Digital Stereo Sound Recorder

Elimination of timing errors: a step on the way to digital television recording

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Sound and television signal processing is beginning to undergo radical changes with the introduction of digital techniques. Once expressed as a series of binary numbers, the signal resembles those handled by computers, and important advantages associated with computer processing can be realized. For example, provided that digital errors are avoided the original signal quality can be preserved, however complicated the subsequent operations, with a mathematical precision. Moreover, the circuits used are not susceptible to drift and so there is no need for frequent adjustment. These advantages would be particularly valuable in recording, and work is therefore on hand at the B.B.C's Engineering Research Department to investigate the possibilities and potentialities of digital sound and television recording.

To fully describe a high-quality television signal in digital form, one requires an extremely high data rate. If, for example, one samples the signal at a frequency of three times the colour subcarrier frequency and then uses 8 bits to describe each sample, the resulting serial data rate is over 100 megabits per second. The recording of the 200 gigabits of data generated by this method during a half-hour programme presents formidable problems. It seems very likely, however, that a satisfactory solution to these problems will be found and that digital methods will in due course be applied to television recording.

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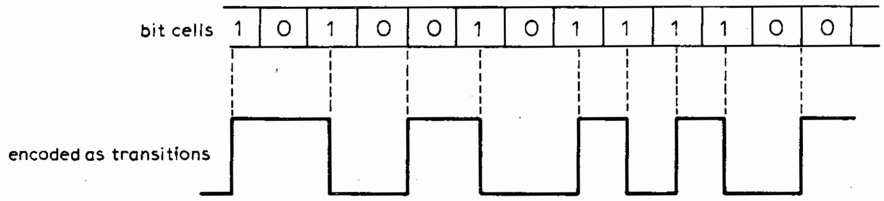


Fig. 2. Typical stream of digital data (top) encoded using "delay modulation" method.

It is as yet too early to say what form the digital television recorder of the future will take. A number of new recording technologies are being developed for the high-speed storage of large quantities of data, and maybe one of these will ultimately be used for television. They employ laser or electron beams directed at a variety of recording media, and offer the prospect of very high packing densities, but most are still at a relatively early stage of development. Meanwhile, multi-track magnetic recorders can cope with the data rate required for digital television, though at present they require a high consumption of medium as compared with high-quality analogue television recorders. Medium consumption is not an overriding factor, however, in a research programme which is devoted to the investigation of basic signal processing techniques. This article describes a digital stereo sound recorder, built as an introductory project, which contains a number of interesting features, notably timing correction, and could have a direct application in future digital television recorders.

The chief parameters of the stereo recorder are:

Tape speed	15in/sec
Tape width	½in
Tape	3M type 951 instrumentation tape
No. of tracks	16 (13 for data, 2 parity, 1 stereo switch)
Audio bandwidth	14.6kHz
R.m.s. signal to r.m.s. weighted noise ratio	72dB
Crosstalk between stereo channels	—45dB (occurs within the analogue input and output circuits)

Fig. 1 is a block diagram of the recorder. The two audio input signals are sampled at 32kHz, the samples being interleaved in the multiplexer to give a 64kHz sample rate at the input to the 13-bit analogue-to-digital converter. The 13 outputs from the a.d.c. are made up to 16 by the inclusion of two parity bits and a channel identification signal. After further processing the signal is recorded on 16 longitudinal tracks on ½-inch tape.

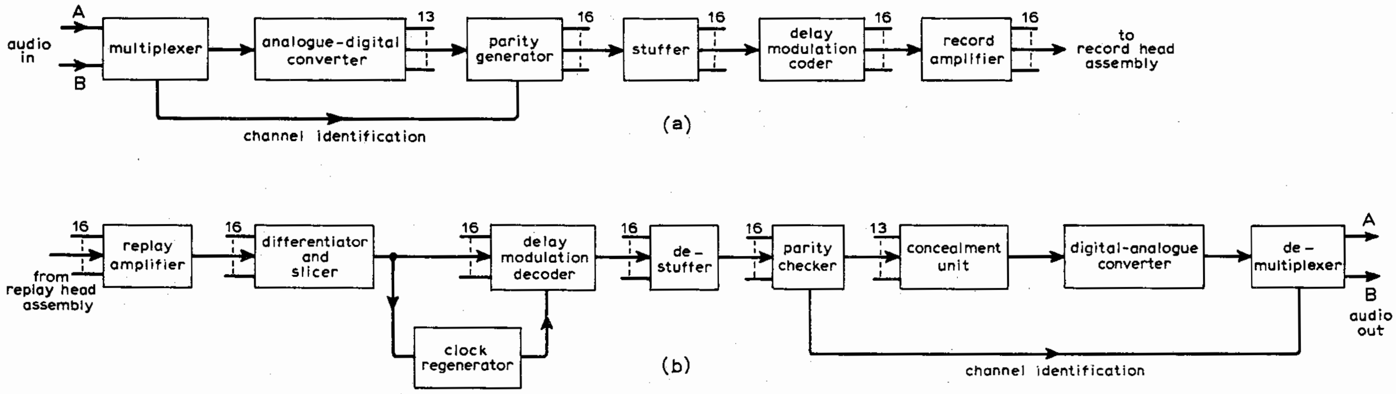


Fig. 1. Block diagram of the recorder: (a) signal processing system for recording, (b) for replay.

Thus the 13 bits corresponding to each sample of the signal are recorded simultaneously, "in parallel" across the tape.

The signal recovered on replay is processed to remove timing errors and after parity checking and error concealment is passed to a digital-to-analogue converter. The interleaved analogue samples emerging from the d.a.c. are then separated and filtered to provide the two output signals.

The recording process

One of the advantages of digital recording is that it is not necessary to linearize the recording process by the use of bias. This leads to a considerable simplification, as there is no need to provide a bias oscillator and the recording amplifier need not be linear. Indeed, all that is necessary is an electronic switch, controlled by the data to be recorded, which changes the direction of a fixed current through the head to magnetize the tape in one direction or the other.

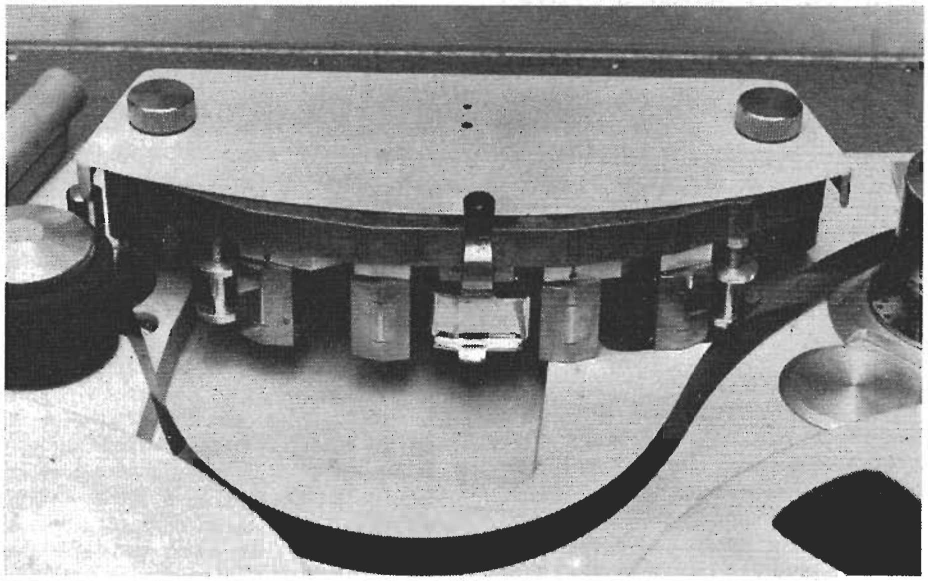
Digital data are commonly represented by two voltage levels, one for a digital "0" and the other for "1", and it might at first sight be thought that all that is necessary to record this information on magnetic tape would be to represent a 0 or a 1 by opposite directions of magnetization. However, the data may well contain long strings of noughts or ones, and as the replayed signal is proportional to the rate of change of recorded flux, long periods could then occur in which there was no output from the replay head. This is an undesirable feature and the signal must therefore be re-encoded in such a way that frequent changes of recorded flux take place even when the data stream does not change. A number of coding techniques have been proposed; the one chosen for this application is known as "delay modulation" (sometimes also called Miller code).

For delay modulation the rules are as follows: A transition (polarity unspecified) occurs in the centre of bit cells in which 1s are being conveyed. Transitions also occur between adjacent 0-bit cells.

Fig. 2 shows the signal obtained by applying this coding method to a typical string of data. Note that polarity is unimportant, thus no special precautions need be taken to specify such things as direction of head windings, etc. This is a useful advantage when many channels are being considered.

Signal regeneration on replay

Fig. 3 shows at (a) a two-level signal applied to a recording head. The replayed voltage, given at (b), is formed from positive and negative pulses whose peaks correspond to the transitions in the recorded signal. The width of these pulses depends on the magnetic properties of the tape and the resolution of the replay head. When high packing densities are being attempted, the pulses overlap, but the data can still be recovered provided that inter-pulse crosstalk is not too severe. Fig. 3(c) shows a commonly used method of data recovery, which is



The experimental digital recorder uses a modified audio deck. The 16 recording heads are arranged in two staggered 8-head assemblies; likewise the 16 replay heads. Signal processing functions are carried out largely by integrated circuits mounted on printed circuit boards.

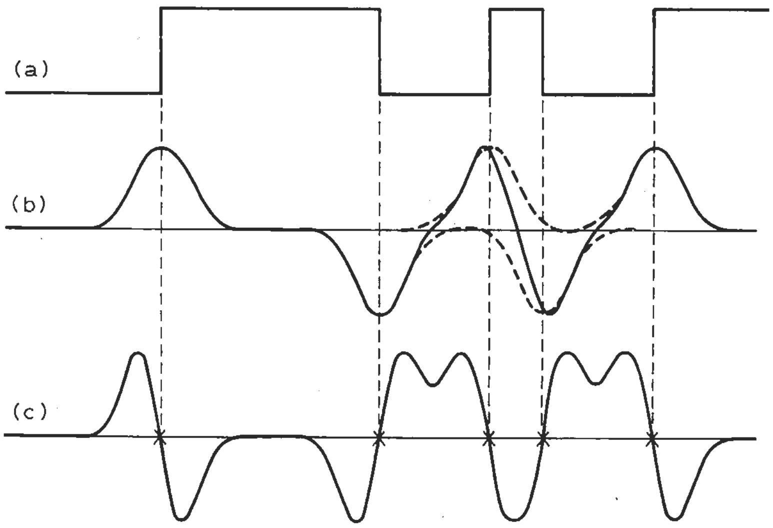


Fig. 3. Basic waveforms: (a) two-level signal applied to recording head; (b) replayed voltage; the broken lines show individual replay pulses and the solid line the composite waveform; (c) waveform resulting from differentiating (b); from this the recorded signal can be obtained using the information of the zero crossings.

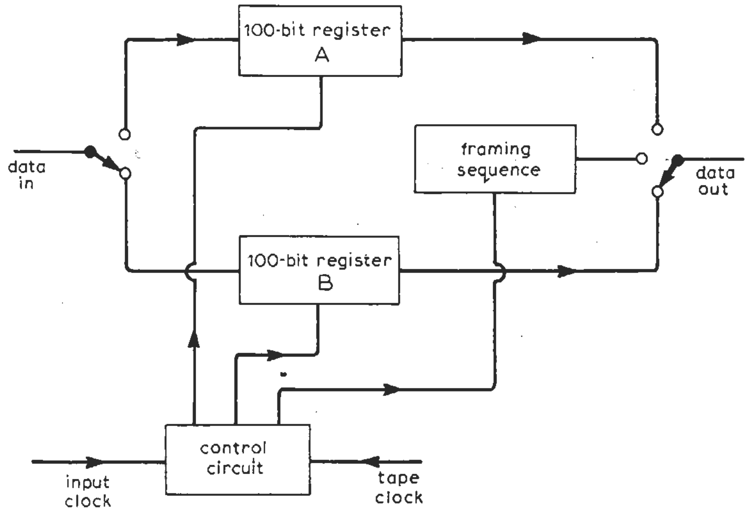


Fig. 4. "Stuffer" used for insertion of framing pulses for timing correction.

employed in the sound recorder. The replayed signal is passed through a differentiating circuit, the output of which has zero-crossings at times corresponding to the input peaks. The recorded signal may now be recovered by slicing. As Fig. 3 indicates, this method relies on some degree of inter-pulse crosstalk because the output of the differentiator returns to zero if the transitions are widely spaced. This is one reason for using the modulation technique described above.

Timing correction

The signal recovered from the tape is subject to two types of timing error, static and dynamic. Dynamic errors are caused by irregularities in the transport system and are usually evident as "wow" and "flutter". Static errors are those caused by errors of head alignment; when working at high packing densities only a small error in the alignment of the replay heads relative to the recording heads can cause the bit streams obtained from different tracks to be incorrectly associated. However, digital techniques allow for the removal of both types of timing error, and with the appropriate circuits installed, the sound recorder is unaffected by gross skew errors and timing fluctuations.

In broad terms, the timing correction is carried out as follows. Time markers, or framing pulses, are inserted into the data in each channel at regular intervals before recording. On replay, the data stream is clocked into temporary stores at times governed by the arrival of the associated framing pulses. The signal is arranged in the stores in such a way that when clocked out by crystal-controlled "station clocks" (i.e. without timing errors) the data that immediately follow the framing pulses emerge simultaneously in each channel.

In choosing the form of the framing sequence, several factors had to be considered. The sequence must not be so long as to occupy a disproportionate amount of time, nor must it occur so frequently as to raise the data rate by an unnecessarily large amount. It was decided to have a sequence 8 bits long, repeated after every 100 input data bits, the actual sequence being 101011*xx* where *xx* indicate two additional bits comprising a "label" used to convey elapsed time and a tape reference number, i.e. they do not form part of the framing sequence proper. It is desirable to include the sequence 101 in the framing sequence to facilitate the correct decoding of delay modulation.

The insertion of framing pulses is carried out in the circuit marked "stuffer" in Fig. 1; this is shown in greater detail in Fig. 4. It has two main sections, that containing two 100-bit shift registers, A and B, and that which generates the necessary pulses to control them. Although the block diagram shows only one channel, shift registers and input and output switching are provided for each of the sixteen channels, while the clock generation and "housekeeping" portion controls all sixteen channels.

Data is clocked at the input rate into the two 100-bit shift registers alternately, under the control of the input switch. While the data stream flows into one of the registers, it is clocked out of the other, but at a slightly faster rate (108/100 × input rate). Thus each register is emptied before the other one is completely filled, leaving time to insert the 8 framing digits. Thus the data string is broken into 100-bit blocks, with synchronizing information between them. It is important to note that this is happening simultaneously in all sixteen channels and that the framing pulses occur at the same instant in all of them; thus synchronizing information is provided for removing static as well as dynamic timing errors.

The delay modulated data contains a strong component at half the clock frequency which can conveniently be extracted on replay and used to control the circuits which clock the replayed data. Because of skew errors, separate clock regenerator circuits are provided for all of the sixteen channels. Their outputs are, of course, subject to the same timing fluctuations as is the data stream itself.

Timing errors are now removed within "de-stuffer" circuits, one of which is shown in greater detail in Fig. 5. Its operation is similar to that of the stuffer, in that the data is clocked at different rates into and out of an array of shift registers. In the de-stuffers, however, the steering of data between the shift registers is controlled by the framing sequence.

Referring to Fig. 5, data is first clocked through a short shift register in which the presence of the framing sequence is detected. The arrival of this sequence operates the input selector switch and the next 108 bits of data are clocked into, say, shift register X, under the control of the tape derived clock (the last-mentioned having the same timing errors as the data). As the register is only 100 bits long, the 8 bits of the framing sequence are lost, and register X is left containing the same block of data which was originally in one of the stuffer shift registers. By the time register X is full, the next framing sequence arrives and switches the data into register Y which is in turn filled, and so on. This process occurs in each of the sixteen channels independently under the control of its own clocks and framing sequences.

Clocking out of the registers may now take place simultaneously in each of the channels, under the control of the slightly slower station clocks formerly used to generate the data. Thus both static timing errors, due to skew, and dynamic ones, due to wow and flutter in the transport mechanism, are removed. It will be noted that because the de-stuffer has 3 × 100-bit shift registers, the delay which it introduces into the data can vary from 100 to 200 bits without violating the condition that reading and writing must always be taking place in different registers. Thus timing fluctuations of $\pm \frac{3}{4}$ ms can be accommodated. A low bandwidth servo control of the tape capstan keeps the timing errors within these limits.

In addition to steering the data between the shift registers the arrival of the framing sequence in the short 8-bit shift register initiates the decoding of the last two bits which constitute the label.

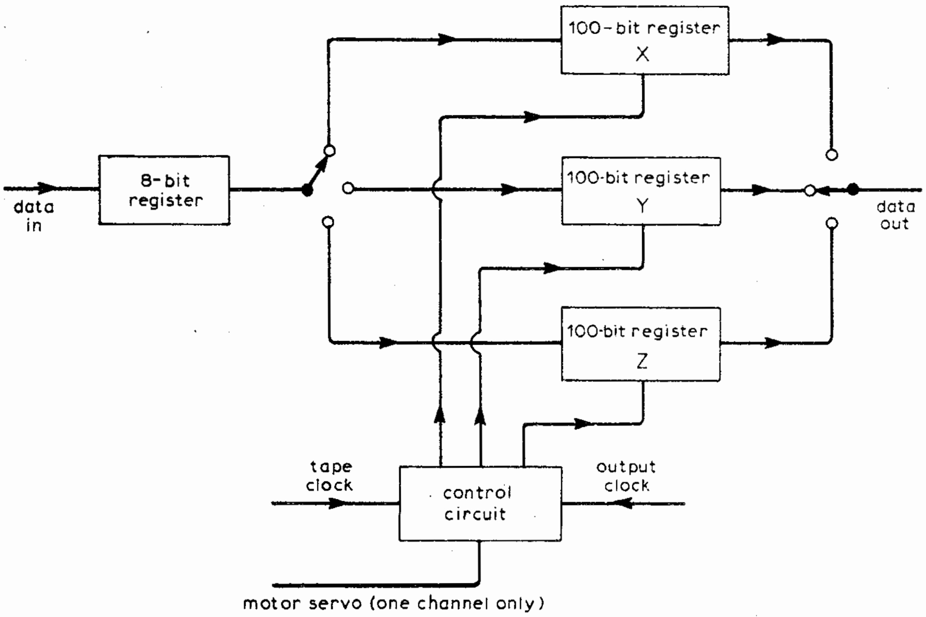


Fig. 5. "De-stuffer" for removal of timing errors.

Error concealment

The effect of errors in a digital system is to cause gross disturbances to the decoded analogue signal; in the case of sound signals these disturbances are heard as loud clicks and crackles. The magnitude of the interference is dependent on the significance of the digits affected; if digits of high significance are in error, then some action to conceal the errors is essential. In the case of randomly occurring single digit errors, it is generally sufficient to omit each erroneous word, repeating instead the previous word and thus arresting the analogue signal until the next word arrives.

Errors in a magnetic recording system are generally caused by "drop-outs" due to imperfections in the tape or temporary separation between the tape and the heads. When high packing densities are used, the duration of drop-outs can be such as to cause a prolonged burst of digital errors. The above technique of retaining the last good word until the end of the disturbance continues to give some improvement, however, even under these conditions, and this form of error concealment is therefore employed in the sound recorder.

Two of the sixteen tracks are provided for parity bits generated to facilitate the detection of digital errors. One of the parity bits is associated with digits 1 (most significant bit), 3 and 5, the other is associated with digits 2 and 4. This assignment of parity bits was chosen because the location of the tracks carrying digits 1 to 5 is such that there is only a very small risk of simultaneous errors in two or more of the associated tracks. A simple parity technique can therefore be used.

Performance

The performance figures mentioned above as chief parameters of the recorder are those which result when the a.d.c. is connected directly to the d.a.c. and are not altered when the rest of the circuitry including the magnetic tape system is inserted. The a.d.c. and d.a.c. do not give the optimum 13-bit performance; had they done so, the signal-to noise ratio achieved would have been about 3dB better, namely 75dB.

The packing density of about 5k bits per inch per track at which the machine operates represents a very modest requirement in this application. It is possible to improve packing density and therefore reduce tape consumption by at least 2:1, at the cost of more expensive heads.

The timing correction circuitry is, as mentioned above, capable of removing "wow" and "flutter" up to a maximum timing error of $\pm \frac{3}{4}$ ms.

The simple error concealment technique works reasonably well, though some impairment to sound quality is still apparent when lengthy drop-outs are encountered. Further work is needed to provide improved error protection in these circumstances.

The experimental stereo recorder has established the feasibility of digital sound recording and has provided a convenient test bed for the development of a number of useful processing techniques, notably those relating to timing correction. The application of these techniques to the digital recording of high-quality television signals is now being investigated.

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The Domestic Video Recorder

Magnetic-tape cassette machines available at £300

The first British radio and television set manufacturer to produce a video cassette recorder at a "domestic" price level put the machine on view to the public at the Internavex 72 show (International Audio-Visual Aids Conference and Exhibition) at Olympia, London, from 25th to 28th July. The machine is the British Radio Corporation's model 8200 Colour Video Cassette Recorder, which is selling at "about £285" (without cassette) and is available for renting at "about the same payment as for a 26in colour television set, approximately £96 per year". At present the video recorder is available only to organizations — schools, colleges, industrial training establishments, hospitals etc. — through an associated company in the Thorn group, Radio Rentals Contracts Ltd (1-15 Clyde Road, Tottenham, London N.15). There is no commercial machinery for retail buying or renting. In fact the recorder is being presented, for the moment, as basically a low-priced professional machine, but B.R.C. are making no secret of the fact that they see it as their first domestic video cassette recorder when the domestic market gets under way.

What makes this machine the probable archetype of future domestic recorders is the fact that it is a cassette equipment,* allowing simpler operation than with open-reel recorders, and makes use of the well tried and inexpensive Philips deck. The Philips VCR equipment, using $\frac{1}{2}$-inch tape, has been commercially available direct from Philips Electrical Ltd for some time (see July 1970 issue, p.340), and recently Philips have been licensing receiver manufacturers (mainly in Europe) to use their recording "format" — which in practice means using the deck made at this company's tape recorder factory in Austria. For example, Blaupunkt, Bosch, Grundig, Loewe-Opta and Telefunken are among the German licencees. In Britain, Philips Electrical are selling the latest machine — the type N1500, which also was on show at Olympia — again only to organizations. Their original projected price of £230 (July 1970) has not been adhered to, and the machine now costs £315. This, however, includes a television tuner, whereas the lower-priced B.R.C. recorder does not have a tuner, so, if the B.R.C. machine is needed to record programmes "off the air", it must be used in conjunction with a television receiver. A 26-inch schools colour TV receiver, the model 8733, and a monochrome receiver, were shown at Olympia with the B.R.C. recorder.

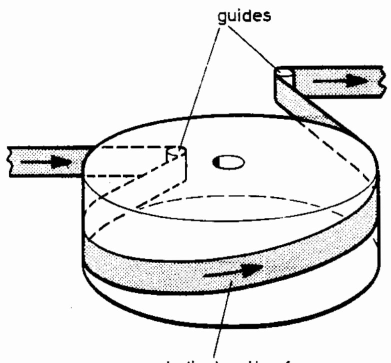

Fig. 1. Helical-scan principle: the tape passes round the head drum in a helical path; also the rotating heads trace helical magnetic paths obliquely across the tape.

Another cassette video tape recorder, put on show by E.M.I. as distributors, was the Sony VO-1700, working in conjunction with a Trinitron monitor. This, however, is priced at "about £600", uses a $\frac{3}{4}$ inch tape and has been designed to operate on the N. T. S. C. 525-line colour television standard, whereas the Philips and B.R.C. machines shown work on the European 625-line PAL standard. A video cassette recording made on this Sony machine can only be played back on the same machine or on two or three other Japanese made cassette recorders. There is no interchangeability of cassettes possible, or "compatibility", to use the current phrase, between the Sony machine and the Philips and B.R.C. machines. Even when a version of the Sony cassette recorder designed to work on European television standards becomes available, the Sony and Philips systems will not be compatible.

The question of compatibility, and of video tape recording standards generally, is a very vexed one. A video tape standard includes not only the standard of the

*The term "cassette" is used in this report to include what is called a "cartridge". There are basically three types of cassette: (a) a rectangular box containing two tape spools in the same plane; (b) a rectangular box containing two spools stacked vertically on the same axis; (c) a flat cylindrical or rectangular container holding a single spool (cartridge), from which the tape is drawn while recording or playing back and on to which the tape is re-wound afterwards.

television broadcasting system providing the signal to be recorded and afterwards played back into a television receiver, but a whole host of mechanical quantities, such as tape width, tape speed, number of recording/playback heads, the head drum diameter and the geometrical layout of the magnetic tracks carrying vision and sound information formed by this machinery on the tape. First of all there is no world standard recommended by an international organization. Several bodies, such as the C.C.I.R., the E.B.U. and the S.M.P.T.E., are studying temporarily established commercial "standards"—resulting from several recorder manufacturers agreeing to use the same basic design of machine — possibly with a view to recommending official standards. But behind these technical investigations fierce commercial battles are being fought to see who can sell the greatest numbers of machines of particular designs, for no doubt the winners will establish the ultimate standards.

The possible standards for domestic video recorders are automatically divided into two groups by the principal colour television broadcasting standards — the 625-line, 50 fields/s PAL system in Europe and the 525-line, 60 fields/s N.T.S.C. system on the American continent and in other countries. There is a further division, into broadcasting quality standards, which means large machines costing in the region of £20,000, and the standards used for small semi-professional recording, which at present means machines in the price region of £300 to £1000. It is the last-mentioned category, for both 625-line and 525-line television standards, which includes cassette and open-reel operation, that will almost certainly provide the basis of the domestic video recorder of the future.

The main reason for this is that these machines use a technique for obtaining adequate head-to-tape "writing" and "reading" speed (in the region 500-1000 inches per second), called helical scan recording, which allows them to be mass-produced at the lower prices mentioned. Helical-scan recorders are so called because a narrow tape (¼in, ½in ¾in or 1in) is wrapped round a drum, incorporating rotating recording heads, in what amounts to part of a helix (Fig.1). In addition, if the tape is considered as a helical "slice" belonging to an imaginary cylinder of magnetic material rotating round the head drum of the machine it can be seen from a vector diagram that any point on the cylinder has a vertical component of velocity, parallel with the cylinder axis, as well as an angular velocity due to the rotation. Consequently the path traced by a rotating recording head on the inside of the imaginary cylinder, and therefore obliquely across the tape, is also helical.

Removing a cassette from the British Radio Corporation's colour video cassette recorder, model 8200.

The Sony type VO-1700 video cassette recorder, using ¾ inch tape, with a Trinitron colour receiver acting as a monitor.

There are at present four important and contending standards for helical-scan recording — "important" in the sense of having been extant for several years and having established substantial markets for recorders: (1) the Philips ½-inch tape standard, as seen in that company's video cassette recorder and those of licensed manufacturers; (2) the Sony ¾-inch tape video cassette standard, also being used by other Japanese manufacturers; (3) the Electrical Industries Association of Japan (E.I.A.J.) standard for ½-inch tape, to which a group of Japanese manufacturers (e.g. Ikegami, Matsushita, National, Nivico, Sanyo, Shibaden and Sony) are supplying open-reel machines, and Ampex a cassette machine; and (4) the Cartrivision standard, of the American company Cartridge Television Inc., which uses ½-inch tape in cassettes. Since the various manufacturers see the possibility of export markets in each other's countries these "standards" must not be linked too closely with their names. For example, as mentioned above, Sony are going to produce in Japan a version of their ¾-in video cassette machine for the European 625-line television standard, while Philips are intending to make in Austria a version of their video cassette recorder adapted to work on the 525-line N.T.S.C. television standard and conforming to the Japanese E.I.A.J. standard.

In a forthcoming issue we shall publish a more detailed analysis of techniques and standards used in the lower priced helical-scan video recording machines.