Microcomputer-Based Pulse Code Modulation Data-Processing System for Rocket and Balloon Observations

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A microcomputer-based PCM (pulse code modulation) data-processing system for rocket and balloon experiments with data acquisition from a single-board microcomputer and an 8-in. dual-sided single-density floppy disk with two drives for storage of data is described. The maximum rate for data acquisition is 4096 bytes of data/986 ms. A double-precision Basic-based personal computer was used for data analysis.

INTRODUCTION

The introduction of computers into chemical instrumentation and data processing for convenience, for development of new instruments, and for invention of new methodologies in chemical research is a topic of great importance. For example, in the session on "Application of Microprocessors in Chemical Instrumentation and Processing" at the 28th IUPAC (International Union of Pure and Applied Chemistry) congress in Vancouver in 1981, many lectures were presented concerning the application of microcomputers in data-aquisition systems,[1–3] the control of the chemical instruments,[4–6] laboratory computer acquisition considerations,[7] the application of microprocessors in minicomputer environments,[8] the applications of microprocessors in the industrial environment,[9] and standards in microprocessor hardware and software.[10] In other sessions of the congress, participants also discussed the application of the computer in chemical instrumentation and processing.[11,12] For example, Hirschfeld[11] made the following statement: "The revolution that occurred in analytical chemistry in the past with the advent of instrumental analysis is paralleled now by a second revolution, sparked by the introduction of machine intelligence into analytical equipment". As another interesting example of the application in chemical research, Wilson[13,14] developed specialized instrumentation which he calls NEWTON for theoretical research on the molecular dynamics of many-atom chemical reactions.

New rocket- and balloon-borne spectrometers have been developed to perform spectral measurements on atmospheric molecules.[15,16] For exclusion of the effect of rocket motion on the spectrum, these spectrometers are based on multichannel spectroscopy and measure a spectrum within 10 ms by using fast electronic scanning of the spectrum. Such spectrometers using semiconductor imaging devices are becoming increasingly important in space science. Since the scan rate to measure a spectrum is faster than the data transmission rate of the telemetry, the spectral signal is stored in memory after conversion to digital data and then transmitted to the ground. The spectrum consists of 1024 8-bit words in our rocket experiments.[15,16] The transmitted data are stored on tape or disk at the observation station, and the stored data are brought to the laboratory for data analysis. In the data analysis, the corrections for inhomogeneity in sensitivity and base line of each pixel of the image sensor and the assignment of the wavelength are made first for the spectrum. The data are plotted as a spectrum, and finally the altitude distribution of atmospheric molecules can be obtained from the analysis of these integrated absorption intensities. A curve-fitting method is also often used to obtain the rotational temperature from the rotational profile of the absorption spectrum.

The use of a computer is indispensable for acquisition and analysis of such a large amount of data. Since a large amount of data must be sent quickly and exactly in these experiments, a digital data transmission method is preferable. In digital data transmission, data can be transmitted without distortion from the dynamic range and the bandwidth of the telemetry. The digital data from PCM telemetry can be processed directly by the use of a computer system. However, unfortunately, a computer system for processing the PCM data has not yet been prepared for rocket and balloon experiments. Therefore, the authors constructed a microcomputer-based PCM data processing system for use at a personal level. Recent developments in microcomputers make it possible to build such a personal-level system easily at low cost. In the present system, two types of microcomputers have been used: a single-board microcomputer has been converted for high-speed data acquisition, and a personal computer is used for data analysis. Such a personal-level system is convenient for use at different observation stations, since the system can be connected easily to different PCM telemetry systems with a simple interface and is small enough to be portable. By the use of a personal computer, we can carry out data analysis whenever we need to. This paper reports the construction of the system and discusses its characteristics. Particularly, we show how to construct a high-speed data acquisition system with the use of a low-cost single-board microcomputer and how to combine it with a personal-level computer for precise data analysis.

METHODOLOGY

Figure 1 shows the overall process of PCM telemetry. The data from a rocket- or balloon-borne physical instrument are edited in a PCM frame pattern with an encoder and then transmitted by the PCM telemetry to the ground. The PCM data are decoded and acquired in a LK-16 microcomputer system with an 8-in., dual-sided, single-density floppy disk. In data analysis, the data recorded in the floppy disk of the LK-16 microcomputer system are sent to a C-15E personal computer through a parallel I/O interface. An X-Y plotter and a printer are used to record the result of the data analysis.

The characteristics of LK-16 and C-15E microcomputers are given in Table I. The LK-16 mirocomputer used in the fast data acquisition is developed from an Lkit-16 single-board microcomputer[17] and is based on a 16-bit MN1610 microprocessor. The program to control the LK-16 computer is written in the Assembler language, which is convenient for high-speed hardware operation. The storage of a large amount of data can be made quickly with the use of a DMA-controlled floppy disk. The bus of such a single-board microcomputer-based system can be extended easily. The total RAM space of the LK-16 microcomputer is 36.25K 16-bit words.

The C-15E microcomputer used for data analysis in the present system is a commercially available personal computer[18] and is based on the 16-bit MN1610A microprocessor. The

Table I. Characteristics of LK-16 and C-15E Microcomputers

microcomputers	LK-16	C-15E
microprocessors	MN1610 (16 bits)	MN1610A (16 bits)
purpose	data acquisition	data analysis
classification	a computer developed from an Lkit-16 single-board microcomputer	a commercially sold personal computer
programming language	Assembler	double precision Basic (15-significant-digit calculation)
memory	RAM, 36.25K words; ROM, 4K words + a maximum of 8K words	RAM, 62K words; ROM, 2K words
software	convenient to high-speed hardware operation	convenient to numerical calculation
storage of data	an 8-in. floppy disk (DMA controlled)	digital cassette tape recorder
an external device for output of data	printer	printer and X-Y plotter
input/output port	(1) subchannel bus, 8 channels maximum (2) extended bus, 6 channels maximum	(1) 16-bits parallel interface (handshake method): input, 2 channels; output, 2 channels (2) the following interface boards are available: (a) IEC-bus adapter (IEEE-488-1975), drive maximum of 24 external devices; (b) serial interface, 2 channels maximum

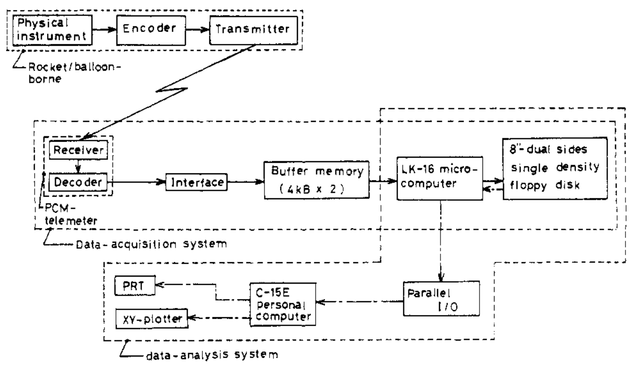

Figure 1. Overall process of PCM telemetry. The solid and dashed arrows represent the flow of process in data acquisition and data analysis, respectively. PRT is a printer.

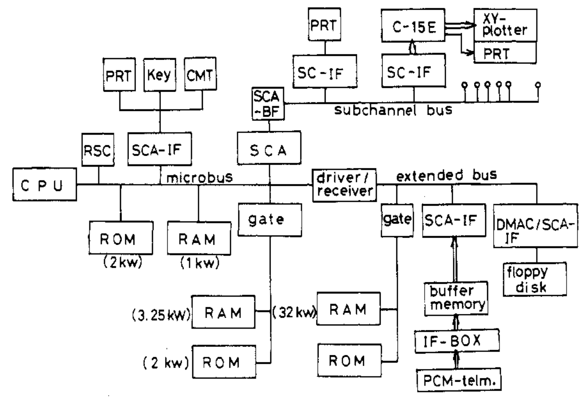

Figure 2. LK-16 microcomputer system developed from a one-board microcomputer for data acquisition. Abbreviations are as follows: CPU, an MN1610 microprocessor; RSC, an MN1640 real time system controller; SCA, an MN1630 subchannel adapter; ROM, a read-only memory; RAM, a random-access memory; SCA-IF, an interface with the use of an MN1630 chip; DMAC/SCA-IF, an interface with the use of an MN1650 direct memory access controller and an MN1630 chip; SCA-BF, a subchannel adapter buffer; PRT, a printer; KEY, a key and an LED display; CMT, an audio cassette magnetic tape recorder; C-15E, a C-15E personal computer; PCM-tem, a PCM telemeter.

maximum clock rate of the MN1610A microprocessor is twice that of the MN1610 microprocessor. The RAM space of the C-15E microcomputer is 64K 16-bit words. Data analysis can be carried out with 15 significant digits with the use of double-precision Basic language. Many subroutines are available for numerical analyses.[19]

Figure 2 shows the PCM data-processing system, which was constructed in the present work, based on the LK-16 microcomputer. The 4K bytes of 8-bits of parallel data from the PCM telemeter are stored in a buffer memory and then stored in the RAM of the LK-16 microcomputer. After that, the data are transferred to the 8-in. floppy disk via a DMA controller interface. The LK-16 microcomputer has two kinds of buses to communicate with an external subsystem, an extended bus and a subchannel bus. A subsystem can be connected to the extended bus by the use of a subchannel adapter (SCA) or by a combination of the SCA and a direct-memory-access controller (DMAC). Since the extended bus can communicate directly with the microbus, which is shown in Figure 2, the extended bus is preferable for fast data transference between the microbus and the external subsystem. However, there is a limit to the number of external systems which can be connected to the extended bus because an increase in the number of them causes the capacitance of the extended bus to increase. Since the same pulses are running in the microbus and the extended bus, the increase in the capacitance of the extended bus gives the same result as the increase of the microbus capacitance. On the other hand, since the subchannel bus is opened by only one subchannel adapter (SCA), one of the external devices connected to the subchannel bus must be selected in order to communicate with the microbus. This means that direct communication between the external devices which are connected to the same subchannel bus is impossible and that the subchannel bus is not preferable for rapid communication between the external device and the microbus either. Since no pulse in the microbus is running in the subchannel bus, an increase in the number of external devices in the subchannel bus does not give the same effect as the capacitance of the microbus increases. The pulses running in the subchannel bus are much less sensitive to an increase in the capacitance of the bus compared with those in the microbus and the extended bus, and therefore more external devices can be connected to the subchannel bus. In the present system, the extended bus is connected to only the buffer memory and the DMA-controlled floppy disk for the quick transfer of data. Other devices such as a printer and a digital I/O port are connected to the subchannel bus. The interface of the C-15E personal computer to the LK-16 microcomputer is connected to the subchannel bus of the LK-16 microcomputer.

Figure 3A shows the schematic diagram of the buffer memory circuit. The buffer memory consists of two blocks of 4K bytes of memory. The 8-bits of parallel data from the PCM telemetry are stored in one block of the buffer memory until 4K bytes of data are stored. After the block is filled by the 4K bytes of data, the data from the PCM telemeter are sent to another block of the memory. During the storage of

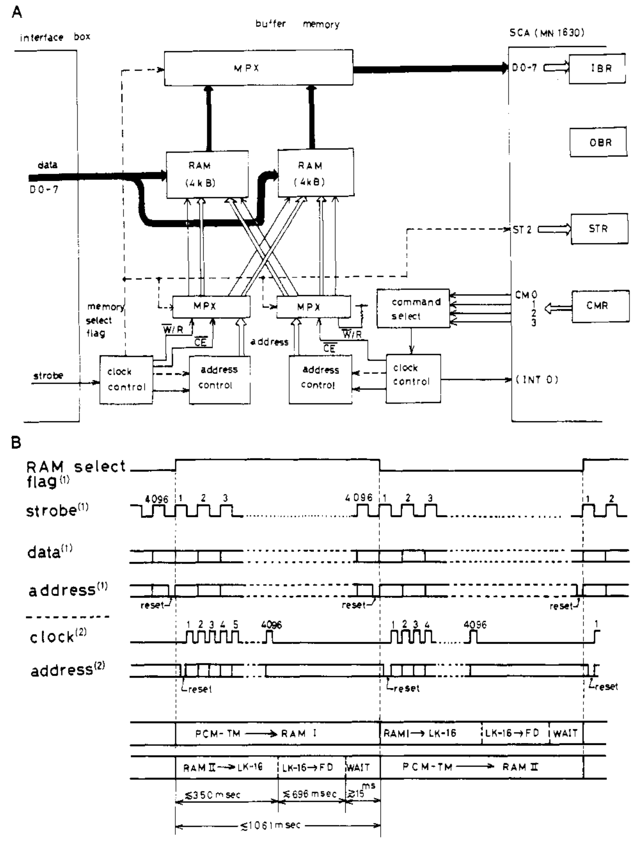

Figure 3. (A) Schematic diagram of the buffer memory circuit. MPX is a multiplexer. IBR, OBR, STR, and CMR are an input buffer register, an output buffer register, a status register, and a command register of an MN1630 subchannel adapter, respectively. (B) The timing diagram in the buffer memory circuit. The superscripts (1) and (2) indicate the control pulses for data transference from the PCM telemetry to the buffer memory and for data transference from the buffer memory to the LK-16 microcomputer system, respectively. RAMI and RAMII are the buffer memories, PCM-TM is a PCM telemeter, LK-16 is an LK-16 microcomputer, and FD is a floppy disk.

the PCM data in one block of the memory, the 4K bytes of data in another block are transferred to the LK-16 microcomputer through the input buffer register (IBR) of the subchannel adapter (SCA) and recorded by the DMA-controlled floppy disk. These processes are repeated by changing the blocks of the buffer memory alternately. The address data and control pulses for the memory to read the data from the PCM telemetry are derived from the strobe pulse which is sent simultaneously with an 8-bit parallel datum from the PCM telemetry. For transference of the data from the buffer memory to the LK-16 computer, the address data and control pulses are derived from the command data which are written in the command register (CMR) of the SCA of the LK-16 microcomputer by the control program. The passage of these address data and these control pulses to the buffer memories are controlled by tristate gates. The control pulse for the tristate gate is called a memory-select flag and is derived from the strobe pulse by the use of a 4K-byte counter and a flip-flop. The memory-select flag is connected to the data status register (DSR) of the SCA. The timing diagram for the transference of the data from the PCM telemeter and the LK-16 microcomputer system is shown in Figure 3B. As can be seen from this figure, the memory-select flag changes its logic as the 4K bytes of data are transferred from the PCM telemetry to the buffer memory.

The flow chart of the program for data acquisition is shown in Figure 4. The bottom of the stack pointer is defined in order to ensure the return address from the subroutine, and

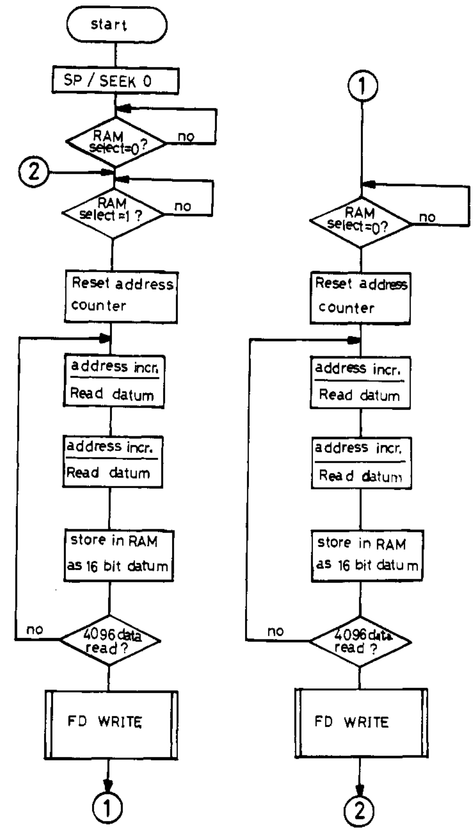

Figure 4. Flow chart of the program for the data acquisition.

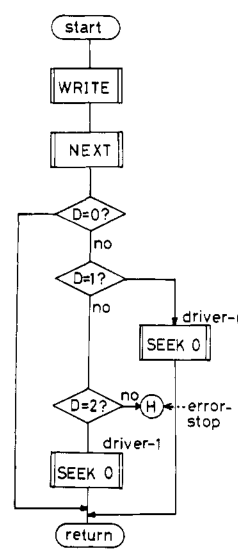

Figure 5. Flow chart of the FD-WRITE subroutine.

then the SEEK-TO-ZERO subroutine is executed to set the head of the floppy disk to the initial position. The status data of the DSR is checked to find the moment when the logic of the memory-select flag changes from low to high. After the flag changes, the 4K-byte address counter is reset, and then two 8-bit data are read from the buffer memory. These two data are combined to be a 16-bit datum which is stored in the memory. After 4K bytes of data are stored in the memory of the computer, these data are transferred to and recorded on the floppy disk by the FD-WRITE subroutine. After the return from the FD-WRITE subroutine, the computer waits until the memory-select flag changes. Similar processes are repeated after that. Figure 5 shows the flow chart of an FD-WRITE subroutine. In this subroutine, the 4096 bytes of data are written on the floppy disk (WRITE subroutine), the parameters such as the track address and the driver address are changed

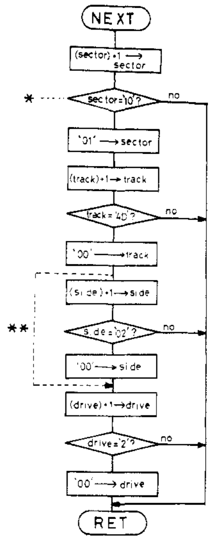

Figure 6. Flow chart of the NEXT subroutine.

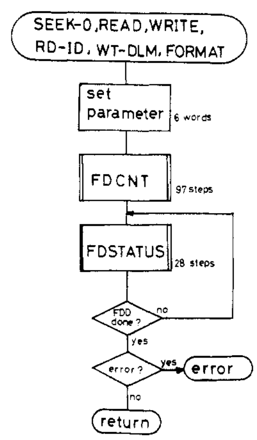

Figure 7. Flow chart of the SEEK-TO-ZERO subroutine (or the WRITE, READ, READ ID-FIELD, WRITE DELETED MARK, and FORMAT subroutines).

word	bit 0–7	bit 8–15
0	driver address	command
1	track address	sector address
2	modifiers	sector count
3	memory address	
4	FDD/ STATUS	
5	STATUS/ 2	

Figure 8. Parameters for operating the floppy disk. Here, "modifiers" indicates whether the interrupt is carried out or not. The step indicated by the asterisk mark in Figure 6 is unnecessary for the case of writing the data by 4096 bytes/track in a 512-byte/sector diskette because all eight sectors in a track are accessed continuously. The process indicated by the double-asterisk mark is for a single-sided diskette; that is, there is no necessity to change the side address in this case.

(NEXT subroutine), and the process of seek-to-zero is executed if it is necessary (SEEK-TO-ZERO subroutine). The flag "D" is to judge whether SEEK-TO-ZERO subroutine is necessary or not and which driver requires the SEEK-TO-ZERO subroutine process. Figure 6 shows the NEXT subroutine in which necessary changes are made to the sector address, the track address, the side address, and the driver address. As is shown in Figure 7, the flow-charts of the SEEK-TO-ZERO subroutine and the WRITE subroutine are similar to those of the READ subroutine, the READ ID-FIELD subroutine, the WRITE DELETED MARK subroutine, and the FORMAT subroutine.[20] In these subroutines, first the parameters which consist of 6 words, as shown in Figure 8, have to be set, second the FDCNT (floppy disk control) subroutine is executed, and third the result of the execution of the FDCNT subroutine is checked by reading the status data in the FD-STATUS (floppy disk status) subroutine.

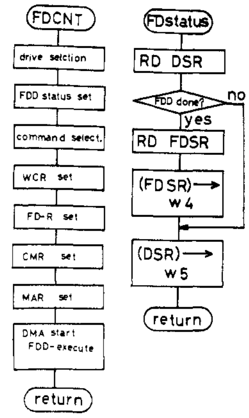

Figure 9. Flow chart of the FDCNT and the FD-STATUS subroutine.

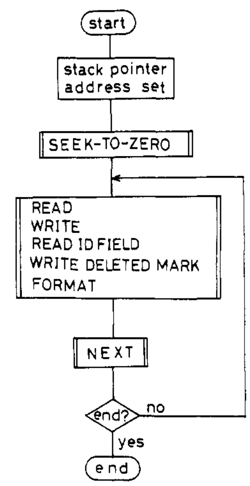

Figure 10. Flow chart of a typical program for floppy disk operation.

The command parameter in Figure 8 selects the subroutine to execute from the SEEK-TO-ZERO, the WRITE, the READ, the READ ID-FIELD, the WRITE DELETED MARK, and the FORMAT subroutines. The flow charts of the FDCNT subroutine and the FD-STATUS subroutine are also shown in Figure 9. In the FDCNT subroutine, the DMA mode starts, and the floppy disk driver executes after (1) the parameter of the driver address is set in the driver address register (DAR), (2) the initial parameters are set in the status register (FDSR) and the sector count register (SCR) of the floppy disk, (3) the command parameter is set in the floppy disk command register (FDCMR), (4) the number of words of data to be transferred is set in the word count register (WCR) of the DMA controller, (5) the parameters, track address, sector address, and the sector count are set in the track address register (TAR), the sector address register (SAR), and the sector count register (SCR), respectively, (6) the parameter is set in the command register (CMR) of the subchannel adapter (SCA) in the DMA controller interface, and (7) the initial memory address of the data is set in the memory address register (MAR) of the DMA controller (DMAC). In the FD-STATUS subroutine, the status data in the floppy disk status register (FDSR) and the data status register (DSR) of the subchannel adapter (SCA) in the DMA controller interface are written in word 4 and word 5 of the parameters, respectively. The parameters in word 4 and 5 are called FD/STATUS and STATUS/2, respectively. The flow chart of a typical program for floppy disk operation is shown in Figure 10.

Figure 11 shows schematically the DMA controller interface which was originally designed by the author. This interface is controlled by a combination of LSI's: MN1650 (DMAC, i.e., DMA controller) and MN1630 (SCA, i.e., subchannel

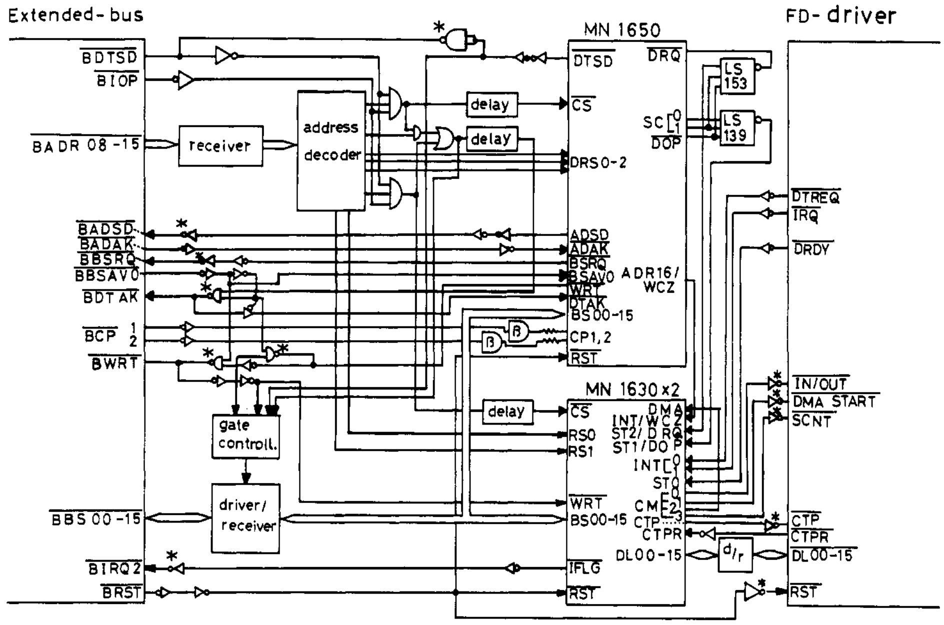

Figure 11. Schematic diagram of the DMA-controller interface. Here, the asterisk indicates an open-collector gate, d/r is a driver/receiver, and β is an SN75365 IC. In an extended bus the following abbreviations are used: $\overline{\mathrm{BDTSD}}$, data send; $\overline{\mathrm{BIOP}}$, input/output operation ($\overline{\mathrm{BIOP}}$ = high for a memory-chip access and $\overline{\mathrm{BIOP}}$ = low for an SCA-chip access); BADR, address data; $\overline{\mathrm{BADSD}}$, address send; $\overline{\mathrm{BADAK}}$, address acknowledgment; $\overline{\mathrm{BBSRQ}}$, bus request; $\overline{\mathrm{BBSAVO}}$, bus available 0; $\overline{\mathrm{BDTAK}}$, data acknowledgment; $\overline{\mathrm{BCP1,2}}$, two-phases clock pulses; $\overline{\mathrm{BWRT}}$, write/read operation; $\overline{\mathrm{BBS00\text{-}15}}$, data bus (bit 00–bit 15); $\overline{\mathrm{BIRQ2}}$, interrupt request; $\overline{\mathrm{BRST}}$, reset. In an MN1650 chip abbreviations are as follows: $\overline{\mathrm{DTSD}}$, data send; $\overline{\mathrm{CS}}$, ship select; DRSO-2, DMA register select 0–2; ADSD, address send; $\overline{\mathrm{ADAK}}$, address acknowledgment; $\overline{\mathrm{BSRQ}}$, bus request; BSAVO, bus available 0; $\overline{\mathrm{WRT}}$, write/read operation; $\overline{\mathrm{DTAK}}$, data acknowledgment; BS00-15, data bus; CP1,2, two-phases clock pulses; $\overline{\mathrm{RST}}$, reset; $\overline{\mathrm{DRQ}}$, DMA request; SC0,1, subchannel counter 0 or 1; $\overline{\mathrm{DOP}}$, DMA operate; ADR16/WCZ, address 16/word count zero. In an MN1630 chip the abbreviations are as follows: $\overline{\mathrm{CS}}$, chip select in program control mode; RS0,1, register select; IFLG, interrupt request flag; DMA, program control mode/DMA mode select line; INT/WCZ, interrupt 2/word count zero; ST2/DRQ; status input 2/DMA request; ST1/DOP, status input 1/DMA operate; INTO-1, interrupt line 0–1; STO, status input 0; CM0-3, command line 0–3; DL00-15, data line 00–15.

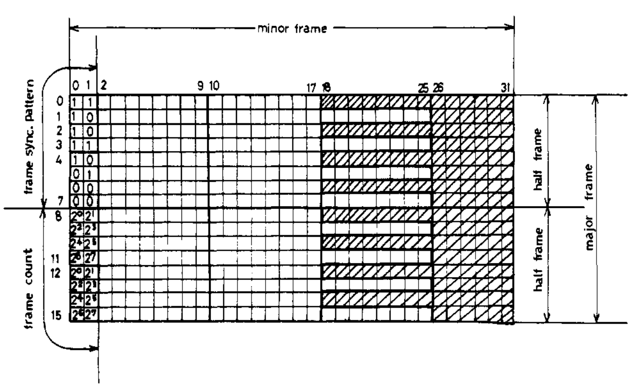

Figure 12. Frame pattern of PCM telemetry for rocket observations. Here, shaded bits are data of the ASL payload and blank bits are data of the TNP-O_2 payload.

adapter).[21] The details of the DMA controller interface are described in the notes.[22]

RESULTS AND DISCUSSION

Figure 12 shows the frame pattern of the PCM telemetry for the rocket observation. The bit rate of the data transmission is 25.6K bits/s. The first 2 bits of each minor frame are the frame-synchronizing data for the 0–7 minor frames or the frame-count data for the 8–15 minor frames. Other bits are the data from the physical instruments. For example, in Figure 12, they are the data of the ASL (aerosol) and our TNP-O_2 (temperature and number of O_2) payloads which were carried on the S-310-11 rocket. These data are output from the PCM telemetry as 8-bit or smaller than 8-bit parallel data with a strobe pulse. All these parallel data are assigned to channels in order to select the necessary data by decoding the channel number.[23] Figure 13 shows part of the dumped data of the S-310-11 rocket experiment. The data X′EB′ and X′90′ are the frame-synchronizing pattern and are marked by solid lines. The frame-count data are also marked by solid lines. The data of the TNP-O_2 are marked by a broken line.

Since 19 words of data are transmitted in four minor frames in the case of the S-310-11 rocket experiment, the time to transfer 4096 words of data is calculated to be (1/19 words) $\times$ (126 bits/25.6 $\times$ 10^3 bits/s) $\times$ 4096 words = 1061 ms. This is the time to read 4096 words of data into one block of the buffer memory; the memory-select flag changes its logic every 1061 ms. The maximum time for the floppy disk to read the 4096 bytes of data from the memory of the LK-16 microcomputer is 635 ms which is calculated by summation of the 240-ms maximum for the SEEK-TO-ZERO process (this process is necessary only in the case when the driver address changes), 10 ms for putting up the head of the floppy disk, a maximum of 166-ms for seeking the first sector address, 3 ms for changing the track address, 50 ms for loading the head, and a maximum of 166 ms for recording the 4096 bytes of data in one track. Since it takes 5 μs for the LK-16 microcomputer to execute one program step which is written with Assembler, the time necessary to write the 4096 bytes of data in the memory of the LK-16 microcomputer is a maximum of 350 ms. The time necessary for execution of the FD-READ subroutine is a maximum of 1 ms. The total of 986 ms (=635 ms + 350 ms + 1 ms) is the maximum time for the LK-16 microcomputer system to store the 4096 bytes of data. Therefore, it turns out to be smaller than the time of 1061 ms for the PCM telemetry to transfer the 4096 bytes of data to the buffer memory. This means that it is no problem for the present system to process the PCM data in our rocket ob-

15DB	0000	0000	0000	0000	0000	0000	00EB
15E2	0000	0000	0000	0000	0000	0000	0000
15E9	0000	0000	9000	0000	0000	0000	0000
15F0	0000	2C00	0005	CF00	002C	0800	0000
15F7	0000	0000	0000	0000	0000	0000	0000
15FE	4E00	0000	0000	0000	0000	0000	0000
1605	0000	0000	00EB	0000	0000	0000	0000
160C	0000	0000	0000	0000	0000	9000	0000
1613	0000	0000	0000	0000	0000	0000	0000
161A	00AC	0000	0000	0000	0000	0000	0000
1621	0000	0000	0000	4E00	0000	0000	0000
1628	0000	0000	0000	0000	0000	00EB	0000
162F	0000	0000	0000	00B1	B2B1	0000	B8B0
1636	0000	90B8	B0BB	0000	B2BA	0000	B1BD
163D	B200	00BE	B600	006C	BEB7	BE00	00B5
1644	BE00	00B4	BFB7	0000	C0B9	0000	4EC0
164B	B7C2	0000	BAC4	0000	B9C3	BB00	00C7
1652	BC00	00EB	C5BB	C300	00BA	C600	00BC
1659	C7BE	0000	C0C0	0000	90C0	BEC7	0000
1660	C0C7	0000	C0C8	BE00	00C9	8000	00EC

Figure 13. Dumped data of the S-310-11 rocket observation. The data are represented by a hexadecimal scale. The numbers in the first column indicate the addresses of the memory where the data in the second column are stored. The data marked by a solid line are the frame-synchronizing data (X'EB' and X'90') and the frame-count data. The data marked by a broken line are the data of the TNP-O_2. The unmarked data are of the ASL. The data X'05' and X'CF' in the addresses 15F2 and 15F3 are the code for indicating the beginning of the spectrum data of the TNP-O_2.

servation. When the channels consist of PCM data with fewer bits, the time to transmit the parallel PCM data increases and will be beyond the ability of the present PCM data processing system. Even in this case, the system can completely store the data of our instrument by selection of some channel numbers. The increase of buffer memory from 4096 × 2 bytes to 8192 × 2 bytes is of no use for the present single-density floppy disk but may be effective for a double-density floppy disk since the recording volume per a track in a double-density floppy disk is 8192 bytes. The use of multiprocessors for data acquisition will be effective to some extent. For example, when a microprocessor for data processing is used with an additional one for initializing the floppy disk, the time for the SEEK-TO-ZERO process will be saved. There are other methods for improving the speed of the system, but such improvements may not be very effective.

To decrease the capacitance of the extended bus of the LK-16 microcomputer, we have improved the system from that described in ref 15. In the present system, as is shown in Figure 2, the number of subchannel adapters for the buffer memory has been reduced from two to one, and the interface between the LK-16 microcomputer and the C-15E personal computer has been connected to the subchannel bus of the LK-16 microcomputer.

Although no PCM telemetry has been set up in our balloon center, digital data serialized by a shift register are transmissible with the use of analog telemetry. In this case, FM analog telemetry is useful for relatively low-speed transference of data and a direct modulation method for high-speed transference. The drift of the DC level of the serial data pulses is negligible in FM telemetry but is usually large in a direct modulation. Malfunctions due to this drift can be avoided by mixing both the high and low bit pulses periodically in the serial data pulses. For example, Figure 14 shows an example of the simple frame pattern which was actually used in the B-30-38 balloon observation.[26] Here, the bit rate was 25.6K

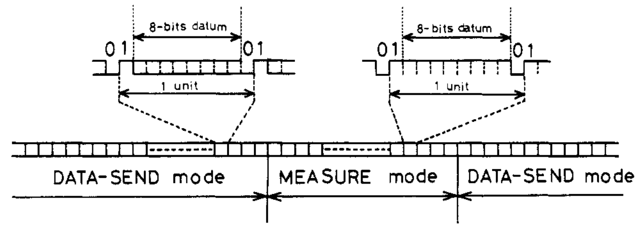

Figure 14. Simple frame pattern which was used in the B-30-38 balloon observation.

bits/s, and the data pulses were transmitted with direct modulation. The high-bit and low-bit pulses are set before and after the 8-bit serial data, respectively, in order to avoid a malfunction due to the DC drift. The bit-synchronizing pulse can be obtained from the detection of these high- and low-bit pulses. In the MEASURE mode, when the instrument is measuring the spectrum and is sending no data to the encoder, all-high-bit data are set between the high-bit and the low-bit pulses instead of the observational data. These data are used for frame synchronization. Thus, the present system turns out to be useful for digital data transmission even when no PCM telemetry system is available in the observation center by the aid of the simple encoder and decoder.

The result of the construction of the present PCM data-processing system indicates that the use of microcomputers is effective in the following ways: (1) the data-processing system can be connected easily to different PCM telemetry systems with simple interfaces, and (2) a personal-computer-based data analysis can be made. Recent developments in computers enable us to make a satisfactory analysis of scientific data with the use of a personal computer. In fact, the memory size, the significant digits for calculation, and the software library of the personal computer used in the present system are sufficient for analysis of balloon and rocket observational data. A personal-level system with the use of microcomputers will become more popular in the future in such experiments. It seems to be inefficient to develop an expensive computer system for rocket and balloon experiments, because only six rockets are launched every year from our rocket observation center, and the period of experiments is only about 2 months every year. Finally, we would like to emphasize the validity of a combination of microcomputers. Since the microprocessor is somewhat smaller, the required task is often beyond the ability of a single microprocessor. Therefore, it is effective to specialize microcomputers and use them in a multiprocessor system. In the present system, one microcomputer is used for high-speed data acquisition and another for data analysis with 15-significant-digit calculation ability and a sufficient software library.

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(20) The READ subroutine is for reading the data from the floppy disk to the host computer. The READ ID-FIELD subroutine is to read data such as the track address, the head number, the sector address, and the recording length in the ID-FIELD[24] in order to confirm the format of the diskette. The WRITE DELETED MARK subroutine is for writing the DELETED ADDRESS MARK instead of the DATA ADDRESS MARK of the DATA-FIELD.[24] This subroutine is used to skip a defect in a sector of the diskette. The FORMAT subroutine is for writing the format of the diskette when the format of the diskette has been broken or needs to be changed.

(21) "Manual of PANAFACOM L-16A LSI"; PANAFACOM: Fukami 534, Yamato, Kanagawa, Japan, 1977.

(22) The MN1650 chip has four sets of two kinds of registers: a memory address register (MAR) and a word count register (WCR). The MAR is a 16-bit register for keeping the memory address during the transference of data in the DMA mode. The WCR is also a 16-bit register and consists of a 4-bit MODE datum and a 12-bit WORD-COUNT datum. The MODE designates the mode of the DMA execution; that is, bit 0 indicates the direction of the DMA transference, bit 1 the subchannel interlace mode or the subchannel burst mode,[25] bit 2 the word transference or byte transference, and bit 3 the upper byte or the lower byte in the case of byte transference. In the present system, bit 1 and bit 2 always select the subchannel burst mode and the work transference, respectively, in order to transfer the data quickly. The WORD-COUNT datum indicates the number of words of the data to be transferred. These data in the DMAC registers are written with a program mode (PM mode) under the control of the CPU. The DMAC is controlled by two control pulses, CP1 and CP2, whose phases are different from each other and whose frequencies are the same, with a maximum of 2 MHz. The DMAC repeats the TEST cycle until it receives the DMA-REQUEST ($\overline{\mathrm{DRQ}}$) signal from the SCA. When the DMAC detects the $\overline{\mathrm{DRQ}}$ signal, the mode changes from the TEST cycle to the EXECUTE cycle. In the EXECUTE cycle, one datum is transferred between the memory of the microcomputer and the SCA under the control of the DMAC. After that, the datum in the WCR is reduced by one, the datum in the MAR increases by one, and then the EXECUTE cycle turns to the TEST cycle. These processes are repeated until the datum in the WCR becomes X'001'; here X'001' means that the number is represented by a hexadecimal scale. With respect to the interface of the DMA controller with the floppy disk driver, the INPUT/OUTPUT signal ($\overline{\mathrm{IN/OUT}}$) indicates the direction of data transference. The SCA sets the $\overline{\mathrm{DRQ}}$ signal to the DMAC by receiving the DMA TRANSFER REQUEST signal ($\overline{\mathrm{DTREQ}}$) from the floppy disk driver. The DMA-START signal ($\overline{\mathrm{DMA\ START}}$) with logic "high" starts the DMA transference. The CONTROL PULSE signal ($\overline{\mathrm{CTP}}$) is low when the datum is read from the OBR or written in the IBR of the SCA or when the $\overline{\mathrm{DOP}}$ signal is sent from the DMAC. The $\overline{\mathrm{CTP}}$ is reset by the CONTROL PULSE RESET ($\overline{\mathrm{CTPR}}$) signal. The INTERRUPT REQUEST signal ($\overline{\mathrm{IRQ}}$) becomes low when the floppy disk finishes the execution of the command and the low signal of $\overline{\mathrm{IRQ}}$ resets the DMA-START signal in order to stop the DMA transference. The STATUS CHANGE CONTROL signal ($\overline{\mathrm{SCNT}}$) designates the FDD READ STATUS or the FDD READ SECTOR COUNT according to whether the $\overline{\mathrm{SCNT}}$ is high or low, respectively. The DRIVE READY STATUS signal ($\overline{\mathrm{DRDY}}$) which can be read from the DSR of the SCA indicates whether the floppy disk is ready to execute.

(23) The frame-synchronizing data X'EB' and X'90' are assigned to channels 0 and 1, respectively. The two words of frame-count data are assigned to the channels 2 and 3. In the case of the S-310-11 experiment, the 8-bit datum which consists of bits 2–9 in the minor-frame 0 are designated as channel 4, the bits 10–17 as channel 5, the bits 18–25 as channel 6, the bits 26 and 27 as channel 7, the datum with the bits 2–9 in the minor-frame 1 as the channel 8, the bits 18–25 as channel 10, the bits 30 and 31 as channel 12, and a combination of the bits 28–31 in the minor-frame 0 and the bits 26–29 in the minor-frame 1 as channel 11. Since the formation of the parallel data for the TNP-O_2 and the ASL are repeated by two minor frames, all the following data can similarly be designated by channels 4–12. For example, the data with bits 2–9 in the minor frame 2 is assigned to channel 4, the next datum to channel 5, and so on. The frame-synchronizing patterns and the frame-count data are repeated by a major frame, and therefore all the synchronizing patterns and the frame-count data can be represented by the channels 0–3.

(24) The sector of the diskette consists of the ID-FIELD, the DATA-FIELD, the gap to separate them, and the gap to separate the neighboring sectors. The ID-FIELD is for specifying the sector, and the ID-ADDRESS MARK and the data concerning the track address, the head number, the sector address, and the recording length are written there. The DATA-FIELD consists of the DATA ADDRESS MARK (or the DELETED ADDRESS MARK) and the 128, 256, or 512 bytes of data.

(25) An MN1650 (DMAC) can control four sets of subchannel adapters (SCA) with the SC0 and SC1 (subchannel counters 1 and 2) pulses in the DMA mode. Although all four sets of subchannel adapters are accessed alternately in interlace mode, one set of subchannel adapters is accessed in the burst mode. Therefore, the burst mode is convenient for the high-speed DMA control of one terminal.

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