

## A COMPARISON OF ROTARY- AND STATIONARY-HEAD VIDEO TAPE RECORDERS

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**Summary** - In magnetic tape recording, two approaches have emerged in which essentially the same medium is tracked in two different ways: rotary- and stationary-head recorders. Both approaches are commonly employed in digital audio and data recording, but since the introduction of the first analog video recorders in the early 50s, rotary-head recorders (either helical or transverse scan) have held undivided sway in the video domain. The advent of various new enabling techniques such as (MPEG) source coding and multi-track heads may affect the hegemony of the rotary-head machine. The article will appraise both types of transport in an attempt to establish which approach might be considered for a given application.

### I Introduction

In video recorders, both analog and digital, rotating heads are used against a slowly moving tape to realize the high tape/head speed necessary to record and reproduce images. State-of-the-art stationary-head recorders have relative to rotary-head recorders a much lower maximum bit rate and lower information capacity. As a result, the application of stationary-head recorders has been confined to data or audio recording. However, two recent developments allow stationary-head recording to be used for digital video. Firstly, source coding has drastically reduced the bit-rate necessary for high-quality video recording. Secondly, thin-film technology has made integrated multiple heads of high quality possible. In the Digital Compact Cassette (DCC) recorder system [1], [2], a 9-track head is used for storing and retrieving digital sound. Extending the DCC head technology to a higher bit rate and information density is clearly within practical reach. The key question is now whether a stationary-head video recorder will provide more customer satisfaction than the conventional accomplished rotary-head recorder.

The way the tape is scanned, linear versus helical, has a different effect on various essential recorder features. In analog video recording, the signal is written on a helical track in such a way that one complete TV frame fits exactly onto the part of the tape wound around the rotating head wheel. By its very nature, this format has the advantage of such special-effect capabilities as slow-speed, still, and high-speed search modes. These special

features can only be accomplished so easily because a full picture or field is stored on a single track. There are, as a result, major challenges of implementing trick play on a compressed-video (MPEG) rotary-head VTR having the same performance as the one possible in conventional analog VTRs. The ideas presented in [3], [4], [5], [6] for solving these difficulties require 10-20% extra area on the tape and are also inflexible with regard to fast playback speeds.

In this article, we will appraise system aspects of both rotary- and stationary-head digital video tape recorders. We start with relevant recording basics followed by a discussion of the various tape formats, where particular attention will be paid to variable data rate recording and feature mode playback of source coded video signals. In the final section, we will show the characteristics of a stationary-head recorder, called *video streamer*, whose attributes will make it almost ideally suited for recording and replaying source coded video signals.

### II Tape recording basics

As track widths of the order of 10-20  $\mu\text{m}$  are in tape use today, clearly a single track on a tape would be a waste of recording area. There are two alternatives for solving this matter in a stationary-head recorder. We can use a multi-track head that spans the entire width of the tape with a significant number of parallel tracks across the tape and the bit stream will be divided between them. An estimate of the number of tracks is easily found: for a track width of say 10  $\mu\text{m}$  and a tape width of 8 mm, we find 800 tracks. The feasibility of such a recorder was demonstrated by Colineau and Lehureau [7].

As an alternative, only a part of the tape width is scanned by a head stack in a serpentine fashion (see Figure 1). In the time required to reverse the direction of the tape speed, information is taken from an electronic buffer memory. For a typical reversal time of say 100 msec and an average bit rate of, say, 4 Mbit/sec we need an electronic data buffer of approximately 0.4 Mbit, which is a feasible option. It is possible to use interleaved head stacks in which only one in  $N$  tape tracks is furnished with a magnetic circuit. Depending on the bit rate required, the transport may have  $N$  head stacks or may transport the tape  $N$  times through the machine in a ser-

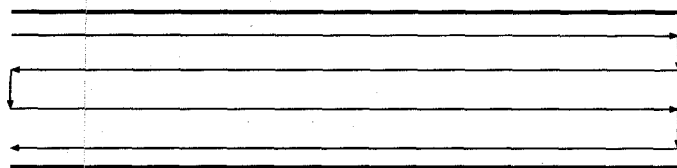


Figure 1: Principle of serpentine recording.

pentine fashion. High-density machines will need servo systems to actively follow the tracks. Prerecorded tapes with servo information will be required.

In a high-density rotary-head recorder, the head/tape interface is complex and delicate. The revolving scanner builds up an air film and the film thickness stabilizes when the tape tension balances the air pressure. This is one reason why tape tension is critical in rotary head recorders. As a result of the air film the scanner itself does not touch the tape and friction around it is very low. The head pole must project out of the scanner by a distance equal to the film thickness plus an amount needed to deform the tape to give the required contact pressure. The conditions are in a region midway between the firm contact of a slow speed stationary head tape and the non-contact system of a hard disk.

One significant difference between rotary and stationary recording is that the rotary-head recorder is usually equipped with *azimuth recording*. The azimuth effect reduces crosstalk between adjacent tracks, and it therefore allows the replay of tracks without the need of guardbands between adjacent tracks. Consequently, redundancy of the tape area is minimized.

### III Trick mode

Besides an excellent picture quality at normal speed, a key requirement of a video recorder is the ability to play video sequences at variable speeds in both the forward and reverse direction. The different transport designs react differently to the requirement to operate at variable speed, and we will examine, in this section, trick mode for both the linear and rotary head recorder.

In a stationary-head recorder, the data rate from the heads is directly proportional to the tape speed. If a variable bit rate is required, then changing the tape speed will require a corresponding change in electronic filter in any record or read channel. In machines where analog detection and clock recovery circuitry is used this becomes very complex. If, however, all the required signal processing is done in the digital domain, the adaptation to the varying scanning speed is very easily accomplished by "locking" the sampling rate of the analog-to-digital converter and the clock of the digital reproduce filter to

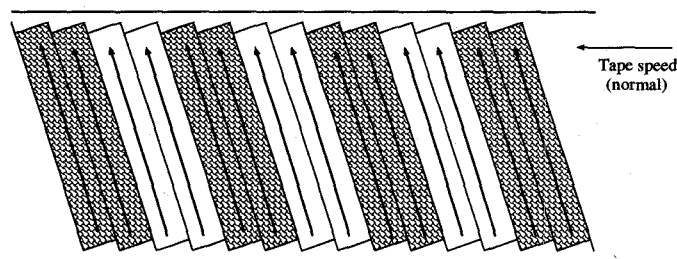


Figure 2: Footprint of rotary-head recorder at nominal speed.

the servo loop controlling the tape speed. At high speeds, the frequencies seen by the heads and electronics may become very large. Although a speed increase by a factor of ten is perfectly feasible, high speeds (100x - 200x) are not easily implemented. Of course, there is no limitation to a reduction of the speed. In both fast and slow speed mode, the MPEG decoder, whose output is fixed at the relevant (analog) video format, must skip or repeat video frames in order to keep in pace with the variable input bit rate.

The serpentine recording format, see Figure 1, offers the attractive feature of *jump* search access. By moving the read head transversally an even number of tracks we arrive at a track that can be read in the same direction. As a result, we skip large amounts of data. For the parameters listed in Table 3 jump search access can be accomplished in steps of 3 minutes playing time.

Rotary-head recorders are not capable of operating over a wide range of transfer rates. This is because the transport aerodynamics must be optimized for one speed. Changing the transfer rate requires the scanner and capstan to change speed by the same amount and this results in a significant change to the pumping effect of the scanner, with consequent changes to the air film thickness and tip penetration. An increase of bit rate in a rotary-head system is therefore only possible by increasing the speed of the tape. Then, however, it is difficult to retrieve a useful image because of data loss in the fast forward/fast reverse playback of compressed video signals. On the other hand the requirement in a digital video recorder is only that a 'recognizable' picture shall be available at non-standard speeds, and so a great deal of data can be lost. This process is explained in Figures 2, 3, and 4. Figure 2 shows the process of reading at nominal speed. Video recorders fitted with deflecting heads are capable of following entire tracks over a range of speeds typically from -1 to +3. Figure 3 shows the effects of increasing the tape speed by a factor of two while the scanner speed is not changed in proportion. An advantage of helical scan is that the head to tape speed is much greater than the scanner speed. The result is that the replay electronics

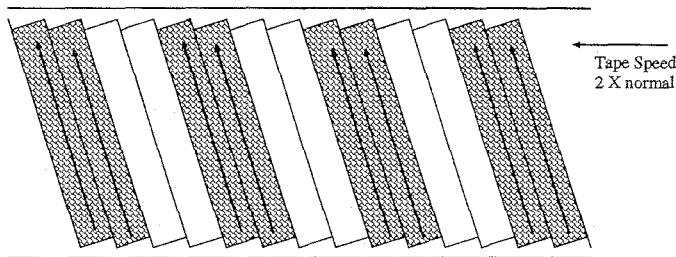


Figure 3: Fast play at 2x normal speed

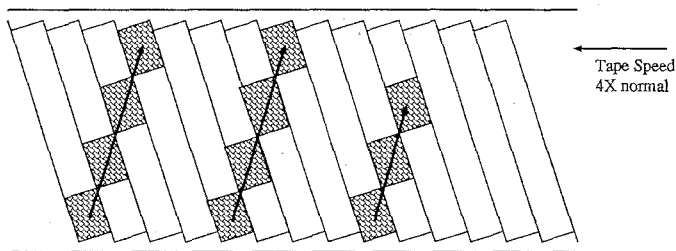


Figure 4: Footprint of rotary-head recorder in shuttle mode.

will see constant frequencies and electronic filters such as data equalizers operate almost normally. At very high speeds or if the recorder is not equipped with deflecting heads, the tracks will be crossed as shown in Figure 4. Despite that, it is possible to recover around 40% of data as heads cross tracks at a grazing angle. Provided the track crossing angle is sufficiently shallow, sync blocks on the track can be recovered and if they are uniquely addressed the data can be used to update a frame store. If MPEG video-compression is used there is no longer a simple correspondence between tracks and fields as in the conventional analog recorder. When trick play is performed, see Figures 3 and 4, the readable data could be from any section of any frame. The resultant image is likely to be very poor. The above will make it clear that it is not trivial to implement trick play on a compressed-video rotary-head VTR having the same performance as the one possible in conventional analog VTRs. The proposals [3], [4], [5], [6] made to meet these challenges require 10-20% extra area on the tape and are also inflexible with regard to fast playback speeds. Essentially, in this format the extra area on the tape is used to record an abstract of the video movie. By judiciously positioning the abstract data on the tracks, it can be accessed at high reading speeds in shuttle mode.

#### IV Variable data speed

The amount of data needed to represent a digital compressed MPEG video signal is essentially of variable size. Different scenes carry different amounts of information.

If, as in a Procrustean bed, the data is compressed into a fixed data size, we lose either too much bandwidth or the picture quality will be too low. Detailed studies [8] [9] have revealed that the storage capacity required for variable bit rate codecs is approximately 20-30% lower than required for a fixed bit rate codec. In this context, it is appropriate to mention that it is not unlikely that we may anticipate a proliferation of MPEG bit rates trading playing time and picture quality.

Analog VCRs are capable of recording at different levels of quality for different lengths of time. It is obvious that it is desirable for digital VCRs to have the same capability. A rotary-head recorder cannot easily accommodate this requirement of recording at variable rate without making special arrangements. In [10], methods have been presented for recording at reduced data rates by switching off the heads in specific sequences. If two heads are used that are distributed uniformly around the head wheel then head switching strategies allow reduced data rates of  $1/n$ , where  $n$  is a positive odd integer. With  $H$  heads positioned on one side of the head wheel, it is possible to write and read at data rates of  $2m/pH$  times the normal data rate, where  $m$  is a positive integer between 1 and  $H/2$  and  $p$  is a positive integer. With, for example,  $H = 6$  heads, we can record at factors  $1/9$ ,  $1/6$ ,  $2/9$ ,  $1/4$ ,  $1/3$ ,  $1/2$ ,  $2/3$ , etc times normal speed.

#### V The video streamer

It is of interest to study state-of-the-art recorder systems and to find out which parameters have to be altered to turn it into a digital video recorder. In order to make it possible to compare the linear and helical scan recorder systems we have listed their basic attributes in Table 1. Table 2 shows the main parameters of a state-of-the-art multi-track audio recorder [1] while Table 3 shows the parameters of a future multi-track recorder.

If technology allows we can upgrade some of the parameters of this recorder. The results are shown in Figure 3. The primary differences are that the video streamer uses 6.35 mm (1/4 inch) wide tape and the track width is reduced from 200  $\mu\text{m}$  to 50  $\mu\text{m}$ . The result is a recorder which is capable of storing 7.2 Gbytes of information on a 228 m (750 feet) long tape. Typically, this is room for 3 1/2 hours of wide-screen (16:9 aspect ratio) video at MPEG-2 quality accompanied by multiple audio and subtitle channels with a variable speed data transfer at an average rate of 4.69 Mbit/sec. The capacity of the DVD (single sided) [11] is "only" 4.7 Gbyte, and has therefore a playing time of at most 2 1.2 hours.

Table 1: A comparison of properties of linear and helical scan recorders.

	Helical	Linear
Multi-speed recording	yes	yes
Multi-speed reading	yes, less flexible	yes
<i>Trick mode</i>		
Fast visual search	?	yes
Jump search	no	yes
Stop/slow motion	frame store	frame store
<i>Drive</i>		
Estimated cost	1 X	0.5-0.75 X
Complexity	moderate-high	low
<i>Cartridge</i>		
Areal density (bit/ $\mu\text{m}^2$ )	0.3-0.6	0.03-0.06
Tape path	external	external
<i>Duplication</i>		
Mass reproduction	real-time	multi-head

Table 2: Main parameters of the state-of-the-art multi-track recorder.

tape speed	4.76 cm/sec (fixed)
tape width	3.78 mm
number of channels	8 + 1 aux.
channel bit rate/track	96 kbit/sec
user bit rate	0.38 Mbit/s
track width (write)	185 $\mu\text{m}$
track width (read)	70 $\mu\text{m}$ .
tape length	171 m (1 hour playing time)
capacity	0.17 Gbytes

Table 3: Main parameters of the video streamer.

tape speed	15 - 150 cm/sec (variable)
tape width	6.35 mm (1/4 inch)
number of channels	8
channel bit rate/track	0.4 - 4 Mbit/sec
user bit rate	1.6 - 16 Mbit/s
track width (write)	50 $\mu\text{m}$
track width (read)	40 $\mu\text{m}$ .
tape length	228 m (750 feet)
capacity	7.2 Gbytes

## VI Conclusions

It has been shown that infusion of two enabling technologies allows recorders with stationary heads to be used for the recording of digital video signals. Firstly, source coding has drastically reduced the bit-rate necessary for high-quality video recording. Secondly, thin-film technology has made integrated multiple magneto-resistive (MR) heads of high quality possible. It has been shown that bit rates can easily be varied in stationary-head recorders, while rotary-head recorders are not capable of operating over a wide range of speeds without losing data. Efficient video source coding schemes have by necessity a variable bit rate, and are thus naturally complemented by stationary-head recorders.

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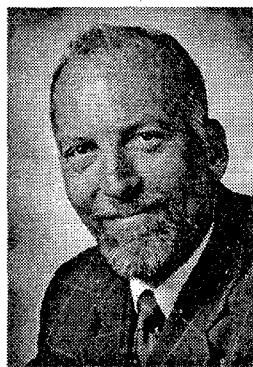
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## Biographies



**Kees A. Schouhamer Immink** received the M.S. and Ph.D degrees from the Eindhoven University of Technology. He joined the Philips' Research Laboratories, Eindhoven, in 1968, where he currently holds the position of Research Fellow. He has contributed to the design and development of a wide variety of digital consumer-type audio and video recorders such as the Compact Disc, Compact Disc Video, R-DAT, DCC, and DVD. Immink holds 30 US patents and has written numerous papers in the field of coding techniques for optical and magnetic recorders. He is the chairman of the IEEE Benelux Chapter on Consumer Electronics, a governor of the Audio Engineering Society (AES) and the IEEE Information Theory Society. He was named a Fellow of the AES, IEE, and IEEE; furthermore he received the AES Silver Medal in 1992, the IEE Sir J.J. Thomson Medal in 1993, the SMPTE Poniatoff Gold Medal for Technical Excellence in 1994, and the IEEE Masaru Ibuka Consumer Electronics Award in 1996.

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