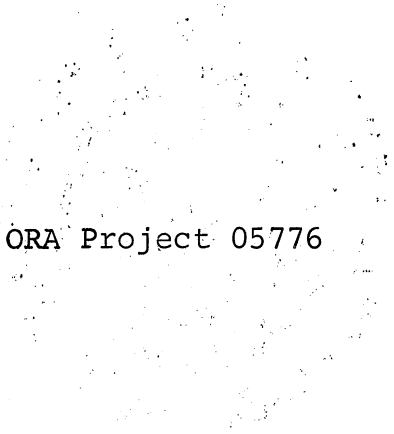
THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Electrical Engineering
Space Physics Research Laboratory

THE SPACE PHYSICS RESEARCH LABORATORY DATA CONDITIONING SYSTEM



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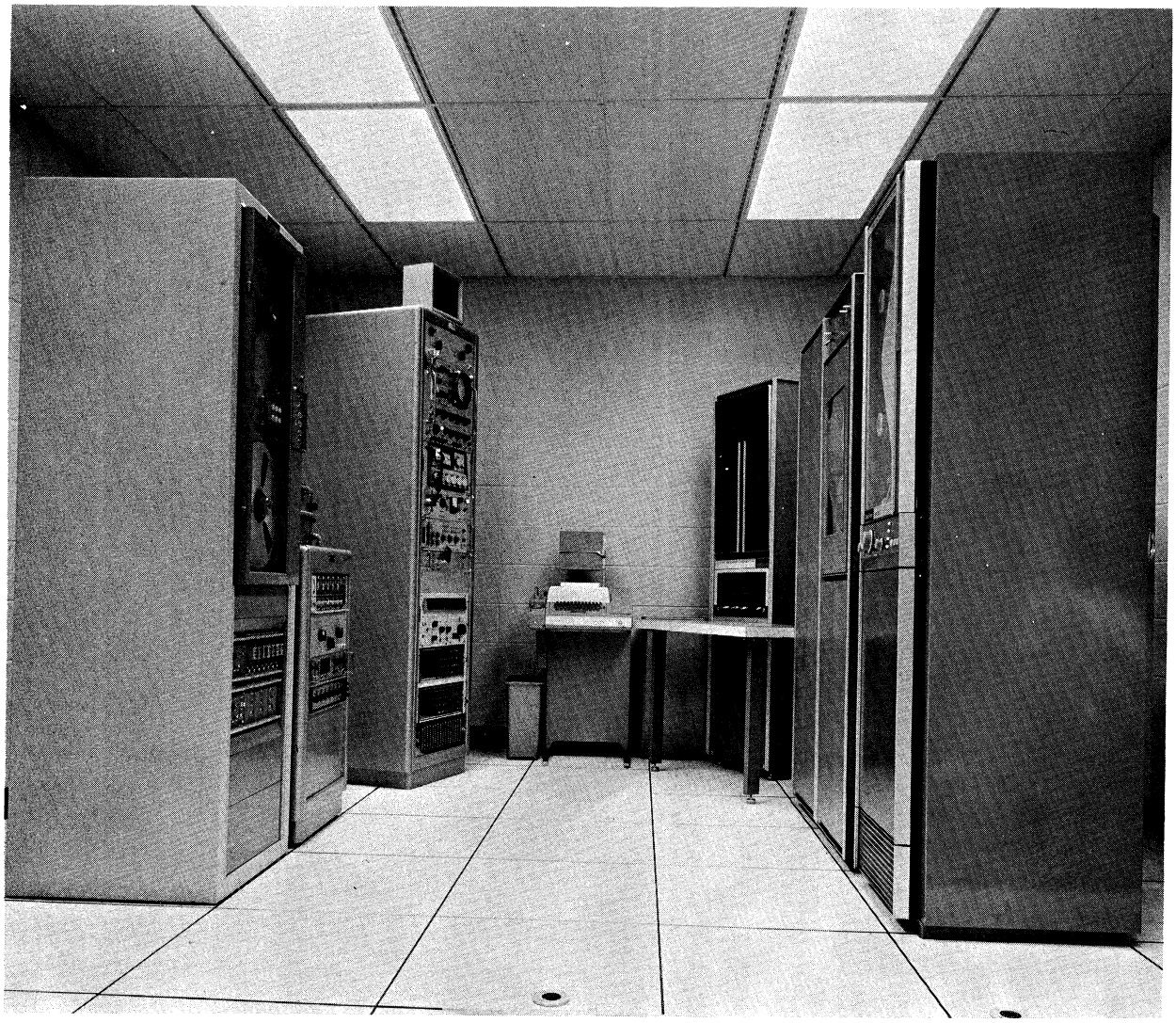

Figure 1. The Space Physics Research Laboratory data conditioning system.

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1. INTRODUCTION

By 1963 the volume of data obtained by the Space Physics Research Laboratory from rocket-borne experiments was burdening the existing data reduction facilities and it was evident that, without a major increase in data reduction capability, data from a large meterological program for 1964 and 1965 sponsored by the Goddard Space Flight Center could not be processed in time to be of maximum utility. One of the most time-consuming operations that it was clearly possible to shorten was the digitization of data. An automatic system, proposed to and subsequently funded by the NASA Goddard Space Flight Center, was designed to make the time required to digitize data negligible compared to the total data reduction time and, also, to provide an increase in digitizing accuracy. This report describes the capabilities of the system.

2. CAPABILITIES

2.1 General

The data conditioning system will automatically digitize analog data at rates as high as 13,000 samples per second and store the digitized data on magnetic tape in the format required by the University of Michigan IBM 7090 computer.

2.1.1 Data Inputs. The system is designed to digitize any analog data of up to ±10 volts amplitude and frequency content less than 2000 cycles per second; in addition, since the bulk of data acquired by SPRL from rocket-borne experiments is IRIG* Standard analog FM and pulse-amplitude-modulated (PAM) FM data recorded on magnetic tape, the necessary special equipment is provided for playback and detection of these forms of data to prepare them for sampling.

*Inter-Range Instrumentation Group

2.1.2 Digitizing Capability. The system will time-multiplex and digitize as many as ten channels of analog data into 12-bit samples at a maximum rate of 1,300 samples per second per channel. A single channel may be sampled at a rate as high as 13,000 samples per second (See Appendix B for table of sampling rate versus number of channels). Sampling rates may be synchronous, synchronized to a reference frequency on the analog magnetic tape, or asynchronous, under control of an external command signal. The sampling rate may be set at any frequency between zero cps and the upper limits of the system. Also, a time code may be sampled at the same time the analog data are being digitized, and stored on the magnetic tape with the digitized data. The capabilities of each major component of the system are described in the following paragraphs to effect a methodical detailed description of the capabilities of the entire system. Figures 1, 2 and 3 illustrate the physical configuration of the system. Figure 4 illustrates the paths of data and control flow between major system components.

2.2 Analog Magnetic Tape Recorder/Reproducer.

This unit is a Mincom C-100, capable of speeds of 1 7/8, 3 3/4, 7 1/2, 15, 30 and 60 inches per second. It is a seven track (1/2 inch tape) machine with IRIG-Standard heads and will accomodate 14 inch reels. The frequency response of the machine at 60 ips is 120 kc, and at 30 ips, 60 kc. The flutter specification is .2% peak-to-peak at 60 ips for a .1 cps-10kc bandwidth; the speed accuracy specification is $\pm$.15% of nominal.

2.3 FM Discriminators

Four EMR 210 discriminators are available in the system, with a fifth discriminator being used to provide 100 kc-reference tape-speed compensation. However, it is possible to add discriminators to the system if a requirement develops

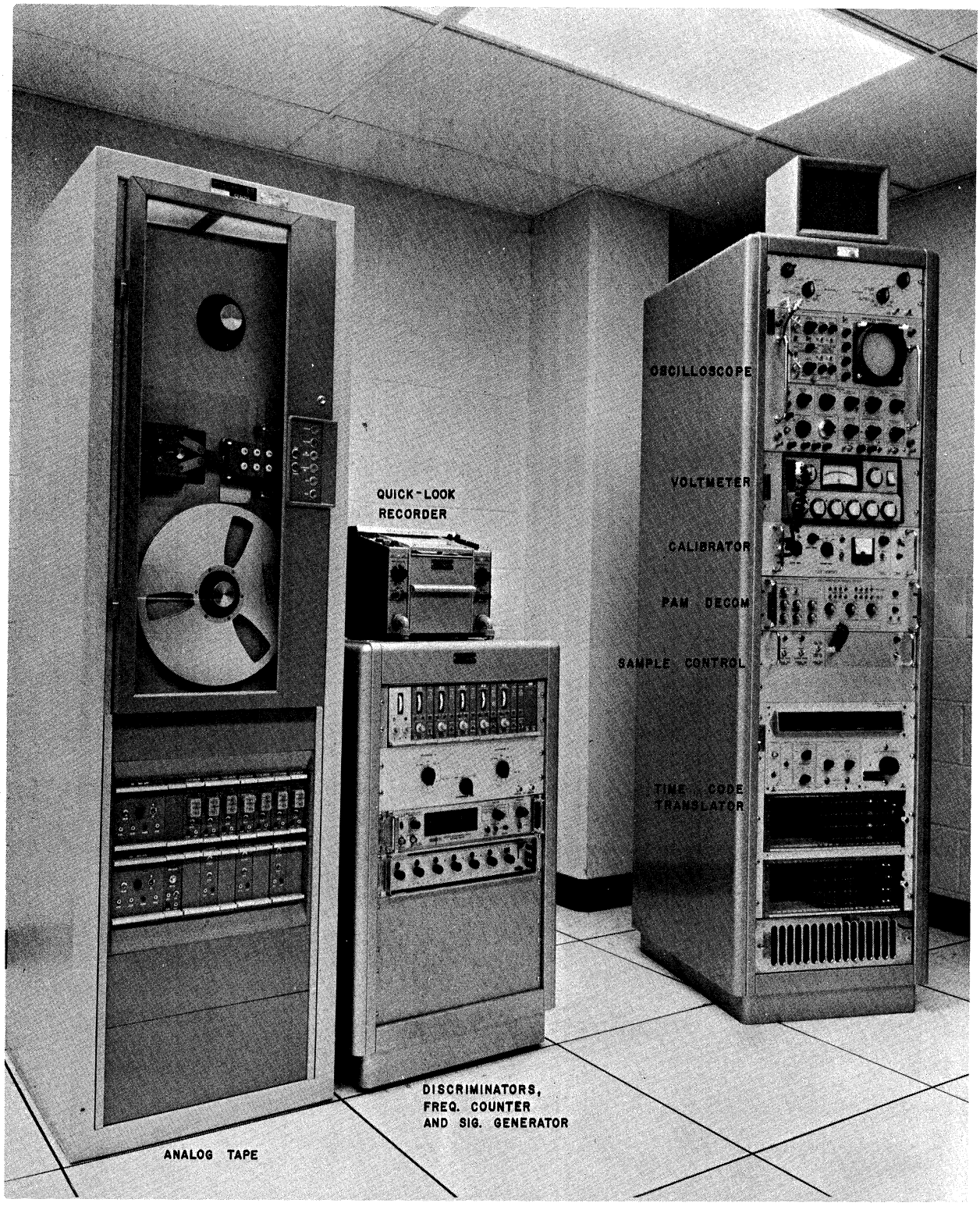


Figure 2. Analog magnetic tape recorder/reproducer, FM discriminators, PAM decommutator, sample controller, time code translator, and auxiliary equipment.

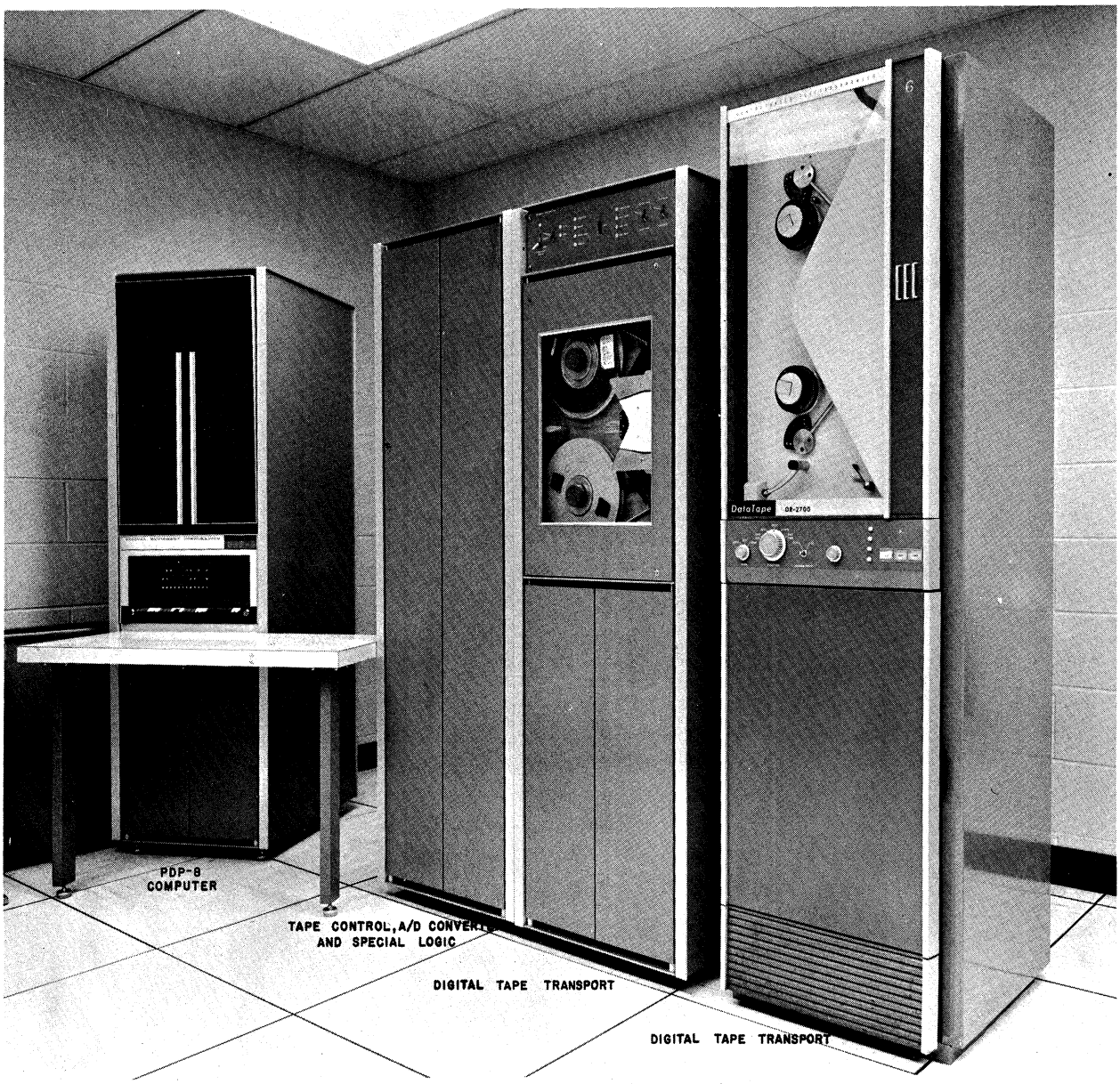


Figure 3. Digital sub-system.

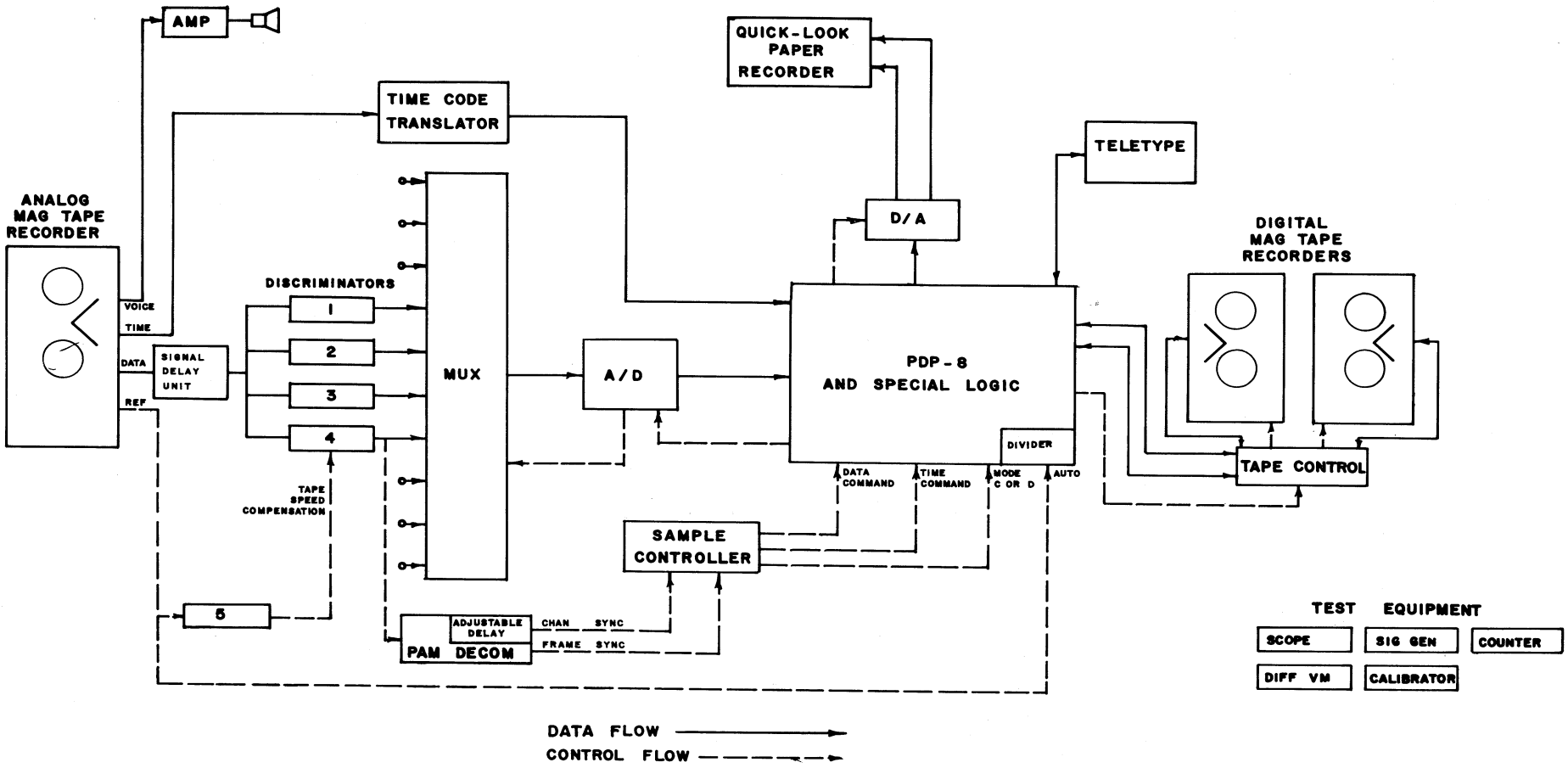


Figure 4. Conditioning system data and control flow.

for simultaneous playback of more than four channels of data. The channel selectors are plug-in units and the following IRIG channels are on hand: 10, 11, 12, 13, 14, 15, 16, 17, 18, A, C, and E. The accompanying low-pass filters are switchable from "constant delay" to "constant amplitude". Measurement of the linearity of the discriminators has shown that the deviation of the output voltage from the best straight line is less than .05% of the full bandwidth peak-to-peak voltage, as specified. The output impedance of the discriminators is less than 2 ohms and the phase-locked-loop circuits have been optimized for a modulation index of five.

2.4 PAM Decommutator

To enable the sampling rate of the system to be synchronized to the PAM commutation rate, a Vector DZ-1113 PAM decommutator is utilized mainly as a PAM synchronizer. Rate cards are available to phase-lock PAM rates of 30, 75 and 150 channels per second; other rates are possible if cards are obtained. The output of the decommutator is then frame sync pulses and channel sync pulses. An extra feature of the unit is a quick-look decommutator capability where any one channel may be selected for decommutation. The output corresponding to this channel is normalized to 0 to +5 volts and the data level is held after each sample until the next frame provides a new sample.

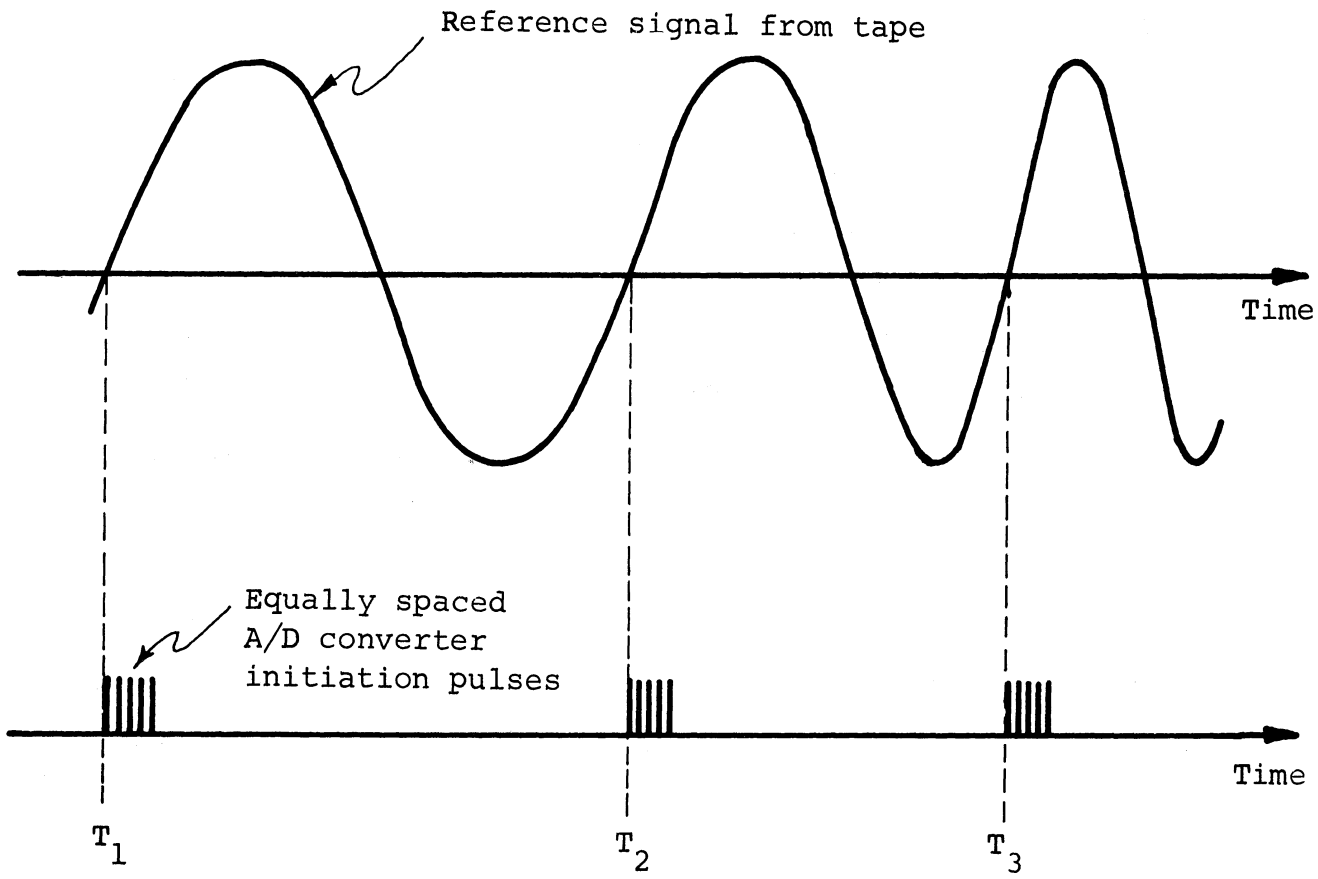
2.5 Time Code Translator

One of the tracks of the analog data magnetic tape recordings made during a rocket flight carries time information in a binary or BCD format, amplitude-modulated on a 1000 cps carrier. The translator, an Astrodata 6220, strips the serial time data from the carrier and provides an operator display and a parallel BCD output which includes hour, minute, second and millisecond (not displayed) information, updated every millisecond. An internal oscillator is synchronized

to the incoming time code and enables the translator to continue to provide valid output in spite of a loss of as many as 3 frames of input. Plug-in decoding modules available with the system are for the NASA 36 Bit, AMR D-5, and IRIG A time codes, others being obtainable if necessary.

2.6 Sample Controller

The data conditioning system was designed to allow the sampling rate of the system to be synchronized to the analog magnetic tape recorder speed to eliminate errors caused by tape flutter and speed drift. To obtain this capability, the system was designed so that each multiplexer scan could be initiated by a signal external to the system. If, for example, each zero crossing of a reference frequency on the analog magnetic tape is used to initiate a multiplexer scan, the desired synchronization will be achieved. However, the channel-to-channel rate of the multiplexer is controlled by an internal clock which does not vary with the analog tape speed and if the multiplexer is to scan more than one channel some error will be introduced. This error will be small if the channel-to-channel rate is high compared to the number of scans per second (see Figure 5). Four modes of sampling are available; these are defined as the automatic data-automatic time, automatic data - command time, command data - automatic time, and command data - command time modes. Automatic data sampling takes place when the system is programmed to electronically divide a cyclic reference signal (usually 100 kc from the analog magnetic tape) by any desired integer from 1 to 4096 and initiate the multiplexer scans at the rate corresponding to the quotient. Command data sampling takes place when the system is programmed to sample immediately (25 microsecond delay) after receipt of an external command pulse. Automatic time sampling provides one time sample at



T_1, T_2, T_3, etc., indicate unequally spaced times of initiation of a 5-channel multiplexer scan.

Figure 5. Effect of increasing analog tape speed on sampling rate.

the beginning of each new digital tape "record"; the time of the sample being the time corresponding to the particular data sample specified by the program. Command time sampling allows for the immediate sampling of the time code upon receipt of an external command pulse. The time sampling modes are also under program control. The function of the Sample Controller is to shape these data commands and time commands into pulses of the proper power, rise time and logic levels for driving the sampling circuits. Input signals to the Sample Controller may be sine waves, square waves or pulses, for example, and of any amplitude greater than 2 volts peak-to-peak. A typical data command input is the decommutator channel sync pulse; a typical time command input is the decommutator frame sync pulse.

2.7 Digital Sub-System

The digital sub-system, supplied by the Digital Equipment Corporation, consists of a PDP-8 computer, special logic section, format generator, tape control unit, and several input-output devices.

2.7.1 PDP-8 Computer

Except for initiation of sampling in the "command data" and "command time" modes, the timing of digital sub-system operations is completely under control of the PDP-8 computer. This means that control pulses to the special logic section, format generator, tape control unit, etc., are generated in the computer according to the computer program. In addition, the memory of the computer allows the sampling rate of the system to be independent of the digital tape recorder packing density and tape speed, and allows "record" gaps to be placed on the digital magnetic tape without any loss of data; this is accomplished by storing sampled data in the computer memory until the desired "record" length has been accumulated, then

"dumping" the data onto the digital tape. The PDP-8 has a cycle time of 1.5 microseconds and a memory size of 4096 twelve-bit words.

2.7.2 Special Logic

The function of the special logic section is (a) to sample and hold the time code until the program calls for it, (b) to divide the analog tape reference signal to obtain the desired sampling rate in the "automatic data" mode, (c) to store an A/D sample until called for by the program, and (d) to implement the various sampling modes. Under this last function come the details of stopping or allowing external command pulses and internally generated pulses to pass to the A/D converter and time-sampling logic. Another function of the special logic is (e) to allow the data sampling mode to be changed from "automatic" to "command" during a data run through use of an external control line; a transition from -3 volts to 0 volts puts the system in the "automatic data" mode and a transition from 0 volts to -3 volts puts the system in the "command data" mode. Change-over time is less than .5 microseconds.

2.7.3 Format Generator - Tape Control

The format generator - tape control unit, a DEC 57A and DEC 520, prepares the data for packing onto digital magnetic tape at the density and in the format required by the IBM 7090 computer. The unit provides packing densities of 200, 555½, and 800 characters per inch, and in addition, allows any of up to eight tape recorders to be selected by the programmer with a change-over time of less than 2 microseconds.

2.7.4 Multiplexer/Analog-to-Digital Converter

This unit, manufactured by Adage Incorporated, is an input device and contains a 10 channel multiplexer and the analog-to-digital (A/D) converter. The multiplexer is ran-

domly addressable and the A/D converter will digitize signals of ±10 volts amplitude or less into 12-bit samples. A sample-and-hold circuit is included in the unit to obtain a sampling time uncertainty of less than 100 nanoseconds. In operation the multiplexer - A/D converter will scan once, conforming to a programmed sequence, immediately upon receipt of a sample initiation pulse. The scan channel-to-channel rate can be varied by adjusting a front panel potentiometer control to give rates from about 2,000 to 15,000 channels per second. Each channel of the multiplexer has a 100,000 ohm input impedance which is held constant regardless of whether or not the channels have been addressed. The over-all accuracy of the unit is well within the ±10 millivolt maximum offset voltage specified for the digital sub-system.

2.7.5 Digital-to-Analog Converters

The digital-to-analog (D/A) Converters are output devices and are used to obtain a check on the quality of the analog-to-digital conversion process during a data run. Two D/A converters convert any two of the ten channels back to analog form as the data enter the computer memory. The D/A units are 8 bit converters, and their output is normally displayed and compared with the analog input to obtain a visual dynamic check on the digital sub-system.

2.7.6 Model ASR-33 Teletype

The Teletype unit is an input-output device, providing an eight hole paper tape punch and reader plus a page printer.

2.8 Digital Magnetic Tape Handlers

Two CEC DR-2700 digital magnetic tape handlers serve as input-output devices. Normally, digitized data are stored on the magnetic tapes in an IBM format and then processed on the

University of Michigan IBM 7090; output is then obtained from the associated IBM line printer. The tape handlers also provide a means of loading programs into the computer, since after programs are punched on paper tape and stored in the computer, they may be transferred to magnetic tape. Once programs are stored on magnetic tape they may be loaded into the computer in fractions of seconds, instead of the fractions of hours needed for paper tape entry.

3. OPERATOR CONTROL

To operate the system, the operator adjusts the analog equipment, places the program in the computer, and then types in control information pertaining to an individual data run. The information consists of the following: identification, sampling mode, reference frequency division ratio if the "automatic data" sampling mode is specified, multiplexer sequence, D/A converter sequence, and start and stop times (to be taken from the time code). Once this information is entered in the computer, the operator needs only to start the analog tape and push the computer start button; the remaining operations are automatic.

4. AUXILIARY EQUIPMENT

The auxiliary equipment consists of equipment for system calibration and testing, and "quick-look" display of data.

4.1 Calibrator

Calibration of the A/D converter is accomplished by providing the converter with a series of steps from a calibrator of $\pm$ 0,2,4,6,8 and 10 volts and comparing the A/D reading with the known calibrator output. The calibrator also provides simultaneous outputs of ten different voltages for checking the Multiplexer sequencing.

4.2 Potentiometric Voltmeter

The potentiometric voltmeter, a Honeywell 852 certified to .01% accuracy, is used to check the calibrator accuracy.

Since at null, it has infinite input impedance, it can be placed across the Calibrator during calibration. An Eppley Type 100 unsaturated standard cell is used to calibrate the voltmeter.

4.3 Quick - Look Recorder

A two-channel heated stylus Texas Instrument "Oscilloriter" is utilized to compare analog signals with their D/A representation and to display decommutated data from the decommutator.

4.4 Oscilloscope

A Tektronix RM35A oscilloscope serves as a means of displaying analog inputs, decommutated outputs and D/A outputs, in addition to its normal maintenance role.

4.5 Voice Annotation Amplifier

An AM detector, amplifier and speaker are utilized to monitor the voice annotation normally recorded on the analog data magnetic tape recordings by the launch-site telemetry stations.

4.6 Frequency Counter and Signal Generator

These units are used in testing and calibrating the discriminators. They are also useful for providing signals to the Sample Controller and Special Logic divider for testing the automatic and command sampling modes without playing back magnetic tapes. The frequency counter is a CMC 603A and the signal generator is a Vidar 820.

5. SYSTEM ACCURACY

Assuming noiseless, slowly changing discriminator outputs, the maximum offset voltage of the system is $\pm$20 millivolts; $\pm$10 millivolts due to discriminator non-linearity and $\pm$10 millivolts due to A/D converter inaccuracies. Other major sources of error in the system are analog tape wow and flutter, discriminator amplifier noise, and signal $\frac{dv}{dt}$ during the 100 nanosecond sampling time uncer-

tainty. For .2% peak-to-peak wow and flutter and a nominal tape speed compensation improvement ratio of 20, the maximum offset would be ±6 millivolts. The discriminator amplifier output noise is 30 millivolts peak-to-peak. The effect of the 100 nanosecond uncertainty varies with the analog data frequency content; an example of an extreme case is sampling a 20 volt peak-to-peak, 2000 cps sine wave at the zero-crossing where the sine wave changes 12 millivolts during 100 nanoseconds. Over-all then, one can say that the offset of the system is less than about 50 millivolts, or less then .5% of full scale.* In addition to the voltage offset, there is a time offset which can occur when sampling the time code. Since the Time Code Translator up-dates every millisecond the time samples can be known to no better than a minus zero, plus one millisecond accuracy.

6. POWER REQUIREMENTS

The total power requirement for the system is about 10,000 watts. The CEC DR 2700 recorders each require a 30 ampere, 120 volt line and the remainder of the system requires one 30 ampere, 120 volt line.

7. AMBIENT TEMPERATURE LIMIT

Although the PDP-8 uses all silicon semiconductors, most of the remaining equipment uses germainium semiconductors and an ambient temperature above 85°F is not desirable for the equipment.

8. SYSTEM MANUALS AND DRAWINGS

In addition to the manufacturer's operating and maintenance manuals and the Space Physics Research Laboratory acceptance test folders for each piece of equipment, the following manuals and drawings were prepared:

SPRL System Drawings

SPRL Special Instructions for Operating and Maintenance

DEC Special Logic Description, Timing Diagram, and IOT List

* All of the above numbers are based on a discriminator output voltage of ±10 volts for band edge signals.

DEC PDP-8 Users Handbook

DEC PDP-8 Programming System (4 volumes)

APPENDIX A

Equipment Inventory

1 ea Mincom C-100 Analog Tape Recorder/Reproducer
- 7 direct playback amplifiers
- 3 direct record amplifiers

5 ea EMR 210 Discriminators
- 1 100 Kc channel Selector
- 1 Signal Delay Unit
- 12 IRIG Channel Selectors
- 12 IRIG Low Pass Filter
- 1 Power Supply
- 1 Rack Adapter

1 ea CMC 603A Frequency Counter

1 ea Vidar 820 Signal Generator

1 ea Texas Instrument Oscilloriter

1 ea Tektronix RM35A Oscilloscope

1 ea Sample Controller

1 ea Calibrator

1 ea Honeywell 852 Potentiometric Voltmeter

1 ea Vector DZ 1113 PAM Decommutator

1 ea Astrodata 6220 Time Code Translator
- IRIG A Module
- AMR D5 Module
- NASA 36 Module

2 ea CEC DR 2700 Digital Tape Recorders/Reproducers

1 ea Digital Equipment Corporation Sub-System
- 1 PDP-8 Computer
- 1 Multiplexer - A/D Converter
- 1 Special Logic Section
- 1 Format Generator - Tape Control
- 1 ASR-33 Teletype
- 2 D/A Converters

APPENDIX B

MAXIMUM SAMPLING RATES PER CHANNEL VERSUS NUMBER OF CHANNELS SAMPLED

Number of Channels	Maximum Sampling Rate Per Second Per Channel
1	13,200
2	4,500
3	3,400
4	2,800
5	2,300
6	2,000
7	1,800
8	1,600
9	1,400
10	1,300

Over-All Rate Equals (Number of Channels) X (Sampling Rate Per Channel).