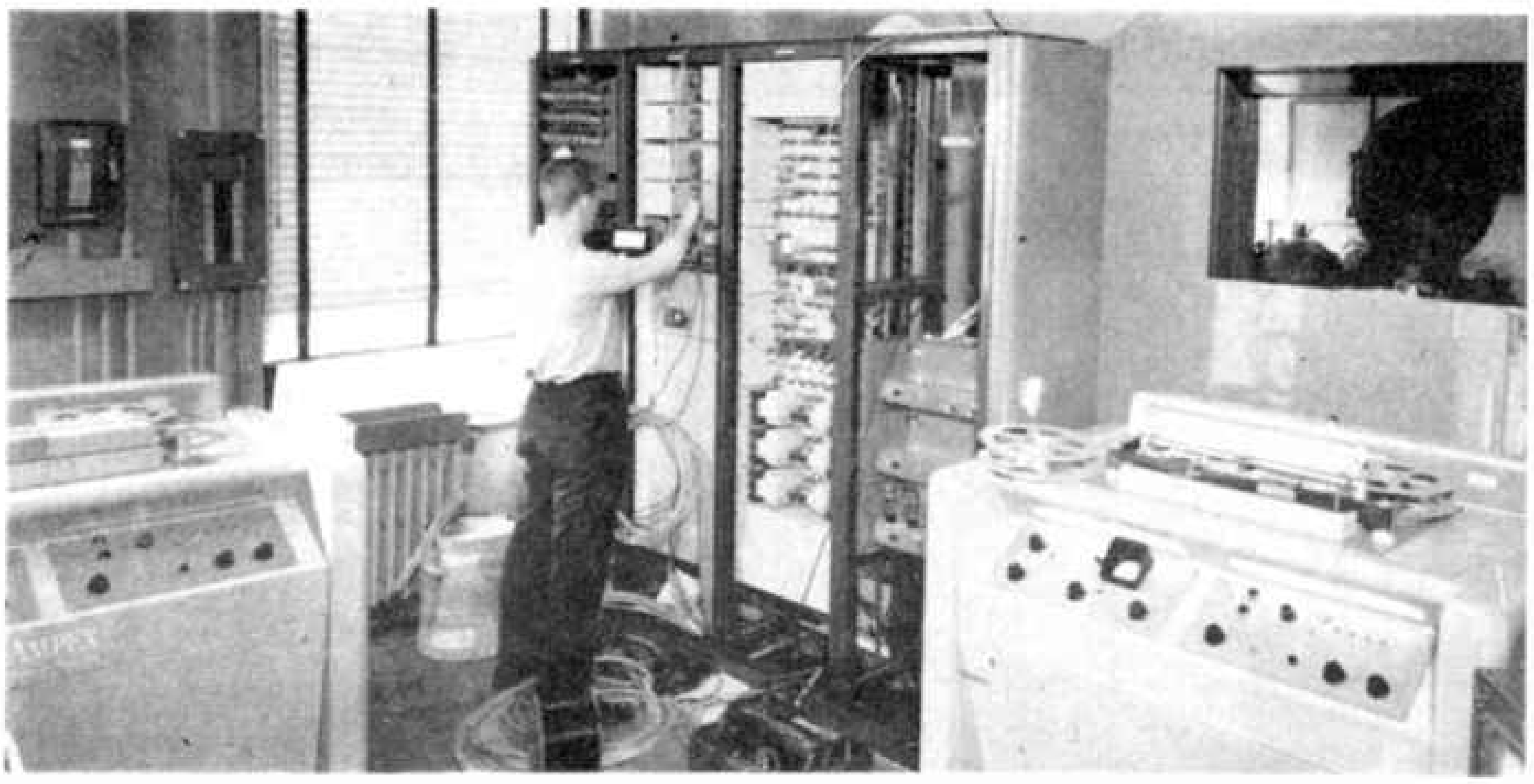

Technician wires rack equipment in ABC's Chicago video-tape recorder installation

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VIDEO TAPE RECORDER

SUMMARY — Low tape speed and extended high-frequency response are achieved in magnetic tape recorder by revolving four recording heads transversely across tape while tape moves only fast enough to keep successive tracks from overlapping. Recorded tapes have signal-to-noise ratios of 34 to 36 db with better than 300-line resolution and high contrast ratio

THREE POSSIBLE WAYS to extend the uppermost frequency response of magnetic tape recorders have been investigated. The brute force techniqe pulls the tape past the heads fast enough so a 4-mc signal appears on the tape as a wavelength about the same as the shortest used in audio. A second approach uses a number of channels in a time-multiplex arrangement. Both of these methods present mechanical difficulties.

This article described a third approach that revolves the head rapidly across the tape, while the tape moves only fast enough to keep successive transverse tracks from overlapping one another. This method presents a series of problems which are unique, but which are soluble in a practical, manufacturable machine.

Video-tape Recorder

As illustrated in Fig. 1, the Ampex recorder has four heads mounted at the outer circumference of a rotating disk with their gaps parallel to the disk axis.

Each head is spaced as nearly as possible at 90 deg from the next on the disk. With a disk diameter of about 2 in. and a rotational rate of 14,400 rpm (240 rps), the writing speed or relative head-to-tape velocity is about 1,500 ips.

The reel-to-reel tape velocity depends upon the width of the tracks which are to be laid down, one after another, transversely on the tape and upon the necessary space between them. These tracks are 10 mils wide, with an edge-to-edge separation of 5⅝ mils and a center-to-center spacing of 15⅝ mils. It is thus possible to obtain a great reduction in tape speed and to operate at the familiar 15-ips velocity. Using thin tape, 64 min of recording are obtained on a 12½-in. diam reel of 2-in. wide tape.

A 120-deg arc is described during the complete sweep of a head transversely across the tape.

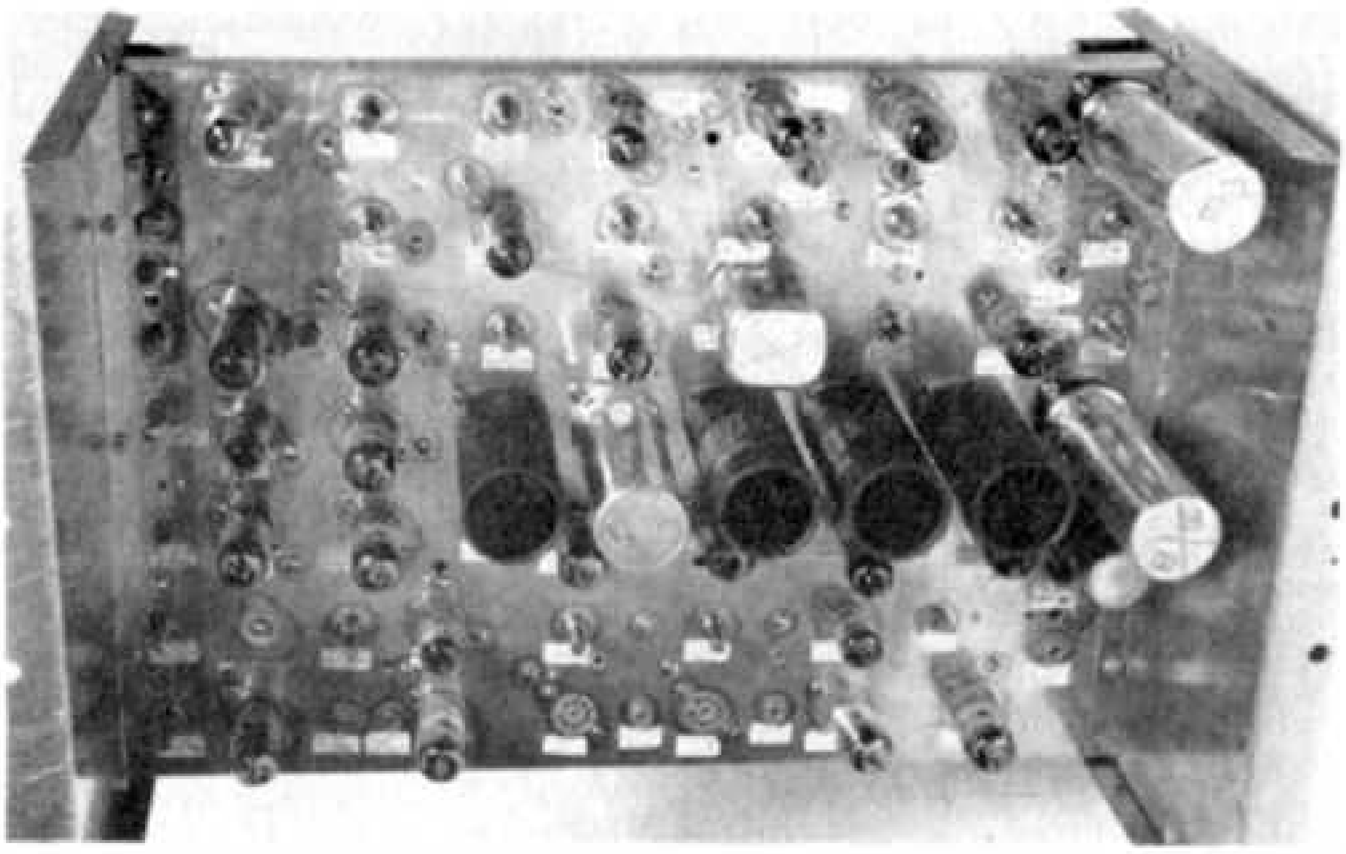
Since all four heads are fed the same currents during recording, there is a duplication of information toward the end of one track on the tape and at the beginning of the succeeding one. Advantage is taken of this duplication in the switching system used to deliver continuous transient-free signals during replay.

With four heads performing 960 sweeps transverse to the tape each second or each 15 in. of tape, one frame occupies ½ in. of tape longitudinally and the 525 horizontal lines which make up one full tv frame are recorded on 32 successive sweeps or tracks on the tape. Each track carries 16 or 17 horizontal lines of television information.

Three Tracks

The recorded tape has three separate, but synchronized magnetic tracks as shown in Fig. 2. The first (Fig. 2A) is the series of transverse video tracks; the second (Fig. 2B) is the sound track that accompanies the picture, which is im-

Playback of first regularly scheduled broadcast of CBS using video-type recording



Rack-mounted video processing amplifier corrects deformation of demodulated signal during playback

USES REVOLVING HEADS

pressed at the top of the tape; the third (Fig. 2C) is a signal that comprises a record of the alternating currents which fed the rotating disk motor during that recording.

During recording the sound track is wiped clean by the preceding erase head, for maximum signal-to-noise ratio.

Erasure has proved to be unnecessary on the control track. Even after erasure of the top 100 mils of the tape (for the sound track) and the destruction of the lower 100 mils of the recording by the control-track recording head, more than 90 deg of arc are still recorded on each transverse track. The overlap of information is approximately two tv picture lines, or around 130 μsec. During replay this allows a generous time interval during which electronic switching from head-to-head can take place.

Tape Transport

The transport mechanism used is similar to that found in many professional magnetic audio recorders. As illustrated in Fig. 3, the tape is supplied from a reel on the left; it is stabilized in its motion by passing around an idler whose motion is dominated by a heavy flywheel. It passes by the rotating video head assembly then goes on to a stationary pair of heads on one stack.

Of this stack, the upper one is an erase head which clears a 100-mil strip at the upper edge of the tape. The lower head records the control track in a similar strip along the bottom edge of the tape, without erasure. The tape then moves to a second stationary head stack which contains only the combination audio track record-replay head.

The tape next passes between a

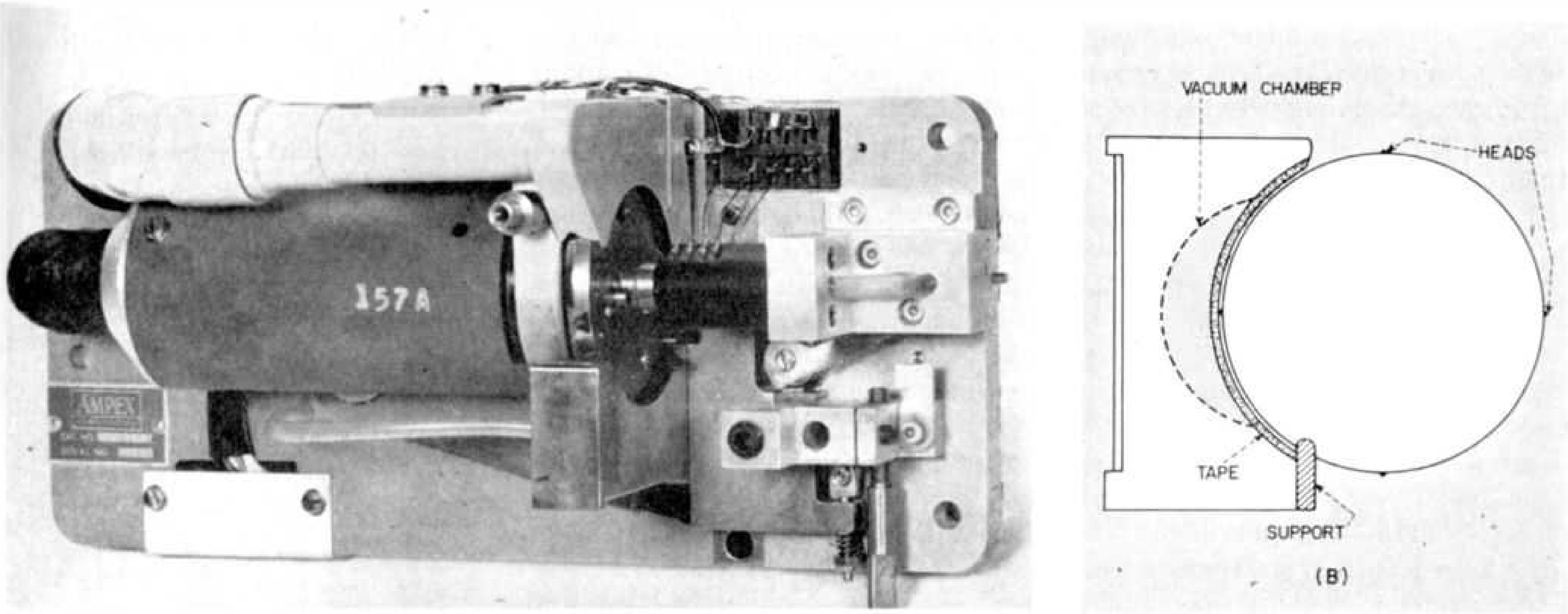


FIG. 1—Head subassembly (left) includes rotary heads, motor, commutator and vacuum guide chamber (right) to align tape

drive capstan and its pressure idler, around a takeup idler and on to a tape takeup reel at the right. The erase, audio and control track magnetic heads are stationary.

Guiding of the tape past the rotating disk is accurately, yet delicately controlled by the concave guide, shown in Fig. 1, which is used to cup the tape around the disk. The relation of tape to rotating heads must necessarily be intimate and good head contact at nearly constant pressure is required. This is accomplished by maintaining the fit of the concave guide within small tolerances to the exact path of the rotating heads and through the use of vacuum applied from the guide side of the tape.

System Operation

The recording system is shown in block form in Fig. 4.

During both recording and replay, an intimate relation must exist between the rotation of the revolving heads and that of the capstan. This process begins at the time the signal is recorded.

While recording, the 60-cps power-line frequency is first applied to a frequency multiplier, which produces a 240-cps signal. This signal drives a three-phase power amplifier during the original recording which in turn supplies 240-cps power to the synchronous motor which drives the rotating disk.

A portion of the revolving mechanism is coated half black and half white. A light source is focused on this revolving black and white disk and reflected into a photo cell to produce a 240-cps square-wave output. This is passed through a frequency divider, coming out at 60 cycles. The signal is then passed through a filter, whose output is a clean 60-cps sine wave, which in turn is fed to a power amplifier, whose output drives the capstan motor.

The whole chain is electrically analogous to a mechanical gear train, coupling the rotation of the capstan firmly to the rotation of the head disk. Neither the head disk motor nor the capstan motor are driven directly by the 60-cps power line frequency, although the power which is supplied to the disk-driving motor is directly derived from the incoming 60-cps signal.

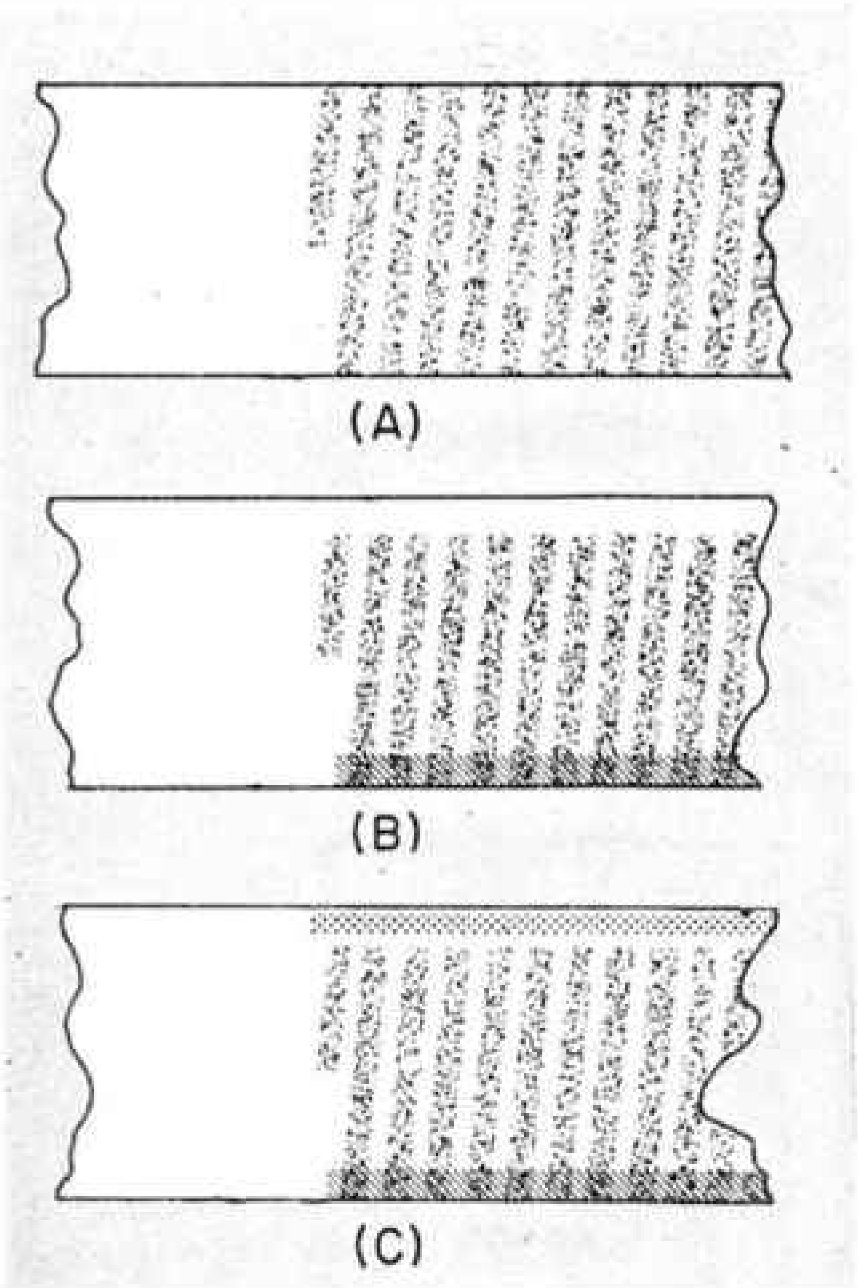


FIG. 2—Signal pattern after passing video head drum (A) paired audio-erase and control-track record heads (B) and audio-record head (C)

The power supplied to the capstan is generated from the actual motion of the revolving heads, enslaving the capstan to the head disk. Thus, during the recording process, the tape is moved precisely 62.5 mils longitudinally during each complete revolution of the head disk. During this period, four lateral tracks are recorded, one for each head, each track being separated from the next by a center-to-center space of 15⅝ mils.

Control Track

During this process, the 240-cps 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 on the control track at the bottom of the tape (Fig. 2B). This control track becomes the magnetic equivalent of the sprocket-holes of a sprocketed film machine. Since the 240-cps signal is derived directly from the revolving heads, the signal on the control track bears a direct relation to the spacing of the lateral tracks on the tape and this information is available as a reference to control the relative positions of the head disk and capstan shaft during replay.

When the recorded video tape is to be played back, power line frequency is again multiplied to 240 cps, amplified and fed to the head disk motor, driving it at a rate which is at least approximately correct, for the purpose of tracing the previously recorded magnetic tracks. Again, the photocell produces a signal corresponding to the revolutions of the disk, this signal, once more being fed through a 240-cps bandpass filter and then, not to the control track recording head, but instead as one of two 240-cps signals to a phase comparator in the capstan servo amplifier chassis.

The second of these two 240-cps signals is that derived from the recorded control track, which is simultaneously amplified and fed to the phase comparator. The resultant signal is a function of the phase difference between the two signals. This is applied to a low-pass filter and then to the grid of a reactance tube which is one of the frequency-determining elements of a conventional Wien-bridge oscillator.

The oscillator functions nominally at 60 cps, but is slightly modified, up or down, by the correction-signal from the phase comparator. This signal is then fed to the power amplifier which drives the capstan in the same relation to the rotating disk, within narrow limits, as it did during the recording process.

Once the disk is adjusted on center to the tracks at the beginning of replay, the servo system holds the relation constant and the revolving heads indefinitely trace accurately the recorded video tracks.

The output of the photocell can also be used to determine in advance, the approximate moment during playback when it will be

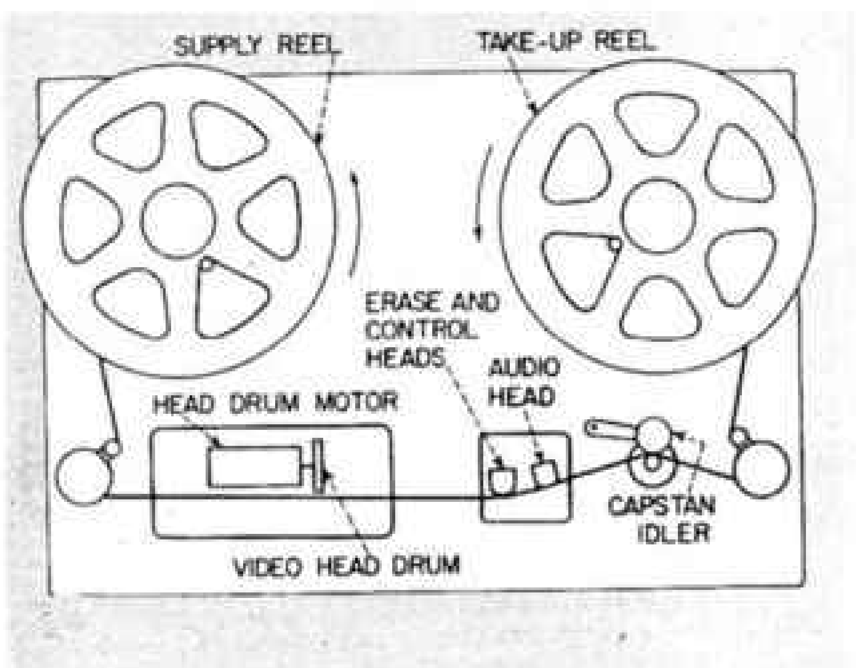


FIG 3—Tape transport mechanism

necessary to switch from one playback head to the next.

Editing and Splicing

There is a means of identifying that line on the tape which represents a vertical synchronizing pulse. The tape is wiped with a harmless solution that renders the magnetic recording visible. Since the vertical pulses have a characteristic and recognizable appearance, they may be located with precision. In equipment of more recent development they are used to identify the line along which the tape may be cut and spliced to another tape similarly cut.

Modulation System

It was necessary in the development of the recorder to seek a means of recording and reproducing the range from d-c to 4 mc or more and not just the upper end of that spectrum. A modulation system came naturally to mind, a f-m system being immediately appealing and ultimately adopted, in an unusual form.

Classically, it is assumed that the highest modulating frequency used in an f-m transmission system will not exceed one-tenth the carrier frequency and that deviation will be large compared with maximum modulating frequency. This implies a carrier of 40 mc, so the use of f-m would have to be abandoned, if these conditions were to be observed.

Recording the 40-mc carrier frequency requires either a large increase in head-to-tape velocity, or a large reduction in the shortest wavelength handled or both. It seemed as if a low-frequency carrier might do. Since it was desired that the range of modulating frequencies be large, compared with the total transmissible bandpass, it was evident that it was also desirable to use an f-m system in which the frequency of deviation was small with relation to the frequency of modulation. Thus, both classical assumptions in f-m transmission were to be violated.

Deviation Ratio

When the ratio of deviation to maximum modulating frequency is small, one pair of the sidebands is attenuated. When the ratio of deviation to modulating frequency is 0.1, the second pair is only 0.1 percent of the unmodulated amplitude of the carrier; where this ratio is 0.5, the second pair is still only 3 percent of the unmodulated amplitude of the carrier, while the first pair has increased to 24 percent of the unmodulated carrier amplitude. It can be seen that an unbalanced sideband condition is developed as the ratio of deviation to modulating frequency is decreased.

The exact solution to the dominant equation for the case where the ratio of deviation to modulating frequency is less than one-half is in the literature.[1] When this solution is applied to a series of sidebands under the conditions obtaining in the video-tape recorder, where carrier frequency equals 5 mc and deviation frequency is 1 mc or less, the unbalance of sidebands becomes quite great. These are no longer the relatively simple upper and lower sideband relations of the classical f-m system, but a new species of transmission system which might be called semi-single-sideband f-m transmission or just lopsided f-m.

In single sideband transmission of a-m signals, it is only necessary to handle enough of the vestigial sideband to insure that the filter employed does not introduce undesirable phase shift at the carrier frequency. With the lopsided f-m system, however, intelligence is preserved in the series of instantaneous frequencies which are created by the two side bands simultaneously. Since it is in the deviation that the intelligence lies, both its upper and lower excursions are meaningful.

In the case of the video-tape recorder, when the carrier is 5 mc, maximum modulating frequency is 4.5 mc and deviation is held to 500 kc; the head-tape system must efficiently pass frequencies from 5 mc less 4.5 mc or 500 kc, up to 5 mc plus the deviation frequency or 5.5 mc.

This configuration of carrier, modulating frequency and deviation can encompass the television spectrum within the recordable bandpass of the magnetic recording system required. It is a comparatively simple matter to preserve frequency relations approaching d-c in an f-m system. At a later stage of development it may be preferable in handling the lowest frequencies to use d-c restoration techniques in the interest of simplified video amplifier circuitry.

Signal-to-Noise-Ratio

In f-m, when the ratio of deviation to modulating frequency is large, the bulk of the transmitted

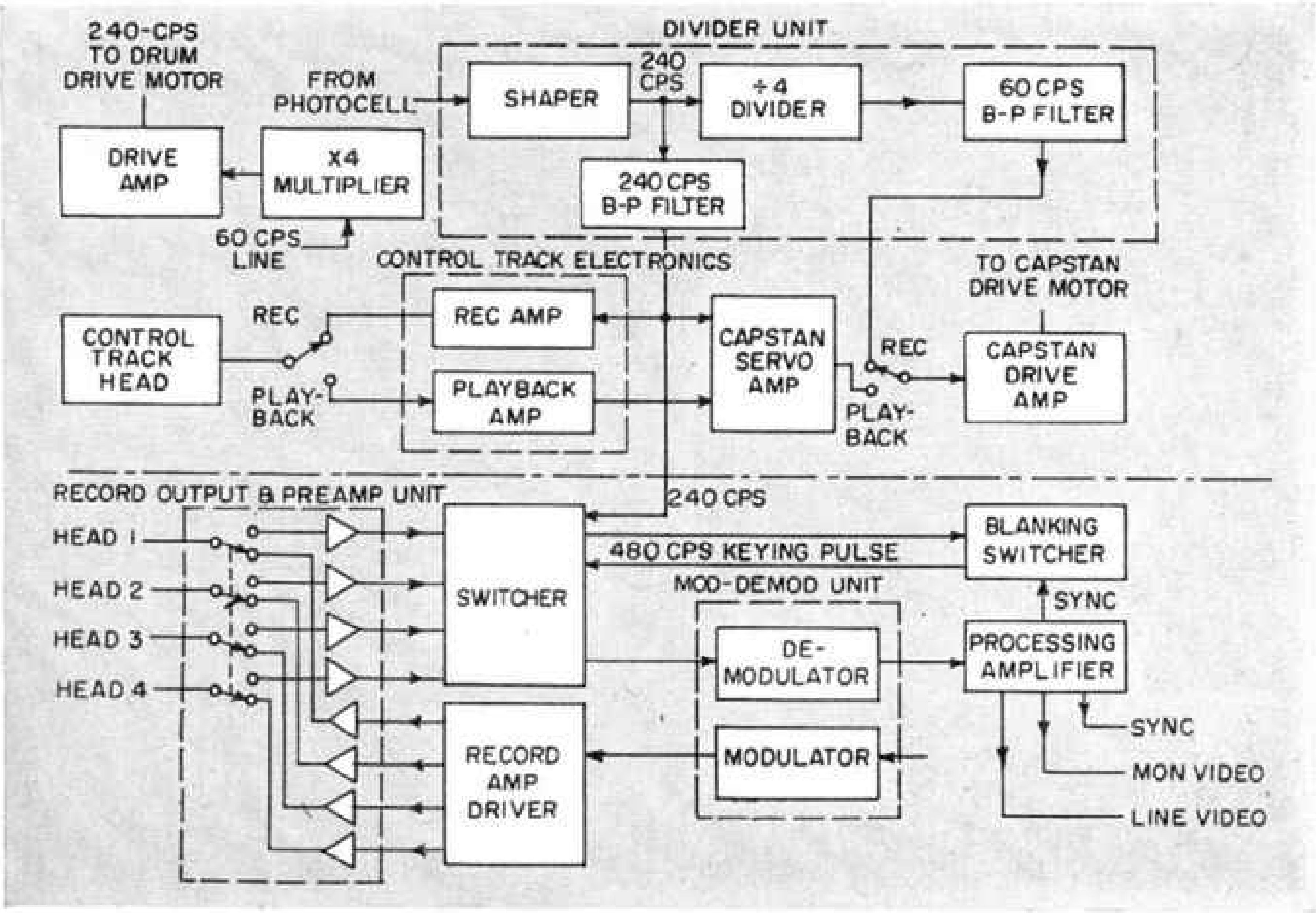


FIG. 4—System block diagram is divided into control system (top) and video (bottom)

energy is in the sidebands and the noise rejection capability of the system is greatly superior to that of a-m systems. As this ratio is decreased the advantage decreases and finally disappears entirely when the f-m sideband energy is less than that which is obtained in 100-percent amplitude-modulation.

In the video-tape recording system, the deviation is 1 mc or less, giving a ratio of 0.25 or less. This results in a wide-band signal-to-noise ratio which is less than that which would be obtained with an a-m system. It was found that by holding within the tape velocity figures which were the aim, a signal-to-noise ratio well in excess of 30 db was attained over the 4-mc bandwidth.

Distortion

The classical assumption that carrier frequency in an f-m system should be ten times the highest modulating frequency or more, was made to avoid the distortion which the higher modulation frequencies must suffer as they approach the carrier frequency. The effect of distortion of video frequencies in the band above 1 mc in the video-tape recorder is a certain amount of zig-zagging of closely spaced vertical lines.

Not only is this effect evident only on such visual material, but the effect of the blurring is greatly reduced by the nature of human vision. When images thus distorted are viewed by the eye, which integrates its experience over a substantial period of time, the result is entirely acceptable, even for images representing a horizontal resolution of 300 lines or better.

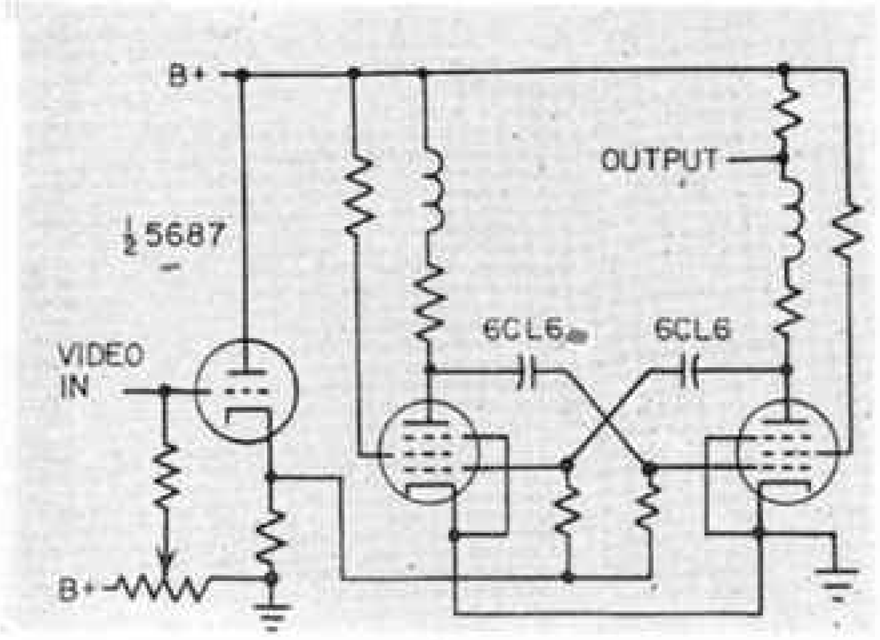


FIG. 5 Basic modulator used for recording

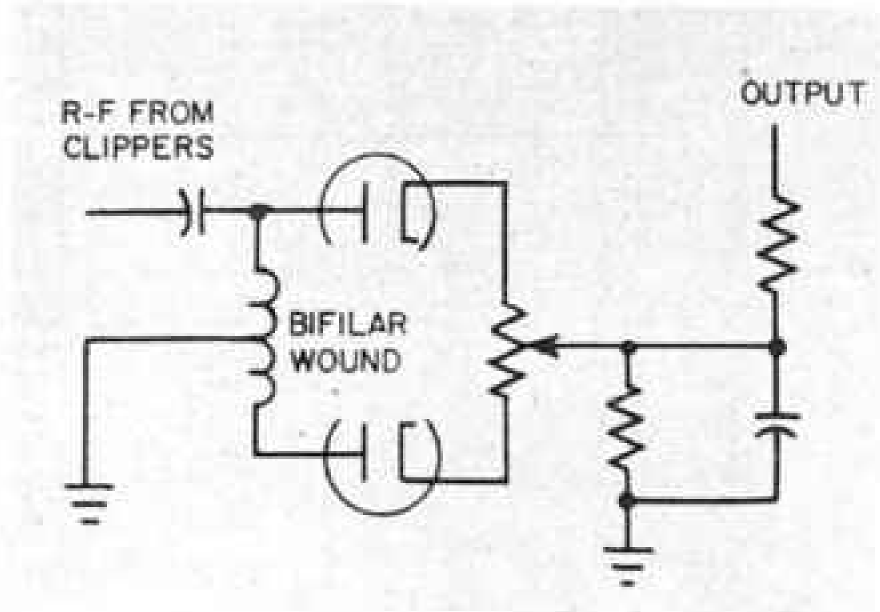


FIG 6—Basic demodulator for playback

Modulator-Demodulator

The circuitry employed in the modulator and demodulator of the video-tape recorder is lacking in novelty. Where deviation does not exceed a megacycle, and with carriers which do not exceed perhaps 6 mc, a multivibrator type of oscillator whose frequency is controlled by direct application of video to its control grids is entirely satisfactory and simple to maintain.

As shown in Fig. 5, two 6CL6 tubes are connected as a multivibrator, with special attention to switching time; the grids of the 6CL6 tubes are driven by one section of a 5687. The multivibrator output is amplified through conventional wideband video amplifiers and then applied in parallel to the two 815 tubes which drive the heads. Each section of the 815's drives a single head continuously during recording.

During replay, the output of each head is fed to its own preamplifier; the four channels feeding into a switcher. From the switcher a single channel of f-m r-f is fed to limiters. The last of these feeds into a bifilar coil, shown in Fig. 6, with a grounded center-tap. This coil resonates outside the system bandpass and the slope of the resulting response curve forms an f-m to a-m translator.

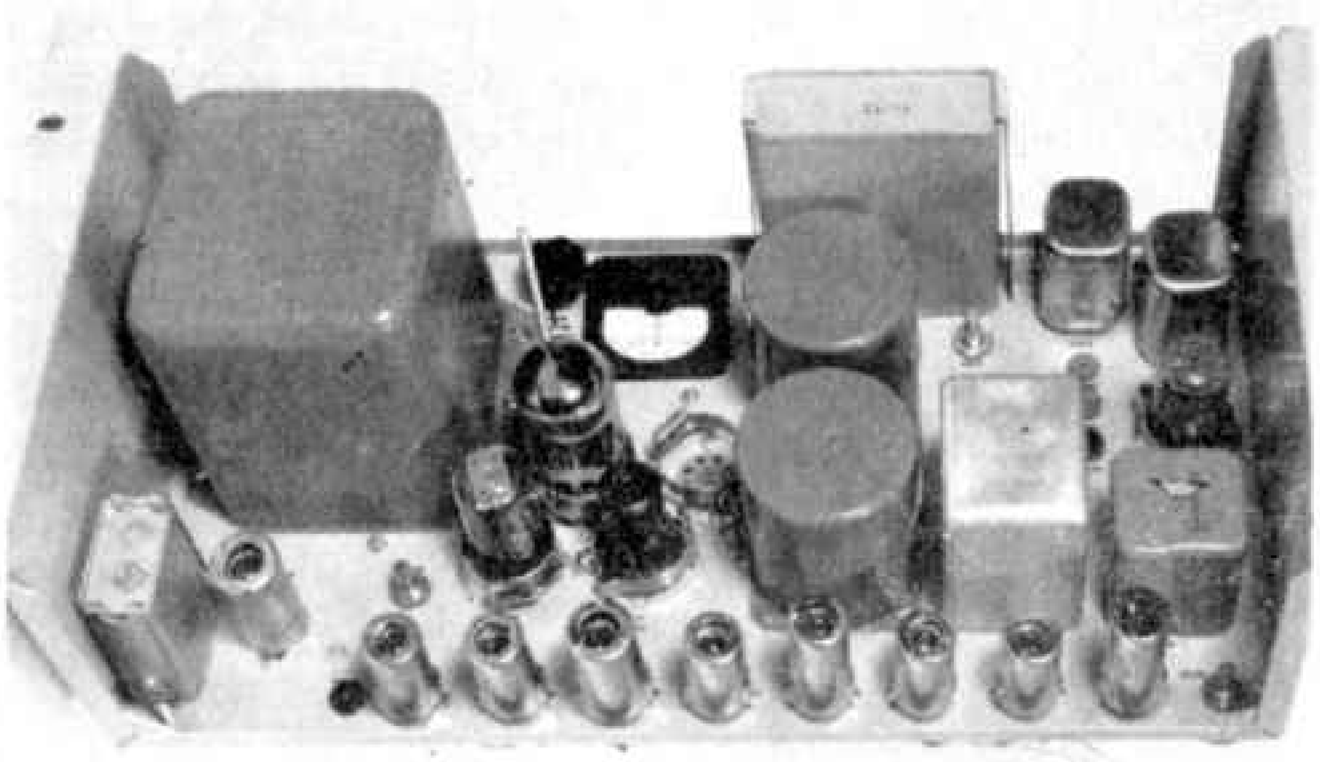
The resulting a-m is rectified through full-wave diodes, which feed a variable resistor acting as a balance control for the carrier. A low-pass filter, next in the chain, further reduces the level of carrier in the output.

Good linearity is readily achieved, so that grey-scale transfer is substantially undistorted.

Playback Switching

During replay, 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 will be introduced into the reproduced picture and later to demodulate the amplified r-f output of the playback heads. The electronic switching arrangement shown in Fig. 7 was developed for this purpose.

A network of coincidence gates is employed with a get-ready signal sent to each gating tube in turn from the 240-cps photocell source; a go signal is delivered with pre-



Rack-mounted capstan-drive servo control chassis supplies 240-cps driving signal to capstan

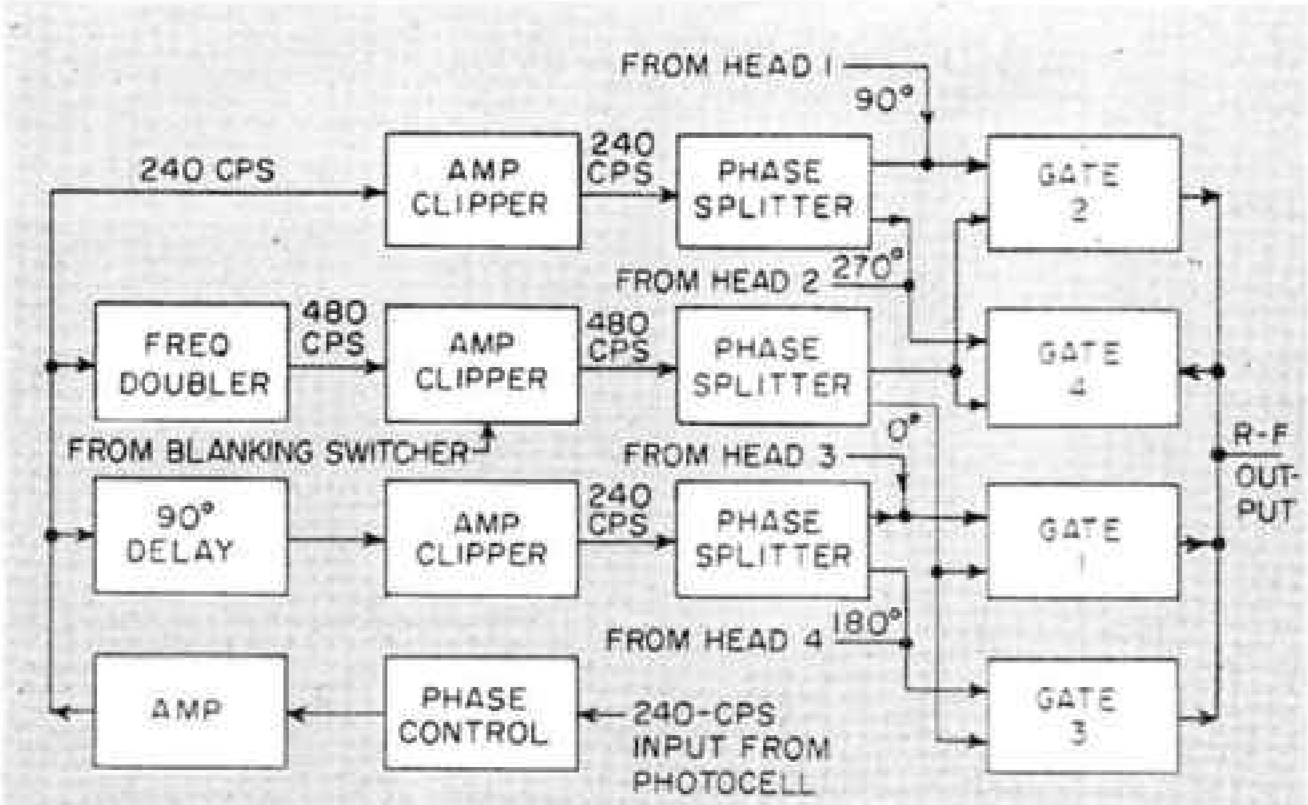


FIG. 7—During playback, electronic switcher derives output from one head at a time

cision to each gating tube from the television signal itself. Switching occurs only on the back porch of a horizontal pulse. Therefore it does not appear in the reproduced picture, even as a transient.

The 6BN6 gating tubes pass the r-f signal to their plate circuits only when each of two grids are 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 sequential switcher, as well as to the servo amplifier control system. This 240-cps signal, whose phase is directly related to the instantaneous position of the rotating head disk, is fed through a vernier phasing control to a 90-deg lag network that controls two related channels in conjunction with other signals. The same signal is continuously fed to a frequency doubler and an in-phase network.

The in-phase 240-cps signal is clipped and fed to a phase splitter, which produces two signals, one in phase and one 180-deg out of a phase. These two signals are applied to the gating tubes, 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 same grids to which the amplified r-f from heads one and three are fed.

The 240-cps signal, which is fed through a 90-deg lag network, is similarly clipped, fed to a phase splitter, and applied to the control grids of gates two and four. In the same way, these gates receive the amplified r-f output of heads two and four at intervals of 90 and 270 deg.

Gate Keying

To cause these gates to pass r-f at the desired times, appropriate positive swings of a 480-cps square wave are applied to the coincidence grids of these gating tubes. The necessary 480-cps square-wave signal is obtained from a frequency-doubler whose input is also fed from the common 240-cps source.

Symmetry of the 480-cps 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 time of about 0.05 μsec, this 480-cps square wave gives the final go signal to each switching operation, so that interruption of the composite signal is exceedingly brief.

The 480-cps square wave, like the two 240-cps control signals, is fed through a phase splitter, one phase

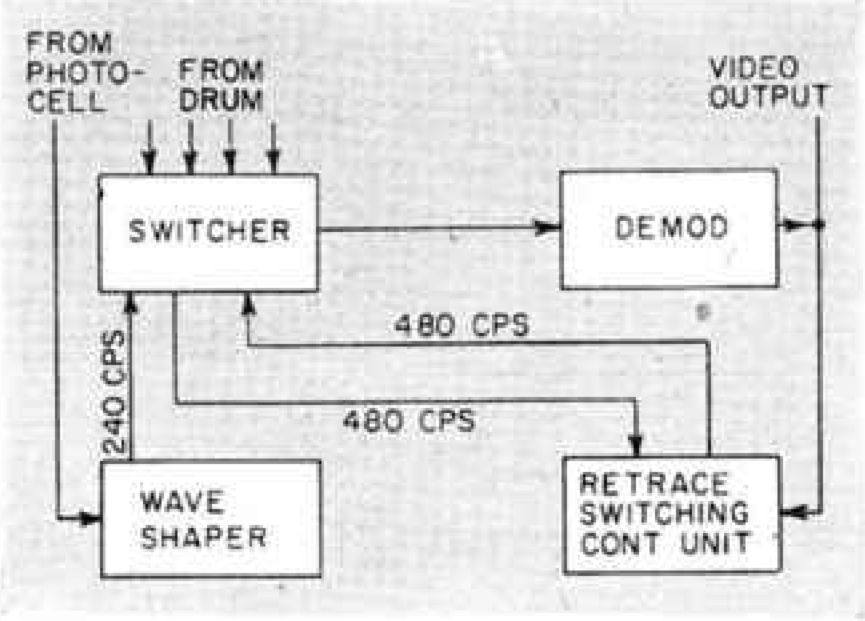


FIG. 8—Retrace control switcher prevents overlap of information in playback

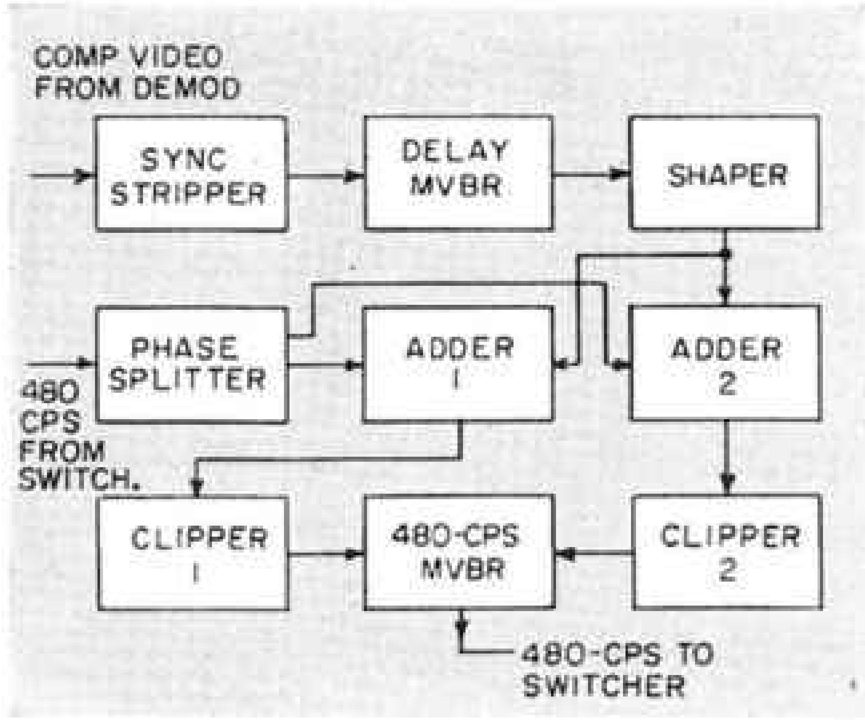


FIG. 9—Elements of retrace switching control unit

going to gates one and three, the other to gates two and four.

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 240-cps control signal is at this time going positive. The phase of the 480-cps square wave is such that it too goes suddenly positive at one point in the rotation of the head disk. At this moment, the gating tube begins to conduct r-f.

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

About 90 deg later in the rotation of the head disk, the 240-cps delayed signal goes positive at the control grid of gate tube 2. This tube is fed from the opposite phase of the 480-cps control-signal from gate 1, so it too goes suddenly positive at the screen grid of this second gate and the tube conducts.

Since this rapid occurrence is coincidental with the negative phase of the 480-cps signal at gate 1, the gate ceases to conduct at the same moment that gate 2 begins to conduct. Gates three and four are both in the negative-going portion of the 240-cps control signal which is applied to them, so that gate 2 is, at this moment, the only one conducting. The same sequence of events occurs next at gate three, as the rotating head disk reaches approximately another 90 deg of rotation.

Retrace Control Switcher

Since approximately two television lines of information are duplicated from track to track on the magnetic tape, the bottom of one line 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 480-cps wave is opened before it feeds the corresponding phase splitter, and this signal is delayed momentarily in accordance with the synchronizing information in the television signal, the switching can be done during retrace when the crt beam is off the television screen. The arrangement used is shown in Fig. 8. The retrace switcher control unit, shown in Fig. 9, contains a 480-cps multivibrator oscillator, which is locked jointly to the 480-cps photocell-derived signal and to the synchronizing pulses in the demodulated r-f video signal. Over a relatively narrow range, this oscillator's frequency may be varied, effectively delaying its output with respect to the 480-cps switcher signal, so that the exact moment at which the outgoing 480-cps square-wave goes positive may be made to coincide with a desired point in the controlling video signal.

As illustrated in Fig. 10, the switching time may be positioned on the back porch interval, which places the switching transients on the extreme left-hand side of the reproduced picture, out of view. Should the video signal fail, the multivibrator oscillator in the re-