Digital Video Recording in the 625-Line System

By HUBERT FOERSTER
and JOSEF SOCHOR

Multiple generation copies of videotape recordings are, even today, still subject to considerable reductions in quality. At the present time, it is difficult to foresee any progress being made in the tape, head, and amplifier fields which will bring about any noticeable improvement, as long as the analog FM recording method is retained. On the other hand, recording with digitized video signals would bring definite improvements without incurring any basic disadvantages such as increased tape consumption. The quality of copies (generations) would, with the exception of dropouts, no longer be influenced by the machine. At the moment, tape recorders with rotating head arrangements offer the highest storage density by far and, for this reason, are particularly suitable for digital video recording. Wavelengths of approximately 1 μm, using a corresponding code of 2 bits/μm, can be read with certainty. A track width of 40 μm yields a S/N ratio better than 26 dB and a corresponding BER (bit error rate) of about 10 ^{6}. Including safety margins, a recording density of 3 Mbit/cm^2 can be achieved. Assuming that a future European digital video system will use a data rate of approximately 160 Mbit/s, a transport velocity of about 24 cm/s is required when 1-in tape is employed. A tape speed close to 24 cm/s is customary for the present generation of helical-scan machines in the 625-line system, recording analog signals.

In recent times there have been intense efforts in the field of digital video recording because the development of this field has brought about new requirements concerning the storage of video signals. On the one hand, the present state of development of digital semiconductors offers low-cost technical solutions for the problem of digital picture storage; on the other hand, the quality of the broadcast video signal is affected by the copying procedures in the TV studio. At best, the third-generation copy is used; it is, however, not unusual for a much greater number of copies to be produced during electronic editing.

Table I shows, for a quad-format machine, the most important measuring values and their degradation up to the sixth-generation copy. The sixth-generation copy shows significant interference factors which lead to a considerable loss in picture quality. The most critical factor affecting the quality of a multi-generation copy is the color noise.

In short, we can say that the quality of a sixth-generation copy is not satisfactory but must be tolerated since, at present, there are no methods known to improve it. The traditional recording formats have reached their limits and the narrow-band modulation plays an important role in this development. Here, the recording of digitized television signals could offer a true alternative because it is possible, by regeneration of the playback signal, to prevent error propagation due to copying.

Digital video recorders differ from data recorders in two essential points. First, the video signal to be recorded has a high degree of redundancy, which, as in analog recording, can be utilized for error concealment. As we know from the analog recording technique the procedure of dropout compensation causes practically no restriction as to the number of usable copies. This also applies to the digital recording technique. In data recording this method is not applicable.

The second difference concerns the recording density. To bear comparison with the traditional analog video recorders, the tape consumption of a digital recorder should be approximately 24 cm/s when a 1-in tape is used. This, of course, results in a recording density considerably higher than the normal recording density of today's data recorders.

There are different data-reduction techniques available to reduce the bit rate of the digital video signal. The use of redundancy-reducing methods (differential PCM, for example) is not advisable, because this would, on one hand, limit the possibility of dropout replacement by the information of the adjacent picture element (error concealment) and, on the other hand, it would require effective methods to prevent error propagation in case of a dropout. The recording system presented by Bosch uses the sub-Nyquist sampling method with 2 × f_{sc} sampling rate. With this method, the possibility of error concealment is fully maintained, and the picture quality is not significantly affected when certain conditions are fulfilled. By using this method we were able to demonstrate—by the reduced volume of the recorder electronics compared to an analog VTR—that a digital videotape recorder is not necessarily more complicated or expensive than an analog machine.

At this point, however, we would like to emphasize that the method of sub-Nyquist sampling is only one of the possible solutions considered by us for use in digital recording systems. Future methods of video signal processing in TV studios that are presently under discussion include different sampling methods, such as component encoding, at a bit rate of approximately 160 Mbit/s.

Without discussing in detail the problem of source encoding, we want to demonstrate that for these formats there are also practicable recording methods available; furthermore, digital video recording, which is discussed as one of the possible

Table I. Degradation of Video Quality as a Result of Copying with a Super High-Band Quadruplex (Analog) 2-in VTR and with a Digital VTR.

Generation	SNR (dB)	Chroma Noise (dB)	Diff. ϕ (deg)	Diff. Gain (%)	K-Factor (%)	Chrom.-to-Lum. Delay (ns)	Moire (dB)
Analog Videotape Recorder							
1st	45	0	4	4	1	30	40
2nd	42	−2	8	8	1	60	40
3rd	40.3	−4	12	12	1	90	40
4th	39	−4.5	16	16	1	120	40
5th	38	−5	20	20	1	150	40
6th	~37	−6	24	24	4	180	>36
Digital Videotape Recorder							
1st	>54	0	2	2	1	10	nonexistent
10th	>54	0	2	2	1	10	nonexistent

None of the figures are influenced by a digital machine. Only dropouts can degrade the quality.

Presented on 2 February 1980 at the Society's 14th Annual Television Conference in Toronto by Hubert Foerster and Josef Sochor (who read the paper), Robert Bosch GmbH, P. O. Box 429, D-6100, Darmstadt, West Germany. This paper was received on 7 January 1980. Copyright © 1981 by the Society of Motion Picture and Television Engineers, Inc. Previously published in unedited form in the SMPTE book *Digital Video, Vol. 3,* 1980.

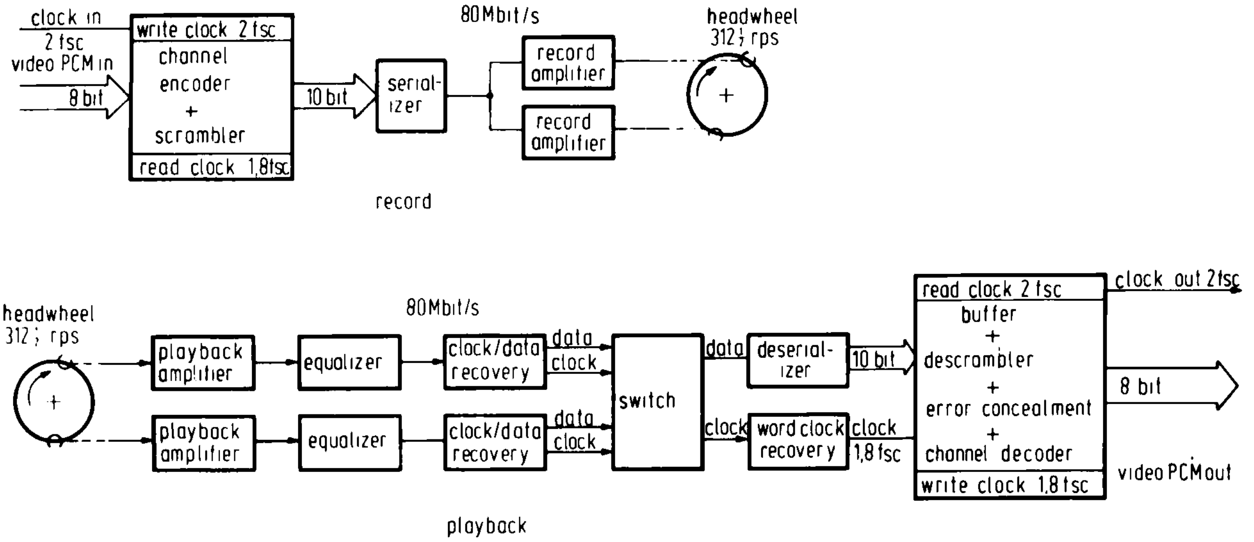

Fig. 1. Record and playback block diagram for digital video recorder with $2f_{sc}$ sampling rate.

source encoding techniques, causes no restrictions whatsoever.

Functional Description of the Digital Recording System

The electronic section of the recorder is designed to meet the following four requirements (Fig. 1):

1. Matching of the transmitted signal to the transmission characteristics of the channel. This includes scrambling, code conversion from source code to recording code, equalization of the recording signal in the recording amplifier, and saturation of the storage medium.

2. Matching of the playback electronics to the characteristics in the channel. This includes low-noise reading and equalization of the playback signal. It should be borne in mind that it is the processing of the analog signals which represents the main problem we have to deal with in digital video recording. The signal path between the equalizer output is realized by a very complicated analog transmission channel which is characterized by a strong nonlinearity of the storage medium, a bandpass characteristic, and strict requirements concerning group delay distortion. In the high frequency range the bandpass characteristic of the transmission channel is determined by the finite gap width of the playback head and the finite size of the magnetic particles of the tape. At lower frequencies it is determined by the law of magnetic induction and the rotating transducers.

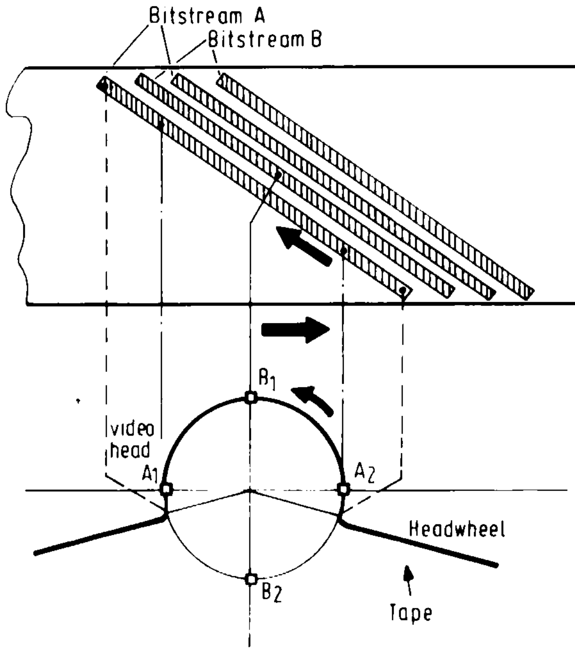

Fig. 2. Four-head scanner assembly with two bit streams.

3. Regeneration of the playback signal and restoration of clock and word synchronization.

4. Error detection, error concealment, and regeneration of the time base.

The Most Important Data of the Video Recorder for $2 \times f_{sc}$ Sampling Rate

The tape deck and scanner of the machine are identical to the BCN standard version except for the preamplifier, which has a greater bandwith, a rotary transformer, and special heads. The rotational speed of the heads is double and the tape transport is half the corresponding values in the analog BCN version. The servos are modified accordingly. The bit rate of the transmitted signal is 80 Mbit/s, and the transmission channel has a bandwidth of 50 MHz. The bit stream is generated by combining the signals from the two heads. Like the analog BCN version, the new machine uses the helical recording technique. The track angle is somewhat different due to the differing speeds; track spacing is four times narrower than in the analog version, that is, 50 μm. This results in 400 tracks per inch over the width of the magnetic tape.

Twenty-five video lines are recorded on each track, one line comprising 512 words of 10 bits each. With a relative head-to-tape speed of 48 m/s and a bit rate of 80 Mbit/s, the linear storage density obtained over one track is 1.67 bits/μm. Considering that the video tracks occupy 83% of the tape area, the storage density comes up to 3.15 Mbit/cm^2 of the tape area. Such a high recording density could be obtained only by reducing the space between the tracks in a 1:4 ratio compared to analog recording.

Future Developments

Our efforts in the development of the digital video recorder were concentrated principally on the solution of the mechanical and electrical problems involved in the recording of signals with a bit rate of approximately 160 Mbit/s at a tape speed of 24 cm/s. The recorder for $2 \times f_{sc}$ sampling rate operates with a 12-cm/s tape speed. To double the bit rate at normal speed a further increase of the relative head/tape speed up to 48 m/s seems to be of little advantage. Furthermore, the data processing in one bit stream exceeding 80 Mbit/s becomes increasingly difficult.

Using the normal tape speed of 24 cm/s, however, offers the possibility of filling the resulting intervals by recording the information of a second equivalent bit stream by means of another pair of heads (Fig. 2). This means that the circuit design need not be changed, but the number of circuit components has to be doubled. With 400 tracks/in, we still have the 100 recorded tracks per recording amplifier, which is a favorable value.

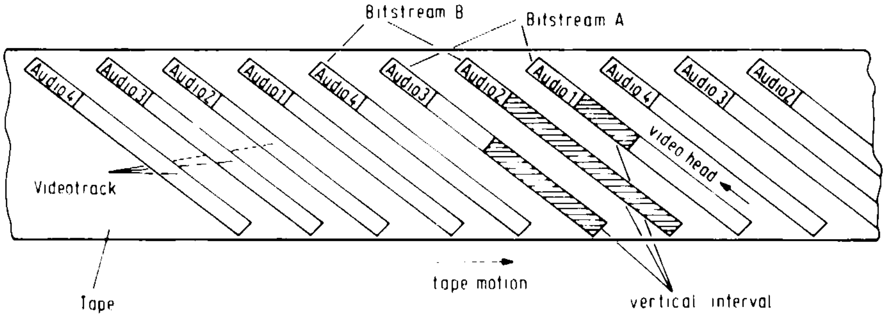

Fig. 3. Position of video and four-channel audio information on the tape.

A specific problem we have to deal with is the recording of digital audio signals together with digital video signals on the same tape. The problem, in this connection, is the requirement of separate processing during electronic editing. There are several approaches being discussed to solve this problem. One of the solutions that we are working on uses the same heads for both video and audio signal recording. The result of this method is a combined video–audio track (Fig. 3). The two track sections have to be separated by a safety interval, the duration of which has to be somewhat longer than the time needed for the determination of the time base (approximately 10 μs). In addition, the erase oscillators and recording amplifiers have to be switched on selectively during the time of the safety interval. To obtain two continuous data streams in the video channel when using this track configuration, overlapping of the two data streams has to be increased by extending the wrap angle of the scanner so that all of the audio information lies within this overlap area. The four digital-audio channels are recorded on the tape with a bit rate of 1.2 Mbit/s each. The track space available on the tape for the recording of these channels is approximately 1.5 mm, that is, about 6% of the tape area. The channel code is 8,10 block code.

THE LIGHTER SIDE OF TV ENGINEERING

The Hazards of Divination

Any attempt to foretell the future is fraught with hazard. One possibility is that the forecaster will incur the laughter of future generations. One example of a *divination* that went wide of the mark is a piece written 56 years ago by a sports writer who is no longer with us. . .

"Science seems to be working out the doom of professional sports. A dispatch from Washington says that Mr. C. Francis Jenkins (first President of the SMPTE) has perfected an apparatus by which persons may see moving objects miles away by radio. Dipping only casually into the future one can see the time coming when thousands of these radio-cinemas, or whatever they want to call them, are dumped upon the market.

"Persons possessing these machines will be able to sit in their homes or offices and watch a World Series or a heavyweight championship fight without having to contribute to the gate receipts. It sounds very ominous for the promoters of professional sports. Professional sports cannot exist without customers, but here is Mr. C. Francis Jenkins sitting in his laboratory calmly working out a scheme for the elimination of customers. Perhaps if he realized just what he was bringing about he would desist. Being a mere scientist he may not realize the apparatus upon which he is working threatens dire disaster.

"Mr. C. Francis Jenkins does not consider the number of sterling athletes who would be thrown out of work when this nefarious instrument is perfected. It means the unemployment of practically all of our professional athletes from Mr. Jack Dempsey and Mr. Babe Ruth down to the preliminary prize fighters and the semi-pro baseball players. The man Jenkins must be without a heart if he really grasps the full possibilities of what he is doing."

W. O. McGeehan in *The New York Herald Tribune*, January 1925