through the Central Computer Complex or manually by the operator. When the station is computer controlled, a choice of automatic or single-step operation is available. In manual mode, the station is programmed and controlled by the operator.

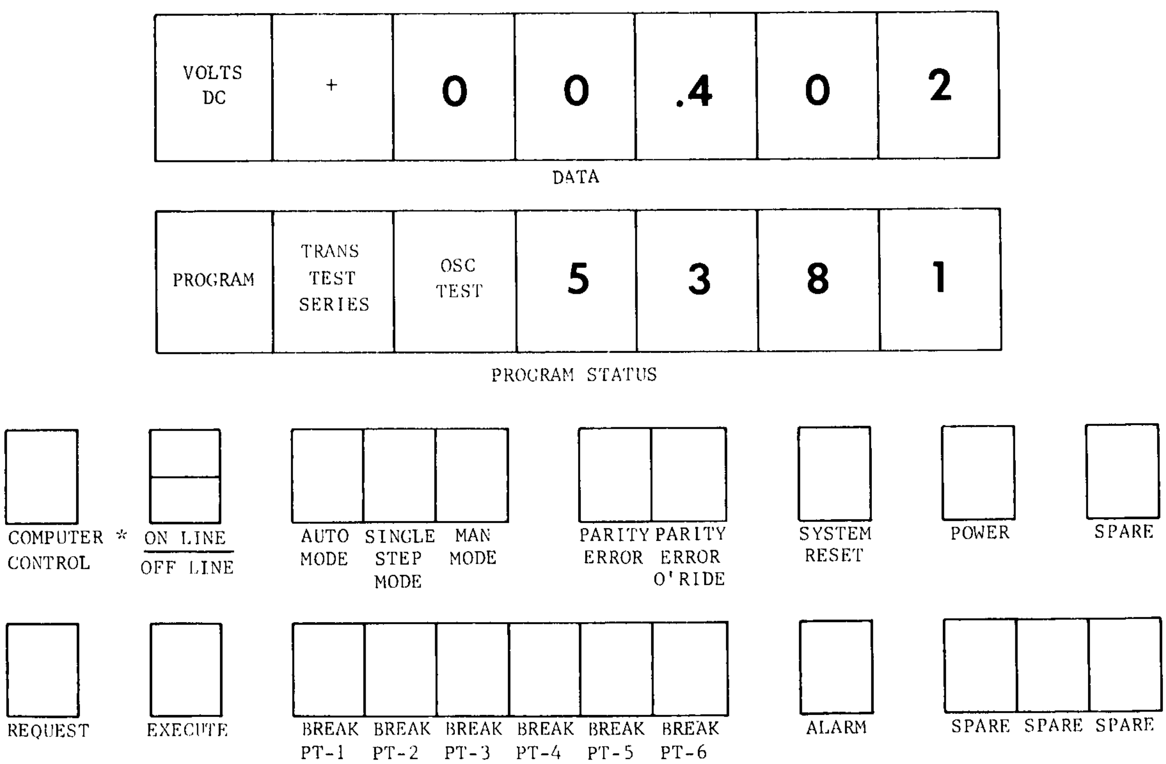

Figure 9. Test Station Operator's Console

In manual mode, the station is electrically disconnected from the decision-making elements in the Central Computer Complex. The station will stop operating when a decision is required, and the operator must furnish the decision before the operations can be resumed. The operator-furnished decision is in the form of a command loaded by the flexowriter. Commands may be loaded into the station using a prepunched paper-tape and the flexowriter tape reader, or commands may be loaded using the flexowriter keyboard.

C. NETWORKS TEST STATION

The Networks Test Station, pictured in figure 10 and illustrated in block diagram form in figure 11, performs the two major functions of monitoring and control. The station monitors all signals passing between control panels, relay boxes, and the vehicle, so that stimuli and corresponding vehicle responses can be fully analyzed. The response may be ac or dc voltages or currents, resistances, contact closures, and on/off indications. Responses generated by either the vehicle system or its associated equipment are brought in through the patchboards and controlled by the response selector matrix. The Networks Test Station includes the following equipment:

1. Console. The area immediately in front of the operator, including the flexowriter and all numeric displays, is known as the common area. The common area is where the Networks Test Station operator monitors and controls all functions concerned with either automatic or manual operation of the station.

2. Auxiliary Display Panel. The auxiliary display panel contains three displays, the alarm indicator lights, the satellite station buffer, and the matrix selector display.

a. Alarm Indicators. The alarm indicators are connected to certain certical points around the vehicle and ground station where malfunction would require the immediate attention of the operator. The ground inverter phase, grounded indication, and the vehicle inverter phase, grounded indication, are connected to the alarm indicators.

b. Satellite Station Buffer Display. The satellite station buffer display is an eight position octal character display which is controlled by the output of the station buffer. It displays the last command executed from either the computer or the flexowriter by the station buffer until the station is reset or a new command is executed.

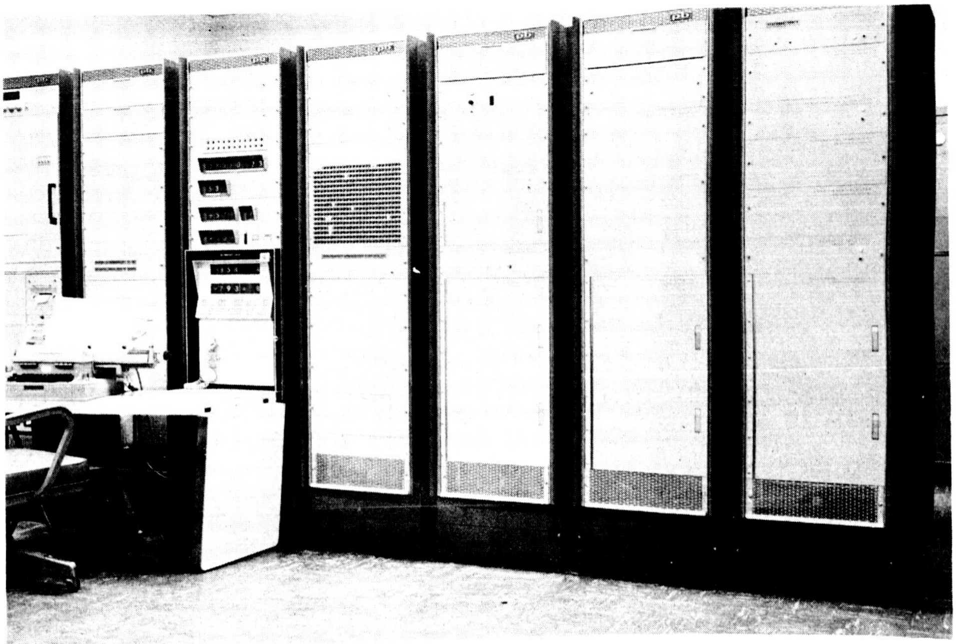

Figure 10. Networks Test Station

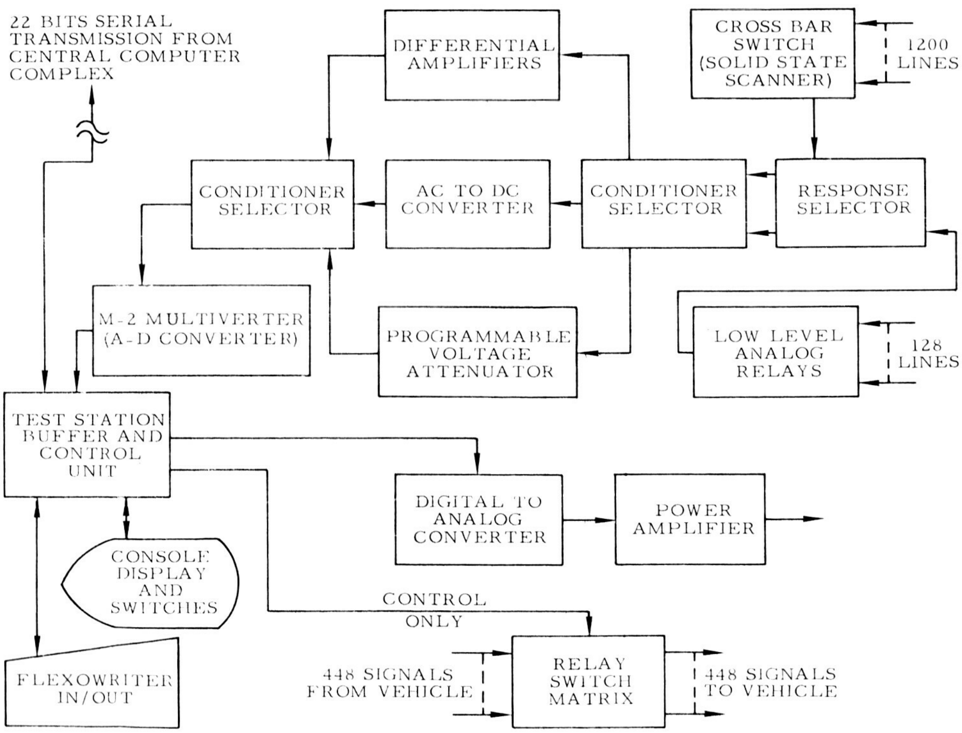

Figure 11. Networks Test Station Block Diagram

The information displayed will be the address, command, and the data field. The first three characters are the address. The address denotes to what specified area the word is going. The fourth character is the command. The command denotes the type of operation to be performed by the area addressed. The last four characters are the data field. The data field is capable of subdividing an address into 4, 095 parts.

c. Matrix Display. The matrix display is located just below the satellite station buffer display. The matrix display indicates which, if any, select and hold coordinates of the response selector matrix are energized.

d. Participating Stations Display. The participating stations display denotes which, if any, satellite stations are working with the Networks Test Station. This is a programmed function.

3. <u>Actuator Position Display Panel.</u> The actuator position displays are unique in that they are not completely controlled through the buffer. The upper display is for the pitch position and the lower display is for the yaw position. The number of the engine being monitored is displayed to the right of the pitch position indicator. The engine number display can be controlled by a four position switch (one position for each engine) and two pushbuttons.

4. <u>Satellite Station Buffer.</u> The control unit in the satellite station buffer serves to interpret computer instruction and control functions in the station. Binary indicators are provided on the buffer (SSB-4) to permit observation of its contents.

5. <u>Matrix Display.</u> The matrix display indicates which of 448 magnetic latching stimulus selection relays have been activated. The display contains 448 individual lights which are numbered to correspond to the relays selected.

6. <u>Digital-to-Analog Converter.</u> The digital-to-analog converter (DA-6) converts digital inputs to analog output voltages. Digital numbers are entered in parallel and are represented as binary input voltage levels. The analog output voltage is proportional to the digital input number. By knowing the range to which the DA-6 power amplifiers have been set, the operator, by utilizing the display, can determine the output voltage. The first bit is the sign bit, and the test of the display is a binary representation of the voltage. Decimal conversion is required to evaluate the level of the signal.

7. Relay Switch Matrix. The relay switch matrix responds to stimuli by individually setting or resetting 448 latching relays. The relays are in 7 groups of 64 relays each. Each group is enabled by a store command or an execute command and addresses 030 through 036 respectively. The relay switch matrix is used to route externally generated discrete stimuli to points on the vehicle.

8. AC to DC Converter. This converter changes either 60 or 400 cycle ac voltages to dc signals for processing by the M-2 multiverter.

9. Time and Frequency Digitizer. The time and frequency digitizer provides the capability to count the number of cycles per controlled time period (frequency count) or the length of time to count a predetermined number of cycles (time count). It will also measure the time difference between two input signals. The gating, or starting, of the counting process can be on either the leading or trailing edge of one or two input signals, depending upon the application.

10. Response Selector Matrix. The response selector matrix is a crossbar switch with 12 "select" coils and 10 "hold" coils, which can be energized in all combinations of any one select or one hold. When a select and hold coil is energized, ten contacts (levels) are closed. The crossbar switch has 1200 contacts (levels), 830 of which are used to discrete responses, routed straight to the buffer in groups of 10. The remaining 360 contacts are used for 180 analog responses; analog signals are switched in pairs. Although five analog responses (10 levels or contacts) are selected by the crossbar switch with each select hold combination, the response selector allows only one of these analog responses to be routed out of the chassis. The matrix display panel indicates the "select" and "hold" coils which have been energized.

11. M-2 Multiverter (Analog-to-Digital Converter). The M-2 multiverter receives dc voltage outputs from either a differential amplifier, the ac/dc converter, or the programmable voltage attenuator. The voltage is digitized and fed into the station buffer (SSB-4). Maximum input voltage to the M-2 is $\pm$ 5 volts dc. The low level selector chassis contains 128 nonlatching relays through which analog responses of low voltage amplitude are routed. Programming one of these relays and the conditioner selector will connect the analog signals to any programmed conditioning device. The programmable voltage attenuator (PVA) is a voltage divided network with 999 individual ranges of attenuation. It is used to attenuate large voltages and measure the potential difference from chassis ground.

12. Differential Amplifiers. There are four differential amplifiers in the Networks Test Station, each with a different input voltage range. Voltage ranges for these amplifiers are: 0 to 2 volts, 0 to 10 volts, and 0 to 60 volts. The maximum output voltage of each differential amplifier is ± 5 volts dc. The differential amplifiers are used for measuring lox amplitude analog responses and/or rated-input responses.

13. Conditioner Selector. The conditioner selector is used to switch one of the seven analog signal conditioners (four differential amplifiers, ac/dc converter, time and frequency digitizer and the programmable voltage attenuator) into the response channel. Both the input to and from any conditioner are switched simultaneously. The same command that selects a conditioner can also start the M-2 conversion after a programmed delay for conditioner setting.

14. Response Selector. The response selector chassis contains the logic that operates the response selector matrix (crossbar switch), which switches either the low level relay analog responses or crossbar switch analog responses into the proper conditioner selector channels.

D. INSTRUMENTATION AND TELEMETRY TEST STATION

The Packard Bell Computer Instrumentation and Telemetry Test Station (figures 12 and 13) is computer-controlled with three major functions: to initiate, monitor, and interpret calibration and test results of three arbitrarily designated systems: the UMA Calibration System, Miscellaneous Sensor-Response System, and Pneumatic Pressure Distribution System.

Hardwire output signals are brought out from the stage and latching relays select the individual wire for monitoring. In addition, high-level and low-level differential signals are brought out through the umbilicals of the stage and directed to the station for monitoring by means of relay multiplexers.

High-pressure and low-pressure digital-to-pressure generators are supplied for stimulating pressure transducers. Relay closures are provided to select the pressure, and relay closures are provided to switch manifold configurations for directing the proper pressure to the proper transducer under computer control. Stimulation of other transducer types is primarily manual or mechanical, but under computer control.

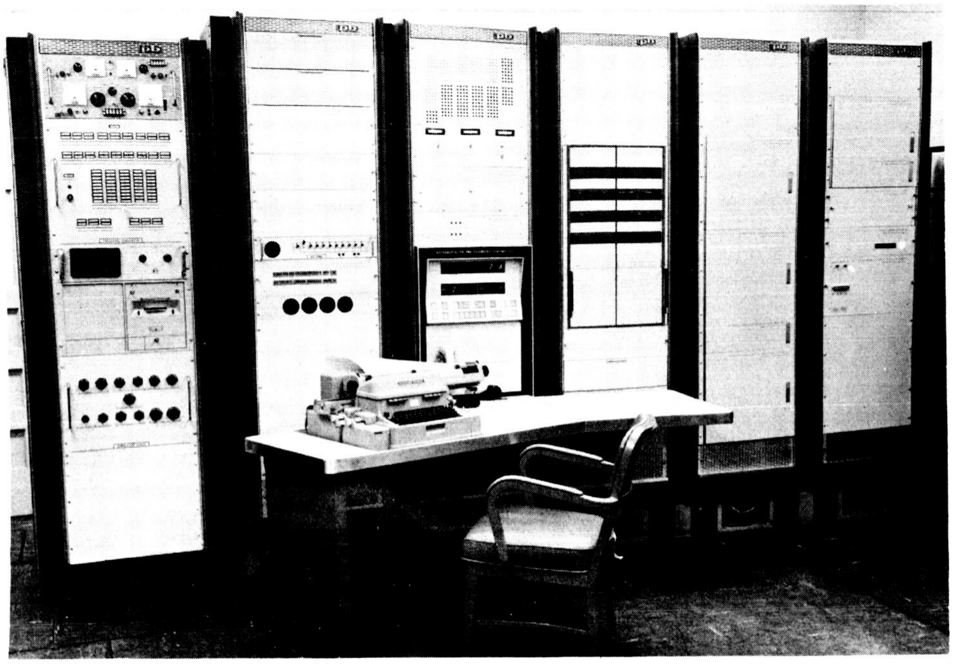

Figure 12. Instrumentation and Telemetry Test Station

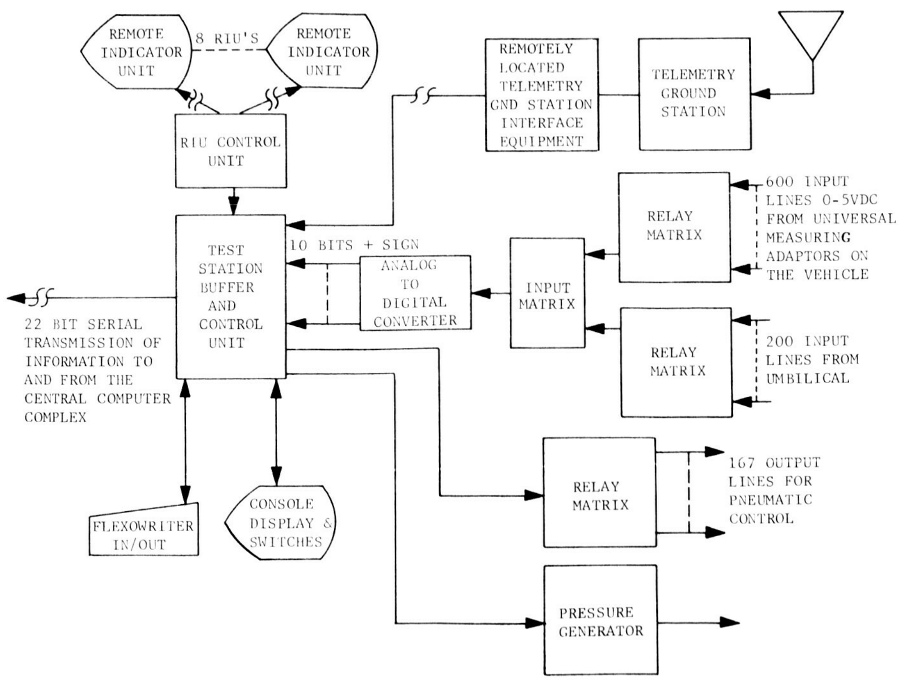

Figure 13. Instrumentation and Telemetry Test Station Block Diagram

The telemetry substation is located remotely from the main satellite station. It is provided with contact closures for setting up the proper receiver-discriminator combination required by the various telemetry channels. It is also provided with circuitry for decoding and measuring decommutated PAM data trains. It also has the capability of driving calibration devices for calibrating the telemeter equipment itself. All operations are under computer control, and all measured data are returned to the test station for processing.

1. Functional Description. The test station proper consists of a telemetry interface, universal measuring adapter calibration interface, pneumatic pressure interface, pressure generating equipment, measuring devices, and a remotely located substation. The substation is used for the reduction of telemeter signals, and calibration and/or test signals from the vehicle.

2. UMA Calibration System. Near the tail section of the vehicle there are racks containing Universal Measuring Adapters (UMA), which consist of a relay and amplifier. Each UMA accepts signals from sensors throughout the vehicle and converts them to 0 to 5 volts for subsequent application to telemetry equipment. Each UMA is calibrated at a high-level or low-level as required. The calibration cycle consists of energizing the appropriate calibration relay to provide the stimulus to the UMA.

There are approximately 600 measuring devices or sensors with hardwire outputs to the test station, and approximately 125 sensors and control signals from the umbilical. These signals are compared with the same signals after transmission over telemetry links.

The computer through the UMA calibration register relay contact closures scans each UMA in the vehicle by supplying signals to the vehicle UMA digital calibrator. To select an individual calibration relay in a specific UMA module, the stimulus selection matrix is energized by a programmed signal from the computer. The calibration register energized the proper relays in the vehicle UMA digital calibrator by contact closure. The calibration register selects the UMA to be scanned. The computer automatically scans all UMA modules for the UMA programmed characteristic wave curve. If any curve is out of tolerance, the computer, after scanning all the UMA's, will type in hard copy the locations of the UMA's not meeting specifications.

If a UMA required adjustment, the operator in the vehicle follows a test procedure, and where necessary makes the proper adjustments. To aid in making the adjustments, the operator in the vehicle uses the indications on the portable remote display unit.

Calibration of the modules is done by the operator in the vehicle. The remote indicator unit shows the measurement or UMA canister, rack, channel, test step, and whether the readings are above or below tolerance. Wrong direction indicators light when adjustement is made in the wrong direction. When the calibration is within tolerance, a lamp lights. The computer proceeds to the next step in the test when the STEP pushbutton is depressed. When the test is complete, the operator depresses the TEST COMP pushbutton to allow the computer to proceed to the next test.

3. Miscellaneous Sensor Response System. The miscellaneous sensor response system required either electrical, manual or mechanical stimulus for measurement purposes. The operator can apply the stimulus manually or with a mechanical device, or the stimulus can be supplied from another satellite station. The computer or the satellite station operator directs vehicle operators, by means of the portable remote indicator units to the proper sensor to be manually stimulated.

Various types of measurements are made: temperature, position indication, angle-of-attack, vibration, liquid flow rate, tachometer, liquid level, and other miscellaneous measurements. All manual operations and tests are commanded by the computer at the proper point in the test sequence. The result of the manual operation or test must be fed to the computer before the computer will permit the test sequence to continue. In this manner, complete data will be obtained and stored by the computer for future reference and analysis.

The connection between the sensor UMA output and telemetry equipment may be interrupted and the outputs brought out by hardwire connection. These signals are fed to the central computer for comparison with the signals received by the telemetry ground station.

4. Pneumatic Pressure Distribution System. The pneumatic measurement part of the test station provides different pressure ranges to individual pressure sensors. Both pressure range and stimulation are completely under computer control.

A pressure distribution relay matrix controls the operation of the vehicle manifolds to select the proper pressure transducer. The pressures used to stimulate the transducers are selected under computer control by means of relay contact closures.

A pressure generator is connected to the vehicle transducers through a system of manifolds. The generator is used for calibration of high and medium range pounds per square inch gages (psig) and pounds per square inch absolute (psia) transducers. The computer system contains a relay-holding register which provides contact closures to activate the solenoid valves in the generator.

5. Satellite Substation. The substation is remote from the satellite station. All actions at the station are commanded and controlled by the computer.

Under the control of a computer program, the substation automatically connects the appropriate receivers, discriminators, or decommutators, so that selected telemeter data can be routed to an analog-to-digital converter. The digitized response signal is then transmitted back to the computer for analysis.

E. VEHICLE TEST STATION

The Vehicle Test Station (figure 14) provides onboard tests of the electrical heaters, pressure systems, main lox and fuel valves, and digital events in the performance of the vehicle. The Vehicle Test Station functionally consists of a satellite buffer, a stimuli section, and a response section. A block diagram of the test station is shown in figure 15.

The computer originates and stores digital test loop data and program information. The Vehicle Test Station checks out and tests the electrical heaters, pressurized systems, and fuel and lox valves

Figure 14. Vehicle Test Station

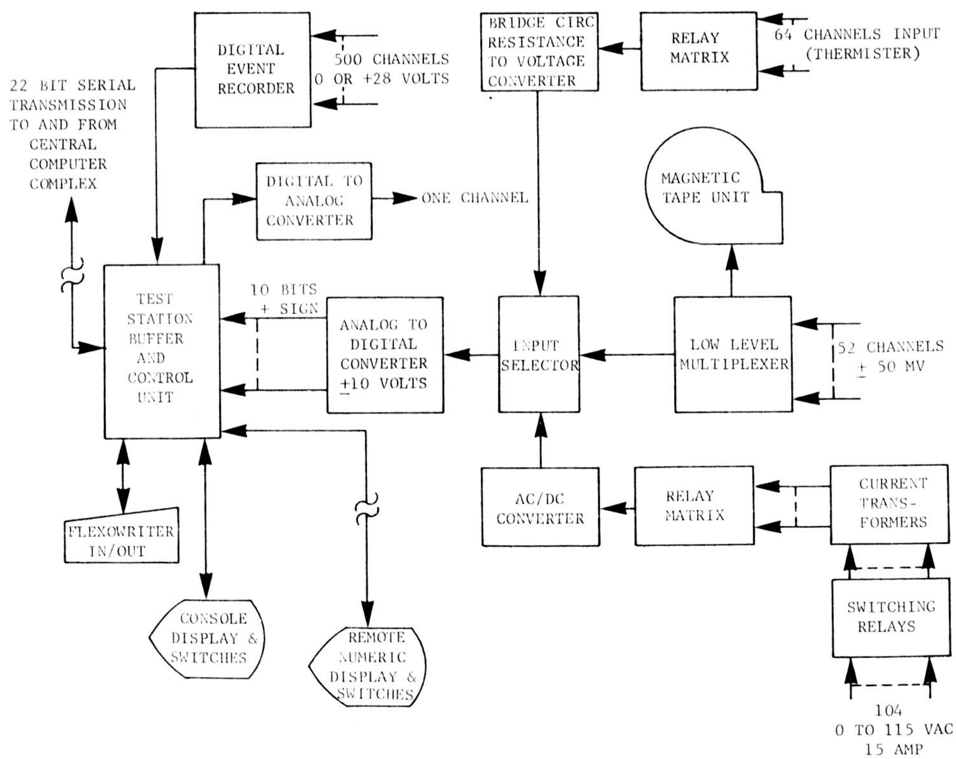

Figure 15. Vehicle Test Station Block Diagram

of the Saturn first stage by means of programmed test loops. The programmed test loops are serially transferred to the test station buffer from the computer. The test station buffer decodes the message from the computer into address, command, and data signals which activate addressed digital-to-analog conversion and stimuli circuits.

The test station stimuli circuits actuate selected transducer elements in the stage. The transducer elements respond with analog output signals. The analog signals are applied to the test station response circuits and are converted to corresponding digital signals. The digitized data is transferred in parallel to the satellite buffer for temporary storage, and then serially transferred to the computer.

The test station automates the specified tests by accepting digital coded instructions from the computer. These instructions select the point of measurement, the conversion and/or signal conditioning path, any local stimulus necessary, and display of printout of data. The test station contains all the necessary (addressable) measurement and conversion components required to perform the specified tests. Internal self check (addressable) measurement paths are incorporated into the test station as an aid to the operator when analyzing malfunctions or verifying measurements. To test for proper operation of the stage heaters, the Vehicle Test Station switches on and off, by program control, 43 heaters, through the activation of the switching relays. The current drawn by the heaters is measured with current transformers, an AC to DC converter, and an A to D converter. Upon the completion of three cycles of the thermostatically-controlled heaters, the computer turns off the heater. The computer prints out the peak and average temperatures and notifies the operator of abnormal temperatures or currents. The computer may or may not, as determined by the program, turn off the heaters if abnormal currents or temperatures are detected.

The test station includes provision for measuring and recording the electrical output of up to 52 pressure and pressure test related transducers mounted external to the station proper. These pressures are measured by a high speed relay matrix in the low-level multiplexers.

The Vehicle Test Station includes a magnetic tape transport and associated control and read/write equipment to continuously record on a 12 minute (minimum) automatically reversing tape the measurements from the 52 pressure and pressure test related transducers.

The station also provides a means for continuous dynamic monitoring of up to a maximum of 250 discrete digital event lines so as to record the time at which any of the lines changes state from on to off or vice veras. The equipment for this purpose is the Digital Events Recorder (DER) which is capable of automonous operation.

The test station includes all of the standard operator controls and displays except the flexowriter which is mounted on a mobile cart to permit remote operation of the Vehicle Test Station at a distance up to forty feet.

F. ELECTRICAL TEST STATION (CABLE ANALYZER)

The purpose of the Electrical Test Station (figure 16) is to test and checkout both the vehicle and GSE wiring and cabling systems. The checkout of the wiring system is made primarily to verify that interconductor or intercircuit resistor insulation is adequate and that point-to-point circuit resistances do not exceed the prescribed maximum. One test made with the test station cable analyzer is the circuit continuity check. This test verifies that the unit is wired as specified, by determining that the point-to-point resistances of selected terminal pairs are within the specified resistance values. A second test made with the test station is a fault test, which determines if a short exists from one ordered wire to another wire of lower order. A fault (short) is found by checking that actual circuit resistance values are less than or equal to a programmed resistance value. If shorts in the circuit wiring exist, the test station scans all the connected terminals and locates the specific shorted terminal or terminals.

The Electrical Test Station operates in conjunction with a computer of the Central Computer Complex and time shares computer space and information with the other test stations. The primary function of the test station cable analyzer is to check out wire and cable systems of up to 4000 test points (terminals) by testing for terminal-to-terminal current continuity and faults (leakage). The functional units of the test station are a cable analyzer and test station buffer.

The central computer complex originates and stores four Electrical Test Station test loop and program words. These programmed words specify: the type of test being run, continuity or fault; the terminals of pin numbers used in the test, and the specific parameters used

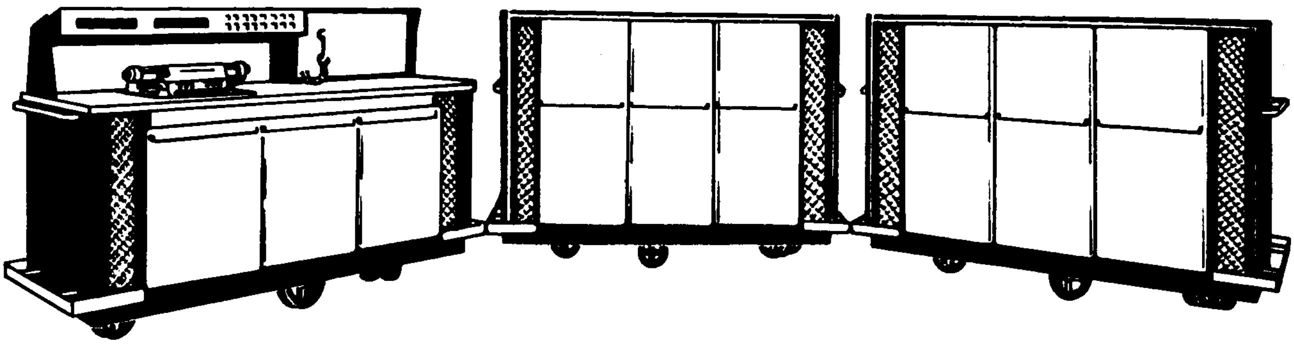

Figure 16. Electrical Test Station (Cable Analyzer)

to run the test. The four programmed words of the computer are serially transferred to the test station buffer which decodes the words directly into address, command, and data signals. The addressed signals activate the cable analyzer circuits to make the specified continuity or fault test.

The test station is an automatic cabling and wiring system analyzer, which functions with a minimum of information from the computer. The cable analyzer control cart controls the testing and logical analyses of the system under test. The system under test is initially connected to the switching card input connectors, which are wired to numerically ordered switching module connector terminals. The selection of specific test terminals, type of test, and test parameters are provided by either the automatic computer programmed input to the control cart, or by the test station operator manually selecting these test parameters on the OVERRIDE panel of the control cart.

The test station cable analyzer control cart contains all of the equipment necessary to initiate and control the range of input parameters and type of test desired, and to analyze and determine the specific terminals within the switching cart connector matrix which contain the circuit fault or discontinuity. The control cart contains the indicators and indicator switches which display to the station operator the resultant condition of the switching cart system under test. The control cart logic section decodes and transmits the test results to the buffer cart satellite buffer, which, in turn, transmits information to the buffer cart display panel and to the computer.

The cable analyzer switching cart contains the patchboard inputs and cable input connectors used to check out a system. The switching cart uses four terminal-switching and bulk-shorting switching modules, each of which provides for an independent selection and use of input/output terminals. Each switching module provides: up to 1000 terminal connections; a partial selection of an output terminal (five terminals selected from 1000); the partial selection of an input terminal (50 terminals selected from 1000); and the means to short any portion of 1000 terminations in groups of 50 terminals to the system short line.

The selection of either input or output connector terminals is made through two 50-pole, 20 position stepping switches and twenty 50-pole bar relays within the switching module. These switches and relays obtain switching information from the control cart input lines.

The test station cable analyzer performs its continuity and fault test on three types of switching cart input points:

a. 66 Bendix connectors of 61 pins each.

b. A 3264 point AMP patch panel.

c. A 2560 point IBM patch panel.

Connectors and terminals are numbered in accordance with a fixed connector and pin assignment. The numbering of 80 connectors and 50 pins (4000 points) is made on an ordered arrangement, so that the lowest order terminal is designated as connector 00, pin 00, and the second lowest terminal point is designated as connector 00, pin 01. The terminals are wired consecutively up to highest order, designed as connector 79, pin 49.

The cable analyzer fault test checks the current flow condition between two selected terminals (insulated from each other) one of which is shorted (connected and used as a node terminal) to a number of other terminals. An address specifies the shorted terminal to which all terms of lower order are also connected and shorted.

A continuity test determines the resistance value between two specified test terminals. If the resistance value is more than the programmed value, a discontinuity or continuity error is determined and displayed on both the control cart indicator display and the buffer cart operators control panel.

G. SOFTWARE SYSTEM THEORY

Under automatic checkout operation the computers are designated as Master, Slave 1, and Slave 2. The Master computer is capable of communicating with the slave computers and vice versa through common memory lines. In this configuration, an executive routine called the Saturn Master Monitor is loaded into the Master computer. Lesser executive routines called Slave Monitors are loaded into each slave computer.

1. Saturn Master Monitor. The Saturn Master Monitor program is the heart of the entire system. It is an elaborate routine offering control, monitoring, and input-output for the console and remote test stations.

The Saturn Master Monitor continuously monitors the remote stations for requests to perform checkout tests. To initiate a checkout test, the test station operator first consults a station program list for the identification number of the program to be run. The request switch is then depressed on the test station console. The Saturn Master Monitor senses the request. If a test is being performed in that test station, the program is automatically stopped by the monitor. The monitor begins communication with the test station operator by typing "BUSY, READY, or PROGRAM".

a. BUSY. BUSY indicates that all slave computers are in use and it will not be possible to run the test. The Saturn Master Monitor continues its operation.

b. READY. A slave computer has been connected to the test station and the operator may select one of five options.

(1) UTL. By typing UTL the operator causes control of the slave computer to be transferred to a utility program. The station operator may then communicate with the slave computer. This option is primarily for use by the programmer in debugging test routines.

(2) END. The Saturn Master Monitor will type out END, program number, time and date, and will release the slave computer for other tests.

(3) RST. The Saturn Master Monitor turns on the execute light on the test station console. By depressing the execute switch, the operator signals the Saturn Master Monitor to restart the test at an appropriate place.

(4) GO. By typing GO the operator causes the test program to resume operation.

(5) TEST. TEST indicates another test program is to be loaded into the slave and operation is continued as described under PROGRAM below.

c. PROGRAM. The test station operator requests the test program by typing the program number (PP). The Monitor replys by typing out "START PROGRAM PP", the time, and date. The Monitor then searches the program magnetic tape for the requesting program. If the program is not on the tape the Monitor will type "NO PP" to the station operator. If the program is found, it is loaded into the slave computer and control is transferred to the slave to perform the checkout test.

2. Slave Monitor Program. The Slave Monitor is a small executive routine used for control of the slave computer and for transmission of information to and from the Master computer. During the operation of checkout programs the Slave Monitor is inoperative. The operation of the Slave Monitor is under control of the Saturn Master Monitor. The Slave Monitor contains utility subroutines which may be used by the checkout programs.

When a checkout program is to be loaded into the slave computer, the Slave Monitor receives the program 256 words at a time from the Master computer and stores it in a designated location. Storage information is contained at the beginning of each line of information transferred to the slave.

H. SYSTEMS EVALUATION

When the Packard Bell Saturn Automatic Checkout System was first being implemented in the Quality and Reliability Assurance Laboratory, many changes in the design of the Saturn I stage were being made. This necessarily affected the implementation of automated systems in that many changes had to be made to both the ground support equipment and to the software involved. Many of the changes were minimized because of the design of the software. Since the computer programs were developed to allow for changes in tables of data, the requirement for making extensive and time consuming changes to the program instructions were minimized. However, many changes were made to the computer programs due to changes in stage systems and introduction of new stage systems.

As anticipated, however, by the end of the Block II Saturn I stages, the stage design had become essentially fixed and the number of changes to software were held to a minimum.

The Packard Bell Saturn I Automatic Checkout System has been a topic of conversation for many years and will be a topic of conversation for years to come. Although there is a great deal of controversy over the number of computers or the arrangement of computers for an automated checkout, it is commonly agreed among personnel of the Quality and Reliability Assurance Laboratory that the Packard Bell concept of the "master-slave" arrangement has been the most satisfactory and optimum type of arrangement of computers for an automatic checkout. Although the Packard Bell PB-250 computer is outmoded in terms of the speed and capability of computers being manufactured today, the Packard Bell System continues to be used effectively and to advantage in the automatic checkout of the uprated Saturn I stages at Michoud.

It is believed that the master slave arrangement utilized in the Packard Bell Central Computer Complex was the state-of-the-art design at the date of its conception and only recently has the concept been introduced into large multicomputer time sharing complexes of the third generation. The modularity of the design of the Central Computer Complex has been demonstrated by expanding the number of slave computers to four and the number of test stations to five. Total expansion capability of the system is 9 slave computers and 32 test stations with no additional software requirements.

SECTION IV. RCA-110 GROUND COMPUTER SYSTEM

Automation of checkout of the many systems onboard the Saturn I Instrument Units (IU) proved a formidable challenge to both hardware and software designers.

The computer system selected for checkout of the Instrument Unit was the Radio Corporation of America's model 110 computer system (RCA-110). This system fulfilled in most respects the requirements of automatic Saturn I Instrument Unit checkout. (See figures 17 and 18.)

A. GENERAL DESCRIPTION

The RCA-110 computer system is a general purpose, solid state, binary, fractional, digital computer. The operational sections as applied to an RCA-110 computer system are described in the following paragraphs.

1. Input/Output. Information is transferred into, and out of, the computer by means of input/output devices. Data to be processed, or programs to be performed, are "read" into the machine by paper-tape, by magnetic-tape readers, or by other peripheral equipment. Information is returned from the computer by a paper-tape punch, a magnetic-tape recorder, typewriter, or other type of visual display. Within the computer are several registers that sense, select, and control the information to and from the input/output equipment.

2. Control. The control section is the command unit. It governs all operations in the machine such as information transfers, arithmetic performance, and the sequence of instructions. The control section may be a complete unit consisting of several registers, such as the program counter, the instruction register, and the timer.

3. Arithmetic. This section of a computer performs mathematical operations: addition, subtraction, multiplication, and division. It also performs "logical" operations. The arithmetic section will contain such units as the left and right accumulators, the adder, and the counter.

4. Storage. The storage unit is where information is placed (in machine language) until it is required for use during program

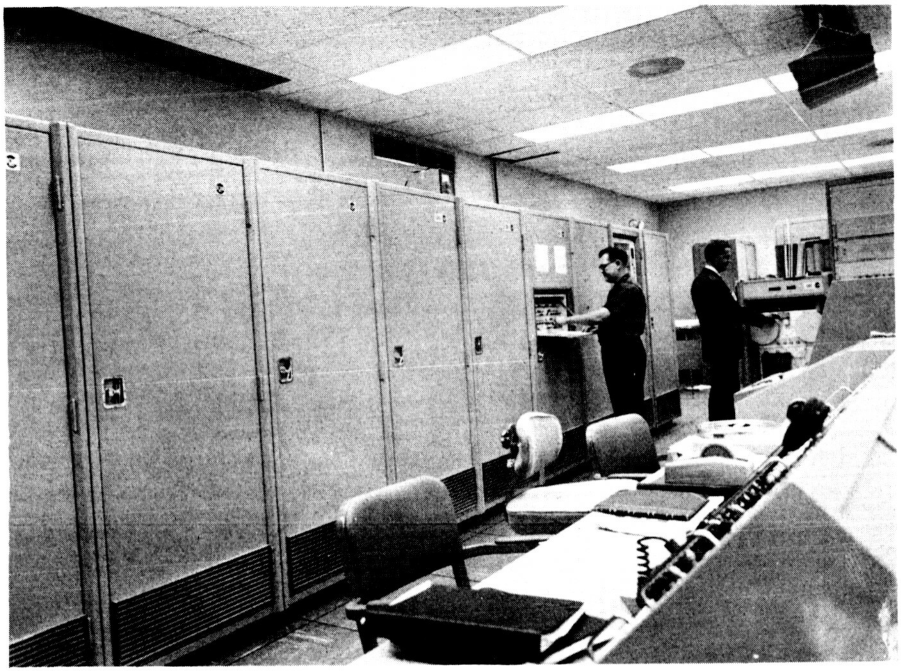

Figure 17. Saturn I Instrument Unit Checkout System

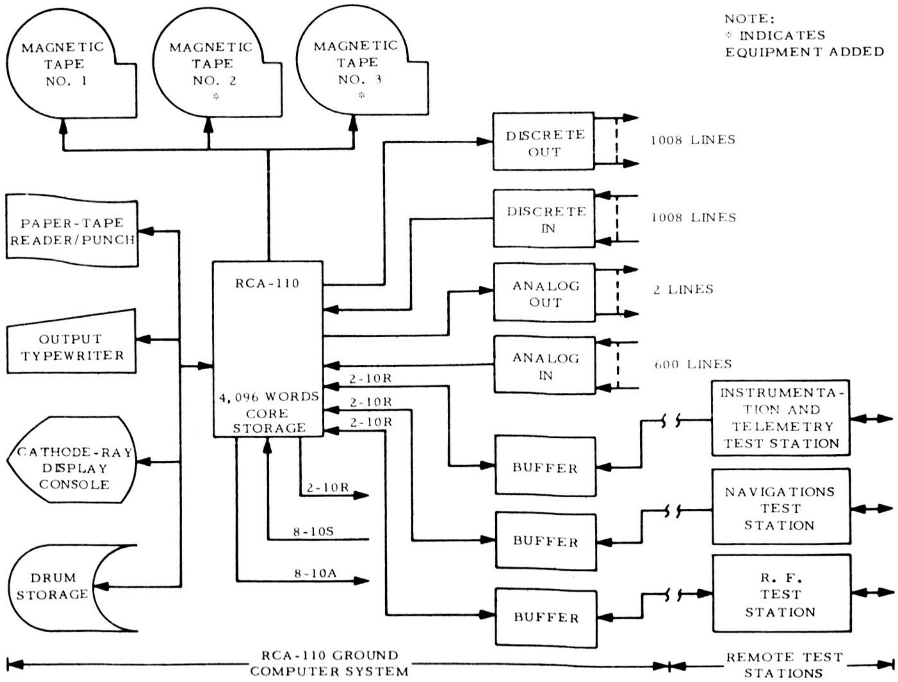

Figure 18. Saturn I Instrument Unit Checkout System Block Diagram

execution. "Memory" is usually referred to as the storage within the computer. Information is retained in units such as a coincident core or a magnetic drum. Storage outside the computer is generally on paper-tape or magnetic tape.

B. HARDWARE SYSTEM THEORY

The RCA-110 computer is a binary fractional computer equipped with a 4096-word, high-speed magnetic core memory, a 32,768 word magnetic drum backup memory, and eight priority interrupt lines. The basic computer also includes eight input/output sense lines (IOS), eight input/output address registers (IOA), eight general input/output buffered registers (IOR), a paper-tape reader/punch, one magnetic tape transport (using the standard IBM 729 mod II format and later increased to 3 magnetic tape units), an IBM electric typewriter, and a direct-view display tube. The IBM electrical typewriter can be used as an output device only. The other equipment is two-way, input and output, provided the automatic checkout computer programmer elects to program the system.

For application as a control device, the RCA-110 computer system has the following ancillary equipment:

One thousand and eight discrete input lines and 1,008 discrete output lines capable of sensing or sending a 28-volt signal.

Six hundred analog input lines for receiving converted analog signals (analog to digital).

Two analog output lines (not used in the Saturn I Instrument Unit automatic checkout).

Three remote satellite stations which duplicate some of the input-output equipment in the RCA-110 racks, are associated with the automatic checkout equipment of the Saturn I Instrument Unit. These stations are the Interim Instrumentation and Telemetry Station, the Navigations Test Station (formerly Guidance and Control Systems), and the Radio Frequency Systems Test Station. The Vehicle Systems Electrical Networks and Digital Data Acquisition Systems are operated from the standard RCA-110 ancillary equipment through the electrical support equipment.

1. Memory Systems. An important factor affecting the speed of the computer is the memory system. The RCA-110 computer memory consists of a high-speed, coincident - current core and magnetic drum.

The core normally has a storage capacity of 4,096 words, with an access time of 3.5 microseconds and a cycle time of 10.25 microseconds. The drum has a maximum of 256 tracks with 128 words per track, and can store as many as 32,768 words. The average access time for the drum is 8.5 milliseconds with a maximum of 17 milliseconds.

2. Registers. The RCA-110 computer contains several arithmetic and control registers which are of interest to the programmer. These registers perform the basic arithmetic operations and control the sequential operation of the computer.

a. Left Accumulator. The Left Accumulator (L) is the principal arithmetic register where most operations are performed. Containing 24 bits, it is used to hold an operand and most of the results of all arithmetic operations. Most conditional control transfers are also dependent on the contents of L.

b. Right Accumulator. The Right Accumulator (R) contains 24 bits and is primarily used as an extension of L. It holds the least significant half of double-length operands and results. R is also used to hold the remainder in division or the multiplier in multiplication.

c. Index Registers. The Index Registers (XR) are actually seven consecutive HSM locations (0001 to 0007) which are individually addressable. They are treated as 12-bit registers when an instruction is being interpreted. The primary function of the index registers is to provide for address modification; however, they may also be used for counting and looping. The status of an XR may be tested by the use of the instructions TXI and TXD.

d. Program Counter. The Program Counter (PC) is a 12-bit register which controls the sequential operation of the computer. At the conclusion of each instruction, the PC is updated, and specifies to the computer the HSM location from which the next instruction is to be taken.

e. Priority Register. A system of automatic program interrupt is available with the RCA-110 computer. This system allows a program with a higher priority to interrupt a current program on the computer.

(1) Priority Request Register (JR). This is an eight-bit register which holds incoming priority interrupt requests from eight request lines until the computer can process them.

(2) Priority Status Register (JS). This is an eight-bit register which holds the priority level and program number of the program on which the computer is currently working.

3. Word Format. The RCA-110 computer has a fixed-word length, using two basic types of 24-bit computer words: an instruction word and a data word.

a. Data Word. The two types of data words are numeric and alphanumeric. Numeric data words consist of data stored in binary form as 23 magnitude bits plus a sign bit. The binary point is fixed and is placed to the left of the magnitude bits. Each bit occupies a particular bit position which is numbered from right to left, bit position 0 through 23. Each bit position corresponds to a power of 2. A zero in bit 23 (the sign position) is used to signify positive number, and a "one" signifies a negative number. Negative numbers are stored as sign plus two's complement. A numeric data word as used in the RCA-110A computer is illustrated in figure 19.

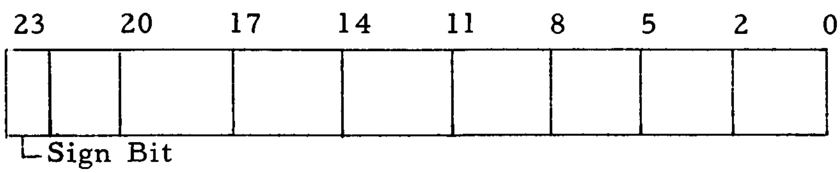

Figure 19. Numeric Data Word

An alphanumeric data word consists of a special configuration of bits which can uniquely represent an entire character set. In the RCA-110, six bits are required for each alphanumeric character; therefore, four alphanumeric characters can be stored in one computer word. An alphanumeric data wordas used in the RCA-110 computer is illustrated in figure 20.

23 — 18	17 — 12	11 — 6	5 — 8

Figure 20. Alphanumeric Data Word

b. Instruction Word. An instruction word consists of three basic groups of bits which are used to provide information for performance of various operations on the RCA-110 computer. The RCA-110 computer instruction word is illustrated in figure 21. The three basic parts of the instruction word are the operation code, the indexer, and the operand address.

23 — 18	17 — 15	14 — 12	11 — 0
OP	V	T	Y

Where: OP = Operation Code; V = Special Tag (extension on OP); T = Index Register; Y = Operand Address

Figure 21. Instruction Word

(1) Operation Code. The operation code, or OP portion of the instruction word, contains 9 bits (bits 15 - 23) which specify the operation to be performed. On instructions TXI and TCD which modify the index registers, bits 15 through 17 are used to specify K, the amount the index register is to be modified (0 K 7). With the input/output instructions SUN, STN, LDN, and SDN, bits 15 through 17 are used to specify N, the I/O register, and sense lines or address lines affected by the instruction (0 N 7).

(2) Indexer. The indexer, or T portion (bits 12 - 14) of the instruction word, contains 3 bits which specify an index register to be used (1 T 7) for address modification.

(3) Operand Address. The operand address, or Y portion (bits 0 - 11) of the instruction word, contains 12 bits which

specify a memory address in HSM for the operand, and most instructions. However, on the transfer instruction, bits 0 through 11 specify the address to which the control is to be transferred.

C. SOFTWARE SYSTEM THEORY

After a careful investigation of the required programming effort, a relatively simple concept of Saturn I Instrument Unit programming was developed, based on the more sophisticated control system of the PB-250 for the Saturn I, S-I Stage automatic checkout. However, the physical size of the high-speed magnetic core memory of the RCA-110 limited all approaches.

The method of programming, depicted by block diagram in figure 22, includes a very limited on-line monitor or executive routine necessary to monitor certain lines, principally during Networks and Overall tests. The chief area of difficulty in automatic checkout computer programming is the area of the executive and monitor programming. While much can be done (through proper scheduling) to eliminate some of the simpler problems of the executive routine, a monitor and control area must also develop as the system continues to develop.

Interruption is being used to provide the necessary fail-safe operations. This means that a routine such as a gyro caging or an emergency power down routine is indicated when and if the test conductor or cognizant personnel decide it is necessary to protect the equipment under test.

Interruption by ancillary equipment has been provided in the computer logic for certain input/output communications under program control.

The test and subroutines for each functional area are debugged as independently as possible, remembering that some tests will be required for the overall test. To facilitate this independence of debugging, an allocation of high-speed memory and drum memory has been made. This allocation is as follows with all addresses given in octal notation:

1. Locations 0000 through 0777 are used for the computer systems standard location, the system program loader, and the executive routine.

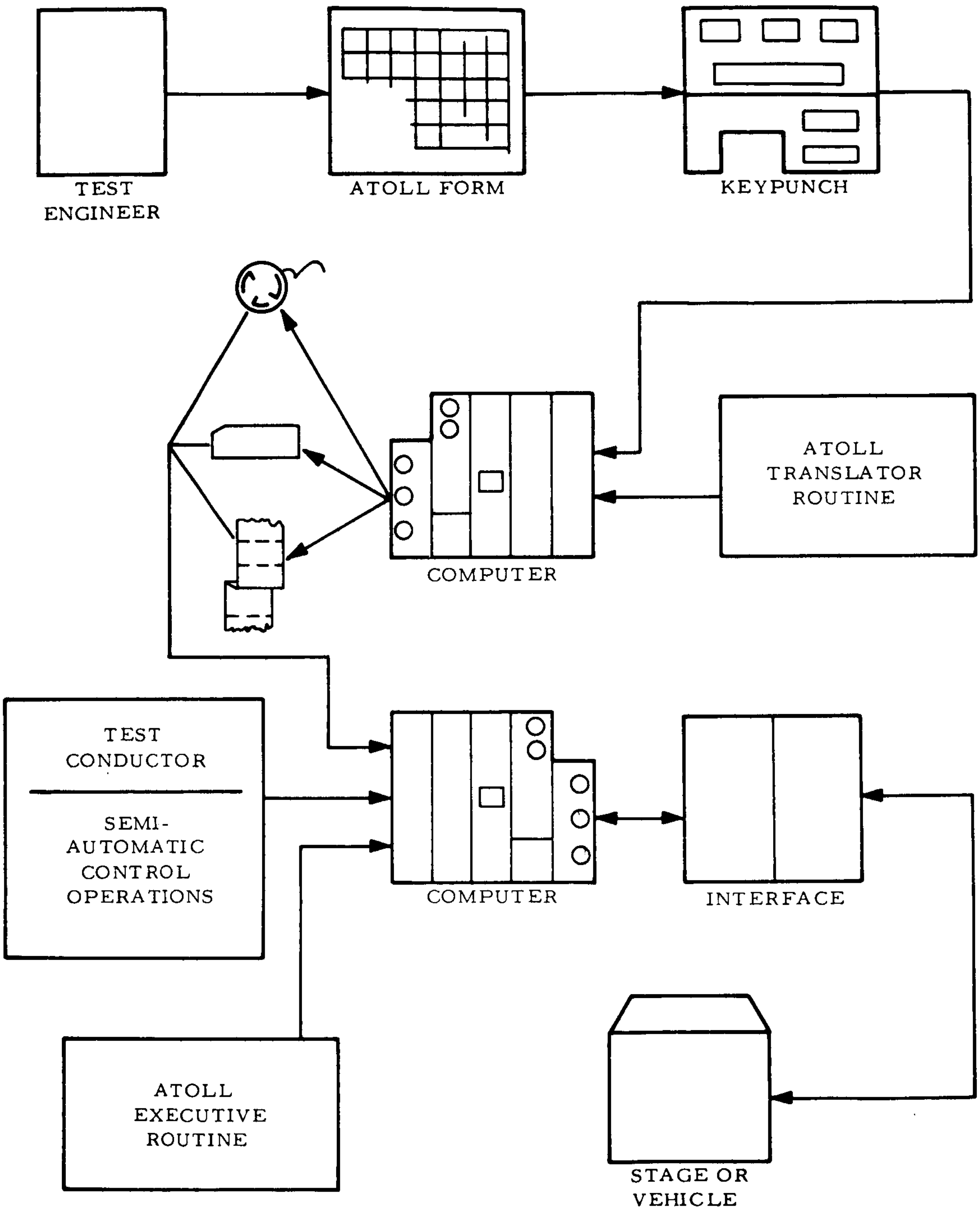

Figure 22. ATOLL Programming System Block Diagram

2. Locations 1000 through 7777 are used for the operating test program and necessary subroutines.

3. Drum tracks 000 through 137 are used for the navigation tests written by Astrionics Laboratory and overall tests by Quality and Reliability Assurance Laboratory must make provisions for their inclusion. Two 40-track (octal) segments are required for the exclusive use of Astrionics Laboratory. However, the area is not required if no onboard flight computer functions are deleted.

4. Drum tracks 140 through 177 are used for the storage of Quality and Reliability Assurance Laboratory Navigation Systems test.

5. Drum tracks 200 through 237 are used for the storage of the Instrumentation and Telemetry Systems test.

6. Drum tracks 300 through 337 are used for the storage of the Electrical Networks tests.

7. Drum tracks 340 through 377 are used for the storage of high-speed magnetic core memory when required.

After test objectives are supplied to the RCA-110 computer systems programmer by the cognizant functional area, they are organized into automatic checkout computer concepts which conform to standard of computer formatting and operation. The sequence of events is as follows:

1. The requirements are received from the test engineer and should include all data input and output requirements, a procedural block flow or detailed word flow, documentation or detailed information on all digital or associated equipment to be operated, and detailed time requirements.

2. A joint development then follows on the input/output requirements and formats. Information as to form of hardware input function and what, when, and where for the output and data reduction is discussed.

3. The automatic checkout computer programmer then develops a flow chart and a technical solution to the problem is presented.

4. The test concepts and flow charts are converted to coding to be run against hardware or software simulators to validate their correctness.

5. The test is then documented and run against the vehicle to certify the vehicle is capable of accomplishing its assigned function.

Several basic computer programs are used for the checkout of the Instrument Unit. These include the following:

1. The General Networks Test Program. This routine permits the automatic checkout of the GSE and the Networks Functional Tests.

2. General Flight Sequencer Test Program. This is the routine which is in the computer just prior to the simulated launch during the simulated plug drop on simulated flight. In general, it allows the computer to act as a monitor program, rather than a monitor and control. The data is then reduced from this program to determine whether the proper sequence has been followed during the test.

3. Priority Interrupt Package. This particular routine is the overall executive routine used for the overall tests, such as the simulated plug drop and simulated flight tests.

4. DDAS Average Routine. This routine is used to verify the Digital Data Acquisition System. It samples and averages many readings together and then compares them with predicted values.

5. Instrumentation and Telemetry Compatibility Test. This particular routine allows SCAN and COMPARE measurements of such things as DDAS vs Predicted, DDAS vs PCM, TM vs Hardware, TM vs Predicted, etc.

6. General Verification Routine. This routine is used in the navigational area to monitor the output of various G&C components.

7. A_0 Gain Test. This routine is used to verify proper feedback to the Instrument Unit after sending out a stimulation to the Instrument Unit to simulate the control system.

These and other requirements indicate that a more sophisticated system was needed. Though many limitations are imposed by the hardware configuration, most of the system is developed on a basis of the job with sufficient time permitted for timing. The present Saturn I Instrument Units are approximately 70 to 80-percent automatically checked out. The areas are stage electrical networks, instrumentation and telemetry, navigation, and radio frequency systems. No mechanical areas have been automated because of hardware limitations in the support equipment and state-of-the-art of onboard equipment.

D. SYSTEMS EVALUATION

The RCA-110 was used as the control computer for automatic checkout of the Saturn I Instrument Unit. The RCA-110 had one distinct advantage over the Packard Bell PB-250 computer namely, that of having a random access core memory. Optimization of the computer programs with the RCA-110 was not the problem that it was with the Packard Bell system. However, serious problems did exist. Because the RCA-110 was connected through buffers to the Instrumentation and Telemetry and Navigational and Radio Frequency test stations, there was a problem of time-sharing the computer. The computer could be connected to only one station at a time and thus, parallel testing operations could not be performed.

The paper-tape input requirement was also a problem area. Modification and updating of data and programs originally was accomplished on a flexowriter (a typewriter which punches a paper-tape). This problem was alleviated to a great extent with the installation of the GE-215 support computer. In this way, programs and data could be prepared on punched cards (for ease of making changes) and converted to paper-tape by the GE-215.

Another serious limitation was the single magnetic tape unit. This was an obvious limitation and a request was made for the addition of two magnetic tapes. This addition was an important improvement especially in the implementation of ATOLL and the overall operation of the automatic checkout system.

The 4,096 word core memory limited the size of the programs that could be executed and necessitated the use of overlay techniques. The 32,000 word drum made it possible to store portions of programs and important subroutines for call on short notice.

Another handicap of the system was that all information to be recorded as hard copy was printed out on the typewriter. This proved, as in the case of the Packard Bell system, to be tedious and time consuming. This was especially true in the instrumentation and telemetry areas of checkout where large tables of data were printed. Here again, the GE-215 support computer system partially relieved this situation.

SECTION V. DIGITAL EVENTS EVALUATOR (DEE-3)

The Digital Events Evaluator, Model DEE-3 (figure 23), is manufactured by Scientific Data Systems. This system became an integral part of the checkout equipment for the Saturn first stage when the need for high speed, high resolution monitoring of digital events became evident.

A. GENERAL DESCRIPTION

The Model DEE-3 Digital Events Evaluator is a special digital system which provides a convenient, self-controlling facility for detecting changes in the ON and OFF status of up to 768 input lines. Under the control of a computer program stored internally, the DEE-3 can continuously scan all 768 input lines at the rate of 4 milliseconds per scan and detect any change in the status of the lines that may occur. This is done by comparing the state of each input line being read with the stored copy of the state of the lines made during the previous cyclic scan. Each change in status is processed by the program and is output on a typewriter or punched on paper-tape. The processing of a status change results in the output of the identifying label of the input line, its present status, and the time at which the change occurred. Identifying labels for the various input lines are assigned by the test engineers.

The operation of the DEE-3 is closely directed by the equipment operator. During the initialization of a test procedure, a special program-preparation phase allows the equipment operator to specify various operating modes. During this phase, the operator names the input lines which will be used in the test. The number of input lines is also variable and is set at this time.

During the actual events evaluation run, the equipment operator has several control features available. These take the form of special functions that the operator may request by keying them into the DEE-3 via the input typewriter. Such controls are: the ability to change the mode of output from typewriter to paper-tape punch during a test run, or the ability to request the output of all of those input lines which are in the ON state at the time of operator request. Operating modes such as calling for the previously mentioned sequence comparison feature are also available.

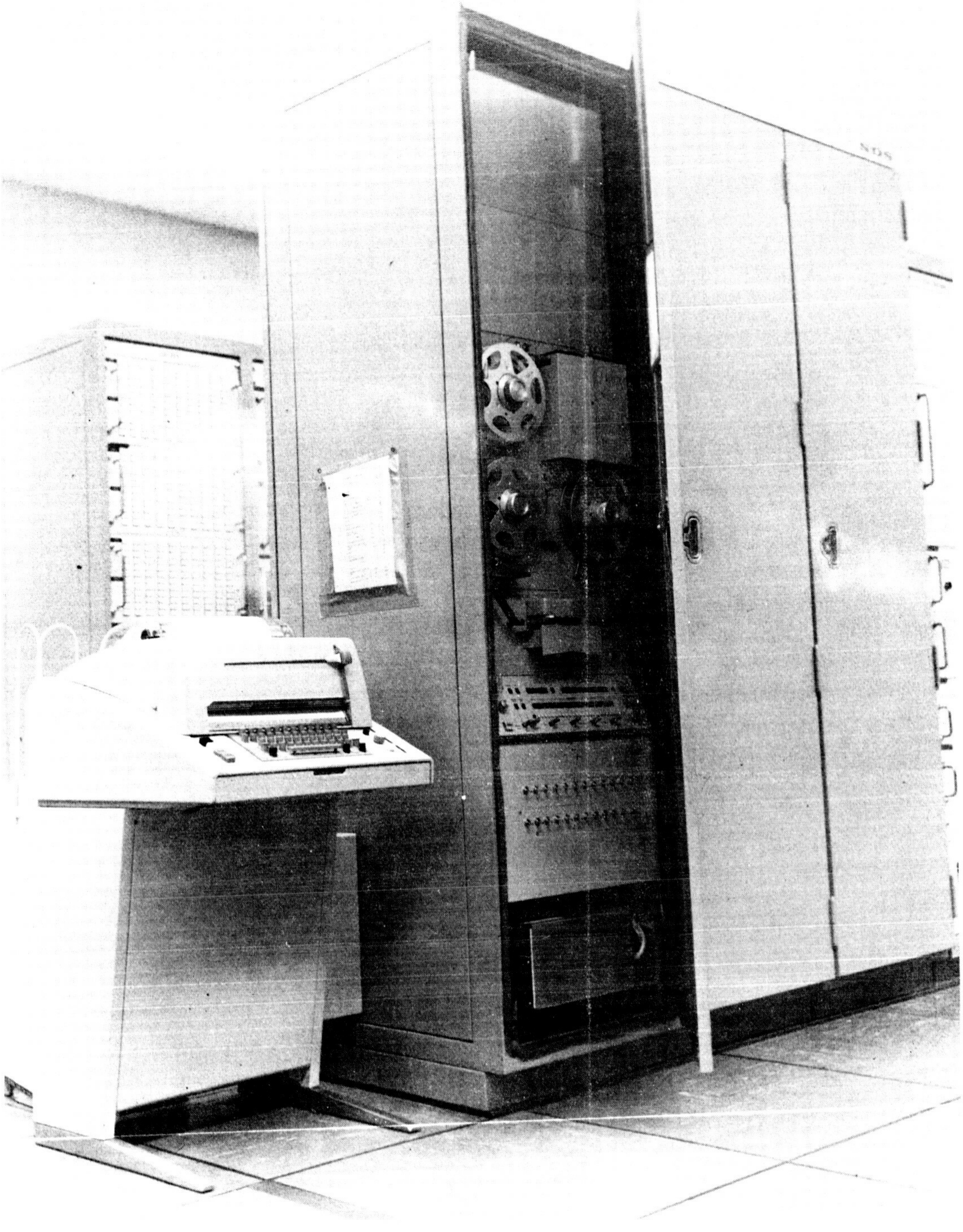

Figure 23. Digital Events Evaluator (DEE-3)

B. HARDWARE SYSTEM THEORY

The system description of the DEE-3 hardware has best been made by considering first its characteristics and then its operation.

1. Characteristics. The DEE-3 is physically composed of an SDS-910 solid-state core memory digital computer and associated circuitry. This associated circuitry is used to implement the scanning capabilities of the DEE-3 system, giving it a capability of monitoring up to 768 input lines and evaluating "digital events" that occur on any of the input lines.

The DEE-3 system is mounted in a 3 bay, RFI-proof relay rack occupying a floor area of 1,738 square inches. An additional 900 square inches of floor space is required for the table upon which the input/output typewriter is mounted. The main rack of the system measures 63.2 inches wide by 27.5 inches deep by 87.6 inches high and weighs approximately 2,500 pounds.

Input/output capabilities are implemented by a Teletype typewriter, a Tally paper-tape punch, and a Rheem paper-tape reader. The paper-tape punch is capable of outputting at the rate of 60 characters per second and is mounted in the main racks of the system. The Rheem paper-tape reader, also mounted in the main racks, is capable of reading paper-tape at the rate of 300 characters per second. The input/output typewriter, which is mounted on a table immediately adjacent to the main racks, is capable of accepting input or output information at the rate of 15 characters per second. The typewriter may be extended up to 30 feet from the main racks without requiring additional drivers.

External connections for the system are required only for the input lines which are to be monitored and for the input operating power to the system. Input power requirements are 110 volts, single phase, 60 cycles per second. The input power is received through two receptacles which must be in series with circuit breakers of not less than 30 amperes each.

The input lines to the system are terminated at a bulkhead and distributed to the input filters by means of module terminated cables. Any of the input modules may be replaced by a special test module, which is connected to a test panel and allows any of the input lines to be checked manually.

2. System Operation. A block diagram of the DEE-3 system is shown in figure 24. It should be noted that the component blocks in this diagram are composed in part, of actual hardware circuits, and portions of the core memory reserved for the DEE-3 program. The input circuitry, the comparator chassis, and the control chassis are all system electrical components. The previous Scan Cycle Memory and the Output Buffer are programmed tables set up in the core memory to facilitate processing of information concerning the digital inputs to the system.

C. SOFTWARE SYSTEM THEORY

The digital computer at the heart of the DEE-3 system is an SDS-910 Computer. A Binary Comparator functions with the computer to compare the status of input lines during successive scan cycles. Operation of the computer and comparator are controlled by the programming system as described in the following paragraphs.

Controlling Programs. Primary functional control of the DEE-3 system is provided by the stored programming system which operates in the SDS-910 computer. The programs which make up this programming-control system are listed as follows:

Program	Control Function
Scan Program	Controls the system during the scan and comparison operations while status information is being placed on the input lines.
Processor Program	Controls the processing and formatting of all data to be output including the correlating of proper identification of input lines and the maintaining of proper sequence checks.
Output Program	Controls the output of status change information.
Control Program	Controls the system during the time that the operator is entering control and change directives.

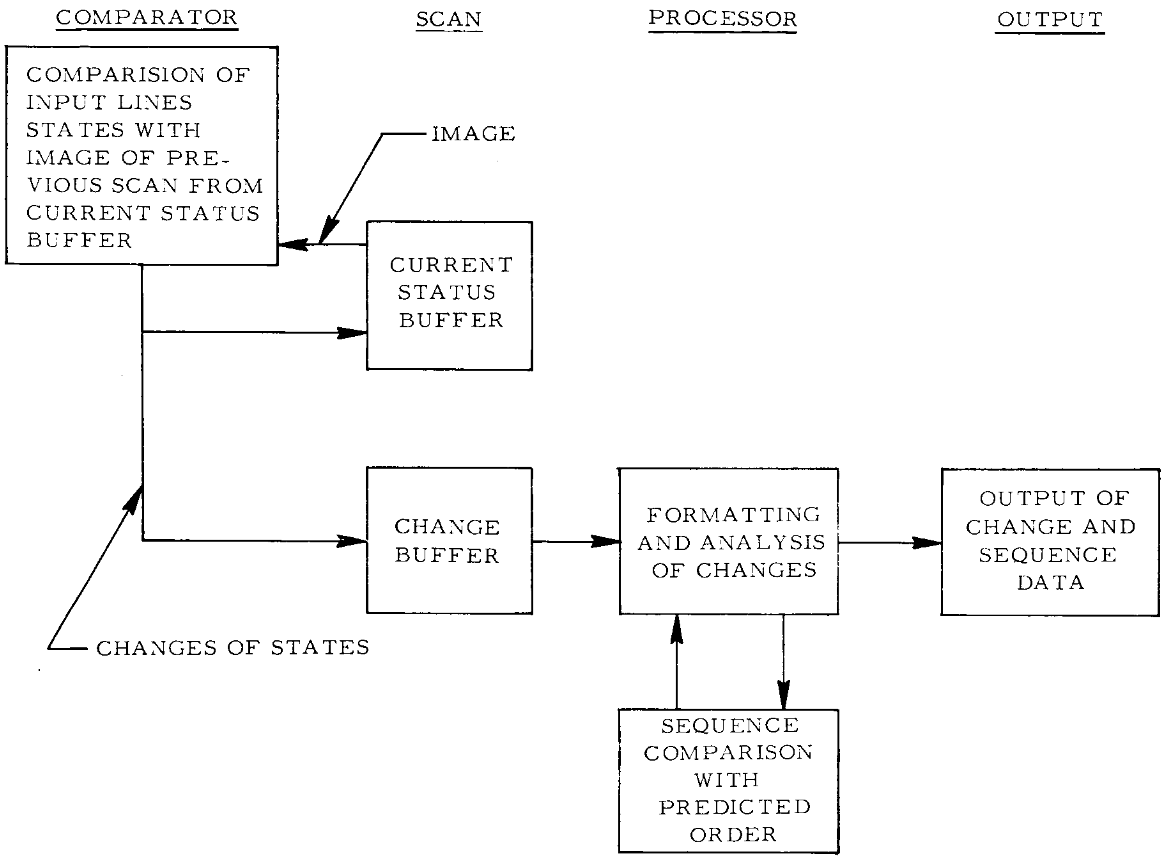

Figure 24. DEE-3 Programming System Functional Block Diagram

The contents of a relative time counter are stored by the Scan Program with each change of state or error condition. These relative times determine the order of occurrence and the time of occurrence, relative to the beginning of the test run. Under the operator control function, the operator can enter the "absolute" time that the test will begin. This time is held in the DEE-3 memory. When this absolute time has been entered and stored in the DEE-3, the relative time count is added to this absolute time to determine the actual time of each change of condition or error. The DEE-3 will continuously update the relative time counter with each CLOCK interrupt.

D. SYSTEMS EVALUATION

The Digital Events Evaluator (DEE-3 and its successor the DEE-3A) has been used successfully in checkout operations of the Saturn I Instrument Unit and Saturn V, S-IC stage at MSFC and various other stages and units at other installations. The DEE-3 has performed as it was originally designed. However, it was designed with very little expansion of capability without additional hardware. Several modifications to the software were attempted, some with success, for the purpose of improving the DEE operation.

Ordinarily, the paper-tape input-output limitation would be undesirable in terms of preparing new programs and data for the computer. This has not been a problem, however, since the programs prepared for use in the DEE-3 have not been changed often.

Because of the increasing number of test points and operational requirements beyond the original scope of the DEE-3, the system is approaching it's limits of capability. The DEE-3 can only backlog a certain number of events and if the typewriter or punched tape cannot keep up with the changing events, some event changes will be lost. As a result of this inadequacy, additional core memory and magnetic tape units have been requested for some of the DEE-3 systems.

To increase reliability and provide additional buffered capability, the DEE-3 was modified and became known as the DEE-3A. The DEE-3 used an IBM Selectric typewriter which did not withstand the continuous, day after day, print-out of test resulted from the computer. This typewriter was replaced with the more durable Teletype units in the DEE-3A.

In addition, another buffer was added to the DEE-3A to increase the output speed.

SECTION VI. DIGITAL COMPUTER CONTROLLED TRAINING DEVICE (TRAINER)

With the increased use of digital computers in automatic checkout of Saturn Vehicle stages and units within the Quality and Reliability Assurance Laboratory, it became evident that training courses for this area of technology would have to be established for both MSFC and contractor personnel. The technical training group of the Quality and Reliability Assurance Laboratory has outlined five courses pertaining to automatic checkout, computer programming, maintenance, and orientation. Since all of these courses pertain to the use of digital computers, it was evident that a training device which contained a digital computer as an integral part could be used to definite advantage. In February 1964, a specification was developed for the digital computer controlled training device (TRAINER). (See figure 25.) The purpose of the equipment was to:

1. Demonstrate digital computer controlled automatic checkout of space vehicles.

2. Allow students to acquire practical experience in actual checkout applications.

3. Familiarize students with checkout oriented languages.

4. Allow students to acquire an understanding of the importance of systems integration, real-time control, signal conditioning, and interface systems.

5. Familiarize the student with data conversion techniques.

6. Provide practice and experience in automatic checkout programming techniques.

7. Demonstrate various aspects of automatic checkout in orientation courses.

8. Provide examples, practical experience, and theory as required in basic computer courses.

9. Provide practical simulation of specific computers to satisfy requirements of training in existing automatic checkout systems.

10. Provide practical experience in basic digital circuit theory and maintenance.

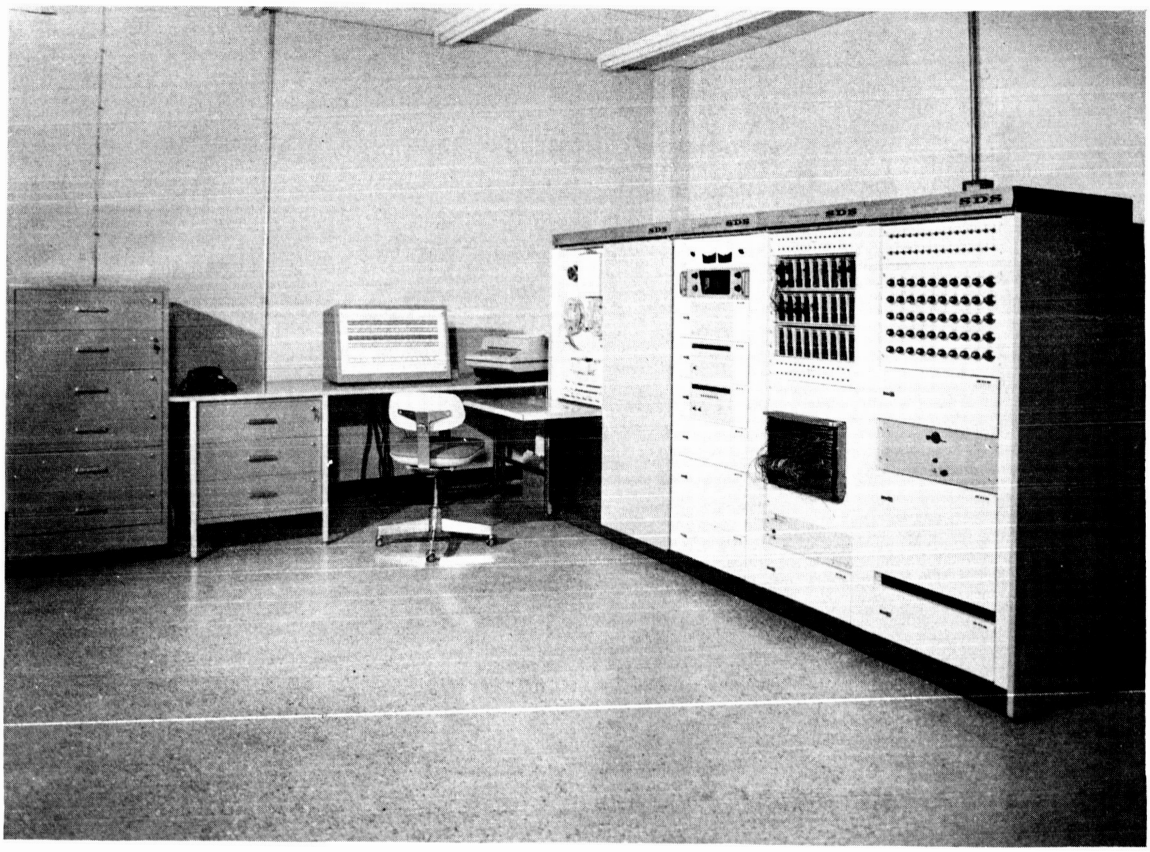

Figure 25. Digital Computer Controlled Training Device (TRAINER)

The contract for designing, developing, fabricating, installing, and checking out the TRAINER was awarded in June, 1964 to the Brown Engineering Company. The TRAINER was delivered and tested in February 1965.

A. GENERAL DESCRIPTION

Because a variety of computers were utilized in the checkout areas within the Laboratory, it was impossible to procure a computer which could perform all of the functions or one which would perform the functions in exactly the same manner as the checkout computers. However, it was desirable to obtain a computer, which through the use of special programming techniques, could perform some of the functions of most of these computer systems and in a similar manner. It was also the purpose of the procurement to acquire a computer which would have the basic equipment configuration of the checkout computers and be versatile enough to allow for the addition of peripheral devices to the computer system.

B. HARDWARE SYSTEM THEORY

A functional block diagram of the TRAINER is shown in figure 26. The TRAINER was developed in two phases. Equipment marked with an asterisk "*" indicates items that were added after the original contract was awarded and completed.

The TRAINER consists of five functional areas: The central processor (computer), online peripheral equipment, a control console, interface equipment, and simulation equipment.

1. <u>Central Processor.</u> The Central Processor is a Scientific Data Systems Corporation's SDS-910 digital computer for scheduling, sequencing, and executing all events within the TRAINER. A description of the SDS-910 digital computer is contained in section V.

2. <u>Online Peripheral Equipment.</u> The online peripheral equipment includes an input/output typewriter, a high speed photoelectric paper-tape reader, and a high speed paper-tape punch.

a. Typewriter. The input/output typewriter is an IBM Selectric typewriter capable of receiving print instructions from the computer at the rate of 15 characters per second. The computer is capable of interrogating the typewriter and receiving information that is entered on the typewriter keyboard.

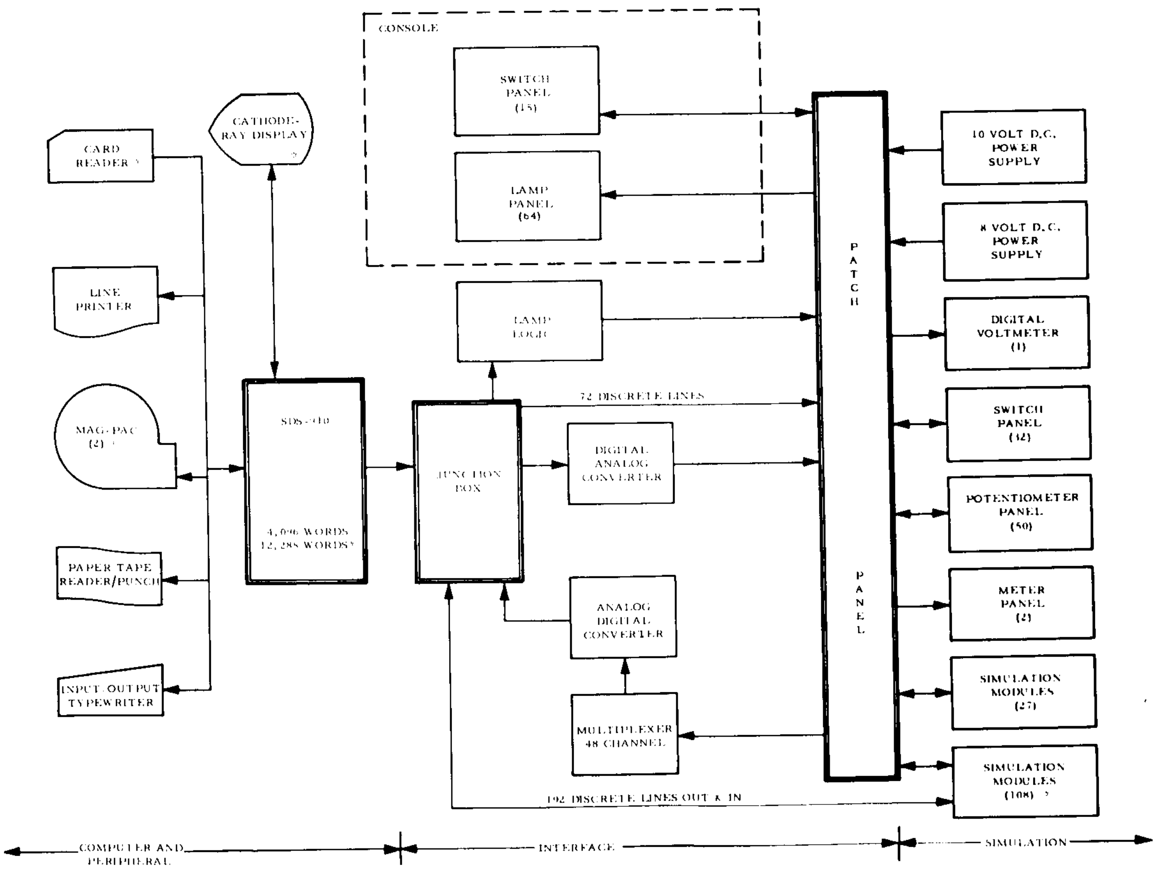

Figure 26. TRAINER Functional Block Diagram

b. Paper-Tape Reader. The paper-tape reader is a modified Rheem transport and spooler model RR-301-RTA. The unit is capable of reading 5, 7, or 8 channel punch paper-tape at a rate of 300 characters per second.

c. Paper-Tape Punch. The paper-tape punch is a Tally model 420 and is capable of perforating paper-tape of varying widths (5 to 8 channel) up to 60 characters per second. The unit may be operated at any speed below maximum since each character is initiated by a separate pulse.

3. Control Console. The Control Console provides displays and controls for the operator of the TRAINER system. The display console includes a panel of 64 display lamps. The lamp panel is designed and arranged to allow overlays to be used to provide a visual representation of the system being simulated. These overlays may be clipped on or removed by an operator. There are four groups of 16 lamps, each group being a different color of lamp. The lamps are connected into the patch panel in the simulation equipment to provide for the capability of driving the lamps from the flip-flop modules or from alternate action switches. The display console also includes a panel of 16 alternate action double pole, double throw,back-lighted switches. These switches are also connected into the patch panel. The setting of these switches may initiate some action in the simulation equipment or be interrogated by the central processor.

4. Interface Equipment. The Interface Equipment (figure 27) provides for the compatibility between the central processing unit and the simulation equipment. All necessary input/output registers and control signals are provided in this area for transmission of data and other information between the central processor and simulation equipment. The interface equipment is composed of standard off-the-shelf hardware and includes a digital to analog converter, an analog-to-digital converter, a multiplexer with extender, and a junction box.

a. Digital-to-Analog Converter. Digital output of the computer is fed through the junction box to coupling transformers in the digital-to-analog converter to isolate the analog circuits. Output of the coupling transformers provide an eight-bit plus sign input to the digital-to-analog converter module where it is converted to a bi-poler output through current summing techniques. The output to the digital-to-analog converter is connected into the patch panel.

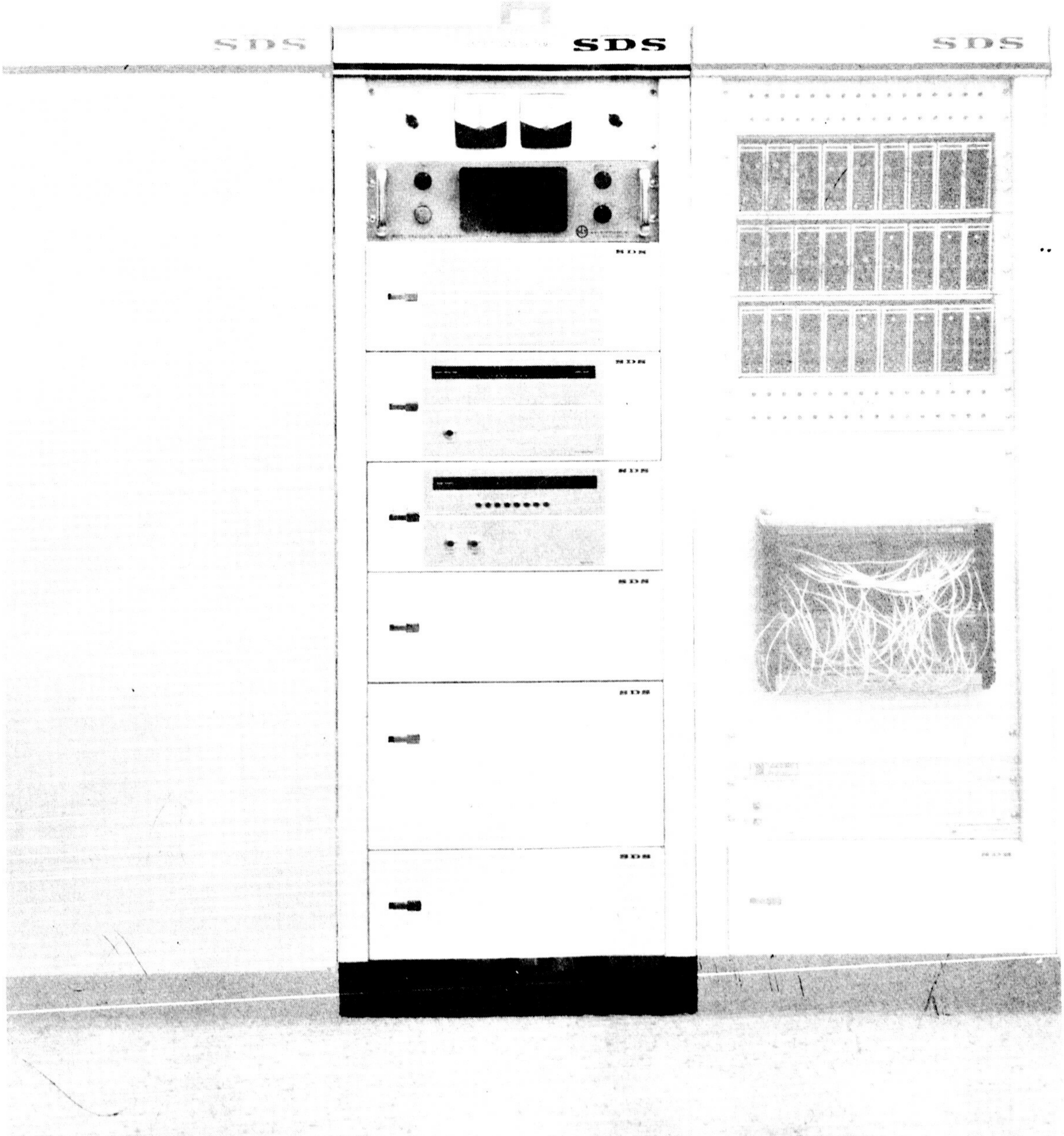

Figure 27. Interface Equipment

b. Analog-to-Digital Converter. The analog-to-digital converter converts the analog signal which it receives from the multiplexer into ten bits of digital information. Through the use of a parallel input command, this digital information may be read into the memory of the computer.

c. Multiplexer. Functionally, the multiplexer is divided into digital and analog sections. The digital section controlled by the junction box provides input amplification, an eight-bit binary counter register, and generation and timing of output control signals. The analog section contains switching modules and operational amplifiers. Thirty-two analog inputs are provided for first level switching and an additional sixteen inputs, from the multiplexer extender, at the second level, to furnish a total selection of forty-eight inputs. Output of the multiplexer is fed to the analog-to-digital converter.

d. Junction Box. The junction box connects the central processor to the external input/output lines of the converters and simulation equipment and provides for the necessary selection and buffering circuits for interconnection. Control of the junction box is through standard computer programming addresses.

5. Simulation Equipment. The Simulation Equipment (figure 28) provides for the simulation of items under test. Various systems and subsystems of Saturn vehicle stages and units may be simulated with this equipment. The simulation equipment includes simulation modules, a switch panel, patch panel, and a display voltmeter panel.

a. Simulation Modules. Simulation modules (figure 29) provide for the simulation of discrete and delay functions. The original contract included provisions for 27 modules and the contract modification provided for an additional 108 modules. These modules are plug-in units and may be patched in such a manner as to simulate the various electrical networks of a space vehicle.

The discrete simulation modules are flip-flops. The state of these flip-flops may be set to the on or off condition by the central processor. This allows for simulating the setting of a relay, the closing of a valve, etc. The input and output connections of the flip-flop modules are provided on the patch panel. This enables a combination of inputs and outputs to be arranged for the setting and resetting of the flip-flops either from the central processor or from switches on the control console or simulation equipment.

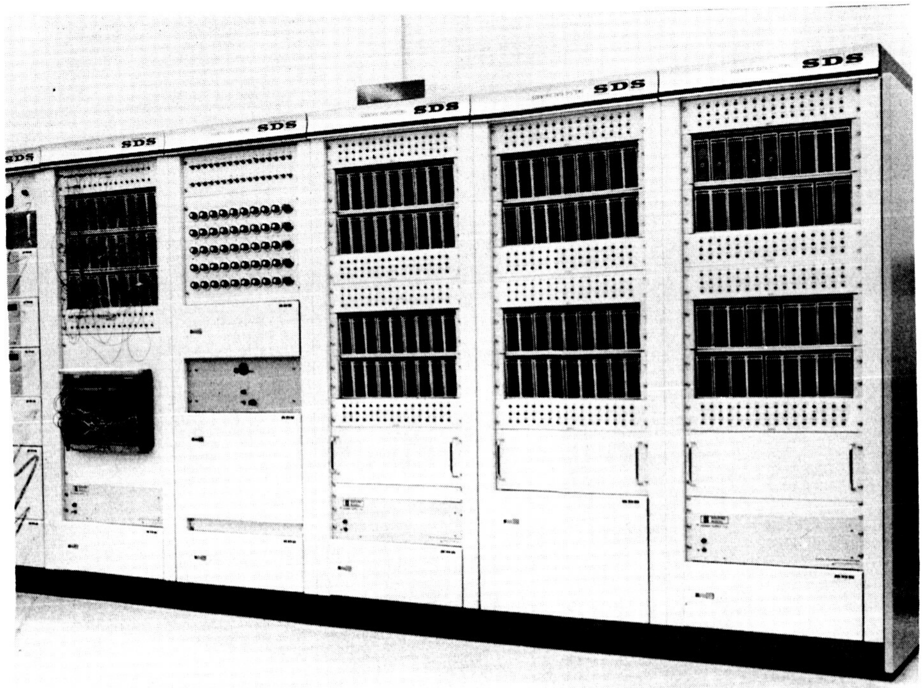

Figure 28. Simulation Equipment

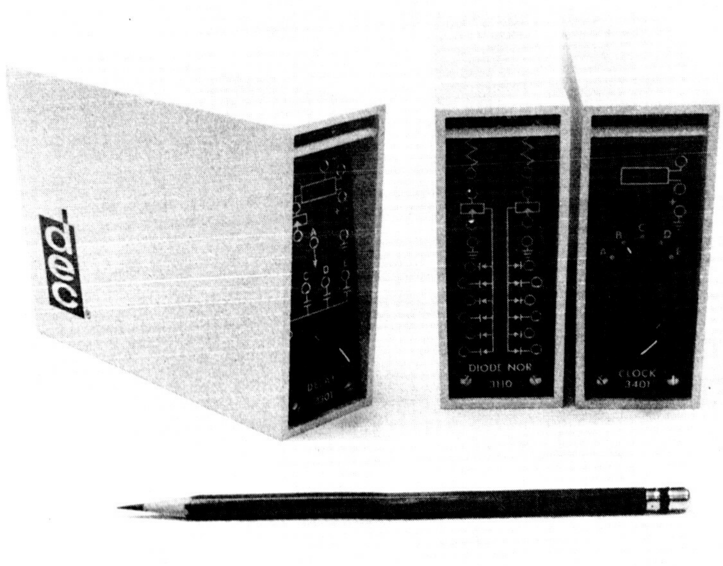

Figure 29. Simulation Modules

Delay modules are provided to allow up to 0.2 seconds or more from the time a pulse is supplied to the input, to the time the pulse appears at the output. These delays are used to simulate the starting of a generator, etc.

Diode NOR modules are provided to allow for numerous logical circuits to be developed.

The simulation modules are packaged in enclosed containers which protect the internal circuitry. Each module has a graphic front panel which illustrates the logical functions of each modules. Input/output and other pertinent connections of each module are displayed on the front panel and allow for interconnections to be made with other modules.

b. Switch Panel. The switch panel contains 32 double pole double throw switches, each with a center-off position. All poles of the switches are connected into the patch panel. These switches may be "patched in" to introduce errors into other simulation functions, i.e., to inhibit the setting of a flip-flop, etc. The setting of these switches may also be sensed by the central processing computer.

c. Analog Panel. The analog panel provides 45 single-turn and 5 ten-turn potentiometers for control of the simulated analog voltage inputs. The potentiometer output terminals, wipers, and arms, appear on the patch rack. The output of a potentiometer may vary from 0 to 10 volts by setting the potentiometer and may be patched into the multiplexer channel for input to the analog-to-digital converter.

d. Patch Panel. The patch panel provides for the interconnecting of various modules and components of the control console and simulation equipment. The patch panel is a standard AMP patch board with 1,632 connections.

e. Display Voltmeter Panel. A display voltmeter panel provides two voltmeters with the simulation equipment for monitoring outputs or troubleshooting simulation equipment and central processor outputs. A separate digital voltmeter provides an adjustable scan rate for reading the output of the digital-to-analog converter.

C. SOFTWARE SYSTEM THEORY

The original TRAINER was a small, simple hardware system and as a result required a relatively simple software system. Computer programs were loaded individually into the computer memory without the aid of a monitor or executive routine. Each program was contained on a paper-tape and each paper-tape contained a short binary loader routine at the beginning of the tape.

Programs for the computer itself which are developed by the instructors and students at the school are written in the language of one of the two SDS assembly systems: META-SYMBOL or its compatible subset, SYMBOL. These assemblers make available to a programmer the full capability of the computer and its peripheral equipment.

Three significant programs have been developed for the TRAINER as a system.

1. TRAINER Diagnostic. The Diagnostic Routine has been developed to determine if the console switches, simulation switches, console lamps, potentiometers, and digital-to-analog converters are performing properly. A small executive routine in the program allows each of these five tests to be selected from the console typewriter. A special patch panel must be prepared in advance for these tests to be conducted. This patch panel however, is usually prepared beforehand and left in its testing configuration to avoid unnecessary delays in preparation for each diagnostic test. The diagnostic program can be executed in 11 minutes. This routine, with other diagnostic tests for the computer and its peripheral equipment, comprise the test (self checking) software.

2. ATOLL TRAINER. ATOLL TRAINER was developed to enable the computer controlled training device to be used to simulate vehicle checkout and execute test procedures written in the ATOLL language. ATOLL TRAINER makes available to a programmer the full capability of the computer, peripheral equipment, interface, and simulation equipment as a system. The ATOLL TRAINER will execute test procedures written in accordance with MSFC drawing no. 85M06078 (revision A) with the following exceptions:

1. Operators EXEC, GATE, RECD, SETT, and CALL are not implemented in the program.

2. Only one item may be listed in the variable field for an operator. For example, multiple discrete lines cannot be listed in the variable field for a DISO operator.

3. The analog equipment available on the TRAINER has an operating range of $\pm$ 8 volts; therefore, an entry in the value, lower limit or upper limit field, which is not included in this range, will be tagged as an error.

4. A negative tolerance entry in the lower limit or upper limit field of the READ or DELAY operator will be tagged as an error.

ATOLL TRAINER is a one pass online compile and execute routine with two modes of operation: (1) Automatic Control Mode, (2) Semiautomatic Control Mode. During the operation of the automatic control mode, a line of information is read from paper-tape (representing an ATOLL statement on the test procedure). This information is examined and appropriate action is taken to perform the functions specified by the operator. During automatic control mode operations, the semiautomatic control mode may be entered in the following ways:

1. A NO-GO encountered during the execution of a SCAN, READ, or DELAY operator in the automatic mode.

2. Execution of the SEMI operator.

3. Setting the breakpoint mode switch to semiautomatic.

4. Setting breakpoint 2 following the execution of the END operator.

In the semiautomatic control mode, information may be entered into the computer through the typewriter keyboard in the same format as the information contained on the ATOLL coding form. In this manner all of the operators which are available in the automatic mode are available in the semiautomatic mode. The automatic control mode may be entered from the semiautomatic control mode by means of AUTO or RECY as discussed in the following.

Additional options were required to facilitate operations in the semiautomatic control mode. These options are comparable to some of the options required in the ATOLL test procedures used in automatic checkout. However, because ATOLL TRAINER is a one pass compiler, it was logical to include these options as a part of the ATOLL language and thereby make them available for use in the automatic control mode. Options such as RECY and AUTO have no practical use in the automatic control mode. The options added include:

a. ZERO - Zero is used to clear the discrete input-discrete output reference tables in memory and turn all discrete outputs to the off condition.

b. RECY - This operator enables operating personnel to reexecute the last operation performed in the automatic control mode.

c. AUTO - This will cause the computer to enter the automatic control mode and execute the next statement.

d. REPL - This will update the entire discrete input reference table to the result of the last SCAN operation (actual setting of all discrete input lines).

e. INTR - An interface dictionary has been devised to correlate RCA-110 and SDS-910 TRAINER discrete and analog systems with the INTR operator. The interface dictionary is segmented to allow changes to be made in either the discrete out, discrete in, analog out, or analog input section of the interface dictionary.

An events trail is recorded on the typewriter and displays the test procedure step number and the action taken during performance of a simulated test. Further information concerning ATOLL TRAINER may be obtained from the Computer Programming Specification for ATOLL TRAINER, dated December 5, 1964, or the ATOLL TRAINER Technical Description, Catalog Number 8-QH-00-910-2-06, dated June 1, 1965.

3. RCA-110A Simulator. A program has been written on the SDS-910 which will execute programs that have been written for the RCA-110A computer. This program allows the TRAINER to be used in teaching RCA-110A computer programming. The program can execute all of the instructions of the RCA-110A (113 instructions). Input/output instructions are interpreted as "no operation" instructions except for those instructions utilizing equipment which can be simulated on existing equipment of the TRAINER. The limited memory of the TRAINER also restricts the size and storage locations used by the RCA-110A program. The restrictions are insignificant in this case and it is possible to provide practical training for one computer on a different computer. Additional features of the program include a trace routine and the presentation of the contents of the simulated registers of the RCA-110A.

D. SYSTEMS EVALUATION

The TRAINER system has been used to advantage in the five courses which were outlined for its use. Primary disadvantages of the original TRAINER system include: Paper-tape input/output, typewriter input/output, small computer memory size, and small number of simulation modules. The use of ATOLL TRAINER has allowed for the execution of simulated tests using actual test procedures. Preparation of tests by the students can be accomplished in a minimum amount of time. Use of overlays on the control console has been advantageous and has been used to illustrate the hardware circuit which the simulator represents. The development of the one pass compile and execute program allows for fast development of a program and provides for the versatile use of the simulator equipment.

The design of the computer and its peripheral equipment leave much to be desired. Many functions which are taken care of by hardware in other computers have to be accomplished with software in the SDS-910. For example, an end of file code has to be stored in the SDS-910 memory and recorded on tape at the appropriate time. This is usually accomplished by executing an end of file instruction in other computers. In addition, a "hopper empty" signal is not available when all of the cards have been read from the hopper of the card reader. To check for this condition, the computer program in the SDS-910 halts and waits for an operator to depress a switch on the card reader to indicate "hopper empty".

These examples are used only to illustrate that such conditions result in time consuming activities and cause undue waste of computer memory. With the present applications of the TRAINER, this waste is somewhat balanced out by the low cost of the equipment and the fact that timing and memory are not too critical.

Because of some of the inadequacies of the original hardware system, additional peripheral equipment was installed and an extension to the original TRAINER contract was made for the additional simulation capability. Additional peripheral equipment include:

1. Line Printer
2. Card Reader
3. Magnetic Tape Unit
4. Mag-Pac
5. Cathode-Ray Tube Display System

The original TRAINER was designed to allow for future expansion and addition of simulation equipment. The contract extension provided for the addition of 108 simulation modules and 192 additional discrete input/output signals. With the addition of the simulation modules, more elaborate vehicle systems can now be simulated with the equipment. Portions of the vehicle that have been simulated include stage power logic, stage sequencing, engine cutoff logic, and simulated flight logic. The additional peripheral equipment allows for a more practical representation of existing checkout computer systems. With the addition of the simulation equipment and peripheral equipment, an expanded ATOLL TRAINER program has been developed. The concept used in the development of this program is similar to the concept used in the original ATOLL TRAINER. ATOLL statements are now keypunched and put on cards in lieu of paper-tape. A simple first pass is made to read the cards, perform error checks, compact the data, and record the program on a mag-pac tape. The card images are then read from mag-pac and executed.

SECTION VII. VEHICLE INSTRUMENTATION SIMULATOR (VIS)

To insure the operational status of the automatic checkout computer programs and ground support equipment used in checkout of the Saturn stages, it is necessary to have some device which takes the place of the vehicle. The ultimate simulator of a Saturn vehicle would, of course, be the vehicle itself; however, this would not be practical. Development of computer programs and ground support equipment takes place many weeks before the stage actually goes into checkout. It is necessary therefore to have this simulator available prior to the delivery of the vehicle. In the Saturn I S-I stage checkout, a Ground Equipment Test Set (GETS) was used in verifying the electrical networks portions of the ground support equipment. In addition to the GETS, another hardware simulator was developed for use in verifying the computer programs used in the instrumentation and telemetry area. These hardware systems were not adequate because they did not simulate completely the onboard telemetry systems. With the introduction of the Saturn V S-IC Stage into automatic checkout, many functional areas of the checkout equipment could not be verified prior to the arrival of the vehicle. In addition, it was impossible to adequately verify new or revised test procedures, test techniques, and computer software. Further, personnel had little opportunity to increase their proficiency as checkout personnel either individually or as a team, or become familiar with new routines or techniques prior to vehicle arrival. Not only were slippages in checkout schedules imminent, but also flight systems were threatened by extreme periods of operation. These reasons and many more prompted action for the acquisition of a simulator for the instrumentation portions of the vehicle. The requirements for such a system were satisfied by the installation of the vehicle instrumentation simulator in November, 1965. (See figure 30.)

The simulator is capable of duplicating exactly the vehicle systems operations. In addition to periodic checks being performed on the electrical support equipment, the simulator is effectively used in isolating trouble areas in the hardware. This is especially true when a vehicle or stage is in checkout, since the fault can easily be isolated to the vehicle or electrical support equipment by simply retuning the telemetry ground station receivers to the simulator's frequencies.

Much time can be lost in vehicle checkout operations because of inaccurate calibration of the ground equipment and inaccurate or poor interconnections between pieces of equipment. Since the simulator actually takes the place of the stage, the interconnections of the hardware and the calibration of the equipment can be verified prior to the arrival of the stage.

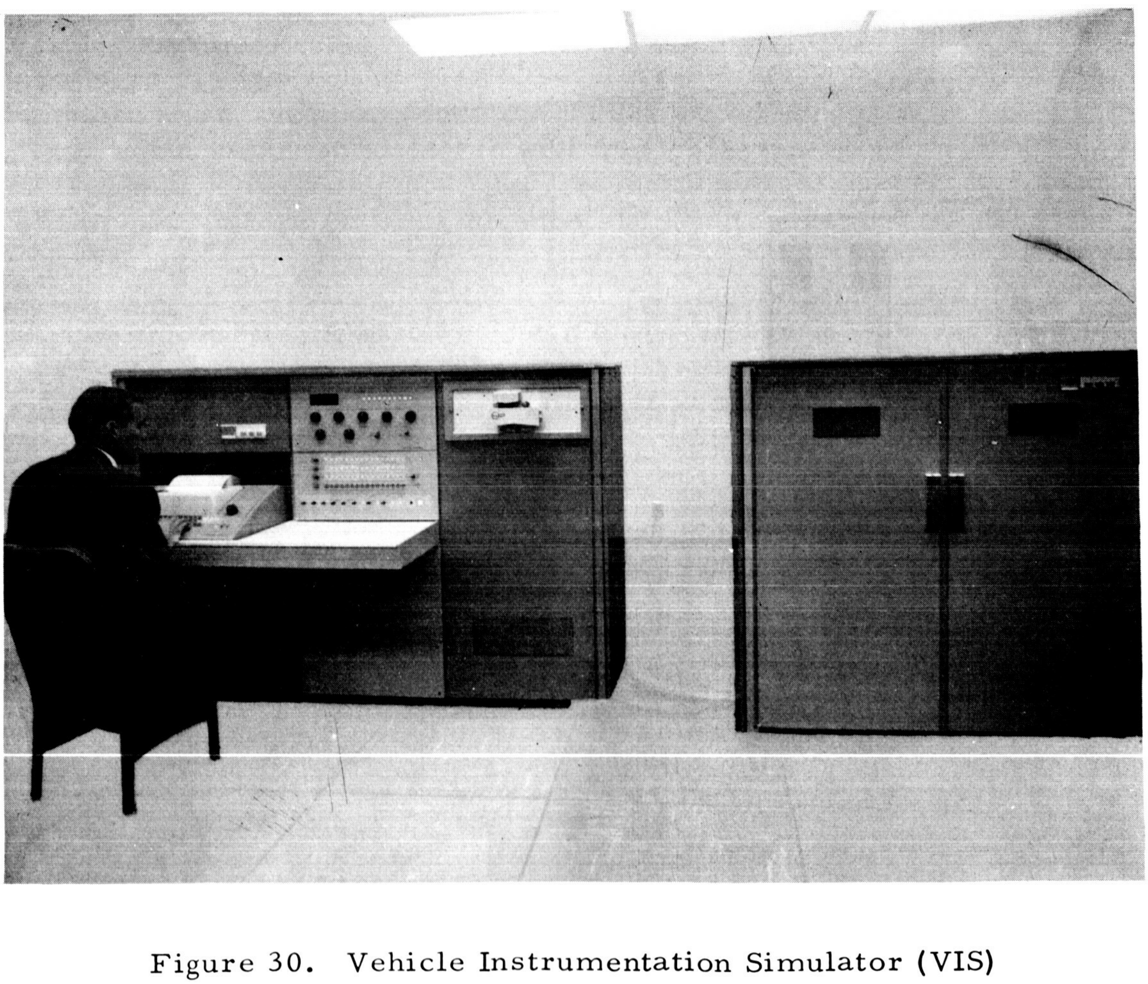

Figure 30. Vehicle Instrumentation Simulator (VIS)

By precisely simulating the vehicle instrumentation systems both in proper and malfunctioning operations, all test procedures, test techniques, and computer software can be completely verified and corrected, if necessary, prior to vehicle checkout. Although many techniques are available for use in developing automatic checkout software, errors and inadequacies are inevitable. Many unforeseen problems may exist, and often hardware and software incompatibilities go undetected until the software is actually exercised under the intended operating conditions. Because the simulator looks exactly like the vehicle, all of the test procedures and test programs can be exercised and all such problems can be resolved prior to vehicle checkout again, saving much time not only in checkout, but also in the operation of the flight item.

Because the simulator is available at all times, personnel may be trained in the operation of the ground support equipment even though the stage is not in the area. Personnel assigned both to the ground support equipment and the vehicle can become familiar with new and revised procedures and techniques prior to vehicle checkout. In this way, vehicle checkout becomes more significant and operations on the actual stage are more sophisticated and well organized.

A. GENERAL DESCRIPTION

The Vehicle Instrumentation Simulator (VIS) is a general purpose Saturn telemetry simulator. It is capable of simulating various combinations of the standard PCM/FM, PAM/FM, SSB/FM, FM/FM, and FM^3, that are found on all stages of Saturn vehicles. These simulated signals are in the form of transmitted FM or hardwired outputs simulating the prelaunch checkout. A block diagram of the simulator appears in figure 31.

The simulator includes a general purpose digital computer with a stored program to output the various telemetry wave trains. The program contains the values of data for each signal to simulate the various onboard measurements, which in turn are used in the PAM/PCM wave trains. The computer used in this application is the Systems Engineering Laboratories SEL-810.

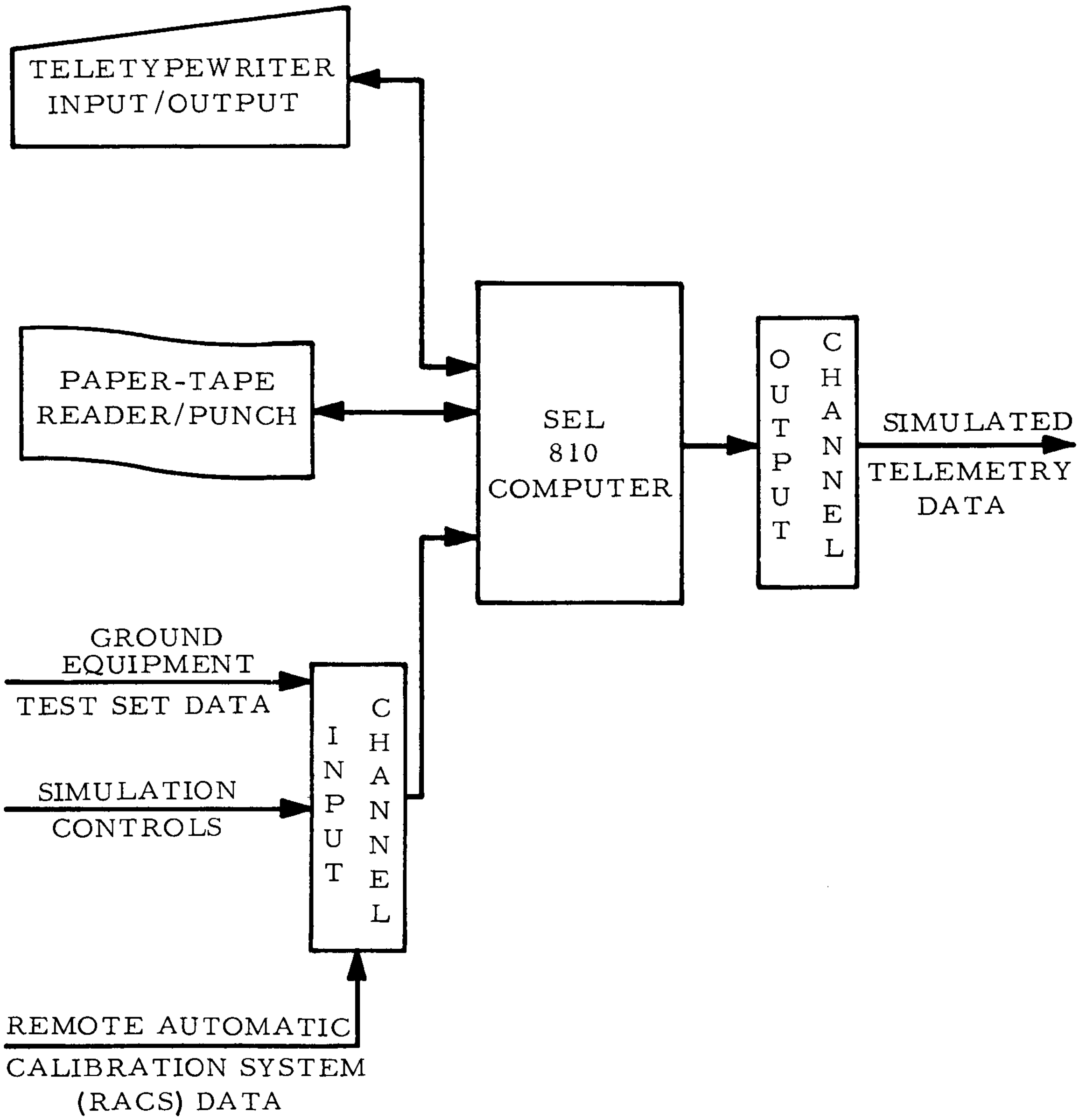

Figure 31. Vehicle Instrumentation Simulator Block Diagram

B. HARDWARE SYSTEM THEORY

The Vehicle Instrumentation Simulator is divided into three functional areas: An input section, the central processor and peripheral equipment, and an output section.

1. Input Section. Input commands can be received from either the remote automatic calibration system or the ground equipment test set. The remote automatic calibration system (RACS) input commands the simulator to use one of three data values (high, low, or run) to simulate the output of a signal conditioning measuring rack. Many of these signal conditioners are contained on a Saturn stage and during checkout can be selected by the RACS system. Therefore, the simulator has to respond to the request of the RACS by giving the simulated high, low, or run output of the measuring rack. This simulated output is applied as data in the PAM, PCM, SSB, or FM system in the simulator. The incoming RACS commands may be handled at the rate of one every 50 milliseconds. Commands of all RACS and all channels can also be processed. There are a total of 3240 RACS commands (1080 high values, 1080 low values, and 1080 run values).

The ground equipment test set input consists of 22 bits in parallel. Eleven of these bits provide an address code which specifies the time slot in the PCM wave train in which the remaining 10 bits of data will be inserted. The other bit in the input is a strobe pulse. The address code represents a binary value of 1 to 1800. This code defines the PCM channel into which the accompanying data work is to be inserted.

Included in the simulator is a unique, controllable random noise generator which facilitates evaluation of the effect of noise on vehicle signals and the developing of noise elimination techniques. A noise selector switch is available and is decoded by the computer in addition to the selection of the noise magnitude. Other inputs include level selector, force calibration, and inflight-preflight.

2. Central Processor. The central processor of the Vehicle Instrumentation Simulator is the SEL-810 general purpose computer. The computer is a stored program, 16 bit binary parallel computer. The storage element of the computer is a magnetic core memory capable of storing a minimum of 2048 words and expandable to 32,768 words. The computer in the vehicle instrumentation simulator contains 12,000 words of storage. The time required to read or write a word from or to the memory is 1.75 microseconds. The SEL-810 has 57 instructions, most of which require only 1 or 2 memory cycles to be completely

executed. The basic machine includes two input/output channels, one for eight-bit character transfer and one for 16-bit word transfers, each of which may be connected to 16 different input/output units. The simulator contains an A buffer which is used to control the teletype typewriter and the photoelectric reader. The B channel was installed to handle the input commands from the GETS and RACS and to issue control information to the output section of the simulator.

The SEL-810 computer is formed by 4 major units; memory, control, arithmetic, and input/output. The memory stores the instruction words which define the operation of the computer and the data word on which the computer operates. The control unit calls up the instruction words, decodes them, and issues commands to operate the computer. The arithmetic unit performs computation with data words supplied by the input/output unit and the memory unit under the direction of the control unit. The input/output unit transmits data words, commands, and status reports between the computer and peripheral equipment. The computer operates on and from, 16-bit binary words which are transmitted in parallel between the computer units. Arithmetic operations are performed using two's compliment binary arithmetic stored in the two's compliment form.

The SEL-810 is equipped with a teletype ASR-33 keyboard/printer that contains a paper-tape punch and reader. The speed of the paper-tape punch and reader is approximately 10 characters per second. Also included in the system is a modified Rheem photoelectric paper-tape reader which reads at the rate of 300 characters per second.

3. Output Section. The output section of the Vehicle Instrumentation Simulator contains the transmitters patch panels and other equipment necessary for providing the RF and hardwired output signals of the simulator. The output section receives a 10-bit data word from the computer and determines which area of the output section this data goes by the address contained in control information from the computer. The 10 bits can be directed to the three channels of FM/FM, the FM/FM/FM channel, the PAM channel, the PCM channel, or the SSB channel. There are six FM transmitters used to generate the telemetry RF carrier frequencies. These units are Saturn flight type hardware and insure complete compatibility with the Saturn vehicle characteristics. The output of each transmitter is applied to the input of an RF multiplexer where they are summed into one antenna.

C. SOFTWARE SYSTEM THEORY

Simulation is accomplished by storing predetermined data in computer memory and then outputting this data to generate FM, PAM, PCM, and SSB signals which are transmitted to ground receiving and processing equipment. Both predicted data and descriptive data are stored in memory. The predicted data, which represents onboard analog data signals, must be in accordance with specified formats. The descriptive data, which identifies the stage configuration, must include PCM A and B commutator strapping, FM channels to be calibrated when simulating in-flight calibration, and the PAM (s) to be transmitted.

A control routine, entered by depressing appropriate sense switches on the computer control panel, loads the predicted and descriptive data into the computer memory and sets up tables in memory that are used by the process routines in servicing the telemetry outputs.

An initialization and spin routine, which operates as the system background routine, initializes the processing routines, monitors various control panel and sense switches, and services the system control panel display.

Seven routines are entered by priority interrupt signals. The seven routines are as follows:

Routine	Priority Rating
PAM/PCM Processing Routine	1
GETS	2
Calibration	3
RACS	4
Force Calibration	5
Single Sideband (SSB)	6
A Channel	7

The power fail-safe routine, entered when loss of power is detected, halts the program and shuts off the computer memory.

The PAM/PCM routine, entered at a 3.6 kc rate, processes and outputs two PCM's, one random noise word, and three PAM's.

The GETS routine, entered under control of the GETS priority interrupt, inputs and stores a GETS address and data word.

The calibration routine, entered by manual control, processes system preflight and in-flight calibration.

1. Initialization and Spin and A Channel Routines. In order to start simulation, control is transferred to the initialization routine. The initialization routine will initialize all other routines, service all FM's, and enable all system priority interrupts. Control is then transferred to the spin routine. The spin routine continuously monitors the preflight/in-flight switch, the noise select, noise magnitude switches, sets flags in, and modifies other routines as the operator changes the position of the switches. The spin routine can be interrupted by any of the system priority interrupts and operates as the system background program.

The spin routine monitors computer sense switches, 1, 2, 3, and 15. Sense switches 1 and 15, if set, initiate a transfer to the data store portion of the control routine. Sense switch 2, if set, initiates a transfer to the manual change portion of the control routine. Sense switch 3, if set, allows the operator to type in a new time slot to be displayed. The time slot (1-1800) will be offset by -1801 and stored in the PAM/PCM routine (DISA).

The executive routine also services the binary and BCD displays. The contents of the display buffer (DISB) are compared with the last word outputted (DIC). If the two words compare, the display is not serviced. If the two differ, the contents of DISB are stored in DISC and outputted to the binary display. Offset is then removed, the number is descaled, rounded, converted to BCD, rounded again, and outputted to the BCD display.

The RACS routine, entered under control of the RACS priority interrupt, inputs and processes RACS control words.

The force calibration routine, entered by manual control, informs the calibration routine of an in-flight calibration request.

The single sideband routine, entered under control of the SSB priority interrupt, processes and outputs data to 15 SS/FM channels.

The A channel routine, entered under control of the A channel priority interrupt, is used by the initialization and spin routine to input and process a PCM time slot for display.

The VIS is capable of simulating up to 1620 data inputs (1080 RACS and 540 straights). Memory is arranged such that there are three tables of RACS data words (HIGH, LOW AND RUN), and one constant table (540 data values).

The VIS can simulate up to six PAMS. Multiplexer super and subcommutation can be specified by the operator, allowing complete versatility in simulating any multiplexer configuration.

There are six PAM output tables in memory. These tables contain addresses of data stored either in the CCB (Current Condition Buffer) or the constant table. The CCB is initially filled with the data values contained in the RUN table. As RACS inputs occur, the corresponding data values are transferred from the HIGH, LOW AND RUN tables to the CCB.

The VIS can simulate up to 15 SSB channels with complete super and subcommutation capability. (The one restriction being that the subcommutators must be two or four channel).

The VIS can service up to 61 FM channels. The operator can specify RACS or constant inputs, and can select which channels are to be calibrated in the inflight calibration mode.

2. <u>Processing Routines.</u> The processing routines have been grouped into five routines, i.e., PAM/PCM Routine, GETS Routine, Calibration and Force Calibration Routine, RACS Routine, and SSB Routine.

a. PAM/PCM Routine. Entry to the PAM/PCM routines (P36I) is provided by means of a priority interrupt occurring at a 3.6 kc rate. The PAM/PCM process routine processes three PAM's and two PCM's (PCM A and PCM B). The PAM's to be outputted (PAAT) and the commutation for PCM A and PCM B (PCAT) can be specified by the operator.

Any PCM time slot (1 to 1800) may be selected for display on the decimal and binary displays located on the system control panel. The data displayed on the binary display is uncorrected for scaling and offset. The decimal display data is corrected for scaling and offset.

The PAM/PCM process routine continuously compares the last display request (DISA) with the time slot number that it is currently processing (PCMC). When the time slots match, the data word to be outputted is stored in a special memory cell (DISB). The display service routine continuously monitors and displays the contents of this memory cell.

The PAM/PCM process routine also services GETS. This is done by continuously comparing the last inputted GETS address (GETA) with the time slot that it is currently processing (PCMC). When the time slots match, the GETS data word (GETC) is substituted for the data that would normally be outputted at this time. Complete flexibility is provided in that a time slot requested by GETS can also be displayed.

The routine also generates random noise from 0 volt to 660 millivolts magnitude. This random noise can be added to PAM, PCM, FM, SSB or ALL outputs, and is selectable by the operator by a switch on the system control panel. If PCM or ALL is selected, noise is added to the PCM outputs by the routine. Noise is added to all other system outputs by the system hardware. In all cases, one noise word per time slot is outputted by the routine to be selectively added to the PAM, SS/FM, and FM outputs. The algorithm used to generate random noise is as follows:

$$R_n + 1 = R_n (2A + 1) + L$$

Where K is odd and $A \geq 2$

In order to insure a high degree of randomness of the noise, the following storage and access scheme is used:

It is necessary to use a total of 54 different random noise words each PCM frame (27 time slots x 2 PCM's/time slot = 54 PCM data words/frame). From T_0 during the first frame, the first 54 words of an 84 word noise table (NOIT) are accessed by means of a noise access counter (PN01). At the end of the frame, the starting address used to reference the table is incremented by one so that during the next frame, noise words 2 to 55 are used. It can be seen that the program would have to generate 30 complete frames of data (PCM master frame) before all of the table was used.

It can be seen that, if the noise table was not changed, a pattern could be detected in the noise. In order to prevent this from happening, the noise table is constantly being refreshed. Three new random noise words are generated each frame, and stored in the noise table (NOIT) by means of a noise refresh counter (PN02). This means that a total of 90 (3 words x 30 frames) new noise words are generated each PCM master frame. In other words, the noise is being changed somewhat faster than it is being used.

b. GETS Routine. On entering the GETS routine, the registers are stored and the higher priority system interrupts (PAM/PCM) are disabled.

Unit 2-channel 1 is now selected and the GETS time slot (1-1800 binary count) is inputted, offset by -1801, and stored in GETA.

Unit 2-channel 2 is now selected and the GETS word to be inserted in the PCM wave train is inputted and stored in GETC.

The registers are restored and the routine exits.

c. Calibration and Force Calibration Routines. Entry to the calibration routines (PI 14) is controlled by a 140-millisecond system priority interrupt. The calibration routine simulates both preflight and in-flight calibration of PAM/PCM, FM, and SSB.

Preflight calibration is initiated by placing the preflight/in-flight switch, located on the system control panel, to the preflight condition. A level selection switch located on the system control panel allows operator selection of 0 percent, 25 percent, 50 percent, 75 percent, 100 percent or CYCLE. If the calibrate local-remote switch is in the remote position, calibration can be controlled from a remote control panel. If the level select switch is in one of the first five positions, the corresponding constant will be outputted to all FM channels. If the level select switch is in the CYCLE position, a step function will be outputted to all FM channels.

Preflight calibration will continue until the preflight/in-flight switch is placed back into the in-flight position.

In-flight calibration is initiated by placing the preflight/in-flight switch in the in-flight position and depressing the force cal switch. In-flight calibration can be terminated by releasing the force cal switch. (The FM group and PAM being calibrated will finish calibration.) Calibration is automatically terminated after all FMs and PAMs have been calibrated.

If the preflight/in-flight switch on the system control panel is in the preflight position when the routine is entered, control will be transferred to DXZX by the software preflight switch (PI14+4). The software preflight switch is set by the SPIN routine.

The routine will examine the control panel switch to determine if it is still in the preflight position. If yes, the level select switch on the control panel will be examined. If it is in the cycle position, DFMS will be used to access a calibration step constant to be outputted to all 61 FM channels (all channels selected by unit 9, channel 0). DFMS will now be examined to determine if all steps have been outputted. If yes, DFMS is initialized to step 1. If no, DFMS is incremented.

If the level switch is not in the CYCLE position, the actual position of the switch (0 percent, 25 percent, 50 percent, 75 percent, 100 percent) is used to access the correct step constant to be outputted to all FM channels (unit 9, channel 0).

If the preflight/in-flight switch is no longer in the preflight position (determined at DXZX), DFMA and DRFM are used to restore RACS data to all 61 FM channels, the ignore switch (PI14+1) is set, the registers are restored, and the routine exits.

d. RACS Routine. The RACS routine (RACR) is entered under control of the RACS priority interrupt. The routine inputs the RACS command word and determines which group, rack (s) and channel (s) to be calibrated is (are) being requested (HI, LOW, or RUN).

The routine then uses the group, rack, and channel date to access the proper location (s) within the HIGH, (RACH) LOW (RACL) or RUN (RACR) date tables. The constant (s) is (are) then stored in the current condition buffer (CCB) in the proper location (s). The routine will process the following types of inputs:

Group (x), Rack (y), Chan (z)	HI, LOW or RUN
Group (x), All Racks, Chan (z)	HI, LOW or RUN
Group (x), Rack (y), All Channels	HI, LOW or RUN
Group (x), All Racks, All Channels	HI, LOW or RUN

The RACS process routine also services all FM and SSB channels that are affected by the requested mode change. This is accomplished in the following manner: If a RACS amp has been assigned to a SSB channel or subchannel, a SSB flag is set in the unused bits of the RACS RUN data word.

The routine will examine this SSB flag as it processes the RACS command and, if it is a 1, will extract the channel number (xxxx) and store it in the SSB process routine (SSCC).

The routine will also examine the FM flag and, if it is a 1, will pick up the RACS LOW data word and extract the FM channel number (xxxxxx). The requested data word will then be outputted to the FM channel.

At this time CFMA (FM unit/channel address code) and DRFM (RACS addresses for FM) will be used to address and output RACS data to all FM channels. The registers are then restored and the routine exits.

e. SSB Routine. The SSB routine simulates up to 15 SS/FM channels. Two or four subchannel commutations are allowed on all channels. The SSB routine will initially service channel 1. As RACS data is inputted, the SSB routine will automatically start servicing the SSB channel associated with the RACS input.

When the preflight/in-flight switch is placed in the preflight position, the SSB routine will automatically output the data associated with the last selected SSB channel to all SSB channels. When in the preflight cal mode, the operator can optionally specify an amplitude and frequency to be outputted on all SSB channels via the computer sense switches.

When the VIS is placed in the in-flight cal mode, all SSB channels will output 1 V P-P 1700 cps. SSB calibration will continue until the first two FM links have been calibrated.

D. SYSTEMS EVALUATION

The Vehicle Instrumentation Simulator has been used to advantage on the Saturn V, S-IC checkout program in verification of software, training personnel, verifying equipment setups and interconnections, etc. New techniques for sampling readings to eliminate relay chatter problems, etc., were run against the VIS. Evaluation of the techniques were made and certain of these were chosen to be used in checkout operations. Although the computer is small and presented some problems with program loading and assemblies, the system has operated as it was designed. The problems of program loading and assembling have been minimized, because the simulation routines are essentially fixed and have not required appreciable modification. If future requirements make it necessary to reassemble the programs to any great extent, the paper-tape input, typewriter output, and multipass assemblies will result in serious turn around times.

Expansion capabilities of the computer are limited since the memory is now 12,000 words. Unless requirements change, however, this will not present a problem.

SECTION VIII. TELMETRY DIGITIZING SYSTEM (TDS)

The purpose of the Telemetry Digitzing System (TDS) is to acquire and digitize data from 20 analog inputs, perform real-time processing of the acquired data, and provide calibrated, reformatted serial and parallel data outputs with logic levels as required by external equipment. The system also accepts a 10-bit serial PCM input which is converted to parallel and time gated to the control unit (SEL-810 Computer) of the TDS. A serial time data input (pulse duration coded) is also decoded and made available for printout.

A. GENERAL DESCRIPTION

The Telemetry Digitzing System (figures 32 and 33) consists of an SEL-810 Computer and an I/O rack which contains the following major logic circuits:

1. Serial-to-parallel conversion logic for a 10-bit PCM input
2. Multiplexer, coder and serial-to-parallel conversion logic for 20 analog inputs
3. Gating logic for a 10-bit external word
4. Time code converter which accepts serially coded time data and provides a parallel BCD output to an external printer
5. System sync logic
6. Output register and converters which provide both parallel and serial outputs for a 10-bit data word and a parallel output for a 9-bit control word.

The Telemetry Digitizing System (TDS) I/O rack is housed in one AMCO metal cabinet. The cabinet is 84.50 inches high, 21.06 inches wide, and 27.88 inches deep. It is shielded against RF energy transmission. Signal input and output lines are connected through shielded connectors mounted on the cable entry box at the top of the cabinet.

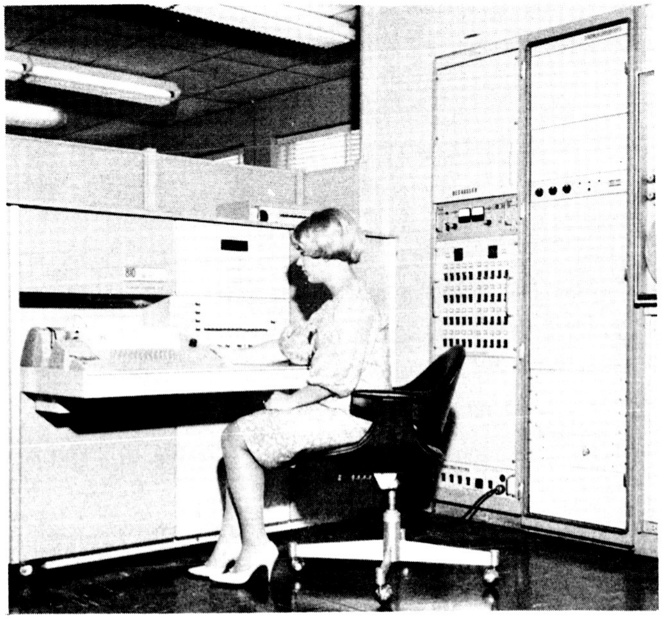

Figure 32. Telemetry Digitizing System

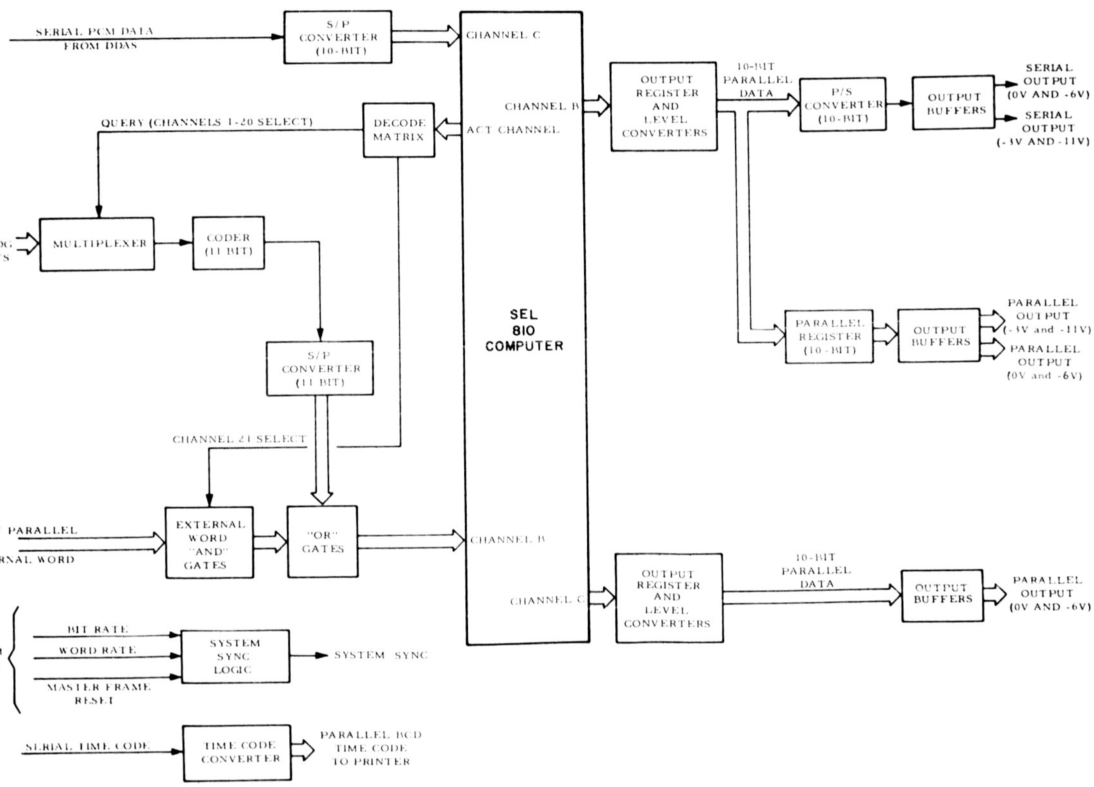

Figure 33. Telemetry Digitizing System Block Diagram

All logic circuit components are mounted on circuit card modules measuring 5 inches by 3.25 inches. The logic cards are terminal mounted in four vertically-mounted trays. Each tray contains four card files and is mounted on ball-bearing slide rails for easy access to circuit cards, test points, and adjustments.

B. HARDWARE SYSTEM THEORY

1. PCM Inputs. The TDS I/O rack receives a serial digital PCM input from an external DDAS as shown in figure 33. The PCM input is received through a pulse isolation circuit and is reconstructed in a NOR latch circuit. The reconstructed PCM input is shifted into a serial-to-parallel conversion register by bit rate pulses from the DDAS. Once each word time (the PCM data input is in the form of 10-bit words), a word rate pulse from the DDAS is received by the TDS synchronizing circuits, is delayed to permit a complete 10-bit PCM input word to be loaded into the serial-to-parallel conversion register, and is then applied to transfer the PCM word, in parallel, to a time buffer register.

Outputs of the 10-bit time buffer register are applied through cable drivers to the computer channel C input. Control logic is included in the I/O rack so that each time a new data word is assembled and loaded into the time buffer register, a channel C "date ready" signal is transmitted to the computer. The computer will then, if so programmed, accept the PCM data word for processing.

2. Analog Inputs. The TDS analog inputs are received through 20 high level gates in the I/O rack multiplexer. The analog inputs are in the range of ± 10 volts and are derived from discriminators in the Telemetry Ground Station. The individual high level gates are enabled by outputs of a decode matrix which receives channel select codes from the computer ACT (activate, command, and transfer) channel.

When the multiplexer logic receives a mux command from the system sync logic, the high level gate selected by the computer ACT channel output is enabled and the analog voltage present at its input is gated to the analog-to-digital converter for coding.

The analog-to-digital converter (coder) employs the method of successive approximation to convert each gated analog voltage to an equivalent 11-bit binary word. The output of the coder is an 11-bit serial RZ digital word which is shifted, most significant bit first, to the serial-to-parallel conversion logic.

The coder output is shifted into an 11-bit serial-to-parallel conversion register by shift pulses generated by the coder during the coding process. When the coding process is complete, and end-of-conversion pulse from the coder transfers the 11-bit word, in parallel, to a buffer register.

Outputs of the 11-bit buffer register are applied through gating logic to the required logic level converters and cable drivers at the computer channel B input. Control logic is included in the I/O rack so that each time a new analog input is coded and the digital word is assembled in the buffer register, a channel B "data ready" signal is transmitted to the computer. The computer will then accept the coded channel B input for processing.

3. External Digital Word Input. Also applied to gating circuits at the computer channel B input is a 10-bit parallel digital word from an external source. For programming purposes, the 20 analog inputs to the system are designated channels 1 through 20 and the external digital word input is designated channel 21. When a channel 21 command is received by the decode matrix on the output of the computer ACT channel, a one-word delay circuit is activated and, after the delay, the coded analog input to computer channel B is inhibited and the external digital word gates are enabled. The external digital word is then received by the computer channel B input. The one-word delay circuit is included so that the channel 21 input will appear in the proper time slot (channel 1-20 inputs are delayed one word time by the coding process).

4. Time Code Converter. Pulse duration coded serial time data is received through a pulse isolation circuit, reconstructed in a NOR latch circuit, and applied to the time code converter. The time code converter contains logic circuits to distinguish master sync pulses, ONE bits, and ZERO bits on the input time data. When a master sync pulse is detected, the input gate to a flip-flop shift register is enabled and the ONE bits and ZERO bits of the time data are then shifted into the register. The time code converter also contains a downcounter circuit which, after the 26th time data bit is received, produces a pulse to load the contents of the shift register into a buffer register. The data thus loaded into the buffer register is parallel BCD seconds, minutes, and hours of time data which is applied to the printer logic.

5. System Sync Logic. The Telemetry Digitizing System is synchronized with the input DDAS by bit rate, word rate, and master frame reset sync pulses from the DDAS.

The bit rate input advances a 10-stage bits-per-word (B/W) counter and shifts the parallel-to-serial output register. The B/W counter produces 10 discrete outputs per word time which are used for all system timing pulses. The bit rate input is also inverted and a control panel switch is set to select either true or inverted bit rate for shifting the PCM serial-to-parallel conversion register. The bit rate phase selection switch aids in synchronizing the system with the PCM input.

A B/W RESET switch on the I/O rack control panel is set to select the bit time during which the input word rate sync pulse is to be received. When the system is in sync, an output of the B/W counter enables a gate during the time that the word rate sync pulse is received and the output of the gate causes the BIT SYNC indicator to remain illuminated. If the system is out of sync, the word rate input does not arrive at the bit time selected and the system sync logic detects an out-of-sync condition. When an out-of-sync condition is detected, the BIT SYNC indicator is extinguished and the B/W counter is forced to the correct bit time count.

Word rate inputs are also delayed by a flip-flop counter delay circuit and applied to transfer the PCM input word out of the serial-to-parallel conversion register to a PCM word buffer register.

Outputs of the B/W counter are applied to a patch panel, from which bit times may be selected for mux commands, word rate, priority interrupt inputs to the computer, and word rate outputs to an external system.

In the computer, the word rate inputs are counted to determine whether the system is operating in word synchronization with the DDAS. The computer provides "word sync in" and "word sync out" signals to the system sync logic and the sync logic extinguishes a control panel WORD SYNC indicator when word sync is lost.

Outputs of the B/W counter are also applied to a control panel O/R LOAD switch which is used to select the bit time for loading of the channel B parallel output register.

The master frame reset input from the DDAS is applied to the sync logic. This logic extinguishes a control panel LOSS OF MFR indicator if the master frame rate input is interrupted. The MFR is also applied to a priority interrupt circuit in the computer and used by the computer in checking word synchronization.

The Telemetry Digitizing System also provides bit rate, word rate, frame rate, and master frame rate output signals for synchronization of external systems at the output of the TDS. The bit rate input is routed through the output buffer and isolation circuits, the word rate output is taken from the B/W counter patch panel so that any phase is available and applied through an output buffer; the frame rate and master frame rate outputs are derived from the computer ACT channel outputs which are routed through output buffers.

6. Output Registers and Converters. The computer channel B output is loaded into a 10-bit parallel-to-serial output register at the bit time selected by patch panel connections and is loaded into a 10-bit parallel output register at the bit time selected by positioning of the O/R LOAD switch. The output of the parallel-to-serial conversion register is shifted at bit rate through output buffers and isolation circuits to provide true 0/-6 volt logic level outputs and both true and inverted -3/-11 volt logic level outputs. The output of the 10-bit parallel output register is also applied through output buffers and isolation circuits to provide 0/-6 and -3/-11 volt logic level outputs.

The computer channel C output is loaded into a 9-bit parallel output register. The outputs of the channel C output register are applied through buffers which provide true 0/-6 volt outputs to the external system.

C. SOFTWARE SYSTEM THEORY

The software package for the TDS was developed by SEL Inc. The operational software consists of one main program which contains all the necessary subroutines for the operation of the TDS.

The TDS program is contained on a formatted paper-tape delivered with the system. This paper-tape is loaded through the ASR-33 tape reader by a loader program provided with the system in the SEL 810 diagnostic package. The loader may be bootstrapped in by following the directions in the SEL 810 diagnostic manual. After the loader has been put into memory, the program may be loaded.

The computer will halt and type CK on the ASR-33 if a check-sum error is detected during loading. If a check-sum error does occur, the entire tape should be read again. When loading is finished, the computer will recognize a stop code (two rows with all levels punched) and halt.

For ease of operation, the TDS program establishes linkages with the next step in the program throughout the course of calibration and initialization procedures. Starting the program causes a 0-percent calibration to be performed. Upon completion of the 0-percent run, the program will halt on a linkage to the 100-percent calibration run.

To perform a 100-percent calibration, the START button is pressed. An option to print out the calibration values is included in the 100-percent run. If sense switch 0 is set, the values will be printed on the AST-33 along with the corresponding multiplexer channel. The program halts on a linkage to the run initialization program after the 100-percent calibration run is completed. (The program also executes both 0 percent and 100-percent runs for PAM channels 1 and 20 during the 100-percent runs.)

The run initialization program may be entered by pressing the START button. The multiplexer table is generated for run F1 or F2 during initialization. If sense switch 1 is set, the multiplexer table for run F1 is generated. If sense switch 2 is set, the multiplexer table is generated for run F2. The multiplexer table is also generated for run F1 if both sense switches (1 and 2) are set or if neither sense switch is set.

After initialization is complete, digitizing of data commences. The program is set to receive real-time data requests during the digitizing run. To display calibrated data, a request should be typed on the ASR-33 in the following format:

Display number - Channel number (Group) - Frame Count*

The displays are numbered as follows:

1 = Binary display number 1

2 = Binary display number 2

3 = Nixie display

4 = ASR-33

The channel number and the frame count range from 1 to 30. The group is either A or B. If a mistake is made during the course of a display request, a carriage return and line feed will reinitialize the type-in.

D. SYSTEMS EVALUATION

The Telemetry Digitizing System was installed as a part of a telemetry ground station and has been used by the Chrysler Corporation in testing operations during the static firings of the Saturn IB first stage. The system replaced the previously used manual and semi-automatic equipment that had been used in digitizing the Pulse Amplitude Modulation (PAM) signals received in the ground station from the vehicle.

The system has performed satisfactorily and has met its design requirements. The system has been reliable and has had insignificant malfunctions and downtime.

Like the Vehicle Instrumentation Simulator, the TDS has little input-output capability. But, likewise, this has not been a problem with the TDS since the software has remained relatively unchanged.

SECTION IX. GENERAL ELECTRIC GE-215 SUPPORT COMPUTER SYSTEM

When electronic digital computers were introduced as the controlling element in automatic checkout operations, it was evident that a separate computer system would be required for the processing of data and other information in support of automatic checkout. On August 10, 1962, the first official action was taken for the procurement of such a supporting computer for the Laboratory's automatic checkout operation. Several problems were evident in the automatic checkout operations and provided justification for the support computer. These problems were primarily associated with manipulation of data for the programs which were to perform the checkout operations of the Saturn I stage. Operations to be performed by the Packard Bell automatic checkout system would not allow for lengthy data reduction processes to be performed which would result in delays in checkout. Computer programs in the checkout computer had to be optimized in order to perform checkout in the scheduled time period. An important factor to remember about the automatic checkout system was that the computer system itself was designed primarily for automatic checkout operations and not for handling the large quantities of data involved in data processing. The method of reading data into the checkout computer was through the medium of paper-tape and magnetic-tpae. Because the checkout computer system was not designed for data processing, the performing of such activities would result in unreasonable delays in checkout operations for data reduction and processing.

Objectives in the procurement of the support computer included:

1. Installation by October 1, 1963, of a digital computer system onsite in the Quality and Reliability Assurance Laboratory to facilitate the preparation of data and computer programs for input to the checkout system and for data reduction and high-speed output printing of the data and information acquired during testing operations.

2. Establish policies and procedures concerning the operation and application of the equipment.

Figure 34. General Electric GE-215 Support Computer System

A. GENERAL DESCRIPTION

The GE-215 computer was purchased with a 4, 096 word core memory, two magnetic-tape units, a card punch, card reader, output typewriter, and line printer. Statistics of the hardware are shown in table 1. The GE-215 computer was a medium size, solid state, general purpose computer with the capability of being expanded to meet future needs. This capability was exercised when the equipment was later expanded to the GE-235 computer.

Table 1. GE-215 Computer Features

Central processor	General purpose, single address, binary, solid state, 36 USEC time, 4096 word memory
Magnetic tapes	2-15 KC, 200 BPI AMPEX TM-4 type
Card reader	400 Cards per minute
Card punch	300 Cards per minute
Line printer	450 LPM, 120 columns
Output typewriter	10 Characters per second (IBM)
Paper-tape reader	300 Characters per second
Paper-tape punch	110 Characters per second

B. HARDWARE SYSTEM THEORY

A block diagram of the GE-215 computer is shown in figure 35. The computer operates under both stored program and operator control. It is a buffered computer with an input-output priority system that permits simultaneous operations such as reading, writing, and processing.

C. SOFTWARE SYSTEM THEORY

The limited number of magnetic-tape units necessarily resulted in the use of an unsophisticated method of operation. When a

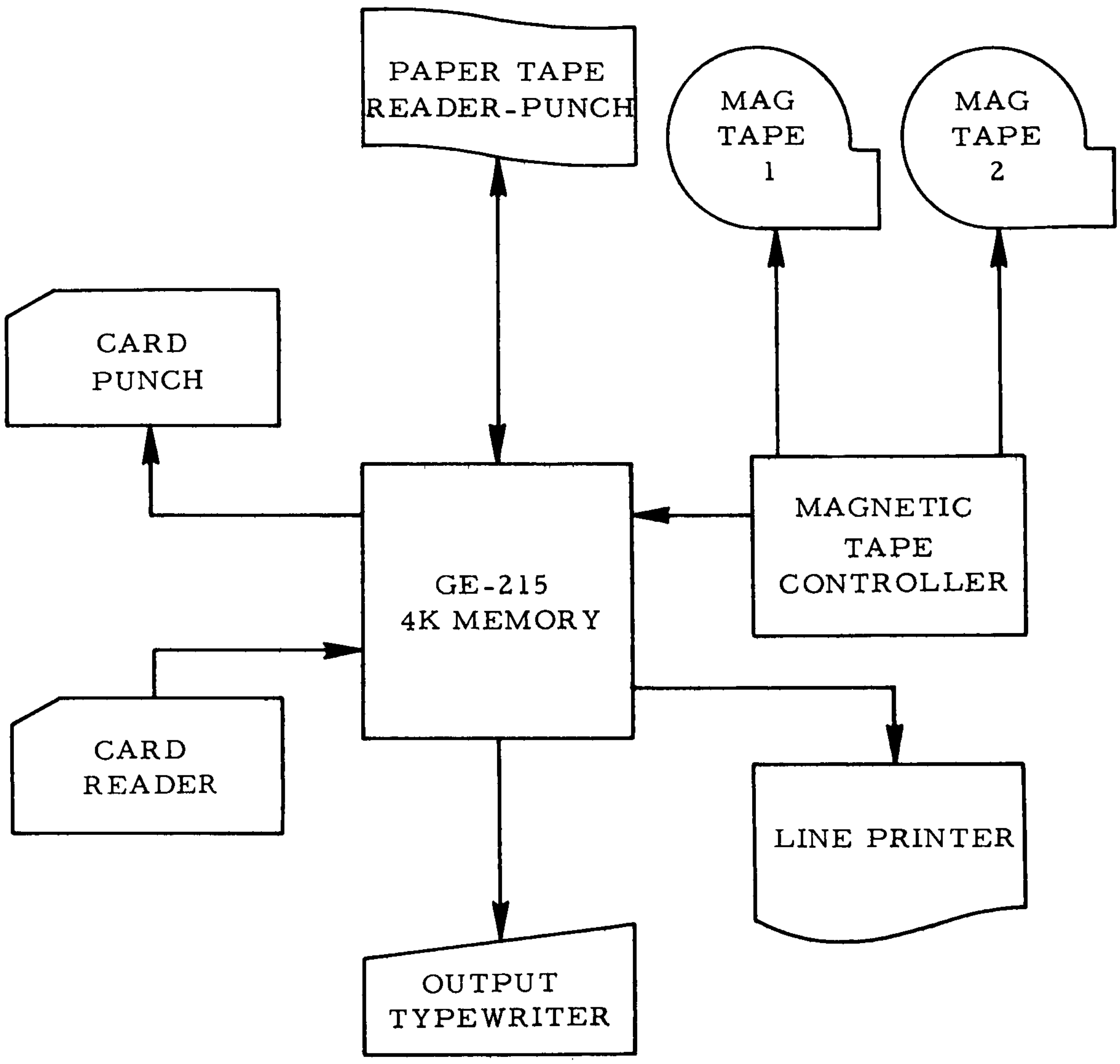

Figure 35. GE-215 Computer System Block Diagram

program had to be run on the GE-215, the program was loaded through the card reader. An executive, as such, was never used.

There were numerous programs written to run on the GE-215 in support of the Saturn I checkout. A partial list is included below:

1. Electrical Test Station sequence data to PB-250 binary paper-tape.
2. Astrionics electrical wiring cards to binary paper-tape.
3. Universal Measuring Adapter PB-250 magnetic tape to GE-215 printer.
4. Temperature sensor PB-250 magnetic tape to printer.
5. Instrumentation and Telemetry Scan magnetic tape to printer.
6. Test data cards to PB-750 binary tape.
7. DDAS test data cards to PB-250 binary paper-tape.
8. Cards to PB-250 paper-tape (Pressure Calibration Test).
9. Temperature Sensor Data cards to PB-250 binary paper-tape.
10. DDAS hardwire printout program.
11. Telemetry Data cards to PB-250 binary paper-tape.
12. Telemetry/Hardwire Data PB-250 magnetic tape to line printer.
13. Digital Events Monitor Data Reduction
14. Digital Events Monitor Translation Print
15. Instrumentation and Telemetry Data Processing.

D. SYSTEMS EVALUATION

One area in which the support computer was used to advantage was that of Instrumentation and Telemetry. Each of the test programs for this area required large tables of data (3, 000 to 5, 000 words), and when a new stage was tested, the data in these tables changed and required reprocessing.

Special circuitry had to be incorporated into the magnetic tape units to provide for the reading and recording of the PB-250 magnetic tapes. Likewise, special circuitry was incorporated into the paper-tape equipment to allow for the handling of the random 8-channel paper-tapes of the PB-250. However, the small additional changes were compensated for by the increased speeds of processing the bulk data for the testing operations. For example, to print out the results of a telemetry scan on the PB-250 flexowriters would require 45 minutes. It was a simple matter, however, to record this data on magnetic tape and print the information out on the GE-215 in 5 minutes. During this printout period, the test computer was released to continue checkout operations.

Utilization of the GE-215 was as expected. The basic rental cost of the computer included a use of 200 hours per month before additional fees would be charged. A summary report of the utilization is shown in table 2. The hours indicated include computer time used for assembly of programs, debugging of programs, and production runs.

Actually, more than one shift was required on many occasions in order to complete the required work on a timely basis. Failures of the air conditioning system frequently added great discomfort to the work areas, and malfunctions in the GE-215 resulted in extended turn around times on various jobs. The GE-215 system proved to be adequate in reliability and performance.

Table 2. GE-215 Computer Utilization Summary

DATE		UTILIZATION
MONTH	YEAR	(HOURS PER MONTH)
November	1963	115.43
December	1963	111.62
January	1964	91.07
February	1964	110.58
March	1964	184.02
April	1964	162.79
May	1964	144.92
June	1964	139.10
July	1964	101.30
August	1964	196.20
September	1964	128.13
October	1964	125.51
November	1964	78.62

SECTION X. GENERAL ELECTRIC GE-235 SUPPORT COMPUTER SYSTEM

With the increasing number of checkout computers in the Laboratory, it soon became apparent that a more powerful support computer system would be required. Although the GE-215 had some undesirable characteristics, it was determined that the most practical approach to solving the problem would be to expand the GE-215 system. This action was initiated on August 27, 1964, for the expanded system.

In December 1964, the GE-235 was installed in the Laboratory (figure 36). The GE-235 has subsequently been used to support the checkout operations of the Saturn V S-IC stage and Instrument Units and the Saturn IB Instrument Units. In addition to supporting the automatic checkout computers, it has performed data processing operations, served as an important tool in developing automated management systems for the Quality and Reliability Assurance Laboratory, and has been used in other research and development operations in this Laboratory.

A. GENERAL DESCRIPTION

A block diagram of the GE-235 system is shown in figure 37. Hardware statistics for the GE-235 system are shown in table 3.

Table 3. GE-235 Computer Hardware Statistics

Central processor	16,384 words of core memory
Card reader	1,000 cards per minute
Card punch	300 cards per minute
Magnetic tape handlers	8-41.6 KC, 200/556 BPI
Automatic arithmetic unit	1
Line printer	1,000 lines per minute
Disc storage unit	16 disc's - 6×10^6 words
Paper-tape reader	300 characters per second
Paper-tape punch	110 characters per second
Digital input-output unit	4 channel -22 bits serial

Figure 36. General Electric GE-235 Support Computer System

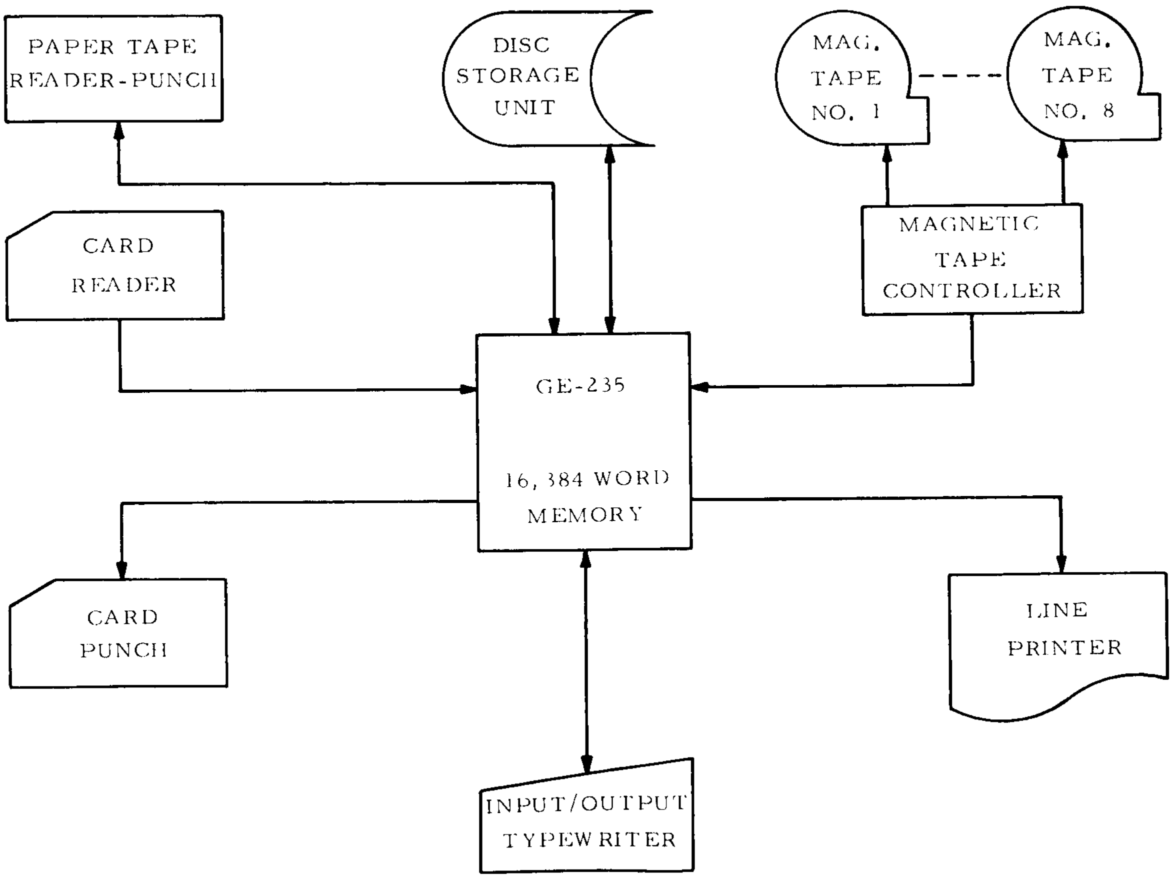

Figure 37. GE-235 Computer System Block Diagram

B. HARDWARE SYSTEM THEORY

The hardware operation of the GE-235 is similar to that of the GE-215 described in section IX. The major difference is the operating speed of the central processor and the increased capacity provided by the Disc Storage Unit and magnetic-tape units. One significant difference was the addition of the Digital Input-Output Unit (DI/OU). The DI/OU consists of a modified group 2 DI/OU, an interface rack consisting of four independent and identical channels, and a 100 kc timing generator common to all four. Each channel may be connected through coaxial cables to a remote station.

Each channel contains a shift register used to transmit or receive from the remote station, a parity generator/checker, a synchronizer to detect the leading edge of a data word from the remote stations for timing purposes, and hardware to control the sending of data, status, and control information between the channel and the processor through the DI/OU.

The DI/OU is a general purpose controller designed to interconnect the GE-235 processor with special purpose interfaces. In this case, it is modified slightly to allow more independent operation of the individual channels and provide more appropriate branch conditions.

The DI/OU is also adapted for a particular application by 5 plugs which are wired for that application (these points should be kept in mind if there is any possibility of confusion with the normal, ground 1, DI/OU).

The DI/OU has a parity generator/checker which functions on all communications with the processor. It should not be confused with parity error in the channels or remote stations, which pertain to errors in communications between the DI/OU and a remote station.

Presently under consideration is the use of the DI/OU in providing a digital communications link with the Instrumentation Data Test Station (IDTS) and the Advanced Test and Checkout Methods Evaluation Development (ATCOMED) facility.

C. SOFTWARE SYSTEM THEORY

The GE-235 software system has been organized for batch processing of programs (jobs) from the card reader. A system monitoring program, SLEM (Systems Liaison Executive Monitor), is used to bring all symbolic and object programs under one system, thus eliminating as much system housekeeping as possible. A program executed using SLEM may be initiated with the use of two cards which precede the program deck. These two cards are the SLEM call card and the SLEM job card. Programs may be stacked in the card reader, in which case the SLEM call card will be needed only before the initial program.

The SLEM call card is a binary card which will be furnished to all operators. It will rewind the system tape, call in and transfer to a routine called ITOCS (which resides in memory at all times), and reads the next card, which should be a SLEM job card.

The SLEM job card is a symbolic card and has two purposes:

1. It calls in the SLEM executive program, which in turn reads and prints on the typewriter the contents of the internal clock (which is the chargeable time for the preceding job), zeroes the clock, sets memory as specified, checks the AAU for ready, sets the AAU to normalized floating point mode, and initiates a card for the following program.

2. As an aid to record keeping, column 1 through 60 of the job card, which contains the programmer's name, job number, job code, and number of peripherals used, are printed on both the typewriter and printer.

D. SYSTEMS EVALUATION

At the time the GE-215 was removed and the GE-235 was installed, utilization, in terms of hours of computer time expended, was expected to drop sharply due to the increased speed of the GE-235. However, because of the anticipated work loads, the utilization was expected to increase rapidly thereafter. As expected, the utilization dropped to a low of 85.56 hours in January 1965, but more than doubled by June 1965 (198.61 hours). Two working shifts and even an extended second shift has not been uncommon in the use of the GE-235. Table 4 gives the utilization in hours for each month since the installation of the GE-235. It is important to stress once again that these figures more than justify the use of the GE-235 in terms of the workload being removed from the checkout computers. Without the use of such a support computer, automatic checkout operations would have been seriously affected if not impossible altogether.

Table 4. GE-235 Computer Utilization Summary

DATE		UTILIZATION
MONTH	YEAR	(HOURS PER MONTH)
January	1965	85.56
February	1965	64.13
March	1965	104.02
April	1965	122.49
May	1965	106.86
June	1965	198.61
July	1965	189.43
August	1965	216.56
September	1965	166.36
October	1965	228.53
November	1965	190.27
December	1965	211.78
January	1966	207.70
February	1966	172.06
March	1966	250.55
April	1966	176.64
May	1966	166.39
June	1966	181.49
July	1966	181.52

SECTION XI. INSTRUMENTATION DATA TEST STATION (IDTS)

The purpose of the Instrumentation Data Test Station (IDTS) is to receive actual data from one of several sources, compare the values of the data with predicted values, and indicate whether or not the values fall within the tolerances specified. The IDTS continuously processes the information and when the required number of values have been received, the IDTS can give an immediate printout of results obtained. A Remote Selector Indicator Unit (RSIU) facilitates selection of individual channels from a remote location and permits identification of sensors and other devices as well as determination of the GO or NO-GO status of these devices. The IDTS is capable of being controlled by a Master Station and transferring data to and from the Master Station. To date, no computer has been connected to the IDTS for use as a Master Station. Originally the RCA-110A was selected; however, present plans do not include the RCA-110A. (See figure 38.)

A. GENERAL DESCRIPTION

The IDTS consists of computer equipment (SDS-930), System Control Unit, Remote Selector Indicator unit. A block diagram is shown in figure 39.

1. Computer Equipment. The computer is a Scientific Data Systems SDS-930 digital computer with the following features:

Words of core memory	16,384
Channels of priority interrupts	20
24-bit I/O channels	1*
6-bit I/O channels	1*
Central processor unit	1
Card reader	1 (400 cpm)
High speed printer	1 (300 lines/min)
Paper-tape reader	1 (300 cps)
Paper-tape punch	1 (60 cps)
Magnetic tape unit	2 (200, 556, 800 bpi)
Power fail-safe unit	1

*The 6-bit I/O channel and one 24-bit channel are combined in a Time Multiplex Communications Channel

Figure 38. Instrumentation Data Test Station

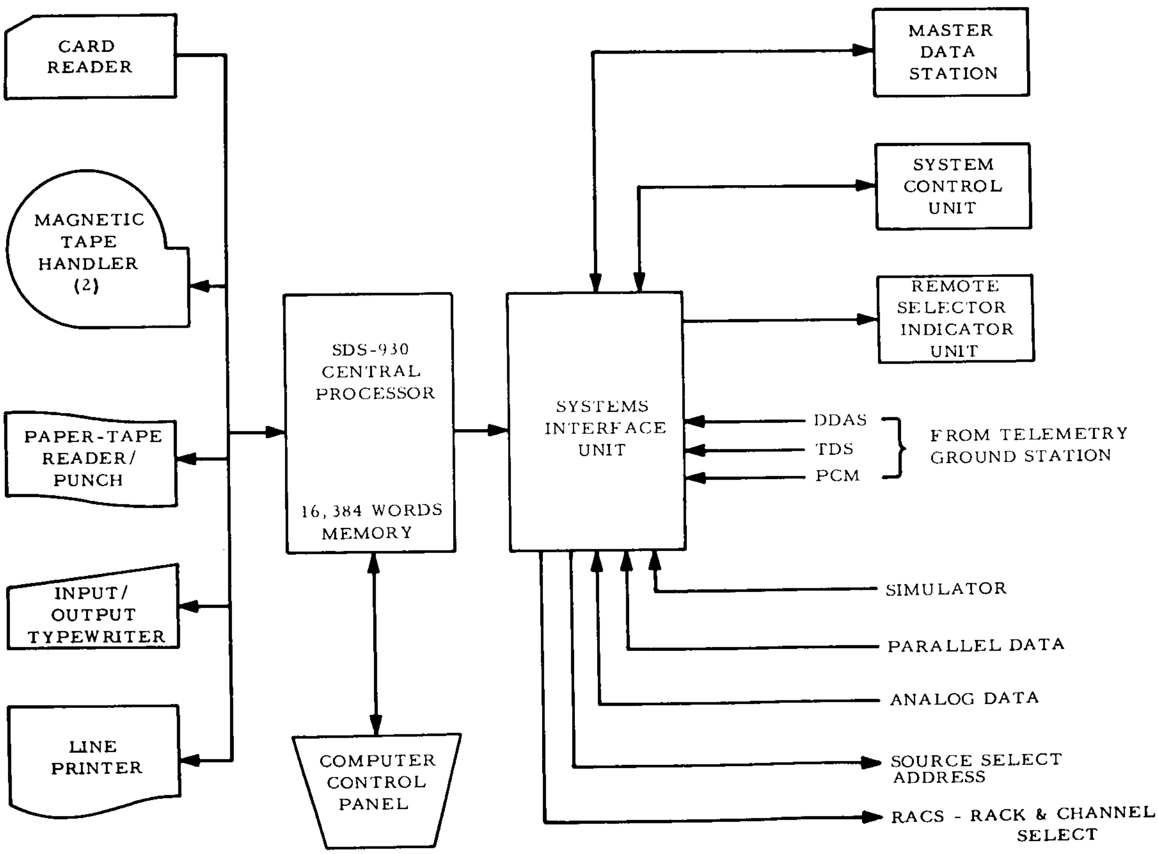

Figure 39. Instrumentation Data Test Station (IDTS) Block Diagram

2. <u>System Control Unit.</u> The System Control Unit (SCU) contains the necessary controls to make selections of programs, modes, and tolerances, and to print out results. Indicator lights are provided on the SCU to give visual indication of system status and operational sequence of the test in progress. (See figure 40.)

Figure 40. System Control Unit (SCU)

3. Remote Selector Indicator Unit. The Remote Selector Indicator Unit is a small portable unit, which is used in the identification and adjustment of Universal Measuring Adapter (UMA) channels. The RSIU contains two voltmeters; one indicates the actual voltage being received, and the other indicates the percent difference between the actual and the previously predicted voltages stored in the SDS-930 computer. Indicators on the RSIU light when the system is ready to receive the selection of the channel number and when the system is processing data. (See figure 41.)

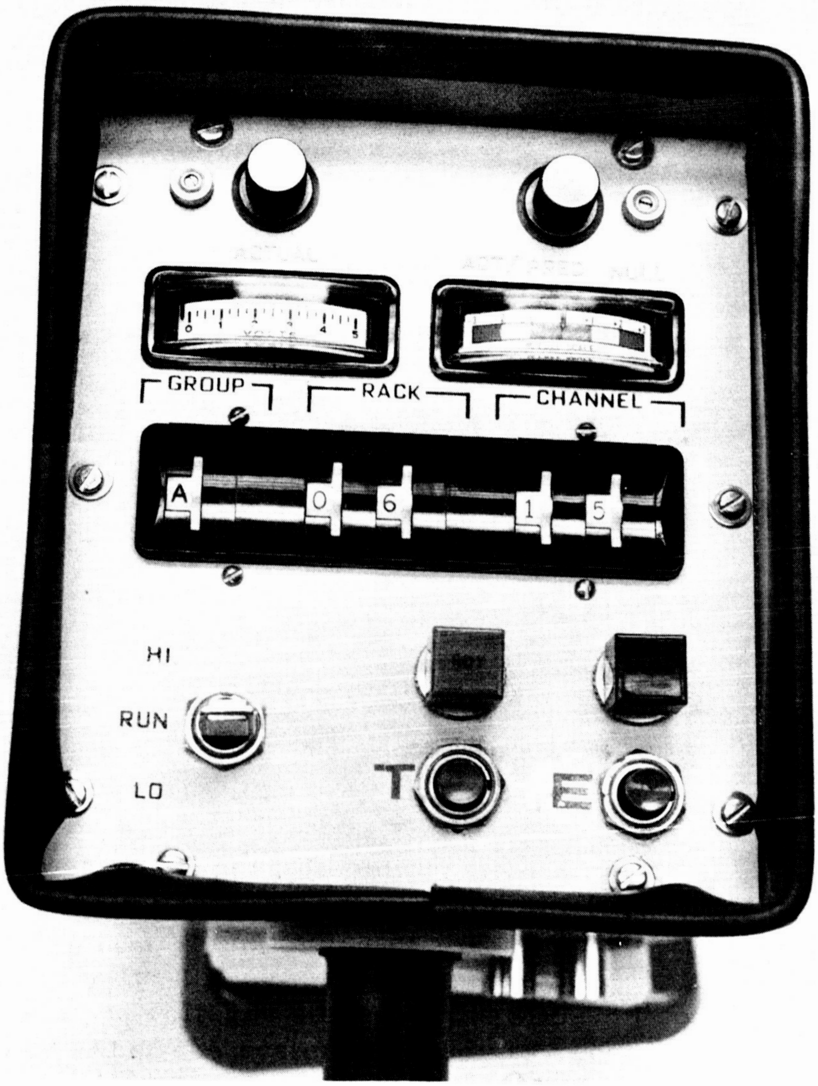

Figure 41. Remote Selector Indicator Unit (RSIU)

4. System Interface Equipment. The System Interface Equipment consists of an interface unit, an analog-to-digital converter, and power supplies.

a. Interface Unit. The interface unit contains the necessary logic to provide communications between the SDS-930 and external equipment other than the standard computer I/O devices. These communications include the following:

(1) Two-way data transfer between the SDS-930 computer and a Master Station (not in use at this time).

(2) Addressing and selecting a peripheral device.

(3) Accepting data from peripheral devices in digital or analog form for computer entry.

(4) Selection of racks and channels in the RACS.

(5) Accepting data from PCM ground stations for entry into the computer.

(6) Verifying synchronization information contained in PCM, TDS, DDAS and Simulator data, and notifying the computer of the sync status.

The interface unit also contains the logic required for control of operational programs and for display of system status on the SCI and the RSIU.

b. Analog to Digital Converter. The A/D converter accepts an analog input in three voltage ranges (± 5 volts, ± 15 volts, and ± 30 volts) and provides a binary output in parallel form. The output (12 bits plus a sign bit) is routed to the computer through the interface unit. Selection of the voltage range, as well as connection of the A/D converter to the computer,is accomplished by command from the computer through the interface unit.

B. HARDWARE SYSTEM THEORY

Two major components comprise the IDTS. These are the SDS-930 computer and the System Interface Unit. The theory of operation of the SDS-930 hardware will not be described in this text.

The System Interface Unit provides the following functions:

Logical Interface between the computer and the external data sources.

Two way communications between the computer and a master station (not used at present).

One-way communication from external data sources to the computer.

Verification of frame and master frame sync patterns in PCM, TDS, and DDAS data input.

Encoding of control words from the SCU and RSIU to the computer.

Decoding of addresses, instructions, and status requests from computer.

1. System Interface Unit. The System Interface Unit provides the required communication paths for data transfer into and out of the computer, and the control lines that enable the computer to control the traffic flow. A System Control Unit facilitates operation of the system, and the RSIU permits operation and observation of results during operation of the channel ID and UMA Adjust programs. (See figure 42.)

During operation of a program, data flow is from a ground station (DDAS, TDS, or PCM) to the C-register of the SDS-930 computer. Input gates are enabled by EOM commands originating in the C-register of the computer and decoded by the EOM/SKS decoder. OR gates combine the data flow from a ground station with the parallel data input (24 bit), and the digitized analog data input. Level shifts are provided at the input and output of the C-register.

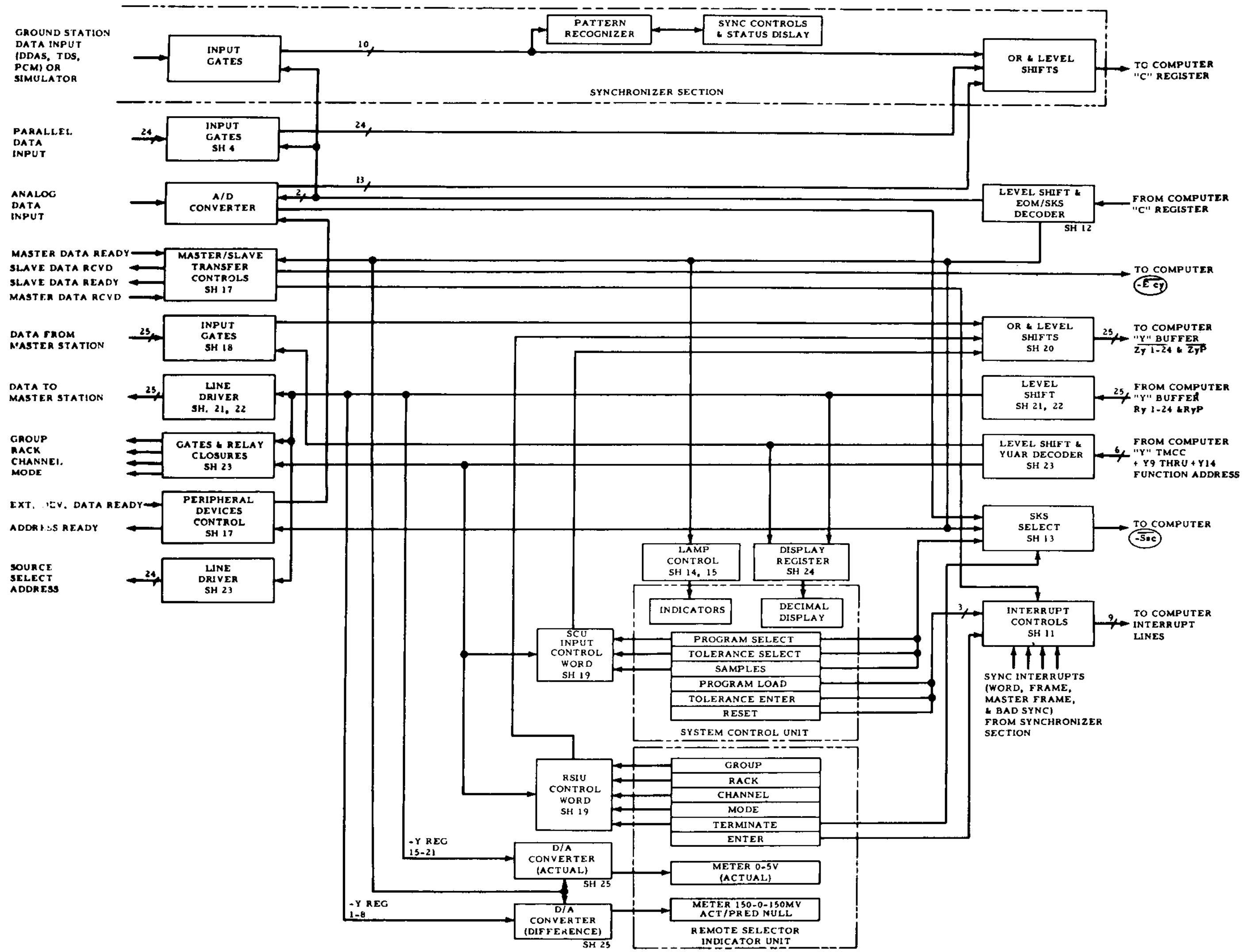

Figure 42. System Interface Unit Block Diagram

Data transfer between the Master Station and the computer takes place via the Y-buffer, and is controlled by the master/slave transfer controls. Data from the Master Station is gated into the System Interface Unit, OR gated with the SCU and RSIU control words, and sent to the computer Y-buffer through level shifts. Data from the Y-buffer is level shifted and sent to the Master Station through line drivers.

The six Unit Address Code bits (± Y9 thru ± Y14) from the Y - Time - Multiplexed - Communications - Channel (TMCC) of the computer are level shifted and decoded to select the inputs to the Y-buffer and to address specific data channels for transmission of calibration modes from the Y-buffer.

The decoded SKS address from the computer C-register, combined with signals from the external devices or the SCU or RSIU switch setting, generate the signals necessary for status indications to the computer.

2. Block Diagram Description. The two primary paths of communications with the computer are by way of the C-register and the Y-buffer. In the input mode, the C-register accepts data from one of the selected data sources. In the output mode, it is connected to an EOM/SKS decoder for initializing conditions within the system through EOM commands and for testing various functions and conditions throughout the system with SKS commands.

The Y-buffer is used for the transfer of data between the computer and the Master Station and for the exchange of information between the computer and IDTS peripheral equipment. The Y-buffer contains a unit-address register which selects the particular peripheral device with which data transfer will be carried on. The Y-buffer also contains a 24-bit parallel register (Word Assembly Register) which is used for the transfer of data between the computer and the peripheral equipment selected by the Y-unit address register.

Selection of a data source for processing is accomplished by an EOM command from the computer. When the proper EOM command is placed into the C-register, it is decoded by the Interface Unit, which gates one of the external data sources into the Interface Unit to be subsequently gated into the C-register. If the selected data source is a telemetry ground station (DDAS, TDS, or PCM) or a simulator, the data is routed through a sync pattern recognizer circuit. The pattern recognizer circuit has the capability of recognizing both frame and master frame sync patterns. Frame sync, master frame sync, as well as lead sync indications are sent to the computer on interrupt lines.

A RACS unit is selected by the Y-buffer. An EOM command initially alerts the Y-buffer, and a second computer command places the information for transfer to the RACS unit into the Y-buffer register. The outputs of the Y-buffer are routed through the Interface Unit to relay contacts, and place appropriate voltages on the RACS Rack and Channel Select Lines.

Source Select Address Lines are used to select a channel of a peripheral device. When the peripheral device has been selected, and data is ready, the data ready signal is routed through the Interface Unit to provide an SKS status signal to the computer.

Master-slave data transfer is controlled in a similar manner; however, the master ready signal, received from the Master Station, generates an interrupt signal to the computer. This interrupt signal causes the computer to go into a routine which affects the data transfer.

The System Control Unit provides program control. It provides the operator with a means of selecting programs and setting up the program parameters such as tolerance, calibration, etc.

The RSIU contains rack and channel select switches as well as a mode select switch. These are used to request data from individual channels when the system is processing data from one of the PCM sources. Data values are converted to analog voltages and displayed on voltmeters on the RSIU panel.

C. SOFTWARE SYSTEM THEORY

The software description has been classified into two groups, support and test software.

1. Support Software. Support software is defined as that software required to develop the necessary data and magnetic tapes for the operation of the system as it was designed to perform.

The two support programs to be discussed are the System Magnetic Tape Generator and the Predicted Value Update Routine.

a. System Magnetic Tape Generator. During an operational run of a program, the predicted values, and system programs are stored on magnetic tape. The first file on the tape contains the predicted values. The predicted value file is a one-record-per-card copy of the predicted values deck. Each card contains a time slot identification (rack and channel), the predicted values for the various calibration modes, a time slot number and the rack and channel code.

The system magnetic tape generator routine adds four more files to the magnetic tape. These are: the program file, the rack and channel map, the time slot file and the update file. The routine causes the computer to first locate the end of the predicted values file, then it writes a direct binary copy of the program paper-tape that contains the operational programs.

When the program file has been recorded, the magnetic tape is rewound, and the computer reads through the predicted values file. The predicted values are converted to counts and stored in cells, corresponding to time slot numbers, of time slot images. Each time slot image contains 1,800 cells, and there is one time slot image for each calibration mode.

Similarly the computer prepares the rack and channel map. The rack and channel codes (from the predicted values file) are stored in the cells of the rack and channel map according to the time slot numbers. The rack and channel map is an 18,000 word table specifying the rack and channel code for each time slot.

When the end of the predicted values file has been reached, the magnetic tape is advanced to the end of the program file and then the computer writes the rack and channel map file followed by the time slot file. At the end of the time slot file, an extra end-of-file mark is recorded to mark the location of the update file. At this point, the magnetic tape is rewound to the load point, the I/O typewriter prints a tape generation completed message and the computer halts, ready for operation.

b. Predicted Value Update Routine. The predicted value update routine provides the operator with facilities to call up for display the current predicted value for any time slot, and to make changes in the predicted values.

The number of changes that may be made is limited by the size of the update table (1,800 words); however, since only one change is stored per word, no practical limit on the number of changes exists.

If a large number of changes in the predicted values are required, it would be more practical to generate a new magnetic tape.

The predicted value update routine may be selected by selecting program 08 and operating the PROG LOAD switch. The program is loaded into memory and shifts to the program.

The program reads the time slot file and the update record into the core. The current predicted value may be called up for display by the operator by typing the calibration mode, (H, L or R) the time slot number, and the command "D" (for display) on the I/O typewriter.

To change a predicted value, the operator types the calibration mode (H, L, or R), time slot number, the command "E" (for enter), and the new predicted value.

The change is made in both the update record and the time slot images.

When the operator types the letter "T" (terminate), the computer rewrites the time slot file and the update file on the magnetic tape, using the modified time slot images and update record.

Upon completion, the I/O typewriter prints a message to the operator that the update program is completed.

2. Test Software. Test software is defined as those programs which actually cause the computer to perform the testing operations. Thirteen test routines will be briefly described.

a. DDAS versus Predicted. The DDAS versus Predicted Program compares incoming data values from the DDAS with predicted values and checks whether the incoming values are within tolerance. The program may be run in any one of five calibration modes (0.00, 1.25, 2.50, 3.75, or 5.00 volts).

b. UMA Scan versus Predicted. The UMA Scan versus Predicted Program compares incoming data values from the DDAS with predicted values and checks whether the incoming values are within tolerance. The program may be run in any one of three calibration modes (HI, LO, or RUN).

NOTE: The UMA Scan Revision Program reads in tolerances from cards so that each measurement may have its own tolerance.

c. UMA Adjust versus Predicted. The UMA Adjust versus Predicted Program may be used for calibration purposes. It allows adjustment of measurements on vehicle to a null compared to predicted data in any one of the three calibration modes, (HI, LO, or RUN).

d. Channel I.D. versus Predicted. This program is used for quick identification of vehicle transducers by operator selection of a channel, observing the display on the meters and manually applying stimuli to the transducer. If a change in the observed channel is noted, the operator is assured that the channel assignment for that transducer is correct.

e. DDAS versus TDS versus Predicted. The DDAS versus TDS versus Predicted Program compares incoming data values from the DDAS and TDS with predicted values and checks whether the incoming values are within tolerances. Then it also compares the values received from the DDAS with those received from the TDS and checks whether the differences (if any) are within tolerance.

f. DDAS versus PCM versus Predicted. The DDAS versus PCM versus Predicted program is identical to the DDAS versus TDS versus Predicted program except that the TDS data source is replaced by the PCM data source.

g. PCM versus TDS versus Predicted. The PCM versus TDS versus Predicted is identical to the DDAS versus TDS versus Predicted Program, except that data sources are PCM and TDS instead of DDAS and TDS.

h. Quick Look PCM Scan. This program is similar to the UMA Scan. The printout contains only selected measurements. It scans, averages, compares to predicted value, and prints particular PCM measurements requested via the teletype.

i. PAM Telemetry versus Predicted. This program is similar to DDAS versus Predicted. At present, the necessary hardware is not available to run this program.

NOTE: All of the above programs use common data input formats.

j. PCM Display. This is a program to scan a particular PCM measurement input via the teletype and display the actual reading or the difference between the actual and the predicted.

k. Automatic Calibration Technique. This technique takes the hi cal and lo cal for both the predicted and measured values and computes the run values for both. Then, computes the correction required by drift (assuming drift to be linear).

m. Noise Analysis. Determines the amount of noise and peak noise levels on PCM.

n. Servo Loop Analysis. This program selects in turn each of three gyro loops and three accelerometer loops on the stable platform; sends a command to reset the real-time clock and shock the platform, gathers on magnetic tape 6000 time readings and 6000 voltage readings for each loop.

NOTE: The UMA Scan, DDAS versus TDS versus Predicted, DDAS versus PCM versus Predicted, and PCM versus TDS versus Predicted programs are all contained in one package.

D. SYSTEMS EVALUATION

The IDTS has been used in support of several mainstream Saturn programs. PCM data tapes that have been recorded during various test and checkout operations have been read back through the DDAS ground station for analysis. The programs written for IDTS to do this were developed around the Saturn telemetry design and allows the PCM tapes from most any Saturn stage to be analyzed. Examples include North American Aviation tapes, IBM Instrument Unit tapes, and Chrysler S-IB tapes.

An RF (coaxial) link between the Quality and Reliability Assurance Laboratory and the Test Laboratory enables the IDTS to be used in support of the S-IB static firings. In addition, the IDTS has been used in support of the in-house S-IC checkout operations.

The station has been used in analyzing the effects on data accuracy due to reduction or removal of power from the ground station; training of personnel, support of DEE-3 program development, and research and development projects of the Quality and Reliability Assurance Laboratory.

One purpose for the development of the IDTS was to have the facility as an example of the extent that automation can be used in the telemetry area. IDTS can be invaluable in developing new techniques in this area of technology and can be used as a design guideline in developing systems for future Saturn type programs.

The IDTS hardware has been reliable and has encountered little downtime due to hardware failure.

SECTION XII. SATURN V, S-IC CHECKOUT SYSTEM (RCA-110A)

It was a policy that all testing possible would be automated on the Saturn V, S-IC stage and the RCA-110A computer was selected to control the automated operations. The selection of the RCA-110A computer (figure 43) was the subject of long and often clouded discussions and studies. Some clarification of this selection must be given at this point. It was the decision of MSFC to use the RCA-110A for checkout of the S-IC since the same computer would be used as the launch computer at Kennedy Space Center. This was based on the fact that the active components of the Saturn V at the time of launch would be the S-IC stage and the Instrument Unit. Thus, it seemed logical that the computer used in the launch activities also be used in factory checkout of the same components. Since the other stages of the Saturn V were not to be active at the time of launch, the computer used for factory checkout of those stages could be other than the RCA-110A. In the cases of Douglas and North American (contractors for the upper stages of the Saturn V) the Control Data Corporation's CDC-924A computer was used in factory checkout.

Only the hardware and software system for the S-IC checkout will be described here. A similar hardware system was used in this Laboratory for checkout of the Saturn V S-IU-500FS Instrument Unit; the software system used in 500FS checkout was similar to that used by the International Business Machines Corporation in checkout of the uprated Saturn I Instrument Units.

A. GENERAL DESCRIPTION

Figure 44 is a block diagram illustrating the RCA-110A computer and peripheral equipment, and its relationship with the ground support equipment. Discrete input-output and analog input-output equipment was purchased as an integral part of the RCA-110A system. This interface equipment, along with the DDAS channel, provides communications from the RCA-110A proper through a distribution system to other ground support equipment and the stage. A display console is located in the test conductor's area and provides for the display of error messages, test results, critical measurements, and provides for remote inquiry and response to the checkout computer.

Figure 43. RCA-110A Computer System

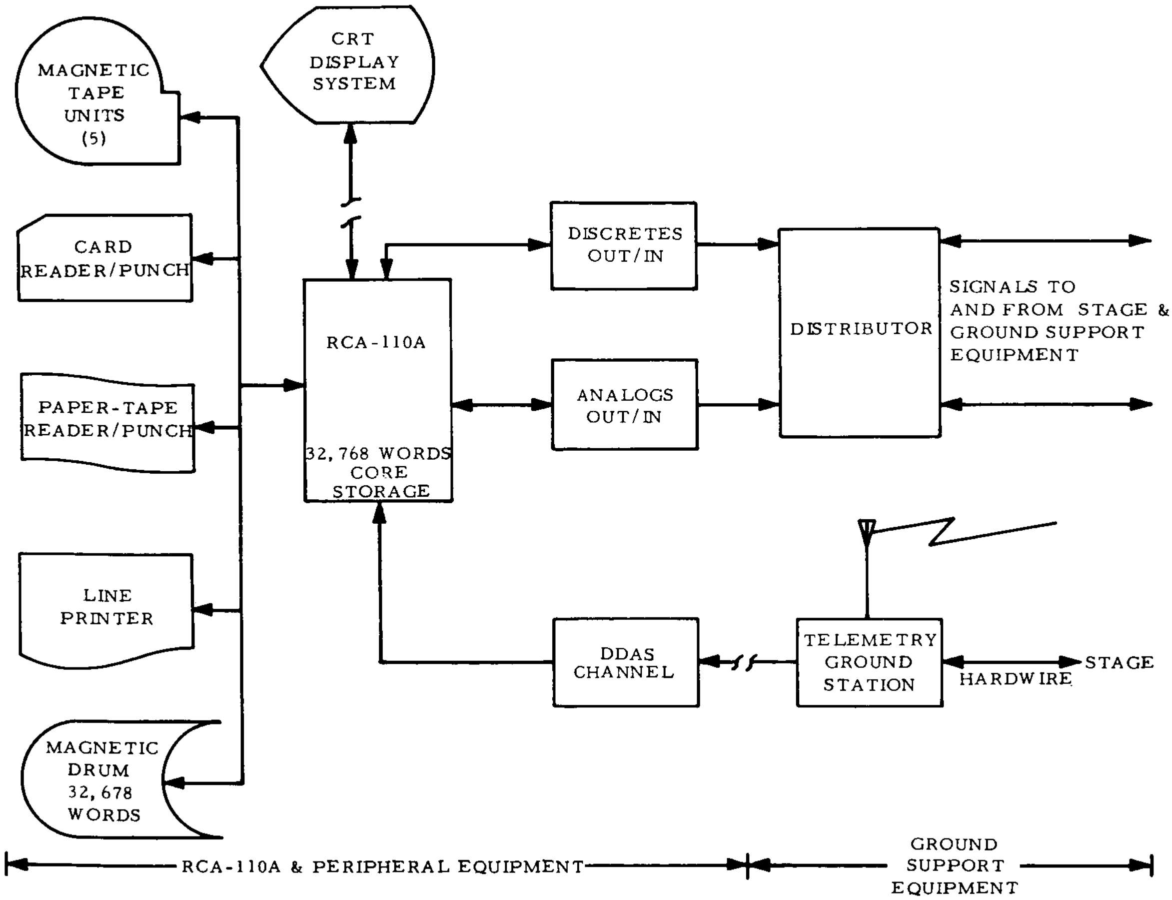

Figure 44. RCA-110A Computer System Block Diagram

B. HARDWARE SYSTEM THEORY

The computer is a solid state serial machine with the following characteristics:

1. 24-bit word plus parity
2. 936 kc clock rate
3. 28.9 microseconds word time
4. Fixed point, two's complement binary arithmetic
5. Add time: 57.7 microseconds
6. Multiply time: 779 microseconds
7. Random access core memory: 4,096 to 32,768 words
8. 121 instruction repertoire
9. 6 index registers
10. Indirect addressing
11. 4 priority interrupt levels: 2 programs per level
12. Multiple I/O block transfers simultaneously with normal processing

The computer has a priority interrupt system consisting of four priority levels, each level being capable of serving two different programs on separate interrupt lines. Upon receipt of an interrupt, the computer stores all current program parameters necessary for later return-after-interrupt. Priority interrupt inhibit and activate instructions are available for protecting critical program segments.

An important part of the RCA-110A system is the cathode-ray display unit (figure 45). The display unit provides for the communications between the test engineer and the RCA-110A computer. The display unit was designed by the Boeing Company and built by the Raytheon Corporation and is, therefore known as the Boeing-Raytheon Display System. The system is a random access display and character/vector generator driven by the computer.

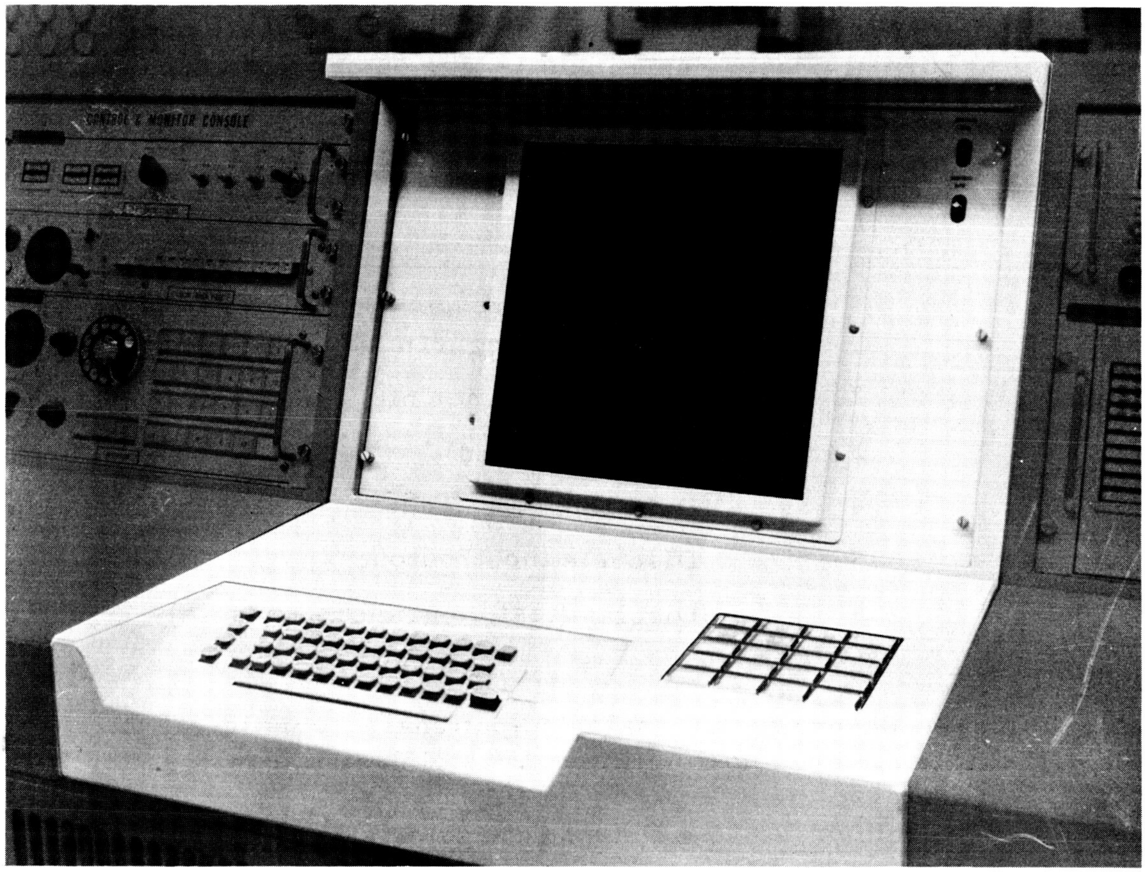

Figure 45. Cathode-Ray Display Unit

The system consists of two units: a control and monitor console which includes the cathode-ray tube display, keyboard, and control assembly and the auxiliary equipment unit which includes the computer interface, core storage, character/vector generator, and program control unit.

The display has a viewing area 12 inches by 12 inches and the capability of displaying three sizes of characters at two levels of brightness. The screen has a capacity of 64 characters per line and 63 lines. The symbol size and brightness level combination can be intermixed.

The information to be displayed may be entered on a keyboard or transmitted to the display from the computer. This information is stored in a 4096 core memory located in the display system. To insure uniform appearance of the displayed message, the message is automatically refreshed periodically.

Six Input-Output Data Channels (IODC's) provide simultaneous, independent input-output operations. These channels have direct access to the computer memory and once activated, carry out their operations in parallel to normal processing within the computer. The IODC's are assigned as shown in table 5.

Table 5. IODC Assignments

IODC Number	Equipment
1	Paper-tape reader/punch, 3 magnetic tape units magnetic drum
2	2 magnetic tape units line printer
3	DDAS (not used)
4	Data link (not used)
5	Discrete input/output
6	Display (test conductors console)

Table 6 describes the analog output characteristics of the system. All converters and amplifiers are solid-state construction.

Table 6. Analog Output Characteristics

Voltage Range	Output Lines	Self-Check Lines	Volts Resolution	± Volts Accuracy	± Percent Accuracy (Full Scale)
0 to ± 5 vdc	12	2	0.005	0.025	0.5
0 to ± 10 vdc	12	2	0.010	0.050	0.5
0 to ± 15 vdc	12	2	0.015	0.075	0.5
0 to ± 35 vdc	12	2	0.035	0.175	0.5
0 to ± 100 vdc	12	2	0.100	0.500	0.5
0 to 30 vrms, 400 cps	12	1	0.030	0.150*	0.5*

* Relative to user supplied reference

Table 7 describes the analog input characteristics of the system. All multiplexers and converters are of solid-state construction. The maximum dc selection, conversion, and processing is at an input rate of 8,700 lines per second. The maximum ac selection, conversion, and processing is at an input rate of 90 lines per second.

Table 7. Analog Input Characteristics

	Input Lines	Self-Check Lines	Input Impedance (Ohms)	Conversion Accuracy (%)
0 to ± 10 vdc	228	4	1 meg	0.2
0 to ± 30 vdc	20	2	100 k	0.2
0 to ± 60 vdc	12	2	100 k	0.2
0 to ± 100 vdc	12	2	100 k	0.5
0 to 30 vrms, 400 cps	12	1	100 k	0.5
0 to 150 vrms, 400 cps	12	1	100 k	0.5
0 to 150 vrms, 60 cps	12	1	100 k	0,5

Peripheral equipment for the RCA-110A system is shown in table 8.

Table 8. Peripheral Equipment

Component	Speed or Other
(5) Magnetic tape units	15 kc, 75 inches per second
Magnetic drum	32,678 words
Paper-tape reader	400 characters per second
Paper-tape punch	150 characters per second
Card reader	800 cards per minute
Card punch	450 cards per minute
Line printer	1000 lines per minute
Cathode ray display	
Keyboard (inquiry device)	

C. SOFTWARE SYSTEM THEORY

1. General. The software for the RCA-110A was developed by the Boeing Company under contract to MSFC. The software operation was under the control of an executive routine called the Boeing ATOLL Operating System.

The purpose of the Boeing ATOLL Operating System is to provide the means by which computer code developed from translated ATOLL Test Procedures (supplemented as needed by programmer written assembly code) may be executed on the RCA-110A computer. Additionally, the Operating System provides for the man-machine interface necessary to allow on-line decision making and control necessary for automatic checkout.

The Boeing ATOLL Operating System provides the capabilities described in the following paragraphs.

a. Centralized Information Input/Output. The Operating System utilized the RCA-110A computer equipped with line printer, card reader, card punch, five magnetic tape stations, and magnetic drum.

Through the computer the Operating System interfaces with the Eastern Standard Clock, Test Step Indicators, the Digital Events Evaluator and the CRT Display System.

Input/Output with these devices is accomplished by use of a centralized Input/Output (I/O) processing system called IOPS. IOPS is a system of subroutines entered by macro-generated calling sequences. The 196 IOPS macro definitions are provided as part of the CHAPS II assembly program. Entrances to the IOPS subroutines are identified by SYN cards.

b. Control of Test Procedure Execution. Control of Test Procedure execution is monitored by a series of routines which are executed as the test progresses.

c. Mechanics for Stimulating and Sensing External Devices, Evaluating External Device Responses, Internal Procedure Control, and Performing Utility Functions. ATOLL Test Procedure Statements of the stimuli, response, and utility types are serviced by the ATOLL Processor Subsystem. The ATOLL Processor Subsystem also takes action on priority interrupt requests.

d. Modification of Test Procedures. Modification of Test Procedures execution is provided at appropriate points within the control routines. The ability to make modifications is offered the Test Conductor on the following occasions:

(1) Immediately after entering the precedence list

(2) At any of the hold points

(3) Through use of the SEMI statements in the Test Procedure

(4) As a result of a no-go entrance to the FALT routine.

If the Test Conductor has occasion to modify the Test Procedure, it is done by selecting an option from the list provided by the Option Selection Routine, XOPS. The modification is then performed by the selected option routine and control is returned to the appropriate point in the Test Procedure or the Operating System.

e. Record of Sufficient Detail to Permit Complete Posttest Evaluation. The Operating System generates records of test actions and test results which, with supplementary information, are sufficient to reconstruct the test. These records are generated in several different ways:

(1) On-line printout of any data which is pertinent to the conduct of the Test Procedure.

(2) Event Trail data on magnetic tape consisting of detailed entries to external stimuli and responses as well as test conductor control actions.

(3) Historical Displays which are snapshots made, on Test Conductor option, of the contents of the CRT display screen. Storage is on magnetic tape.

(4) Instrumentation Data Output Generated on magnetic tape by Telemetry Test Procedures.

(5) Data supplied by the Operating System to the Digital Events Evaluator.

2. Program Construction and Usage.

a. Operating System Loading. The Boeing ATOLL Operating System is provided on magnetic tape. The tape is loaded from tape station 1, IODC 1, into computer core and onto drum. The routine that accomplishes this is Magtape to Drum Routine, M2DM.

The Magtape to Drum Routine may be obtained by clearing core and activating the load tape switch with the Operating System tape properly mounted on Station 1, IODCI. Beginning execution at location 02501 will activate M2DM to complete the loading process.

Appendix B contains a portrayal of the Operating System tape formats and a summary of their tape station assignments. Appendix C contains a map of the contents of RCA-110A computer core, as well as an RCA-110A magnetic drum map.

b. Centralized System Control. Centralized control of Operating System operation is provided by several routines stored in computer banks 0 and 1. BLAP is maintained in core to load CHAP II output tapes and routines stored on the Operating System Tape. The Event Trail Control Routine relays event trail data from the point of generation through a buffer and onto the Event Trail Tape. Table Look-Up retrieves routines from the drum for buffered execution in bank 0. Table Look-Up also initiates searches for routines stored on the Operating System Tape. IOPS, Input/Output Processing System, provides centralized I/O capabilities with the RCA peripheral equipment. DIOPS, Display Input Output/Processing System handles all communications with the Boeing-Raytheon CRT display hardware.

c. Test Procedure Execution. After loading has been accomplished, the Identification Routine is automatically executed. The Identification Routine, IDEN, is the Test Conductors tool used to ascertain the correct magnetic tapes have been mounted as inputs.

The Enter Precedence List Routine (EPLR) obtains and displays Test Procedure Tape identification from the tape mounted on station 3, IODCI. EPLR also displays the contents of this tape in the form of a tape directory consisting of from 1 to 150 Test Procedure names. See appendix A for tape format. The Test Conductor may select a sequence of Test Procedures which will make up the execution Precedence List. Any combination of from 1 to 49 Test Procedure names may be submitted.

Automatic execution of the Test Procedures as called by the Precedence List will normally begin at this point; this is opposed to semiautomatic execution which will be described later. Each Test Procedure is individually loaded by Read Test Program Routine, RTPR. Loading is accomplished by locating the file containing the required Test Procedure and loading each even numbered record as specified by the contents of the preceding odd numbered record. Thus, loading is completely controlled by data supplied by BATS.

After the Test Procedure is successfully loaded by RTPR, Beginning of Execution Routine is called. BOEX located the actual Procedure starting point by referencing the loader symbol and block tables supplied with the procedure. BOEX also ascertains that GSE power is applied to the complex and that the required Ground Support Equipment is in automatic mode. Opportunity is provided to reduce the GSE requirements at this point.

Automatic execution will continue past various milestones through to shutdown and end of execution. As each new test block is encountered, a calling sequence in the Test Procedure is executed which calls the BOTB, Beginning of Test Block Routine into core from drum. BOTB, during automatic mode of execution, simply updates the block number displayed and sends appropriate data to the Event Trail and the DEE. Test Steps are the result of BOTS statement generated calling sequence in the Test Procedure. The Beginning of Test Step Routine, BOTS, is kept as a permanent resident of bank 0 in order to optimize its execution time. Like BOTB, BOTS only updated its displayed step numbers and makes appropriate historical records during automatic execution.

After arriving at shutdown, a calling sequence in the Test Procedure causes the Beginning of Shutdown Routine, BSDN, to be executed. At this point the Test Conductor is quizzed as to whether shutdown is desired or whether semiautomatic mode should begin. The Test Procedure will execute until the END statement is reached following depression of the shutdown button. The END statement will call the End of Execution Routine, EOEX, which completes the bookkeeping for that procedure and returns to Read Test Program in preparation for loading the next procedure.

The semiautomatic mode of execution is the execution mode which allows the Test Conductor to modify the execution of the Test Procedure. Semiautomatic mode is allowed on the four occasions listed earlier under Method i.e., semiautomatic mode is provided automatically after entering the precedence list, upon reaching the BSDN statement, upon reaching a SEMI statement, and whenever a no-go occurs. The Test Conductor can further control the mode by depressing the suspend summary button or by use of Set-Up Option.

d. Options. Execution in semiautomatic mode is begun with the Option Selection Routine, XOPS. This routine determines what options are available at the current hold point and provides the Test Conductor a means of selection. After the desired option has been selected, XOPS retrieves the requested routine from drum. The options which are available at each hold point are as specified in appendix D.

A brief description of each option is given in the following:

Execute Option (EXCO). Provides for resumption of execution in automatic mode.

Program Shutdown (PGSD). Provides a jump from the current hold point to the BSDN statement.

Set-Up Option (STUP). Causes the current Test Procedure to enter semiautomatic mode at predetermined hold points which are set up by the Test Conductor.

Override and Clear Option (OACO). Allows the Test Conductor to substitute, at a scan no-go, the actual discrete input profile for the predicted discrete input profile following a scan no-go.

Limited Scan Option (LMSO). Limits the halting at scan no-go's erroneous discrete inputs to only those which are specified by DISI statements which follow initialization of the limited scar. The option also allows limited scan to be discontinued.

Test Step Recycle Option (TSRC). Allows the Test Conductor to reexecute the last step executed.

Critical Scar Option (CRSZ). Allows the Test Conductor to specify individual discrete inputs or groups of discrete inputs as being noncritical under subsequent evaluation by SCAN statements.

Skip Forward Option (ADVO). Allows the Test Conductor to skip from the beginning of any Test Block to the beginning of any succeeding Test Block.

Skip Backward Option (BSTO). Allows the Test Conductor to skip from the Beginning of Shutdown or any Test Block to the beginning of any previous Test Block.

Sub-Step Recycle Option (SSRC). Allows the Test Conductor to repeat the last executed Sub-step.

Sequencing Option (SEQL). Gives the Test Conductor the capability of modifying or completely replacing the Precedence List.

Test Step/Substep - Delete/Restore (TSDR). Permits the Test Conductor to omit undesirable Test Steps or Substeps. The option also provides for their reinstallment.

Transfer to Manual Mode (TMMO). Will check the Ground Support Equipment Manual/Auto busses and, if found to be in manual mode, will give the Test Conductor the ability to go to the END statement. If the busses are found to be partly or wholly in automatic mode, the Test Conductor may recheck or return to Option Selection Routine.

Parameter Manipulation (PRB1, PRB2, PNO%, and PBAR). Allows the Test Conductor to change Test Procedure data generated by an ATOLL TABL statement in fixed or bloating point format.

Display Option (DSPO). Gives the Test Conductor access to any of five CRT display oriented options. The five options are listed next.

Historical Tape Manipulation Option (HTMO). Is entered by TMAN and permits a Historical Display Tape to be remounted.

3. Utility Routines. Utility routines are available for Operating System debugging and construction. They are available without restriction after Operating System loading or during Semiautomatic Mode at any hold point. Computer sense switch 6, when depressed, initiates the Utility Selector Routine, UTLM. The programmer may select from the nine utility routines displayed or return to point of departure by deactivating sense switch 6.

The utility routines are stored on the Operating System tape and are accessible through use of UTLM. The nine routines which are available are:

Add Routine (ADDM). Is the means by which buffered Operating System Routines are initially loaded from CHAPS II output tapes onto RCA-110A drum.

Delete Routine (DELM). Is the means by which buffered Operating System Routines are striken from RCA-110A drum.

Drum Change Routine (DRCM). Allows the programmer to alter a specific location or program on RCA-110A drum.

Drum To Magnetic Tape Routine (D2MM). Generates Operating System Tapes from the contents of RCA-110A computer.

Magtape to Drum Routine (M2DM). Loads the contents of Operating System Tape into the RCA-110A computer.

Drum Table List (DTLM). Provides printed listing relating buffered assignment on RCA-110A drum.

Sub-Routine Merge (SUBM). Brings together the ATOLL Processor Subsystem of the Operating System with the monitor portion of the Operating System.

Core Dump Routine (CRDM). Allows the contents of any portion of RCA-110A core to be listed in an octal or mnemonic format.

Drum Dump Routine (DRDZ). Allows the contents of any portion of RCA-110A drum to be dumped in octal format.

4. Restrictions. There may be occasions when the Operating System is unable to proceed with Procedure Execution. This may occur because of computer hardware failure or improper inputs. If the problem is of such magnitude that the System cannot recover, a computer halt will occur. A list of Operating system halts is given on the following pages. The list includes the location of the halt, the routine in which the halt occurred, and a reference to other more detailed Operating System Documentation.

D. SYSTEMS EVALUATION

The ATOLL Operating System was not completely finished in the Laboratory. The inoperative portion is the command mode on which work is continuing at the Test Laboratory and Michoud. This mode allows the test engineers to execute ATOLL operators on-line and is an important part of the operating system program.

The software system experienced many changes during checkout operations. The software development began over 2 years in advance of its need and was impacted considerably by changes that occurred during that time in the computer and other hardware. This is understandable since the computer changed from the RCA-110 to the RCA-110A. The operating system was rewritten to be more efficient and conserve memory. The allocation of memory was a serious problem. The redesign reduced the requirements for magnetic tapes from five to three. This now allows the system to operate if a magnetic tape unit is out of order.

The operating system contains 20,000 instructions, not including temporary storage, buffer areas, etc. The relative speed of the system is 71.7 microseconds per instruction. For comparison purposes, the IBM operating system contains 16,700 instructions and has a relative speed of 72.71 microseconds per instruction.

The IBM-7094 and GE-235 computers were used for translating the ATOLL and SLAP 2 software for use on the RCA-110A. Using both support computer systems presented problems because of the differences between the IBM-7094 and GE-235 software systems. The GE-235 software system was developed in a short period of time because of the urgent need for the program. The IBM-7094 software system was developed over an 8 to 9 months longer period and included many update features that could not be included on the GE-235. It was not expedient to use the IBM-7094 because of the long turn around times and difficulty with establishing priority runs. The GE-235 on the other hand was under control of the Quality and Reliability Assurance Laboratory and the S-IC checkout operation had first priority on its use.

The test programs depended largely on a data tape generated at the Michoud Assembly Facility in New Orleans, Louisiana. Timely delivery of the data tape was not made and the result was numerous delays in checkout. In fact, telemetry testing had to be rescheduled several times because of bad data tapes. The organization and format of the data tapes were constantly under change and impacted the test programs.

Several hardware problems have caused considerable trouble in the system. These problems can be grouped as follows:

1. Parity errors caused by cracked solder joints and tantalum capacitor failures.
2. Failures of vacuum motors on the Ampex magnetic tape units.
3. Failures of the punch head on the Soraban card punch.
4. Temperature and grounding problems in the Librascope drum.
5. High voltage arcing in the Transval power supply.

SECTION XIII. ADVANCED TEST AND CHECKOUT METHODS EVALUATION DEVELOPMENT (ATCOMED) COMPUTER SYSTEM

At the time the Advanced Test and Checkout Methods Evaluation Development (ATCOMED) facility was being designed, automation was not being seriously considered to be a part. But, because of the increasing role of automation in the space program and the obvious advantages to be derived from the use of automation it was conceived that the DEE-3 with small modifications could be used as the control computer system and the Vehicle Test Station could be used as an interface in the ATCOMED. Since ATCOMED was to be used for developing new and unique testing methods and techniques, it was logical that it be used to advance the state of the art, where practical, in automation as well.

The use of the DEE-3 in the ATCOMED facility (figure 46.) illustrates the advantage of using general purpose computers for control of special purpose items. Not only is this approach economical from the point of the proposed use with the special purpose item, but also from the standpoint of salvage value of the computer from the items. By changing the program in the computer, it can become another special purpose piece of equipment and be used for other tasks to be performed in other areas.

A. GENERAL DESCRIPTION

The original hardware system included the DEE-3 and the modified Vehicle Test Station (VTS). The DEE-3 was modified to include 16,384 words of core memory, a line printer, a card reader, and a magnetic tape unit. Since the installation of the modified DEE-3 and VTS, a contract was awarded (June 2, 1966) to the Scientific Data Systems Corporation for the addition of other equipment. This additional equipment includes:

1. Pressure Select Control Register
2. Parallel Output Register Unit (4 registers, 24 bits)
3. Saturn Data Address Comparator Unit
4. Discrete Output Unit (2 output registers and associated relays)
5. Analog Output Unit

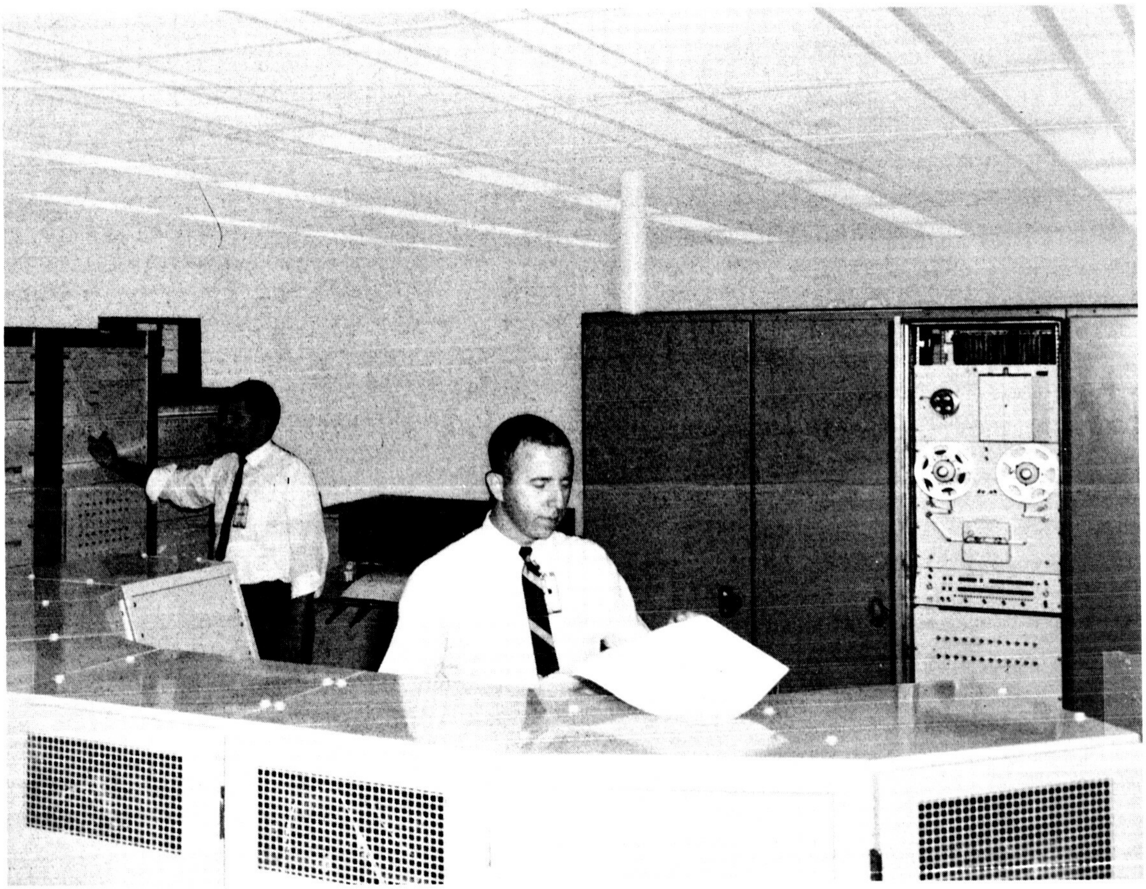

Figure 46. ATCOMED Facility

6. Parallel Input Register Unit (2 registers, 24 bits)
7. Saturn Data System, Data Input Unit
8. Analog Input Unit
9. Card Reader (400-cpm), SDS Model 9152 replaces SDS Model 9150
10. Two, 15-KC Magnetic Tape Unit, SDS Model 9146
11. Control and Monitor Console
12. Perceptoscope 24-bit parallel register

B. HARDWARE SYSTEM THEORY

The block diagram shown in figure 47 illustrates both the present and future system. Items marked with an asterisk "*" indicate those items under contract with a proposed installation date of March 1967. Major items of the system include the Computer and peripheral equipment, the Vehicle Test Station, and contracted items. The Computer and peripheral equipment have been discussed previously under Section V , "Digital Events Evaluator" and the Vehicle Test Station under Section III, Packard Bell Saturn Automatic Checkout System. A description of the contracted items follows.

1. Pressure Select Control Register. The pressure select control is a 24-bit parallel word which will be decoded by the pressure system. The data word will have logic levels of 0 and -6 volts and will be set into the pressure system by a pressure set strobe pulse. The register will have provision for detecting the pressure confirmation reply bit from the pressure generating system, and shall supply this bit for the SKS and priority interrupt input of the DEE-3. The pressure control word registers will receive inputs from any one of the four output registers.

2. Parallel Output Registers. Four 24-bit output registers will be provided to hold four 24-bit data words which will be routed to external devices. Output logic levels will be 0 and +8 volts. The registers shall have a SKS and Priority Interrupt into the DEE-3, indicating the acceptance of the 24-bit word by the external device. The four 24-bit output registers will have connections and space will be provided in the Register Racks for this modification, and for the inclusion of additional registers at a later date.

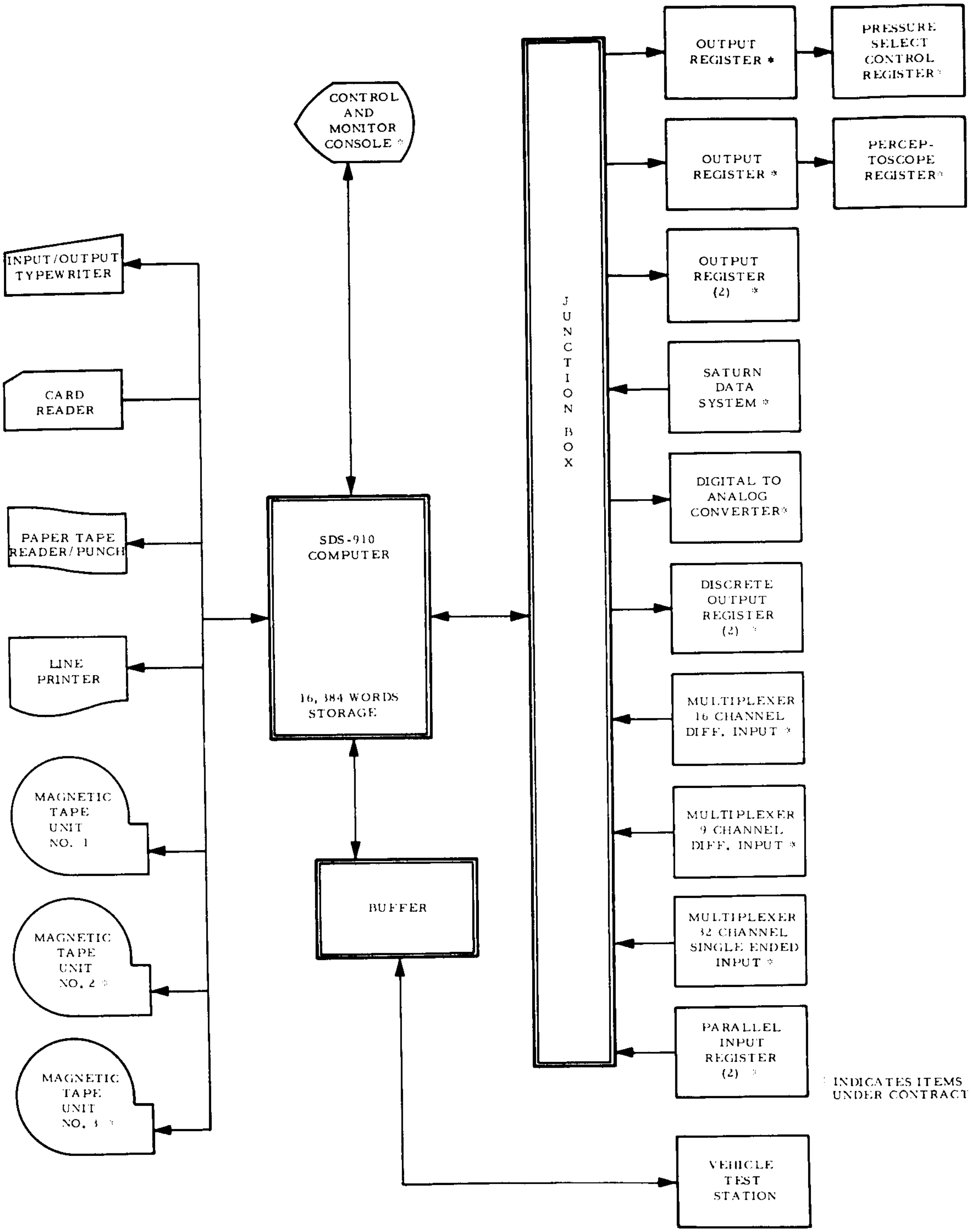

Figure 47. ATCOMED Automatic Checkout Complex

3. Saturn Data System Address Comparator Unit. When the system output address and the on-line data system address compare, a priority interrupt will be generated to cause the Saturn Data System Input Unit to input the on-line Data System word. Interface shall be compatible with the existing Saturn Data System. Ground Station, via a level Converter which will accept a 13 bit, 0 volt and -12 volt address.

4. Discrete Output Unit. A total of 512 discrete outputs will be provided in the system. All discrete lines shall be individually set and reset. The output flip-flops will be operated from remote 28 volts so that the status of the discrete output lines will not change if a system power failure occurs. The discrete outputs will have the following characteristics:

a. Two (2) groups (one group of 72 outputs and a second group of 440 outputs) will be solid state switches with an output of 0, or 28 vdc at 50 milliamperes.

b. 440 relays will be provided which can be driven from either discrete output register. The Relay Contacts shall be rated 28 vdc, 2 amperes resistive load.

5. Analog Output Unit. The system shall provide 12 analog outputs which will be under automatic control. When a given channel has been selected and set to an analog value, the analog value shall remain at its selected value until changed from the DEE-3.

6. Parallel Input Register Unit. Two 24-bit input registers shall be provided to hold two 24-bit input data words which will be received from external devices. Input logic levels shall be 0 and +8 volts. An input data strobe will set data into the input registers.

The two 24-bit input registers shall have provision for the addition of level correcting modules at a later date; spare connections and space shall be provided in the register racks for this modification. The registers shall have an SKS and Priority Interrupt into the DEE-3 which indicates that the external device is ready to send a 24-bit word.

7. Saturn Data System Input Unit. The system shall accept a 10-bit DDAS data word from the existing Saturn Data System Ground Station.

The input will be a 10 bit, 0 volt and -12 volt word. The Data Input Unit shall contain level conversion capabilities to make the word compatible with the DEE-3 system. A Priority Interrupt and SKS line shall be provided to the DEE-3 to indicate when data is ready to read.

8. Analog Input Unit. The system shall accept the following analog inputs in three groups:

a. Group 1. 16 dc Differential Analog Inputs as follows:

4 each, -1 to +1 vdc

4 each, -10 to +10 vdc

4 each, -50 to +150 vdc

4 each, -150 to +150 vdc

b. Group 2. 9 Low Level dc Differential Analog Inputs as follows:

9, 0 to ± 10 millivolts dc

c. Group 3. 32 Single-Ended AC Inputs as follows:

8 each, 0 to 1 vac

8 each, 0 to 10 vac

8 each, 0 to 50 vac

8 each, 0 to 150 vac

The input signals shall be normalized or amplified to +10 volts, multiplexed, and digitized.

The multiplexers shall be addressed under automatic control for proper channel selection for groups 1, 2, and 3.

9. Card Reader. The existing card reader SDS Model 9150 (100 cpm) will be replaced with a card reader SDS Model 9152 (400 cpm).

10. Magnetic Tape Unit. Two 15 kc Magnetic Tape Units (SDS Model 9146) will be added which will be controlled by the existing magnetic tape unit.

11. <u>Control and Monitor Console.</u> A console consisting of the following equipment which communicates with the DEE-3 will be added:

a. SDS Model 9158-01 Oscilloscope Display Coupler

b. SDS Model 9158-22 Character Generator

c. SDS Model 9158-31 Vector Generator

d. SDS Model 9185-11 Display Unit

e. Oscilloscope Display Rack

f. SDS Model SRE-10 Refresher Register

The control and monitor console will be a portion of the modified DEE-3 System. This console will be utilized by an operator to control the DEE-3 and will provide display and monitoring for various signals and functions generated in or received by the test station. The console will be designed to provide the maximum in man/machine efficiency with ease of operation the primary concern.

The control portion of this console will be designed to provide the operator with control capability of the entire system with no operator required at the DEE-3. Located in the control console will be a keyboard display unit which will permit the operator to send instruction messages or single character commands to the DEE-3. This system will provide an 80-character display such that a message of 80 characters in length can be assembled on the keyboard and visually verified by the operator. When a message has been verified to be correct, it can be transmitted to the DEE-3 at a very high rate and not at the standard keyboard printer rate of 15 characters per second. This system will also be used to receive verification of commands or messages from the DEE-3. The control console will also contain twelve (12) pushbutton switches which will be connected to priority interrupts in the DEE-3 to manually initiate signals such as: reset all D/A outputs to 0 volts, set all D/A outputs to +5 volts, reset all discrete outputs, set all discrete outputs, set all discrete outputs, etc.

The control and monitor console will contain a complete SDS oscilloscope display system with refresher memory. This system will operate under the control of the DEE-3 and will provide real time, on line displays of data received by the test station or it can be used to display historical data of measurements which have been recorded on magnetic tape. The display system provided will be complete with character generator and vector generator.

In addition to the oscilloscope display, the control and monitor console will contain 10 sets of display lights for displaying any input/output data word or internally generated word from the DEE-3. These display lights will be connected to individual holding registers which will in turn be connected to a B/BCD converter in the console. The display system will be under DEE-3 control such that the data of a given input measurement can be transferred to the B/BCD converter by the DEE-3 and set into one of the display registers by the EOM instruction. This display system will enable continuous updating of the decimal display of any given input or output register as well as the continual display updating of any input analog signals desired by the operator. A selection of the word to be displayed on any given displays will be controlled by the keyboard in the control and monitor console, and will be selected at the discretion of the operator controlling the system.

12. Perceptoscope Control. The perceptoscope control is a 24-bit word which will be decoded by the perceptoscope logic. The data word will have logic levels of 0 and -6 volts and will be set into the perceptoscope logic by a strobe pulse. The register will have provisions for detecting the film frame acquisition bit from the perceptoscope logic, and will supply this bit to the SKS and priority interrupt inputs of the DEE-3.

C. SOFTWARE SYSTEM THEORY

An Acceptance Test or Launch Language (ATOLL) program was developed for use by engineering personnel to develop test programs. Many test programs may be developed using ATOLL in a short period of time and corrections can be made easily. Other features of the ATCOMED ATOLL will be discussed later. Test programs that cannot be developed with ATOLL are written in the symbolic language SYMBOL or META-SYMBOL.

Because of the increased capability of ATCOMED by the contracted items, a completely new software system will be developed. This system has not been completely defined. It is anticipated that an ATOLL system will be used with a specially designed operating system to make use of the control and monitor console.

The present ATCOMED ATOLL system is a program composed of a translator and an execution routine. Figure 48 illustrates ATCOMED ATOLL functional operation. Test statements which have been keypunched onto cards are read in by the translator which formats the statement, checks for error, and unites the test statements onto a magnetic tape.

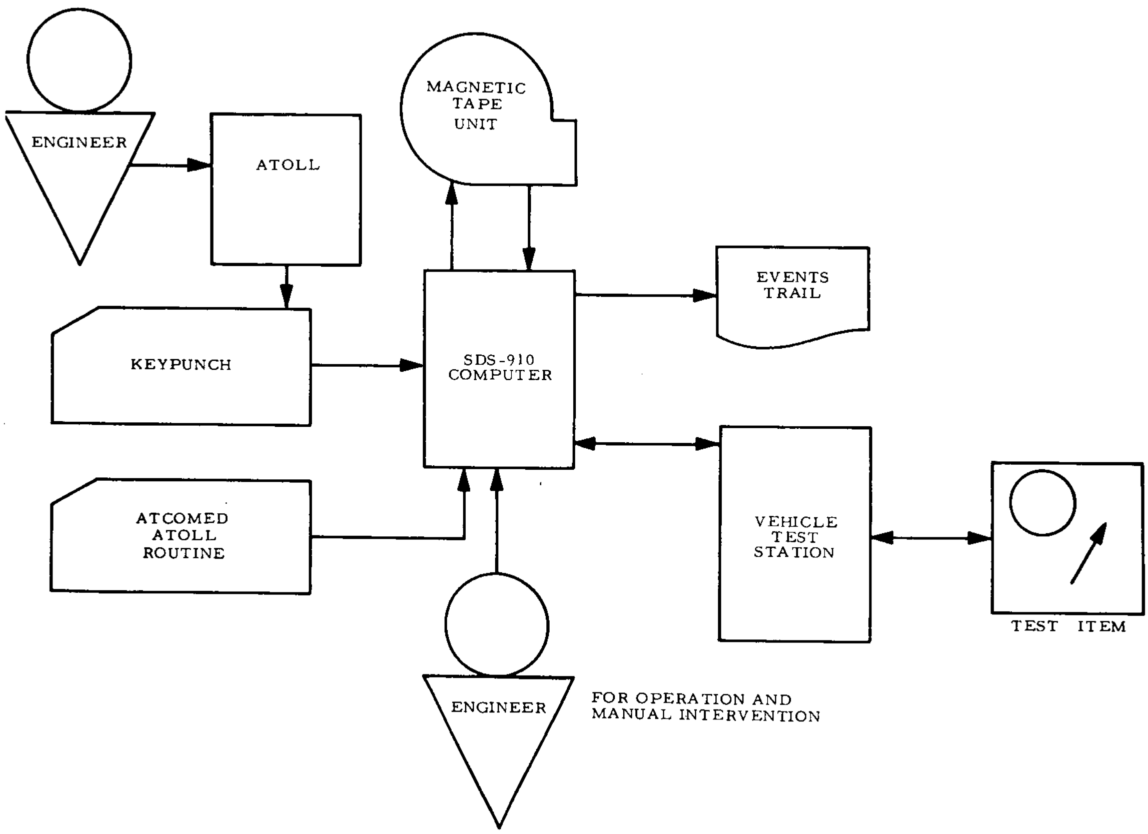

Figure 48. ATCOMED ATOLL Functional Operation

At the time of testing, the executive routine retrieves the test statements from the magnetic tape and executes each to perform the test.

Information may be entered into the computer through the typewriter keyboard in the same format as information on cards. Each field in the ATOLL statement must be separated by a tab character and the statement must be terminated by a dollar sign ($). If an error is made while entering a statement, the carriage return must be depressed and the correct statement typed.

Operators may be initiated by inserting the proper four-character code in the Operator Field of the ATOLL form. The class of these operators may be either Stimulation, Response, Control, or Utility. The definitions by classes are:

1. Simulation operators apply a stimulus to the device undergoing automatic checkout.

2. Response operators are used to verify a response or reaction from the device undergoing automatic checkout.

3. Control operators are used to time and/or control the logical flow of the automatic test statement sequence.

4. Utility operators are the remaining operators which do not fit clearly into one of the above classes.

Due to equipment restrictions of the present ATCOMED, only the operators listed below are implemented in this system:

ALOG	NAME
DELY	RAMP
DISI	READ
DISØ	SEMI
END	TEST
GØTØ	

During the execution of a test program an Events Trail is printed on the line printer. The Events Trail is a history of the test and is composed of the step number, substep number, operator and test results of each executed statement.

D. SYSTEMS EVALUATION

The ATCOMED ATOLL software has been completed and is operational on the DEE-3, Vehicle Test Station portion of the ATCOMED equipment. The software and hardware systems have not been used to an extent that would allow for a proper evaluation. The acquisition of new hardware makes it almost prohibitive to write additional software for the existing system because of its impending obsolescence. The software system for the new equipment is being designed and is expected to add significant capability to the ATCOMED facility.

REFERENCES

1. Funderburk, B. J., Quality and Reliability Assurance Laboratory, Programming for the Saturn I, S-I Stage Automatic Checkout System, NASA TMX-53082, July 10, 1964.

2. Funderburk, B. J., Quality and Reliability Assurance Laboratory, Report on Automation in Saturn I First Stage Checkout, NASA TMX-53 ,

3. Holmes, J. W., and Giddens, B. D., Quality and Reliability Assurance Laboratory, System Description of DEE-3, Digital Events Evaluator, December 2, 1963.

4. Ross, L. W., Quality and Reliability Assurance Laboratory, Instrumentation Data Test Station (IDTS) Software Survey, SR-QUAL-66-19, September 30, 1966.

5. Balentine, R. C., Quality and Reliability Assurance Laboratory, Automatic Checkout Computer Programming for the Saturn I Instrument Units, R-QUAL-PS-64-5, May 19, 1964.

March 16, 1967 NASA TM X-53590

APPROVAL

REPORT ON DIGITAL COMPUTERS USED IN AUTOMATIC CHECKOUT

By

B. Funderburk

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

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

B. J. Funderburk, Chief
Computer Systems Section

L. B. Hall, Jr., Chief
Vehicle Systems Integration Branch

for C. O. Brooks, Jr., Chief
Vehicle Systems Checkout Division

for Dieter Grau, Director
Quality and Reliability Assurance Laboratory

DISTRIBUTION

R-COMP-DIR, Dr. H. Hoelzer
Mr. C. Bradshaw
R-COMP-R, Mr. C. Hubbard
R-COMP-RD, Dr. H. Krenn
R-COMP-RDA, Mr. C. Cozelos
R-COMP-A, Mr. W. Fortenberry
R-COMP-AD, Mr. C. McGee
R-TO, Mr. L. Richard
Mr. C. Vedane
Mr. J. Turner
R-ASTR-E, Mr. H. Fichtner
R-ASTR-ND, Mr. F. Wojtalik
R-ASTR-BE, Mr. G. Barr
R-ASTR-ES, Mr. B. Aden
R-TEST-IE, Mr. W. Lide
R-QUAL-OT, Mr. C. Morrow
R-QUAL-P, Mr. C. Brooks
R-QUAL-PC, Mr. J. Batte
R-QUAL-PF, Mr. R. Kessler
R-QUAL-PI, Mr. H. Rushing
R-QUAL-PS, Mr. L. Hall
R-QUAL-PSC, Mr. C. Balentine
Mr. B. Funderburk (25)
R-QUAL-OCP, Mr. Krone (3)

I-I/IB-S-I/IB, Mr. A. Thompson
I-I/IB-G, Mr. P. Dunlap, Jr.
Mr. J. Hawkins
I-I/IB-T, Mr. O. Wright
I-V-G, Mr. E. Smith
Mr. L. Sommers
I-V-E, Mr. A. Conway
I-V-S-IC, Mr. M. Urlaub
I-MICH, Mr. A. Smith
I-MICH-QPS, Mr. M. Marchese
I-MICH-OC, Mr. E. Brooks
LVO-24, Mr. R. Jenke
LVO-241, Mr. J. Medlock
INS-113, Mr. B. Griffin
EDV, Mr. R. Wright
MSC Code EB4, Mr. W. Bradford
NASA-MAT, Mr. C. P. Wood
MS-IP
MS-IL (8)
MS-T (6)
MS-H
CC-P
HME-P
Scientific & Technical Information (25)
Facility
P. O. Box 33
College Park, Maryland 20740
Attn: NASA Rep S-AK/RKT