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COMPUTER ANALYSIS OF INTERPLANETARY MONITORING PLATFORM (IMP) SPACECRAFT PERFORMANCE

by Frank Piazza

Goddard Space Flight Center
Greenbelt, Md.

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ABSTRACT

A system of analyzing by computer the IMP spacecraft performance prior to launch has been developed at GSFC. The significant features of this method of approach are described in detail, and their successful application to the prelaunch phase of the IMP spacecraft and of the scientific experiments assigned to the IMP missions are outlined. The effectiveness and advantages of this system are emphasized by the use of a compact general purpose computer to provide real-time telemetry data-processing for performance analysis. The analysis during prelaunch has been greatly improved by the system's flexibility, speed, and accuracy of operation compared with methods of analysis previously used. Also pointed out are the advantages of reduction in manpower needed for testing, and of mobility provided by housing the system in a van.

The suitability of this system is evident for use with other types of spacecraft in the future, with minimal hardware modification. It is noted that more effective use of the present system depends on the development of more sophisticated software systems for relevant data-processing.

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INTRODUCTION

The Interplanetary Monitoring Platform (IMP) project provides for placing a series of three scientific satellites in high-apogee earth orbits. The first, IMP-A, was launched November 26, 1963 (Explorer XVIII); IMP-B was launched October 3, 1964 (Explorer XXI); IMP-C will be launched in the near future.

Each IMP spacecraft is designed to conduct nine scientific experiments to provide a wide variety of data during earth orbits, including data on the intensity and charge spectra of cosmic rays, detailed information on the solar wind and environment, and an accurate description of the interplanetary magnetic field.

IMP PROJECT OBJECTIVES

The principal objectives of the IMP projects are:

1. To study the radiation environment of cislunar space and to monitor this region over a significant portion of a solar cycle, as a direct support of Project Apollo.
2. To study the quiescent properties of the interplanetary magnetic field, and its dynamic relationship to particle fluxes from the sun.
3. To develop a solar-flare prediction capability for the Apollo project.
4. To increase knowledge of solar-terrestrial relationships.
5. To accelerate the development of relatively inexpensive, spin-stabilized spacecraft for interplanetary investigations.

PREFLIGHT SPACECRAFT PERFORMANCE ANALYSIS

The electronic system of the IMP spacecraft is necessarily complex to provide the various capabilities required to measure the phenomena encountered beyond the earth's atmosphere. Before the spacecraft is launched, the electronic packages and experiments must be thoroughly tested and evaluated, to ensure reliability of operation and accuracy of measurements.

1	2	D				0	0	2	4
	6			-	0	0	0	0	0
3			2		0	0	1	4	5
	8	B			0		0	0	0
	8	A			0		0	0	0
	5	A		-	0	0	0	0	0
	2	B			0	0	0	0	0
	2	A			0	0	0	0	0
	7	B			0	0	0	0	0
	7	A			0	0	0	0	0
	4	B			0	0	0	0	0
	4	A			0	0	0	0	0
	1	B			0	0	0	0	0
	1	A			0	0	0	0	0
1	5				0	0	6	1	4
1	4				0	0	0	0	0
1	3				0	1	0	2	3
1	2				0	0	0	0	0
1	1							2	7
	4	D				0	0	2	4
	6			-	0	0	0	0	0
3			1		0	0	0	0	1
		P	1	5	0	3	9	9	5
		P	1	4	0	3	2	8	1
		P	1	3	0	6	9	5	6
		P	1	2	0	0	6	7	8
		P	1	1	-	-	-	-	-
		P	1	0	-	-	-	-	-
		P	0	9	0	0	1	7	6
		P	0	8	0	1	1	8	9
		P	0	7	0	1	9	4	2
		P	0	6	0	3	4	3	7
		P	0	5	-	-	-	-	-
		P	0	4	0	0	2	0	0
		P	0	3	0	3	4	6	2
		P	0	2	0	4	9	8	5
		P	0	1	0	1	7	8	5
	8	B			0		0	0	0
	8	A			0		0	0	0
	5			-	0	0	0	0	0
	2	B			0	0	0	0	0
	2	A			0	0	0	0	0
	7	B			0	0	0	6	4
	7	A			0	0	0	0	0
	4	B			0	0	0	0	0
	4	A			0	0	0	0	0
	1	B			0	0	0	0	0
	1	A			0	0	0	0	0

Figure 1 - Sample of digital recorder printout.

1. *Integration:* Assembly of the required electronic packages and experiments on the spacecraft structure.

2. *Testing:* Environmental tests, such as vibration and thermal vacuum to assure that the spacecraft will survive launch and operate in space.

3. *Launch operations checkout:* Final performance analysis of the spacecraft at the launch site.

During all three phases, spacecraft performance is analyzed by many procedures, including exciting the experiments and observing the resultant output of the telemetry. Methods of exciting the experiments vary from the use of radioactive sources for particle experiments to setting up a controllable magnetic field to calibrate a magnetometer. This often requires accumulation of data over long periods of time to provide meaningful outputs from an experiment, and has in the past required time-consuming mathematical calculations based on accumulated data.

To achieve an analysis beyond a simple, satisfactory-unsatisfactory appraisal of performance, it was necessary to undertake a lengthy examination of large amounts of data printed out on digital recorders, and to sort and transfer the data to a particular experiment data sheet. The data sheets were then submitted to the experimenters for use in making mathematical calculations, checking limits, plotting graphs, and performing many other tasks to derive an adequate picture of the operational status of the experiments. Samples of the digital recorder printouts are shown in Figure 1.

The length of time required to process the data in this way precluded obtaining information from this source which was needed immediately during environmental testing. The experimenter needed this ready access to permit examining any problem developed at the same environmental level.

This time-lag objection was overcome by using the computer system for analysis, thus providing information automatically and rapidly from the spacecraft telemetry system for each telemetry channel.

IMP SPACECRAFT TELEMETRY

The IMP telemetry system uses a hybrid, time-multiplexed, pulse-frequency-modulation (PFM) encoding technique. Through time-multiplexing, this system achieves high efficiency and convenience by combining a variety of experimental data bit rates and modes (e.g., digital, analog, or continuous signal).

The basic IMP telemetry format, shown in Figure 2, is considered one sequence, and consists of 256 channels arranged 16 channels in a frame, with 16 frames in a sequence. One sequence is required to commutate all experiments, and requires 81.92 seconds. The 256 channels which make up a sequence are samples of data in the form of an audio frequency as the experiments are being commutated.

Under the PFM system of the IMP spacecraft, the video signal consists of an audio reference-frequency burst, followed by bursts containing data (Figure 3). Each burst is 160 milliseconds in

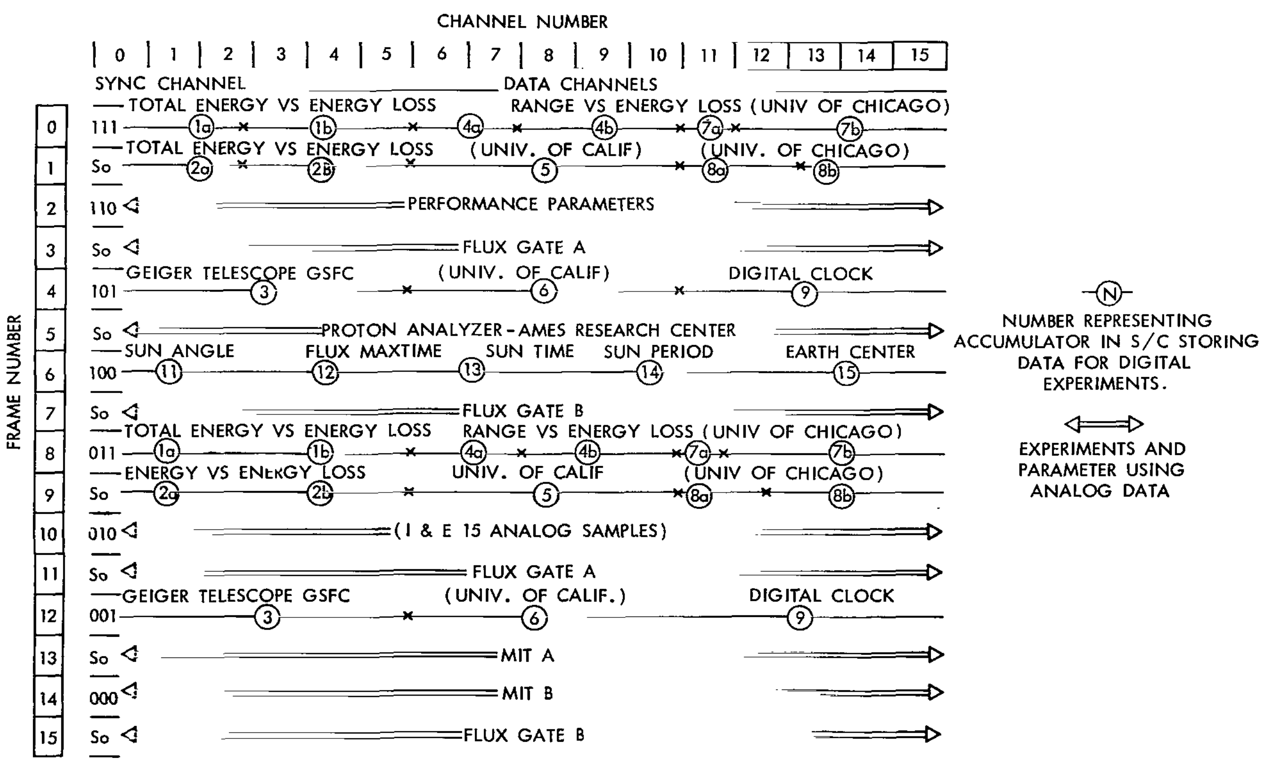


Figure 2 - IMP telemetry format.

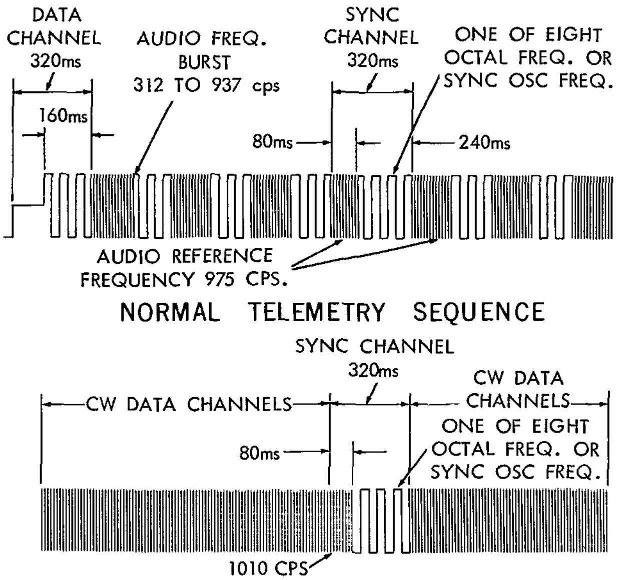


Figure 3 - IMP telemetry sequence.

duration, except for the frame synchronization burst of 240 milliseconds. The latter is preceded by an 80-millisecond reference-frequency burst, with the exception of every fourth sequence, where the zero-channel, reference frequency is replaced by a frequency of 1010 cycles per second to identify the sequence. A continuous wave replaces the reference and intelligence frequencies on all frames of channels 1 through 15. The frame synchronization burst is also coded in frequency, in addition to being coded by the 240-millisecond burst width. The zero channel of each frame is used for frame synchronization identification; all other channels are either for digital data or analog data. Analog data are audio frequencies, the value of which is determined by the quantity being measured in the experiment. Some experiments remain in this form. Depending on what is being measured, other experiments require conversion of the analog data into digital form.

The burst frequency of the analog data channels varies from 312 to 937 cycles; that of the digital data channels and the zero channel frequency identification will be one of eight audio frequencies, which will correspond to an octal number from zero to seven.

The use of PFM in the IMP telemetry system contributes significantly in ensuring that the output signal-to-noise ratio will be adequate at the extreme distance of the IMP missions. It is capable of handling both the digital and analog data outputs of energetic-particle and magnetic-field experiments with a minimum of complexity. The digital data processor now in use in the IMP spacecraft ensures effective utilization of the available telemetry bandwidth.

Data recorded by the IMP telemetry system can be processed 16 times faster than real time. While the system operates basically with a burst-blank time envelope, it provides for continuous data transmission from certain experiments.

COMPUTER ANALYSIS OF SPACECRAFT PERFORMANCE

Utilization of the computer system of performance analysis in connection with the IMP-A mission has clearly demonstrated the advantages of this method of evaluation. The performance parameters for IMP-A (such as temperature, voltage, and current within the spacecraft) were printed in engineering units, instead of in analog periods which previously required manual conversion on a calibration curve to such units. The computer provided a straightline approximation of each curve rapidly and with accuracy.

The computer system proved itself effective in analyzing the Massachusetts Institute of Technology experiment carried in IMP-A, referred to as the "Plasma Probe". This experiment is designed to measure proton and electron fluxes in the energy region within a pre-designated range. It consists of two sensors the outputs of which are sampled and read out once every 160 milliseconds. The computer provided a better indication of the sensitivity of the experiment than was previously obtained.

Another experiment conducted by the University of Chicago in the IMP-A spacecraft, also demonstrates the advantages of performance analysis by the computer system. This is the range versus energy loss detector experiment to measure energy loss, range and total energy of charged particles in the space environment. The apparatus is designed to search for solar-proton or alpha-flare events occurring during transmission from the spacecraft. It requires plots of two pulse height analyzers, and calculation of rate in cumulative and incremental time periods. By using the computer system for performance analysis, the rate information on each sequence was readily and automatically printed out thus providing the experimenters with a short and long term analysis of their experiment.

In still another experiment by the University of California conducted by IMP-A involving use of an integrating ion-chamber, an electron counter, and a background counter, the computer system provided readily available information as needed during performance analysis.

The purpose of the above experiment is to measure electrons and protons of various energy levels. During the performance analysis, basic radiation monitoring combined with detection of electron fluxes required a constant analysis of activity beyond preset limits. Use of the computer made it possible to calculate the number of times preset limits were exceeded, and to record the results automatically at periodic intervals, or upon request. A calculation of percentage of error was also quickly available by this method.

COMPUTER SYSTEM FOR IMP PERFORMANCE ANALYSIS

Use of the computer system to analyze the IMP spacecraft performance has provided the advantages of flexibility, rapidity, and accuracy. The scope and speed of performance analysis have been reduced, and mobility has been added by housing the system in a large van (Figure 4).

The overall system used for IMP performance appraisal (Figure 5), consists of four subsystems: a reception system (RF) for receiving and recording spacecraft telemetry (Figure 6); an input buffer system, which provides an interface between the RF system and the computer (Figure 7); the computer itself (Figure 8); and an output buffer with peripheral equipment (Figure 7).

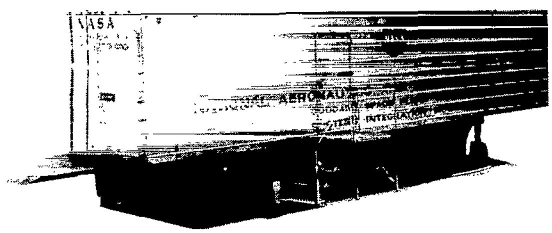


Figure 4 - Computer system installation in van.

Telemetry RF Reception System

The telemetry RF reception system used on the IMP spacecraft checkouts (Figure 9) employs two identical receivers with a phase-lock-loop, phase-demodulation system, in connection with two low-noise preamplifiers. Horizontal and vertical inputs are fed to the receivers and preamplifiers by a NASA-9 antenna. The demodulated video outputs of the receivers are then fed into a diversity combiner, which selects the stronger signal. The signal-to-noise ratio is improved by the diversity combiner when the input signals are equal. The combined video output is passed to the computer input buffer and to an analog recorder, where the telemetry is recorded for future playback.

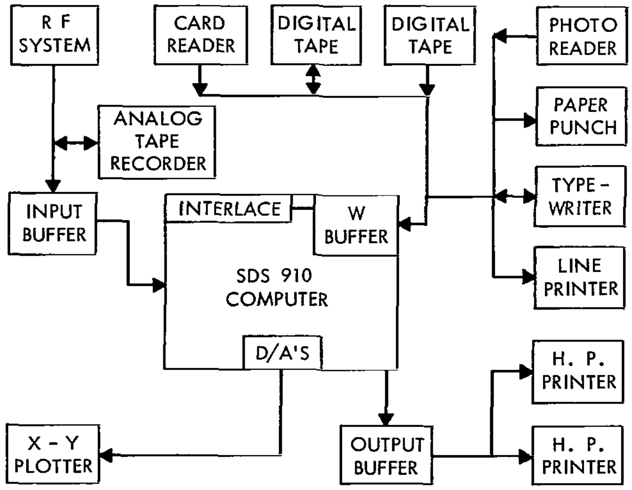


Figure 5 - Block diagram of computer system.

Input Buffer

In providing an interface between the computer and the RF system, the computer input buffer (Figure 10) has three functions to perform:

1. To establish synchronism with the spacecraft telemetry system, providing a reference from which the computer can determine how the telemetry format is operating.
2. To add the frequency of the data into a period sum, and convert this to a digital equivalent acceptable to the computer.
3. To prompt the computer to halt its functions at a given time to permit acceptance of the digital data at that time. This condition may be described as the "interrupt status".

Computer

The heart of the performance analysis system is a compact medium-speed, general-purpose computer with paper tape punch, paper tape reader, and typewriter. Peripheral equipment used consists of two magnetic tape units for secondary memory, a three-hundred line-per-minute line printer, and a card reader.

Features of the computer operation are the use of a twenty-four-bit word, binary arithmetic, and single-address instructions with index register, indirect addressing, and program operators.

Three registers are available for programming:

1. The A register, the main accumulator.

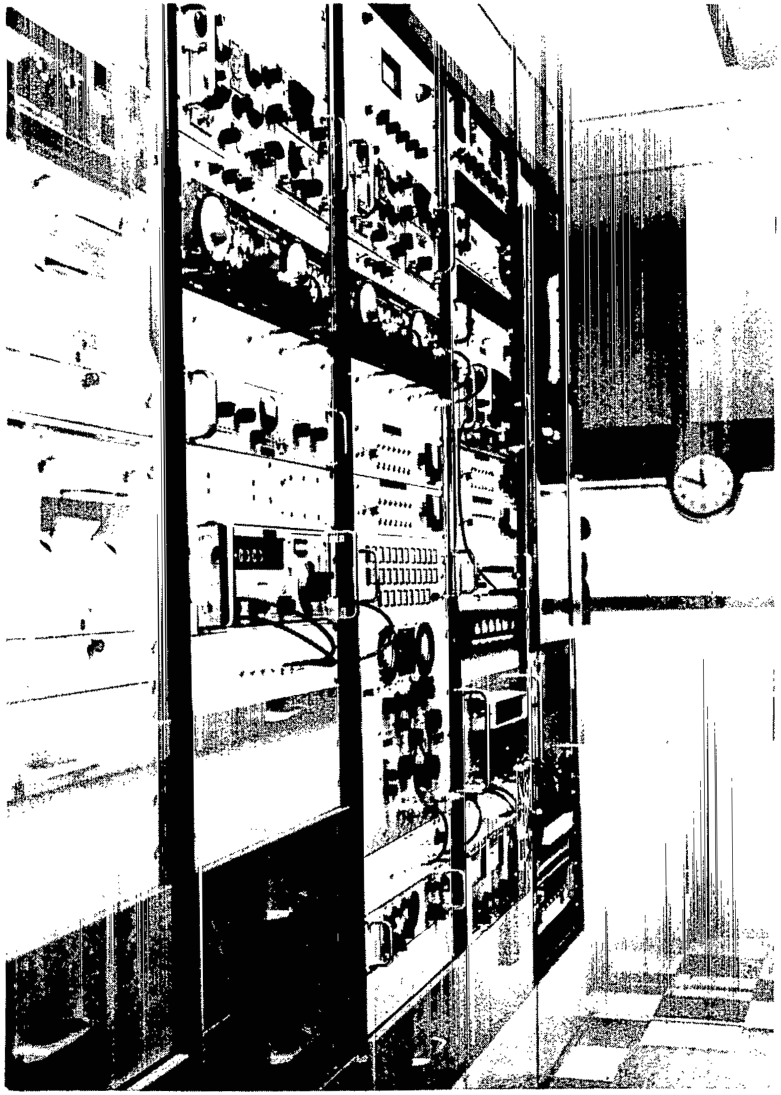


Figure 6 - RF section of the system.

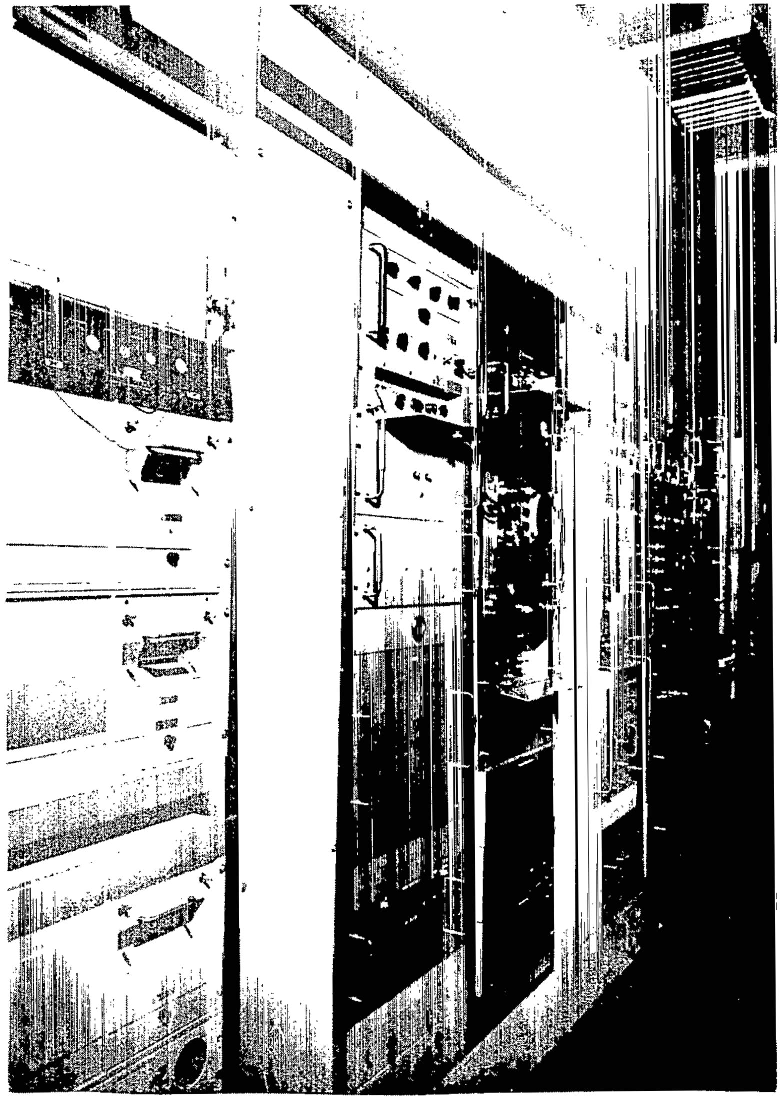


Figure 7 - Input and output for IMP computer.

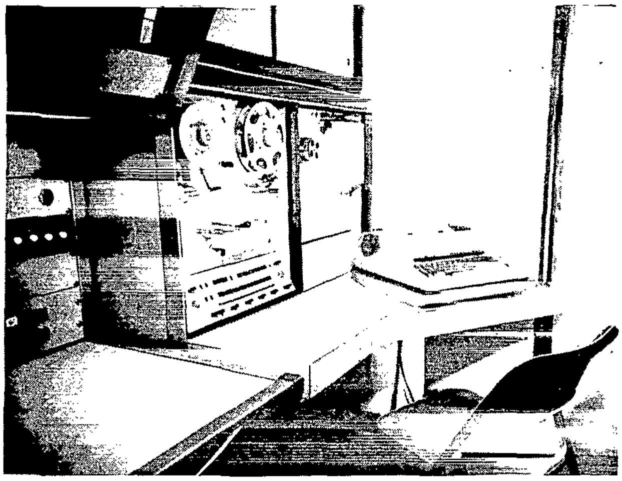


Figure 8 - Computer for the system.

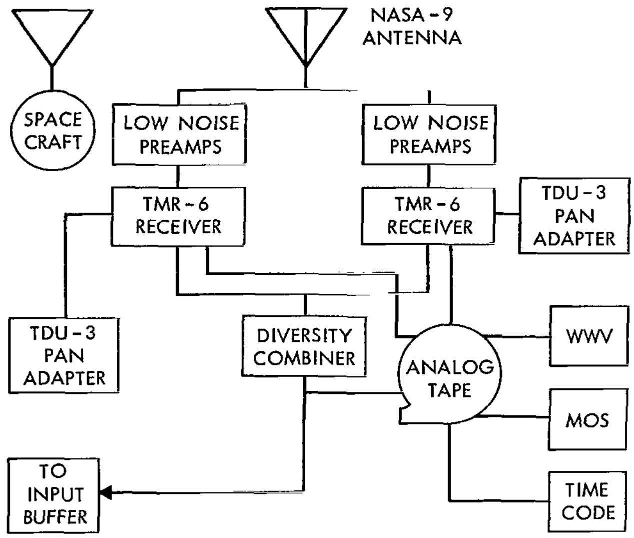


Figure 9 - Block diagram of RF system.

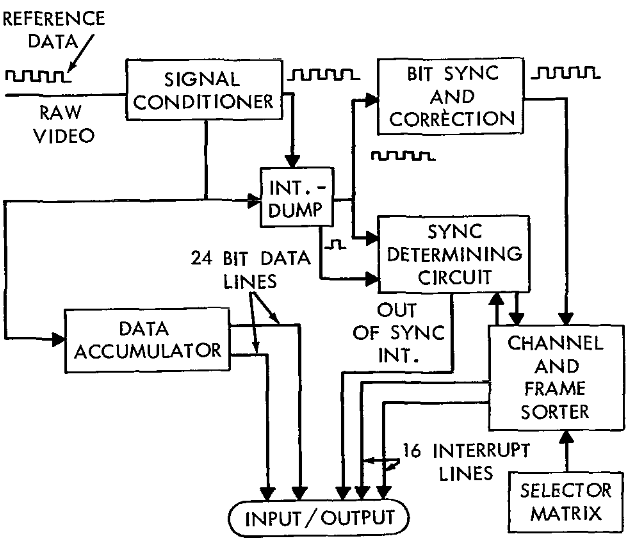


Figure 10 - Block diagram of input buffer.

2. The B register, an extension of the A register, which contains the least significant portion of double-length numbers.
3. The X register, the index register for address modification.

The main memory of the computer consists of from one to four random-access, magnetic-core modules of 2048 or 4096 words each. The directly addressable computer memory is composed of 16,384 words, all of which may be used by this system.

The hardware of this computer, which includes the peripheral equipment, a paper tape reader, a paper-tape punch, and a typewriter, necessitates the use of a buffer operating on an interrupt status for input and output, because of their relatively slow speed. Four internal interrupts are available in the computer, two for each of two buffers, if employed, with the capacity for 896 additional channels for interrupts as optional equipment.

Three features of the computer are of particular value in real-time programming: *priority interrupts* for signalling on a specific channel that data are available for transfer to the computer; *instructions for selecting* and checking the ready status of a peripheral device; and *instructions for paralleling* 24 bits of data into or out of the computer.

Twenty interrupt channels are employed by the computer system. Each priority interrupt channel is in inactive status, in an interrupt-received-but-waiting status, and in an interrupt-received-and-active status. The "waiting" condition prevails if the computer is processing a higher priority interrupt, or if the interrupt system is disabled as a result of setting a console switch, or of programming.

An interrupt occurring on a given channel causes the computer to branch to a memory location unique to that channel. This unique location contains the next instruction to be executed. Interrupts can be used to interrupt the main program of the computer, to input data as received, and to return the computer to the main program. For example, if the computer is executing an instruction in memory location 1000 at the time an interrupt signal is received on channel 200, indicating data are available for transfer, the computer completes execution of instruction 1000 and takes the next instruction from memory location 200. The instruction in 200 will branch the computer to a subroutine for reading the available data into the computer. When this read-in is complete, the interrupt is cleared, and the computer returns to the main program at location 1001.

Two instructions are available for selecting a particular peripheral device, and for interrogating it to determine whether it is in readiness for either input or output. The computer sends a configuration of ones and zeros, corresponding to the bits of the address portion of the instruction, to a peripheral device. Only one of the devices will have the correct code, identifying it as the one to be operated.

The parallel output instruction permits any word in memory designated by its address portion to be presented, in parallel, at a particular connector. Inversely, the parallel input instruction permits signals sent to the connector to be stored in any memory location designated by the address.

Output Buffer

The output buffer provides the interface between the computer and the peripheral output devices. Its two principal functions are (1) to decode the address bits of interrogation instructions, permitting selection of one to nine printers, and (2) to combine two 24-bit parallel words from the computer into a 48-bit accumulator in the buffer for transfer to the printers.

Four computer instructions are required to output information on a printer: the status instruction, the designating instruction, and two parallel output instructions.

The status instruction is executed to determine whether or not the output device is ready to operate, by decoding the address bits of the instruction in the buffer status decoder shown in Figure 11. The printer employed requires 60 milliseconds to accept data, and 200 milliseconds for printing. The 48-bit buffer-accumulator must, therefore, be frozen for 60 milliseconds, and the same printer must not be called upon for another 200 milliseconds. The ready test is made in the buffer by ANDing the output of the status decoder, which selects the printer being tested, with the 60-millisecond inhibit pulse from the printer and with a 200-millisecond output from a

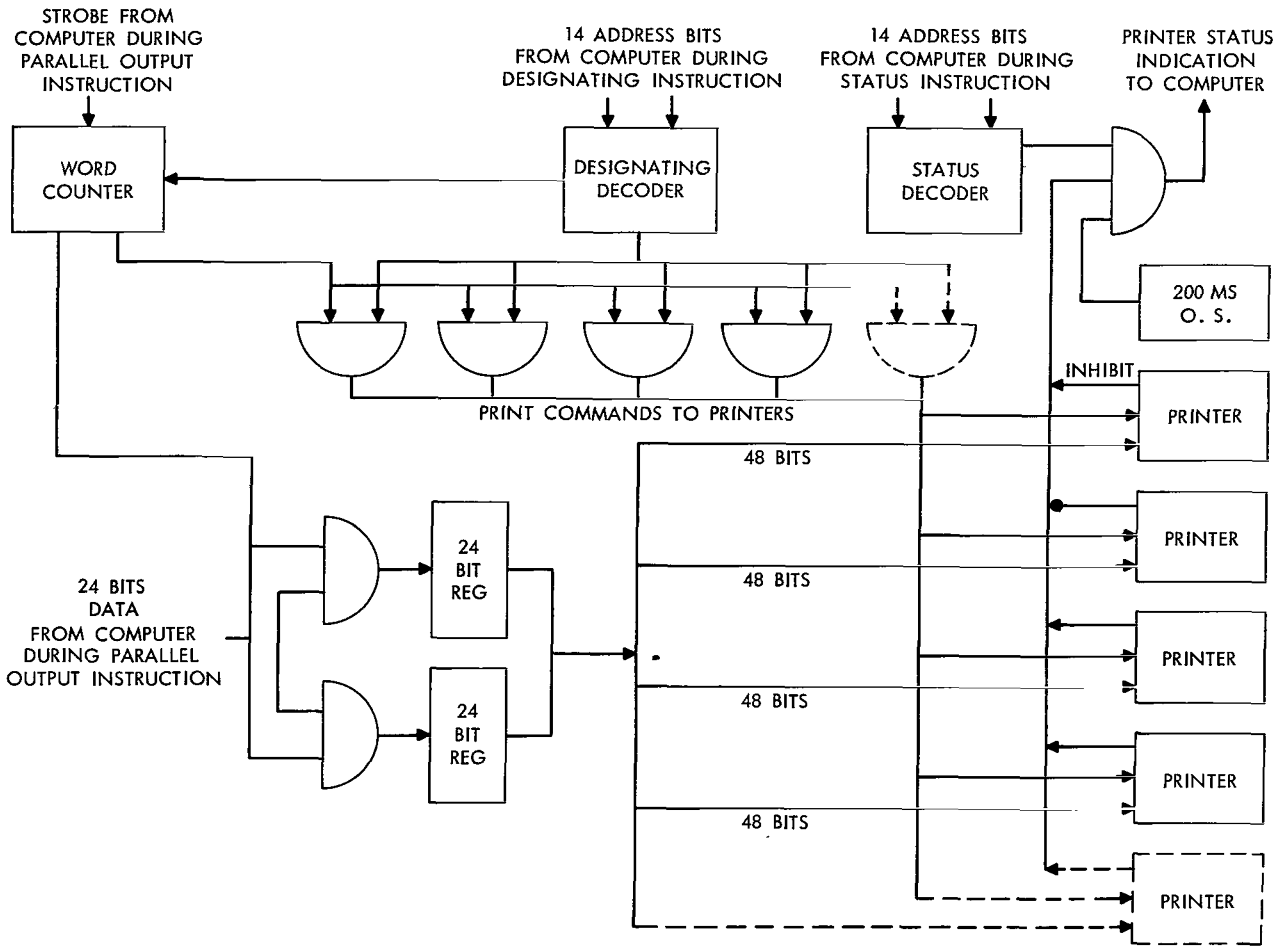


Figure 11 - Block diagram of output buffer.

one-shot in the buffer, triggered from a print command. A logic "one" from the AND gate indicates that the three inputs are true, producing a drop from +8 volts to zero volts on the line to the computer. The printer is then ready to print.

The designating instruction follows, initiating a print command to the printer selected by the designating decoder in the same way selection is made by the status decoder. The designating decoder sets a print-command flip-flop (word counter), whose output is ANDed with the output of the word counter, to provide a print-command pulse to the printer selected.

Two parallel output instructions complete a print operation. Execution of the first parallel output instruction will output 24 bits of parallel information from the computer to the buffer. Two flip-flops (word counters) determine into which half of the 48-bit accumulator in the buffer the 24-bit word is stored. A strobe pulse in the parallel output instruction opens the gates to the 48-bit accumulator, permitting storage. When the second parallel output instruction is executed, the gates on the first 24 bits are closed, and those on the second 24 bits are opened by changing the status of the word counter. In addition to filling the second half of the 48-bit accumulator, the second parallel output command, in conjunction with the designating command, generates a print command to the printer, allowing information to be transferred from the buffer to the printer. This step completes the operation.

COMPUTER PROGRAMS

Of paramount importance to the efficient use of the computer system to analyze IMP spacecraft performance is achieving accurate, rapid, comprehensive, and precise performance analysis in real time.

The principal functional requirements of the software developed for this system are:

1. To establish synchronism of the spacecraft systems with the input buffer.
2. To accept and store telemetry data as they become available.
3. To process received data during periods when data are not being received.
4. To output received information in a selected form, upon command.

Transfer of the telemetry data to computer storage is a basic requisite of the data analysis procedure operating in "real-time on-line". With transfer accomplished, synchronization can then be established, followed by data processing and output.

Programming to reach the goals of the computer system for performance analysis may be separated into five main parts: (1) synchronization program, (2) master program (idle, analog/digital, and processing programs), (3) interrupt and linkage program, (4) executive program, and (5) buffer input/output program.

SYNCHRONIZATION PROGRAM

The synchronization program ensures that the computer and spacecraft systems are synchronized by checking every channel-zero, and indicates to the computer, by the data provided in channel-zero, in which frame of the format the spacecraft telemetry data are to be found.

MASTER PROGRAM

The master program basically provides for three modes of operation. Its overall purpose is to provide a mode of operation to allow the computer to stay in synchronization with the spacecraft when analysis is not required, to provide output information for the printer, and to process data for the experiments

IDLE PROGRAM

The section of the master program designated as the idle program is one of short duration, which permits the computer to operate in a stand-by mode, while remaining in synchronization with the spacecraft program.

ANALOG/DIGITAL PROGRAM

The analog/digital program provides a decimal, sixteen-period average printout of a video burst on one of two printers, in microseconds-per-channel. The sequence, frame, and channel identification of this operation is shown in Figure 12. This program furnishes, on the second printer, the digital data word for each experiment requiring digital output, with mnemonic identification corresponding to the digital-data processor in the spacecraft (Figure 13).

SEQ.	FR.	CH.	PERIOD μ SEC.
3	0 2	0 4	1 5 1 0 1
3	0 2	0 3	1 1 5 8 8
3	0 2	0 2	2 0 1 5 7
3	0 2	0 1	2 0 7 0 0
3	0 1	1 5	2 3 3 4 8
3	0 1	1 4	1 1 4 3 0
3	0 1	1 3	1 1 4 2 7
3	0 1	1 2	1 1 4 3 6
3	0 1	1 1	1 1 4 3 1
3	0 1	1 0	3 1 4 3 8
3	0 1	0 9	3 1 4 8 8
3	0 1	0 8	3 1 4 9 5
3	0 1	0 7	3 1 4 8 7
3	0 1	0 6	3 1 4 8 5
3	0 1	0 5	1 1 5 7 5
3	0 1	0 4	1 1 5 7 3
3	0 1	0 3	1 7 5 8 0
3	0 1	0 2	1 1 5 8 0
3	0 1	0 1	1 7 5 7 7
3	0 0	1 5	1 1 4 3 5
3	0 0	1 4	1 1 4 2 6
3	0 0	1 3	2 0 3 6 6
3	0 0	1 2	1 7 5 8 7
3	0 0	1 1	3 1 5 7 3
3	0 0	1 0	3 1 4 8 2
3	0 0	0 9	3 1 4 9 1
3	0 0	0 8	3 1 4 9 7
3	0 0	0 7	1 1 5 7 7
3	0 0	0 6	1 1 5 7 2
3	0 0	0 5	1 1 5 8 1
3	0 0	0 4	1 1 5 7 8
3	0 0	0 3	2 0 3 1 2
3	0 0	0 2	1 1 5 8 5
3	0 0	0 1	2 0 3 1 2
2	1 5	1 5	1 3 8 7 8
2	1 5	1 4	1 3 7 3 8
2	1 5	1 3	1 3 6 6 8
2	1 5	1 2	1 3 8 1 6
2	1 5	1 1	1 3 8 0 1
2	1 5	1 0	1 3 8 3 3
2	1 5	0 9	1 3 8 3 0
2	1 5	0 8	1 3 7 2 1
2	1 5	0 7	1 3 8 1 8
2	1 5	0 6	1 3 7 5 0
2	1 5	0 5	1 3 7 4 5
2	1 5	0 4	1 3 8 1 7
2	1 5	0 3	1 3 8 2 6
2	1 5	0 2	1 3 7 4 6
2	1 5	0 1	1 3 1 8 0
2	1 4	1 5	1 5 5 6 2

Figure 12 - Sample of analog data.

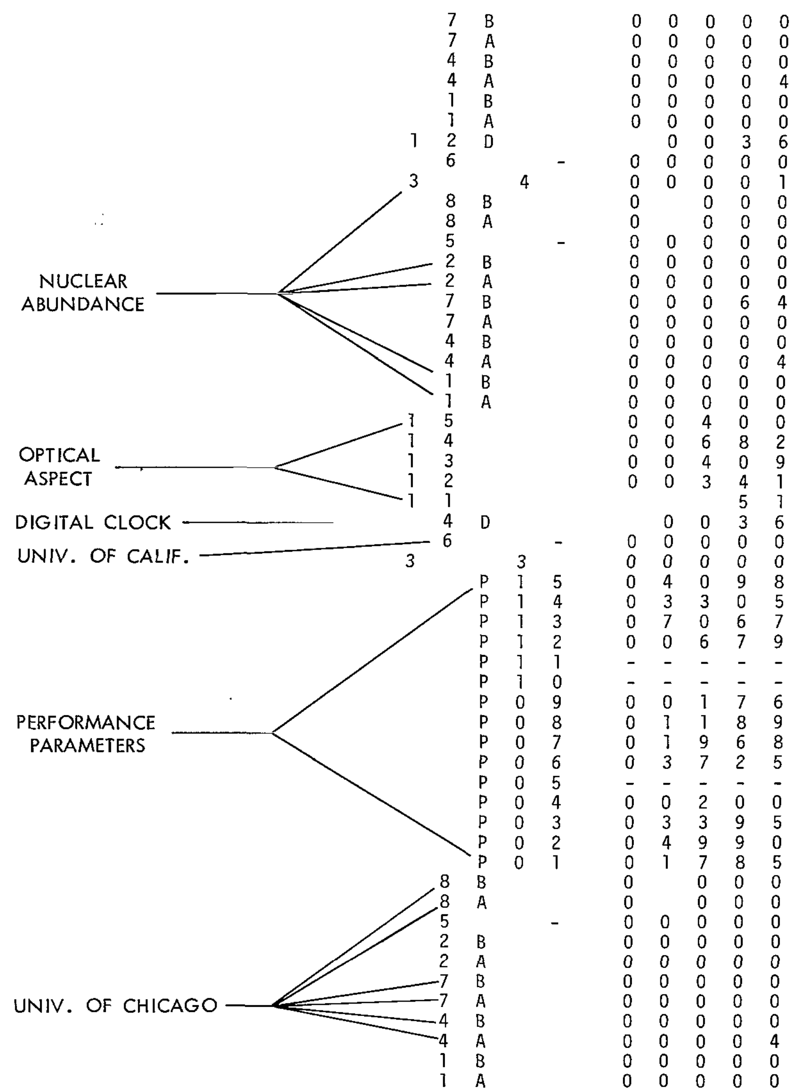


Figure 13 - Sample of digital data.

PROCESSING PROGRAM

The third segment of the master program consists of the processing programs, which provide all real-time data processing. Each experiment requires a particular kind of data processing ranging from mathematical calculations (e. g., standard deviations, averages, and equations) to checking of limits, or setting up coordinates for plotting, depending on the capability of the programmer and the computer. The varied analysis requirements of differing experiments demand individual and different programs which can be set up in modular construction.

Any segment or all of the experiment programs can be read into memory, and can be connected upon request by means of the linkage program, described later under the Interrupt and Linkage Program. The number of programs is limited by the core memory of the computer. While the system is programmed to accept any number of processing programs, processing is performed only in those experiment programs whose linkages are connected. There are several advantages in this type of construction: processing programs can be removed by disconnecting the links; changes can be made in the program, and the original program restored without affecting another program in operation; or a processing program may be left out completely when the particular experiment is not being tested. It should be noted that the processing programs are placed inside the data interrupts to eliminate the necessity of storing data for processing. The relatively slow data rate of the IMP telemetry permits the data to be processed as they enter the computer, thereby saving core memory.

INTERRUPT AND LINKAGE PROGRAM

By making program connections in the master program as determined by input from the typewriter, the interrupt and linkage program offers three options of operation provided in the master program by the idle program, the analog/digital program, and the processing programs.

EXECUTIVE PROGRAM

The executive program is considered the main program of the computer programming because the computer is operating most of the time in the executive program. Its principal purpose is to control the input and output functions of the computer.

This program consists mainly of input/output programs, and flags (an alert signal) set by the processing program, or the typewriter, for the purpose of outputting processed data in various forms. When data are requested, a command can be entered by means of the typewriter. As soon as the most recent telemetry data for that experiment have been processed, a flag is set in the executive program from the appropriate processing program.

When the interrupt is cleared and the computer is returned to the executive program, provided no other data are being read out and no other flags are set, status and designating instructions are executed, data are read out on the device selected, and the flag is reset.

BUFFER INPUT/OUTPUT PROGRAM

The buffer input/output program operates in a priority interrupt status to accommodate the paper tape reader, the paper tape punch, and the typewriter, all of which have relatively slow input-output capabilities. This is necessary to prevent possible drop-out of data or other processing and analysis functions while the computer is occupied. The buffer is programmed on the lowest priority interrupt to permit its being interrupted by any higher priority. An interlaced block transmission, operating independently of the central processor, is used in conjunction with the computer buffers to transmit data to and from the digital tape recorder, and to the line printer.

OVERALL COMPUTER SYSTEM FLOW

The combination of the five main programs (synchronization, master, interrupt and linkage, executive, and buffer input/output) constitutes the overall program system for analysis of IMP spacecraft performance.

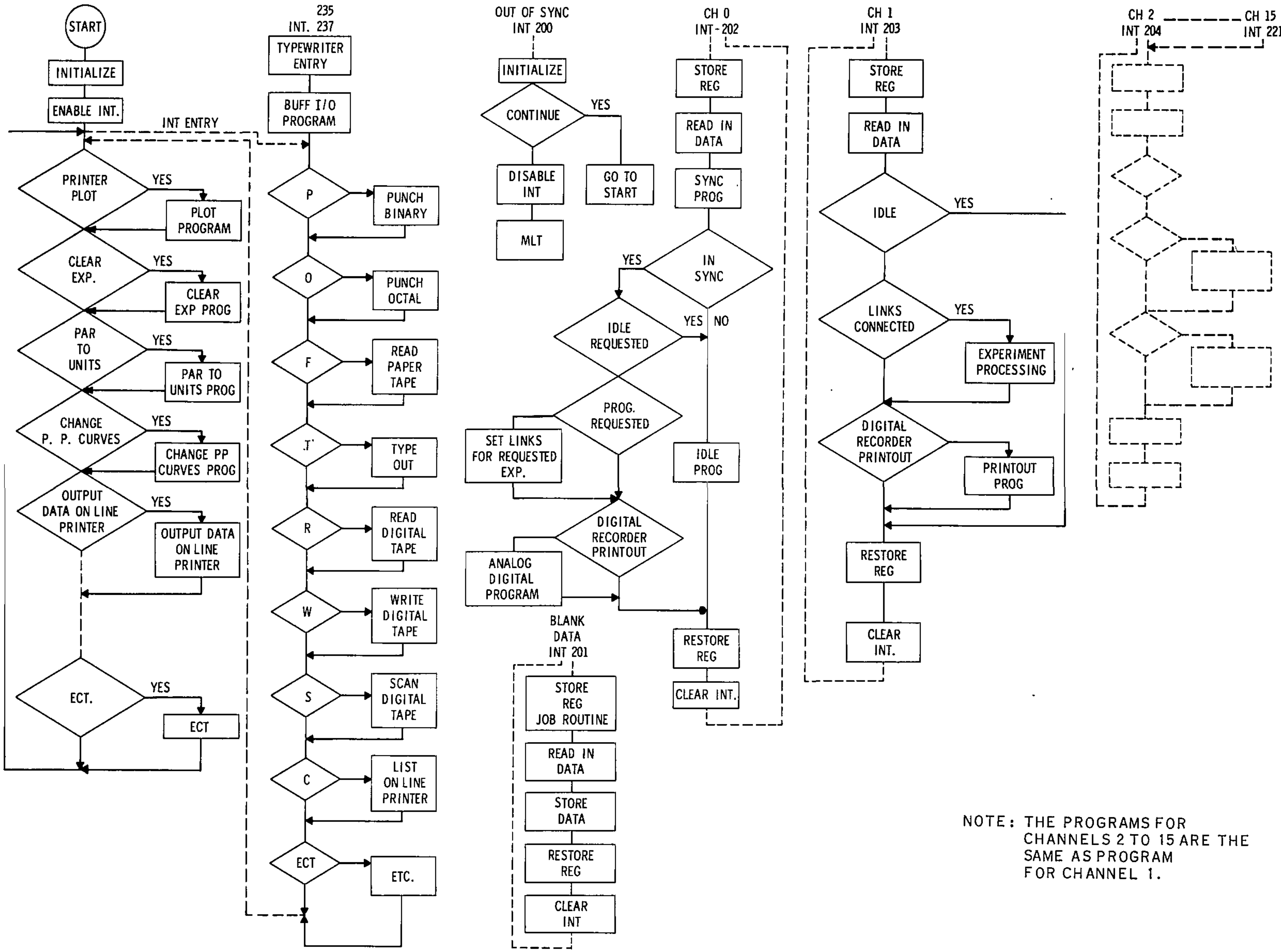
In general, programming for the processing of IMP spacecraft data was built around the interrupt system because of the real-time requirements. This system also satisfied the requirements for transfer of data and the necessity for priority operation.

Figure 14 shows the program flow in simplified form. The computer initially enters the executive program after initializing and enabling the interrupts. Once in the executive program, the computer continually monitors for requested input/output functions, such as plotting, outputting data to the printer, and other input/output functions. This continues until an interrupt occurs either from the typewriter, which is able under the interrupt control to enter control information into the computer without halting operations, or from the input buffer when data are available, for transfer to the computer. Since the interrupts are enabled as soon as data are available, an interrupt of higher priority will occur, permitting interruption from the executive program, or typewriter operation, and allowing in all cases the transfer of data.

Depending on the interrupt that occurs, one interrupt being associated with one specific channel, the computer will be interrupted to the particular programs associated with the interrupt.

The channel zero interrupt provides entry into the synchronization and linkage programs. In this case the data will be used to establish or verify sychronism. Depending on what is requested, these two programs will provide the proper control functions, such as connecting certain linkages, to process all, none, or certain programs in the indicated frame, and to output data on the printers and to perform other similar functions.

Should the interrupt be channel 1, or any of the interrupts from channel 1 through channel 15, the data would be entered into the computer, and depending on what frame is indicated by the synchronization program, processing of a particular experiment will take place, along with other functions.



NOTE: THE PROGRAMS FOR CHANNELS 2 TO 15 ARE THE SAME AS PROGRAM FOR CHANNEL 1.

Figure 14 - Block diagram of software system flow.

For example, in the case of the Range versus Energy Loss experiment conducted by the University of Chicago, the program requirements for analysis are to display the rate, pulse height analyzer, and miniature telescope values, and to provide processed data in the form of incremental and accumulated rates for four detectors, and the pulse height distribution plots for two pulse height analyzers. The rate data for the University of Chicago experiment are located in frames 0 and 8, channels 6 through 15, and the pulse height analysis data are in frames 1 and 9, channels 11 through 15, as shown in Figure 2.

Data are entered by interrupts on the above channels, and the linkages, determined by the frame identified in the synchronization program, are connected. The computer then enters the University of Chicago experiment's processing program, as shown in Figure 15.

Since the experiment is digital, the analog data for each channel are converted to digital values, as required, and are checked for validity. The digital values, determined by the channel interrupt, are then formed into the required digital rate words. The stored words are processed into incremental and accumulative values and stored again. The incremental and accumulative values are then checked to determine whether or not certain criteria are met, and the total information is stored for a printout. The interrupt is cleared, and the computer returns to the executive program. The same process is involved in determining the pulse height analysis. However in this instance, the processed data are stored for plotting.

At the end of the sequence, when all other data requested from the experiments have been processed and stored, a printout occurs, giving all the data for each experiment at one time, as shown in Figure 15.

In analyzing the performance of the University of Chicago experiment, when plots are requested for the pulse height analysis, a command is entered by means of the typewriter, and a plot of each pulse height analysis is produced, as shown in Figure 16.

CONCLUDING REMARKS

The use of the computer system described herein for analyzing the performance of the IMP spacecraft has resulted in greatly increased effectiveness and speed of spacecraft performance analysis.

Compared with previously used analysis methods, which required accumulation of data over long periods and time-consuming mathematical calculations by hand, the computer system successfully used in the IMP performance analysis has provided a relatively simple, flexible, accurate, and rapid means of spacecraft checkout. Also, additional advantages are a reduction in manpower requirements and mobility of the installation.

The advance made in IMP spacecraft performance analysis with the present computer system are convincing for its adoption for use in checkout of other types of spacecraft in the future.

SEQ. 1 TIME AT START OF SEQ. D092 H15 M48 S17

UNIV. OF CHICAGO:

4A	4B	7A	7B	8A	8B	MT	4A AVRG RATES ACC	4A AVRG RATES INC	4B AVRG RATES ACC	4B AVRG RATES INC	7A AVRG RATES ACC	7A AVRG RATES INC	7B AVRG RATES ACC	7B AVRG RATES INC	√	TIME (HRS)
000	0000	00	007296	000	000	00	066.7	008.3	137.7	003.0	022.3	010.5	623.4	633.8		00.15
000	0000	00	002368	003	000	00	062.3		128.6		020.9		622.5			00.16

CONDITIONS: 1. (*) NO. SIMULTANEOUS PHA READINGS 2. (√) 7A < 4A ■ 4B < 7B

3. (#) 4B > NO. PHA D-1 READINGS 4. (*) 4A > NO. PHA D-3 READINGS

UNIVERSITY OF CALIFORNIA:

GM-1	GM-2	ION	GM-1 ANALYSIS EVENTS	GM-1 ANALYSIS AVERAGE	GM-1 ANALYSIS ERROR	GM-2 ANALYSIS EVENTS	GM-2 ANALYSIS AVERAGE	GM-2 ANALYSIS ERROR	ION ANALYSIS EVENTS	ION ANALYSIS AVERAGE	ION ANALYSIS ERROR	TIME (HRS)
0006	0003	0000	0012	0005	100.	0010	0003	100.	0002	00.5	000.	
0005			0013	0005	100.							00.206

FR 4 D CLK= 00084

FR12 D CLK= 00084

NUCLEAR ABUNDANCE:

1A	1B	2A	2B		
09	393	17	081	AR =	0125
04	004	03	003	C =	012739

OPTICAL ASPECT:

SA	FN	ST	SP	EC
025	0341	0268	0582	0183

	FR.	CH 1	CH 2	CH 3	CH 4	CH 5	CH 6	CH 7	CH 8	CH 9	CH 10	CH 11	CH 12	CH 13	CH 14	CH 15
P. P.	2	19.71	50.14	223.00	01.64	-04.35	33.51	-03.40	12.07	02.31	----	02.00	----	94.21	14.50	05.17
		0465	0587	0754	0689	0765	0710	0754	0464	0622	0925	0915	0923	0674	0636	0694
AMES	5	1085	1086	1087	1066	1068	1065	1084	1065	1068	1065	1086	1064	1086	1085	2 1444
I. E.	10	1.25	0.00	2.49	2.52	2.56	2.62	2.67	2.73	2.75	2.78	2.82	2.86	2.89	3.01	3.01
F. G. A	3	1080	1082	1083	1034	1061	1083	1082	1042	1082	1081	1081	1061	1062	1042	1061
F. G. A	11	1063	1082	1080	1078	1032	1063	1082	1062	1061	1079	1083	1066	1078	1080	1060
F. G. B	7	1033	1084	1084	1080	1082	1083	1081	1034	1030	1061	1083	1062	1084	1082	1077
F. G. B	15	1083	1081	1082	1082	1083	1082	1081	1062	1042	1063	1083	1061	1065	1062	1064
MIT(BRST)	13	0.19	0.26	0.27	0.30	0.29	0.23	0.25	0.32	0.31	0.25	0.25	0.26	0.29	3.85	0.34
MIT(BLNK)	13	1.16	0.24	0.29	0.23	0.30	0.32	0.24	0.26	0.29	0.36	0.28	0.26	0.27	3.67	0.31
MIT(BRST)	14	0.17	0.28	0.32	0.29	0.28	0.27	0.29	0.32	0.31	0.24	0.27	0.28	0.30	3.36	0.22
MIT(BLNK)	14	0.71	0.27	0.33	0.30	0.31	0.35	0.34	0.28	0.29	0.28	0.30	0.27	0.23	3.69	0.22

Figure 15 - Sample printout of processed data of nine experiments.

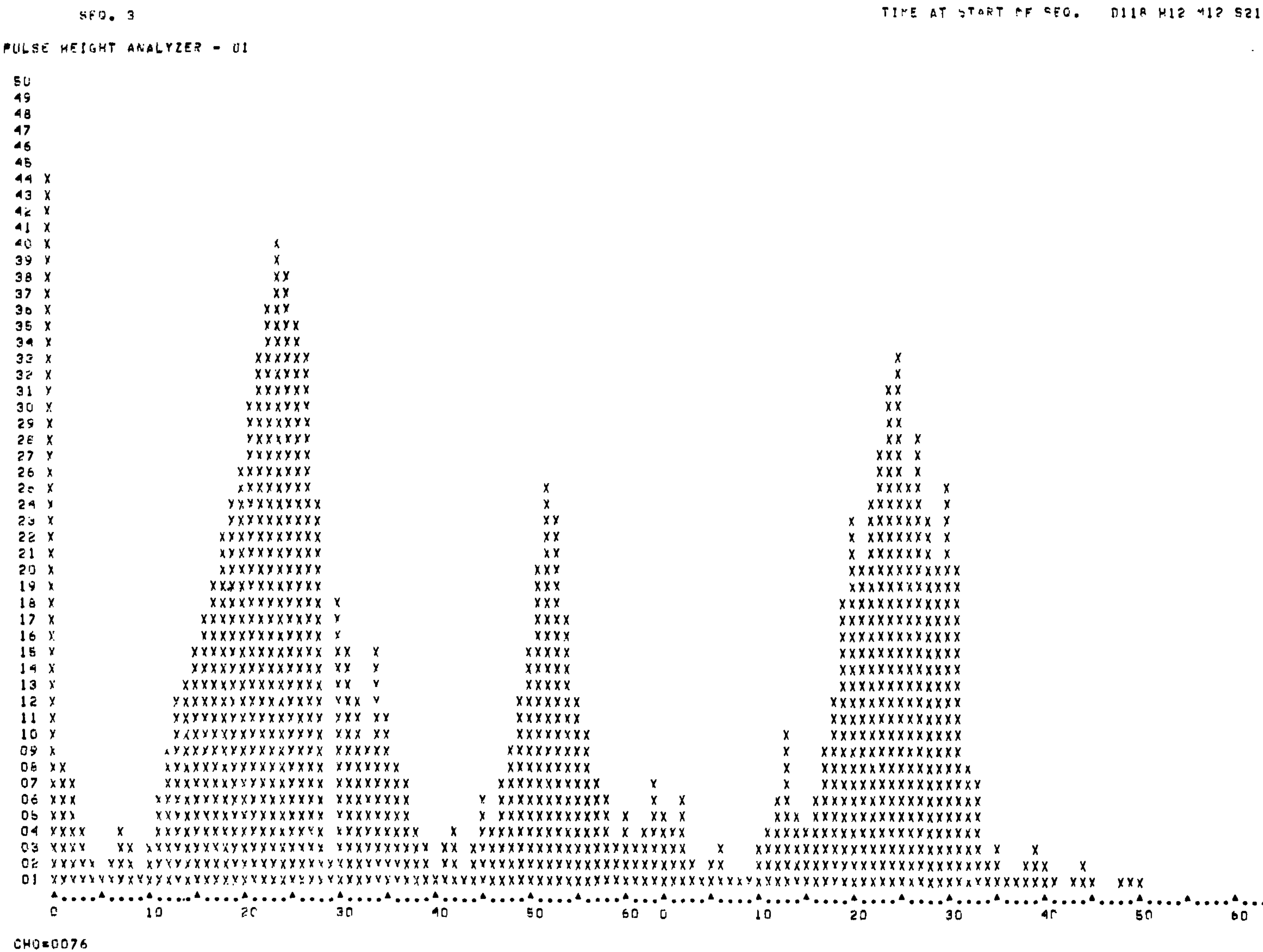


Figure 16 - Sample plot of the University of Chicago pulse height analysis.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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