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Computer Controlled Power Application for the Saturn Launch Vehicle

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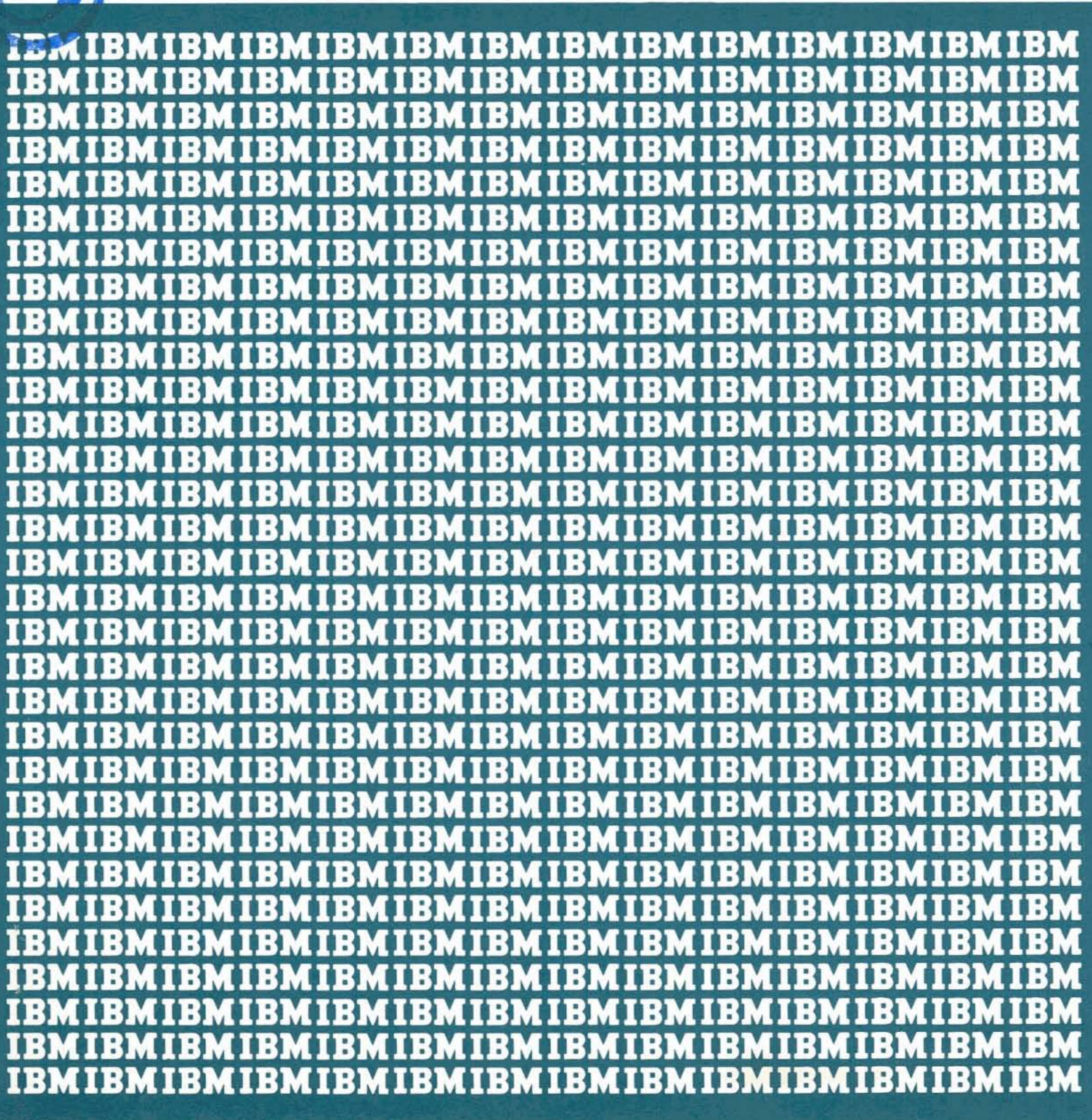

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COMPUTER CONTROLLED POWER APPLICATION FOR THE SATURN LAUNCH VEHICLE

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COMPUTER CONTROLLED POWER APPLICATION FOR THE SATURN LAUNCH VEHICLE

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ABSTRACT

This paper describes a real-time digital computer program that controls the application of electrical power to the S-IVB stage of the Saturn vehicle at Cape Kennedy, Florida.

Douglas Aircraft Company, the S-IVB stage manufacturer, provided NASA with program requirements relative to energizing sequence, voltage and current measurement tolerances, and vehicle system operational tests.

International Business Machines Corporation provided NASA with the computer program to satisfy the task requirements. The program conjoined the components of the Electrical Support Equipment (two RCA 110A computers and control and instrumentation devices) into a closed loop system. The supporting operating system program by IBM is described.

INTRODUCTION

In common with all space launch vehicles, the Uprated Saturn I requires extensive testing prior to launch. Before the Saturn program, most of the prelaunch testing was accomplished manually. The test conductor followed rigorous written test procedures designed to simulate the vehicle systems and prove their operability.

At the inception of the Saturn program, NASA introduced, as a primary objective, the progressive automation of the prelaunch testing and checkout. Although automatic testing is frequently employed for factory checkout of the launch vehicle, only launch site checkout at Cape Kennedy will be discussed here.

The vehicle electrical support equipment (ESE) consists of the power control and instrumentation systems necessary to control and monitor the vehicle prior to launch. An integral part of the ESE is a pair of computers that allows automatic prelaunch checkout. The design of the ESE also permits semiautomatic or manual modes of operation.

To apply the progressive automation concept, NASA selects several manual checkout tests to be automated for each vehicle in the series. The particular manual test discussed here is the Power Distribution and Control Switching Test for the S-IVB stage; the automatic version of the test was assigned the name, S-IVB Power Control Test. The automation of this test early in the series served several purposes. The test is quite comprehensive, providing experience with most of the capabilities of the ESE and computers. It resulted in a program, part of which could be executed every day to apply and remove power to the stage; and the other part, executed once for each vehicle to check out the interface of the stage with the ESE.

The functional requirements of the test were furnished to NASA by the Douglas Aircraft Company, the manufacturer of the stage. The International Business Machines Corporation provided NASA with the computer to satisfy the test requirements.

SUPPORT EQUIPMENT

A Saturn launch complex is composed of the Saturn launch vehicle and all the associated ground support equipment (GSE) necessary for launch.

The GSE is usually divided into the structural, mechanical, and electrical portions.

The structural and mechanical support equipment includes the blockhouse, launch umbilical tower, propellant storage and loading facilities, gas storage facilities, and similar items.

The ESE systems providing power, control, and instrumentation for the launch complex are directly affected by the execution of the Power Control Test program. A general description of the ESE without undue detail will serve to familiarize the reader with the systems.

Power

The S-IVB power system is shown in Figure 1. The ESE portion of the system is divided into four separate subsystems corresponding to the stage power distribution subsystems.

The primary source of ESE power is AC furnished by the Florida Power and Light Company, with an alternate source of AC power generated at the Cape. The AC power is converted to DC by three 28-volt and one 56-volt solid state rectifiers.

Each of the subsystems contains a series of main and submain buses which may be energized in sequence to ultimately energize the S-IVB Stage buses. There are also numerous branch buses not shown in Figure 1. An individual battery at each rectifier provides power in the event of rectifier failure.

A special power system consisting of a 28-volt solid state rectifier with an isolated return provides power for the umbilical connector monitoring circuits.

The controls necessary for the operation of the ESE power system consist of the relays, switches, indicator lights, power contactors, and wiring necessary to energize the systems and to produce the required configuration.

Control and Instrumentation

The heat of the control and instrumentation system is a pair of digital computers (Figure 2). Also shown in Figure 2 are the major hardware components of the Saturn Launch Computer Complex (SLCC). The medium-speed (28.85 µs word time) general purpose computer was designed primarily for reliability. Most of the features of a real-time control, monitoring, and logging computer application are incorporated in the computer. It contains a 32K high speed, random access core memory, 32K drum, and multiple magnetic tape stations. The word length is 24 bits, and there are 121 instructions in the repertoire. There is a four-level hardware priority interrupt system and seven input/output (I/O) data channels. Figure 3 shows the I/O system and the peripheral equipment on each channel.

The two computers operate asynchronously and are joined by a coaxial cable data link approximately 1/2 mile long. The data link and the second computer are more reliable and economical than the thousands of conductors they replace and allow many times the programming and operating flexibility of a single computer system.

The basic control I/O systems are the digital data acquisition system (DDAS), the discrete activity system, and the display control consoles (DCC).

The DDAS is a measurement system capable of processing both analog measurements and discrete signals. The development of a solid state vehicle multiplexer, with no operating life limit, allowed continuous monitoring for the first time on a NASA vehicle. Prior to launch, the pulse code modulation (PCM) data stream from the multiplexer is intercepted by the vehicle DDAS before it reaches the transmitters and is sent to the ground DDAS stations via an umbilical cable. A DDAS ground station processes ESE data. The in-flight data is sent to the DDAS ground stations via the telemetry transmitters.

The discrete activity system allows the computer to send discrete signals to energize relays, sequencers, devices, etc. associated with the vehicle and ESE systems. The computer is also capable of receiving discrete signals from an ESE or vehicle system device.

The display control console allows keyboard input to the computer: this is the method by which programs are called into execution. Discrete signals may also be issued or sensed. The DCC contains a cathode ray tube (CRT) display tube which displays messages from the computer, indicating program execution status system malfunctions or other information.

The ESE is designed to operate in the manual, semiautomatic, or automatic mode.

In the manual mode, vehicle system functions are controlled and monitored, bypassing the computer, by blockhouse switches and indicators. The control circuits for extremely critical functions only have this capability to bypass the computer and go directly via hardwire to the vehicle. These circuits generally have parallel paths through the computer for other modes of operation.

In the semiautomatic mode, vehicle system functions are controlled and monitored by blockhouse switches and indicators and the DCC. All control circuits pass through a program phase within the two computers. Indications including DDAS and discrete also pass through a program phase in the computer.

In the automatic mode, the switches on the ESE panels are placed in their "auto" position. This permits the computer, under program control, to take over the decision-making process and operation of the functions associated with the switches. No attempt is being made to implement a completely automatic countdown. All actions are initiated by the launch engineers through the DCC and ESE panel switches.

The digital event evaluator (DEE), another separate digital computer system, is used to sense and log all discrete action. That is its only function.

The remote automatic calibrate system (RACS) allows calibration of all measurements by switching known inputs to each measurement circuit under program control of the checkout computer.

FUNCTIONAL TEST PROGRAM REQUIREMENTS

A computer program to apply and remove power to the S-IVB stage would have to merge the components of the ESE and computers into multiclosed loop control and instrumentation systems to accomplish the task.

The Douglas Aircraft Company provided NASA with the functional test program requirements in a degree of detail readily adapted to a computer program. The requirements were adapted from the automatic factory checkout procedures. The factory checkout programs cannot be directly applied to prelaunch checkout for several reasons: the computers and ESE are different and the computer operating system programs are different. Because of greater standardization, a greater degree of automation is possible at the factory.

Although factory programs temselves are not directly applicable, the program documentation forms a good basis for prelaunch programs.

The purpose of the test program was twofold:

1. Apply and remove power to the stage each day.
2. Check out the stage to ESE interface once for each new vehicle.

The program would verify the integrity of the power distribution system. The various tests would establish that no static loads are excessive and verify the capability of the GSE to provide and control power to and within the S-IVB stage.

Initial Conditions

To establish system initial conditions the program is required to check each of the ESE panel switches for correct position (approximately 250 switches). The AUTO position is required for computer program control of the function associated with the switch. The ON or OFF position causes the associated function to assume a certain configuration and to inhibit program control under the philosophy that hardware always overrides program control. The numbers of all switches not in the correct position are displayed on the CRT. The program also senses approximately 100 of the discrete output lines for proper status. The numbers of the discrete outputs having incorrect status also are displayed on the CRT. If any error conditions are sensed, the program holds for manual intervention until corrective action can be taken. The test operator may choose to retest, resume, restart, or terminate. All the optional actions available to the test operator and their associated keyboard entries also are displayed on the CRT. Other options available to the test operator are to set up program holds at predefined breakpoints, display the numbers of the breakpoints at which the program will hold, and in some instances allow jumps from one breakpoint to another or back up the program to the preceding breakpoint.

Power Application

After the system initial conditions have been established, the output voltage of each of the four power supplies is checked. The power supplies were manually energized prior to program execution. The DDAS system allows measurements to a realistic 2 percent accuracy. The ESE bus voltages are checked to ensure that none is energized. A malfunction or error indication will cause the program to hold for manual intervention, and to display a message specifying the error condition and all optional keyboard entries permitted at that point.

A message is displayed, requesting the operation to energize the buses associated with power supply No. 1. Voltage and current measurements are checked for magnitudes within predefined tolerances and the associated stage bus is checked for deenergized state. Any malfunctions or errors will cause a program to hold for manual correction similar to that described above.

Energizing the No. 1 ESE buses allows the indication bus to be energized. This bus provides power for the ESE and vehicle indications that are brought back to the computer in the form of discrete signals. It is now possible to check approximately 100 vehicle indicators for correct status. This check will determine that no vehicle systems are energized.

The remainder of the program follows an operational sequence similar to that previously described. The system configuration is checked, the system is then stimulated in some specific respect, and the resulting configuration is checked. Any error or malfunction condition detected by the program will be displayed and printed and will cause a hold for manual intervention.

The general monitor items are then activated. The general monitor is an operating system program designed to continuously scan critical measurements and indications specified in its subroutines. Because the programs are in different computers, this program has the capability to operate during the execution of a test program. Upon detection of an undesirable condition, it can interrupt the test program and take the necessary corrective action to restore safe conditions. The general monitor can be programmed to monitor indicators on command from a test program. The Power Control Test program causes monitoring of the four ESE main bus currents. A bus overcurrent causes that bus to be deenergized. The general monitor discontinues its monitor function also on command from a test program.

The system is now in the most safe configuration for power application to the S-IVB stage.

Power is applied to the No. 1, No. 2, and No. 3 stage buses, but not to the No. 4 bus. The No. 4 bus powers the chilldown pump inverters, which have a short duty cycle and will not be checked during this part of the test.

Certain subsystems are checked for operability; these include the switch selector, sequencer, DDAS, checkout measurements group, recorded measurements group, and others involved in the tests that will follow this one during the remainder of the day.

The stage is now energized and, at this point, the program may be terminated; a jump to the power-off routine may be executed to restore system initial conditions; or the Power Distribution Test portion of the program may be entered.

Power Distribution Subsystem Test

Figure 4 shows the four main stage buses and the major subsystems energized by each.

The test sequence philosophy remains the same for this part of the program. It will suffice to say that each subsystem is energized in sequence and that power indicators are checked. In some cases load current is measured. In a few cases the system is exercised for a cursory operability check. The power distribution controls for the following stage systems are checked:

1. Propellant level sensor system

   Wet condition simulation commands

2. Engine control system
3. Component test system
4. Engine cut-off voting logic

   Propellant level sensors are simulated wet sequentially and tested to ensure that any two out of the six indicating dry will produce an engine cut-off command.

5. Propellant utilization system (propellant mixture, ratio control)
6. Auxiliary power system (roll and attitude control)
7. Engine ignition system
8. Telemetry system
9. Stage power bus No. 4 system
10. Chilldown pump inverter systems
11. Power transfer test

    This tests the ability of ESE relay logic to remove the ground power from the stage and to substitute the stage batteries for the power source.

The Power Distribution Test provides a gross check of the stage subsystems to determine that the ESE and stage interface is correct and that the systems do become energized on command. This is the first test to be executed after the stage is stacked on top of the S-IB stage.

The power removal subprogram, which is the reverse sequence of the power application program, may be entered from any program breakpoint to restore initial system conditions. There is also a shorter emergency power-off subprogram, which may be entered by a termination request from the DCC keyboard or by the operating system if determined necessary for higher priority activity.

Operating System Program

To code the S-IVB power control program or other programs of similar magnitude independently would require an intolerable amount of effort. The operating system resolves this problem. This system includes all those programs that can be standardized and made independent of a specific vehicle or test program; for example, the master scheduler, input/output, mathematical and self-test routines. Such programs need be written only once, reducing chances of error, eliminating duplication of effort, minimizing the test program changes necessary from one vehicle to the next, ect. In the interest of economy and time, it is neither required nor allowed to program a discrete output routine each time a discrete output is required; rather, a standard routine is required. Adequate safeguards and error checks must be included in all standard input and output routines; it is redundant, as well as risky, to require that each programmer always include such error checking for each of the thousands of times his program is to input or output data. All standard routines should therefore be part of the operating system and all test programs should use them.

Another important feature of the operating system is the monitoring and recording of selected parameters needed for historical purposes. The operating system contains many more features than those mentioned. The Power Control Test Program accesses the operating system for every function that the Test Program executes.

Programming the Power Control Test Program and similar programs in symbolic machine language allowed the programmer still too much latitude, because of the flexibility and versatility of the operating system program calling sequences. It was therefore decided to develop a set of standard calling sequences that would further reduce the duplication of effort and the possibility of neglecting safeguard. Thus evolved a problem-oriented pseudo-symbolic language called CTEX, which reduced each calling sequence to one operator word and a few data words and which produced the required standardization.

The Power Control Test Program was ultimately coded at Cape Kennedy in the CTEX language and debugged at the Systems Development Breadboard Facility at NASA's Marshall Space Flight Center in Huntsville, Alabama. All the test requirements were satisfied.

CONCLUSIONS

It may seem, on the first encounter with the system described above, that an excessive amount of ESE hardware and supporting computer programs is involved in the automation of the manual procedure to apply power to the S-IVB stage. That would be true if it were not for the fact that all the other test programs that have been written and will be written will use the same ESE and supporting programs. Programs are required in the networks, propellant, telemetry, flight control, vehicle computer, and in many other areas and subareas. Certain vehicle systems such as the Launch Vehicle Digital Computer cannot be checked out manually and must rely on the ESE computer for testing.

Although a completely automated countdown is not practical and is not an objective of the Saturn project, it is true that the Saturn vehicles cannot be checked out and declared launch-ready without the ESE computers. As a consequence of the primary Saturn Project objective of progressive automation, NASA is advancing the state-of-the-art of digital computer application to control and instrumentation. The automatic testing and process control fields should benefit greatly.

A new vocational discipline is being developed--the engineer-programmer. The practitioner of this new discipline must become well versed in both the system to be tested and the system he will utilize for the execution of the test. He must be able to arrive at test requirements, often with little more information than the system schematics. He must be able to work with the system design engineer to get every detail of each phase of the test and every detail of the action to be taken for every possible outcome of every phase of the test.

The engineer-programmer must be fully aware of the capabilities of his computer and its peripheral equipment. He must be able to design a computer program that will accomplish the task within the limitations of the hardware and program support systems. For instance, he must know (1) the time it takes the computer to issue a command and receive the response without regard to test system time, (2) the accuracy of any measurement, (3) the amount of noise that can be expected, (4) the time it takes the general monitor to respond to a malfunction condition, (5) the scan rate of the general monitor, (6) the restrictions of the launch complex operational procedures, (7) the suitability of the various coding languages available, (8) the degree of diagnostics the program should attempt, and (9) the degree of manual intervention that should be allowed. The list of considerations is virtually endless, and the vocational challenge is unlimited.

Configuration management is assuming a more important role than ever before. The design of program documentation is evolving so that program specifications describe more accurately the program design and are able to be revised more easily with changing requirements. These advancements in technology and management techniques will contribute greatly to the state-of-the-art.

NASA is achieving its objective.

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ILLUSTRATIONS

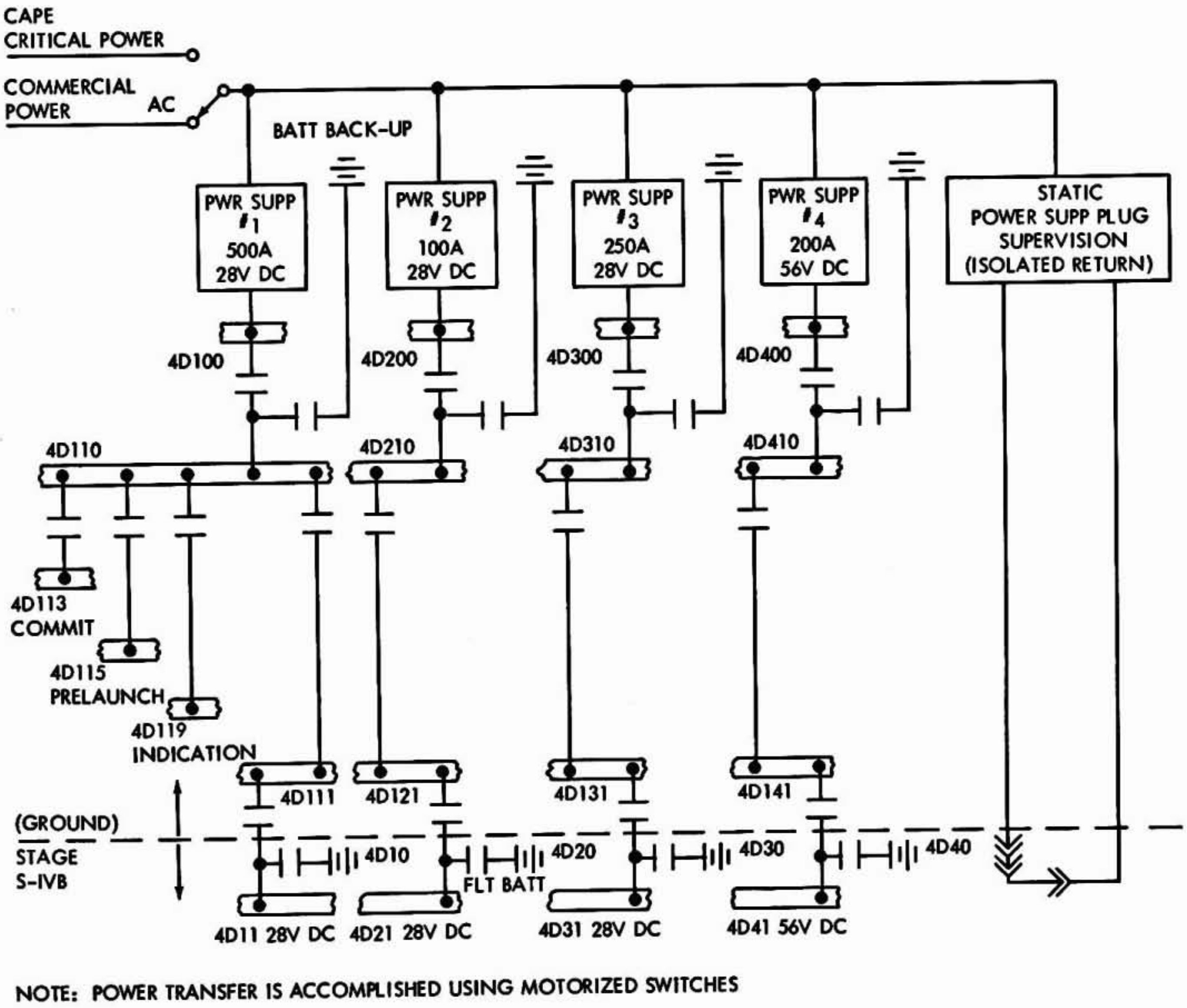

Figure 1. S-IVB Stage and ESE Power Supplies and Buses.

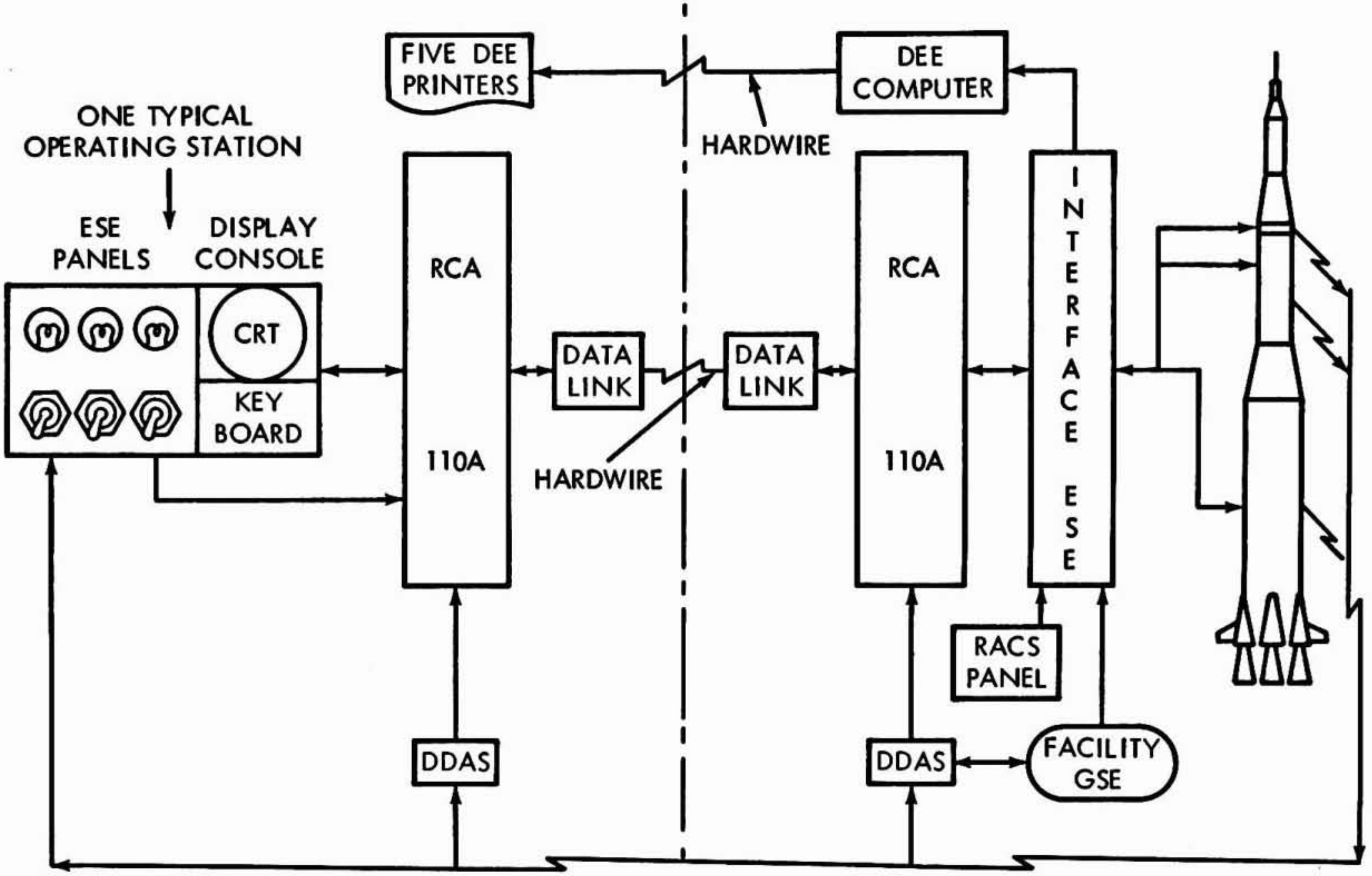

Figure 2. Blockhouse Launch Pad.

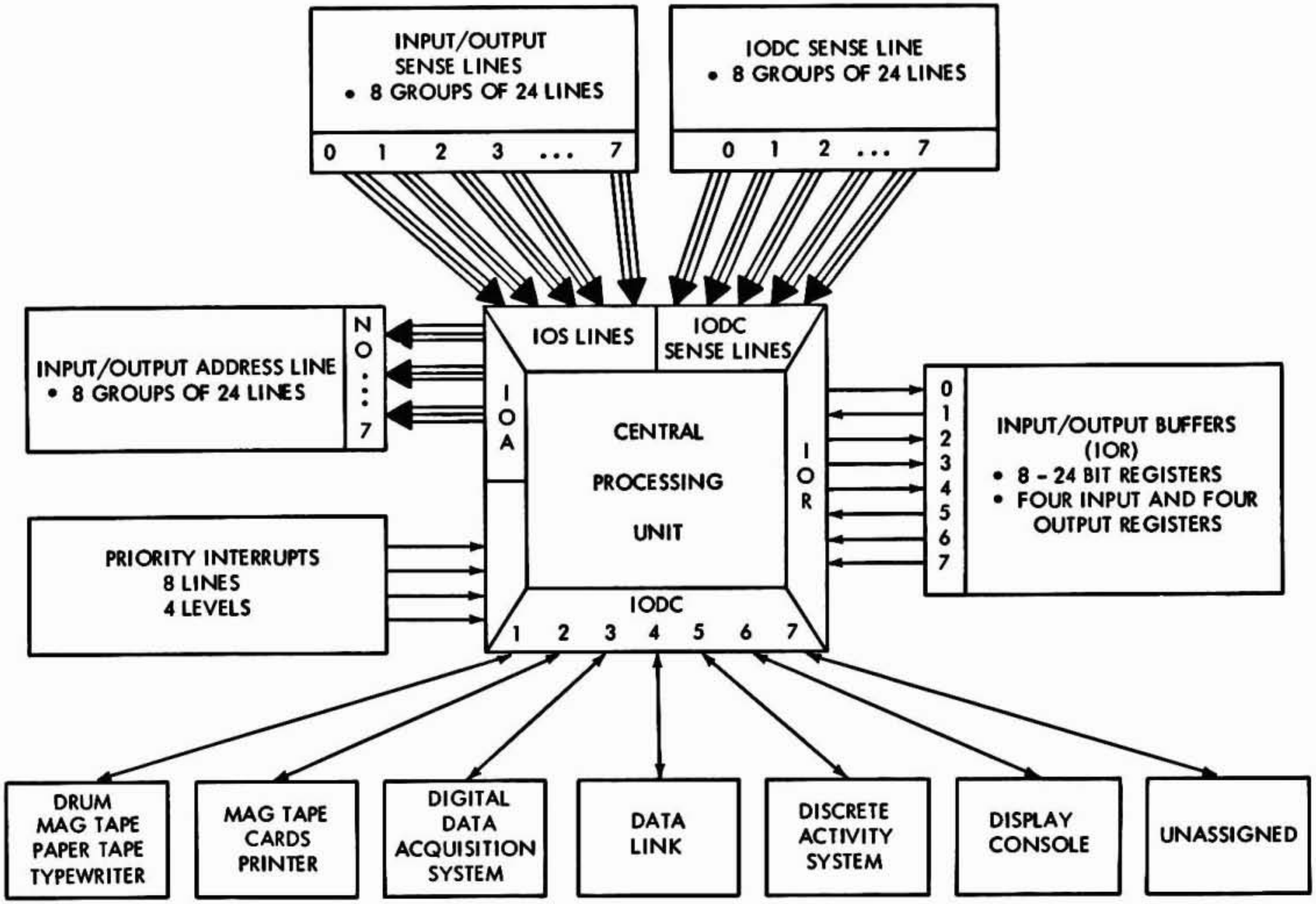

Figure 3. Computer Input/Output System.

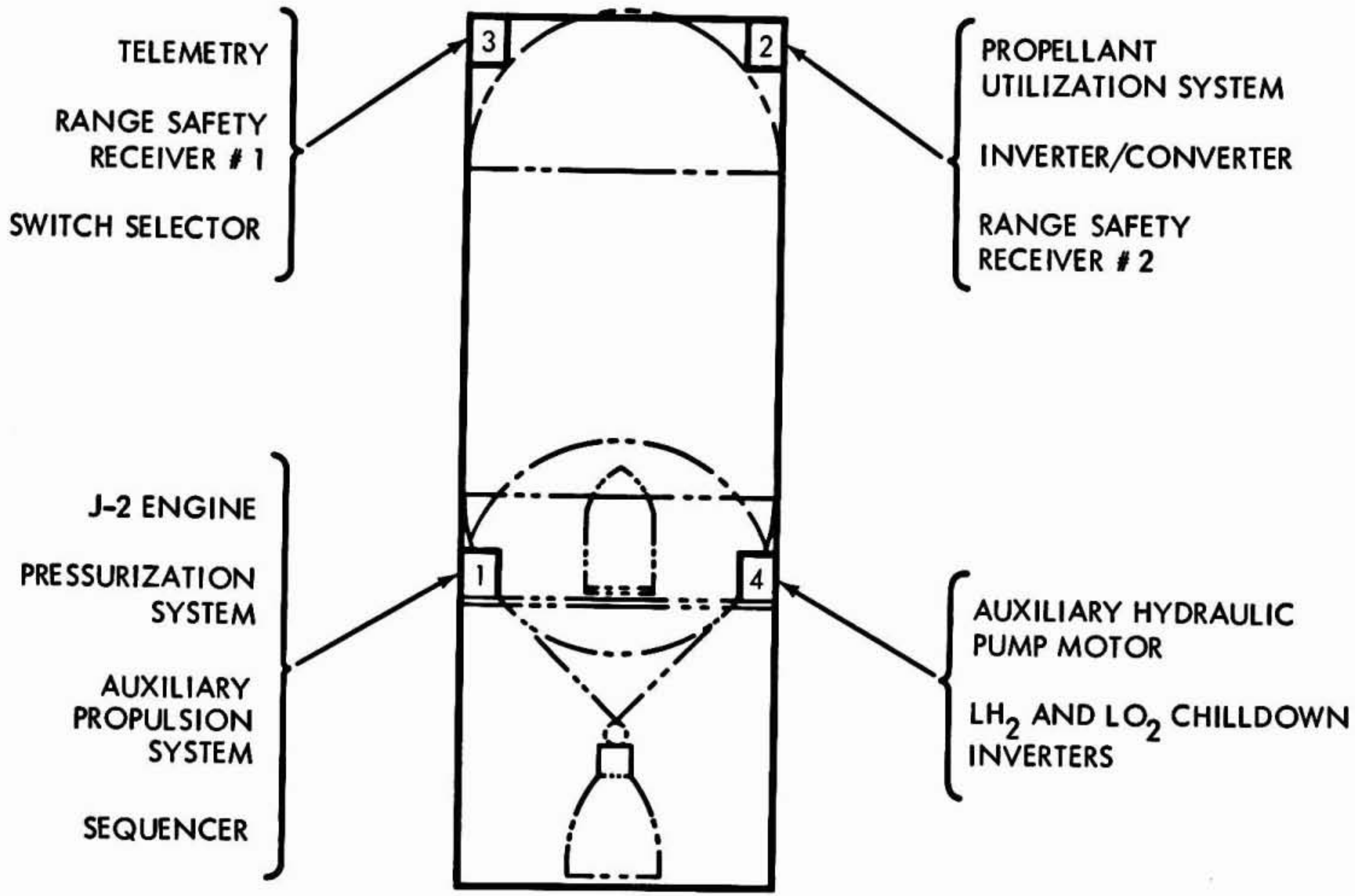

Figure 4. Saturn IB/S-IVB Basic Electrical Power System.

Federal Systems Division, Space Systems Center, Huntsville, Alabama