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INVESTIGATION OF A HIGH SPEED DATA HANDLING SYSTEM  
FOR USE WITH MULTISPECTRAL AIRCRAFT SCANNERS

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INVESTIGATION OF A HIGH SPEED DATA HANDLING  
SYSTEM FOR USE WITH MULTISPECTRAL AIRCRAFT  
SCANNERS

By W. Lane Kelly and Barry D. Meredith

SUMMARY

A buffer memory data handling technique for use with multispectral aircraft scanners is presented which allows digital data generated at high data rates to be recorded on magnetic tape. A digital memory is used to temporarily store the data for subsequent recording at slower rates during the passive time of the scan line, thereby increasing the maximum data rate recording capability over real-time recording. Three possible implementations are described and the maximum data rate capability is defined in terms of the speed capability of the key hardware components. The maximum data rates can be used to define the maximum ground resolution achievable by a multispectral aircraft scanner using conventional data handling techniques.

INTRODUCTION

Measurements obtained from multispectral radiometers onboard satellites or aircraft are becoming increasingly important in the fields of forestry, agricultural survey, land use, geology, hydrology, and environmental quality. Multispectral scanner data from aircraft are providing valuable information to bridge the gap between insitu and satellite measurements. The emphasis of current research to support

these measurements is concentrated on expanding the science capability of multispectral aircraft scanners by increasing spatial resolution (instantaneous field-of-view), signal-to-noise ratio, and the number of spectral channels. In system designs which provide high signal-to-noise ratios, data must be digitized prior to recording. To accommodate the increased data rates and quantity of data associated with aircraft scanner development, improved data handling and recording systems must also be developed.

The rate at which digital data can be recorded in real time is often limited by the frequency response of the tape recorder. The data rate seen by the tape recorder can be significantly reduced in aircraft scanner applications since the scanner acquires data during only a small fraction of the time for a complete scan line. This data rate reduction can be achieved by storing the data during the short data acquisition period and recording during the longer passive time before the next scan line.

The purpose of this paper is to define the data handling system requirements in terms of aircraft scanner design parameters and to present three system designs for implementing a buffer memory for temporary storage of data during a scan line. The performance of the data handling system designs presented here is described in terms of the maximum input data rate that could be handled from a multispectral aircraft scanner. The speed requirements for sample and hold amplifiers, analog-to-digital converters, and digital memories are discussed and comparisons are made between system designs to assist in the selection and implementation of a

data handling system for a particular aircraft scanner application. The use of the buffer memory data handling technique should provide the capability to handle the increased data rates from multispectral aircraft scanners with requirements for high ground resolution and high signal-to-noise ratios.

## SYMBOLS

$b$	number of bits in a digital word
$c$	number of spectral channels
$c_r$	clock rate, Hz
$f_c$	upper frequency response limit of a tape recorder, Hz
$h$	aircraft altitude, m
$N_D$	number of data samples per scan line
$N_e$	number of engineering words per scan line
$t_a$	active scan time during which data are acquired, seconds
$t_{AD}$	conversion time for A/D converters, seconds
$t_c$	convert command pulse width, seconds
$t_i$	time between image elements, seconds
$t_p$	passive scan time during which data are not acquired, seconds
$t_{sh}$	acquisition time of the sample and hold devices, seconds
$t_{wc}$	cycle time of the memory in the write mode, seconds
$v$	aircraft ground velocity, m/sec
$\alpha$	angular separation between data samples, radians
$\beta$	instantaneous field of view of the optical system, radians
$\eta$	field of view covered by a scan line, radians
$\omega$	angular rotational rate of scanner mirror, radians/seconds

## CONFIGURATION OF AIRCRAFT SCANNER

The basic configuration of the aircraft scanner, which is shown in figure 1, consists of a scanning mirror, the imaging system, the grating, and the photodetectors. The imaging system is a cassegrain system which images the scene onto an aperture that defines the spatial resolution. The rotating mirror provides the x-axis scan by moving the imaged scene past the aperture. Radiation passing through the aperture is captured by a collimating lens and passed through a diffraction grating which spectrally separates the incoming radiation. The first-order spectrum is imaged by a second lens onto a row of photodetectors. The physical location of each of the photodetectors along the line image determines the wavelength region that each photodetector channel observes. Hence, the number and position of the photodetectors determines the number of spectral channels and their spectral characteristics.

The y-axis scan is provided by the motion of the aircraft in the direction of flight. To provide the desired data sampling interval in the y-dimension, the angular velocity of the scan mirror shaft, equals

$$\omega = \frac{2\pi v}{\alpha h} \quad (1)$$

where  $\alpha$  is the angular separation between data samples,  $v$  is the aircraft ground speed,  $h$  is the aircraft altitude. The above expression assumes a single faceted mirror in the configuration shown in figure 1.

The aircraft altitude becomes an important consideration since for a given instantaneous field of view of the multispectral scanner, the

ground resolution of the instrument is determined. Also for a given altitude there exists a range of desirable velocities for aircraft operation.

The output format for the analog multispectral data can be described in terms of the active time, the passive time, and the time between image elements. The active time,  $t_a$ , is the time that data are actually being acquired during a scan line

$$t_a = \eta/\omega \quad (2)$$

where  $\eta$  is the field of view in radians. The passive time,  $t_p$ , is the period when the rotating mirror is positioned to view regions other than the field of view, and can be described as

$$t_p = \frac{2\pi - \eta}{\omega} \quad (3)$$

The time interval between data samples can be described as

$$t_i = \frac{\alpha}{\omega} = \frac{t_a}{N_D} \quad (4)$$

where  $N_D$  is the total number of data samples during a scan line. For contiguous data samples, the instantaneous field of view ( $\beta$ ) should equal the sampling interval  $\alpha$ , and for overlapping samples,  $\alpha < \beta$ . The instantaneous field-of-view of the aircraft scanner can be expressed in terms of  $t_i$ , aircraft velocity and altitude as

$$\beta = \left( \frac{2\pi t_i v}{h} \right)^{1/2} \quad (5)$$

by combining eq. (1) and (4) for the contiguous sampling case,  $\alpha = \beta$ .

The above expression is plotted in figure 2 for several  $v/h$  values to illustrate practical values for instantaneous field-of-view as a function of image element viewing time.

#### DATA RECORDING

The electro-optical design of the aircraft scanner provides photo-sensor output signal-to-noise ratios which could be as high as 1000. Since analog tape recorders operating in the direct mode have signal-to-noise ratio limitations in the range of 50-100, data must be digitized prior to recording on magnetic tape. In addition to the digitized multispectral data, digital words pertaining to channel identification, calibration, line number, and synchronization must also be recorded. Digital data are transmitted to the tape recorder as a serial bit stream, with the most significant bit of each word transmitted first.

With the tape recorder operating in the direct record mode, the upper frequency response limit of the recorder,  $f_c$ , defines the limit for the effective bit rate that can be recorded. Typical intermediate band recorders have cut-off frequencies around 300 kHz and wide-band machines operate up to 1 MHz. In general, the effective bit rate of the digital recording code should be less than  $0.7 f_c$  to accurately record the digital information. Since analog recorders do not have dc response when operating in the direct mode, errors can result if the digital recording code contains many consecutive digital ones (or zeros).

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To meet the tape recorder requirements, several possible digital recording codes could be used. A brief description of the digital recording codes considered for use with an aircraft scanner is presented in Appendix A. Delay modulation is the most desirable recording code for applications where tape recorder bandwidth limits the system data rate.

It is generally desirable to multiplex all spectral channels onto a single tape track to simplify decoding all of the data in a single tape playback. However, for high spatial resolution and many spectral channels, the data rates exceed the tape recorder frequency response. The following expression can be used to evaluate the tape recorder capacity for recording aircraft scanner multispectral data in real-time

$$f_c \geq \frac{1.43 \text{ cb}}{t_i} \geq \frac{1.43 \text{ cb } N_D}{t_a} \quad (6)$$

where  $b$  is the number of bits per word and  $c$  is the number of spectral channels. The above expression must be modified for digital recording codes, such as Manchester, which requires higher bandwidths than the bit rate.

Figure 3 illustrates the tape recorder frequency response requirement as a function of  $t_i$  for several levels of digital encoding. The frequency response requirement exceeds the tape recorder capability in applications which require both high spatial resolution (small  $t_i$ ) and high signal-to-noise ratios (large  $b$ ).

For the aircraft scanner, incorporating a buffer memory into the data handling system can reduce the tape recorder frequency response

requirement significantly. The active portion of the scan line,  $t_a$ , is generally significantly less than the passive portion,  $t_p$ . By storing the data in memory as it is acquired and reading the data out of memory during  $t_p$  for recording on tape, the bandwidth requirement can be reduced by approximately  $t_p/t_a$ . Additional information such as channel identification, line number, synchronization words, and engineering data can be recorded efficiently during  $t_a$  while multispectral data are being stored in the memory. For data handling systems which utilize this buffer memory technique, the tape recorder frequency requirement can be described as

$$f_c \geq \frac{1.43 \text{ cb } (N_D + N_e)}{t_a + t_p} \quad (7)$$

A typical format for data recorded in this manner is illustrated in figure 4, with the assumption that each spectral channel is recorded on a separate tape recorder track. To identify the beginning of a line of data, several word positions are used to record a Barker word. The Barker code word is often used to provide a multi-bit synchronization pattern which has a very low probability of synchronization error. Additional synchronization words are inserted periodically in the data stream to verify and maintain synchronization, as defined by the decoding system which reads the tape.

#### DATA HANDLING SYSTEM

As aircraft scanner systems are developed with increased spatial resolution, the resulting increase in data rates makes real-time

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recording of digital data virtually impossible. The general technique presented here allows data to be obtained at higher rates than could normally be recorded in real time. This is accomplished by storing the digital data temporarily during  $t_a$ , and recording during the longer time interval  $t_p$  before the next scan line. Applications may arise such as large fields of view, for which it is desirable to begin reading data out of the digital memory before completion of the active portion of the scan. To operate in this mode, the control electronics must cycle the read/write state of the memory between data samples, therefore requiring a memory with twice the speed capacity. In addition, complex control electronics are required to synchronize the read/write operations of the memory with the data flow to and from the memory. Since operating the data handling system in this mode provides only a slight increase in data rate for the additional complexity, only the mode of operation which stores a complete line of data before reading from the memory is described in detail.

To determine the data system requirements, several considerations must be made. Generally, the instantaneous field of view,  $\beta$ , of the scanner is determined from S/N and ground resolution requirements along with limitations imposed by the size of the optics and the detector performance. Practical values for aircraft altitude and velocity must also be considered. Defining the degree of sampling overlap ( $\alpha \leq \beta$ ) allows the mirror angular velocity to be determined according to equation (1). Further, the value of  $t_i$ , the time interval between data samples along a scan line, is defined in equation (4) and serves as one

of the primary data handling system requirements. The second data handling requirement results from the tape recorder bandwidth limitation. Since the data systems described here reduce the necessary frequency response requirement by storing the data during  $t_a$  and recording during  $t_p$ , the required frequency response  $f_c$  is dependent upon the desired field of view  $\eta$  (length of a scan line). The active time for the scanner can be used to define the tape recorder frequency response

$$f_c \geq .23 \text{ cb } \omega \left( \frac{t_a}{t_i} + N_e \right) \quad (8)$$

This expression, along with the  $t_i$  value, defines the operating requirements for the data handling system.

Three data handling system designs are presented here, each of which performs the basic functions shown in figure 5. These functions include sampling the data, digitization, temporary data storage, data formatting, code conversion, and recording.

#### Multiplexed Single Memory System

The digital data acquisition system of figure 6 stores data from each of the scanner output channels into a single parallel memory during the active scan time,  $t_a$ . A timing diagram for the system is shown in figure 7. After the acquisition time of the sample and hold devices,  $t_{sh}$ , the analog levels are stable at the input of the analog-to-digital converters (A/D). The A/D's receive a convert command,  $t_c$ , from the control circuitry and valid digital data are present at the multiplexer input after the maximum A/D conversion time,  $t_{AD}$ . The data from each

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scanner channel is then multiplexed onto the data lines of the memory as the channel number is selected. Selection of the individual channels is accomplished by a counter within the control circuitry whose output is connected to the select lines of the multiplexer. Another counter in the control section provides memory addressing. Both the selection and address counters are clocked at the same rate; therefore, the data and its memory address appear at the memory simultaneously. Once the data and address have settled on their respective memory lines, a chip enable command from the control circuitry writes the data into memory ( $R/\bar{W} = 0$  during  $t_a$ ). The selection and address counters are then incremented and the data from the next channel are written. When the data from the last channel are recorded in the memory, the control circuitry clears the selection counter and inhibits the address counter until the completion of the A/D conversion process for the next data point (figure 7).

At the end of the active scan time, the memory is placed in the read mode ( $R/\bar{W} = 1$ ) by the control circuitry to begin sending data to the magnetic tape recorder during the passive time,  $t_p$ . The data word is addressed and the channel number from which the data originated is selected simultaneously as in the data input process. After the data are demultiplexed to the appropriate parallel to serial shift register, the register receives load and shift commands. The data are then clocked into the recorder code generator.

For the single memory system, the memory must be at least  $b$  bits wide by  $cN_D = \frac{cn}{\alpha}$  words long to store a complete scan line of data. This assumes that engineering data are not stored in the main data memory, but either in a secondary memory or obtained from separate control circuitry.

The maximum input data rate for which the multiplexed single memory system will operate can be determined as follows. The required image element time  $t_i$  for the data acquisition system in figure 6 is defined by the following equation

$$t_i \geq t_{sh} + t_c + t_{AD} \quad (9)$$

The second condition imposed upon  $t_i$  involves the time allotted for all spectral data for each image element to be written into the memory. This constraint can be described as

$$t_i \geq t_{AD} + ct_{wc} \quad (10)$$

where  $t_{wc}$  is the memory cycle time in the write mode. Therefore, the number of channels that can be written into memory during  $t_i$  is equal to

$$c \leq \frac{(t_i - t_{AD})}{t_{wc}} \quad (11)$$

The effect of the A/D conversion time,  $t_{AD}$ , upon the number of channels a system can accommodate and  $t_i$ , could be eliminated by latching the digital data at the output of the A/D converters.

With this configuration, equation (11) reduces to

$$c \leq t_i/t_{wc} \quad (12)$$

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The two requirements for  $t_i$  can be summarized for the latched single memory system as

$$t_c + t_{AD} + t_{sh} \leq t_i \leq ct_{wc} \quad (13)$$

And for the single memory system without latching the requirement for  $t_i$  can be stated as

$$t_c + t_{AD} + t_{sh} \leq t_i \leq t_{AD} + ct_{wc} \quad (14)$$

As noted in eq. (13) and (14), both conditions in each equation must be satisfied for the data handling system to operate successfully.

#### Separate Parallel Memory System

The data acquisition system in figure 8 employs a separate parallel memory for each spectral channel of the aircraft scanner. A timing diagram for the system is provided in figure 9. As in the single memory configuration, data are sampled at the beginning of every image element time interval,  $t_i$ , and analog-to-digital conversion is performed. After the maximum conversion time for the A/D converters, valid data appear on each set of memory data lines. A status pulse, whose width represents this A/D maximum conversion time, is generated by the control circuitry to clock an address counter located within the control section. The counter addresses all of the individual memories. Data are written into each memory simultaneously by a chip enable pulse generated by the control

circuitry at the completion of the A/D conversion process ( $R/\bar{W} = 0$  during  $t_a$ ). To store a complete scan line, each memory must be at least  $b \times N_D$  in size.

At the conclusion of the active scan time,  $t_a$ , the memory is placed in the read mode by the control circuitry ( $R/\bar{W} = 1$ ). Data can then be readout to the tape recorder during the passive time,  $t_p$ .

The clock rate for the address counter is changed in the output process to equal

$$c_{r_1} = \frac{N_e + N_D}{t_a + t_p} \quad (15)$$

After the counter receives a clock pulse and the address has settled on the memory address lines, a chip enable command from the control circuitry transfers the data words from the memories to the input of the appropriate parallel to serial shift registers. The parallel data are then loaded into the registers and a series of shift commands allows data to be clocked into the code generators. These serial data are clocked at a rate equal to

$$c_{r_2} = \frac{b(N_e + N_D)}{t_a + t_p} \quad (16)$$

These clock rates ( $C_{r_1}$ ,  $C_{r_2}$ ) provide a continuous data bit stream to the tape recorder.

The required image element time,  $t_i$ , can be determined in part by the following equation

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$$t_i \geq t_{sh} + t_c + t_{AD} \quad (17)$$

which is the same as for the single memory system. The second condition imposed upon  $t_i$  involves the time required to write all the spectral data for each  $t_i$  into memory. This constraint can be expressed as

$$t_i \geq t_{AD} + t_{wc} \quad (18)$$

Unlike the single memory system, the image element time is not a function of the number of spectral channels. Excluding the single address counter and common memory address lines, each channel of the separate memory system has independent electronics, and hence, the system can be easily expanded or modified.

Once again, the effect of  $t_{AD}$  on  $t_i$  can be eliminated by latching the output of the A/D converters. Equation (18) reduces to

$$t_i \geq t_{wc} \quad (19)$$

The two equations for the latched separate memory system can be summarized as

$$t_{sh} + t_c + t_{AD} \leq t_i \geq t_{wc} \quad (20)$$

The equations for the unlatched system can be stated as

$$t_{sh} + t_c + t_{AD} \leq t_i \geq t_{AD} + t_{wc} \quad (21)$$

### Separate Serial Memory System

The serial memory system in figure 10 utilizes a one-bit-wide memory for each channel and is capable of storing  $N_D$  bits. A timing diagram for the system is shown in figure 11. As in the previously described systems, the control circuitry issues commands to sample and hold the analog data at the beginning of  $t_i$  and then converts the analog data to digital form. Upon completion of the A/D conversion process, digital data are latched into the parallel-to-serial registers by a load pulse to the registers from the control circuitry. Further changes at the shift register's input will be ignored until the next load command. After the registers are loaded, the most significant bits (MSB) of the digital words appear on their respective memory data lines. The rising edge of the clock pulse (CLK1) increments an address counter (figure 11) located within the control section whose output is common to the address lines of all the memories. This clock also strobes the parallel-to-serial registers and runs at a rate equal to  $b/t_i$ . When the address has settled upon the memory address lines, a chip enable pulse,  $\overline{CE}$ , from the control circuitry causes the MSB of the data words to be simultaneously written into the serial memories. On the next low to high transition of the clock pulse, the memory address is incremented and the next most significant bits of the digital words are shifted onto the data lines. Once again, an enable pulse from the control circuitry stores the data bits into their respective memories.

To input engineering data,  $N_e$ , and synchronization words to each tape recorder channel during  $t_a$ , a second parallel-to-serial shift register

per channel is used (figure 10). During  $t_p$ , the output of these registers is inhibited and the data line is selected to input data words,  $N_D$ , to the code generator.

An alternate configuration of the serial memory can be considered for low-speed applications. Many A/D converters provide a serial data output and can be operated using an external clock. If the clock period is greater than the memory cycle time, the data can be written directly into the memory. This would eliminate one parallel-to-serial shift register from each channel.

During the passive time,  $t_p$ , the memories are placed in the read mode by the control circuitry ( $R/\bar{W} = 1$ ) to begin sending serial data to the tape recorder. The address counter, the chip enable input of the memories and the code generators are clocked at a rate that provides a continuous data bit stream to the recorder. This rate is equal to  $\frac{bN_D}{t_p}$ .

The minimum image element time,  $t_i$ ; as in the other systems is limited by the equation,

$$t_i \geq t_{sh} + t_c + t_{AD} \quad (22)$$

Since a parallel-to-serial shift register latches the A/D converter output for the entire  $t_i$ , essentially all of the image element time is available for storing data into the memory. Therefore, another expression for  $t_i$  is

$$t_i \geq b t_{wc} \quad (23)$$

Combining the two formulas, the limiting expression for  $t_i$  becomes:

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$$t_{sh} + t_c + t_{AD} \leq t_i \leq b t_{wc} \quad (24)$$

### System Comparisons

The expressions describing the maximum data rate capabilities of each of the three buffer memory configurations are summarized in Table I. To allow a more practical evaluation of the capabilities of the data handling system and a more realistic comparison between system designs, Appendix B presents typical values for the pertinent hardware components. Also the image element time,  $t_i$ , is determined for a hypothetical system to define the maximum data rate. In addition to the data rate capability, each system must be considered in terms of expansion flexibility, ease of implementation, and suitability for adaptation to a microprocessor for additional data processing, such as offset removal and calibration.

The separate parallel memory system requires the least time to store an image element of the system examined here. It is a factor of  $c$  faster than the single memory configuration because it requires no data multiplexing and a factor of  $b$  faster than the separate serial memory system since the data are written into the memory in parallel. To compare the multiplexed single memory and separate serial memory systems for minimum required,  $t_i$ , the digital data word width,  $b$ , and the number of spectral channels,  $c$ , must be known for the specific scanner application. If  $b > c$ , the multiplexed system has a higher data rate capability than the serial memory system and if  $b < c$ , the reverse is true.

The serial memory system offers flexibility above that of the parallel configurations since it can be modified to accommodate design

changes with less difficulty. Both the separate parallel and serial memories can be expanded to accommodate an increase in the number of spectral channels by simply adding an equal number of memory circuit modules to the system. This advantage can be attributed to the independent operation of the individual memories in both configurations.

However, unlike the parallel technique, the word width in the serial memory system can be expanded without alterations or additions to the memory, assuming memories with unused storage areas are employed in the initial design and  $t_i/b$  is always greater than  $t_{wc}$ . The multiplexed single memory system is the least flexible of the systems examined. For instance, expanding the number of channels it can accommodate involves modifications of counters and multiplex circuitry as well as probable memory alterations.

By inspection of the system configurations and timing diagrams in figures 6 through 11, the separate parallel memory system is the least complicated to implement of the three systems presented. This can be attributed to the absence of data multiplexing and parallel-to-serial conversion during  $t_a$ . Also, data from each image element is stored simultaneously by generating only one memory enable pulse. As a result of these factors, the control section requires less complicated circuitry and timing.

To perform processing of the aircraft scanner data, a microprocessor could be incorporated into the digital data acquisition system. This would expand the system capability to include such processes as data calibration, gain ranging, and subtraction of offsets. The multiplexed

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single memory system would readily interface with a microprocessor since the system has only one set of data lines as well as one set of address lines. The separate memories (parallel and serial) would require one processor for each set of data lines.

Overall system size, power consumption, packaging, and reliability were not considered in the above comparisons since they vary according to the specific scanner configuration and application.

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## CONCLUDING REMARKS

A buffer memory technique for providing a high-speed data handling system for a multispectral aircraft scanner has been presented. Improved aircraft scanner designs produce high signal-to-noise ratio data at high rates which typically are recorded in digital form on analog magnetic tape. As higher spatial resolution, and hence, ground resolution systems are designed, the data rates become too high for real-time recording on magnetic tape. Augmenting the data handling system with a buffer memory allows a significant increase in the aircraft scanner data rates which can be recorded. This is accomplished by storing the digital data in memory during the short active portion of the scan line and recording the data during the longer passive portion.

The handling requirements for multispectral aircraft scanner systems were characterized in terms of spatial resolution, image element viewing time, and tape recorder bandwidth requirements. Three digital memory configurations were presented for implementing the buffer memory technique. The operation and speed capability of each design configuration was discussed in terms of the image element viewing time and the speed capability of the key hardware components.

The speed of each of the three system designs is limited by the time required for the digitization process and the time to store the digital data for each image element. The separate parallel memory system requires the least time to store data for an image element. It is a factor of  $c$  (number of spectral channels) faster than the single

memory configuration because it requires no data multiplexing, and a factor of  $b$  (bits per word) faster than the serial memory configuration since data are written in parallel. The serial memory system has a higher data rate capability than the single multiplexed memory when the number of spectral channels is greater than the number of bits per word. The single multiplexed memory can be readily interfaced to a micro-processor in cases where data processing or reformatting is desirable.

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## APPENDIX A

### DIGITAL RECORDING CODES FOR ANALOG MAGNETIC TAPE

To record digital data on analog magnetic tape, several digital recording codes could be used. In high data rate application, data is recorded in the direct mode. The maximum frequency response of the recorder and the lack of dc response in the direct mode are key considerations in the selection of the digital recording code. The often used non-return-to-zero (NRZ-L) code does not provide a transition for each clock cycle and for certain data conditions (many consecutive ones or zeros) requires almost dc response. The two codes considered here are Manchester (bi-phase) and delay modulation, since both do not require dc response and in addition are self clocking.

The Manchester code is illustrated in figure Ala and can be easily generated using an exclusive OR gate and a clock frequency of twice the bit rate (figure Alb). This code eliminates the need for dc response by representing each data bit with a combination of zero and one, thus always providing a transition during each clock cycle. The Manchester code has the disadvantage of requiring twice the bandwidth when compared to NRZ-L.

The delay modulation code, also shown in figure Ala, is basically a phase shift code and can be defined as follows: a one is represented by a transition in the middle of a bit cell. A zero has no transition, unless it is followed by another zero, in which case there is a transition at the end of the first zero's bit cell. Delay modulation code requires half the bandwidth of the Manchester code and does not require dc response.

One additional flip-flop is required to convert Manchester code to delay modulation (figure Alb). In system applications where the tape recorder bandwidth limits the data rate, delay modulation is the most desirable recording code.

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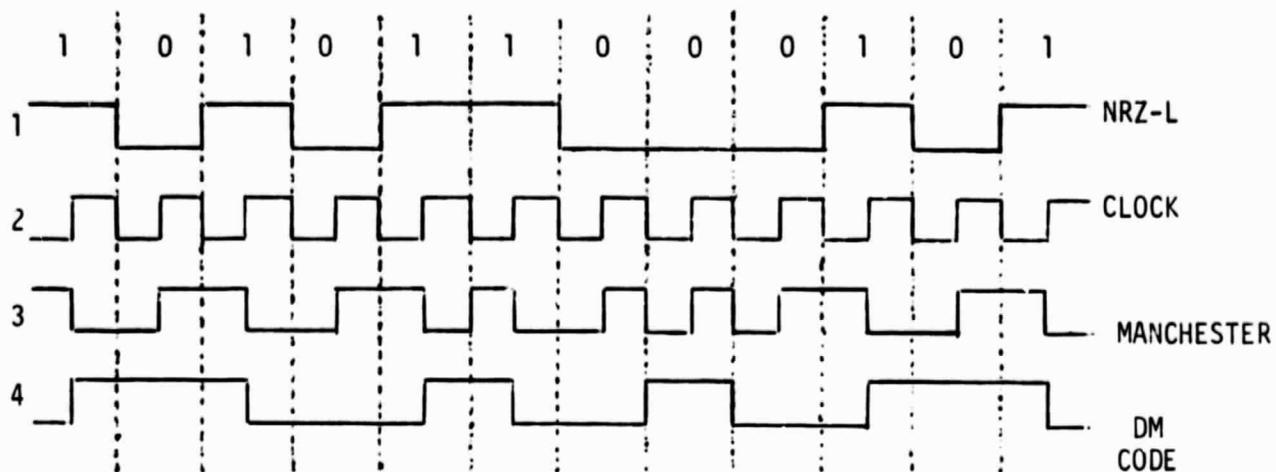


Figure A-1a.- Timing diagram for digital recording codes.

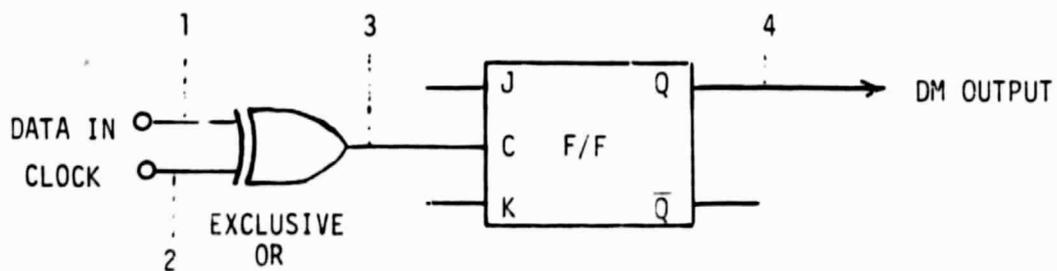


Figure A-1b.- Circuit implementation for recording codes.

## APPENDIX B

### COMPARISON OF SYSTEM DESIGNS USING TYPICAL COMPONENT PARAMETERS

To illustrate the performance and facilitate comparison between system designs, representative values for the operational speed of the pertinent hardware components are listed below:

A/D Converter (8 bits)	$t_{AD} \approx 1 \text{ to } 40 \text{ } \mu\text{sec}$ $t_c \approx 20 \text{ nsec}$
Sample and Hold Amplifier	$t_{sh} \approx 1 \text{ to } 50 \text{ } \mu\text{sec}$
Digital Memory Access Time	$t_{wc} \approx .200 \text{ to } 1 \text{ } \mu\text{sec}$

The performance of the three system designs can be compared by considering a hypothetical aircraft scanner data handling system with the following hardware components and design requirements:

$t_{AD} = 1.0 \text{ } \mu\text{sec}$
$t_c = 0.2 \text{ } \mu\text{sec}$
$t_{sh} = 1.0 \text{ } \mu\text{sec}$
$t_{wc} = 0.5 \text{ } \mu\text{sec}$
$c = 9 \text{ channels}$
$b = 8 \text{ bits}$

The minimum image element viewing time,  $t_i$ , for which the design will operate can be computed for the three system designs as follows:

## (1) Multiplexed single memory system

$$t_{sh} + t_c + t_{AD} \leq t_i \geq t_{AD} + c t_{wc} \quad (\text{unlatched})$$

$$2.2 \mu\text{sec} \leq t_i \geq 5.5 \mu\text{sec}$$

$$\therefore t_i \geq 5.5 \mu\text{sec}$$

$$t_{sh} + t_c + t_{AD} \leq t_i \geq c t_{wc} \quad (\text{latched})$$

$$2.2 \mu\text{sec} \leq t_i \geq 4.5 \mu\text{sec}$$

$$\therefore t_i \geq 4.5 \mu\text{sec}$$

## (2) Separate parallel memory system

$$t_{sh} + t_c + t_{AD} \leq t_i \geq t_{AD} + t_{wc} \quad (\text{unlatched})$$

$$2.2 \mu\text{sec} \leq t_i \geq 1.5 \mu\text{sec}$$

$$\therefore t_i \geq 2.2 \mu\text{sec}$$

$$t_{sh} + t_c + t_{AD} \leq t_i \geq t_{wc} \quad (\text{latched})$$

$$2.2 \mu\text{sec} \leq t_i \geq 0.5 \mu\text{sec}$$

$$\therefore t_i \geq 2.2 \mu\text{sec}$$

## (3) Separate serial memory

$$t_{sh} + t_c + t_{AD} \leq t_i \leq b t_{wc}$$

$$2.2 \mu\text{sec} \leq t_i \leq 4.0 \mu\text{sec}$$

$$\therefore t_i \geq 4.0 \mu\text{sec}$$

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TABLE I

SUMMARY OF IMAGE ELEMENT VIEWING TIME  
DEPENDENCE UPON HARDWARE PARAMETERS

	WITH LATCHING	WITHOUT LATCHING
Multiplexed Single Memory System	$t_i \geq t_{AD} + t_{sh} + t_c$ $t_i \geq ct_{wc}$	$t_i \geq t_{AD} + t_{sh} + t_c$ $t_i \geq t_{AD} + ct_{wc}$
Separate Parallel Memory System	$t_i \geq t_{AD} + t_{sh} + t_c$ $t_i \geq t_{wc}$	$t_i \geq t_{AD} + t_{sh} + t_c$ $t_i \geq t_{AD} + t_{wc}$
Separate Serial Memory System	$t_i \geq t_{AD} + t_{sh} + t_c$ $t_i \geq bt_{wc}$	

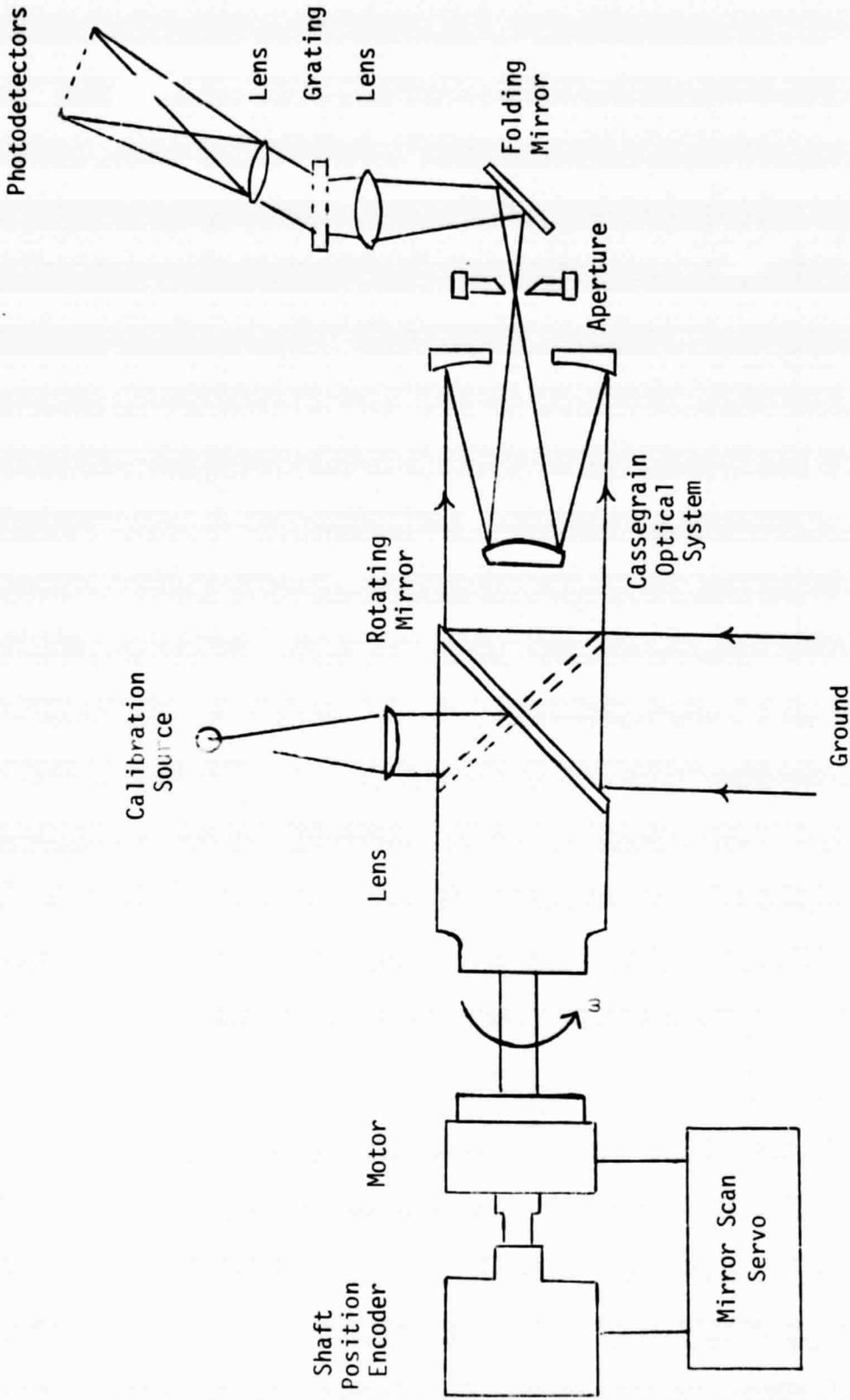


Figure 1. - Basic configuration of a multispectral aircraft scanner.

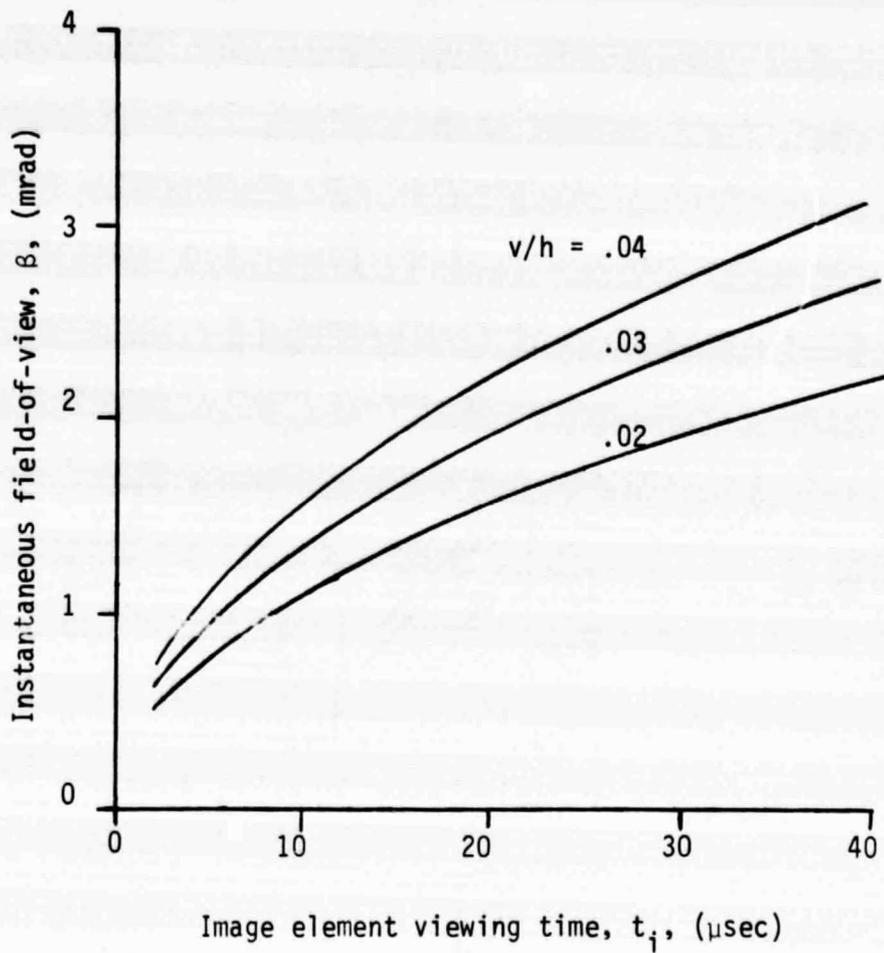


Figure 2. - Instantaneous field-of-view as a function of image element viewing time for contiguous sampling.

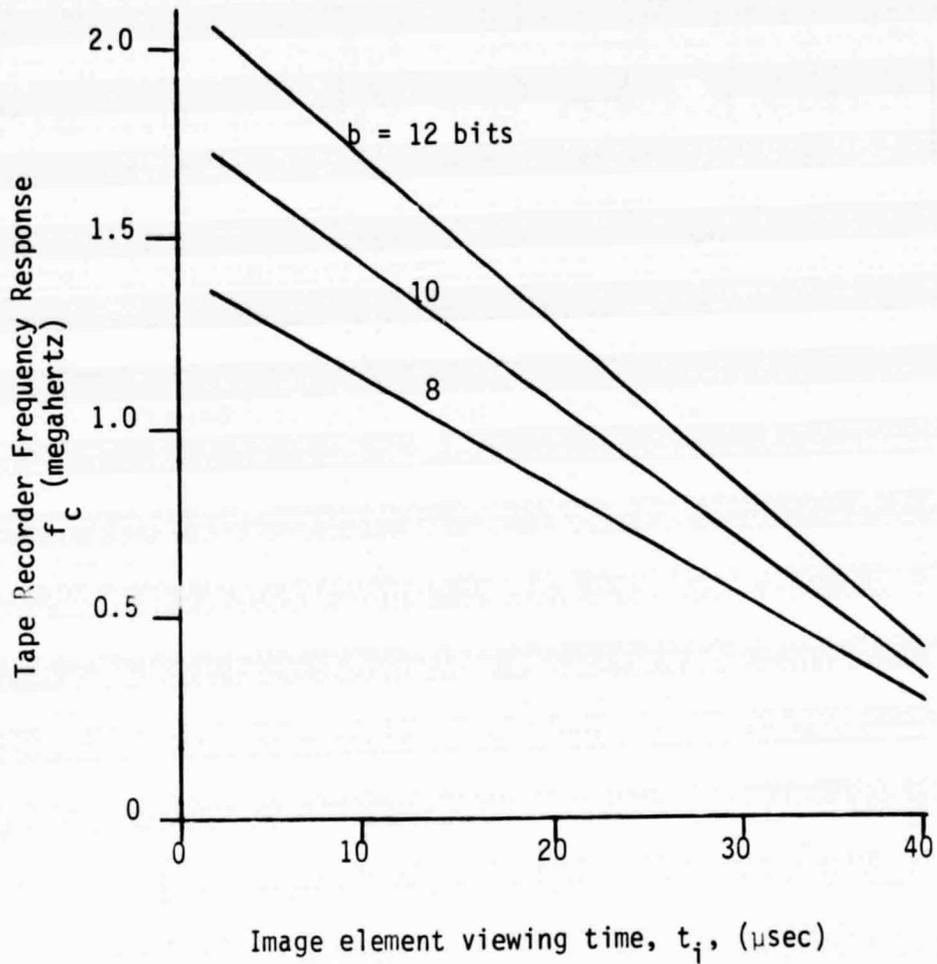


Figure 3. - Required tape recorder frequency response as a function of image element viewing time for three levels of digital encoding.

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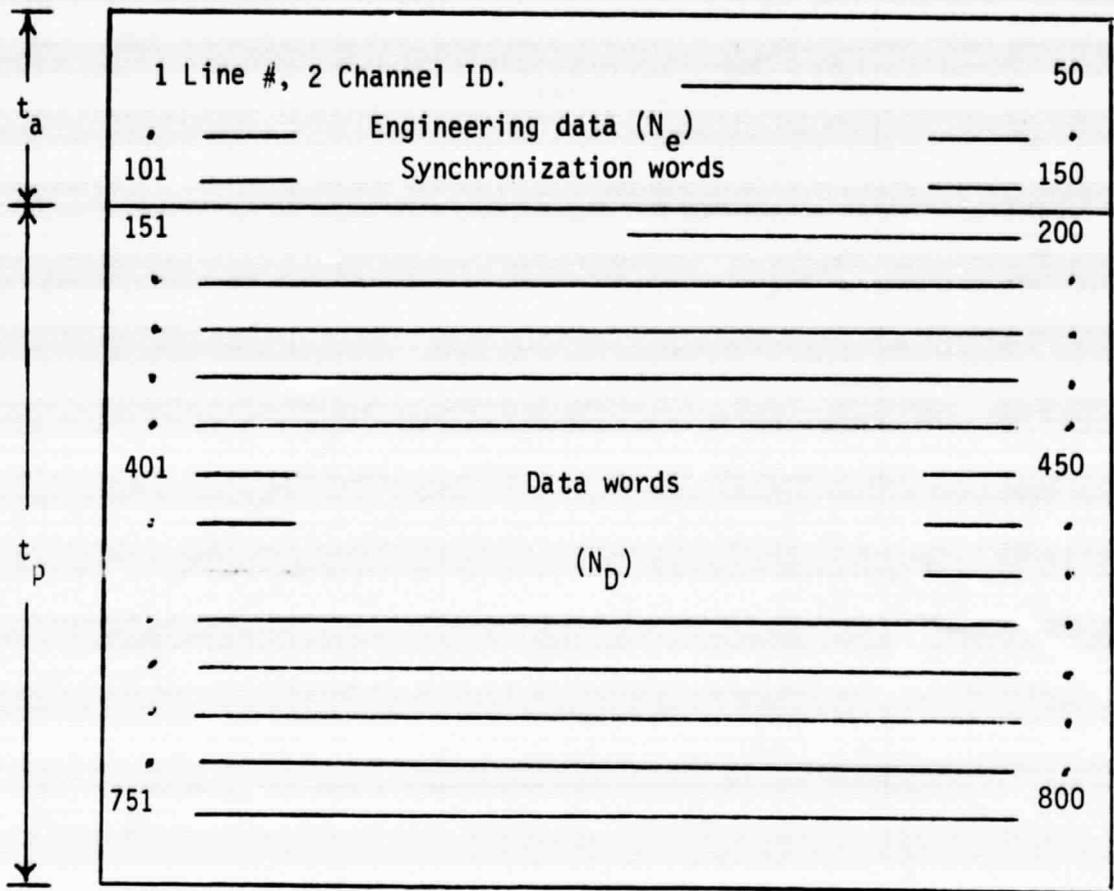


Figure 4. - Typical output data format using buffer memory.

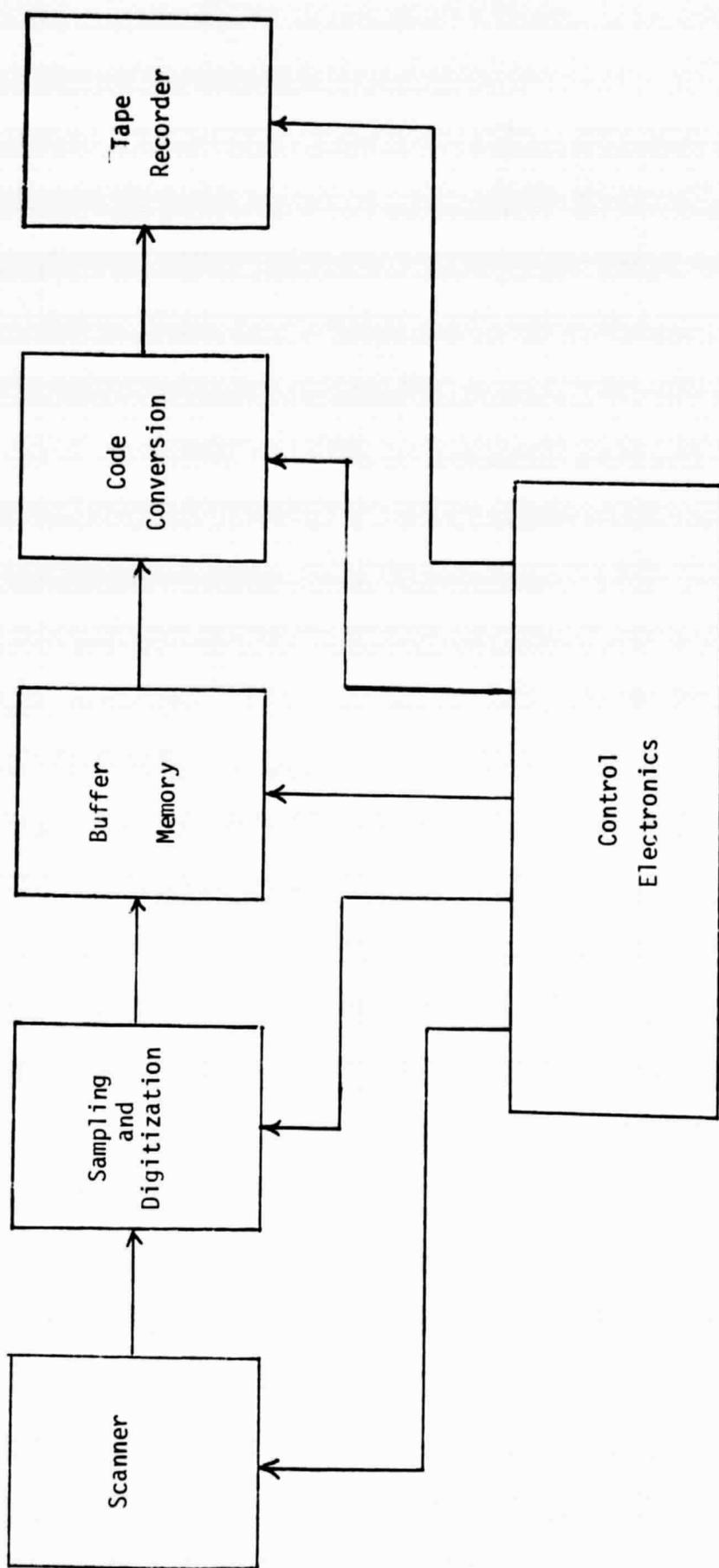


Figure 5. - Basic configuration of the buffer memory system.

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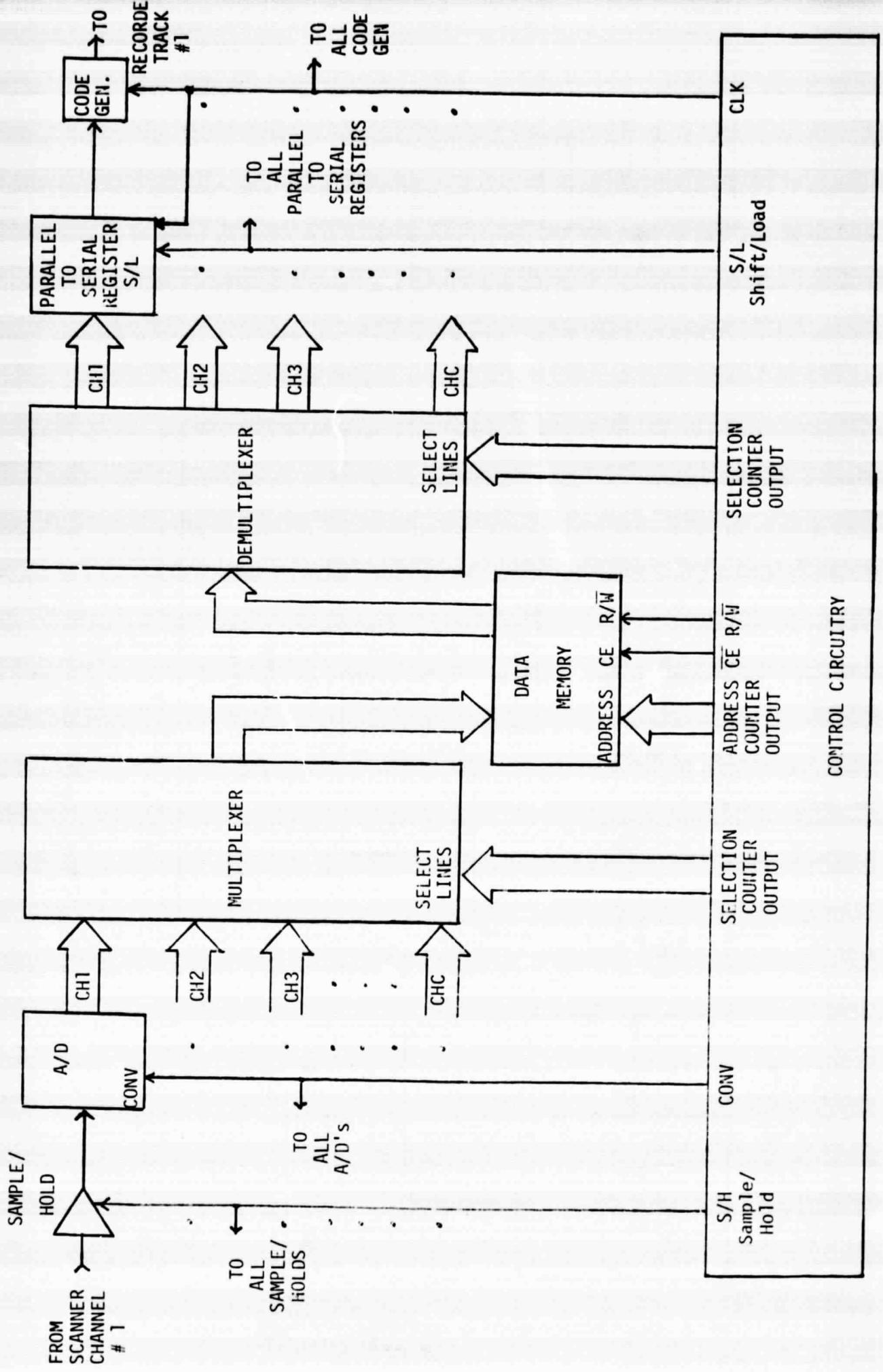


Figure 6.- Multiplexed single memory system configuration.

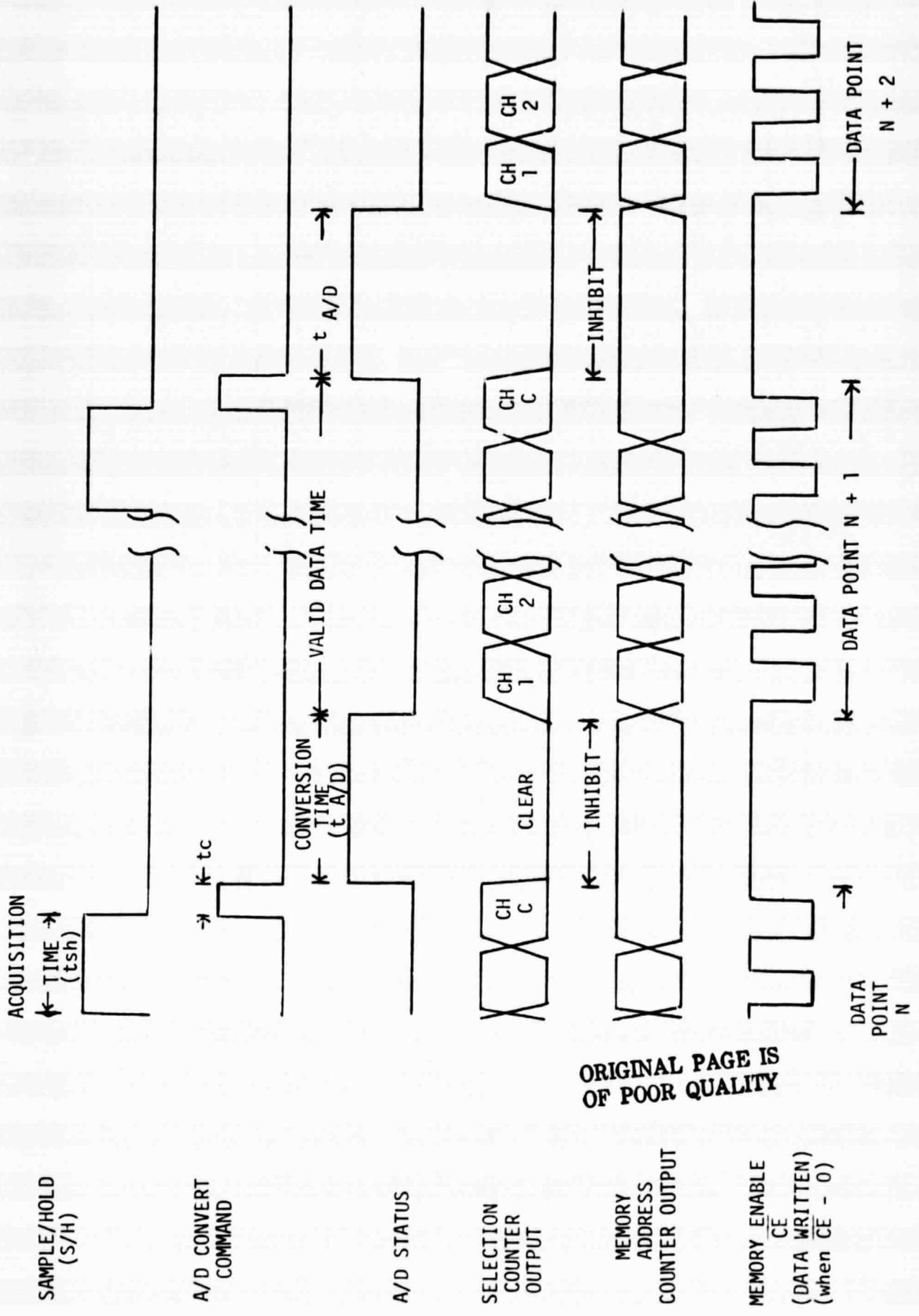


Figure 7.- Timing diagram for data storage process of the multiplexed single memory system.

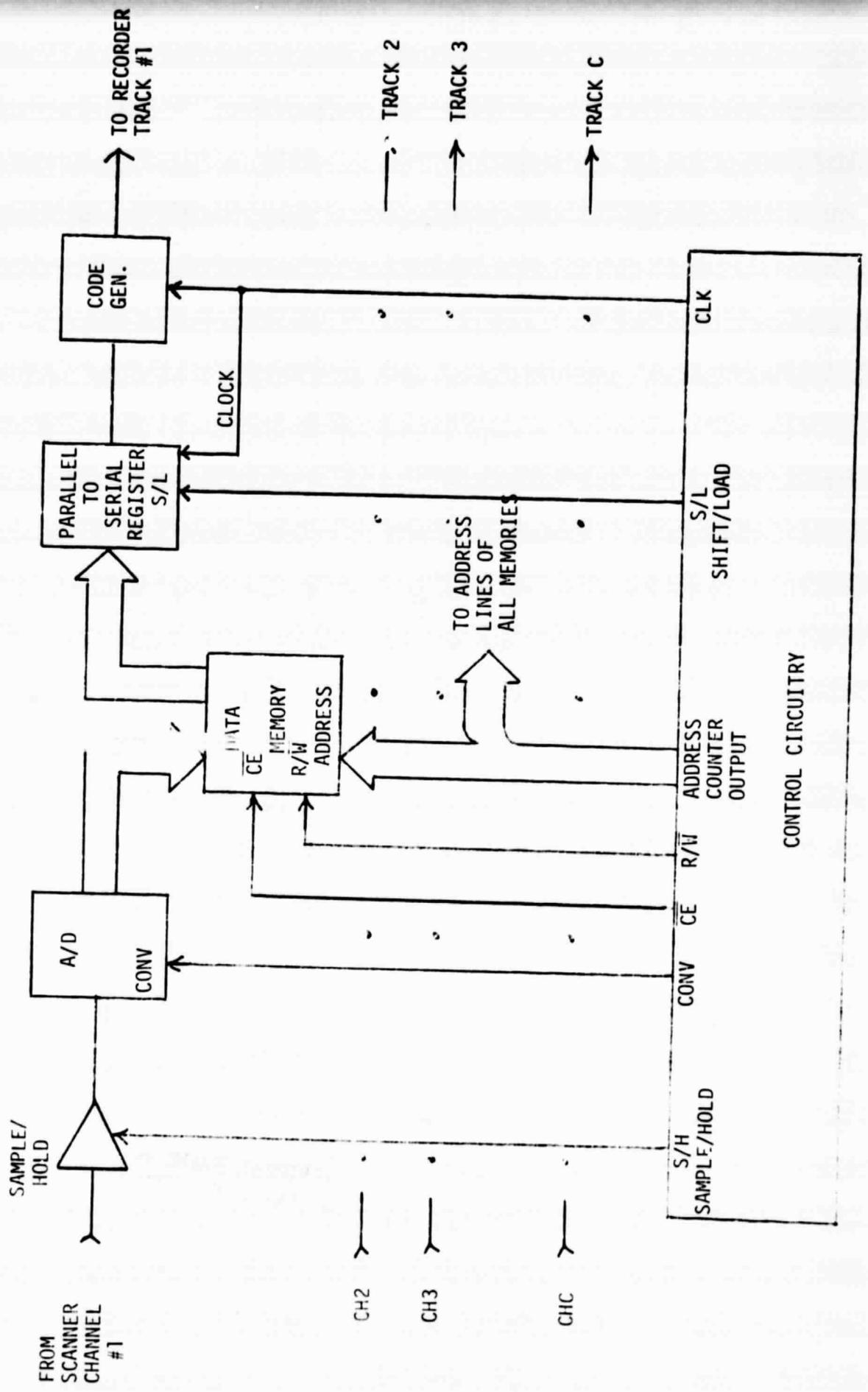


Figure 8.- Separate parallel memory system configuration.

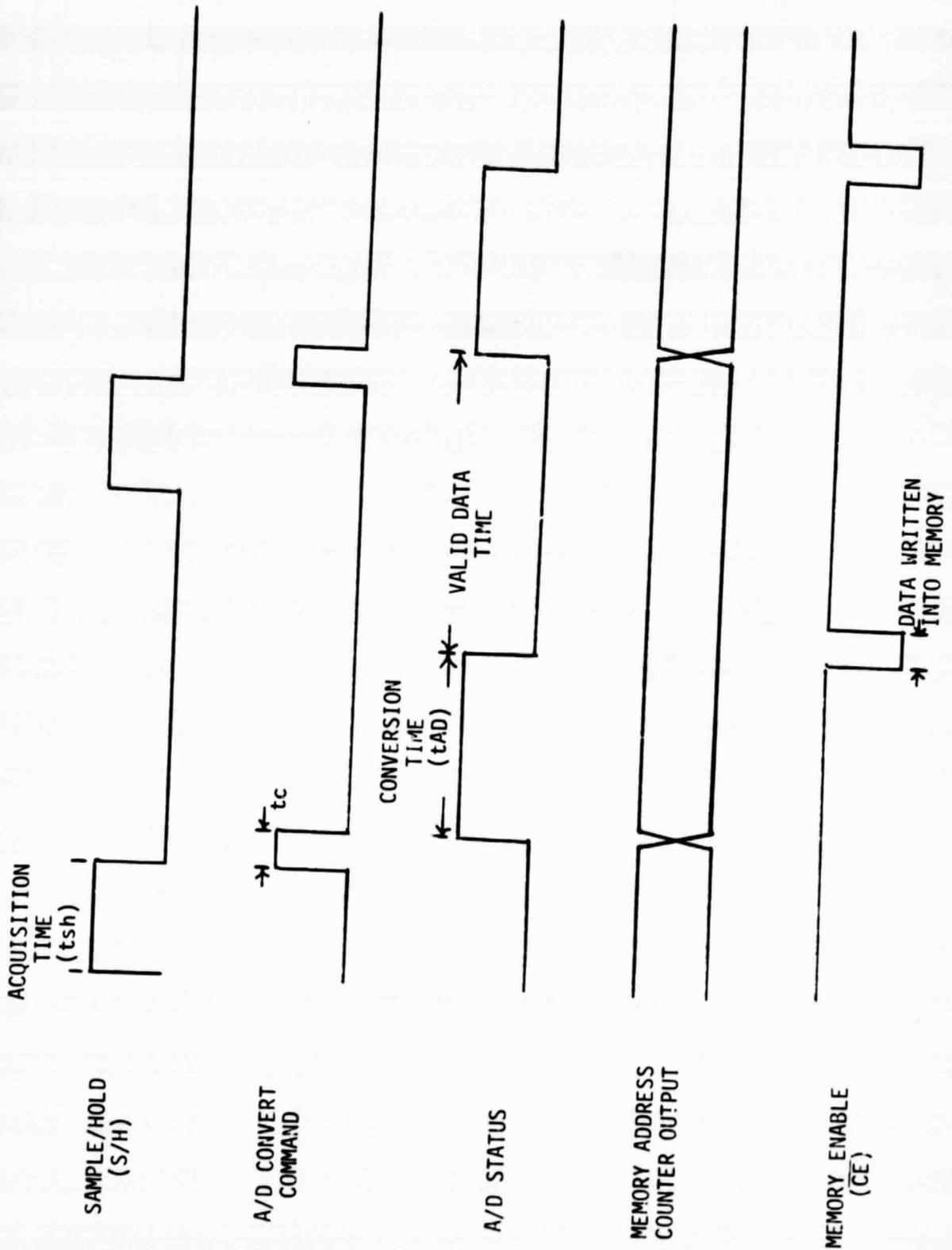


Figure 9.- Timing diagram for data storage process of the separate parallel memory system.

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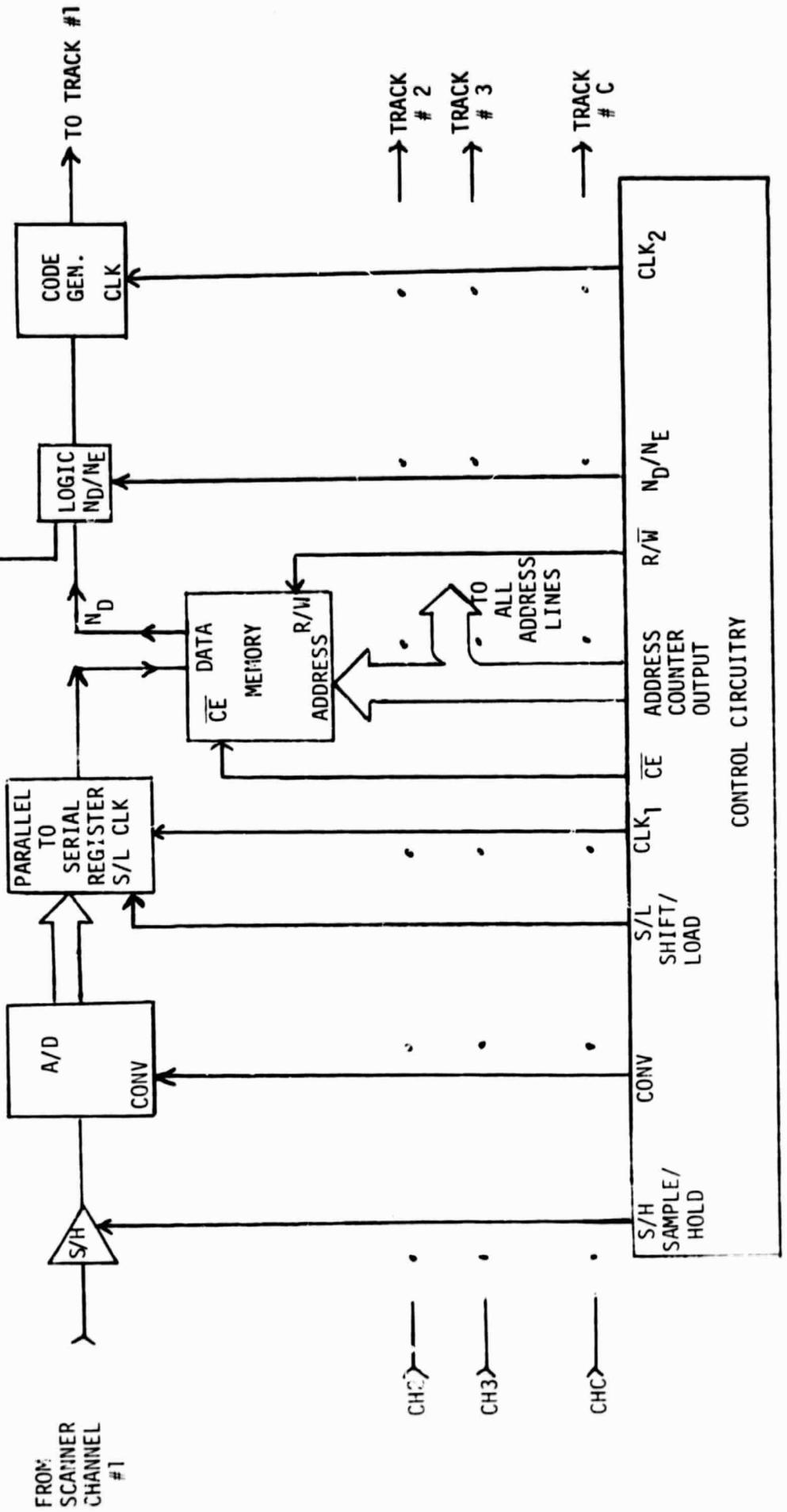


Figure 10.- Separate serial memory system configuration.

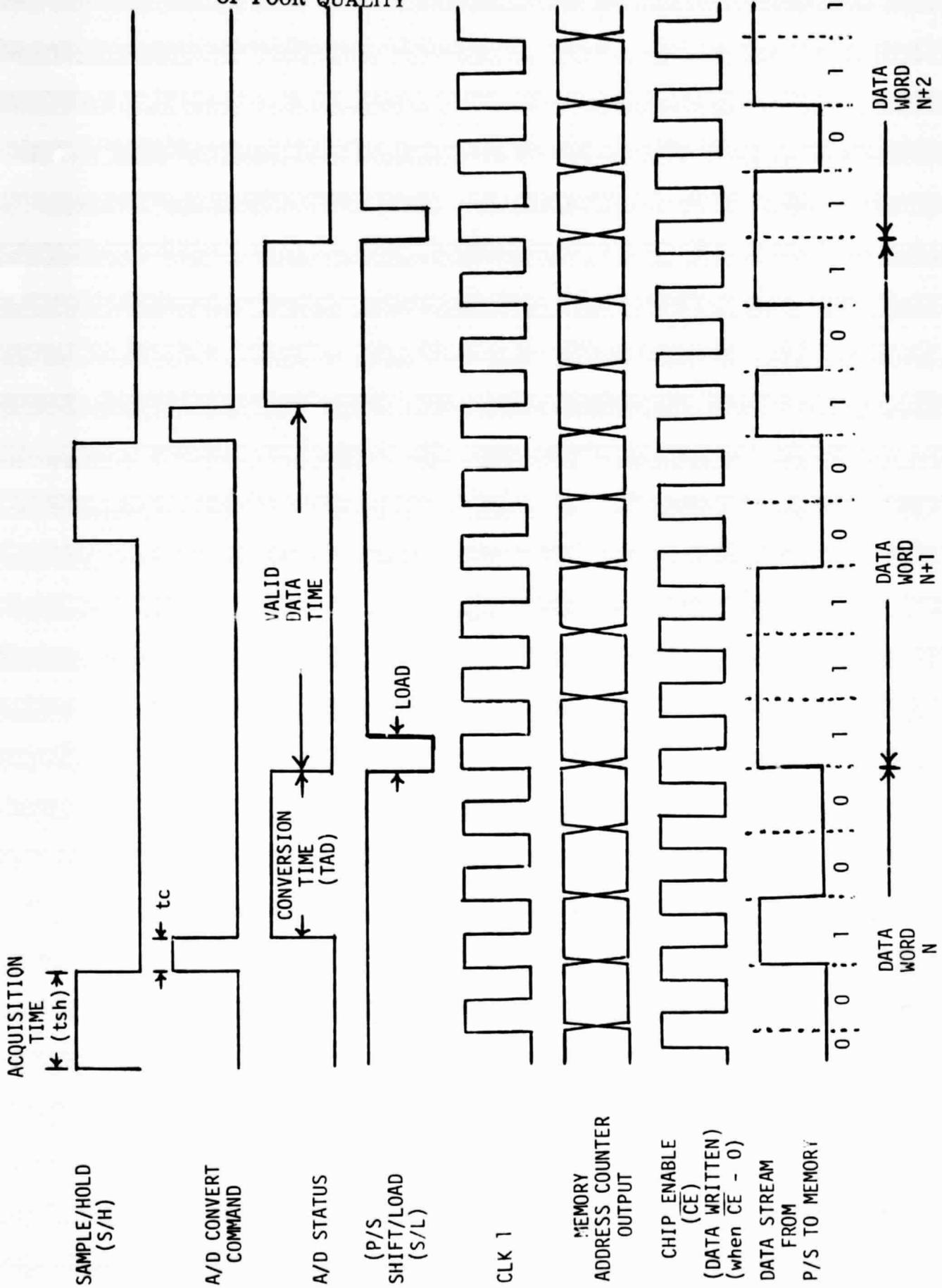


Figure 11.- Timing diagram for data storage process of the separate serial memory system.

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16. Abstract  A buffer memory data handling technique for use with multispectral aircraft scanners is presented which allows digital data generated at high data rates to be recorded on magnetic tape. A digital memory is used to temporarily store the data for subsequent recording at slower rates during the passive time of the scan line, thereby increasing the maximum data rate recording capability over real-time recording. Three possible implementations are described and the maximum data rate capability is defined in terms of the speed capability of the key hardware components. The maximum data rates can be used to define the maximum ground resolution achievable by a multispectral aircraft scanner using conventional data handling techniques.					
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