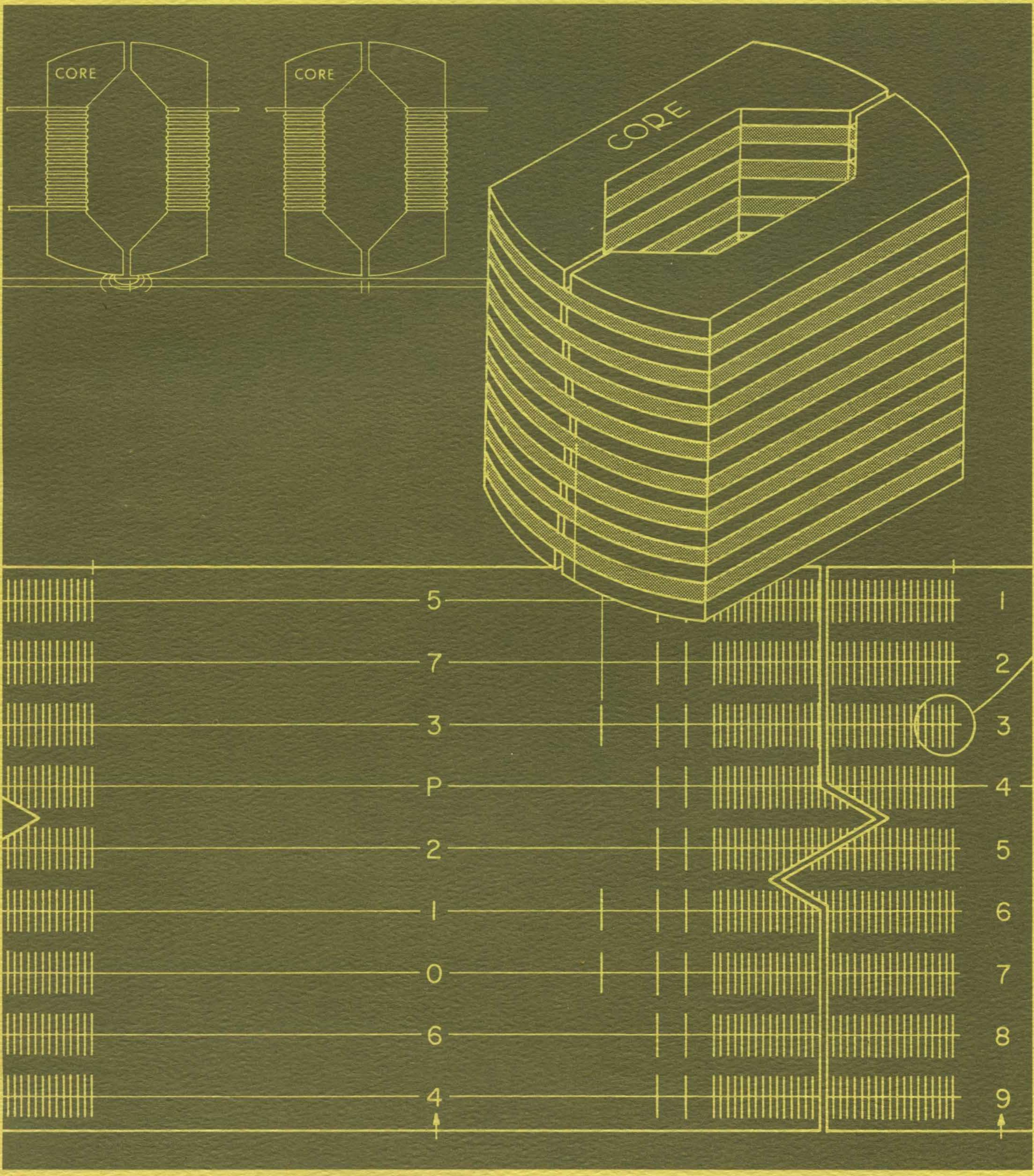
INFORMATION

HEWLETT PACKARD

BULLETIN

DESKEWING

March 1971



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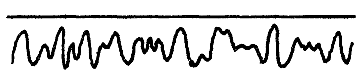
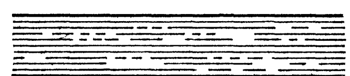
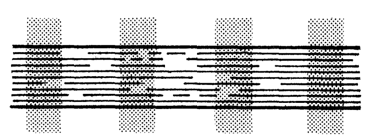
INTRODUCTION

1.1 Recording on Magnetic Tape

Plastic tape with a magnetic coating applied to one surface was first used as a recording medium in Germany in 1935, but it was not until after World War II that it came into general use in the United States. Magnetic tape was first used for audio recording; however, in the late forties and early fifties, at the same time that recording techniques were being perfected, the digital computer was being developed, and it was not long before magnetic tape was being used to store large volumes of digital data inexpensively.

Both audio and digital recording techniques make use of magnetized tracks on the tape surface, but techniques for the two applications are quite different, as described in Table 1. Audio recording uses one continuous track; digital data is recorded on 9 (or 7) separate tracks, shown in Table 1. To record a character digitally, it is represented by a 9 (or 7) part code, which is recorded in parallel on the 9 (or 7) tracks; it is therefore very important that recorded data be well aligned on all the tracks. Figure 1 shows a perfectly aligned character and a misaligned character.

Table 1. Some Differences Between Audio and Digital Magnetic Tape Recordings

AUDIO (MONAURAL)	DIGITAL
1) One track is used: 	7 or 9 parallel tracks on the tape are used: 
2) The track is read and interpreted continuously.	Only discrete sections of the tracks contain data:  Shaded areas read and interpreted
3) One track contains all the information required by the read and write mechanisms.	All 7 or 9 tracks must be read simultaneously, and each track contains part of the recorded data character.

1.2 The Purpose of This Manual

The misalignment illustrated in Figure 1 (b) is called skew; the purpose of this handbook is to describe the factors that contribute to skew, and the methods used to compensate for this phenomenon.

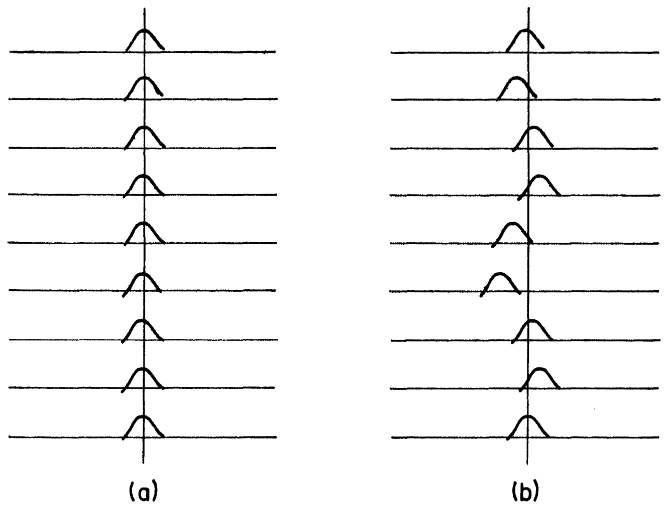


Figure 1. A 9-Track Representation of One Character of Digital Data,

(a) Perfectly Aligned, and
(b) Skewed

1.3 ANSI and Its Standards

A large number of manufacturers market products relating to digital magnetic tape recording systems. In order that these products be compatible, and to insure that data recorded on one manufacturer's unit can be read on another, the American National Standards Institute has adopted standards which are widely adhered to throughout the data processing industry. This handbook describes data recording and deskewing using NRZI (non return-to-zero change on ones) recording techniques at 800 CPI (characters per inch) recording density, with American Standard Code for Information Interchange (ASCII) format.

DIGITAL RECORDING TECHNIQUES

There are three steps needed to convert data to a code suitable for recording on magnetic tape:

1. Every character of data must be represented by a binary digit code.

2. Binary digits must be represented magnetically.

3. A format must be specified for the data on magnetic tape.

The techniques used to record data on magnetic tape are pertinent in discussing skew and deskewing, since skewing is a byproduct of recording methods, and deskewing techniques are dependent upon the design of read and write mechanisms.

2.1 Binary Data Codes

The decimal counting system is based on ten discrete digits, 0 to 9; the binary counting system is based on two digits, 0 and 1. Numbers are translated thus:

0	in binary code is	0
1	”	1
2	”	10
3	”	11
4	”	100
5	”	101
6	”	110
	etc.	

The value of the binary counting system is that it can be represented by the two states: on — off, + or —.

Computers perform all numerical operations using binary numbers. However, when data is recorded on magnetic tape, any code can be used to represent numbers, letters (upper case and lower case), and special characters. It is necessary only that each pattern of zeros and ones have a unique meaning. Standard codes have been accepted by the data processing industry for the binary representation of characters, but they are not described here, since they are of no consequence to the problems of skew and deskewing.

2.2 The Magnetic Representation of Binary Digits

The ANSI standards (see Section 1.3) specify that an erased tape is one that is magnetized so that the rim end of the tape is a north-seeking pole. A write-head is capable of inducing a narrow, reverse flux line along a tape that is moved past the head (see Section 3.1), and this flux reversal is used to generate binary digits on magnetic tape as follows: if in the space allocated for a character a flux reversal occurs, a 1-binary digit (bit) is assumed; if no flux reversal occurs, a 0-bit is assumed. This is illustrated in Figure 2.

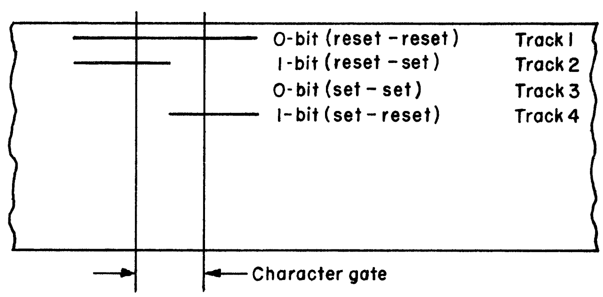
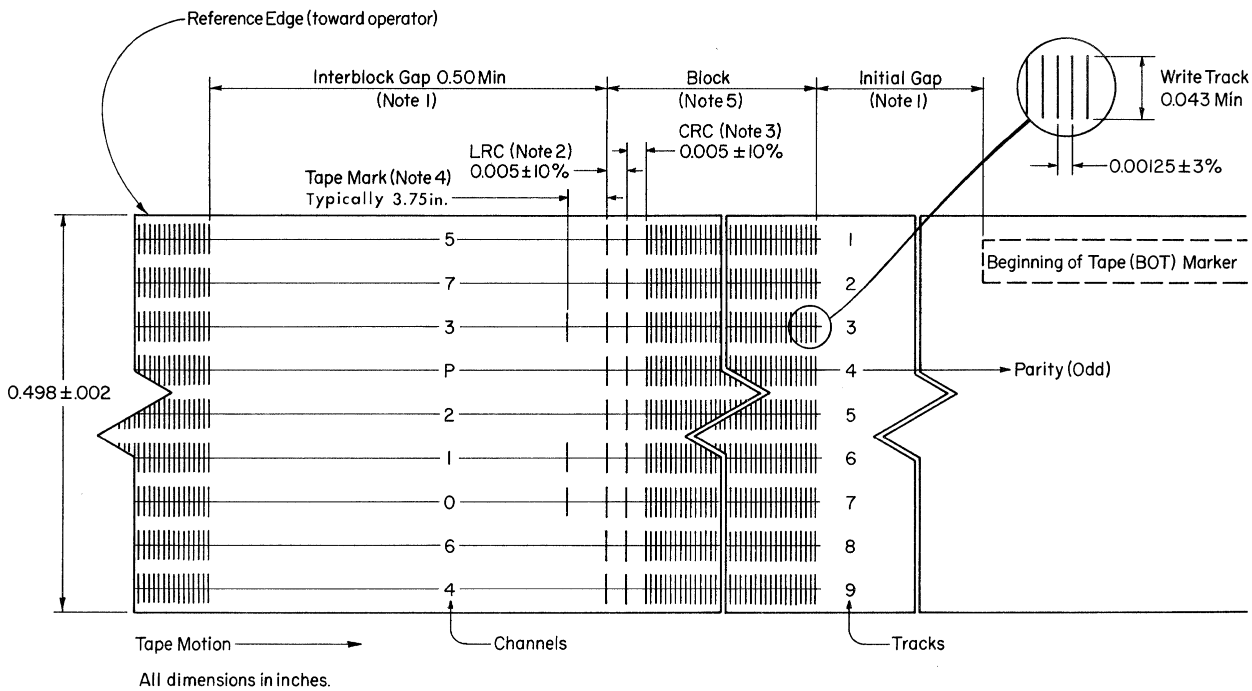


Figure 2. The Representation of Binary Digits on Magnetic Tape Using Flux Reversals (NRZI only).

In the rest of this handbook binary digits are represented by the signs '|' or '⋀'; they refer to a digit such as in Figure 2.

2.3 Data Format

The critical considerations when evaluating the importance of skew are the dimensions, spacings, and tolerances that have been specified for recorded data. These are illustrated in Figure 3.



NOTES:
(1) TAPE TO BE FULLY SATURATED IN THE ERASED DIRECTION IN THE INTER-BLOCK GAP AND THE INITIAL GAP.
(2) A LONGITUDINAL REDUNDANCY CHECK BIT IS WRITTEN IN ANY TRACK IF THE LONGITUDINAL COUNT IN THAT TRACK IS ODD. CHARACTER PARITY IS IGNORED IN THE LONGITUDINAL REDUNDANCY CHECK CHARACTER.
(3) CYCLIC REDUNDANCY CHECK - PARITY OF THE CRC CHARACTER IS ODD, IF AN EVEN NUMBER OF DATA CHARACTERS ARE WRITTEN, AND VICE VERSA.
(4) THE TAPE MARK IS AN OPTIONAL SPECIAL CONTROL BLOCK.
(5) THE LENGTH OF THE DATA BLOCK (NOT INCLUDING THE CHECK CHARACTERS) IS FROM 18 MINIMUM ASCII CHARACTERS TO 2,048 MAXIMUM.

Figure 3. Standard ASCII Format (800 CPI)

On 9-track tape, there are 8 data characters, and a parity character. The purpose of the parity character is to insure that the total number of bits in a character is always odd. (If there are an even number of 1-bits among the eight character bits, a 1 parity bit is written; if there are an odd number of 1-bits among the eight character bits, a 0 parity bit is written.) When data is read, the number of 1-bits in each character is checked; if there is an even number of 1-bits, then an error must have occurred in reading or writing. The mean distance between characters, as measured over 150" of recorded tape, must be 0.00125 (±3%) inches, as shown in Figure 3. The maximum tolerated deviation is 0.00015".

TAPE WRITE SKEW

There are two types of skew:

1. Static skew, defined as that component of skew that is unvarying and independent of tape speed, and

2. Dynamic skew, defined as that component of skew that varies from character to character.

This section describes the ways in which static and dynamic recorded skew errors arise.

3.1 The Read/Write Head

A write head is similar to a transformer with a single winding. Signal current flows in the winding, producing a magnetic flux in the core material. To perform as a write head, the core is made in the form of a closed ring with a short nonmagnetic write gap in it. When the nonmagnetic gap is bridged by the magnetic surface on the tape, the flux detours around the write gap, through the tape surface, thus completing the magnetic path through the core material (see Figure 4). As the tape travels past the write gap, a track on the magnetic surface retains the magnetic flux pattern recorded.

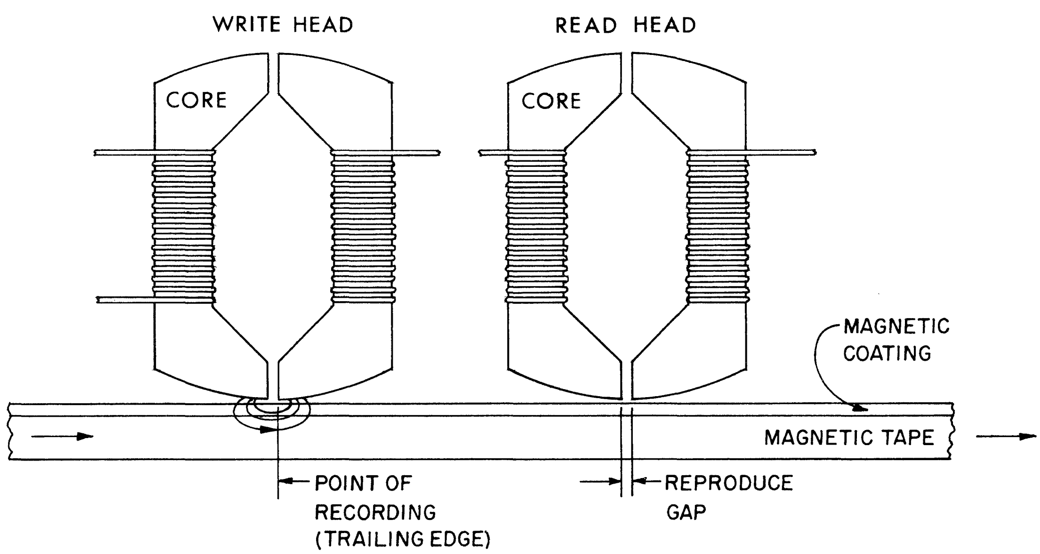


Figure 4. Magnetic Tape Recording and Reproducing Process

To reproduce the signal, the magnetic pattern on the tape is moved across a read gap. Magnetic lines of flux are shunted through the core, and are proportional to the magnetic gradient of the pattern on the tape which is spanning the gap. The induced voltage in the head winding is proportional to the rate of change of the magnetic flux. Thus a 1-bit, as illustrated in Figure 2, produces a short voltage surge in the head winding; a 0-bit causes no voltage surge. This is illustrated in Figure 5.

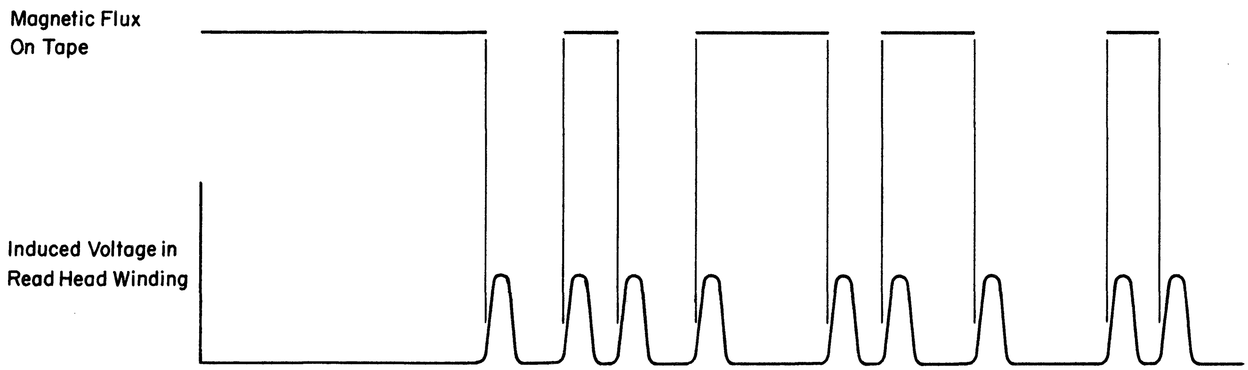


Figure 5. Induced Voltage in the Write Head Winding as a Function of the Magnetic Flux on One Tape Track (rectified)

3.2 Write Gap Scatter

In order to generate nine parallel tracks as in Figure 4, a stack of nine laminated write heads (as described in Section 3.1) are used, one head per track. The nine write gaps should ideally be perfectly aligned, but there is always some scatter, as illustrated in Figure 6.

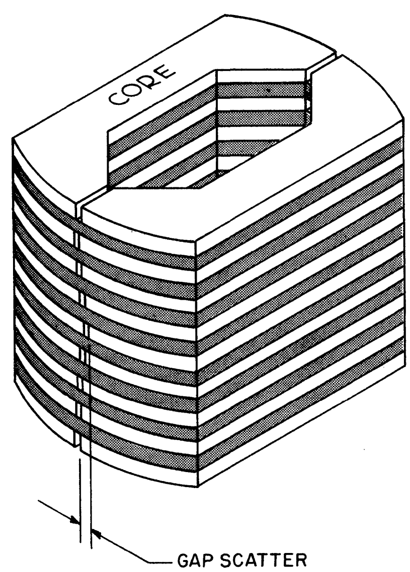


Figure 6. Write Gap Scatter in Nine Laminated Write Heads

Misalignments of 50 to 150 microinches are typical in most head assemblies, and contribute to static skew. It should be noted that the maximum static skew from all sources allowed by the ANSI standards (see Section 1.3) is 150 microinches.

Gap scatter effect is illustrated in Figure 7.

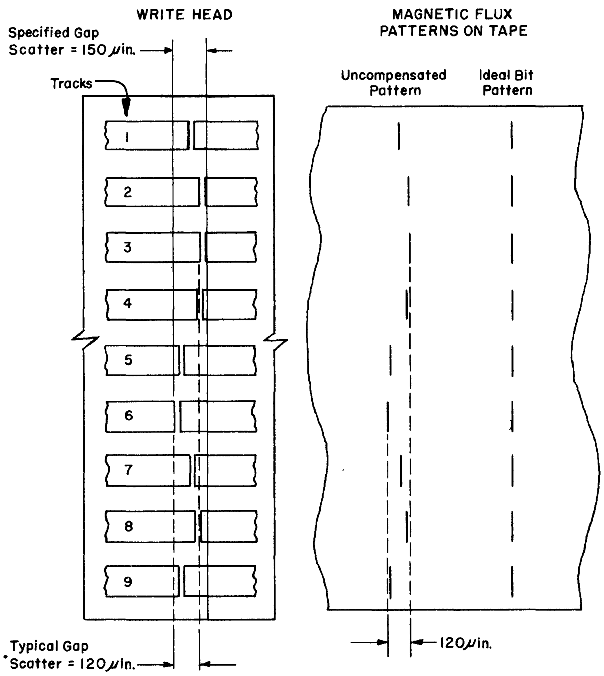


Figure 7. Gap Scatter Effect

3.3 Tape Skew

While every effort is made by manufacturers to cut tape with perfect geometry, there are always certain physical irregularities, as in Figure 8.

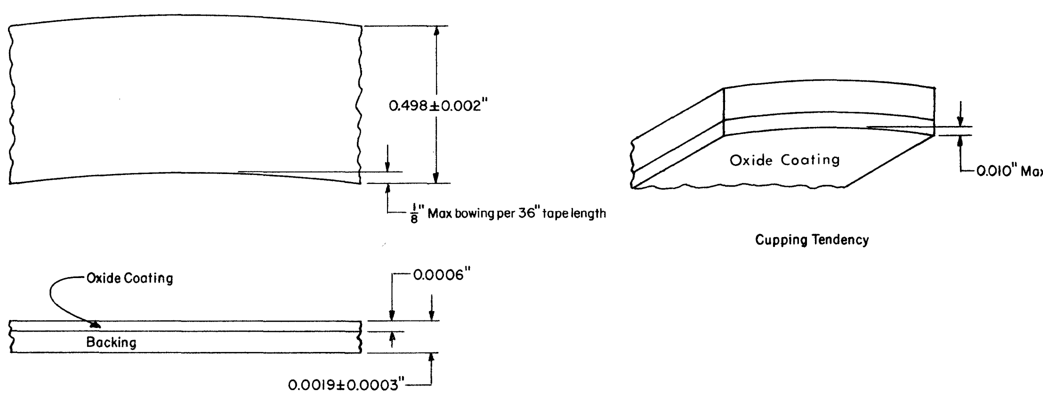


Figure 8. Tape Dimensions and Irregularities

Longitudinal and lateral curvatures interact with the tape guides to produce instantaneous azimuthal (tape wobble) error. This error contributes to dynamic skew, as illustrated in Figure 9, which shows the combined effects of write gap scatter and dynamic recorded skew. It will be seen that azimuthal error causes the tape to oscillate about the center of its perpendicular axis. Thus, the bit displacement is increasingly variable on tracks close to the tape edge.

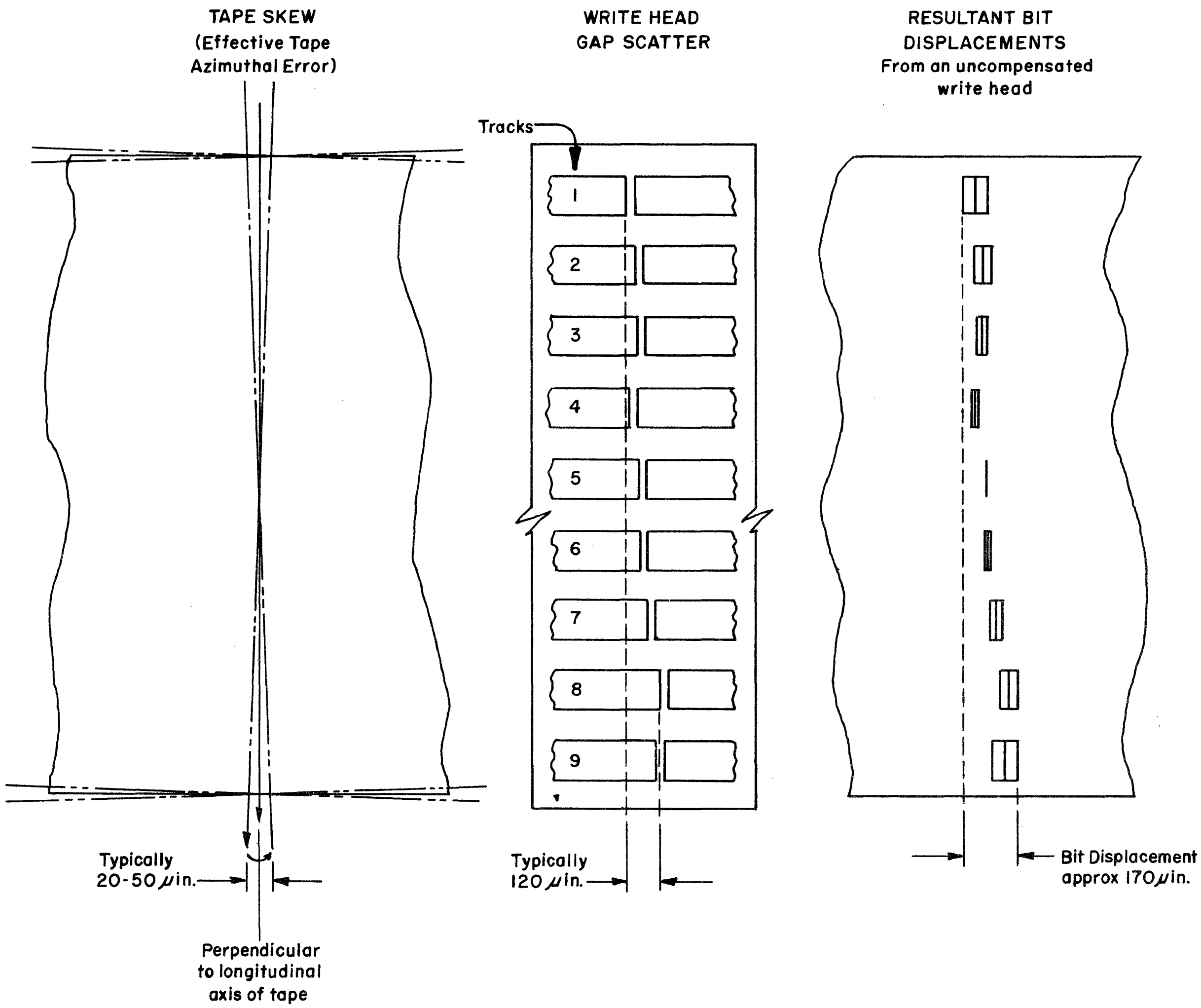


Figure 9. Composite Effects of Gap Scatter and Tape Skew

3.4 Write Time Assymmetry

Figure 10 illustrates character spacing at 800 bits per inch recording density (1250 micro-inches/bit). ANSI specifications (see Section 1.3) allows an average variation of (3%) between any two characters, measured over 150 inches of tape; such an allowance is necessary, since the mechanics and electronics of a tape recording unit could never be so perfect as to insure identical spacing between characters.

The effects of write time asymmetry are illustrated in Figure 11. Write time asymmetry contributes to both static and dynamic skew.

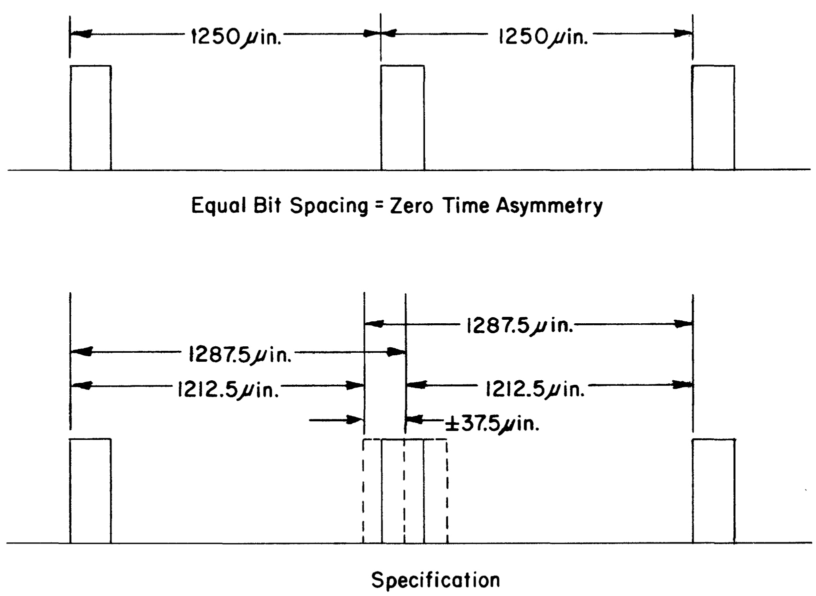


Figure 10. Write Time Asymmetry

3.5 Pulse Crowding

When a number of adjacent flux reversals (ones) are followed by a section on the tape without reversals (zeros), the pulses adjacent to the zero area tend to drift up to 100 microinches or move into this space. This phenomenon is called "pulse crowding". This effect becomes important when recording with bit densities of 800 bits per inch, but is generally not significant at bit densities of 556 bits per inch or less. Pulse crowding is a varying data dependent component, and therefore contributes to dynamic recording skew.

3.6 Combined Effects

The combined effect of all recroded skew is shown on Figure 11. Table 2 summarizes the factors contributing to recorded skew.

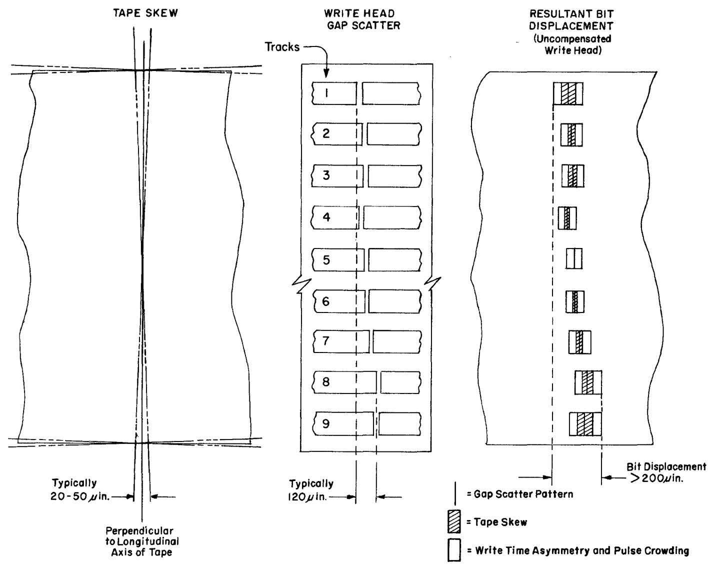


Figure 11. Composite Effects of Gap Scatter, Tape Skew, and Write Time Asymmetry

RECORDED SKEW COMPONENTS	STATIC RECORDED SKEW FIXED COMPONENT ON THE TAPE	DYNAMIC RECORDED SKEW VARIABLE COMPONENT ON THE TAPE
WRITE HEAD GAP SCATTER	YES	
TAPE AZIMUTH/GUIDANCE		YES
WRITE TIME ASYMMETRY	YES (FOR ALTERNATE BITS)	YES (DATA DEPENDENT)
PULSE CROWDING		YES

Table 2. Factors Contributing to Recorded Skew

3.7 Skew and Tape Speed

Any skew that is time dependent will become more serious as tape speed is increased. Write time asymmetry measured at 50 μin. with a tape speed of 100 inches per second is caused by a write time error of 0.5 μs; if tape speed is increased to 200 inches per second, the write time asymmetry would theoretically be measured at 100 μin. (in practice other contributing factors result in an asymmetry/tape speed relationship that is not directly proportional.) Tape azimuthal error also increases with tape speed, and thus as tape speed increases, so do the demands placed upon the tape recorder.

TAPE WRITE DESKEWING TECHNIQUES

4.1 Mechanical Write Head Deskewing

This technique mechanically positions the write head such that the mean scatter of the write head gap (measured in microinches) lies perpendicular to the longitudinal axis of the tape, as shown in Figure 12.

Since head gap scatter patterns are different (generally parabolic), mechanical skew compensation cannot eliminate gap scatter.

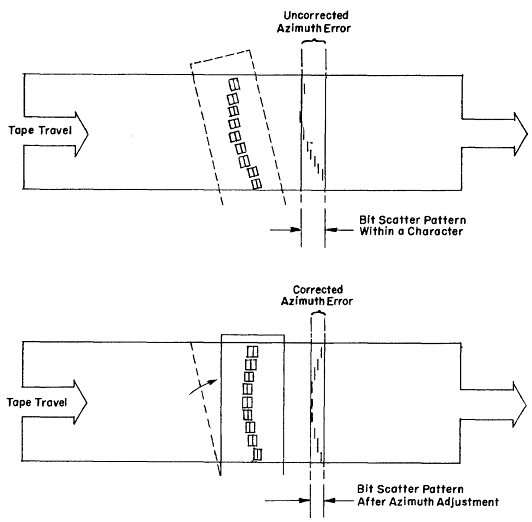


Figure 12. Effects of Mechanical Azimuth Adjustment

4.2 Electronic Averaging

If the azimuth shift in the write head is predictable, it may be compensated for by electronic averaging. This is generally used when the read and write heads are connected and the read head was mechanically compensated. The write head may be compensated for by a single frequency adjustment to add proportional delays between adjacent tracks and provide an electronic azimuth shift.

4.3 Electronic Per Channel Write Head Deskewing

The presentation of data to each track is delayed by a variable adjustment in each track to compensate for the misalignment of the associated write head. This deskewing method eliminates all the static skew components, with the exception of write time asymmetry, to produce a bit pattern as illustrated in Figure 13.

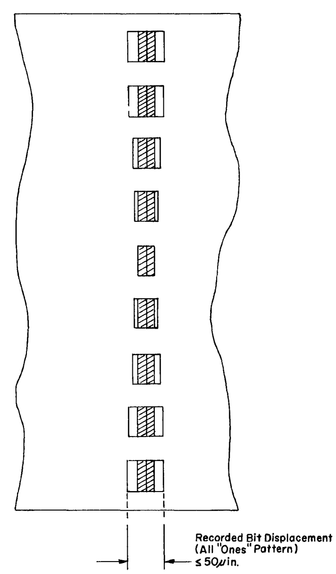


Figure 13. Electronically Compensated Write Head Recording

Electronic delay is measured in μs, whereas bit displacement on the tape is measured in μin. Thus electronic delay only eliminates static skew at the one tape speed, which gives the correct μs/μin. conversion. This is satisfactory since great pains are taken by designers to insure constant tape speeds.

TAPE READ SKEW

5.1 How Data Are Read From Magnetic Tapes

Data are read from magnetic tape using a read head which is adjacent to the tape write head (see Figure 5). The two heads are separated by 0.15" for 9-track tape or 0.30" for 7-track tape. Data are read from tape as follows:

— As soon as a bit is detected on the tape, a time period known as a "character gate" is initiated. During this time period it is essential that all the bits that constitute one character be read. (See Figure 16a.) The character gate is typically timed to be open 40% of the cycle time between characters. Since odd parity is specified, there will always be at least one 1-bit in any 9-track character.

— At the end of the character gate, the detected one-bits are available to the computer interface to be subsequently recognized and processed.

Figure 14 illustrates the transfer of information from a tape through a read head with a certain amount of gap scatter. As shown in the right-hand portion of the figure, the recorded signals are all detected during the time the character gate is open. The bit time lags may be reduced or made to fit the character gate by deskewing techniques.

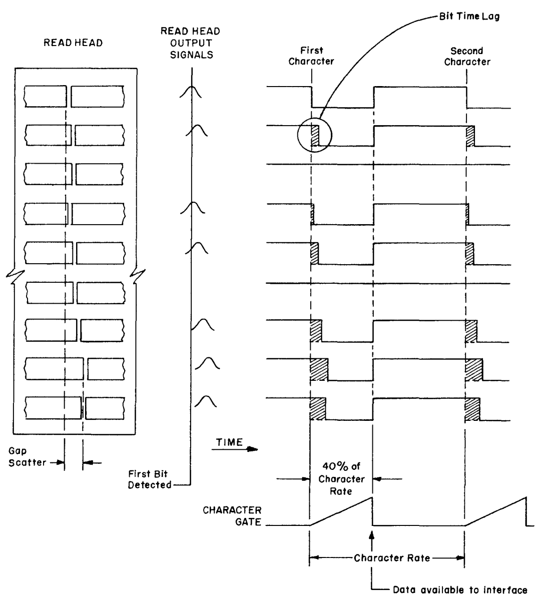


Figure 14. Read Timing Considerations

If the bits on the magnetic tape are sufficiently skewed, it is possible that a trailing bit will be dropped (not read) during the allowed character gate open time. This will generate a data error.

Similarly, a trailing bit may be picked up as a leading bit for the next character, which will again result in a data error. This is illustrated in Figure 15.

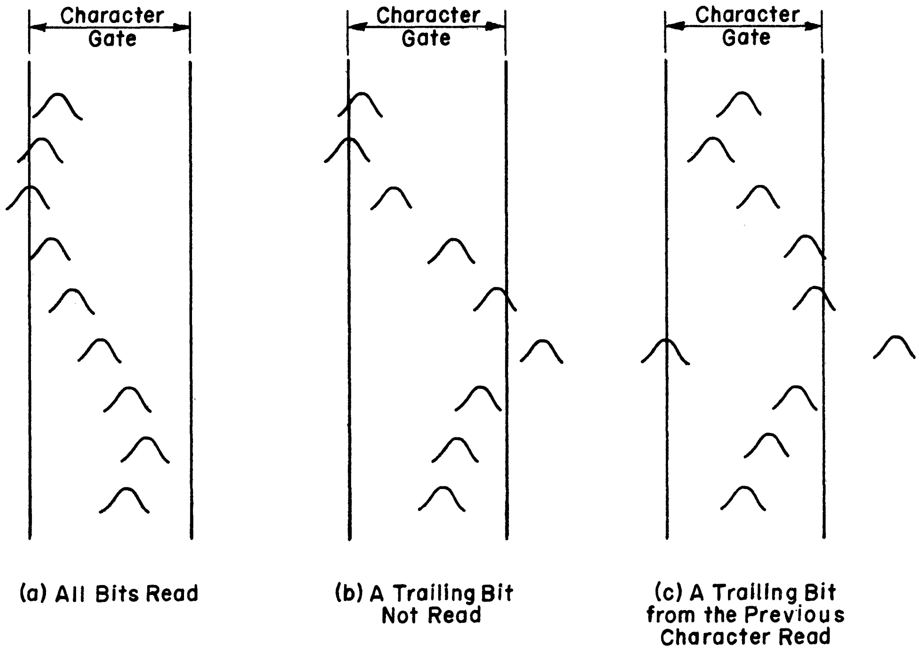


Figure 15. Errors in Reading Bits

5.2 Tape Read Skewing Errors

In addition to the tape write skewing errors which have already been discussed, tape read skewing errors may also occur. These may be caused by:

1) Read Gap Scatter

   This is identical to the write gap scatter discussed on page 3-2.

2) Tape Skew

   Irregularities in tape dimensions produce instantaneous azimuthal error (tape wobble) at the read head, in the same way that the error is caused at the write head.

TAPE READ DESKEWING TECHNIQUES

Figure 16 shows ideal and typical tape read/write head assemblies.

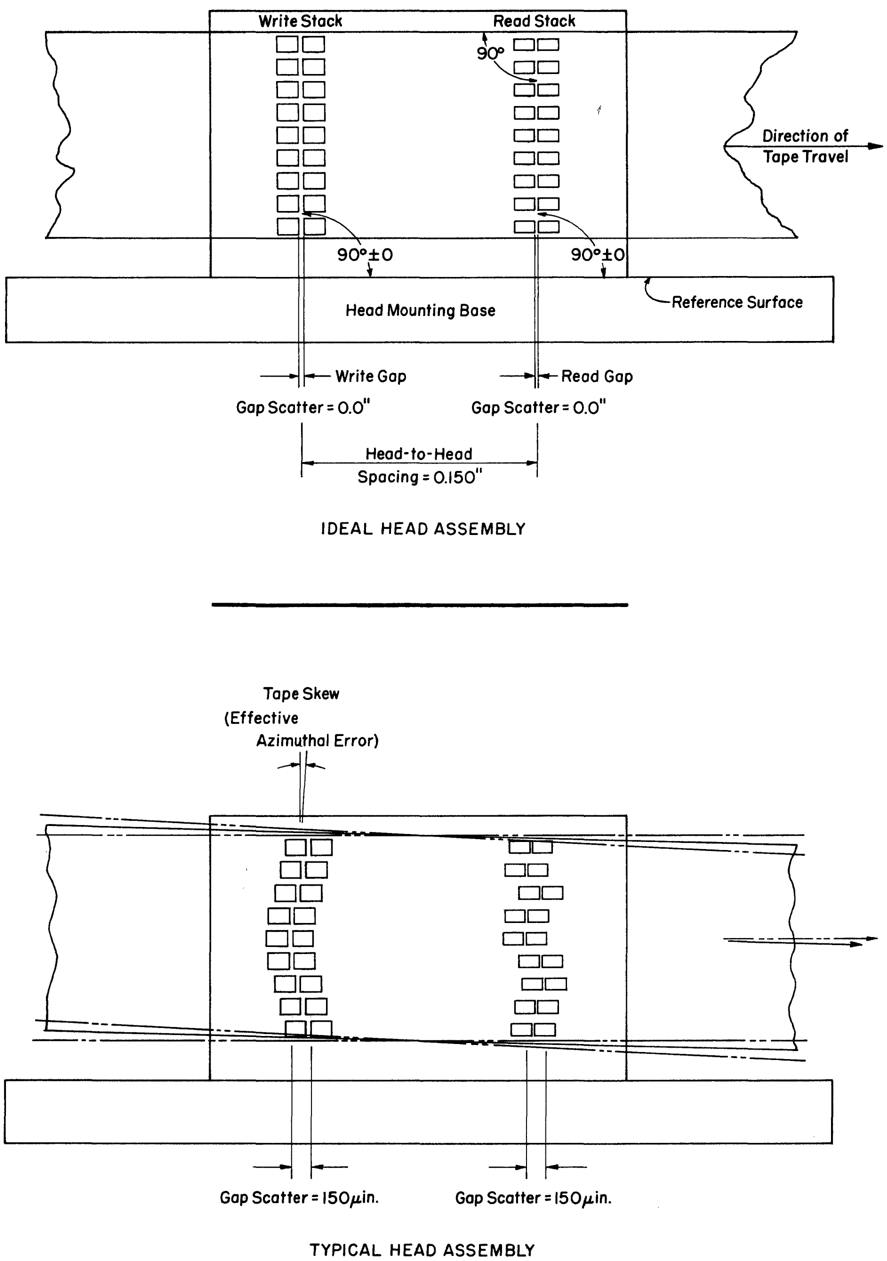


Figure 16. Ideal vs. Typical 9-Track Head Assemblies

Three deskewing techniques are used for the read head, as described below.

6.1 Mechanical Read Head Deskewing

This technique mechanically positions the read head such that the mean scatter of the gaps are perpendicular to the longitudinal axis of the tape as shown in Figure 12. For mechanical compensation on both read and write heads, the stacks must not be connected.

6.2 Electronic Averaging

If the azimuthal shift of a head is predictable, it may be compensated for by adding electronic delays on the read head, to provide a compensating electronic azimuthal shift as described in Paragraph 4.2.

6.3 Electronic Per Channel Read Head Deskewing

An adjustable per channel time lag is added to the time interval between a bit being sensed at the read head and being processed by the read electronics. Thus, as shown in Figure 13, read head gap scatter is accounted for by time delay, and all the bits of a character are presented to the read electronics simultaneously.

CONCLUSION

Tape skew errors are caused by the fact that it is impossible to achieve zero error in mechanical or electronic design. The economics of data processing call for maximum-speed tape drives (to reduce tape search and data retrieval times), and maximum data storage density. By the standards of a decade ago, tape units are being built today with incredible precision; in the next decade tolerances will probably be reduced still further, but tape speeds and recording densities will probably both increase to the limits imposed by tape skew error, and thus tape deskewing will still remain an important part of tape unit design. There is thus little prospect that tape skew will disappear with time as a problem to be solved when recording data on magnetic tape.

A common need is to be able to write data on one tape drive, and read it back on another; for greatest reliability, both the read and write drive electronics should be deskewed, otherwise it is possible for write skew and read skew of the two separate units to compound each other and cause increased potential error.

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