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PROCESSING AND PRESENTATION OF DIGITAL DATA FROM OUTER SPACE

II. EXPLORER VI "PADDLEWHEEL" SATELLITE

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by

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INTRODUCTION

The Explorer VI satellite contained the first of a series of contemplated telemetry systems (Telebit[1]) operating with a digital transmission mode. This situation afforded members of the Computation and Data Reduction Center of STL a unique opportunity to participate in laying the groundwork for future analysis and processing procedures.

A basic understanding of the Telebit system, with its possible perturbations, was obtained in order to assure postflight compatability with digital computer capability. Designs of the digital demodulation equipment, paper tape punching equipment, and output formats were optimized to minimize computer programming and processing times. Either an IBM 704 or 709 was to be utilized for this processing.

The computer program itself was designed with the following restrictions in mind:

1. The output structure of the Telebit system was essentially a string of binary bits emmitted serially in time at rates of 1, 8, or 64 bits per second starting and stopping at random positions within a basic repetitive feature, "the frame", which consisted of 132 bits. Each continuous transmission, or message, might consist of a variable number of frames.

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(1) "An Interplanetary Communication System", by George E. Mueller and John E. Taber, 1959 IRE WESCON Convention Record, Part 5, pp. 68-75.

[redacted]

2. Quick-look information, including basic payload parameters such as battery voltages and temperatures, would be required within one hour of receipt of paper tapes (punched at one of the telemetry ground stations) over a commercial teletype line.

3. Errors in the basic bit sequence due to variations in bit rate, perturbations in the frame size and teletype vagaries would have to be considered.

Detailed analyses were performed to determine the extent and repetition rates of the various deviations from the norm to be expected and a computer program was developed to perturb a set of normal data with such fluctuations. With such input, along with data from aircraft simulation tests, the basic analysis program was subjected to a series of simulation experiments which served to point up prior to flight time any defects either in the statistical approach to the analysis or in the coding of the program. In addition, information relating to the cost of reduction per hour of satellite transmission was developed.

As a result of this extensive preflight simulation study, the first set of digital data telemetered from Explorer VI was reduced in minimal time and delivered to the hands of operations personnel for analysis and necessary action. A continuing effort in the reduction of both quick-look and scientific data has revealed no flaw in the basic thought applied to this problem which will be the subject of the remainder of this paper.

INFORMATION FLOW FOR TELEBIT SYSTEM

Figure 1 illustrates the general flow of information from the transducer in the satellite to the final output listing from the computer. Analog information such as nagnetic field intensity, very low frequency signal strength, and subcommutated data passed through an A to D converter while certain transducers yielded digital information directly (proportional counters, micrometeorite detectors, Geiger-Mueller counter, ionization counter and scintillation counter). Each of the transducers was sampled sequentially and the output fed into one of a pair of registers. While one register was being filled with information, the other was modulating the output signal so as to cause a phase change of 180 degrees to occur in a nondeviated subcarrier each time a "one" was emmitted by the register. A zero caused an absence of a phase change. A ground-based demodulation scheme sensed the presence or absence of a phase change in the given bit timing interval whether one second, 1/8 second, or 1/64 second. Although the timing for satellite based equipment was governed by an extremely accurate oscillator (1 part in 10^{-4}), loss of synchronization in the ground-based demodulator could cause the addition or deletion of bits every so often; particularly under conditions of low signal to noise ratio. Preliminary indications were that one bit might slip every ten frames.

PCM FORMAT

The basic format or sequence of bits generated by the telemetry equipment is outlined in Figure 2. Upon commanding the transmitters on, the bits were constrained to follow the sequence of the table(2) but might begin at any point

(2) To be read from left to right for a given word; and from word 0 through ten in normal sequence.

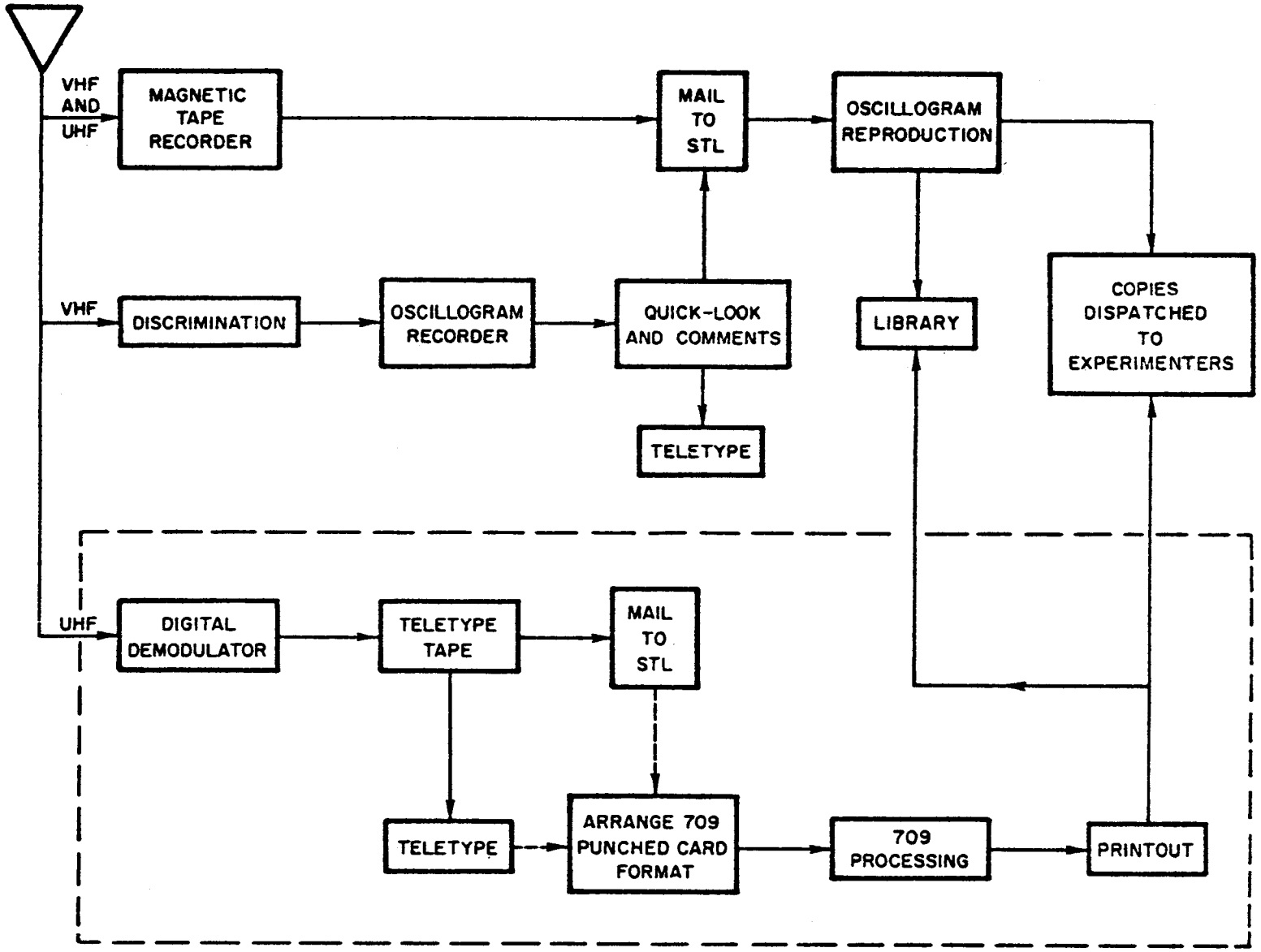

Figure 1. Explorer VI Data Acquisition and Recording System. The section enclosed by the dashed line is the digital portion of the system.

Measurement	Word No.	*	Bit Number 1	2	3	4	5	6	7	8	9	10	11	12
Frame Synchronization	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Proportional Counters(triples)	1	D-1	0	1	512	256	128	64	32	16	8	4	2	1
Proportional Counters(singles)	2	D-2	0	1	512	256	128	64	32	16	8	4	2	1
Micrometeorite	3	D-3	0	1	4	2	1	64	32	16	8	4	2	1
					High Momentum						Low Momentum			
G-M Counter	4	D-4	0	1	512	256	128	64	32	16	8	4	2	1
Ionization Chamber	5	D-5	0	1	512	256	128	64	32	16	8	4	2	1
Scintillation Counter	6	D-6	0	1	512	256	128	64	32	16	8	4	2	1
Magnetometer	7	A-1	0	1	32	16	8	4	2	1	8	4	2	1
							Amplitude					Phase		
Flux Gate	8	A-2	0	1	32	16	8	4	2	1	8	4	2	1
							Range					Range		
VLF	9	A-3	0	1	32	16	8	4	2	1	0	1	1	1
							Range							
Sub-commutator	10	A-4	0	1	32	16	8	4	2	1	8	4	2	1
											Segment Identification			

*D: Digital and A: Analog

PCM Format

Figure 2

within the frame structure. It should be noted that each word consists of 12 bits; two of which are 01 as a word beginning marker. Every tenth word is a frame synchronization word of 12 zeros to allow identification of the beginning of a given frame. Of special interest is the subcommutator word in which a different experiment was sampled each frame. Since there were 16 such experiments, each one occurred at 1/16 the rate of words zero through nine. Subcommutated values were identified by bits 9 through 12 of word 10.

PAPER TAPE FORMAT

Since one of the basic intents of this system was to be able to generate "real time" digital information, the output of the digital demodulator was placed into a register along with a ground-based generated parity bit forcing each line of five bits odd.(3) The bits were punched on the tape at a speed compatible with the transmission rate. In order to allow an accurate time correlation for the data, time was punched each minute as a set of four lines of even parity information. Figure 3 should serve to indicate the information content on the paper tape. For quick-look information, this tape was sent in short bursts from each of the ground stations (Cape Canaveral, Manchester, Hawaii, and Singapore) by teletype to the Space Navigation Center (SPAN) in Los Angeles where the computer evolved calibrated output for operations personnel.

TELETYPE TRANSMISSION

Since quick-look processing necessitated the use of teletype transmitted information, a statistical study of the error rates to be expected was

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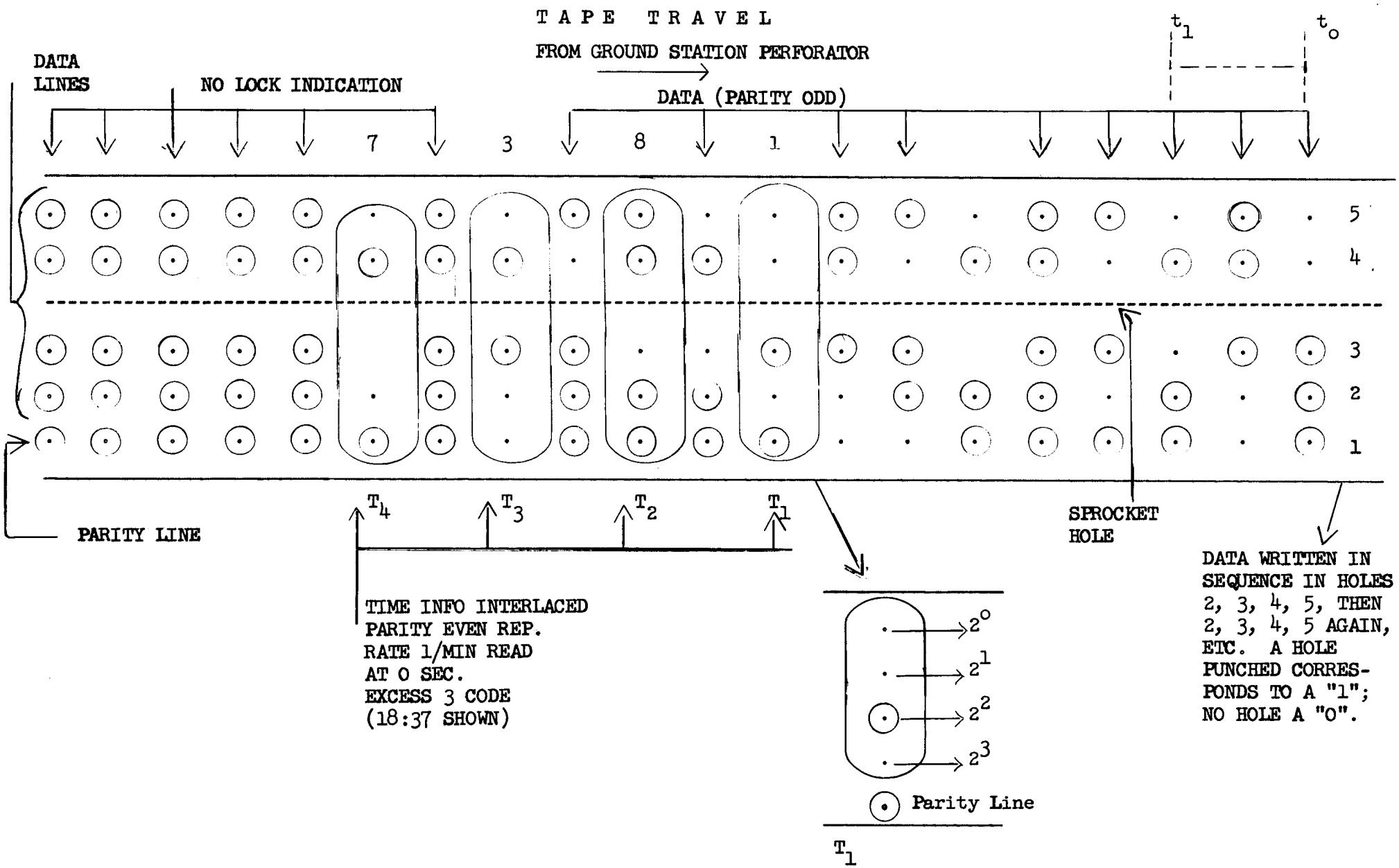
(3) The parity bit was generated to allow error detection resulting from teletype transmission errors.



Paper Tape Encoding

Figure 3

initiated. Test tapes were sent to each of the ground stations with instructions to transmit to Los Angeles at definite times. An analysis of these data indicated that an error rate of one bit per 10,000 lines transmitted (50,000 bits) was to be expected during "good" periods. However, error rates as high as one in 15 lines occurred often enough to make it appear adviseable that the computer be programmed to handle this possibility. Monitoring of battery voltages and payload transmitter temperature was extremely important during the first few days of activity since deviations beyond certain values would have caused permanent loss of transmitting capability. Upon receipt of these data, ground commands were initiated to keep transmitter activity at reasonable levels.

SPECIAL PROVISIONS

The digital demodulation equipment was fitted with three operating modes:

1. Automatic. Data were punched onto tape as long as the receivers were in lock. In the event of loss of lock, ones were to be punched until the next timing set of four lines. Immediately following the timing lines, six sets of ones terminated the punching operation and acted as an end of message marker. It should be noted that if lock were then attained again during a given transmission, it is most probable that bit synchronization would have been lost and that the new message should be treated as such. This was the approach followed when evolving the computer program.
2. Manual over-ride. Data were punched onto tape at all times; yielded random bits in the absence of signal.

3. Stop data. Ones were to be generated until the next timing set after which six lines of ones were to be generated. This provision served as an arbitrary end of message marker.

It can be seen that in the normal automatic mode, an end of message marker followed the last timing information for a given transmission.

THE COMPUTER "FRAME RECONSTRUCTION" PROGRAM

The aforementioned paper tapes were presented to computer personnel in the form of paper tape reels, each consisting of many messages. A message is defined as a sequence of data bits preserving the 132 bit per frame format with minor perturbations. It was the intent of this program to process the paper tape in such a manner as to reconstruct the data in its desired 12 bit by 11 word format and after such reconstruction to present the data in optimum form as calibrated listings.

ANALYSIS PROCEDURE

1. Tape to card conversion.

The reel of paper tape was converted to punched cards in such a manner as to allow visual observation of even parity lines (timing information or teletype errors). This was accomplished by forcing a punch in the upper two rows of the punched card for each even parity character. This permitted the operations personnel to throw out those messages where the overall error rate exceeds 1/15. In addition, it allowed detection of normal English teletype transmissions (half even parity characters) which did indeed somehow find their way into the processing loop. The five bit line of bits

on the tape was therefore transformed into a given column of the card as a typical Hollerith character.

2. Hollerith listing.*

A listing of the Hollerith characters was prepared. It can be seen that odd parity characters on the paper tape will generate a unique set of Hollerith characters as compared to the even parity data. A search was made of each card deck for all end of message signals (five identical Hollerith characters corresponding to all ones). When an end of message signal was found, the timing information immediately preceding it was verified manually and corrected if necessary. When the signal lay within a given card (normal situation), two new cards were constructed each to be associated with a given message. Thus, a stack of cards was constructed for each message and ending with timing information.

3. Time extraction.

The first operation, after a given message was read into the computer, was to extract the timing information leaving the data bits in an unbroken sequence. Since it was guaranteed that timing information would immediately precede the end of message marker, it was decided to extract the times beginning with the <u>end</u> of a message. Utilizing knowledge of the basic transmission bit rate and the fact that timing information occurred approximately once every minute, a search was performed for time in the general area where it was expected. The following tests are made:

* Figure 4.

```
9999999999                                                                  0566
EDYOWWWWWWWWN52P8ZT79LWWWWW6G4WNZWWWWW9IEMTSU9U92KWG8EFYTFSU9UXDK6WOE5EH   0567
HSU9UU2OTWXKMMK5HF4WHGWCH4H2EMWCE2EWXDK6W8HKFTTDWN2FWRW938GNFW9EZ2K6E2HY  0568
SU96KCTWK8TDE2HKFN6SU9UU9G2ED2NYWWWW87T2P2T9LSU9U9G2K8NYWWWWW9N8ZR2PT29L  0569
SU9UUUU99993SEXCWH8C9226S44U4VU2EXC6H4D22263SXW8922E6CSH4N4U4VU2YW6222E6  0570
C3HSFXW89226S44U4EVCUR2E64Y22263SXW8E9C2R2O6S44U4VW2XU2E2C2R2G63SXW89226  0571
S4E4CUR4HVW2X2U22263SEXCWR8R9226S44U4VW2E9CURWK222 63SXW8922E6CSR4C4U4VU2  0572
V88222E6C3RSDXW89226S44U4EVCWR2NYYS222 63SXW8E9C2R2F6S44U4VW2XS4E2C2K2E63  0573
SXW89226S4E4CUK4OVU2XY6222 63SEXCWK8G9226S44U4VU2E6CSKYH22263SXW8922E6CSK  0574
4R4U4VW2XU2222E6C3KSKXW89226S44U4EVCWK2CX2U22263STW8E9C2K2D6S44U4VU2YYWE  0575
2C2K2N63SXW89226S4E4CUK4FVU2VW822264SEXDWE8E369X9V4TVX22EYDYESO2226339ZY  0576
9USEXD9EYG396VU2XU4222E6D3ESHXW89226S44U4EVDUE2RX6622263SXW8E9D2E2K6S44U  0577
4VU26SYE2D2E2C63SXW89226S4E4DUE4DVU2XU222263SEXDWE8N9226S44U4VU2EXD2EUF2  0578
2263SXW8922E6DSO4E4ZUV22Y6W222E6D3OSOXW89226S44U4EVDUO2GVW822263SXW8E9D2  0579
O2H6S44U4VU2Y6SE2D2O2R63SXW89226S4E4DUO4KVU2664999999E9D9O9C999999BBBBSU  0580
9UUUU9TFCW6G4W8MGWEYIWWCCSU9UUSU9EYMIWNZ9WVVSU9999999999999999999999999999  0581
```

Figure 4. Hollerith Printout. Each printed character represents one line from the punched tape. In this case the data message fell on the punched tape so that each frame started at the beginning of a line. Therefore each 12-bit word occupied exactly three teletype lines. The sequence of boxed two's corresponds to the frame synchronization word pattern, where 2 represents a zero data line on the tape. The vertical dividing lines separate the sections of message containing interlaced time: ECHC, ECHD, ECHN, etc. The column of numbers on the right is the prepunched card sequence listing, each printed line corresponding to one punched card.

a. The presence of two or more even parity lines among the four lines expected to be timing information.

b. Internal consistency; the decimal digits within the time information may not have values higher than 2959.

c. The value of time must be one minute less than the preceding time.

If these tests are not passed, the computer will shift by plus or minus one to five lines and test for time in each of these positions. If the tests fail in all positions, a forced extraction of time will take place in the central position. This is necessary in order to preserve the 132 bit per frame sequence. Even if the extraction takes place on data lines, only four lines (two data words) of data will be disturbed by this procedure. Times are listed in decimal notation as they are extracted.

4. Word synchronization pattern.

The most sensitive test to develop the original frame pattern is the detection of the repetitive feature of 01 every 12 bits (excluding the frame synch word which is 00). (To determine the bits on which the test is to be made, the data are searched for an area of no parity error within a message. If this is not possible, an area of minimal parity error is utilized.) Testing consists of selecting a pair of bits every 12 bits for a three frame interval and testing the sum of the first bits of each pair for zero and the second for 27. It can

be seen that this test is extremely sensitive to a shift of one bit. An error rate of 1/15 allows the test to be satisfactory if the first sum is two and the second, 25.

5. Frame synchronization word.

Once the basic orientation of bits is determined, the words are searched to find sequential frame synchronization words (all zeros). A set of 12 bits over three frame intervals is selected every 132 bits and the sum is tested for zero. With a 1/15 error rate, the test is satisfied if the sum is less than two.

6. Overall message reconstruction.

The rest of the frames within a given message are extracted by counting 132 bits in both directions, testing for the presence of frame synch as we proceed. This test will be passed as long as the 132 bit per frame sequence is maintained, as long as signal is not lost and as long as parity error within a given zone of data remains within 1/15. When such synchronization is found lacking within a message, the synchronization procedure is begun again at paragraph 4. A listing of unsynchronized data is provided.

7. Output.

The outputs consist basically of a decimal or binary listing of the data in frame format (Figure 2) versus time. For the purpose of detailed scientific investigations, the

data are merged with trajectory information and calibrated to functional units. Such an output is illustrated in Figure 5. For quick-look purposes, the data are scanned for the desired subcommutated words and listed as in Figure 6.

PREFLIGHT SIMULATION

Prior to launch, members of STL's Space Physics Section prepared a set of simulated scientific data for 16 sequential frames. These data were then made repetitive to simulate a 10-minute transmission from the satellite and perturbed with error rates varying from 1/15 to 1/100 in a random manner. In addition, bit slippages of from one to three bits were inserted every ten frames or so in a random manner. Such data were used to successfully check out the program and to yield information relating to the cost of processing these data (one-half hour processing per hour of transmission at a 64 bit per second rate).

CONCLUSIONS

The use of a digital computer not only to reconstruct such data as mentioned in this paper but to process such data in a detailed analytical manner yields a tool capable of handling many millions of bits of scientific information per day and presenting them in a useable form. To perform such a task with a similar analog system might take many weeks per day of data transmission.

HAWAII CODE 0 MONTH 08 DAW 16 ABLE 3

TIME HR	MI	SC	UC PROPORTIONAL COUNTER TELESCOPE TRIPLES	SINGLES	MICROMETEORITE MEASUREMENTS HIGH	TOTAL	UM GEIGER MUELLER COUNTER	UM ION CHAMBER COUNTER	STL SCIMTILLATION COUNTER	SEARCH-COIL MAGNETOMETER AMPL.	PHASE	FLUX-GATE MAGNETOMETER DATA	RANGE	SU WHISTLER MODE EXPERIMENT	SUBCOM EXPERIMENT NO.	DATA
4	5	17	458	767	1	111	648	512	712	31	7	55	13	25	14	13
4	5	19	458	767	1	111	650	516	713	31	7	55	13	24	15	
4	5	21	458	767	1	111	651	519	714	31	7	55	13	25		43
4	5	23	458	767	1	111	652	522	715	31	7	55	13	24	1	42
4	5	25	458	767	1	111	653	526	716	31	7	55	13	24	2	42
4	5	27	458	767	1	111	654	529	717	31	7	55	13	24	3	24
4	5	29	458	767	1	111	656	532	719	31	7	55	13	24	4	36
4	5	31	458	767	1	111	657	536	720	31	7	55	13	25	5	
4	5	34	458	767	1	111	658	540	721	30	7	55	13	25	6	11
4	5	36	458	767	1	111	788	543	722	31	7	56	13	28	7	44
4	5	38	458	767	1	111	661	546	723	31	7	56	13	25	8	56
4	5	40	458	767	1	111	663	549	724	31	7	56	13	24	9	55
4	5	42	458	767	1	111	665	552	725	31	6	56	13	24	10	39
4	5	44	458	767	1	111	666	556	726	31	7	56	13	24	11	23
4	5	46	458	767	1	111	668	560	727	31	6	55	13	24	12	47
4	5	48	458	767	1	111	669	564	728	30	7	55	13	24	13	16
4	5	50	458	767	1	111	670	568	729	31	7	55	13	24	14	13
4	5	52	458	768	1	111	672	571	730	30	7	55	13	24	15	
4	5	54	458	768	1	111	673	574	731	31	7	55	13	24		43
4	5	56	458	768	1	111	674	577	732	30	7	55	13	24	1	42
4	5	58	458	768	1	111	676	580	733	31	7	55	13	24	2	42
4	6		458	768	1	111	677	584	735	31	6	55	13	24	3	24
4	6	2	458	768	1	111	678	588	736	30	7	55	13	24	4	36
4	6	4	458	768	1	111	680	592	737	31	7	55	13	25	5	1
4	6	7	458	768	1	111	681	596	738	30	7	55	13	27	6	10
4	6	9	458	768	1	111	682	600	739	31	7	55	13	24	7	44
4	6	11	458	768	1	111	684	604	740	31	7	55	13	24	8	56
4	6	13	458	768	1	111	685	607	741	31	7	55	13	24	9	55
4	6	15	458	768	1	111	687	610	742	30	6	55	13	24	10	39
4	6	17	458	768	1	111	689	614	743	30	7	55	13	24	11	23
4	6	19	458	768	1	111	690	618	744	30	7	55	13	24	12	47
4	6	21	458	768	1	111	692	622	745	30	7	55	13	24	13	17
4	6	23	458	768	1	111	694	626	746	30	7	55	13	24	14	13
4	6	25	458	768	1	111	695	630	747	30	7	55	13	24	15	
4	6	27	458	768	1	111	697	634	748	30	7	55	13	24		43
4	6	29	458	768	1	111	698	638	749	30	6	55	13	24	1	42
4	6	31	458	768	1	111	700	642	751	30	7	55	13	24	2	42
4	6	33	458	768	1	111	701	645	752	31	6	55	13	24	3	24
4	6	35	458	768	1	111	702	648	753	30	7	55	13	27	4	36
4	6	37	458	768	1	111	703	651	754	31	7	55	13	26	5	3
4	6	40	458	768	1	111	704	654	755	30	7	55	13	24	6	8
4	6	42	458	768	1	111	705	658	756	30	7	55	13	24	7	44
4	6	44	458	768	1	111	706	662	757	30	6	55	13	24	8	55
4	6	46	458	768	1	111	707	665	758	30	7	55	13	24	9	55
4	6	48	458	768	1	111	708	668	759	30	6	55	13	24	10	39
4	6	50	458	768	1	111	709	672	760	30	7	55	13	24	11	23
4	6	52	458	768	1	111	710	675	761	30	7	55	13	24	12	47
4	6	54	458	768	1	111	711	679	762	30	7	55	13	24	13	17
4	6	56	458	768	1	111	713	682	763	30	7	55	13	24	14	14
4	6	58	458	768	1	111	714	685	764	30	7	55	13	24	15	

Figure 5. Data Printout.

ABLE-3

AUG 7 MANCHESTER

HR	MIN	SEC	BATT MNTR. MA	BATT VOLTS	SINK XMTR DEG F	SINK CNVTR DEG F	BATT TEMP DEG F
16	4	33					
16	4	35					
16	4	37					
16	4	39	619				
16	4	41		17			
16	4	43			120		
16	4	45				97	
16	4	47					
16	4	49					95
16	4	51					
16	4	53					
16	4	56					
16	4	58					

Figure 6

Quick-look Data