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HIGH-CAPACITY MAGNETIC TAPES FOR ON-LINE COUNTER EXPERIMENTS

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ABSTRACT

Storage tapes based on TV video-recording techniques can be used to record huge amounts of raw data from on-line counter experiments. Practical solutions are discussed, in which the contents of up to 700 conventional tapes can be packed in one single video tape.

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1. INTRODUCTION

Almost every on-line counter experiment stores the physics information on seven- or nine-track magnetic tape, recorded at a density of 800 bits/inch. The total storage capacity of such a tape is about 10^8 bits.

Some experiments are recorded on hundreds, or even thousands, of tapes. The development of new, more powerful types of detectors, like the multiwire proportional counters and the advent of higher-energy accelerators and storage rings has potentially opened the way to much bigger volumes of physics information, provided of course that the corresponding storage and data-handling capacity becomes available.

In the present note we discuss ways of increasing the storage capacity of physics information for on-line computer experiments by as much as three orders of magnitude with respect to conventional tape. If the new storage medium (video tape) can be used for data acquisition, most problems connected with magnetic tape administration and storage would disappear.

It is also our opinion that these much higher capacity devices will have a considerable impact on experimental design, since it now becomes feasible to record an experiment with "loose" (or combined) trigger conditions and to perform the off-line analysis in subsequent passes through the tapes looking each time for different reactions with a minimum amount of bias. The over-all setting-up time and the expenses of constructing efficient trigger arrangements would be reduced, the experiment becoming rather similar to a bubble chamber exposure and subsequent analysis.

2. RECORDING TECHNIQUES

The standard seven- or nine-track tape format (800 bits/inch) is already more than 10 years old, and it seems logical that, provided tape compatibility is renounced, higher densities may be nowadays possible. Standard high-performance tape units, recording at 1600 bits/inch and 150 inches/second (as used, for example, for the Omega and SFM facilities), certainly allow higher data rates, but have a storage capacity per tape only about two times better than conventional tape units.

High-density digital tape recorders for data logging have been developed for a number of applications. The recording technique used in some of these is an assembly of 14 heads recording across a one-inch tape in the same way as conventional magnetic tape recorders, but at a density of about 20,000 bits/inch. The total capacity of such a tape corresponds to about 400 conventional tapes. The main advantages of this type of recorder are that it has already been proved in the field and has variable speed, allowing especially a different speed for recording and reading. The main disadvantages are skew problems, if parallel recording is used, the high cost of head replacements and the slow access to remote parts of the tape.

A new technique of storing digital information on tape has been recently derived from standard analog video tape recorders. In the following this is the only solution which will be discussed.

These video tape recorders use a rotating head assembly, of which essentially only one head is active at a time. The head assembly rotates at high speed over the tape which moves at low speed with respect to the transport. The scan of the rotating head is either transverse to the tape, requiring a large tape width of 2 inches and a strongly bent tape, or it is nearly longitudinal to the tape; scan lines as long as 10 inches are written at an angle of about 5 degrees over a tape 1 inch wide. In this case the tape is guided nearly along the circumference of the rotating head, however deviating from parallelism by an angle of about 5 degrees.

Since only one track is written or read at a time, inter-track distance is no longer determined by the number of heads which can be packed into a head-assembly, and transversal track densities of 100 per inch or better can be achieved.

The information density along the track can be significantly increased too:

i) All inter-channel time displacement errors ("skew") are eliminated, since all clock signals are derived from the coded information within a single track.

ii) The tape to head contact is very good, allowing very small head gaps. The head gaps can be made so small that there is no penetration of magnetization through the iron oxide layer.

iii) The iron oxide layer is not magnetized to saturation.

The last measures obviously lead to a lower quality of the head output signals. Because of the bad amplitude, stability equalization circuits are necessary. The coded information, however, is contained in the zero-crossings and can be safely extracted. A further increase of storage capacity is obtained by using tapes which are by a factor 2 wider and a factor 3 longer.

Ampex have developed a system of large capacity storage centred around such a type of transport, the Terabit Memory System. This system, which in its smallest configuration costs about 2×10^6 SF is primarily intended as a centralized data file for large computing systems. Each transport module contains 2 tape drives (the system can be extended to 32 transport modules.) Very sophisticated error correction methods reduce the error rate to $< 10^{-11}$. Figure 1 shows the tape format for the Ampex Terabit Memory System.

For on-line computer data acquisition, probably a more modest solution consisting of a single tape transport with a tape controller and associated buffer memory is adequate. A higher error rate is acceptable, as long as errors are detected. For example, a 10^{-7} error rate corresponds to a loss of one event in 10^4 for events of 10^3 bits; losses due to the inherent inefficiencies of the detection system are much larger. In the tape transport of IVC (International Video Corporation in Sunnyvale, California) the tracks (which are written at an angle of 4 degrees 45 minutes to the direction of tape movement) have a width of 6 mils and a track centre to centre spacing of 9.5 mils. The density along a track is 11,000 bits/inch.

In addition to the high-density tracks, four other tracks are recorded longitudinally in low density. These tracks contain synchronization, address, and status information, relative to the high-density scan lines. Individual high-density scan lines can be selected for reading, writing, or skipping, on the basis of the information contained in the low-density tracks. Figure 2 shows the tape format for the IVC-1000 tape transport. The specifications of the IVC-1000 tape transport are summarized in Table 1.

For initial positioning and file skipping a fast search mode is available with search speeds up to 400 inches/second, in which only the low-density address and status tracks are read out. In this way any individual high-density scan line of a standard 7000 feet reel can be accessed in an average time of 100 seconds.

Thus the main advantages of the IVC digital video recorder are obviously the very high density, the single track recording, the indexing and searching facilities. Hesitations about the IVC recorder are mostly concerned with the present prototype stage of the development: will it ever be produced in reasonable quantities, and how many problems will it experience when put in an experimental data-taking environment?

3. GENERAL ORGANIZATION AND INTERFACE

On a conventional tape the information is blocked into records a few inches long, separated by inter-record gaps of 0.75 inches. This inter-record gap length is sufficient to allow the tape to come to a stop between records. A similar way of recording is impractical for a video tape. The density of information recorded on the tape being as high as 10^6 bits/inch^2, approximately 200 times greater than on a standard tape, huge buffers would be required for only a few inches of recorded information. Only a fast staging disk would be adequate for buffering and would still require secondary core or MOS buffers, since the tape and the disk are not moving synchronously. Furthermore an inter-record gap length of 0.75 inches will not be sufficient, since it takes about 300 milliseconds to achieve phase lock of tape and head movement at the speed needed for data transfer, which is more strictly controlled than the speed of a conventional tape.

For on-line computer counter experiments another method of recording is possible, which has the advantage of requiring only one or two scan-line buffers (104,000 bits or 6500 16-bit words). At the beginning of an experiment the data rate is determined and a decision is made on how many scan lines have to be skipped for each recorded scan line. Assuming that out of N scan lines only 1 scan line is recorded, the tape is filled in altogether N passes. In the first pass scan lines 1, N+1, 2N+1, ... are written, in the next pass scan lines 2, N+2, 2N+2, ... , etc. Each pass takes about 3.5 hours and after each pass the tape is rewound in 3 minutes.

If there is only one scan-line buffer, data taking is interrupted during the 12.8 milliseconds it takes to write a scan line.

If there are two buffers, one buffer is filled, while the other buffer is written onto the tape. Scan lines have to be skipped only if the input rate is lower than the tape transfer rate, or if the buffer memory does not sustain the required rates (8.1 megabits/second during scan-line writing + 6 megabits/second average input rate).

The scan-line buffers can be implemented as hardware buffers external to the controlling computer (Fig. 3), or as the actual computer memory (Fig. 4). Though external hardware buffers are probably somewhat less expensive, there are several advantages in using addressable computer memory buffers: less hardware development is required, there is random access to buffered data, buffer management is by software, i.e. more flexible, and a variety of read-out schemes could be implemented. A suitable computer should have two fast direct memory access data paths (e.g. HP 2100).

Whatever scheme is chosen, it is highly desirable that the tape system be controlled by a dedicated cheap small computer. In this way much of the detailed control of the tape activity (scan-line interlace selection, buffer management, error checking and control, etc.) can be handled in a flexible way by the dedicated software in the small machine, while presenting a clean and simple interface to the experimental data acquisition system. In this way it should be possible to construct a package (video tape plus small computer controller) which can be easily adapted to a variety of experimental systems.

Table 1

Specification of the IVC-1000 tape drive

DATA (ROTATING HEAD)

Input/Output data rate:	8.1 $\times 10^6$ bits/sec for 12 $\times 10^4$ bit record.
Throughput data rate:	7.18 $\times 10^6$ bits/sec.
Tape packing density:	1 $\times 10^6$ bits/inch^2.
Recording density:	11,000 bpi.
Data record length:	120,000 bits max.
Error rate:	Less than 1 in 10^8 bits (uncorrected), 1 in 10^7 bits optional.

CONTROL AND ADDRESS (FIXED HEADS)

Address input rate:	2250 bits/sec (8.1 $\times 10^6$/3600).
Address output rate:	2250 bits/sec at 6.91 ips. 130 k bits/sec at 400 ips.
Address word:	28 bits Permanent Address. 28 bits Updatable Status Address. One address word identifies one data record (track). An additional 28-bit Permanent Address/Index track is available as an option.
Address format:	Series NRZ plus clock.
Address recording density:	280 bits/inch.

TAPE SPEEDS

Record:	6.91 ips linear (723 ips scan head-to-tape speed).
Playback:	6.91 ips for HID data. Address tracks can be read at all speeds.
Search:	400 ips - bi-directional record in search mode is less than 45 sec.
Wind/Rewind:	400 ips (rewinds 7000-foot reel in less than 3.5 minutes).
Reel size:	Up to 12½-in. in cartridge.
Start time:	200 msec from standby to capstan lock.
Start/Stop time at 400 ips:	< 2.5 sec.
Cartridge loading:	Self-threading is standard.
Tape speed accuracy:	±0.25%.
Servo:	Phase lock servo control of the capstan is standard. Reels are individually servo controlled, yielding constant tape tension from end to end of tape in the read or write modes. The Fast Forward and Fast Reverse tape speeds are servo controlled to accurately locate an exact address on a previously written tape.
Rewind time:	< 3.5 min. for 7000 ft.
Heads:	a) Helical scanner contains one read/write, one write verification, and one erase head. b) Four longitudinal tracks are provided: control, address, address clock, and optional or redundant.
Tape:	One-inch 3M video tape.
Local controls:	Push buttons for fast reverse, read/write speed, unload, fast forward, read, stop, write.
EOT and BOT:	Photo-optical sensors.

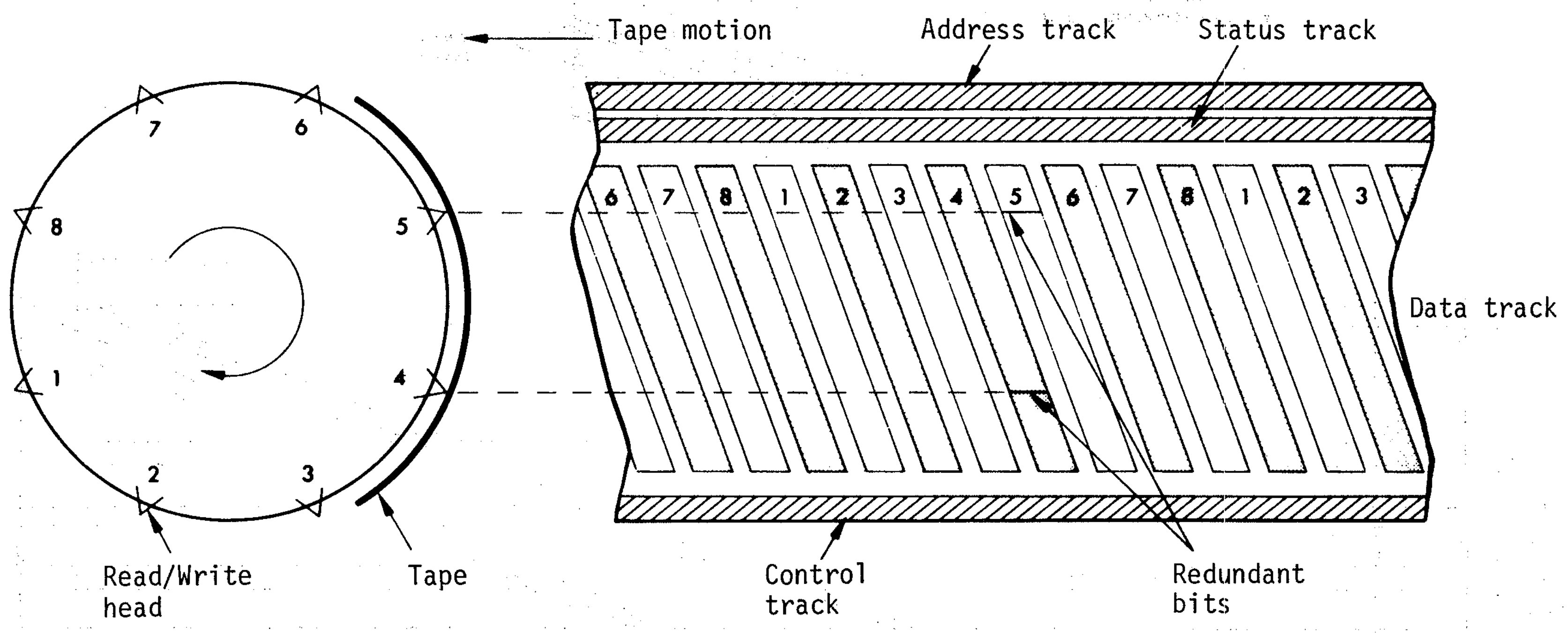
Tape motion
Address track
Status track
Data track
Read/Write head
Tape
Control track
Redundant bits

Fig. 1

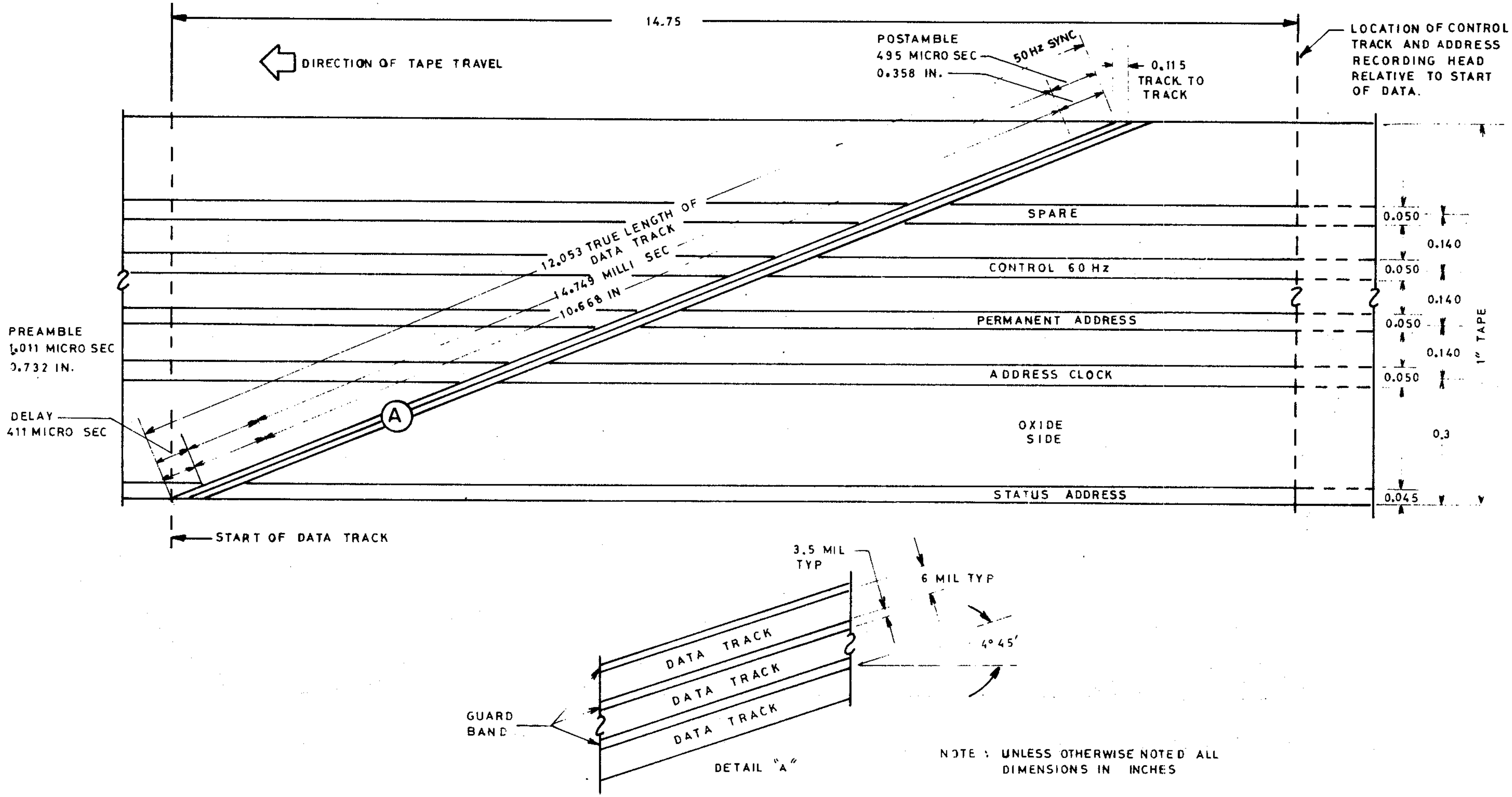
14.75
DIRECTION OF TAPE TRAVEL
POSTAMBLE
495 MICRO SEC
0.358 IN.
50Hz SYNC
0.115
TRACK TO
TRACK
LOCATION OF CONTROL
TRACK AND ADDRESS
RECORDING HEAD
RELATIVE TO START
OF DATA.
12.053 TRUE LENGTH OF
DATA TRACK
14.749 MILLI SEC
10.668 IN
SPARE
CONTROL 60 Hz
PERMANENT ADDRESS
ADDRESS CLOCK
OXIDE
SIDE
STATUS ADDRESS
0.050
0.140
0.050
0.140
0.050
0.140
0.050
0.3
0.045
1" TAPE
PREAMBLE
1.011 MICRO SEC
0.732 IN.
DELAY
411 MICRO SEC
A
START OF DATA TRACK
3.5 MIL
TYP
6 MIL TYP
4° 45'
DATA TRACK
DATA TRACK
DATA TRACK
GUARD
BAND
DETAIL "A"
NOTE : UNLESS OTHERWISE NOTED ALL
DIMENSIONS IN INCHES

Fig. 2

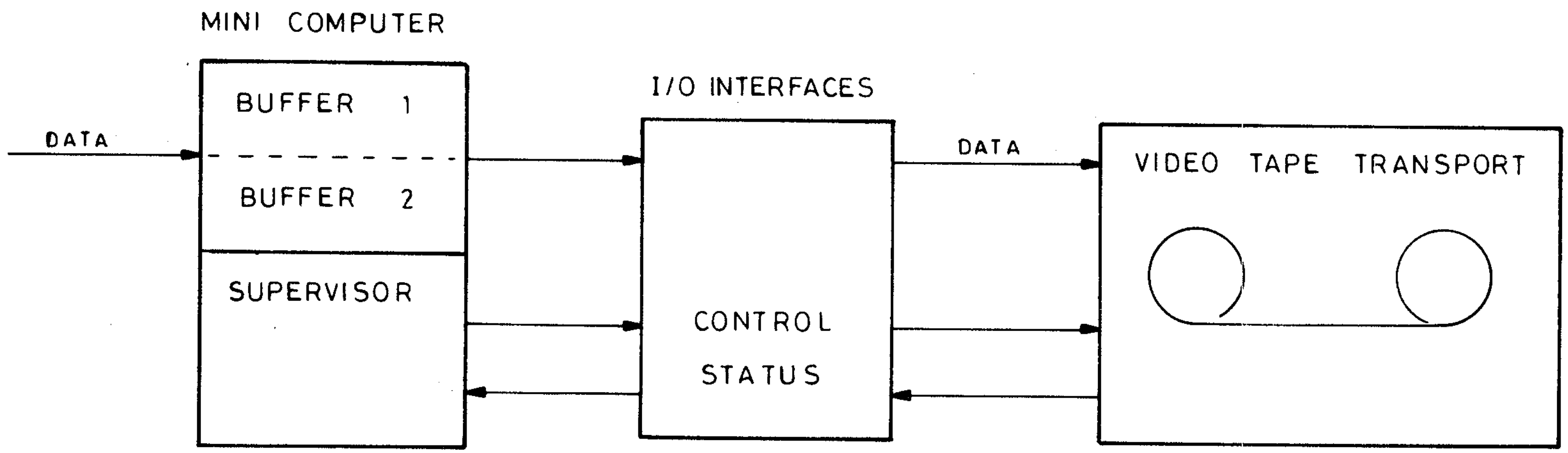
MINI COMPUTER
BUFFER 1
BUFFER 2
SUPERVISOR
DATA
I/O INTERFACES
CONTROL
STATUS
DATA
VIDEO TAPE TRANSPORT

Fig. 3

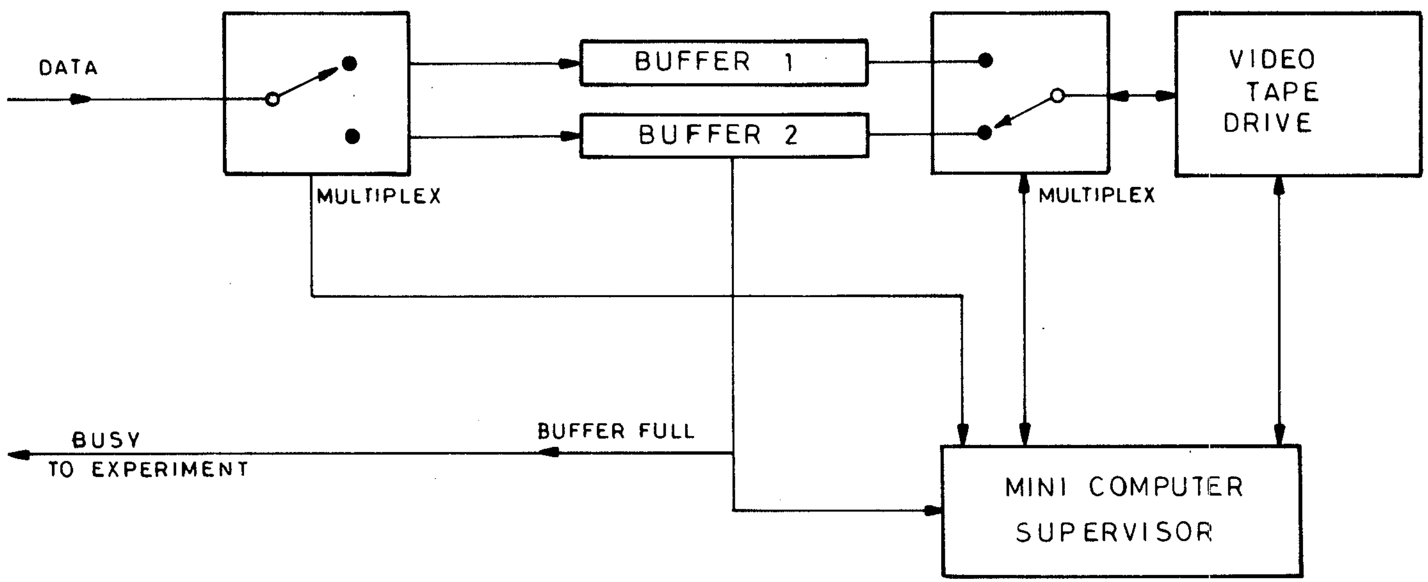
DATA
MULTIPLEX
BUFFER 1
BUFFER 2
MULTIPLEX
VIDEO
TAPE
DRIVE
BUSY
TO EXPERIMENT
BUFFER FULL
MINI COMPUTER
SUPERVISOR

Fig. 4