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AN EFFECTIVE AUTOMATIC DATA PROCESSING SYSTEM FOR PPM AND PCM TELEMETRY IN SOUNDING ROCKETS (ADP FEASIBILITY STUDY)

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MARCH 1969

GSFC — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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INTRODUCTION

This study, prepared by the Instrumentation Section of the Sounding Rocket Branch of Goddard Space Flight Center, examines possible future expansion of the existing pulse-position-modulation (PPM) system. The growing frequency of the use of PPM telemetry in an annually increasing number of rocket flights demands such an inquiry. The primary goals of the present study are reduction in operational costs, and increased speed in providing the experimenters with the final reduced data.

The integration of an on-line automatic data-processing (ADP) unit, to be located in existing facilities at White Sands (the primary PPM launch site), is proposed. The use of automatic data processing will provide system adaptability to the growing diversity in modulation methods of the recovered data. ADP will also save data processing man-hours and greatly reduce the recovery-to-reduction interval.

The planned system is of such flexibility as to permit continued use, and further savings, when such innovations as the shift to S-band frequencies, and the use of Pulse-Code-Modulation (PCM) systems in sounding rockets, are completed by 1970.

PULSE POSITION MODULATION (PPM) AND THE PRESENT PROCESSING SYSTEM

PULSE POSITION MODULATION

In the recent past, the dominant modulation system for sounding rocket telemetry has been Frequency Modulation/Frequency Modulation (FM/FM). The successful use of newly developed Pulse Position Modulation (PPM) equipment in sounding rocket experiments has so forcefully demonstrated its advantages in data recovery and reduction as to quickly create a heavy demand for PPM flight support. A record of 100 percent success for 62 flights, all utilizing PPM telemetry, a minimum demand on payload size, weight, and power requirements, fewer requirements in prelaunch preparations, and high quality data records, all recommend to experimenters the use of PPM.

The trend toward the greater use of PPM by experimenters is indicated in the plot shown in Figure 1. The projection for 1968, indicates approximately a 40 percent increase of the total number of planned flights. A later increase over this figure is expected. It is anticipated that by 1970 as many as 70 percent of all telemetry-carrying rockets will carry PPM or PCM systems. The White Sands site has been equipped with four PPM ground stations and will be the location for the proposed processing system.

Essential features of PPM, as employed in Sounding Rocket instrumentation, are given in the format diagram of Figure 2. Corresponding variations of the analog voltage are shown on the bottom of the diagram for the special case when a single data variation is applied to all channels simultaneously. Synchronization for the PPM system is provided by an airborne clock which may be set to operate at 5 kilohertz, 10 kilohertz, or 20 kilohertz. In transmission, only the triple pulse and the data are used to modulate the carrier. The triple pulse marks the beginning of a set of data, called a FRAME, of sixteen single samples of data (one sample for each of 16 data channels). Reference pulses which mark channel boundaries are not transmitted, but are derived from the triple pulse by a phase-lock servo subsystem of the ground station.

Reference 1 on page 22, describes the SST-1 Airborne Telemeter, an earlier version of the SST-3 Airborne Telemeter now in use. Reference 2 (page 22), provides additional information as to how reference pulses are generated in the ground station, in synchronization with the airborne clock, and then reinserted with the recovered data pulses.

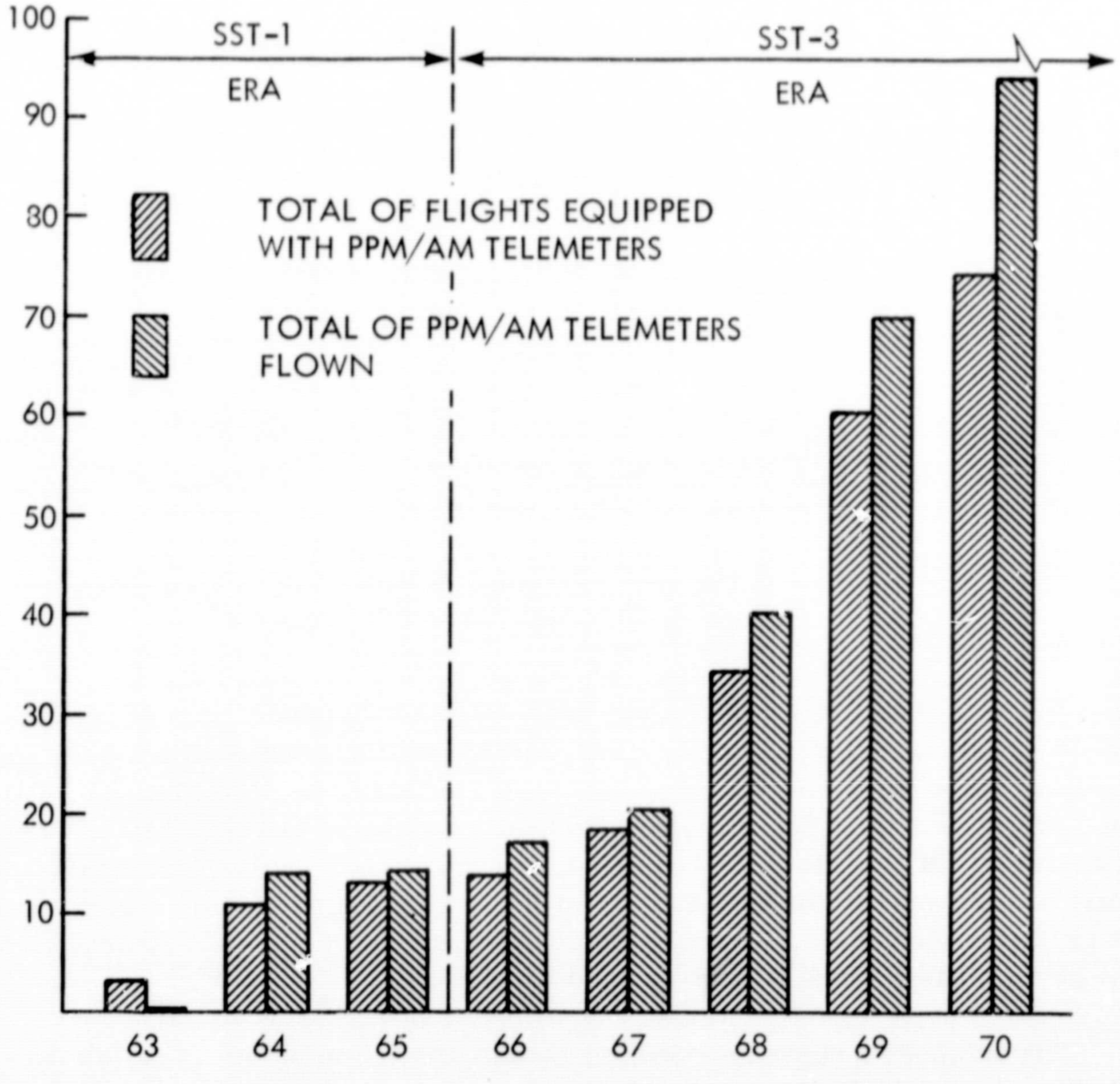


Figure 1. Number of Sounding Rocket Flights and Telemeters, 1963 through 1967, and Projected through 1970

The time separation between a data pulse and the preceding reference pulse constitutes the time analog of the telemetered measurement. To ensure complete separation of reference and data pulses, a guard band of ±12.5 percent of the channel time-width (200, 100, or 50 microseconds) surrounds each reference pulse. See Figure 3.

Inter-pulse spacing, and each single-pulse-width within the triple pulse, are all 4 microseconds, so that the triple pulse has a total fixed width of 20 microseconds. At the 5 kilohertz clock rate, the time of the first pulse of the triple pulse is coincidental with that of the first reference pulse of the frame. Thus

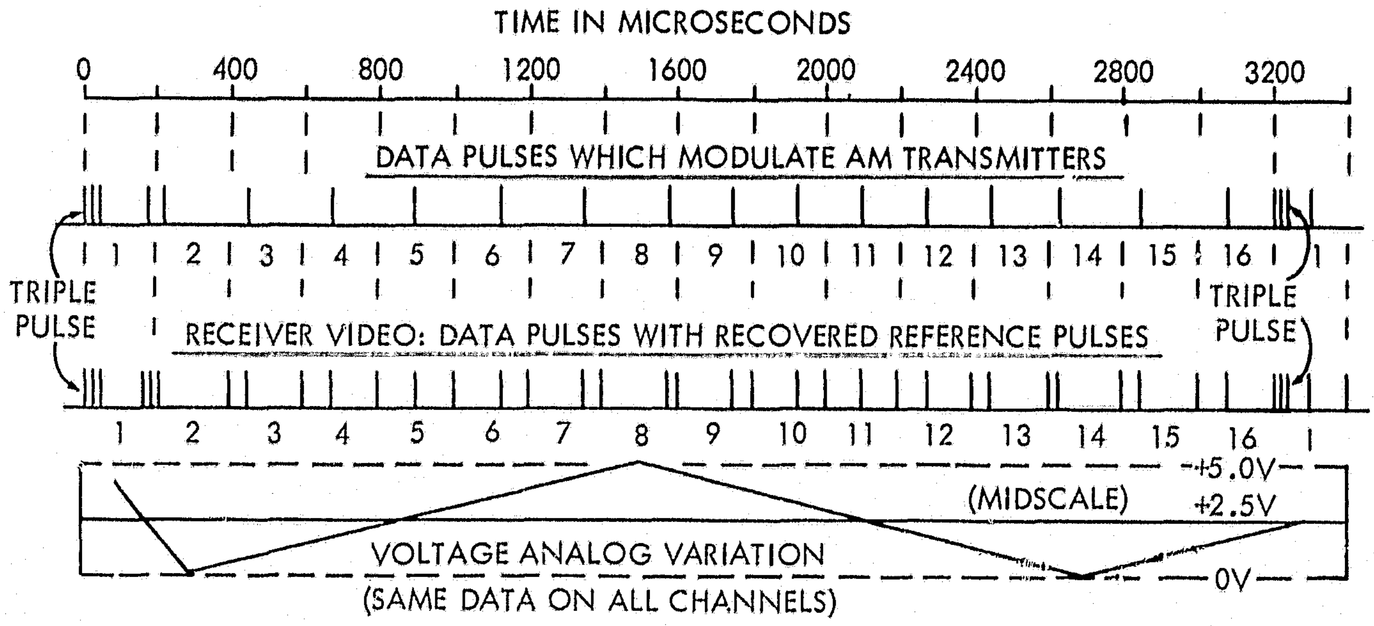


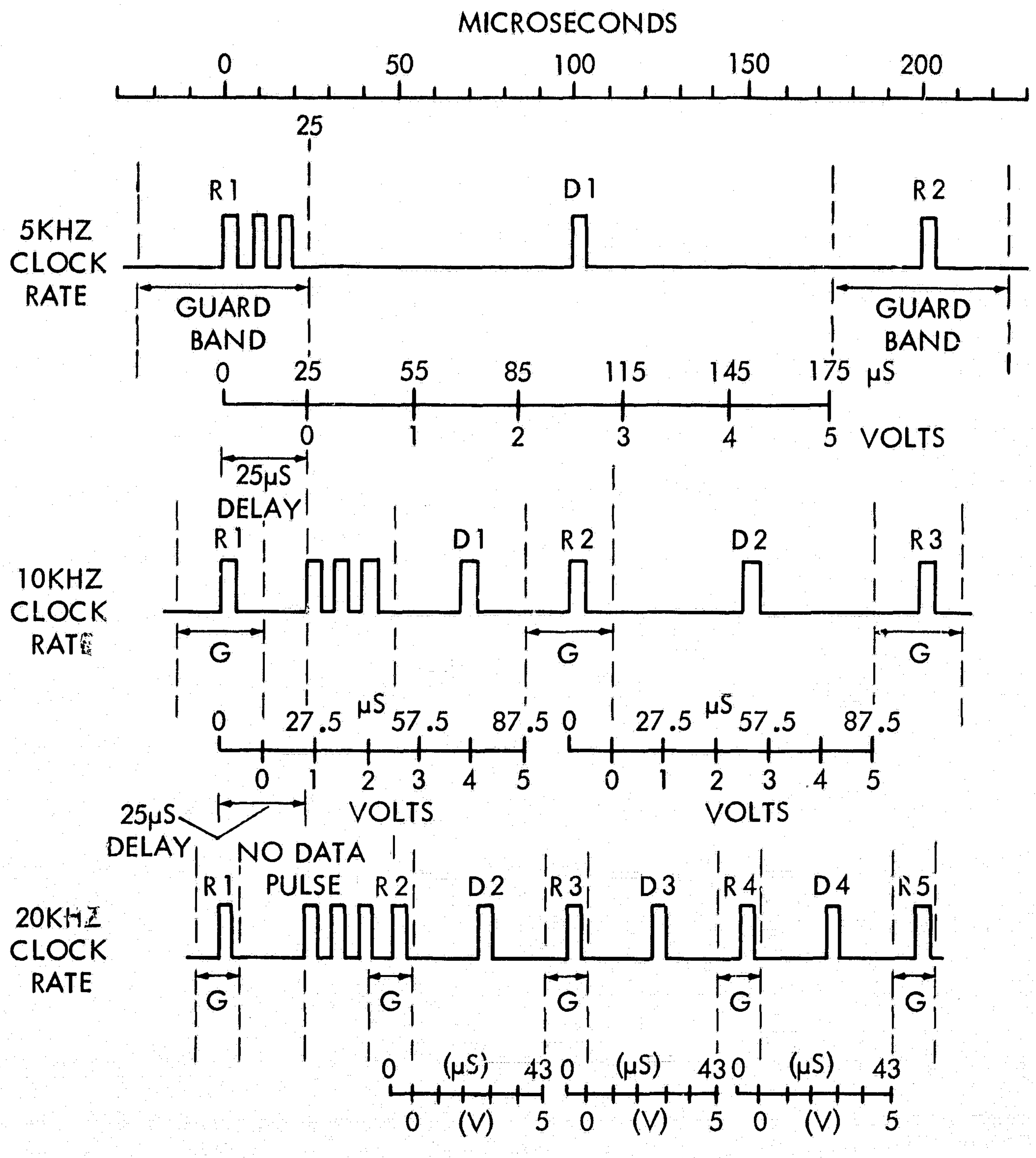
Figure 2. PPM Format (5-kilohertz clock rate) with Analog Voltage Variations when the Same Signal is Applied to All Channels

the triple pulse is in the guard band preceding the Channel 1 data (Figure 3). At the 10 kilohertz and 20 kilohertz clock rates, the triple pulse is delayed, so that the first of the three pulses occurs 25 microseconds after the Channel 1 reference pulse. For this reason, at the 10 kilohertz clock rate only half of Channel 1 is available for the data pulse interval, and the associated transducer channel must be biased accordingly (that is, for a full range of 2.5 to 5.0 volts). At the 20 kilohertz clock rate, the triple pulse completely occupies the Channel 1 interval so that this channel cannot be used for data.

The composite signal, consisting of data and triple pulse, is called the VIDEO signal. After the servo clock has synchronized the ground station with the received video signal, the triple pulse (having served its purpose) is extracted. Thus the data is transformed into parallel, 9 bit, binary words (one parallel word for each data channel), as the data comes out of the servo clock, according to the count scheme shown in Table I. This PPM to binary conversion is performed because binary information, unlike raw PPM signals, is not susceptible to the wow and flutter of magnetic tape recorders. Also, binary information is more directly amenable to further reduction by digital computers.

THE PRESENT SYSTEM

THE BASIC SYSTEM. Under the present system, real-time PPM data is converted to 9-bit parallel binary form, and is then recorded on 9 tracks of a one inch 16-track magnetic tape. The other tracks of the 16-track tape contain



R1, R2, R3 . . . RN – REFERENCE PULSE FOR CHANNEL N.
D1, D2, D3 . . DN – MIDSCALE DATA PULSE FOR CHANNEL N.
G – GUARD BAND

Figure 3. Channel 1 Formats at Each System Clock Rate

Table I

Voltage, Time, and Binary Equivalent Values for Datum Points of the Recovered PPM Signal

Analog Voltage in Volts	PPM Signal Time Difference in Microseconds Between Data Pulse and Preceding Reference Pulse for Each System Clock Rate			Binary Count
	5 kHz	10 kHz	20 kHz	
+5	175	87.5	43.75	330
+4	145	72.5	36.25	270
+3	115	57.5	28.75	210
+2	85	42.5	21.25	150
+1	55	27.5	13.75	90
0	25	12.5	6.25	30

reference and frame pulses, and time information as is shown in Figure 4. Although analog paper records (photographic process strip-charts) are made in real-time, the one-inch tapes constitute the primary permanent records of the flight, and are the basis for further processing.

After the flight, the one-inch tapes are transported to the Beltsville ground station for intermediate processing by the Data Format Converter (Figure 5). The result of this intermediate processing is a set of computer-compatible, half-inch, 7-track tapes. The binary data of the one-inch tape remains unchanged in content; it is simply reformatted to be computer-compatible for further reduction. The binary-coded-decimal (BCD) time information is converted to binary form by the Data Format Converter and recorded with the data. The format of the new all-binary tapes is given in Figure 6. Reference 3 on page 22, gives a detailed description of the Format Converter.

The final step in the reduction process (see Figure 7 for the flow diagram of the entire reduction process) is to take the all-binary tapes to Building 1, of

DATA CHANNEL NUMBERS

TRACK NUMBER	13	14	15	16	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	1	2	3	4		
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2^0 BIT	1ST HALF OF THE BINARY VALUE OF A SINGLE DATUM POINT
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2^1 BIT	
3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2^2 BIT	
4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2^3 BIT	
5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2^4 BIT	
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	REFERENCE PULSE (ONE PER CHANNEL)	
7	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2^5 BIT	2ND HALF OF THE BINARY VALUE OF A SINGLE DATUM POINT
8	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2^6 BIT	
9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2^7 BIT	
10	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2^8 BIT	
11	O	O	O	O	1	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	1	O	O	O	DELAYED FRAME PULSE (ONE PER 16 CHANNELS)	
12	(SEE NOTE 2)																								1 PPS (ONCE EVERY SECOND)	
13																									NASA 36-BIT CODE	
14																									NASA 28-BIT CODE	
15	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	UNUSED TRACKS	
16	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		

1 = BINARY ONE.
0 = BINARY ZERO
(BLANK TAPE)

X = BINARY ONE
OR ZERO

NOTES:

1. THE PRESENCE OF REFERENCE AND DELAYED FRAME PULSES IS INDICATED BY A BINARY ONE. A REFERENCE PULSE OCCURS WITH EACH DATUM PULSE (CHAN.). A DELAYED FRAME PULSE OCCURS WITH CHANNEL 1 (EVERY SIXTEENTH DATUM PULSE).

2. SERIAL BCD TIME-CODE INFORMATION (CHANNELS 13 AND 14) IS RECORDED CONTINUOUSLY WITH A ONE PULSE PER SECOND SIGNAL (CHANNEL 12). IT IS COINCIDENT, BUT NOT SYNCHRONOUS, WITH THE DATA PULSES. ONE SERIAL BIT OF THE CODED TIME DATA OCCURS FOR EVERY 50, 100, OR 200 DATUM VALUES WHEN THE SYSTEM CLOCK FREQUENCY IS 5, 10, OR 20 KILOHERTZ, RESPECTIVELY.

Figure 4. Format of the One-Inch Tape

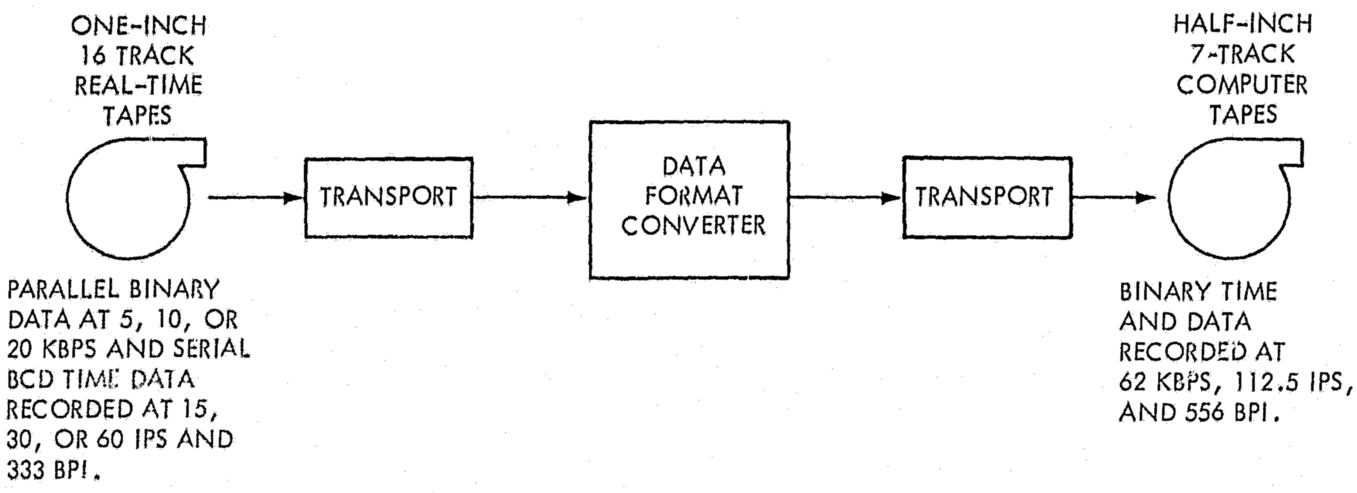


Figure 5. Intermediate Conversion Line

Goddard Space Flight Center for off-line processing on the IBM 360/91 computer. This final processing is done to meet basic and special requirements of the experimenters, and a number of programs are available to that end (see Table II). The basic program locates and extracts the in-flight calibrations and, by a least-squares fit technique, applies these calibrations to the data. Other programs are available to adapt the final calibrated data to 7- or 9-track tapes, according to what the experimenter requires.

ADVANTAGES OF PRESENT SYSTEM. The existing system has already eliminated the laborious and time-consuming method of hand interpolation, from paper analog (strip chart), records associated with FM/FM telemetry data reduction. The strip chart records are still produced for real-time, quick-look monitoring. For cursory data examination, they can again, at a later date, be made from the real-time magnetic tape record.

The usefulness of the data is enhanced by the accuracy and speed with which high-speed off-line digital computers directly convert intermediate data into final data, and correct for in-flight calibration error.

The existing system is also made compatible with FM/FM telemetry systems by first converting FM/FM to PPM, and then converting to binary form. The existing system is directly compatible with PCM, since PCM is already in binary form.

Equipment for a PCM system, which will produce a binary output compatible with the present PPM data reduction system, is in the initial design stage in the Sounding Rocket Instrumentation Section. Once the FM/FM or PCM is in binary form, it follows the same further reduction path as does the binary information which has been converted directly from PPM.

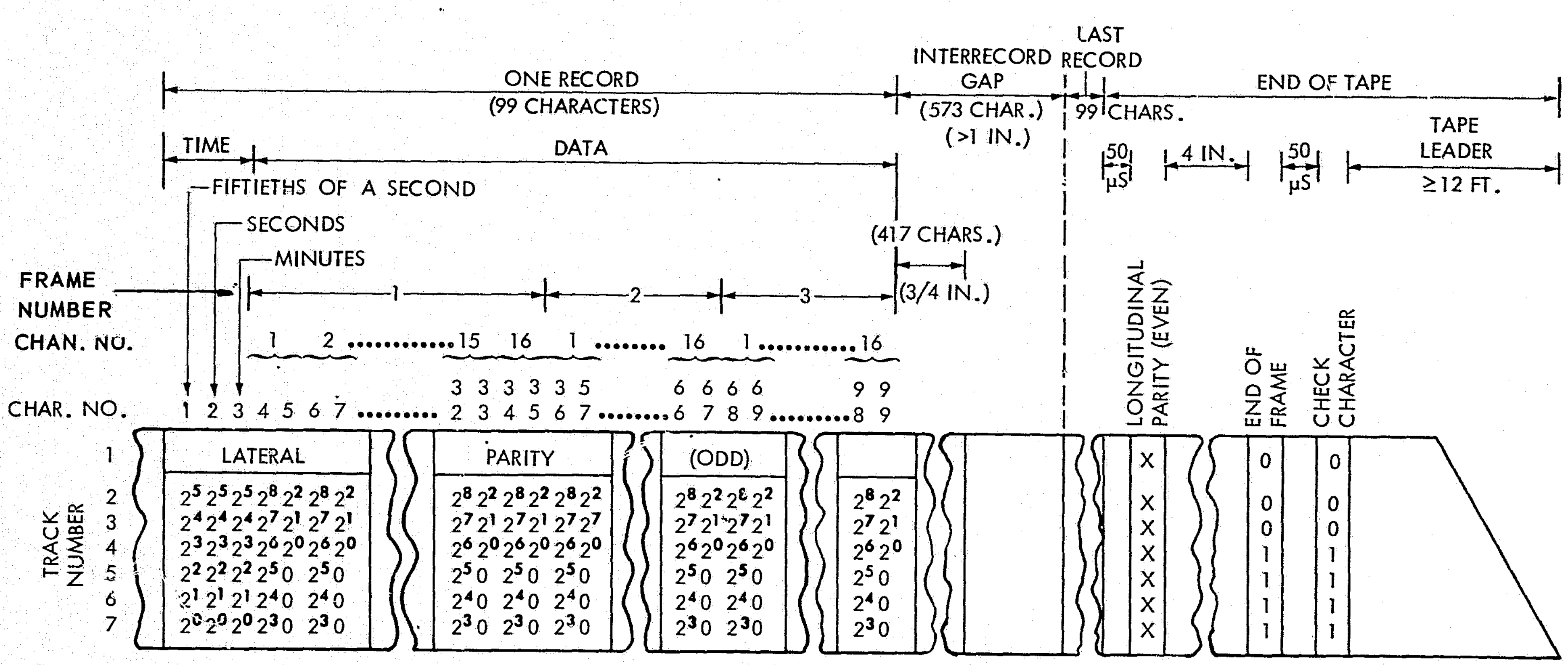


Figure 6. Format of the Half-Inch Tape

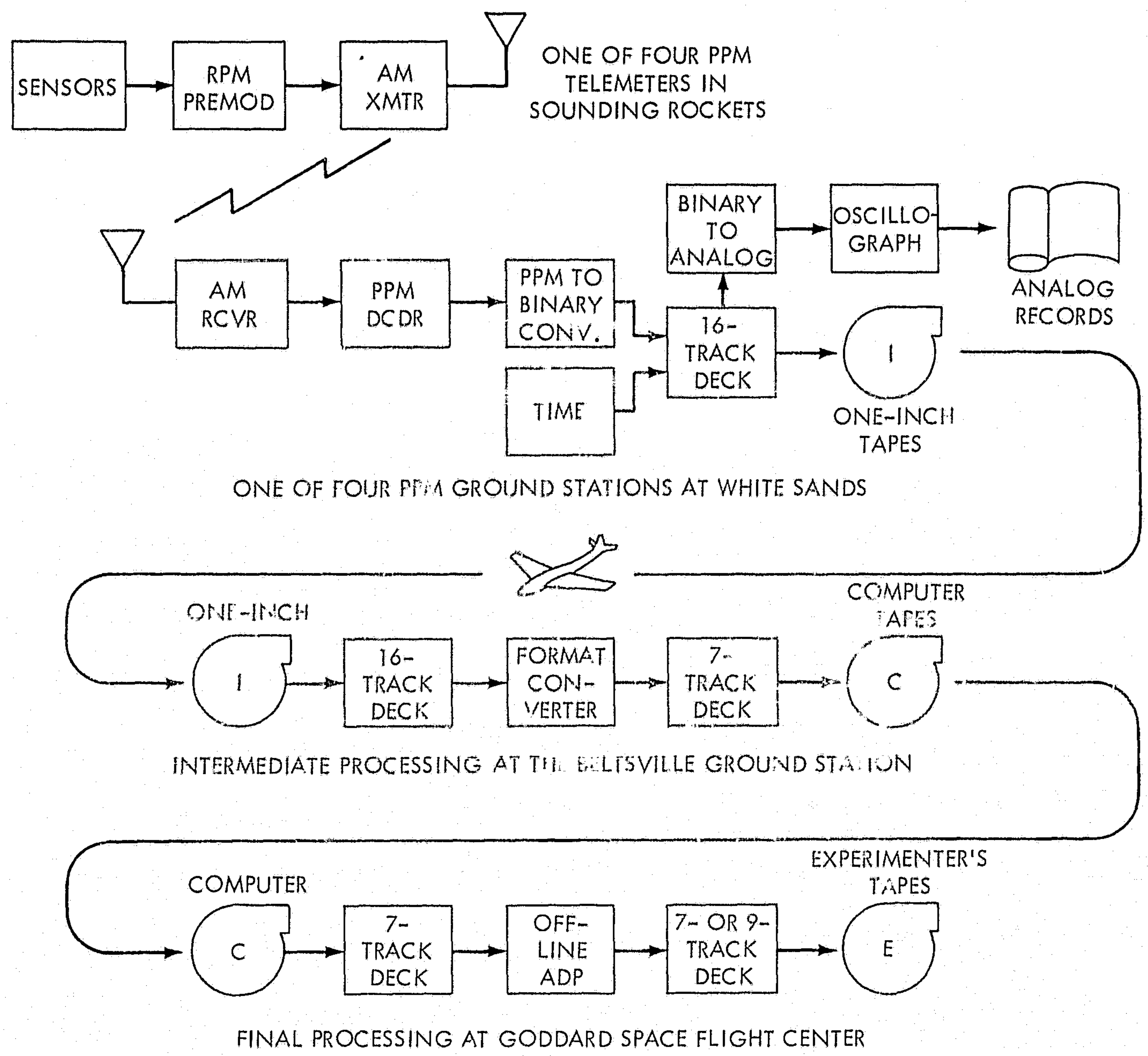


Figure 7. Flow Diagram for the Existing System

LIMITATIONS OF PRESENT SYSTEM. The primary limitation of the present system is the intermediate process of converting the one-inch tapes to half-inch computer compatible tapes. The real-time recording takes only as long as the flight (typically 10 minutes), plus set-up time prior to the flight. The typical final reduction on the IBM 360/91 computer takes about 25 minutes, and this time can be reduced, as will be seen in the proposed system plan. There is also time (on the average, a day or two) involved in getting tapes to the IBM 360/91 computer for final reduction. The intermediate process, however, can easily take up to two weeks. The one-inch tape produced at White Sands must be transported to the Beltsville ground station after the rocket flight (see Figure 7). Time must then be allowed for processing the one-inch tape, through the Data Format

Table II

Programs for Final Data Processing

Program Number	Function of the Program
001	Extraction and application of in-flight calibrations.
002	Reading and writing first 80 records of 7-track tape.
003	Reading routine for 9-track experimenter's tapes.
004	Calibrations for second tape. (Special version of 001)
005	Decommutation of non-standard commutator data.
006	Writing of 9-track duplicate tapes.
007	Conversion of 9-track tapes to 7-track tapes.
008	Time code interpolation.
009	Reading routine for 7-track experimenter's tapes.

Converter in the Beltsville PPM ground station. Since that station is often in use for integration of PPM carrying rockets, this processing sometimes takes several days. The actual reduction process through the format converter is also relatively slow, averaging about one half-hour per one-inch tape. This time includes the necessary set-up time for each half-inch tape which is generated. The half-inch tapes must then be processed on the IBM 360/91 computer. The fact that there are several such tapes per flight (typically, five tapes) leads to inefficient use of the computer time, since the operator must load and unload all of the tapes, and the resulting large inter-record gaps (see Figure 6) allow only about one-sixth of the half-inch tape to contain data.

The reason that so many half-inch tapes are generated for each one-inch tape is the inefficient data blocking by the Data Format Converter (DFC), which is caused by the very limited memory of the DFC. The real-time information must be buffered through the DFC memory, and then put out at 62 kilohertz rather than at the real-time speed (5, 10, or 20 kilohertz). The resulting tape format (shown in Figure 6) consists of one-sixth data, and five-sixths blank tape. This problem could be overcome by increasing the memory size of the DFC, but this is very expensive, both in manpower and in hardware. One DFC requires several man-months to build and it requires about $2,000 worth of micrologic plus several hundred dollars for chassis hardware and fabrication. If the memory were increased, the cost would increase, almost proportionately to the memory increase, since the memory constitutes more than half of the micrologic. Increased memory size would also require additional fabrication time and a larger chassis. Furthermore, a significant increase in DFC size (even just triple the present size) would make the unit so large that it could no longer be housed in the bottom of the half-inch tape deck, as it is now, so this in turn, would require a considerable addition to the present ground station equipment. These aspects will become more relevant once the proposed alternate plan has been set forth, and it is seen how much larger the DFC would have to be made to achieve even part of the objectives of the proposed system.

The very fact that so many half-inch tapes are produced (on a 1970 projection of 70 PPM telemeter flights per year, with an average of six minutes per flight, 420 half-inch tapes would be produced), presents the problem of the orderly storage and handling of a large number of tapes. Tapes would eventually be reused, of course, but only after the experimenter had been satisfied that the data given to him was accurate. This would take months, so the tape backlog in the present system would become quite large, and purchase of such a large number of high quality magnetic tapes is quite expensive.

THE PROPOSED DATA PROCESSING SYSTEM

The initial discussion of the present system covered the question of the use of the system at 3 frequencies: 5 kilohertz, 10 kilohertz, and 20 kilohertz. By 1970, because of the shift to S-Band Telemetry, and other considerations, the lower frequencies will be dropped. The following discussion of the proposed system is therefore based on the use of the 20 kilohertz frequency only. The 20 kilohertz rate will remain the standard PPM frequency for the foreseeable future (at least 5 years), as will the 9-bit data word.

It should also be understood that the proposed plan is for implementation at the White Sands launch site only. The few PPM flights launched from other sites would continue to be processed by the present system, which will be retained, both for this purpose, and as a backup to the proposed plan.

THE BASIC PLAN

The primary objectives of the proposed system are a reduction in operational costs and a speed-up in data recovery-to-reduction interval. The significant feature which is to accomplish these objectives is the elimination of the intermediate processing stage of data reduction. This intermediate stage is to be eliminated by the introduction of an on-line automatic data processing unit at the White Sands launch site. Real-time data, in parallel binary form, would be applied to the Automatic Data Processing (ADP) System for a one-step process which puts out efficiently blocked half-inch, 9-track, computer-compatible tapes. Thus the final product of the real-time process would be half-inch tapes, which are directly suitable for off-line processing at GSFC. Efficient blocking on the tapes would drastically reduce the number of half-inch tapes produced.

Key components of the basic system would be: a small digital computer; input and output channels; a tape control unit; and a tape transport. (See Figure 8). This basic system provides only single station capabilities, but is easily expandable to the ultimate system, in which four stations are handled simultaneously by the single ADP unit. (See Figure 9).

Since the main limitation of the Data Format Converter is caused by its small memory, this is what the ADP unit must overcome. A minimum memory capacity for the proposed basic system is based on a record length of 30 frames of data. This length increases the efficiency of half-inch tape data-blocking considerably, but does not require a very large ADP memory. Blocking 30 frames, as a record, allows usage of 65 percent of the total half-inch tape for data, as opposed to the present one-sixth, or 12 percent, an increase in tape

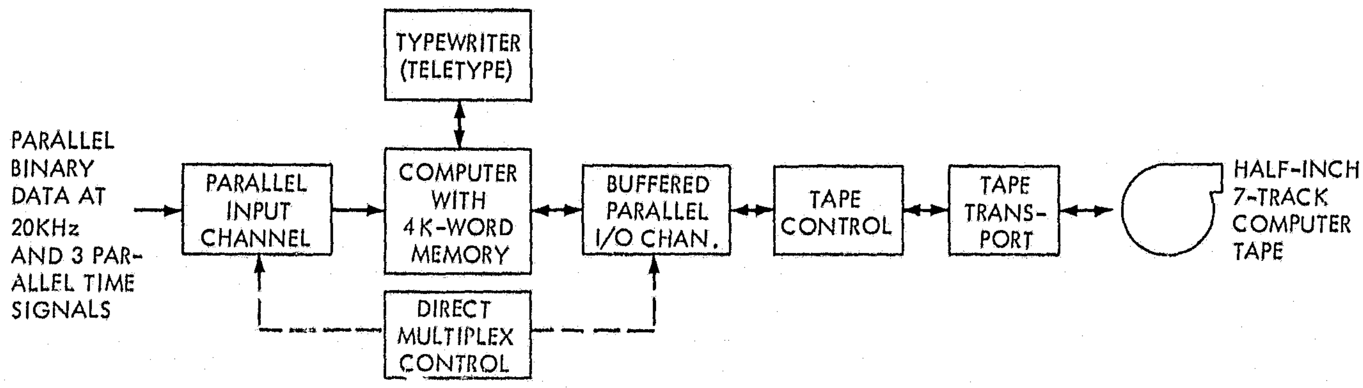


Figure 8. Equipment Configurations for the Basic Planned System

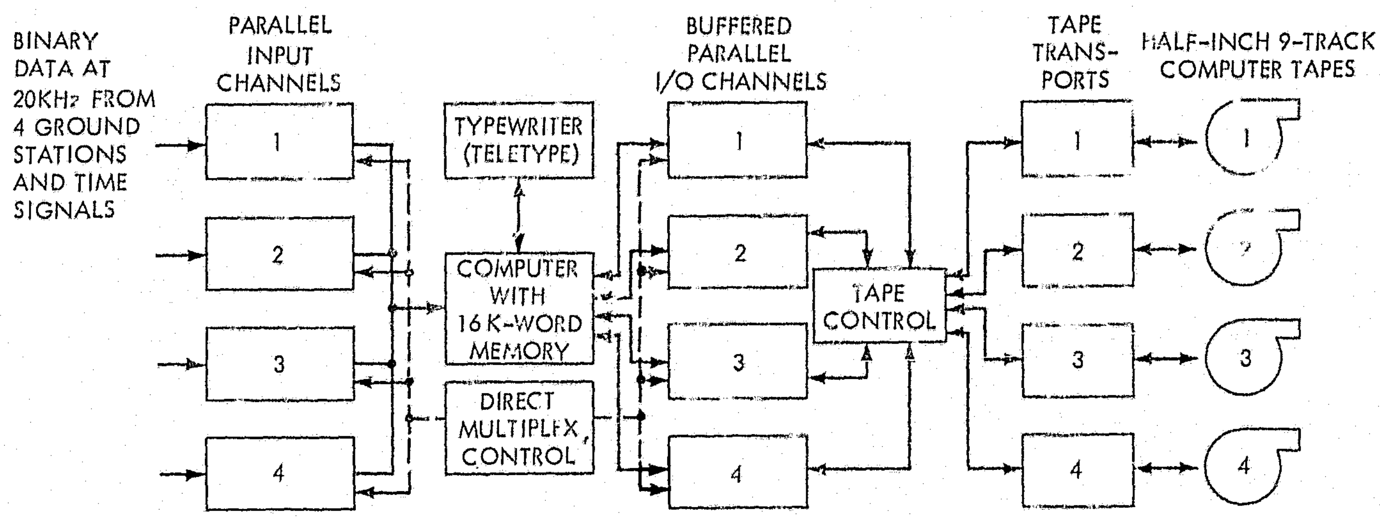


Figure 9. Equipment Configurations for the Final Planned Automatic Data Processing System

usage of 65/12, or 540 percent. Larger records would permit even greater percentages of tape to be used, but the corresponding memory requirements become restrictive, as will be shown later. The proposed blocking of 30 frames per record achieves the desired goal of producing only one tape per ground station per flight. Larger blocks would require additional memory, with no real gain in system performance. Blocking 60 frames of data per record, for example, would raise total tape usage to 78 percent, a gain of only 13/65, or 20 percent over 30 frames per record. The corresponding memory required would be twice that needed for 30 frames per record.

The input to the ADP will always be 9 parallel bits of data. At appropriate times, an additional group of 6 parallel bits of time information will be inserted with the data. This makes at least a 15-bit word necessary for the ADP, and since 15 bits is nonstandard, it is desirable to use the smallest standard word size greater than 15 bits. This, of course, is 16 bits. The data input to the ADP will be the same 9-bit parallel word which now goes to the 16-track, one-inch tape. This tape remains in the proposed system as a backup for the ADP. The time information which goes to the one-inch tape is in serial BCD form, and is not synchronous with the data. It will be buffered before going to the ADP input channel, so as to be made into parallel binary form (6 bits), and synchronous with the data. Although time information will be inserted with the data, it will be separated by the program, and, once separated will require its own storage space. There are 3 time-words per frame, so there must be 19 words of storage per frame. The memory requirements for the basic system are that two 30-frame records may be stored at any one time.

Total words per frame	19
Total words per record (30 frames)	570
Total words for 2 records	1140

Two records must be stored, so that the program can act on one record while the other is being stored. The program will be very simple. It will not perform any arithmetic operations on the data or time, thus eliminating any need for a high-speed arithmetic package. It will perform only a few masking and shifting operations per frame, so as to reformat the time information. The input format has been described in Figure 6. The output format of the ADP is shown in Figure 10. This format is so designed as to be easily used with the IBM 360/91 or a similar computer.

The program which is to handle this reformatting has not yet been written, since it will depend on the specific ADP unit which is procured for the proposed system. As was mentioned earlier, it will be a simple program, consisting primarily of a few masking and shifting operations on each frame (16 words) of data. From previous programming experience, it is felt that this program will take only a few hundred words of core, about 500 at the very most. For purposes of future expansion however, it is desirable to provide a large margin on this estimate. One possible future addition to the program would be internal BCD-to-Binary conversion of the time information. (Note that this is a logical operation and does not require high-speed arithmetic.) It is also felt, on the basis of past experience, that a 1000 word section of core will be entirely adequate for any future program expansion.

THE ULTIMATE SYSTEM

Diagrams of the final system proposed are shown in Figures 9 and 11. The ADP is the heart of the final system, as it is of the basic system. The peripheral

P	P	P	P	P	P	P	P		P	P
0	0	0	0	0	0	0	2^7		0	2^7
0	0	0	0	0	0	0	2^6		0	2^6
0	2^5	0	2^5	0	2^5	0	2^5		0	2^5
0	2^4	0	2^4	0	2^4	0	2^4		0	2^4
0	2^3	0	2^3	0	2^3	0	2^3		0	2^3
0	2^2	0	2^2	0	2^2	0	2^2		0	2^2
0	2^1	0	2^1	0	2^1	0	2^1		0	2^1
0	2^0	0	2^0	0	2^0	2^8	2^0		2^8	2^0

1/50 SEC. — SEC. — MIN. — DATA (30 FRAMES)

9 TRACK OUTPUT TAPE

Figure 10. ADP Output Tape Format

equipment (tape decks, I/O channels) is simply quadrupled so that four ground stations can be handled simultaneously. The Direct Multiplex Control (DMC), and the Tape Control units of the basic system, will handle all four data flow lines of the final system.

The basic system will use a 7-track tape transport, which is already on hand. The final system will use only 9-track tape decks, since this size is most easily made compatible with final processing on the IBM 360/91 computer.

AUTOMATIC DATA PROCESSING SIZE AND SPEED CONSIDERATIONS. The 9-track output tape will be required to be capable of a density of 900 bytes per inch, at a speed of 80 inches per second. Justification for these figures is based on the following considerations. A 2400 foot tape would have space for 23,040,000 bytes. This space cannot all be used, because the data must be broken up into records of a reasonable size, and interrecord gaps are required. The question is, how much of the tape must be used for data, to get all of the data for one flight on a single tape. The time during which sounding rockets put out useful data is currently about 4 minutes. In order to allow a safe margin, a 6 minute

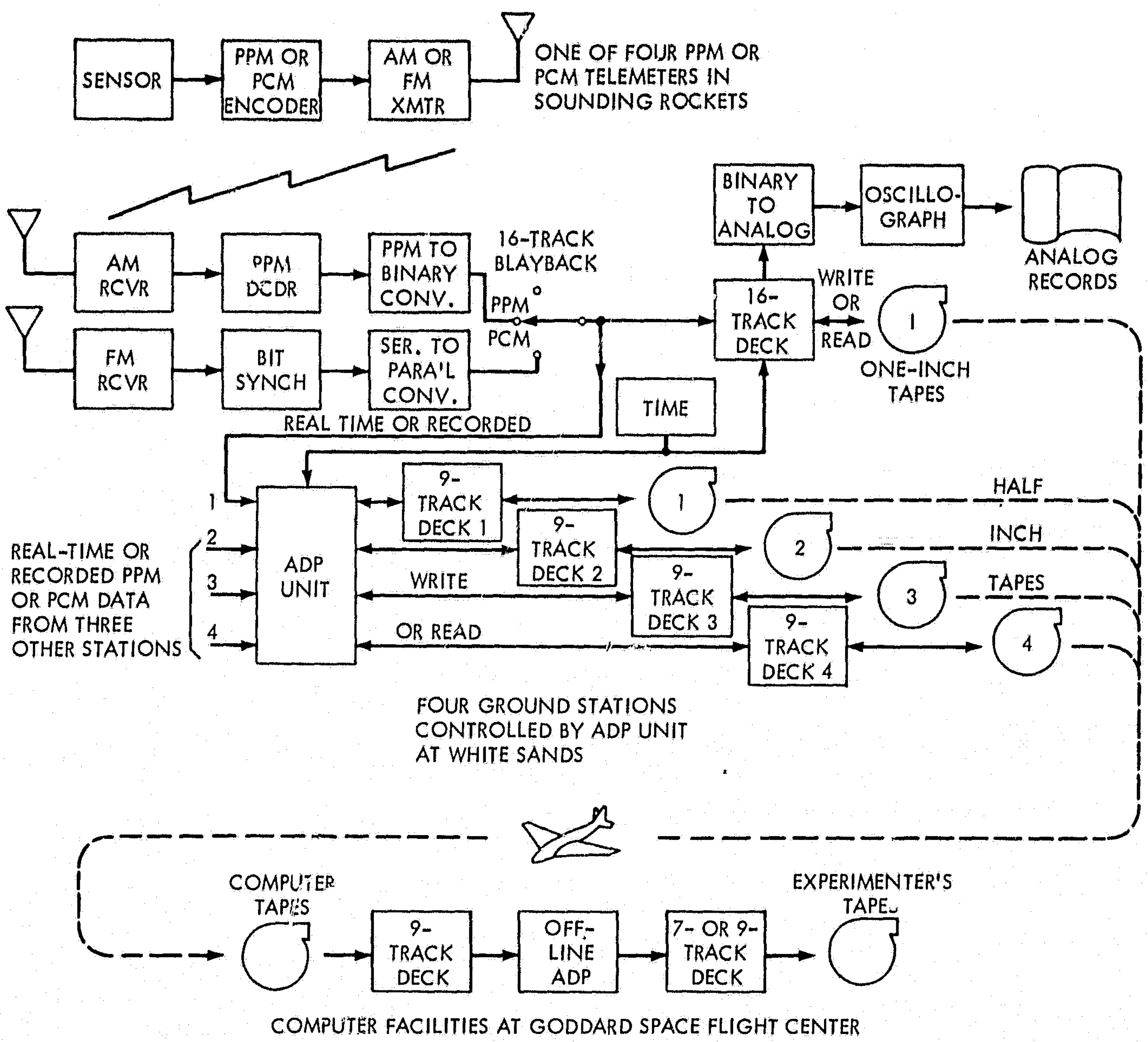


Figure 11. Flow Diagram for the Ultimate System

critical-time flight will be considered. At 20 kilohertz, a 6 minute flight will produce:

$$20\text{K}\ \frac{\text{words}}{\text{sec}} \times 6\ \text{min} \times \frac{60\ \text{sec}}{\text{min}} \times \frac{2\ \text{bytes}}{\text{word}} = 14{,}400{,}000\ \text{bytes}\ . \qquad (1)$$

This represents: 14,400,000/23,040,000 = 63 percent of the total available bits which could be written on one tape. Thirty frames of data requires an output of:

$$30\ \text{frames} \times \frac{19\ \text{words}}{\text{frame}} \times \frac{2\ \text{bytes}}{\text{word}} = 1140\ \text{bytes}\ . \qquad (2)$$

Nineteen words per frame are used because, on the output, each frame contains 3 full words of time information. In both Equations (1) and (2), the 2 bytes per word is used because one word is 16 bits, not all of which are used, and a byte is only 8 bits. The 9 track tape actually has a 9-bit byte, but one bit is parity, which is generated directly by the tape deck and does not go through the ADP. At 800 bytes per second, a three-quarter inch interrecord gap occupies the space equivalent to:

$$800 \frac{\text{bytes}}{\text{inch}} \times \frac{3}{4} \text{ inches} = 600 \text{ bytes} .$$

Thirty frames per block will therefore use: $[1140/(1140 + 600)] \times 100\% = 65 - 1/2$ percent of the total tape for useful data. Since only 63% of the tape must be used to get a 6 minute flight on one tape, 30-frame records will do the job.

As was shown (page 15), the basic system with a 30-frame output record requires 1140 16-bit words of storage for data and time, plus 1000 words for the stored program. The final system will require:

$$(4 \times 1140) + 1000 = 5560 \text{ words.}$$

The program size (1000 words) already contains a good margin for possible expansion, but if the blocking size needs to be increased so that even more than 6 minutes of flight can be recorded, a corresponding increase in memory size will result. A memory size of 8K words would provide some margin for this, but not necessarily enough. It is felt that a 16K word memory capability is necessary to provide a really safe margin for future developments.

Speed considerations for the ADP are based on the necessary capability of handling 4 input-paths at 20 kilohertz each. Each of the four outputs will have an average frequency of 20 kilohertz, since everything put in will come out at one time or another. The peak frequency required by the output tape deck, however, is 64 kilohertz to print 800 bytes per inch, at 80 inches per second. The peak output word-speed of the DMC needs only to be half of this, or 32 kilohertz, because one ADP output word will form two tape bytes. Since the DMC must handle four inputs at 20 kilohertz and four outputs at 32 kilohertz, it must have a peak capability of: (4 × 20 kilohertz) + (4 × 32 kilohertz) = 208 kilohertz.

Since the DMC action is initiated by the CPU, and the CPU cannot perform any masking or shifting operations while it is directing the DMC, there must be some additional time during which the stored program can be executed. The only way to gain additional time is to make the DMC faster than required, so that it will be idle for short intervals, thus allowing some program execution to take place. A DMC speed of 250 kilohertz will allow enough additional time to execute the program. At this speed, one input-to-output (I/O) operation will require 4 microseconds. The I/O speed requirement of 209 kilohertz requires only that an I/O operation be done about once every 5 microseconds. Using 250 kilohertz allows about one microsecond per data word for program execution. A 2 microsecond memory cycle time would allow 8 program instructions per frame of data. Although this would probably be sufficient, it leaves little room for expansion of the program. A one-microsecond memory cycle time would allow for 16 program instructions per frame of data, which would allow sufficient time for the program, as it is currently envisioned, plus an adequate margin for some future expansion. It is felt that, while a memory cycle time of less than one microsecond might be desirable, it is not essential, and it would cost too much for the intended use of this ADP system. Consequently, a memory cycle time of one microsecond is proposed.

The 16 microseconds, per frame of data, available for program execution is an average. The actual time will occur in groups of several microseconds, because the output speed of 32 kilohertz is discontinuous for short intervals of inter-record gaps.

The minimum instruction repertoire of the ADP unit must contain the shifting and masking operations required by the basic program, plus a normal complement of arithmetic and logical operations (ADD, SUB, COMPLEMENT, etc.). Normal program control operations (TRANSFER operations) are also required. No high speed, double precision, or floating-point operations will be required. No parity will be required within the ADP. Adaptability to field addition of priority interrupts is required.

FEASIBILITY OF ALTERNATE PLANS. The most obvious alternative to the proposed plan would be to build four large data format converters. These DFC's would each have to be ten times as large as the present model, in order to have the format consist of a 30-frame record rather than the present 3-frame record. This enlargement would increase the cost to at least $15,000 per DFC, for a total cost of $60,000. or more. These DFCs would take the place of the ADP, the multiplexer, and of the I/O channels, which represent a maximum or $53,000 worth of equipment. However, the cost of the DFCs would not only be higher than that of the proposed system, but the time required to design and build them would be long, and would add even more cost. This alternative is clearly undesirable.

Another alternative would be to use a formatting system specifically designed to do the type of job that is required. Several manufacturers produce such systems, but to handle the amount of data which the system proposed in this plan handles, would cost well upwards of $100,000. Such a system would also be inherently less flexible than the ADP system proposed here. This approach has been examined and discarded as too expensive and too rigid.

A third possibility would be to simply keep the present system, and put more manpower into running it. This, in the long run, would be as expensive as the proposed system, but it does not solve the problem of reducing the large number of tapes produced by the present system. It also has none of the flexibility of the proposed system. The fact that such an approach is undesirable is what has lead to this study.

CONCLUSIONS

The present method of processing PPM data, by means of an intermediate line at the Beltsville ground station, is at present barely adequate, and will soon become inadequate. The proposed plan of replacing the intermediate process with an on-line ADP system at White Sands will save many hundreds of man-hours per year, shorten the recovery-to-reduction time by an average of two weeks, and reduce by 80% the number of magnetic tapes required by the system. This amounts to a saving of at about 100 tapes per year. The plan is comprehensive, flexible, and will serve the long-range needs of sounding rocket telemetry requirements.

SUMMARY OF MANAGEMENT AND PROCUREMENT CONSIDERATIONS

Procurement of new equipment for a new functional approach, to meet existing requirements and anticipated expansion, is planned. The new equipment will be integrated with existing equipment to provide minimum obsolescence of the existing equipment. Such a system should have an indefinitely long and useful lifetime of a minimum of 5 years. All proposed equipment is to be housed in existing facilities at White Sands. No augmentation of staffing will be required. The desired procurement schedule is given in Table III.

The proposed system will support all PPM (and eventually PCM) flights from White Sands for at least 5 years, and probably for 10 years. (The projected savings by using this system are based on calculations of a minimum of five years use.) The direct use rate for the primary system function would be low, since an average of only 1 1/2 to 2 flights per week is anticipated. It is likely that some advantage can be taken of the incidental computational capability of the system.

Table III

PROJECT SCHEDULE

MILESTONES	CALENDAR YEAR							
	1968				1969			
1. PROCUREMENTS								
BASIC SYSTEM (STATION 1) ADP UNIT W/4K MEMORY DIRECT MULTIPLEX CONTROL INPUT CHANNEL (1 EA.) OUTPUT CHANNEL (1 EA.) TYPEWRITING UNIT			Δ					
ULTIMATE SYSTEM (STATION 2) ADDITIONAL 12K MEMORY INPUT CHANNEL (1 EA.) OUTPUT CHANNEL (1 EA.) TAPE TRANSPORT (2 EA.)					Δ			
(STATION 3) INPUT OUTPUT TAPE TRANSPORT						Δ		
(STATION 4) INPUT OUTPUT TAPE TRANSPORT							Δ	
2. SYSTEMS OPERATIONAL								
BASIC SYSTEM					Δ			
STATION 1					Δ			
ULTIMATE SYSTEM								Δ
STATION 2						Δ		
STATION 3							Δ	
STATION 4								Δ

Long term utilization, plus probable equipment modifications, make purchase far preferable to rental. Estimated purchase prices are as shown in Table IV.

Table IV

Estimated Costs

Item	Quantity			Cost ($K)	
	Present	Future	Total	Present	Ultimate
ADP with 4k memory	1	0	1	15-20	15-20
Additional 12k memory	0	1	1	0	23-35
Direct Multiplex Control	1	0	1	2-5	2-5
Parallel Input Channel	1	3	4	1.2-2.0	5-8
Buffered Parallel I/O Chan.	1	3	4	2-5	8-20
Teletype Input Unit	1	0	1	1-1.5	1-1.5
Tape Control Unit	0	1	1	0	8-12
Tape Deck (80ips, 800bpi)	*	4	4	0	80-120
TOTAL COST				21.2-33.5	142-221.5

*On hand

REFERENCES

1. Stattel, R. J. and Pownell, J. E., "Airborne Transistorized Telemeter System Model SST-1," NASA Technical Note D-2151, April 1965.

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3. Fennel, J. W., Jr. and Stattel, R. J., "Data Format Converter," GSFC Report X-721-67-603, December 1967.