TECHNICAL INSTRUCTION
TVX. 8

Principles of the Ampex Videotape Recorder

BRITISH BROADCASTING CORPORATION

ENGINEERING DIVISION

TECHNICAL INSTRUCTION TVX.8

PRINCIPLES OF THE AMPEX VIDEOTAPE RECORDER

ACKNOWLEDGMENTS

The text of this Instruction is based, with the permission of the publishers, on the booklet "Technical Notes on the Ampex VR-1000" issued by the Ampex Corporation. The changes made in the text are to bring it into agreement with British television standards and with modifications made to the recorder for use in this country. Fig. 7 (Pattern of Recorded Tape made visible by use of Carbonyl Iron) is also taken from this Ampex publication.

Figs. 1 to 6 are all taken, by permission of Siemens and Halske Aktiengesellschaft, from their publication "Magnetische Bildaufzeichnungsanlage: System Ampex."

Instruction TVX.8
First issue April, 1959

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Introduction

This Instruction describes the principles employed in the Ampex Videotape Recorder, Type VR1000, which records a video signal and the accompanying sound on magnetic tape.

The equipment is illustrated in Fig. 1; it comprises a desk carrying the recorder itself and two bays containing the associated electronic equipment.

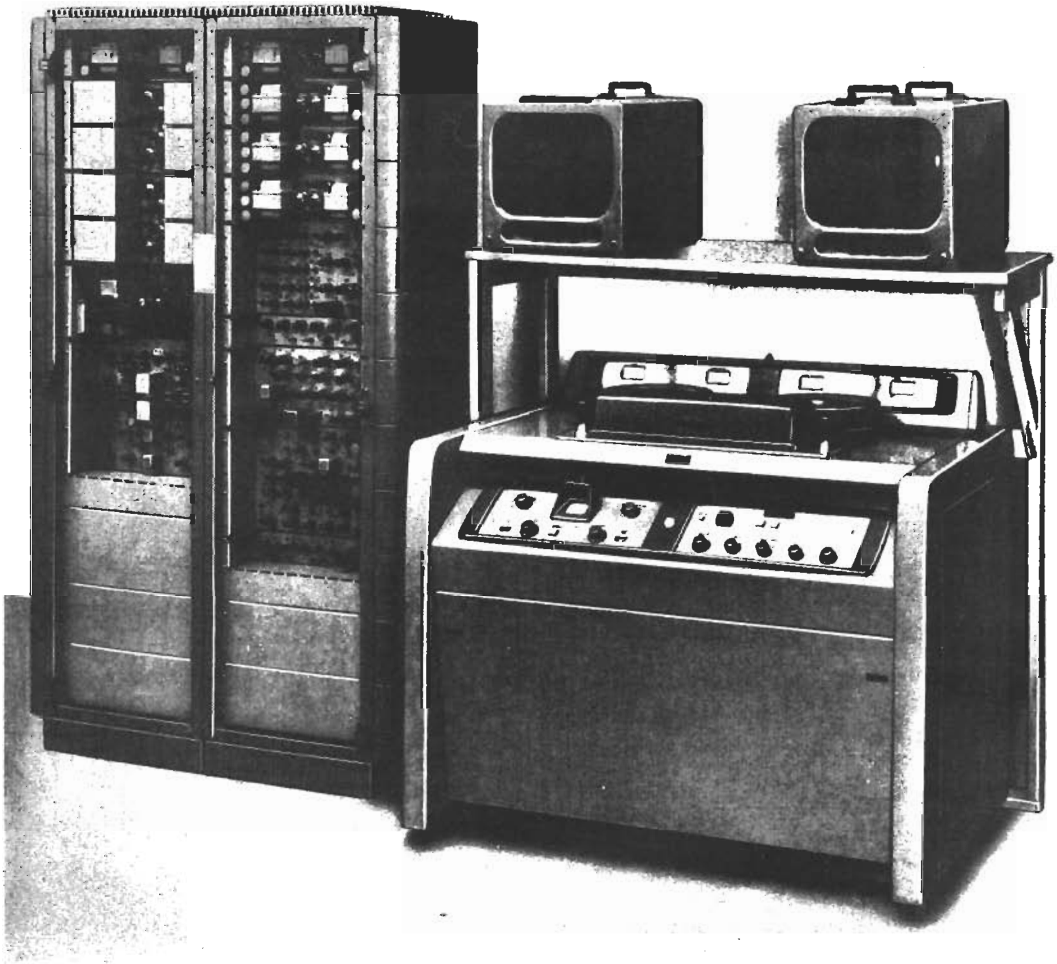

Fig. 1 General View of Ampex Videotape Recorder

Basic Principles

There are three fundamental problems which must be solved in designing a practical magnetic tape recorder for video signals:-

(a) High head-to-tape speed is required to record the high-frequency components of the video signal.

(b) Adequate playing time using reels of reasonable size is necessary.

(c) A means must be found whereby the entire video signal from direct current to the high frequency of 3 Mc/s can be recorded and reproduced.

To solve the first two problems, the Ampex recorder has four heads mounted at the outer circumference of a rotating drum with their gaps parallel to the drum axis, and the video signal is recorded transversely rather than longitudinally on the tape. The recording-head arrangement is illustrated in Figs. 2 and 3. The third problem is solved by use of a modulation process described later.

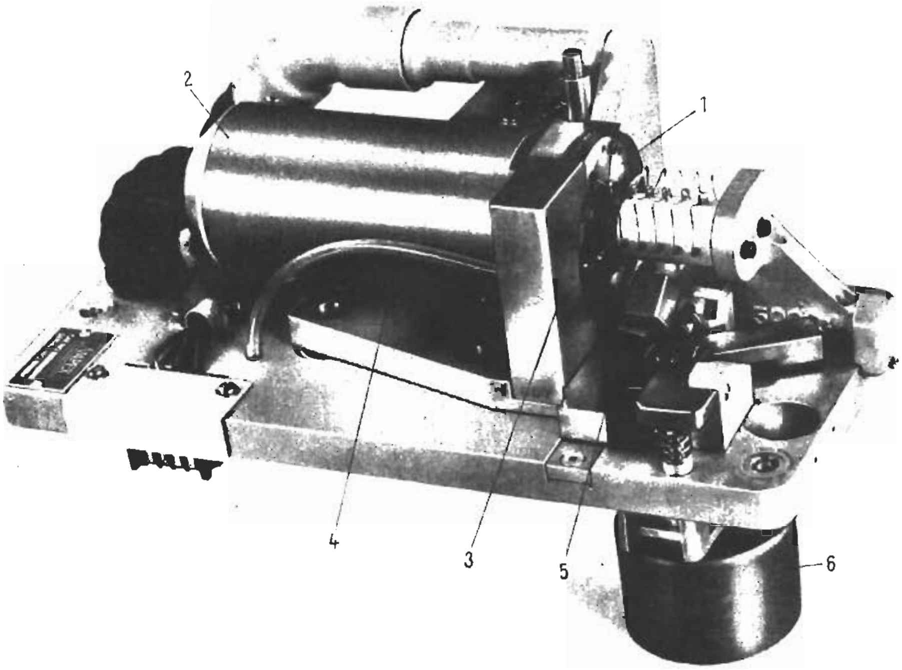

Fig. 2 Illustrating Construction of Vision Recording Head

1. *Recording-head drum*
2. *Drum motor*
3. *Tape guide*
4. *Tube leading to vacuum unit*
5. *Head for recording and reproduction of control track and editing pulses*
6. *Rotary Solenoid bringing the tape guide into the working position*

In the head assembly, each head is accurately spaced at 90° from the next on the drum. The drum diameter is approximately 2 inch and the speed of rotation 15,000 rpm (250 rps), giving a writing speed or relative head-to-tape speed of about 1,600 inches per second.

The longitudinal tape speed depends upon the width of the tracks which are laid down, one after another, transversely across the tape, and upon the space required between them. The tracks are 10 mils wide, with an edge-to-edge separation of 5 5/8 mils and a centre-to-centre spacing of 15 5/8 mils. By this means the longitudinal tape speed need be only slightly in excess of the 15 inches per second employed in audio recorders. Using thin tape, 62¼ minutes of recording can be obtained on a 12 5/8 inch diameter reel of 2-inch wide tape.

A 120-deg. arc is decribed during the complete sweep of a head transversely across the tape and all four heads are in effect fed with the same signal during recording. Thus there is a duplication of information towards the end of one track on the tape and at the beginning of the succeeding one. Advantage is taken of this duplication in the switching system used to deliver continuous transient-free signals during reproduction.

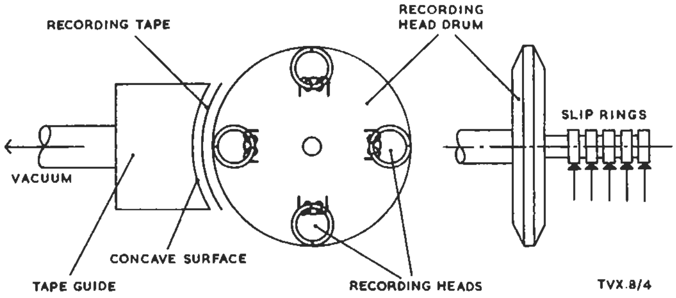

Fig. 3 Schematic Diagram showing Arrangement of Recording and Reproducing heads on Drum

The four heads perform 1000 sweeps across the tape each second. During this time the tape moves 15 5/8 inch longitudinally and because there are 25 pictures per second, each picture occupies 5/8 inch of tape longitudinally and each field 5/16 inch. The 405 lines which make up one complete television picture are recorded on 40 successive tracks on the tape. It follows that each track contains 10 or 11 lines of television information. Because of the duplication of information mentioned above, each track in fact contains more than 10 or 11 lines but only this number are used during reproduction.

Recorded Tracks

The recorded tape has three separate but synchronized magnetic tracks. The first is the series of transverse video tracks; the second is the sound track accompanying the picture, which is recorded at the top of the tape; the third is the control track which comprises a record of the position and speed of the recording-head drum during recording. The control track also contains editing pulses used as reference points in editing and splicing.

During recording, the tape passes over a sound erase head which erases part of the video tracks to give a longitudinal track 90 mils wide at the top of the tape for sound recording: erasing has proved necessary to give a good signal-to-noise ratio. Erasure has proved to be unnecessary for the control track. The sound track effectively erases 90 mils of the video track at the top of the tape and the control track similarly erases 50 mils of the video tracks at the bottom of the tape: nevertheless more than 90 deg. of arc are still recorded on each transverse video track. The overlap of information is just over one television picture line, approximately 130 micro-seconds. During reproduction this allows a time interval during which electronic switching from head to head can take place.

Tape Transport

The transport mechanism used is similar to that of many professional magnetic audio recorders and is illustrated in Fig. 4. The tape is supplied from a reel on the left-hand side of the machine; it passes around an idler and then by the rotating video head assembly which also contains the stationary control-track head. The tape then goes on to two stationary stacks of heads, the first of which carries the audio erase head and the second the audio record-reproduce head.

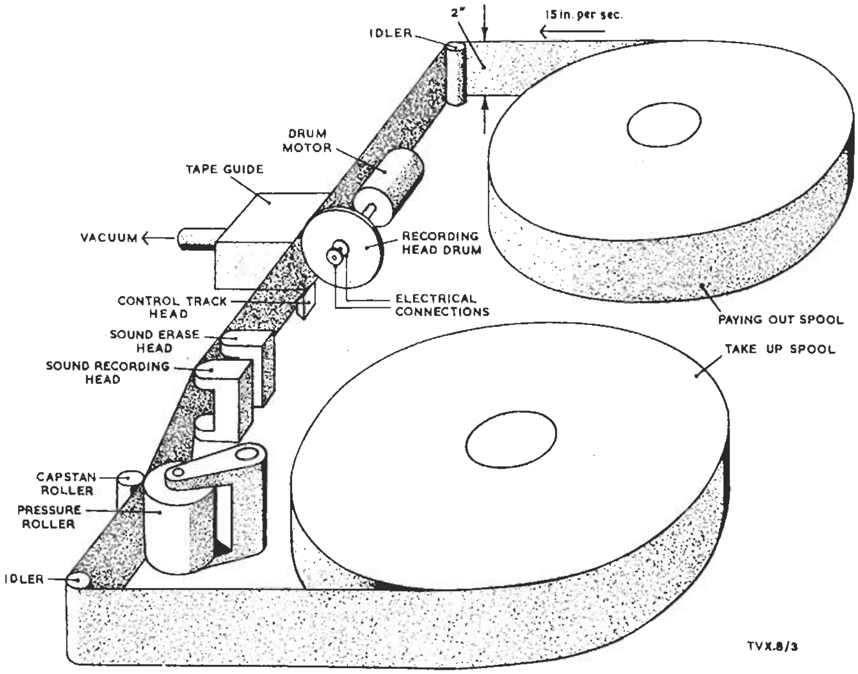

Fig. 4 Illustrating the Method of Tape Drive and and Recording head Arrangement

The tape next passes between a drive capstan and its pressure idler, around a further idler roller and on to a tape take-up reel at the right.

Guiding of the tape past the rotating drum is accurately controlled by a concave guide, which is used to cup the tape around the drum. The relation of tape to rotating heads must necessarily be intimate, and nearly constant pressure between head and tape is required. This is obtained by maintaining the fit of the concave guide within small tolerances to the exact path of the rotating heads and by the use of vacuum applied from the guide side of the tape.

Moreover there is a servo system (described later) which automatically maintains the pressure between tape and drum at the required value.

During both recording and reproduction, an exact relationship must exist between the rotation of the revolving heads and that of the capstan. This requirement is satisfied by use of a servo system described in the following two sections.

Recording

During recording a signal at the field frequency (50 c/s) is applied to a frequency multiplier, to obtain a 250-c/s output signal. This signal drives a power amplifier which supplies 250-c/s power to the synchronous motor driving the recording-head drum. This is illustrated in the block diagrams of Figs. 5 and 6.

A sleeve on the rotating drum mechanism is coated half black and half white. A light source is focused on the sleeve and light reflected from it enters a photocell to produce a 250-c/s square-wave output. This is fed to a frequency divider to give an output at 62.5 c/s. This signal is passed through a filter, to give a 62.5-c/s sine wave output which is fed to the power amplifier driving the capstan motor.

The electronic chain is analogous to a mechanical gear train which couples the rotation of the capstan firmly to the rotation of the head drum and ensures that the tape is moved precisely 62.5 mils longitudinally during each revolution of the head drum. During this period, four lateral tracks are recorded, one by each head, each track being separated from the next by a centre-to-centre spacing of 15 5/8 mils.

During recording, the 250-c/s output of the photocell is also fed, through a bandpass filter and a series of amplifiers, to the control-track head, which records the signal longitudinally as the control track at the bottom of the tape. This track is a magnetic equivalent of the sprocket-holes of a sprocketed film machine. The 250-c/s signal is derived directly from the revolving heads and the signal on the control track bears a direct relation to the spacing of the lateral tracks on the tape: this information is available as a reference to control the relative positions of the head drum and capstan shaft during reproduction.

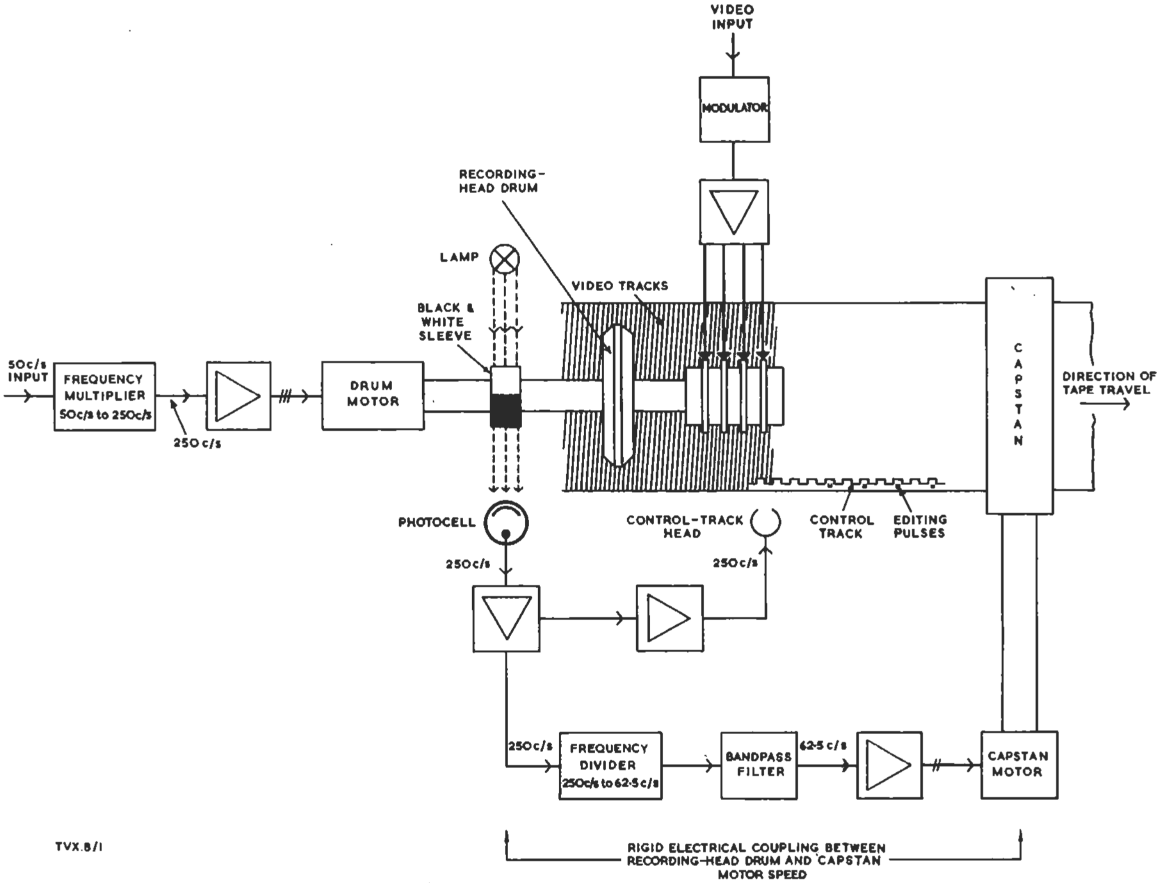

Fig. 5 Block Schematic: Recording

Reproduction

When the recorded video tape is reproduced, mains frequency is multiplied to 250 c/s, and the multiplier output is used to drive the drum motor. Again the photocell produces a 250 c/s signal synchronised with the rotation of the drum. A second 250-c/s signal obtained by reproducing the control track, is amplified, and fed together with the signal from the photocell to a phase comparator. The output signal depends on the phase difference between the control-track signal and the photocell signal. This is applied to a low-pass filter and then to the grid of a reactance valve which is one of the frequency-determining elements of a Wien-bridge oscillator.

The oscillator functions normally at 62.5 c/s but the frequency can be varied over a small range by the correction signal from the phase comparator. The oscillator output is fed to the power amplifier which drives the capstan in the same relation to the rotating drum, within narrow limits, as during recording.

Once the drum is adjusted to be on the centre of the tracks at the beginning of reproduction the servo system holds the relation constant and the revolving heads accurately trace the recorded tracks.

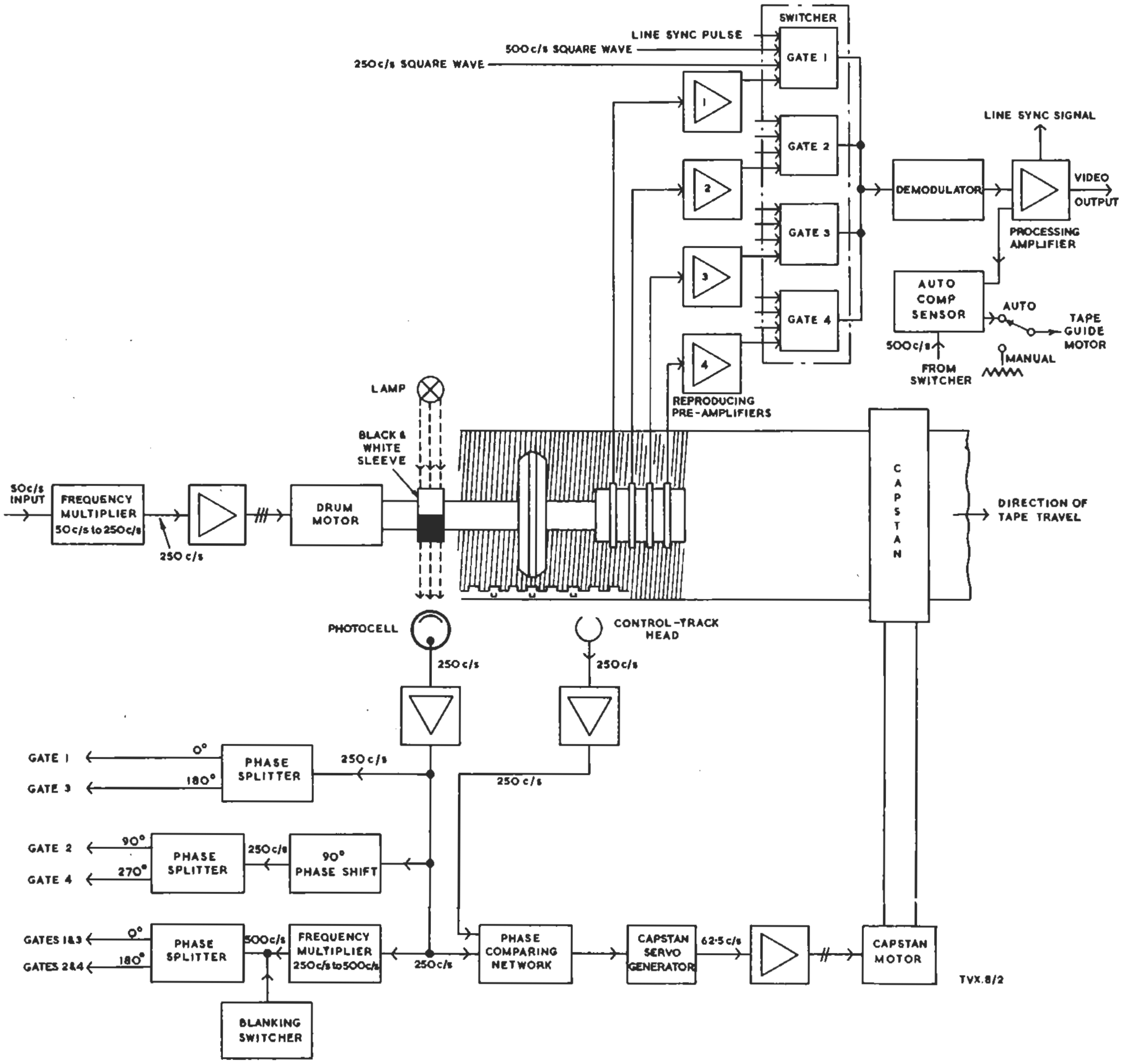

Fig. 6 Block Schematic: Reproduction

The output of the photocell can also be used to determine in advance the approximate moment during reproduction when it is necessary to switch from one reproducing head to the next.

Editing and Splicing

The recorded tape can be edited but to avoid loss of picture information, cuts should be made during field blanking periods. To locate those periods, the control track contains editing pulses which are spaced at one-field intervals. These pulses are recorded by the control-track head and are obtained as a derivative of the field sync signals.

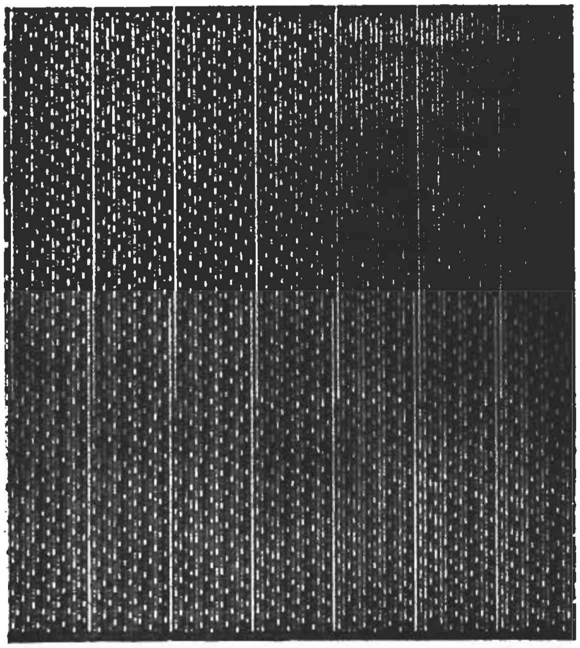

Fig. 7 Pattern of Recorded Tape made visible by use of Carbonyl Iron. This is a Photograph of an American Tape.

The latter part of the field sync signal represents a blanking time between television fields. For a recording at American standards the editing pulse marks where this blanking time appears. To make the editing pulses visible, a solution containing carbonyl iron* can be applied to the tape prior to making a cut. The iron particles adhere to the tape according to the magnetic pattern made by the recording, and reveal the editing pulses. This is shown in the photograph of an American tape given in Fig. 7. The tape is then put in a jig and the cut is made along the line in the video pattern which is marked by the editing pulse. Splicing tape is then applied to the back of the tape to hold the spliced ends together. After the splice has been made, the carbonyl iron particles can be wiped off.

For a recording at British standards the editing pulses appear 2/5ths the way through a field. Each field occupies a longitudinal distance of 5/16 inch on the tape and the distance between field blanking pulses and the following editing pulse is thus 2/5 of 5/16 i.e. 1/8-inch. In splicing a British recording, therefore, the cut should be displaced 1/8 inch from the editing pulses in order to pass through the blanking period. Splicers can be constructed to give the required displacement automatically.

Modulation System

It was necessary in the development of the recorder to find means of recording and reproducing frequencies up to 3 Mc/s. To record zero frequency a modulation system is necessary and a frequency-modulation system was adopted. To avoid too great

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* Fine particles of iron, approximately 3 to 5 microns in diagonal, held in suspension in a volatile liquid such as lacquer diluent or carbon tetrachloride.

a tape speed the carrier frequency must be low but it must nevertheless be above the video spectrum because the significant sidebands of the frequency-modulated wave extend to at least 3 Mc/s on either side of the carrier. The sidebands should not, however, extend substantially beyond 3 Mc/s from the carrier frequency. The method of achieving this restricted passband can be arrived at in the following way.

Consider a video waveform consisting of a 3 Mc/s signal occupying the range between white and black levels: such a signal is choosen because it contains the maximum video frequency at maximum amplitude. If the passband is to be restricted to 6 Mc/s centred on the carrier frequency, we can accept only the first pair of sidebands generated in the frequency-modulating process. In general frequency modulation produces an infinite number of pairs of sidebands symmetrically disposed about the carrier frequency and spaced at intervals equal to the modulating frequency. The amplitude of the sidebands decreases as the order increases and it is possible to omit those with very small amplitudes without introducing appreciable distortion. Sidebands are regarded as significant and must be retained if their amplitude exceeds 1 per cent of that of the carrier. The factor which determines the number of significant sidebands is the modulation index and is defined by:-

$$\text{Modulation index} = \frac{\text{peak frequency shift}}{\text{modulating-signal frequency}}$$

where the peak frequency shift is the difference between maximum (instantaneous) frequency and carrier frequency. For there to be only 1 pair of significant sidebands the modulation index must be less than 0.3*. For this the parameters of the frequency modulation system can be determined in the following (approximate) manner.

A 3-Mc/s component occupying the range between white and black levels has an amplitude equal to 0.35 times the double-amplitude peak value of a video signal representing peak white. Let f_d be the difference in Mc/s between the carrier frequency (corresponding to sync level) and the frequency corresponding to peak white. Then the peak frequency shift due to the 3-Mc/s component is $0.35f_d$ Mc/s and the modulating index is hence $0.35f_d/3$. This must be less than 0.3. Thus:-

$$\frac{0.35f_d}{3} < 0.3$$

$$\therefore \quad f_d < \frac{0.3 \times 3}{0.35} = 2.6 \text{ Mc/s}$$

In practice a value of 2.75 Mc/s is used.

For modulating frequencies less than 3 Mc/s there are more than one pair of significant sidebands. In fact at frequencies around 50 c/s there are literally hundreds of pairs but the bandwidth occupied by the significant sidebands is approximately

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* See, for example, the second edition of "Frequency Modulation Engineering" by C. Tibbs and G.G. Johnstone published by Chapman and Hall.

constant for constant modulating-signal amplitude: this is one of the virtues of frequency modulation.

The overall bandwidth is however greater than the 6 Mc/s implied above because of the d.c. component of the modulating signal. The d.c. component determines the apparent value of the carrier frequency: it is thus necessary to distinguish between the apparent carrier (in the presence of a d.c. modulating signal) and the true carrier (i.e. the carrier frequency in the absence of all modulation). To determine the overall bandwidth consider a video signal with a small amplitude 3-Mc/s component just below peak white level. The d.c. component has a value equal to approximately 0.9 times that of a peak white video signal and this shifts the carrier frequency by 0.9 f_d i.e. 2.4 Mc/s. Thus the upper sideband is 3 + 2.4 i.e. 5.4 Mc/s above the true carrier frequency and the lower sideband is 3 - 2.4 i.e. 0.6 Mc/s below it.

If, however, the 3-Mc/s component is just above black level, the d.c. component is only approximately 0.3 times that of a peak white video signal. This shifts the carrier frequency by 0.3 x 2.75 i.e. 0.75 Mc/s. Thus the upper sideband is 3 + 0.75 i.e. 3.75 Mc/s above the true carrier frequency and the lower sideband is 3 - 0.75 i.e. 2.25 Mc/s below it. The overall bandwidth extends from 2.25 Mc/s below the true carrier frequency to 5.4 Mc/s above it, a total bandwidth of 7.65 Mc/s.

A true carrier frequency of 4 Mc/s is used and the bandwidth extends from 4 - 2.25 i.e. 1.75 Mc/s to 4 + 5.4 i.e. 9.4 Mc/s. Sync level corresponds to 4 Mc/s, blanking level to 4 + 2.75 x 0.3 i.e. 4.8 Mc/s and peak white level to 6.75 Mc/s.

In practice the passband of the equipment does not extend to the required upper limit of 9.4 Mc/s and there is some attenuation of the upper-frequency sidebands, tending towards signel-sideband operation at such frequencies. This occurs for signals with a large white content and a wealth of fine detail, circumstances which do not occur frequently, and distortion due to this assymmetric sideband structure has not proved objectionable.

For an f.m. system such as that discussed above in which the frequency swings are of the same order as the modulating frequencies, the signal-noise ratio is worse than that of an a.m. system using the same carrier frequency and tape speed. Nevertheless within the limitations of the tape velocity figures chosen, a signal-to-noise ratio of 30 dB or better is attainable over the 3 Mc/s bandwidth. The great advantage of frequency modulation is that it is well suited for use with a multi-head recording and reproducing system because spurious amplitude variations can be eliminated.

Distortion arises because the higher modulation frequencies approach that of the carrier and such distortion in the band above 1 Mc/s is apparent as slight zig-zagging of closely spaced vertical lines. Fortunately, such blurring effects are greatly reduced by the nature of human vision. When successive images thus distorted are viewed by the eye, which integrates its experience over a substantial period of time, the result is acceptable, even for images representing a horizontal resolution of 300 lines or better.

Recording and Reproducing Chains

For recording the video input is applied to the frequency modulator, the output of which is amplified and applied via slip-rings to the four recording heads in parallel.

The modulator consists of a free-running multivibrator whose frequency is controlled by direct application of the video signal to the control grids. Special attention is paid to switching time and the input to the multivibrator is from a low-impedance source. The multivibrator output is amplified and applied in parallel to the four output valves which drive the heads. Each valve drives a single head continuously during recording.

During reproduction, the output of each head is fed via the slip-rings to an individual pre-amplifier, the output of which feed into a switcher. From the switcher a single channel of frequency-modulated r.f. is fed to limitere and then to the demodulator.

The demodulator contains an f.m. - a.m. converter followed by a full-wave a.m. detector. Full-wave detection is preferred to half-wave because it doubles the frequency of the r.f. carrier ripple superimposed on the video output and thus aids rejection of this carrier component. Further carrier attenuation is provided by a low-pass filter. The video output is then fed to a processing amplifier which eliminates noise and switching transients. Here, also, line and field blanking pulses are regenerated.

Reproducing Switching

During reproduction it is necessary to derive the amplified output signal from one head at a time, switching from one preamplifier to the next (at a moment in the transmission when minimum disturbance is introduced into the reproduced picture), and later to demodulate the amplified r.f. output of the reproducing heads. This is achieved by electronic switching.

A network of coincidence gates is employed, with a "get-ready" signal sent to each gating valve in turn from the 250-c/s photocell source; a "go" signal is delivered with precision to each gating valve from the television signal itself. Switching occurs only on the back porch of a line sync pulse, and therefore no transients appear in the reproduced picture.

The multi-grid gating valves pass the r.f. signal to their anode circuits only when each of two grids is raised to a predetermined level of bias. Thus the coincidence of two positive bias signals is used to trigger each of the four gates consecutively.

The photocell output is delivered to the switcher as well as to the servo amplifier control system. This 250-c/s signal whose phase is directly related to the instantaneous position of the head drum, is fed through a vernier phasing control to a 90-degree lag network which controls two related channels in conjunction with the other signals. The same signal is continuously fed to a frequency doubler and to an in-phase network.

The in-phase 250-c/s signal is clipped and fed to a phase splitter, which produces two signals, one in-phase and one 180-degrees out-of-phase. These two signals are applied to the gating valves, the in-phase signal to one of the grids of gate 1, the opposite phase to one of the grids of gate 3. These are the grids to which the amplified r.f. from the heads 1 and 3* is fed.

The same 250-c/s signals, after passing through a 90-degree lag network, is similarly clipped, fed to a phase splitter, and applied to the control grids of gates 2 and 4. In the same way, these gates receive the amplified r.f. output of heads 2 and 4 at intervals of 90 and 270 degrees.

Gate Switching

To cause these gates to pass r.f. at the desired times, appropriate positive swings of a 500-c/s square wave are applied to the coincidence grids of these gating valves. The 500-c/s square-wave signal is obtained from a frequency-doubler whose input is also fed from the common 250-c/s source.

Symmetry of the 500 c/s signal is controlled, permitting the instant of switching to be adjusted with vernier accuracy to the desired angular position of the heads on the tape. With a rise of time about 0.05 microsecond this 500 c/s square wave gives the final "go" signal to each switching operation and interruption of the composite signal is exceedingly brief.

The 500-c/s square wave, like the two 250-c/s control signals, is fed through a phase splitter, one phase going to gates 1 and 3, the other to gates 2 and 4.

The sequence of operations then begins with the appearance at the control grid of gate 1 of the r.f. signal from head 1. The phase of the 500-c/s square wave is such that it too goes suddenly positive at one point in the rotation of the head drum. At this moment, the gating valve begins to conduct r.f.

All four gating valves are parallel in their outputs, and an r.f. video signal is fed to the input of the demodulator which follows the switcher.

90 degrees later in the rotation of the head drum the 250-c/s delayed signal goes positive at the control grid of gate valve 2. This valve is fed from the opposite phase of the 500-c/s control-signal from gate 1; this phase goes suddenly positive at the suppressor grid of this second gate and this valve conducts.

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* To simplify the explanation it is here assumed that the heads are numbered in natural order, 1, 2, 3, 4 around the drum.

Since this rapid occurrence is coincidental with the negative phase of the 500 c/s signal at gate 1, the gate ceases to conduct at the same moment that gate 2 begins to conduct. Gates 3 and 4 are both in the negative-going portion of the 250-c/s control signal which is applied to them, and gate 2 is, at this moment, the only one conducting. The same sequence of events occurs next at gate 3, and then at gate 4 as the head drum reaches another 90 degrees of rotation.

Blanking Switcher

Just over one television line of information is duplicated from track to track on the magnetic tape and the bottom of one track contains the same information as the top of the succeeding track. A rearrangement of the "get-ready", "go" signal procedure is desirable to locate the moment of switching.

If the line carrying the 500-c/s wave is opened before it feeds the corresponding phase splitter, and this signal is delayed momentarily in accordance with the synchronising information in the television signal, the switching can be done during flyback when the cathode ray beam is off the television screen. The blanking switcher contains a 500-c/s multivibrator oscillator, which is locked jointly to the 500-c/s photocell-derived signal and to the synchronising pulses in the demodulated r.f. video signal. The frequency of this oscillator may be varied over a relative narrow range, effectively delaying its output with respect to the 500-c/s switching signal and the exact moment at which the outgoing 500-c/s square-wave goes positive or negative may be made to coincide with a desired point in the controlling video signal.

The switching time is positioned during the back porch, which places the switching transients on the extreme left-hand side of the reproduced picture, out of view. Should the sync signals of the video output fail, the multivibrator oscillator in the blanking switcher continues to send triggering pulses to the four-gate circuit insuring continuous output regardless of the nature of the incoming video signal.

If, for example, a synchronising pulse is missing from the signal reproduced from the tape and the time arrives when switching must occur from one head to the next, the unit waits for a brief interval. When no synchronising pulse appears, the unit switches to the next head automatically, with little loss in signal from the tape.

The 500-c/s signal, which originates in the switcher, is thus modified and suitably delayed by the blanking switcher so that upon re-injection, it causes the gating valves to switch from channel to channel only at such a point in the sequence of video signals that there is no visible effect.

Processing Amplifier

The demodulated video signal is not perfect in waveform for the following reasons:-

1. Noise and switching transients are present.

2. Distortion is necessarily introduced into the signal by the closeness of carrier and modulating frequency in the f.m. system.

3. The shape of the overall passband is not ideal.

4. Minute amounts of hunting occur in the rotating drum.

This distortion is of minor importance to the picture signal, but of considerable importance to the shape of the sync pulses. A processing amplifier is therefore included after the demodulator, to improve the waveform of the sync pulses.

In this unit the sync pulses are removed from the reproduced video signal, are sliced to reduce the rise time and are added to the picture signal to produce an improved video signal. The blanking pulses are also regenerated in the processing amplifier.

The relative level of picture and sync signals may be varied in the processing amplifier. There are two video outputs from this unit, one of which is used to feed the line and the other is used for monitoring. There are also two sync-signal outputs one of which is used to feed the blanking switcher.

Tape Guide Servo

It was pointed out earlier that the signal recorded near the end of one video track is duplicated at the beginning of the next. During reproduction the tracks are reproduced sequentially by the four heads, the switcher changing over from the head which is about to leave one track to the next which has just started to scan the following track. To avoid missing or duplicating any information when changeover occurs it is essential that the same item of information should be under the two heads at the instant of switching. This implies that the circumferential distance between these items of information (which subtend 90° at the centre of the drum) must be the same on reproduction as on recording.

The tips of the recording heads project slightly from the drum and into a groove in the concave surface of the tape guide. The tips thus force the tape into the groove with a pressure which stretches the tape slightly over a small area centred around the point of tip contact. This stretch increases slightly the distance between successive line sync pulses recorded on the track. If the recorded tape is reproduced on the machine which made the recording, the tape is stretched during reproduction to the same extent and in the same places as during recording. The time intervals between successive line sync pulses in the reproduced video signal are thus the same as during recording and the reproduced picture suffers no timing errors.

If, however, the tape is reproduced after a long interval, during which the heads have worn appreciably, tape stretch is reduced and so is also the time interval between successive line sync pulses. Thus, on switching heads, a long television line is obtained. The effect this has on reproduced pictures depends on the line synchronising circuit employed. On monitors or receivers with flywheel synchronisation the lines are performed at a constant rate determined by the average interval between line sync pulses in the input signal and the effect of the long line is that vertical details are reproduced as illustrated in Fig. 8 (a) or (b). This is known as the "venetian blind" effect. On monitors or receivers with a hard-locked line time base, one line in each group of 10 or 11 is too long or too short. Details in this line do not therefore take up their correct positions in the picture but the overall effect is not so obvious as in monitors or receivers with flywheel synchronisation. These forms of distortion also occur if the physical properties of the tape have changed (say as a result of temperature or humidity variations), before it is reproduced. It also occurs if the tape is reproduced on a machine other than that which made the recording.

This form of distortion can be eliminated by moving the tape guide horizontally towards or away from the drum to increase or decrease the tape stretch until the correct value is obtained. The tape guide can be positioned either manually or automatically by the tape guide servo. The servo consists of a circuit (the automatic compensation sensor Fig. 6) which detects differences in the time intervals between successive line sync pulses before and after head switching and adjusts the position of the tape guide so as to minimise this difference. This movement varies the stretch of the tape so that there is no abrupt change in line length on head switching.

There is, however, only one position of the tape guide for which the guide and drum surface are concentric; this is the condition for constant tip projection into the guide and thus for constant tape pressure. At all other positions of the guide the surfaces of guide and drum cannot be concentric and variations in pressure are inevitable as a head moves down the tape. Although adjustment of tape guide position can eliminate changes of line on head switching, there still remains a second-order effect due to variations of tape pressure as each head performs its 90° arc. This time modulation within the period of each head traverse causes, on monitors or receivers with flywheel synchronisation, curvature of vertical details repeated every 10 or 11 lines, an effect known as "scalloping": it is illustrated in Fig. 9 (a), and (b). This effect can be minimised by adjustment of the vertical position of the tape guide.

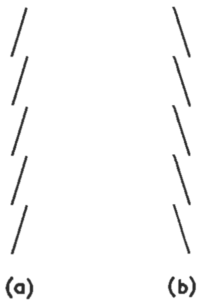

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Fig. 8 Vertical Straight Lines reproduced on a Receiver or Monitor with Flywheel Synchronisation, illustrating "Venetian-blind" Effect

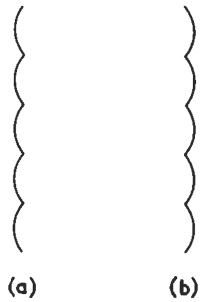

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Fig. 9 Vertical Straight Lines as reproduced by a Receiver or Monitor with Flywheel Synchronisation, illustrating "Scalloping" effect

Adjustment of the tape-guide position is an important facility of the Ampex machine and has made interchangeability of tapes possible: in other words tapes can be reproduced, on any machine.

Present Development

The performance of the Videotape recorder, in the form in which it exists in 1958, has been considerably improved over that obtained from the experimental unit first used in 1956.

The development of special tape, with surface smoothness much finer than that normally provided (or needed) in audio tape, specially-formulated oxides of particularly good resolution and improved mechanical characteristics have all combined to make possible the routine realisation of signal-to-noise ratios of 34 to 36 dB, with occasional attainment of ratios as high as 40dB.

Head manufacturing techniques have also been improved, reducing the abrasion effect, both on the tape and on the heads, to the point where a substantial number of heads have proved usable well beyond the 100 hours which were originally considered a practical life. Tape too is proving capable, under these improved conditions, of being reproduced many more times without deterioration, and of being recorded and rerecorded for an aggregate of well over the 100 passes of the revolving heads which at first were thought to be the practical maximum.

Head Deterioration

Deterioration in heads, due to wear, does not produce deterioration either in resolution or in the linearity of grey-scale transfer; in fact, resolution improves slightly as heads wear and only the eventual increase in noise tells of the approaching end of the useful life of the heads.

The same is true of tape; neither resolution nor grey-scale linearity is affected by the gradual abrasion of the tape which occurs in use. Instead, the signal-to-noise ratio begins to deteriorate, signifying the end of the useful life of the tape.

Linearity of grey-scale is an inherent advantage of the video-tape recording process and is due to the modulation system used. Differential gain measurements give typical readings of under 10 per cent; this remains constant, being quite independent of head or tape condition. The live appearance of the video-tape reproduction is as much due to linear grey-scale transfer characteristic as to any other operating characteristic of the machine.

Resolution of better than 300 lines, with high contrast ratio, is readily obtained.

Tape Duplication

American experience with the recorder in daily network and station operation has established the practicality of making duplicate tapes from an original. There is no method of making copies except by connecting one or more video tape units as recorders, with another used as a reproducing machine but the number of copies which may be made in this manner is substantially unlimited.

First-generation copies of an original video-tape recording are deteriorated in hardly any visible way, resolution and grey-scale linearity being substantially identical to the original. A slight rise in noise occurs, but if this is already well below visibility in the original the copy will appear virtually the same as the original.