DELIVERABLE

AC-018

SMASH

Deliverable #7

a0018/phi/prl/ds/P/007/b1

May 1997

Report on the system specification of an advanced linear system

Project Number	:	AC 018
Project Title	:	SMASH
Deliverable Type	:	Public

CEC Deliverable Number	:	AC018/phi/prl/ds/P/007/b1
Internal Project Number	:	SMS-P-634-2
Contractual Deliverable Date	:	31 May 1997
Actual Date of Deliverable	:	28 May 1997
Title of Deliverable	:	Report on the system specification of an advanced linear system
Contributing Workpackages	:	WP200
Nature of Deliverable	:	Report
Author(s)	:	E.A. Montie (Philips) et al.

Abstract

This report describes the key parameters of the hard disk and linear tape drive that determine the performance of a Combo system for Digital Video Broadcasts (DVB) recording and playback, the most demanding of all SMASH applications. It turns out that, in terms of data throughput rate, the tape drive is the bottle neck in the system. The presently used Tandberg MLR1 linear tape drive is not fast enough to sustain two digital video streams of 6 to 9 Mbit/s, the data rates most commonly encountered in DVB. Although the use of a serpentine partitioning scheme quite effectively reduces the access time to the data, the maximum throughput of the drive itself (now 12 Mbit/s) still needs to be increased further to at least 14 Mbit/s in order to enable parallel recording and playback of two 6 Mbit/s video streams (tape access overhead reduces the effective data rate). A rate of 20 Mbit/s would be desirable, as that would enable two streams of 9 Mbit/s, the highest rate likely to be encountered in a DVB program.

Keyword list

SMASH, Multimedia, Video, Hard Disk Drive, Linear Tape Drive, Storage

Contents

Chapter 1

1 Introduction

A SMASH Combo system contains a hard disk (HD) and a linear tape drive (LTD), and attempts to utilise their good qualities (the disks fast access and high throughput, and the tapes vast storage capacity) whilst concealing their weaknesses (mainly the tapes slow access). The most demanding within the SMASH project, in terms of tape performance, is the DVB-VCR (Digital Video Broadcasting Video Cassette Recorder) application, which requires high data rates for recording and playback of digital video signals.

The most appealing and demanding technical feature of the DVB Combo is its ability to simultaneously record and play back two -different- video streams. While recording on one channel, the user can watch another program that was already on tape. Figure 1 schematically explains how it works:

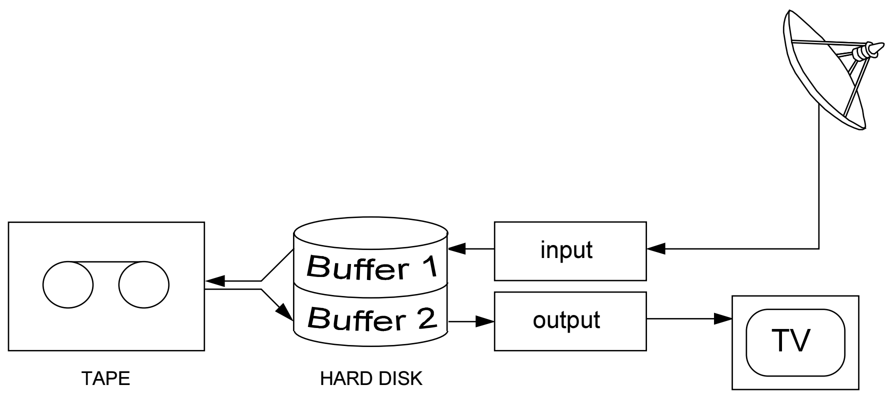

figure 1: simultaneous recording and playback in a DVB Combo

Although the tape drive may have sufficient throughput to sustain two video streams, it cannot actually be in two tape positions at the same time, not even within a few seconds. To serve two video streams (playing back or recording) we must therefore time-multiplex the two, copying large blocks of data alternating between the two tasks. The size of the blocks will need to be hundreds of Mbytes. Buffering in solid state memory is therefore out of the question, and that is where the hard disk comes in. In the example of figure 1 video data is received, e.g. from satellite, and temporarily stored on the hard disk. When a sufficient amount of data is gathered on the hard disk, it is copied to an appropriate location on the tape. In the mean time, data can be copied from the tape to another part of the hard disk to be used for playback. The tape drive has sufficient throughput to build up a large buffer on the hard disk, then complete its other tasks and subsequently replenish the first buffer in time to prevent its exhaustion.

Of course, whether the system can really pull off this ‘tour de force’ depends on the performance of the components, in particular the hard disk and the tape drive, which will be separately treated in the next chapters. It turns out that the hard disk will generally not be the bottleneck, quite common hard disk drives perform well enough to comply. Commercially available tape drives, on the other hand, are still somewhat too slow in terms of data throughput rates and access times for this application.

1.1 DVB boundary conditions

The boundary conditions for the DVB Combo are mainly determined by the data rates encountered in DVB transmissions containing the MPEG-2 encoded digital video signals. The entire DVB stream is 38 Mbit/s, but this bandwidth is shared by several programs. Although high data rates up to 20 Mbit/s are formally allowed, in practice a single program will generally be allotted only about 6 Mbit/s, with a maximum of perhaps 9 Mbit/s. The same maximum rate of 9 Mbit/s was assumed for DVD.

With a single program data rate of 6 Mbit/s, a tape and hard disk throughput of 12 Mbit/s would seem to be sufficient, but that will turn out to be a rather optimistic estimate!

1.2 The experimental DVB-VCR Combo set-up

The DVB-VCR application mentioned above has already been implemented to a large extent and is performing quite well. Figure 2 shows the set-up used, consisting of a PC with additional hardware. The PC is a Pentium 100 running the Linux operating system, chosen for its excellent multi-user and multi-tasking capabilities. The Tandberg MLR1 tape drive and the hard disk are both equipped with a SCSI-2 interface, and are controlled via an Adaptec host adapter. The MPEG-2 decoders and DVB receivers are actually part of professional settop boxes, and custom made PCI cards are used to interface to them.

In this set-up we can achieve simultaneous recording and playback as described above, provided the program data rates are not higher than 5 Mbit/s, for reasons that will be explained in chapter 3. When the performance of the tape drive is increased in future releases, this set-up is capable of supplying the full DVB-VCR application.

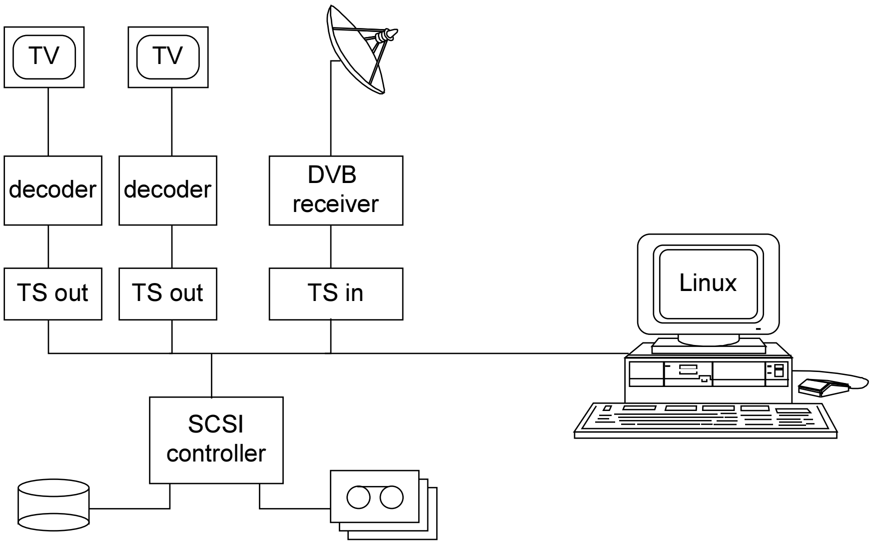

figure 2: experimental DVB-VCR set-up

Chapter 2

2 Hard disk requirements

As can be seen in figure 1, the Combo's hard disk will be attending *three* data streams: the satellite data coming in, the playback data going out, and the data being copied between tape and disk at an increased rate. To estimate the applicability of a hard disk we will use four parameters:

R_0	:	maximum continuous read-write data rate
τ_a	:	access time to an arbitrary location on disk
S_d	:	the disks total storage capacity
S_b	:	size of the data blocks copied

2.1 Storage capacity

A typical disk capacity of 1 GByte corresponds to 23 minutes of video at 6 Mbit/s. This would seem to afford sufficient buffer space to bridge the tape access time of typically two minutes, and detailed calculations show that it does. So, in terms of storage capacity, just about any common hard disk will do in the DVB-VCR application. Now what about data throughput?

2.2 Throughput and access time

The maximum throughput of an ordinary hard disk is around 4 MBytes/s (or 32 Mbit/s), on the face of it quite sufficient for handling two 6 Mbit/s video streams. However, the access time of a hard disk, though infinitely shorter than that of a tape drive, cannot be ignored. Because we will copy data to and from separate buffer locations on the hard disk alternatingly, we will spend quite some time relocating the disks head. This will reduce the effective throughput R_{eff} with respect to the disks continuous bandwidth R_0. The solution, of course, is to copy large rather than small amounts of data at a time, thus reducing the relative amount of time spent on seeking. A simple calculation shows that copying blocks of size S_d while requiring a seek time of τ_a for each block reduces the effective throughput to

$$R_{eff} = R_0 \left(\frac{1}{1 + R_0 \tau_a / S_b} \right) \qquad (1)$$

As expected, the effective throughput drops when the access time is of the order of the time needed to read or write a single block. A typical hard disk will have an average access time of 10 ms, with a worst case value of about 20 ms for a relocation of the head from the inner to the outer cylinders.

Figure 3 shows the effective data rate obtained with standard hard disk parameters as a function of the block size used. Even with a simple 4 MByte/s hard disk, sufficient data rates can be obtained provided the block size is around 64 kBytes or larger. Note that today's high-performance hard disks achieve throughputs of well above 10 MByte/s. Considering the fast rate of performance increase in the hard disk market, this will probably be quite standard in a few years time.

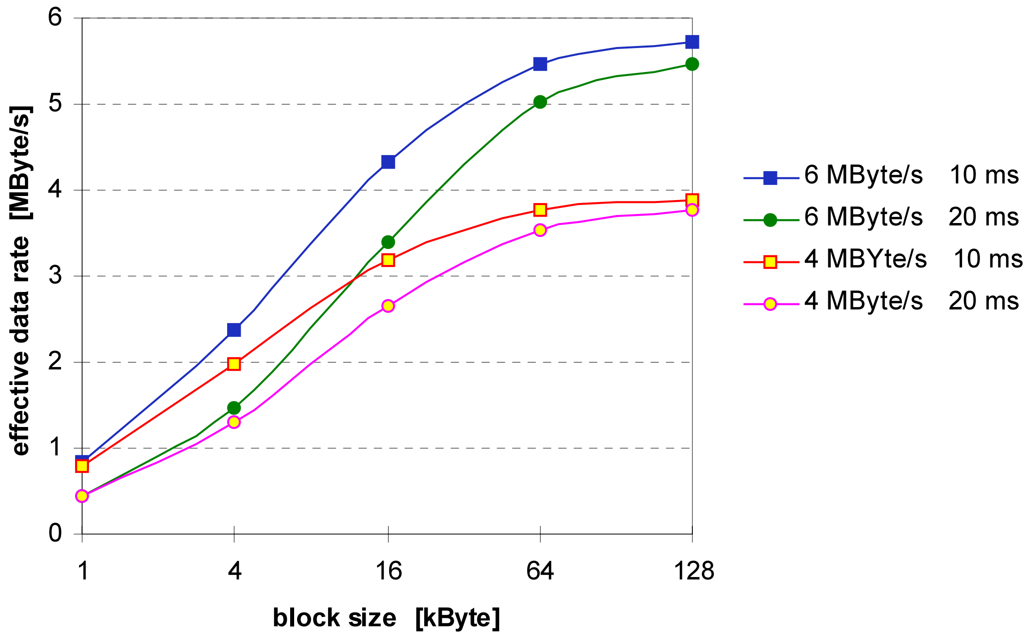

figure 3: effective hard disk data rate depending on block size, continuous read/write data rate and access time (1 seek per block).

On the basis of the arguments mentioned above, it seems safe to conclude that the hard disk need not be a performance bottleneck in a DVB-VCR Combo, because it only needs to meet the following specifications:

Hard disk drive requirements:

R_0	$>$	5 MByte/s
τ_a	$<$	20 ms
S_d	$>$	1 GByte

Chapter 3

3 Tape drive requirements

To assess the behaviour of a linear tape drive in a DVB-VCR we will again use three parameters, analogous to the hard disk modelling in the previous chapter:

R_0	:	continuous read-write data rate
τ_o	:	time overhead for reading/writing an arbitrary partition
S_t	:	the tapes total storage capacity
S_p	:	the size of a tape partition

Because the tape drive is going to be the bottleneck in our system, we will look at several aspects of its performance in more detail.

3.1 Storage capacity

The Tandberg MLR1 tape provides a storage capacity of 13 GByte, corresponding to 5 hours of video at 6 Mbit/s. The new MLR3 may be expected to feature a doubled storage capacity, thus offering 10 hours of high-quality video on a single tape, which is excellent when compared to the present VHS recorders.

Other tape recording systems, particularly those using helical scan recording may be expected in the near future to achieve tape capacities of 100 GByte. As can be seen in figure 4 below, this corresponds to several tens of hours of video. Combine this with a tape jukebox which, when produced in sufficiently large numbers, need not be expensive at all, and a consumer Combo can have a storage capacity of several hundreds of hours, opening the way to quite a new approach to video recording.

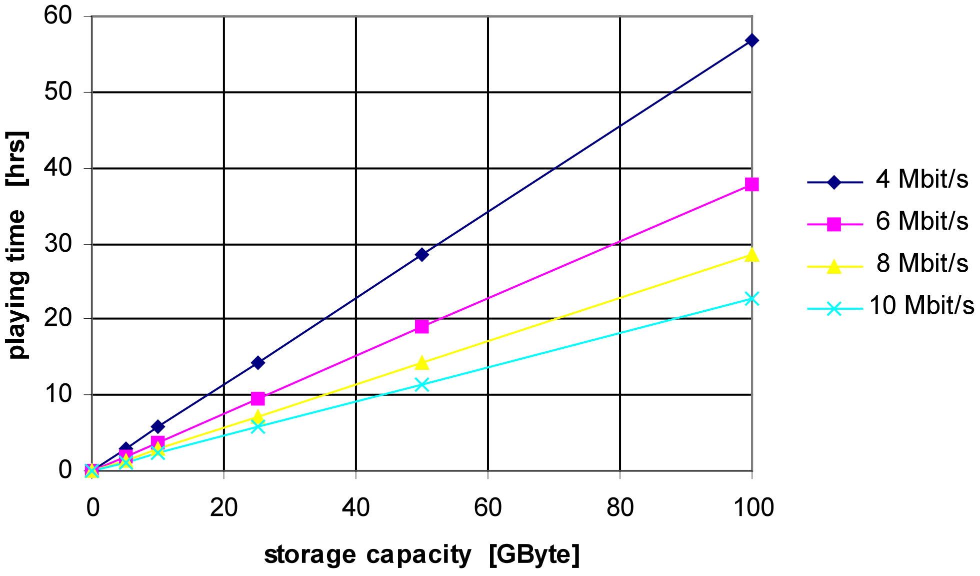

figure 4: playing time depending on tape capacity and video data rate

3.2 Tape partitioning in the Tandberg MLR1 tape drive

An MLR1 tape contains of a number of parallel track sets along the length of the tape, where the odd and even track sets are read in opposite directions. This is referred to as serpentine recording. As shown in figure 5, one odd and one even track set can be combined into a single partition, resulting in a tape divided into 36 partitions.

figure 5: MLR1 tape partitioning

The advantage of such a partitioning scheme is that the beginning of all partitions is at the beginning of tape (BOT). This means that from BOT access to all partitions can be achieved in a matter of seconds (the vertical movement of the head is quite fast), rather than the two minutes needed to wind the entire length of tape. With this particular tape layout it is therefore advantageous to divide the video data of a program over several partitions, always copying entire partitions from and to the hard disk. In this way the access time required to read a single partition, including some overhead for turn-around at the end of the track and one or two read retries, can be as low as 15 seconds. At the end of a partition, the tape is automatically at the beginning of any other partition.

The size of the partitions on a 13 GByte tape equals 360 MByte, which represents 8 minutes of playing time at 6 Mbit/s, an acceptable elementary unit. Remember that a video program will always occupy an integer number of partitions on tape, and if a partition is used only partly by a program, the rest of the partition cannot be use anymore. A consumer would be disappointed if a 5 minute recording would occupy 60 minutes of playing time on tape, but 8 minutes would be acceptable.

The disadvantage of the serpentine partitioning scheme is the long delay that can occur before a new process may begin. If the tape is busy copying a partition, a new process cannot commence before this copying in completed. In the case of the MLR1, this may take up to 4 minutes (see the specifications in Appendix A). If the MLR1's successors increase their capacity by using more tape, this 4 minutes delay will be further increased to perhaps unacceptably long periods. In order to reduce this delay, the partitioning scheme could be easily altered to gain a factor two, as is sketched in figure 6, by letting all partitions begin in the middle of the tape rather than at the beginning. Note, however, that too small partitions will reduce the effective data rate, as is explained in the next section.

3.3 Throughput and access time

Analogous to the hard disk performance described in the previous chapter, the tape drives effective data rate too is reduced by the access time overhead. We arrive at an expression almost identical to equation (1) describing the effective data rate in terms of continuous throughput, partition size and access time overhead:

$$R_{eff} = R_0\left(\frac{1}{1+R_0\tau_o / S_p}\right) \qquad (2)$$

assuming a time overhead τ_o per partition of size S_p.

Figure 7 shows how the effective throughput drops when the size of the partitions is small. In the case of the MLR1, the data rate is 12 Mbit/s and the size of the partitions is 360 MByte, resulting in an effective maximum throughput of about 11 Mbit/s, which is not quite enough to sustain two 6 Mbit/s video streams. A data rate of 14 Mbit/s would be sufficient - but only just! The MLR1 can sustain two 5 Mbit/s streams, which can still be useful for some transmissions.

In order to sustain two streams of 9 Mbit/s, an effective data rate of 18 Mbit/s must be achieved, which means that a continuous data rate of 20 Mbit/s (2.5 MByte/s) is required, assuming 360 MByte partitions.

When a DVB-VCR Combo is equipped with a tape jukebox, the access to a partition on another tape may be quite a bit slower than to a partition on the same tape. The 15 s time overhead used in figure 7 may then be increased to perhaps even 60 s, with quite dramatic results.

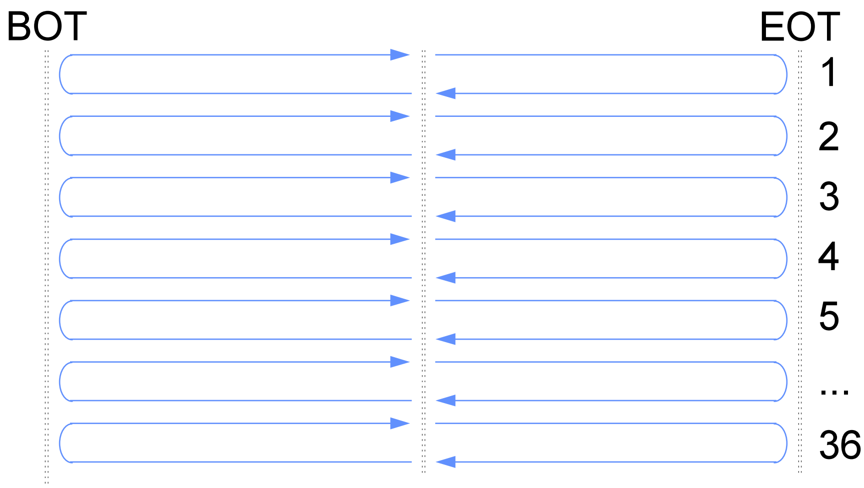

figure 6: Option for improved tape partitioning

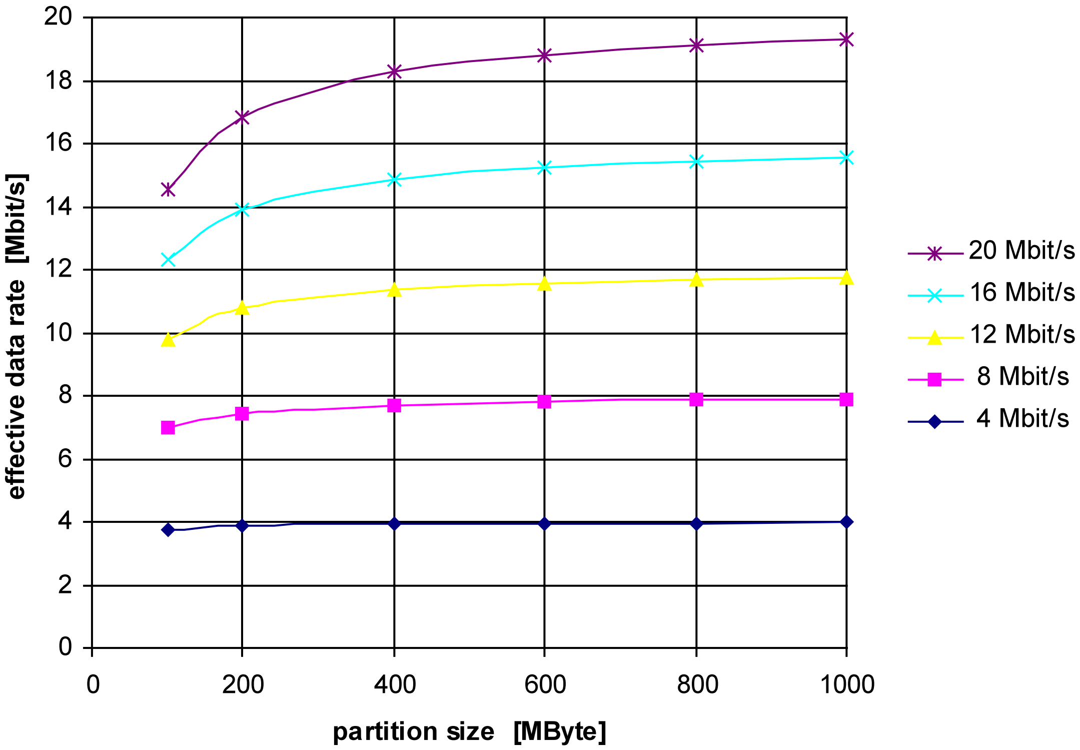

figure 7: effective tape drive data rate depending on partition size and read/write data rate; a time overhead τ_o = 15 s per partition was assumed.

In summary, we can conclude that a future tape drive should meet at least the following specifications in order to satisfy the needs of the DVB-VCR application:

Tape drive drive requirements:

R_0	$>$	14 Mbit/s (rather: 20 Mbit/s)
τ_o	$<$	20 s
S_t	$>$	10 GByte
S_p	$>$	350 MByte

3.4 Tape noise

A last issue, though not a technical performance bottleneck, is the amount of noise produced by tape drives. Although not disturbing in a PC environment, noise is very annoying in a VCR. Consumers are used to extremely quiet VHS recorders, and the racket produced by computer peripherals would be quite unacceptable. Since noise reduction has never been much of an issue in PC peripherals, one might expect that there is ample room for improvement.

Chapter 4

4 Conclusions

The arguments presented in the previous chapters show that, in terms of throughput, the tape drive is the performance bottleneck in a DVB-VCR, which is the most demanding application presently under study in the SMASH project.

Any common hard disk will suffice in this application, provided that data is copied in blocks of 64 kByte or more, in order to prevent excessive time waste on seeking the data, which would result in an undesirable loss of effective throughput. The requirements, listed below, are easily met by today's hard disks.

Hard disk drive requirements:

R_0	>	5 MByte/s
τ_a	<	20 ms
S_d	>	1 GByte

In the tape drive reduction of the effective data rate by time lost on accessing the data plays an important role. Even though the serpentine partitioning scheme used in the Tandberg MLR1 reduces the access time overhead to a mere 15 seconds per partition, the effective data rate of the MLR1 is not quite sufficient to sustain two DVB video streams of the average 6 Mbit/s, let alone the likely maximum of 9 Mbit/s. In order to achieve the latter, the tape drives data rate should be increased to 20 Mbit/s, or 2.5 MByte/s. If a tape changer is to be used, special precautions must be taken to avoid a further reduction of the effective data rate. The requirements are listed below:

Tape drive requirements:

R_0 > 14 Mbit/s (rather: 20 Mbit/s)

τ_o < 20 s

S_t > 10 GByte

S_p > 350 MByte

Appendix A

A Tandberg MLR1 specifications

The tape drive used in the SMASH project is the MLR1, Tandberg latest show piece which stores 13 Gbyte of data on a Quarter Inch Cartridge (QIC). The drives main features are listed below.

Capacity	:	13 Gbyte native
Read/Write Rate	:	1.5 Mbyte/s
Interface	:	SCSI-2 (18 Mbyte/s)
Tape Speed	:	120 ips (read/write/wind/rewind)
Tape Length	:	1200 feet
Recording Format	:	QIC-13 GB (144 tracks 50,800 frpi 67,700 bpi)
Partitions	:	max. 36 partitions (361 MByte)
Data Buffer	:	1 Mbyte (4 Mbyte optional)