

RECONSTRUCTING A SERIAL PULSE TRAIN FROM PARALLEL DATA RECORDED ON MAGNETIC TAPE

R. E. HADADY

**Vice President and Director of Marketing
Kinelogic Corporation
Pasadena**

Summary On-board data stores in deep-space probes, spacecraft, satellites, and aircraft, frequently require the extensive bit storage capability of a magnetic tape recorder. For compatibility with other systems, it is necessary in some cases to be able to reproduce the data in serial form at a synchronous rate. To take maximum advantage of the storage capability of magnetic tape, however, it is desirable in many instances to record the data in a parallel format; i.e., the technique used in magnetic tape recorders used with ground based computers.

Reconstructing a serial pulse train with a synchronous bit rate from parallel data recorded on magnetic tape involves some problems which are peculiar to magnetic tape recording equipment. Variations in tape speed (flutter), dynamic skew (wobble) of tape as it passes over the record and playback heads and static skew of the data on the tape resulting from head gap scatter and mean gap azimuth alignment results in non-synchronous data being generated during playback. To provide synchronous data output, it is therefore necessary to provide a buffer between the output of the magnetic tape recorder and the system accepting the data.

Recorder characteristics are examined with respect to their effect on the degree of non-synchronism. Furthermore, the size and complexity of buffers necessary to provide synchronous output data is considered.

Introduction Reconstructing a serial pulse train with a synchronous bit rate from parallel data recorded on magnetic tape involves some problems which are peculiar to magnetic tape recording equipment. This is particularly true if the output serial data is to be in absolute synchronism with an external clock. An application involving this requirement is a data store for deep-space probes. Information from the data store must be introduced into the RF link in synchronism with an on-board ultra-precision clock to recover the data at the receiver. The extremely faint radio signals at the receiver are separable from the background noise only through the use of sophisticated filtering and correlation techniques which require a known and constant data rate.

Problems peculiar to tape recorders arise from the following tape recorder characteristics, which result in non-synchronous data being generated during playback:

1. Dynamic skew (wobble) of the tape as it passes over the record and playback heads.
2. Static skew of the data on the tape resulting from, a) gap scatter in the record and playback heads, and b) mean gap azimuth alignment in the record and playback heads.
3. Flutter which is caused by variations in tape speed.

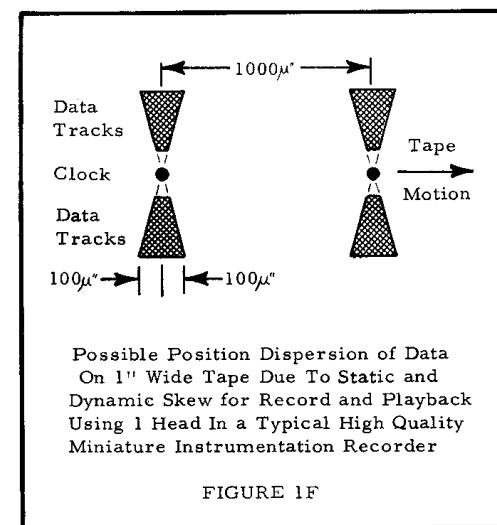
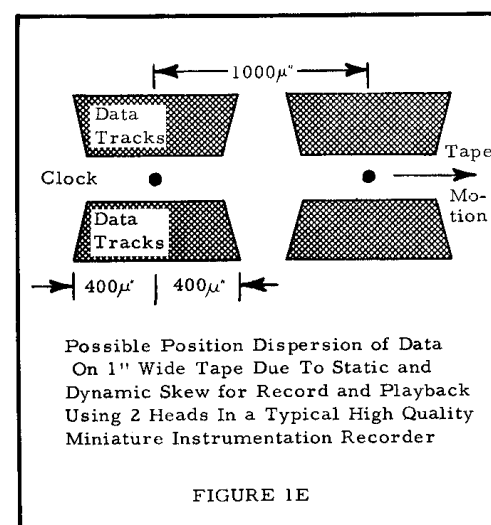
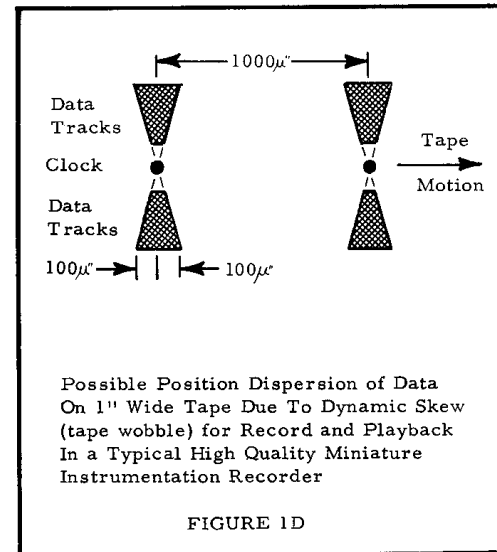
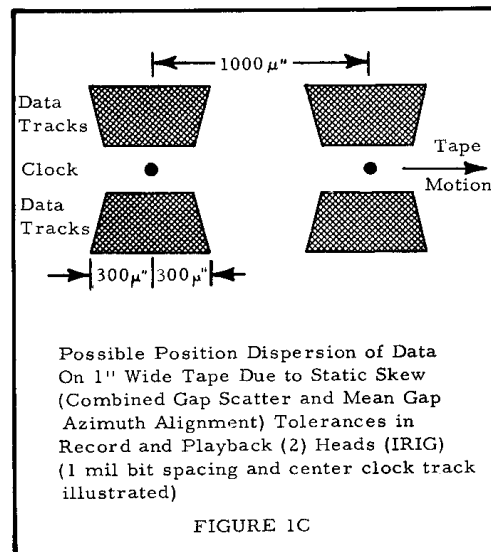
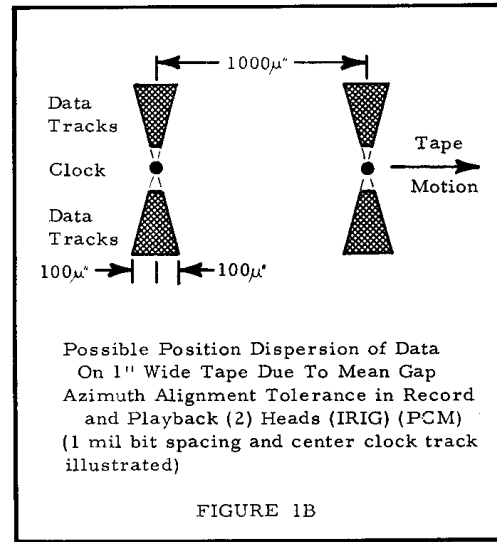
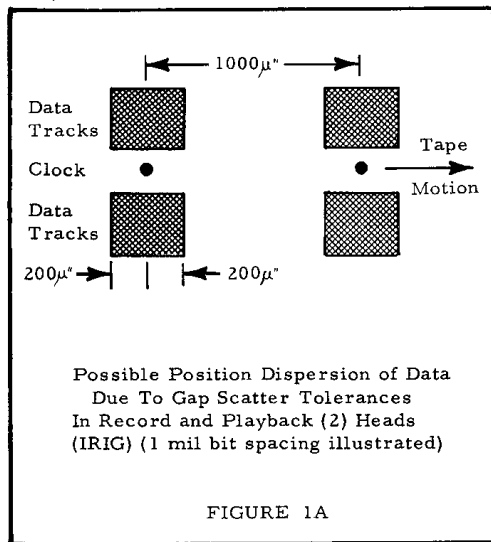
Dynamic and Static Skew The effects of static and dynamic skew in a typical precision instrumentation recorder may be quickly visualized by referring to the series of illustrations in Fig. 1, which show the possible displacement data bits with respect to the clock during playback. Time displacements in Fig. 1 are expressed as a distance-position displacement in microinches. This unusual way of specifying a displacement (microinches, rather than microseconds) is appropriate since the source of the error is due to mechanical misalignments. IRIG specifications limit the gap scatter in a magnetic head, record or playback, to a band of 100 microinches. Mean gap azimuth alignment is limited by IRIG PCM Specifications to ± 20 seconds of arc, approximately 100 microinches per inch, for each head stack referred to the mounting surface. For a specified tape speed, the actual time displacement in microseconds can be calculated as follows:

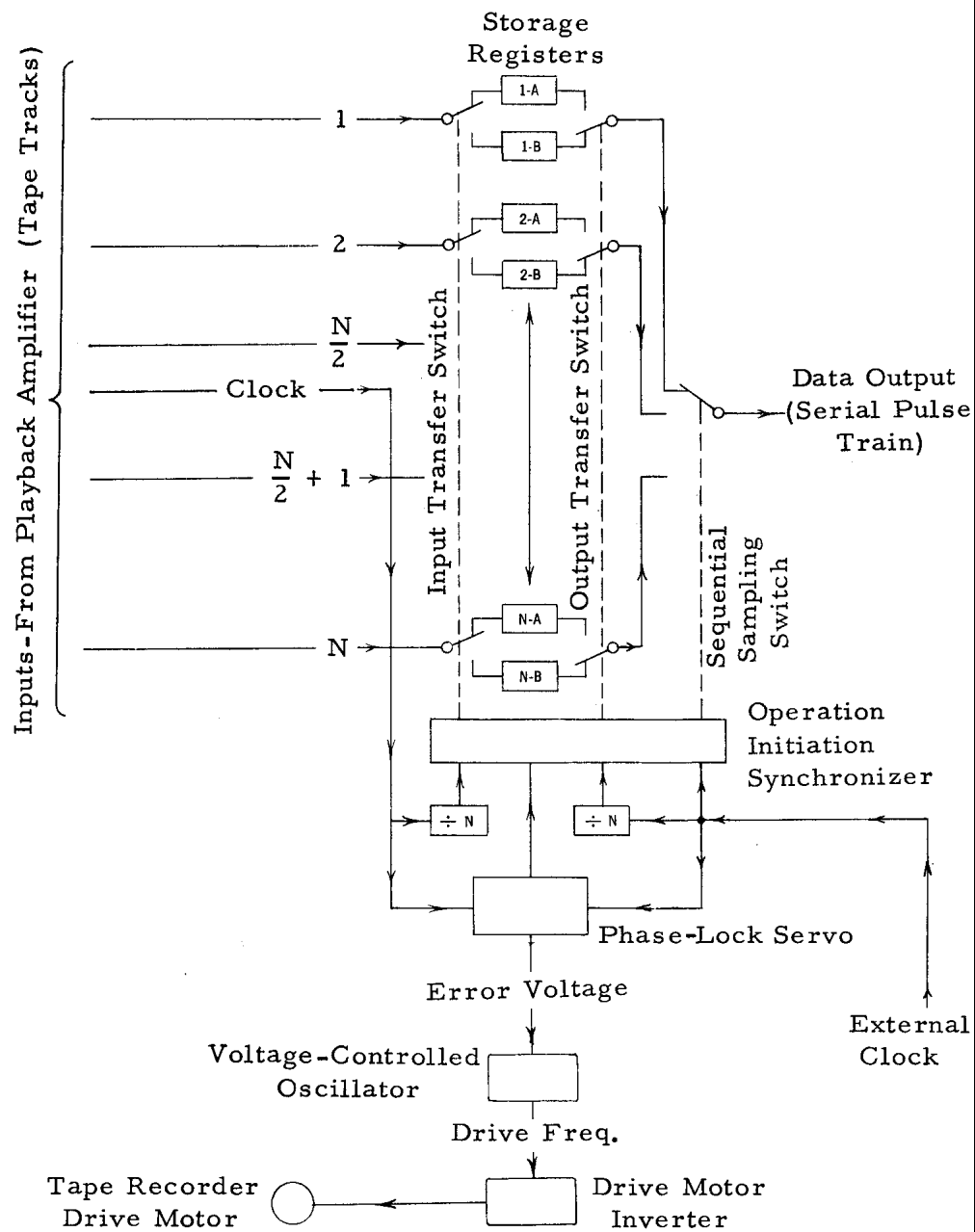
$$\text{Time Displacement (seconds)} = \frac{\text{Position Displacement (inches)}}{\text{Tape Speed (inches per second)}}$$

The effects of temperature variation on static and dynamic skew are not included in the typical values shown in Fig. 1. Recording at one temperature and playing back at another temperature can result in the introduction of additional static skew, which can be quite significant. The use of a single head for both record and playback functions materially reduces the errors caused by static skew since it eliminates gap scatter and azimuth alignment of the head stacks. This is dramatically illustrated by comparing Fig. IE and IF. The use of a single head stack versus multiple head stacks also reduces tape wear and should be considered where maximum life and reliability are of major importance.

From Fig. 1, it can be seen that the spacing between adjacent frames on the tape, after taking into account the possible position dispersion of data bits, normally leaves very little time to accumulate all of the data bits and sequentially sample them before data bits for the next frames start arriving. Without a means of storing the data bits, it is obviously impossible to sequentially sample the tape output at a synchronous rate and provide synchronous serial reconstruction of the data. Fig. 2 illustrates a block diagram of a

Total static skew for a 2 head record/playback system is Fig. 1A + Fig. 1B = Fig. 1C. Total skew, static plus dynamic, is Fig. 1C + Fig. 1D = Fig. 1E. For comparison, total static and dynamic skew for a 1 head record/playback system is shown in Fig. 1F.





PARALLEL-TO-SERIAL CONVERTER

FIGURE 2

parallel-to-serial converter using two storage registers. The two storage registers, A and B, store alternate frames to provide the necessary store between the recorder output and the synchronous output to external equipment. A 2-frame store may or may not be adequate for a given recorder system, but the principles involved remain the same and it simplifies understanding the concept involved.

The complexity of the parallel-to-serial converter having its output synchronized from an external source involves the following two problems:

- (a) De-skewing to collect all of the time displaced frame bits at the same instant in time.
- (b) Maintaining the time interval between reproduced frames (the frame rate) from the recorder at as near a synchronous rate as possible in order to minimize the total store required.

As long as the bits in a frame do not overlap, an instant can be established at which the bit information can be collected and, in effect, de-skewed. Thus, if a suitable storage register is provided to handle the collection of the bits from the tape, static and dynamic skew are not a real problem in providing output data in synchronism with an external clock.

The problem in synchronizing the serial output bit rate with an external clock is reduced to synchronizing the average frame rate coming off of the tape with the external clock. To accomplish this objective, servoing the tape speed during playback is required. This is necessary for the following reasons:

- (a) Changes in tape dimensions occur due to:
 - 1. Tension variations in the tape
 - 2. Ambient temperature changes
 - 3. Humidity changes (not normally a problem in a hermetically sealed recorder filled with a dry gas)
- (b) Mechanical slippage between the capstan or the tape driving elements and the magnetic tape.
- (c) Non-synchronous motor speed (e. g. , there is even a minute slippage in a hysteresis synchronous type motor).

A servo system which provides a synchronous character rate from the tape operates by comparing the bit rate from the tape with the external clock which is being used as the synchronizing standard. Normally, a phase-lock system is utilized in order to eliminate any fixed errors. Utilizing a system of this type, the average tape speed can be made to exactly match the external synchronizing clock.

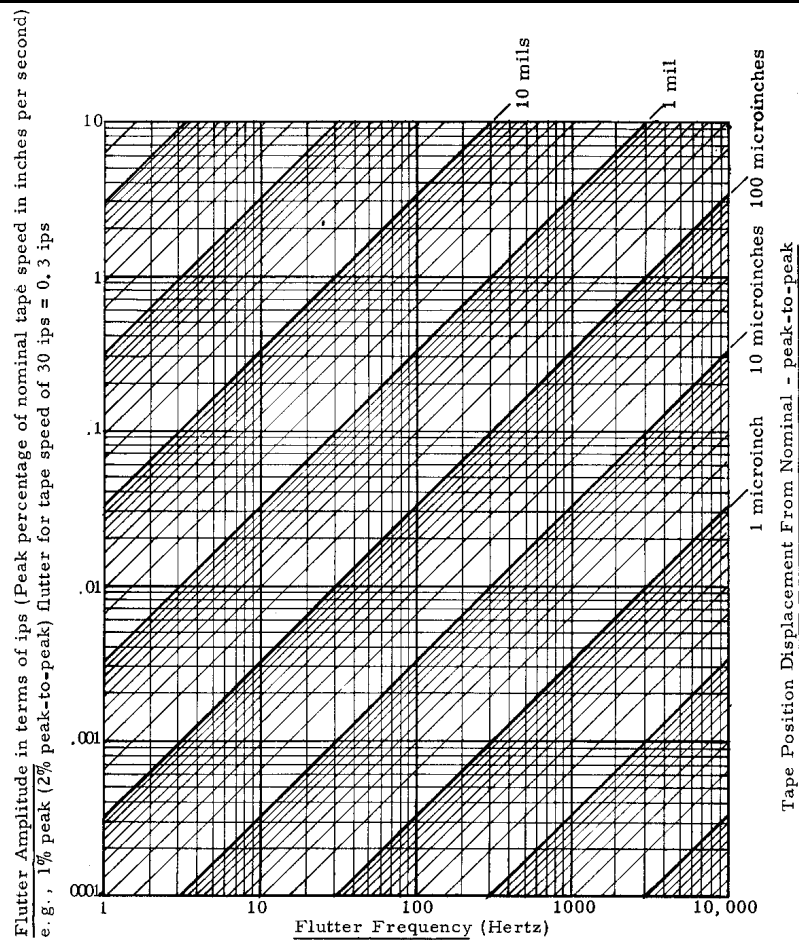
Flutter In addition to matching the average tape speed with the external synchronizing source, it is highly desirable to keep the instantaneous speed error to as small a value as possible in order to minimize the store size. This is a function of flutter.

The relation of flutter to the time displacement error, or the more usable position displacement error, can be readily obtained by referring to Fig. 3. For convenience in assimilating the problem, it is easier to think in terms of tape position displacement from nominal--i.e., how far off in position is the tape from where it theoretically should be if it were moving at constant velocity? This concept makes it easy to compare the instantaneous position error with the bit packing density in bits per inch and determine how many bits (frames) the tape is ahead or behind. Fig. 3 is a nomograph of tape flutter vs. tape position displacement. To determine the tape position displacement, it is, of course, necessary to quantitatively know the two components of flutter--amplitude, and frequency. Referring to the nomograph, it can be seen that for a given flutter amplitude, the tape position displacement from the nominal increases as the flutter frequency decreases. In an optimized system, it is, therefore, of the utmost importance to reduce the magnitude of the flutter at low frequencies, particularly below one cycle.

Typical servo systems of the type required in tape recorders usually employ a hysteresis synchronous motor or a DC servo motor. An AC servo motor could also be utilized, although it is rarely employed. Normally, from the standpoint of servo control, the DC motor is preferable, but the conventional type suffers from the disadvantages of limited life and noise problems due to commutation. Brushless DC motors would circumvent this problem at the cost of additional complexity.

The AC hysteresis synchronous motor provides a relatively straightforward answer to long-term life and reliability if its operating characteristics satisfy the servo system requirements. The principal disadvantage of the AC hysteresis synchronous motor is its under-damped characteristic, which tends to make it "hunt" about the oper-point. This, in effect, is flutter, and the criteria for its acceptability is whether or not the magnitude and the frequency of the flutter is such that it represents a relatively small position displacement error. Conventional AC hysteresis synchronous motors will exhibit a resonance in the range of one to ten cycles, depending upon the motor parameters: i. e. , size, rotor inertia, torque, etc. Through proper design, the motor can incorporate damping characteristics which minimize the excursions and the number of cycles required to damp out motor oscillation.

In a typical spacecraft-type recorder employing a high speed drive motor with servo control, both the amplitude and frequency of the major low frequency flutter component are independent of tape speed. They are dependent almost entirely upon the motor which contains the major portion of the kinetic energy in the system due to its high angular velocity.



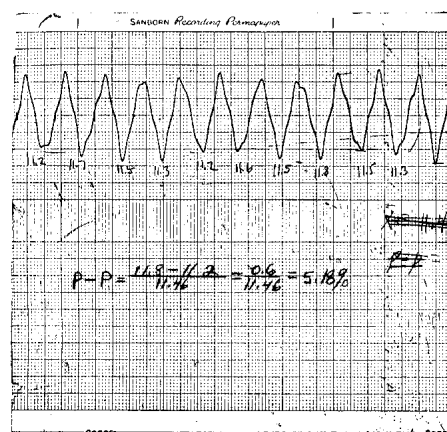
TAPE FLUTTER versus TAPE POSITION NOMOGRAPH

FIGURE 3

(Spaceborne Type Recorder)

Record Speed: 12.8 ips
Bit Density: 833 bpi
P/B Speed: 0.01 ips
P/B Data Rate: 8.33 bps

Peak-to-Peak Flutter
(or jitter) measured
from the time the vari-
ation of bit-to-bit zero
crossings is found to be
5.18%. The predom-
inate frequency of the
flutter is 1.66 cps.



The above shows the reproduced waveform
of a Clock Track (All "Ones")

TYPICAL LOW FREQUENCY FLUTTER RECORD

FIGURE 4

Fig. 4 illustrates the typical flutter performance of a small hysteresis synchronous motor as used in a miniature space-borne recorder operating at a record tape speed of 12.8 ips and playing back at 0.01 ips. Utilizing this flutter performance data (an amplitude of approximately 2.5% peak, 5% peak-to-peak, and a frequency of 1.6 Hz) and referring to the nomograph, (Fig. 3) the position displacement can readily be determined -50 microinches peak-to-peak, 25 microinches peak. For a packing density of 1000 bpi on the tape, this represents only 2.5% of the spacing between adjacent bits. Hence a minimum store between the recorder and the serial output interface is more than adequate.

The number of storage registers required for parallel-to-synchronous serial output can be determined through the use of the nomograph and by knowing the maximum position displacement which can be handled by a given number of storage registers. Fig. 5 illustrates the maximum allowable position displacement which can be tolerated for a 1-frame 2-frame, and a 3-frame store. In examining the maximum allowable position displacement, it should be remembered that:

- (a) The peak negative position displacement is always followed by a positive displacement error. This is readily seen by referring to Fig. 6. The maximum displacement error, whether positive or negative, occurs at the instant the actual tape velocity matches the nominal velocity. At this point, the acceleration of the tape is also the greatest and hence the inertia of the system carries the tape velocity through the nominal to an approximately equal and opposite displacement of the reverse polarity.
- (b) Synchronous serial output must only be initiated after the following conditions, 1 and 2 are present, and also preferably 3:
 - 1. The system is up to speed and the servo system is locked in.
 - 2. The store is approximately one-half full, thus allowing an equal positive and negative position displacement error of the tape.
 - 3. The position displacement error is essentially zero. If synchronous output is initiated when the position displacement error of the tape is at a maximum rather than zero, 50% additional storage is required.

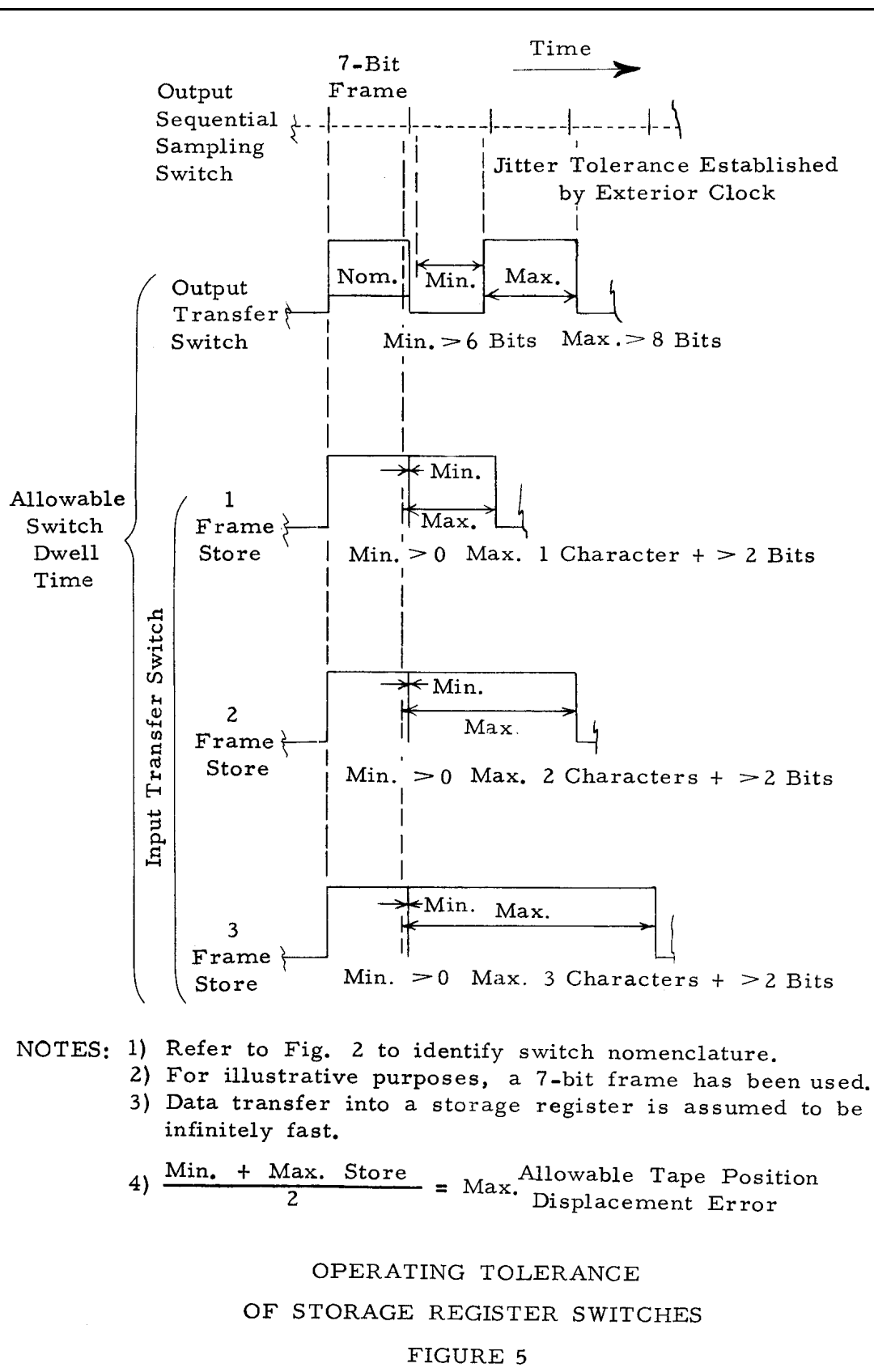
Conclusions Absolute tape position error is the key in determining the size of the register needed to smooth the synchronous output of parallel frames being reproduced from a tape recorder and converted into a synchronous serial format.

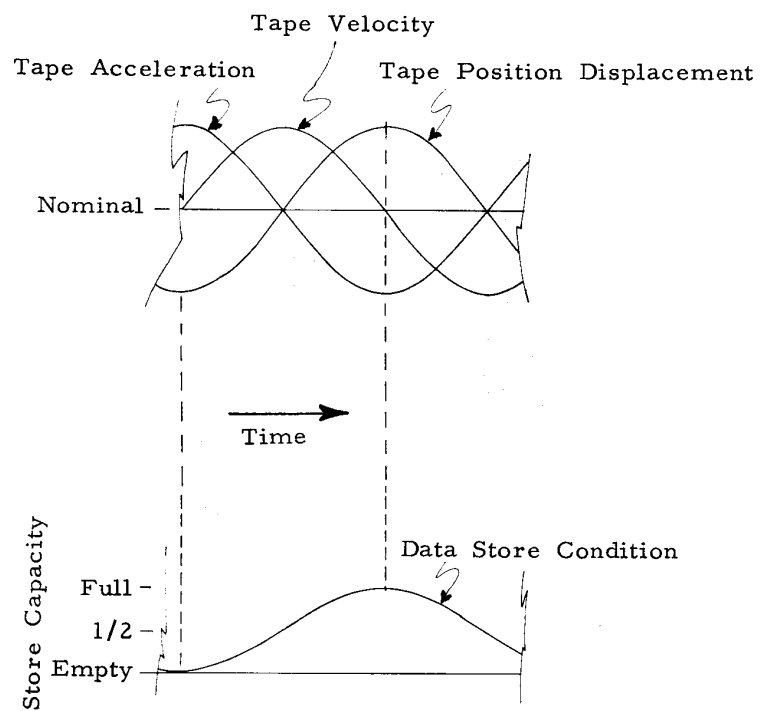
For convenience, a nomograph has been developed for converting tape recorder flutter into absolute tape position error. This error is inversely proportional to the flutter

frequency for a given flutter amplitude and hence, low frequency flutter in the recorder must be minimized.

Servo control of tape speed must be employed in order to make the average tape speed error zero. For low speed recorders, e. g. 0. 5 ips, a simple hysteresis synchronous motor with servo frequency control and a 3-frame register is normally adequate to provide synchronous conversion.

In the tape recorder a single record/reproduce head as compared to two separate heads, has significant advantages with regard to static skew, flutter, tape wear, and power requirements.





TAPE PARAMETER AND DATA STORE CONDITION

FIGURE 6