NEW TECHNIQUES IN TELEMETRY DATA PROCESSING FOR THE APOLLO/SATURN S-11 PROGRAMS.

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Summary The Apollo/Saturn S-II telemetry data processing systems are described from concept through development and fabrication. The systems are large-scale, dual computer-controlled systems that accept PCM, PAM, PDM, FM/FM, and FM data and are capable of processing raw data for display as time-history digital plots, tabulations, or oscillograph recordings. Stored-program decommutators which eliminate distribution patchboards for each data word are integrated into the system, thus, providing a flexible means of routing data with a minimum of human error. High-speed digital plotter/printers produce final annotated plots of selected channels for engineering reports, Small general-purpose computers are integrated in the system to establish data flow discipline. The computers function as an entry for operation control and for preparation and loading information to all programmable equipment, interconnecting digital equipment, process monitoring, and diagnostic testing of subsystem operation. Versatility of computer or manual systems control provides an optimum telemetry data processing environment. Advanced techniques are briefly discussed as related to these and other telemetry data processing systems.

Introduction Early in the Apollo and Saturn S-II programs, it became apparent that existing telemetry data processing systems were inadequate for rapid and efficient handling of the large quantities of measurements that would have to be generated in several different formats, Improvements in the basic concept were required, As a result of the initial study, the following broad requirements were established:

- Flexibility and speed of setup
- Ease of control for recognizing and correcting data errors

- Ease of selecting individual or groups of measurements for plotting and evaluation
- Capability of presenting data at speeds commensurate with electronic digital equipment
- Capability of formatting data to established standards, such as IBM
- Automatic control by small general-purpose computers

These requirements led to the development of telemetry data processing systems that would effectively support development and acceptance testing, vehicle design evaluation, and quality assurance for the Apollo and Saturn S-II programs. The systems were established as an integrated group of telemetering subsystems, under dual computer control.

Personnel of the Space and Information Systems Division of North American Aviation, Inc. , devised and prepared the specifications for these systems in early 1962; fabrication and integration was performed by Radiation, Incorporated, Installation at North American Aviation's Downey, California, facility began in early 1964, and both systems were operational by August 1964. Each system is located convenient to vehicle design engineers with a basic objective of providing processed data, in useful form, to these engineers as soon as possible after each test. Figures 1 and 2 show overall views of the system.

System Data Flow Test- site recorded telemetry data, in either modulated or demodulated form, flows through the data recovery subsystem to the data reduction subsystem. The data recovery subsystem contains the signal conditioning equipment necessary to convert all data, regardless of initial format, to a common digital format with the option of being re-recorded on parallel digital recorders for entry into the data reduction subsystem. The reduction subsystem contains all processing and display equipment for complete arithmetic linearization and conversion to engineering units of the parallel digital data and display of these data in the form of annotated time-history plots, tabulations, and oscillograph recordings. Figure 3 is a simple functional block diagram of these subsystems, and Figure 4 presents a complete block diagram for the Saturn S-II data processing system.

Linkage between the recovery and reduction subsystems is through the programmed digital patch, a large solid-state switching matrix which permits interconnection of any signal conditioner to any related output device. Control of this data routing patch is accomplished by computer or operator console action, permitting extremely rapid, error-free system setup. Display of subsystem integration is presented to the operator on the control console as illustrated in Figure 5.

Data Recovery Subsystem This subsystem is composed of eight units, or rack groups, performing a system logical function. These units are as follows:

- RF unit
- analog patch and discriminator unit
- analog recorder unit
- stored-program decommutator unit No. 1
- stored- program decommutator unit No. 2 (Apollo system only)
- PAM / PDM and A / D unit
- timing unit (tape search and control unit)
- digital recorder unit

Data is recovered from analog tape recordings or PCM digital tape recordings. Data recovery has been improved by using predetection electronics to 1. 5 megacycles in analog tape recorders. All data inputs, regardless of initial format, can be converted to a common parallel digital format and re-recorded on one-inch magnetic tape. The parallel digital recorders are operated at any one of seven speeds at a maximum of 120 inches per second with a maximum packing density of 1000 bits per inch. Figure 6 shows the two digital tape recorders included in the systems. Playback of 120 inches per second permits word transfer rates up to 120, 000 per second. Depending upon the initial analog recording speed, playback rate increases of up to 32 to 1 may be realized from this intermediate recording technique. The advantage of being able to increase the playback rate is illustrated in the next process, where it is necessary to select (decommutate) the measurements within a given time period.

Decommutation and routing to selected outputs is accomplished by the newly developed “stored-program decommutator.” This unit separates, through synchronization, the PCM data into its individual channels. Desired channels are selected by stored routing instructions. These routing instructions are stored in two memories: a 256-word prime memory for storing prime word (non-subcommutated routing instructions) and a 1024-word memory for subcommutated words. The subcommutated memory may also be used as a prime word memory should the number of prime words exceed 256, as in the case of Apollo checkout PCM data. Program instructions can be inserted manually under operator control, but normally are inserted automatically from either of the systems’ computers. Data channels can be skip-edited by increments of 2, 5, 10, 20, 50, or 100 frames. Figure 7 shows the stored-program decommutator and Figure 8 shows the instruction word formats for the memories of this unit.

Data extraction to specified intervals of time is made possible with a “tape search and control” unit. With this unit, serial amplitude-modulated IRIG A, B, or C, as well as AMR D1 or D5 time codes on both analog and PCM digital tapes, may be scanned to provide motion controls for the magnetic tape units. An elapsed-time code generator allows each data sample to be referenced to test events.

Parallel “time-of-year” data words multiplexed with data on PCM digital tape can also be used for tape search operations. Start-stop time for searching magnetic tapes can be under computer control or be controlled by manual switch-setting at the control console, The digital time words from the tape search and control or time code generator are multiplexed with data when recording on IBM tape. This capability enables the time identity of the formatted data to be preserved for accurate off-line plotting of data versus time. This equipment is shown in Figure 9.

Data Reduction Subsystem This processing and display subsystem contains the following eight units:

- process controller computer
- data corrector computer
- format control buffer
- dual tape control unit
- D/A converter and oscillograph unit
- plotter/printer No. 1
- plotter/printer No. 2 (Apollo system only)
- code converter

The data reduction subsystem receives decommutated data from the recovery subsystem and completely processes these data into the following formats:

- IBM-compatible magnetic tapes containing scaled and linearized data
- Completely annotated digital plots of specific data channels versus time (this data is in engineering units)
- Oscillographic recording of selected data channels
- Digital tabulations

Several of these operations may be carried on simultaneously by two, on-line, general-purpose computers (SDS 920). One computer is used as a process controller and the other as a data corrector. The configuration and operation of all digital systems are under the control of the process controller, and data scaling and linearization are performed by the data corrector. Both computers can function as a data corrector or as a process controller.

While functioning as a process controller, the computer commands the solid-state cross-point connections to close, which interconnects selected digital units. An extremely flexible routing of digital data is achieved by this technique of interconnecting system units. The computer also monitors the flow of data by means of 28 priority interrupts applied to the computer from the subsystem units and by computer-generated sense codes. Parity errors, sync loss, end of tape, etc. , cause interrupts which are analyzed, allowing appropriate action. In addition, the computer diagnoses the subsystems for preventative maintenance and malfunction isolation.

The high-speed plotter/printers provided in the systems are Hogan Faximile Corporation machines with specially developed electronics. This equipment is shown in Figure 10. Printing, an electrochemical process, is accomplished by 1024 styli laterally arranged across eleven-inch translucent paper. In the plotting mode, printing is provided horizontally on the plot for annotation of engineering units and timing. In the printing mode, characters are rotated 90 degrees under memory control. Sixty-one characters are provided for printing and annotation.

Plotting rates up to 1000 points per second per channel and up to 16 data channels are available with five selectable speeds from 0. I inches per second to 10 inches per second. The actual time of plotting a "data run" from tapes may be speeded up by factors of 100 to over "real-time" to enable data sampled at low rates during a test to be plotted quickly. In the printing mode, tabular data can be generated at a rate of 3000 lines per minute with up to 128 characters per line.

Advanced Techniques Additional spacecraft testing programs have resulted in new techniques being applied to the present Apollo/Saturn S-II telemetry data processing systems and other systems supporting these major programs.

The use of carry-on data interleavers developed by the General Electric Company for acceptance checkout of the Apollo Command and Service Modules creates a complex serial PCM data stream. Four Apollo PCM data formats are interleaved on a word-by-word basis to form a resultant data stream of four times the original rate or 204.8 kc. The decommutation of this data, which now contains several levels of subcommutation, has resulted in advanced stored program decommutators such as the Radiation Incorporated Series 540 Decommutators. Wide commutation ratios as well as multiple format storage and processing can be handled by this equipment.

One of the most significant trends in telemetry processing is an increase of computer automation of signal conditioners and display equipment as in the Apollo/Saturn S-II systems.

Further current advancements in the industry include:

- automated PCM bit and group synchronizers
- switchable discriminators under computer control
- automatic analog signal switching by use of crossbars

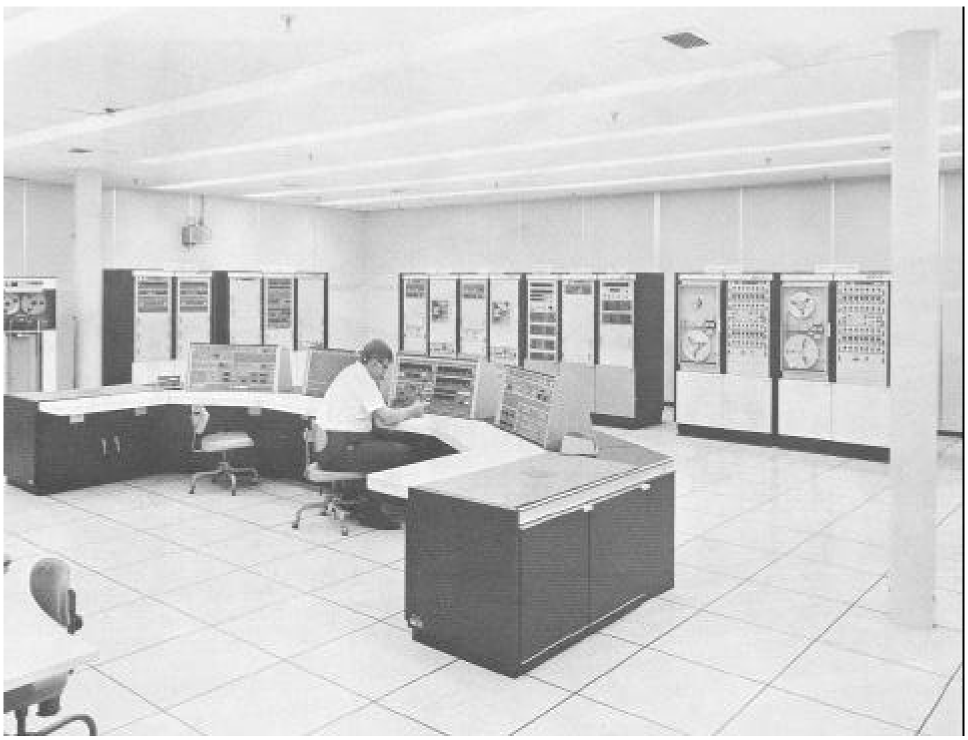


Figure 1. View of Data Processing Laboratory

Figure 2. View of Data Processing Laboratory

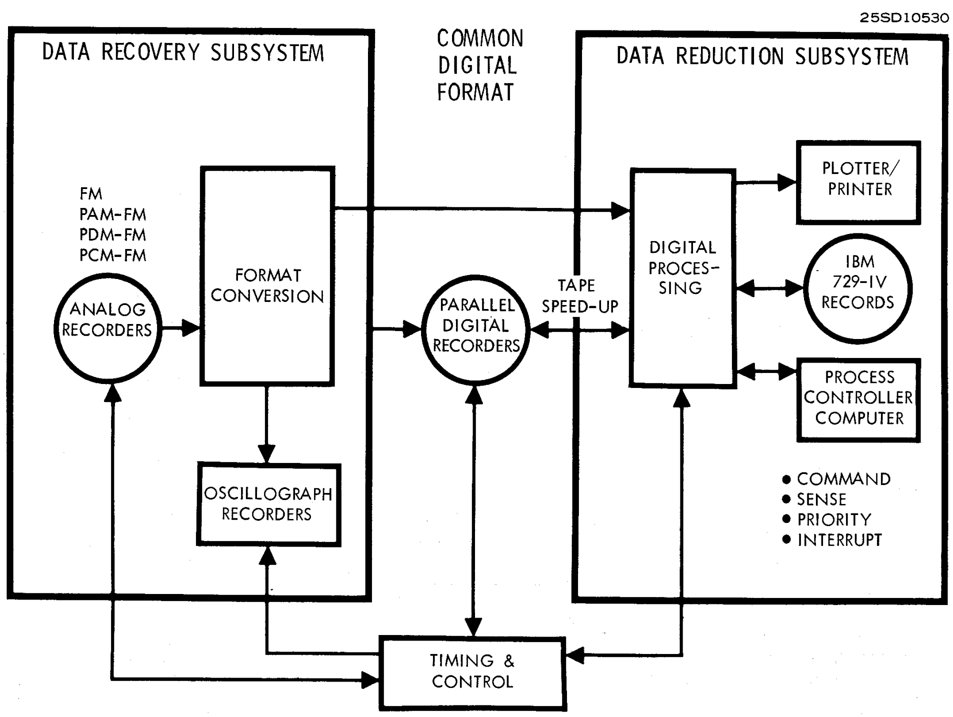


Figure 3. Functional Diagram - Apollo/Saturn S-II Systems

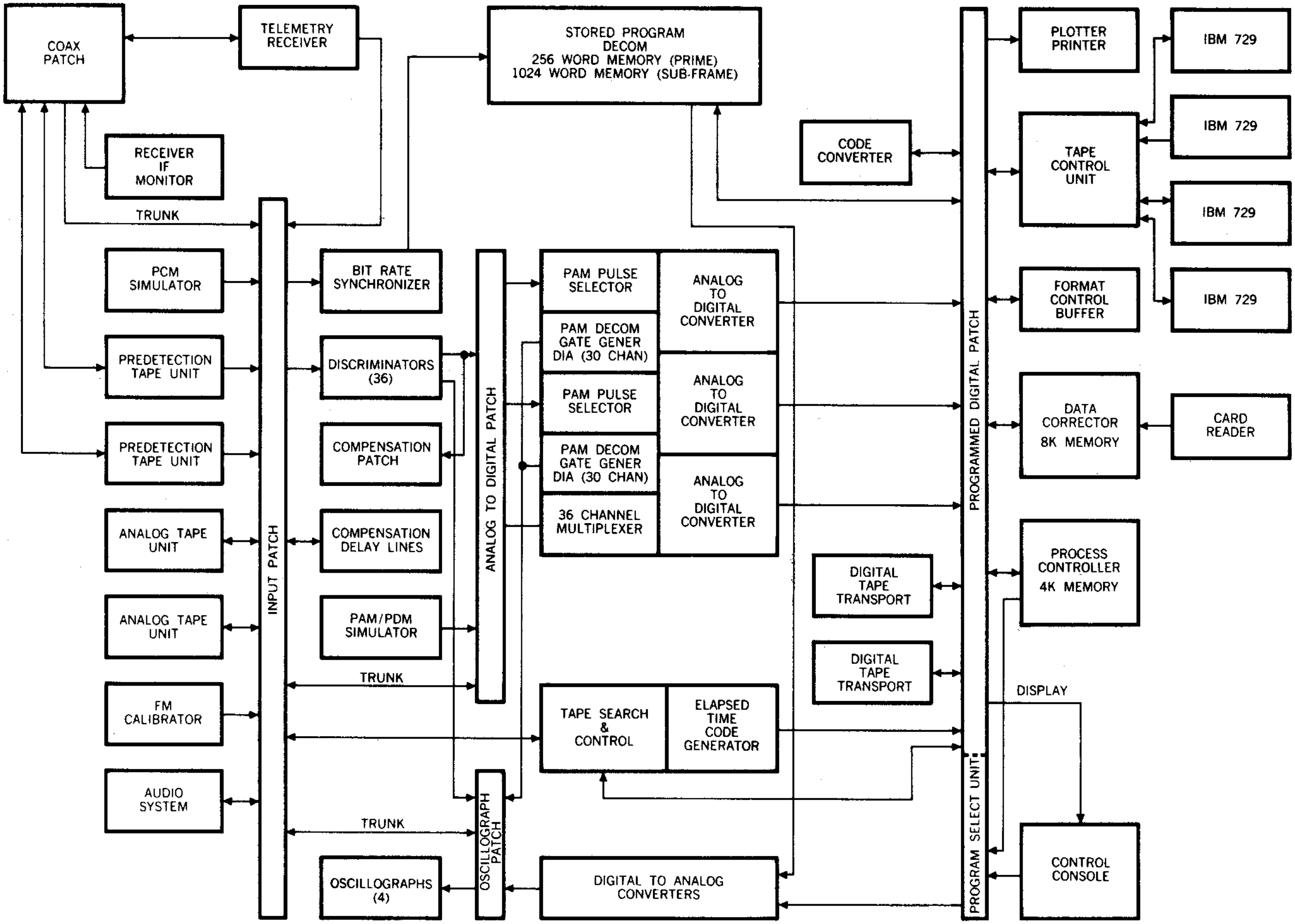


Figure 4. S-II Data Processing System Diagram

Figure 5. Control Console

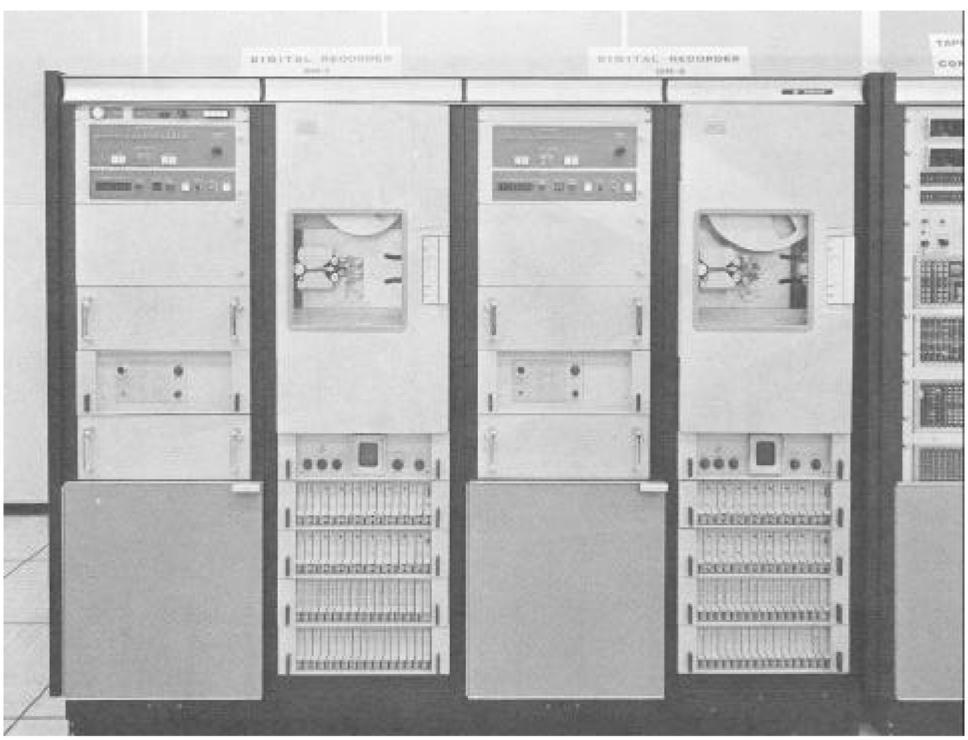


Figure 6. One-Inch Digital Recording Equipment

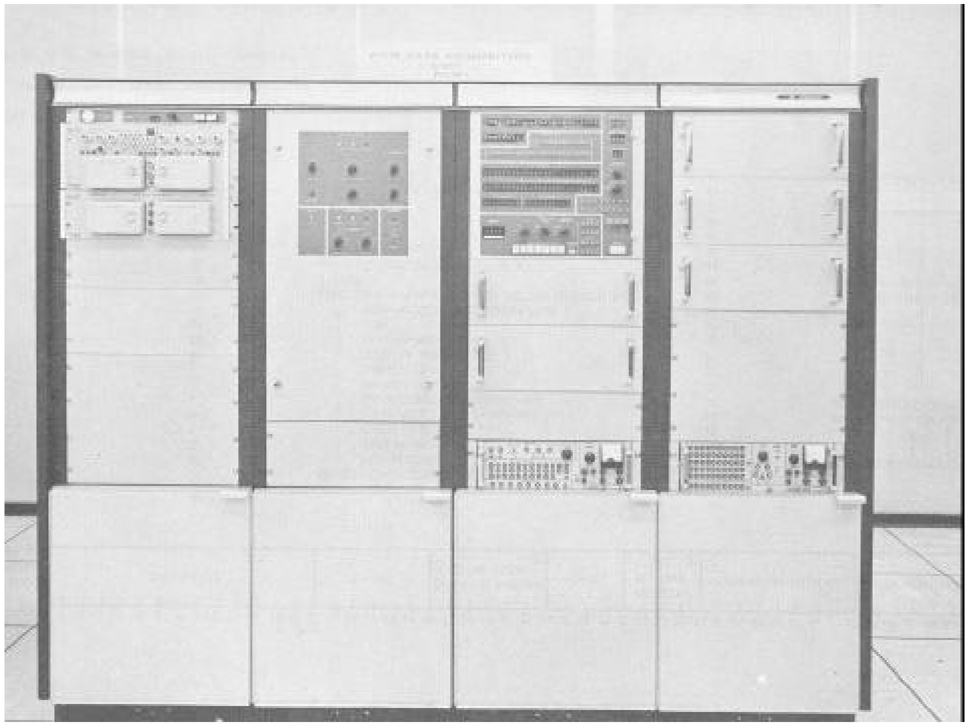
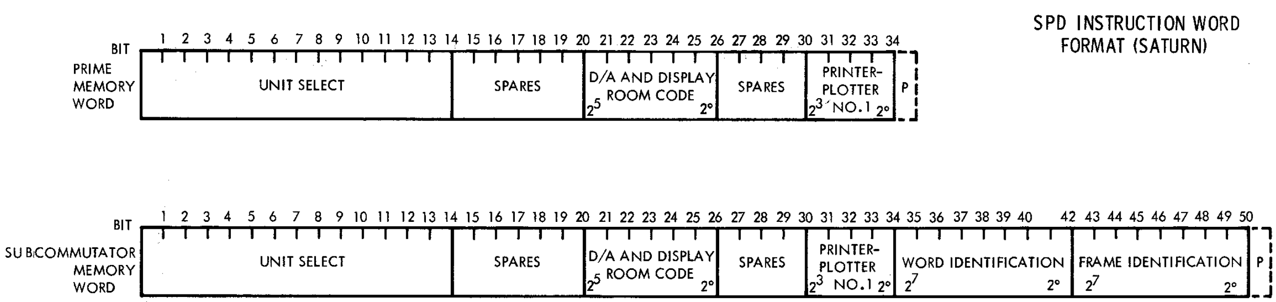


Figure 7. Stored-Program Decommutation Equipment



BIT	FUNCTION	BIT	FUNCTION
1	SELECT PCM RECORDER NO. 1	26-29	SPARES
2	PCM RECORDER NO. 2	30	PRINTER-PLOTTER NO. 1 CODE BIT 0
3	TAPE SEARCH AND CONTROL UNIT	31	
4	CODE CONVERTER UNIT	32	
5	DATA PROCESSOR COMPUTER	33	PRINTER-PLOTTER NO. 1 CODE BIT 3
6	DATA CORRECTOR COMPUTER	34	WORD IDENTIFICATION BIT 0
7	DISPLAY ROOM	35	1
8	DIGITAL DISPLAY NO. 1	36	2
9	DIGITAL DISPLAY NO. 2	37	3
10	PRINTER-PLOTTER NO. 1	38	4
11	D/A	39	5
12	FORMAT CONTROL BUFFER UNIT	40	6
13	SELECT PRINTER-PLOTTER NO. 1 CODE FOR FCB UNIT	41	WORD IDENTIFICATION BIT 7
14 - 19	SPARES	42	FRAME IDENTIFICATION BIT 0
20	D/A AND DISPLAY ROOM CODE BIT 0	43	1
21	1	44	2
22	2	45	3
23	3	46	4
24	4	47	5
25	D/A AND DISPLAY ROOM CODE BIT 5	48	6
		49	FRAME IDENTIFICATION BIT 7

NOTES:

1. BIT 34 OF PRIME MEMORY WORD IS A PARITY BIT
2. BIT 50 OF SUB MEMORY WORD IS A PARITY BIT

Figure 8. Stored-Program Decommutator Instruction Word Format

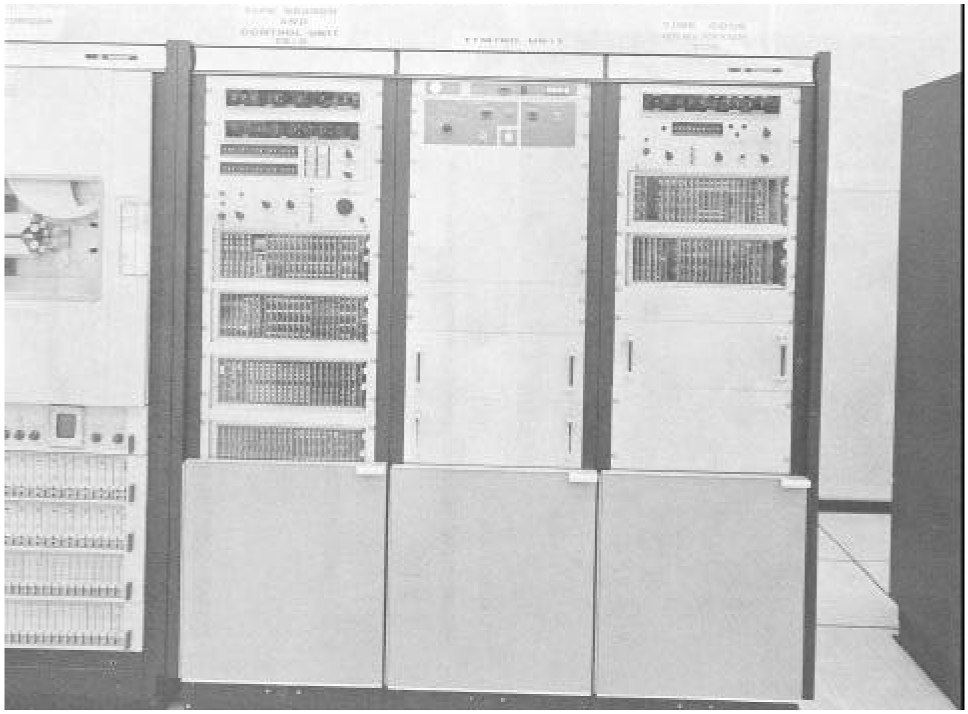


Figure 9. Timing Equipment

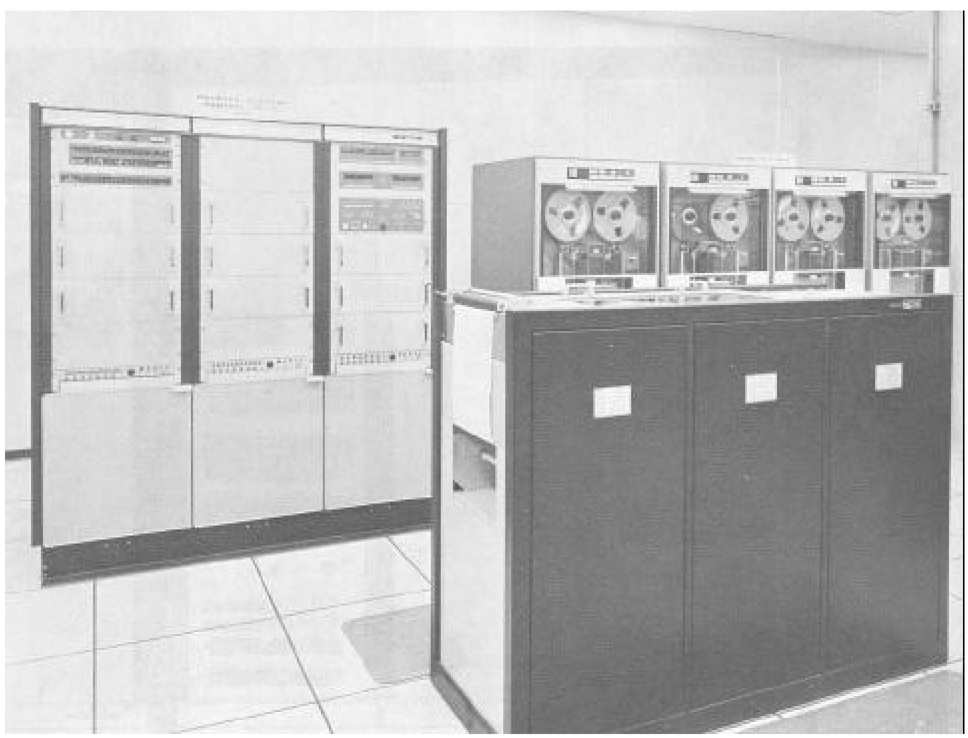


Figure 10. Hogan High-Speed Plotter