SIGNAL TRANSLATION THROUGH THE AMPEX VIDEOTAPE RECORDER

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Signal Translation Through the Ampex Videotape Recorder

By CHARLES E. ANDERSON

Here are described the various operations performed on the video signal as it travels through the Ampex Videotape Recorder. Briefly outlined is the history of each problem and some of the reasons for the solution applied.

The Modulation System

When a standard NTSC monochrome or color signal is fed to the recorder at standard level, the first operation it encounters is in the modulator. The obvious question that comes to mind is, "Why a modulation system?" The reasons for using such a system were covered briefly in an earlier paper.[1] There was not time to develop properly then some of the ideas or to answer all of the obvious questions. It was pointed out in that paper that (a) the use of a carrier system eliminated the problem of reproducing low frequencies from tape, since sidebands generated in the modulation system did not fall much below 500 kc. It also was pointed out (b) that frequency-modulation, in particular, overcame many of the problems inherent in a revolving multi-head device. Unanswered were some questions about what happened to our conventional ideas of frequency modulation (particularly what distortions were generated) when parameters were pushed to the point where the modulating signal approached the carrier in frequency, and the deviation became an appreciable percentage of the carrier. Finally, there was (c) the question of what further distortions were generated by single or vestigial sideband transmission of FM.

All three questions were pragmatically answered in early work by building the equipment and trying it. Fortunately, it worked. As the excitement of early discoveries died, more scientific explanations were sought.

The first question (a) is that of low-frequency response. If 3 mv at 5 mc is considered an adequate output, to still achieve 40 db signal-to-noise, only 3 octaves down from this are possible, giving a lower frequency limit of just under a megacycle. This leaves a usable bandwidth of 4 mc which is adequate for a television image conforming to U.S. standards. The simplest manner in which to use the available spectrum is then to modulate a 5-mc carrier with the 4-mc video signal while utilizing only the lower sidebands.

To take up the second point (b) a complication to a rotating-head method, as used in present recorders, is the chopping of the signal at a 960-c rate. At the present state of the head-building art, it is impossible to build heads that have identical outputs, with the result that each portion of the picture corresponding to one of the four heads will have different contrasts.

The modulation scheme that best handles a fluctuating signal of the variety produced by a rotating, multi-headed scanner is frequency modulation, since the variations in head output can be eliminated by limiting action. If the modulation index is kept smaller than approximately 0.1, only a single pair of sidebands is generated, allowing the information to fit in the allotted space.

Such a statement assumes that a single sideband may be used with frequency modulation, as it is with amplitude modulation.

An apparent answer was found to the questions in point (b) in work by Cambi[2] in which he derived his equations by considering the elementary method for the production of a frequency modulated wave as yielded by a resonant circuit where capacitance or inductance is made periodically variable. Since a multivibrator was used as the oscillator in the Ampex system, there is a logical question as to the validity of applying Cambi's work to this situation.

A means for measuring the amplitudes of the generated sidebands was devised and measurements taken. The results indicate an asymmetrical distribution of the energy, with the higher frequency sidebands having more energy than their lower counterparts. This condition at first seems unfortunate, indeed, for these upper sidebands are those which must be sacrificed if the system is to be squeezed into the limited bandpass available from the tape and heads.

To explore the problem further, a different type of modulator was built and tried. Cambi indicated that a heterodyning process, used to achieve large values of deviations and large values of modulating frequencies with respect to the carrier, would also give the lopsided distribution shown by his theory. If this were true, then a modulator of this type could be compared with a multivibrator, the results observed, and a further check on the validity of the Ampex assumptions be had. Figure 1 is a block diagram of such a modulator. An oscillator operating at 60 mc was modulated by a reactance tube whose input was isolated from the tank circuit by a cathode follower. The output of that oscillator was beat against the output of a second crystal-controlled oscillator operating at 65 mc resulting in a FM carrier having deviations one-fourth of the carrier, with modulating frequencies approaching the carrier.

When the outputs of the two types of modulators were passed through the balance of the system so that each experienced the same frequency sensitive networks, there were no discernible differences in picture quality. The data indicated the shift of energy to the upper

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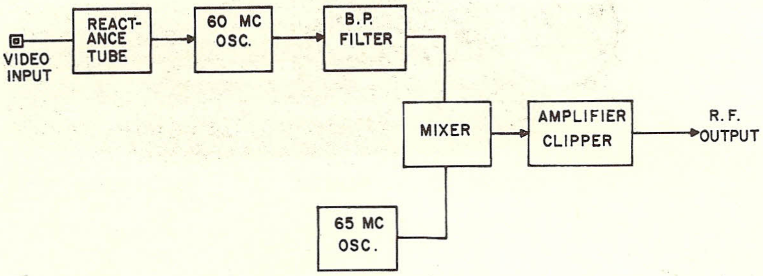

Fig. 1. Block diagram of modulator constructed to test theoretical assumptions concerning sideband and carrier energy in a frequency-modulation system in which modulating frequency approaches carrier frequency, and in which deviation frequency is small in relation to modulating frequency.

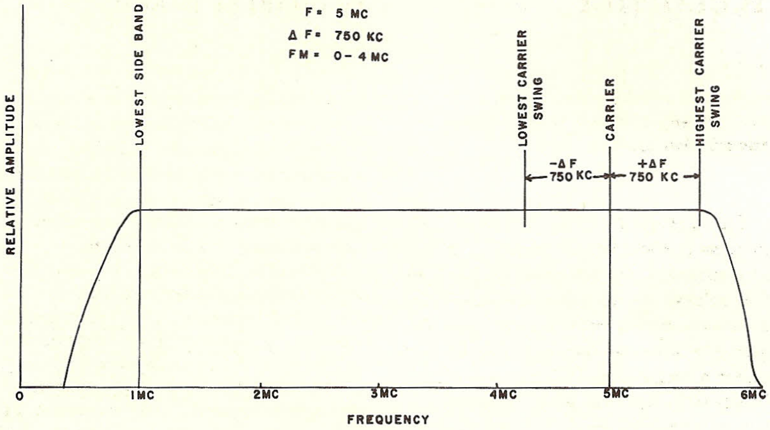

Fig. 2. Bandpass requirements for a frequency-modulation system like that used in the Ampex Videotape Recorder.

sidebands to be generally less than predicted by Cambi. We did not, however, have the time to explore this further.

The third question (c) of single or vestigial sideband transmission has been answered adequately, and it has been found to be no more of a problem with FM than with AM.

My associate, Harold Walsh, shows mathematically what happens when upper sidebands of a frequency-modulated signal are attenuated.

If a sinusoidal carrier $\sin \omega_0 t$ is frequency modulated by the single-tone $A \cos \omega_1 t$, where A and ω_1 are such that, for the system, the deviation-ratio β is about 0.4 or less, then the modulated wave is:

$$i = J_0(\beta) \sin \omega_0 t + J_1(\beta) \sin (\omega_0 + \omega_1)t - J_1(\beta) \sin (\omega_0 - \omega_1)t \quad (1)$$

If the upper component, $J_1(\beta) \sin (\omega_0 + \omega_1)t$, is lost on the way between modulator and receiver limiter, so that the wave entering the latter is:

$$i' = J_0(\beta) \sin \omega_0 t - J_1(\beta) \sin (\omega_0 - \omega_1)t \quad (2)$$

this represents a wave simultaneously amplitude modulated and frequency modulated. This can be shown by adding to Eq. (2):

$$0 = \frac{J_1(\beta)}{2} \sin (\omega_0 + \omega_1)t - \frac{J_1(\beta)}{2} \sin (\omega_0 + \omega_1)t \quad (3)$$

The result yields:

$$\begin{aligned} i' = {} & \frac{J_0(\beta)}{2} \sin \omega_0 t + \frac{J_1(\beta)}{2} \sin (\omega_0 + \omega_1)t \\ & - \frac{J_1(\beta)}{2} \sin (\omega_0 - \omega_1)t \quad \text{FM} \\ & + \frac{J_0(\beta)}{2} \sin \omega_0 t - \frac{J_1(\beta)}{2} \sin (\omega_0 + \omega_1)t \\ & - \frac{J_1(\beta)}{2} \sin (\omega_0 - \omega_1)t \quad \text{AM} \quad (4) \end{aligned}$$

Now if the limiter wipes out the AM, the output is:

$$i'' = \frac{J_0(\beta)}{2} \sin \omega_0 t + \frac{J_1(\beta)}{2} \sin (\omega_0 + \omega_1)t - \frac{J_1(\beta)}{2} \sin (\omega_0 - \omega_1)t \quad (5)$$

and this is the original FM wave, complete with both side frequencies, but down 6 db.

If the reader wishes to extend the simple mathematics shown above, it will be noticed that the reconstruction process produces an upper sideband set whose polarity is opposite to that of the corresponding lower set. This is precisely what is required to match an odd-ordered lower band and precisely what is not required to match an even-ordered lower band. This complication might, in practice, lead to disastrous results if the reconstruction process were not confined to the range below approximately $\omega_0 - 2\Delta\omega$, where $\Delta\omega$ is the maximum deviation of the carrier. A table of significant sideband frequencies versus deviation-ratios shows this range to be practically free of significant even-ordered components.

To prevent the reconstructive process from operating in the range above $\omega_0 - 2\Delta\omega$, which is heavily infested with even-ordered components, all original upper band signal components in the range ω_0 to $\omega_0 + 2\Delta\omega$ must be trans-

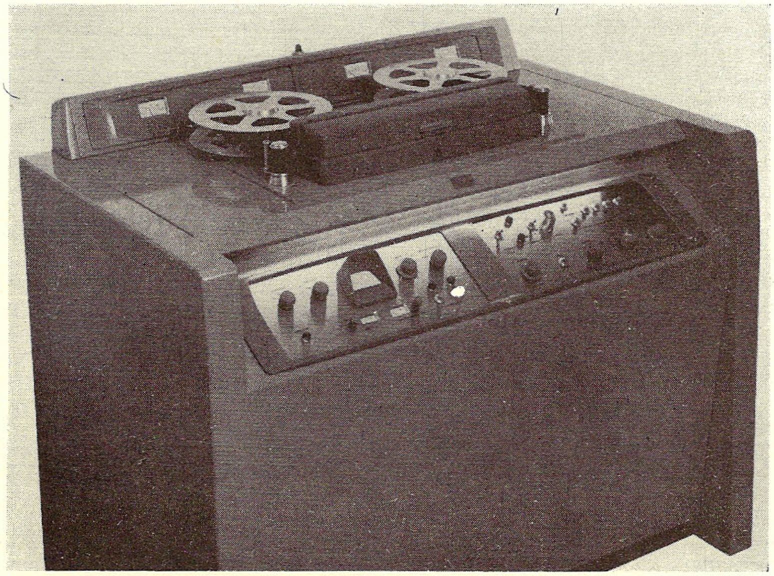

Fig. 3. The production model Ampex Videotape Recorder.

mitted without too much attenuation.

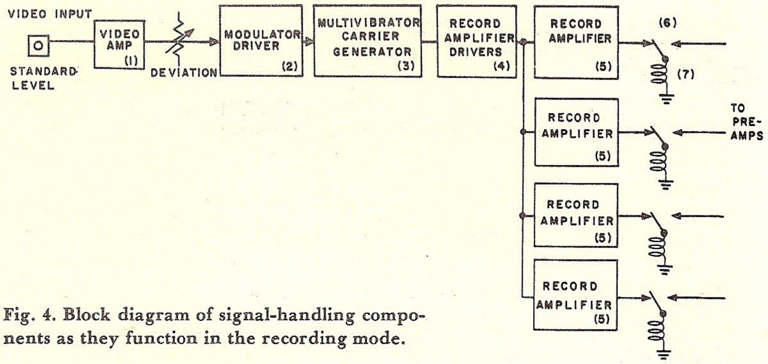

Fig. 4. Block diagram of signal-handling components as they function in the recording mode.

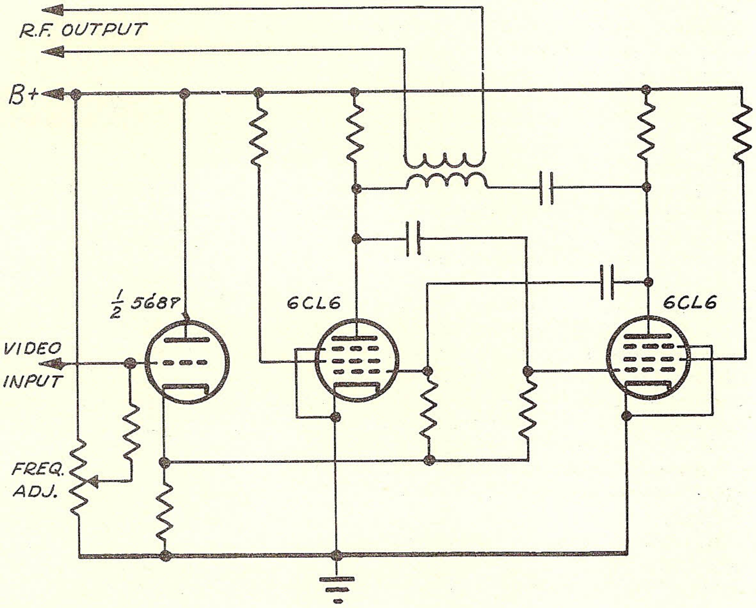

Fig. 5. Simplified schematic diagram of the modulator.

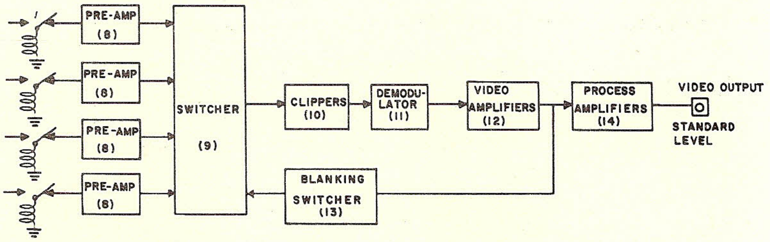

Fig. 6. Block diagram of signal-handling components as they function in the replay mode.

In practice, these limits may be diminished significantly before distortion becomes noticeable. Experience shows that only the upper components in the range $\omega_0 + \Delta\omega$ need be transmitted, and that if this minimum is met, picture quality is acceptable and distortion is either slight or not noticeable. Figure 2 indicates a system bandpass needed to handle a carrier modulated under typical conditions found in Ampex recorders in use today. Using practical values of F (carrier) = 5 mc, ΔF (deviation) = 750 kc, and FM (modulating frequency) ranging from zero to 4 mc, this necessitates a minimum pass band from 1 mc to 5.75 mc.

A Practical System

Production machines resemble earlier models. Externally, the newer equipment is pleasing to the eye, as Fig. 3 testifies. The equipment is also more pleasing to the operator, for pains have been taken to simplify controls and provide a flexible machine. A block diagram (Fig. 4) of the signal-handling portion of the recorder shows where some of this equipment ties in functionally. A signal of standard level and polarity is fed to the recorder, where it is amplified by conventional means (1) and applied to the grids of a multivibrator (3) via a cathode follower (2).

The output of an unbalanced modulator contains components corresponding to the modulating wave. In the case where modulation frequencies approach the carrier, the sidebands and modulating frequencies are added if the latter are not suppressed. This is exactly what happens in a multivibrator type of oscillator-modulator if care is not exercised to remove the modulating frequency components. The form of balancing now used is shown in Fig. 5.

On a black-and-white picture, video feed-through manifests itself as an effect which looks like fine hair waving to the right of sharp transitions. The corresponding effect in facsimile transmission has been called "Kendall effect."[3] On a color picture, where a great deal of energy is present at 3.58 mc, such feed-through is more obvious in the form of beat patterns on the screen as the 3.58 mc beat against the FM carrier.

If video feed-through is present at the output of a modulation process, trouble can be compounded by nonlinearities in the rest of the system. Beat notes become very obnoxious in color while the hair effect on both monochrome and color is objectionable. The head driving amplifiers are a particular nuisance. Each of the four video heads has an inductance of approximately 30 μh. Ignoring resonance, which occurs at slightly above 6 mc, the impedance to which the amplifier must supply constant current ranges from 140 ohms at 750 kc to 1130 ohms at 6 mc. An amplifier utilizing an EL-34 tube, with a 1-mh choke as a plate load, has been found to supply essentially constant current at an adequate level.

Signal Translation During Replay

For playback, the video heads are switched to an array of preamplifiers (see Fig. 6) to build the 2- or 3-mv signal to a suitable level where it can be sent to the switcher. A cascode input stage in the preamplifiers helps control the input noise to a reasonable level.[4,5]

The four-channel switcher has been described by Dolby.[6] Connection is made in turn to each of the four heads as it comes in contact with the tape. Since there is an overlap period of at least one picture line when two heads are reading the tape, switching is made to occur during the synchronizing interval.

The mixed output of the switcher

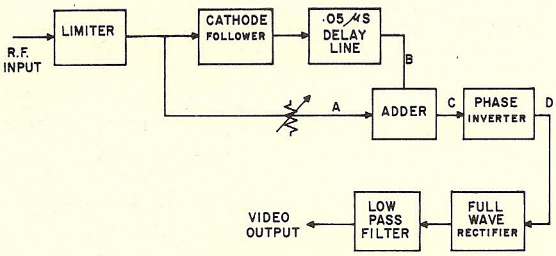

Fig. 7. Block diagram of the delay-line FM demodulator.

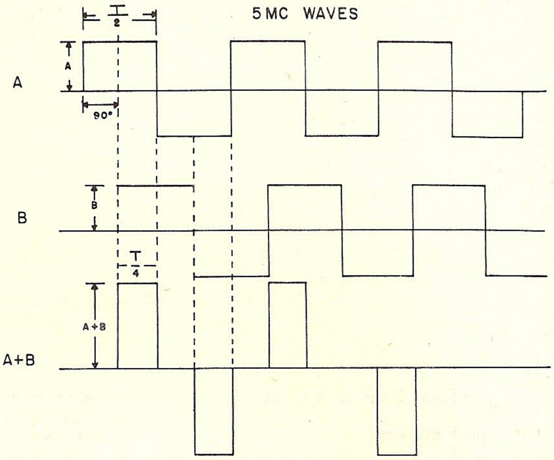

Fig. 8. Phase relations developed in delay-line FM demodulator, between direct and delayed 5-mc waves.

feeds cascaded limiters having 60 db of limiting action. This limiter strip in turn drives a delay-line type of demodulator. A block diagram of the circuit is shown in Fig. 7.

The delay is first chosen to represent a 90° phase shift at the carrier frequency of 5 mc, or 0.05 μsec. Figure 8 shows the phase relationships at the points marked *A* and *B* in the block diagram which are the inputs to the adder. The output of the adder is the series of positive and negative pulses of height *A* plus *B* and width *T*/4 giving an area of $(A + B)T/4$.

Suppose that the frequency be reduced to 4 mc. The relationships that now exist are shown in Fig. 9. The area of coincidence of the two waves is greater, and equals 0.375 *T* instead of 0.25 *T*, as before. If the area enclosed by the pulses is integrated by charging a capacitor, the capacitor will rise to a higher average d-c value as the frequency decreases.

In practice we will be dealing with sine waves.

Let a wave be represented by:

$$e = A \sin \omega t$$

Let *T* = time delay in seconds. The delayed wave will be:

$$e' = A \sin (\omega t - \omega T)$$

Adding the delayed and undelayed signals, we have:

$$\begin{aligned} e + e' &= A[\sin \omega t + \sin (\omega t - \omega T)] \\ &= A[\sin \omega t - \sin \omega t \cos \omega T - \\ &\qquad \cos \omega t \sin \omega T] \end{aligned}$$

This is a wave having the envelope amplitude *E* and phase shift φ, i.e.

$$e + e' = E \sin (\omega t + \varphi)$$

and

$$E = A\sqrt{(1 + \cos \omega T)^2 + \sin^2 \omega T}$$

$$\tan \varphi = \frac{1 + \cos \omega T}{\sin \omega T}$$

From this equation it can be seen that the resultant amplitude will vary as a function of frequency.

The transfer characteristic of the delay line translator is not linear; however, if the operating point of the slope is chosen correctly, there will be an appreciable portion of the curve that will give a straight line for all practical purposes. A plot of the output is shown in Fig. 10. Two values of *T* have been chosen here to illustrate the effect of changing the delay time. It can be seen that by adjusting the amount of delay the linearity and sensitivity of the circuit can be varied at will.

It is now obvious that here is our simple frequency-sensitive device to translate FM to AM. Figure 11 is a schematic of the demodulator. A transformer-type phase splitter is shown here, but a vacuum tube may be used instead if desired.

Figure 12 illustrates the advantages of the new type demodulator over the earlier one. Three curves are plotted together for comparison between the slope detector and the new type using both a transformer inverter and a vacuum tube. The lower end response in the transformer case was seriously impaired by the design of the transformer, but a little care can extend the useful range to a much lower value.

It can be seen that there is still appreciable distortion, but the distortion curve can be more easily matched with corrective networks than could the slope detector.

It might be interesting to note here that the very first FM pictures recovered from tape were not made with the straightforward equipment described here, but were made with a more complex and conventional system, using a heterodyned modulator described earlier. For playback, the recorded signal was heterodyned back to 60 mc with a suppressed carrier ring mixer,

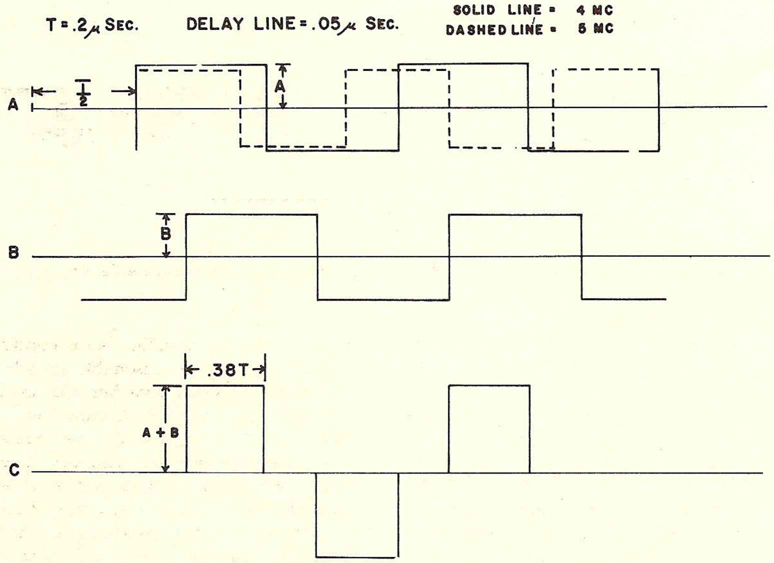

Fig. 9. Phase relations developed in delay-line FM demodulator, between direct and delayed 4-mc waves.

amplified with an IF strip, and demodulated by a discriminator. It worked, but was excessively complex. The heterodyne modulator may offer some advantages, in later work, with its ability to filter out unwanted modulation products, or "feed-through" of the modulating frequencies, but the heterodyne playback system seems far too complicated to warrant further investigation at this time. The present system does a satisfactory job.

The translation of the signal is almost complete at this point except for two additional refinements. If the switching process, described earlier, were allowed to take place more or less at random during the brief period of overlap when two heads are supplying signal, the switching process might produce a blip in the middle of the screen. To avoid this, some of the detected output is fed to a blanking switcher (13 in Fig. 6) which in turn directs the main switcher to change during blanking pulses only. The second feature is the unique processing amplifier, described by Dolby.[7]

Conclusion

At this writing, over one hundred fifty Videotape Recorders are in operation all over the world. All such recorders use the methods outlined here. It is felt that the use of frequency modulation as described is an adequate answer to the problems of video recording, and that any improvements in the immediate future will be refinements upon the basic system.

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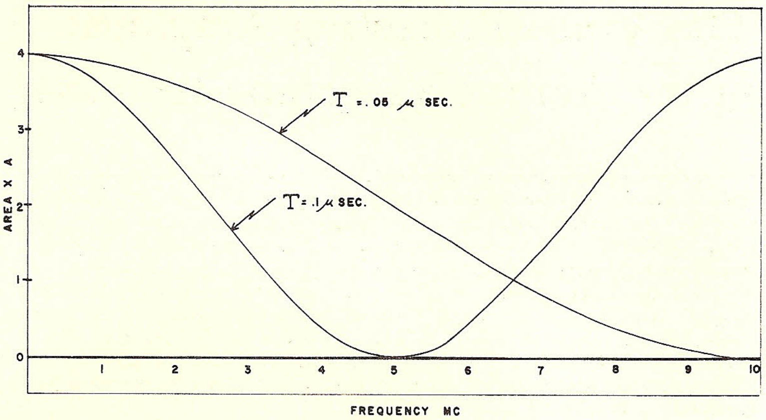

Fig. 10. Plot of output of delay-line demodulator.

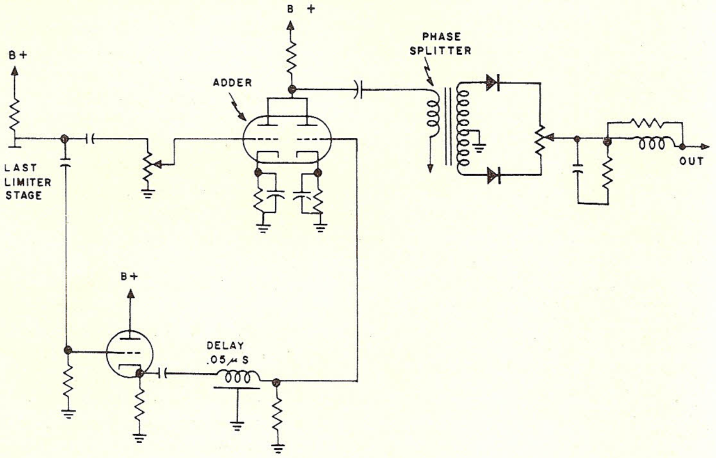

Fig. 11. Schematic of delay-line demodulator.

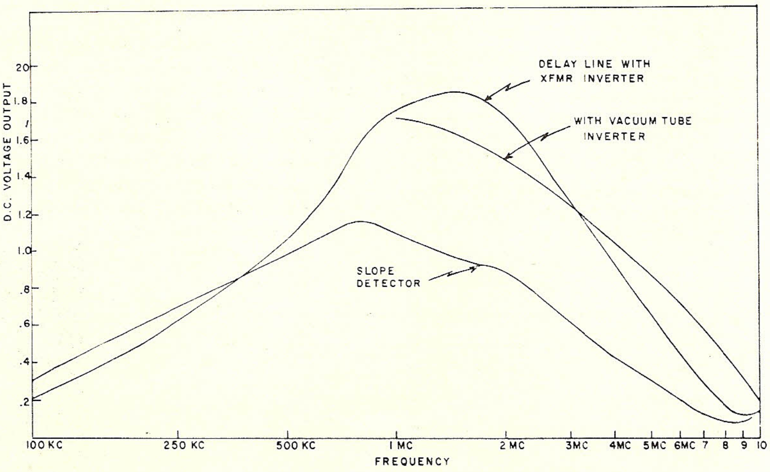

Fig. 12. Plot of comparative response of three types of FM demodulators.

The Video Processing Amplifier in the Ampex Videotape Recorder

By RAY M. DOLBY

Due to stringent requirements of network television, especially with regard to the shape and transient noise content of synchronizing pulses, a special "processing amplifier" has been developed to insure acceptable video waveform at the output of the Videotape Recorder. Similar in concept to a stabilizing amplifier, the new device represents a logical extension of stabilizing techniques. In addition to the usual stabilizing amplifier functions, the processing amplifier provides for complete reblanking of the video waveform and precise gating of the sync pulses, insuring that noise transients in the black direction will not project beyond reference black level during the active portion of the horizontal cycle. These operations are controlled solely by timing information in the incoming sync pulses.

THE PROCESSING AMPLIFIER in the Ampex Videotape Recorder is not an intrinsic part of the video-tape process. The Videotape Recorder will produce high-quality pictures without the processing amplifier, provided, however, that the images are viewed only on local monitors and that the output is not fed directly to network facilities. Designed to bridge this gap between the raw Videotape Recorder (VTR) output and a completely acceptable waveform for network handling, the intermediate processing amplifier is a necessary key to the practical commercial use of video tape.

Briefly, the basic purposes of the new unit (Fig. 1) are: first, to eliminate all objectionable noise in between or on the sync pulses; and second, to reblank the video signal.

Since playback video is not locked directly to local sync generators, timing information needed for the gating and blanking operations must be derived from the video signal itself.

Stripped from the playback video, VTR sync controls the vertical and horizontal gating generators, whose outputs are combined to energize a sync gate designed to pass incoming pulses only during those periods in which pulses should be present. Thus, transient noises between horizontal synchronizing pulses are completely blocked. The gating signal is also fed to the blanking former, which appropriately modifies the gating pulses and drives the reblanker. These operations of reblanking and of sync gating are the main ones responsible for insuring a VTR signal of good waveshape.

Trouble With Stabilizing Amplifiers

The basic difficulty with raw video-tape output is that unavoidable transient noise arising from dropouts as well as head switching is found to be extremely obnoxious to stabilizing amplifiers and sync-tip clampers. Since, by design, a stabilizing amplifier clamps the picture to blanking level immediately after the trailing edge of any pulse which enters the sync region, a picture from a video-tape machine has a very unlucky time. Specifically, several lines of the picture are shaded abnormally by every noise transient. In some cases, depending on circuitry, the sync separators in the stabilizing amplifier will be upset, and patches of sync pulses may be missing from the resultant composite video.

An experiment at CBS in Hollywood illustrates these phenomena: A test pattern was recorded on good tape, played back normally, sent through the processing amplifier, and then fed to the studio facilities, including one stabilizing amplifier. Everything was adjusted properly, and the result was a high-quality image suitable for broadcast. Then the processing amplifier was removed from the system. The finished product (Fig. 2) reveals the sentiments of most stabilizing amplifiers about raw video-tape signal.

Processing Amplifier Design Considerations

It would be most desirable to gate all-synchronizing pulses through the processing amplifier only during those times in which any particular pulse should exist. In practice, this operation is fairly easy for the horizontal pulses, but predicting the arrival of the next legitimate pulse can become hopelessly complex in the vertical blanking period.

Figure 3 shows what actually was done. The idealized gating operation for the horizontal synchronizing pulses is achieved through the use of narrow keying pulses. Then, there is provided in the vertical blanking interval a wholesale passage for everything, including

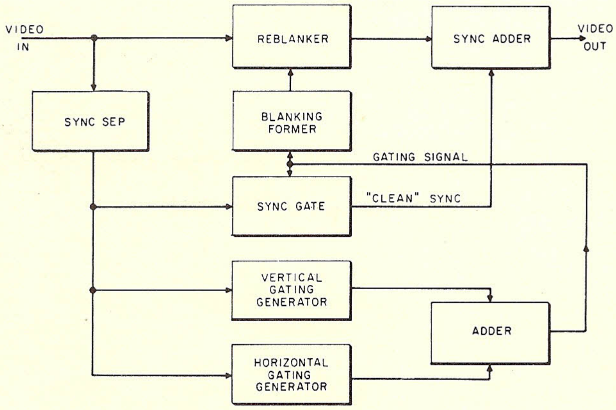

Fig. 1. Basic block diagram of the processing amplifier.

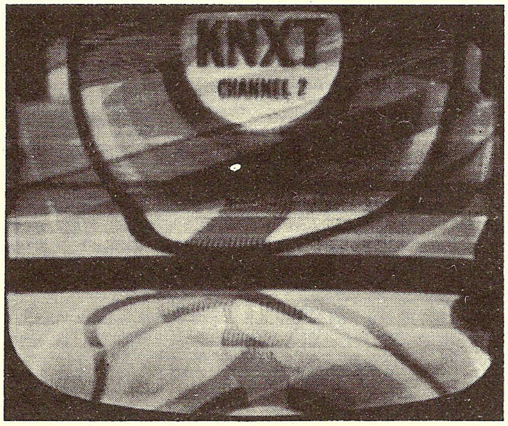

Fig. 2. Appearance of VTR picture after subjection to stabilizing amplifier—without processing amplifier.

Presented on April 29, 1957, at the Society's Convention in Washington, D. C., by Ray M. Dolby (then at Ampex Corp., 934 Charter St., Redwood City, Calif.; now at the Cavendish Laboratory, University of Cambridge, Cambridge, England).
(This paper received on April 29, 1957; in slightly revised form, August 7, 1958.)

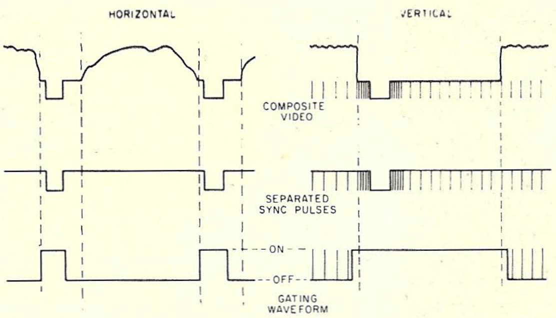

Fig. 3. Timing relationship between sync and gating pulses.

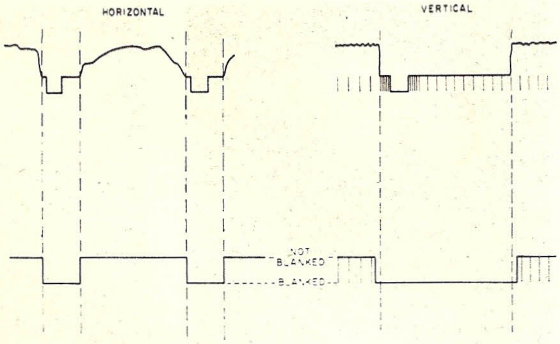

Fig. 4. Timing relationship between video and reblanking pulses.

noise. Justification for this procedure lies in the fortunate circumstance that during the vertical blanking interval noise pulses will cause stabilizing amplifiers to clamp, harmlessly, to blanking level only; therefore if noise is allowed to pass in this interval no difference will be seen in the picture.

In most stabilizing amplifier applications simple black clipping to remove the old synchronizing pulses and to clean up the front and back porches has proved to be satisfactory. But in the case of the Videotape Recorder there are, unfortunately, residual carrier components (remaining from the FM modulation-demodulation process) and other high-frequency noises on the sync pulses and blanking pedestals of the demodulated output. These high-frequency components give a fuzzy appearance to the back porch. Since any attempt to remove the fuzz with a black clipper will destroy setup to such an extent as to cut into the black portion of the video signal, the classical method clearly is not a satisfactory means for reforming the blanking pedestal.

The answer to this problem is to reblank the video signal, and the existence of the vertical and horizontal gating generators makes the formation of suitable blanking signals very easy. An examination of the required blanking signal and of the composite gating waveform shows that it is necessary only to delay the trailing edge of the gating signal a few microseconds in order to provide all of the necessary blanking information. Figure 4 illustrates the time relationship of the composite video and the reblanking pulses. The vertical reblanking pulse begins approximately half a line before the original blanking pulse began, and the end of the new blanking pulse occurs just after the end of the original blanking pedestal. In the horizontal period, the reblanking pulses are seen to coincide exactly with the timing of the original blanking pedestal.

Circuitry

Figure 5 is a basic outline of the circuitry required to perform the operations seen in the previous illustrations.

From the output of the machine, a 1-v video signal is fed to the input of the processing amplifier, after which it is amplified and given a preliminary clipping operation which removes black-going spikes projecting below the

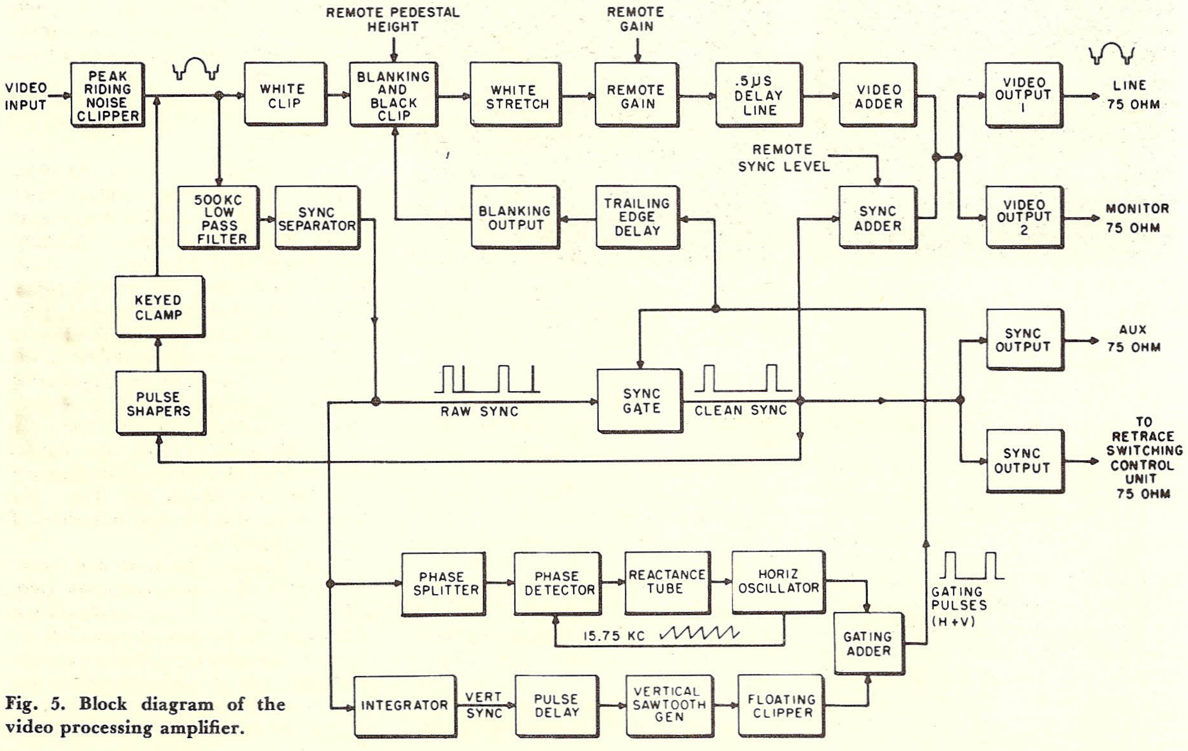

Fig. 5. Block diagram of the video processing amplifier.

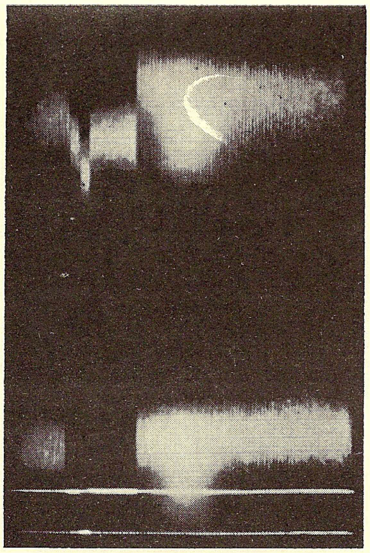

Fig. 6. Oscillogram of processing amplifier input and output with noisy signal — expanded portion of vertical period.

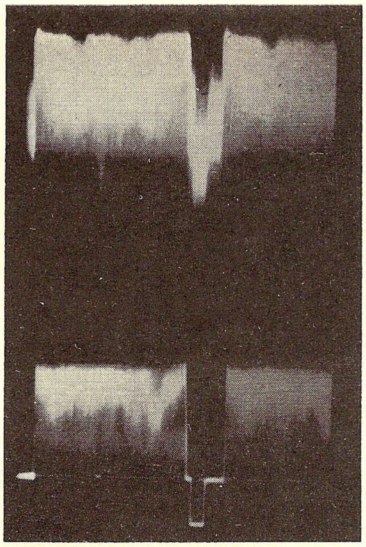

Fig. 7. Horizontal waveforms. Conditions same as Fig. 6.

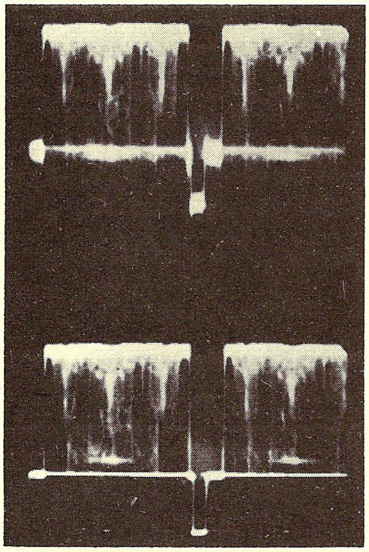

Fig. 8. Output of the VTR demodulator and subsequent output of the processing amplifier.

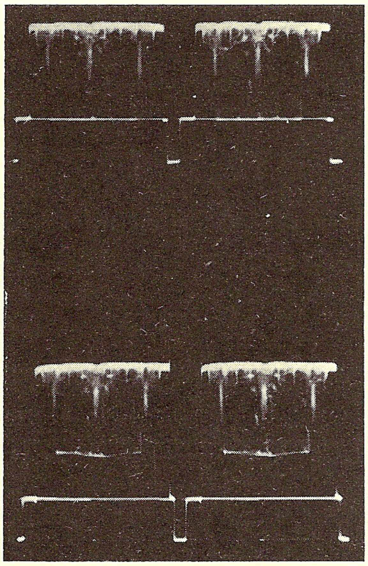

Fig. 9. Performance of processing amplifier in restoring setup to video signal with insufficient setup.

negative tips of sync. Clamped by a comparatively soft clamp only to restore the d-c component, the composite video is subjected to the white clipper and to the blanker and black clipper. The video signal, then without sync, is next applied to a direct-coupled white stretcher, a 6BJ6 variable mu tube. Similarly, the remote gain tube is a 6BJ6 with variable bias on the control grid. The use of variable bias permits remote operation through an accessory unit and switching relay which transfers control away from the main chassis.

Next, a $\frac{1}{2}$ μsec delay line appears in the chain of events, the purpose being to delay the video signal by the same amount as the synchronizing pulses have been delayed in their circuits, so that the timing relationship of the video signal and synchronizing pulses will be proper. After this point, the gated sync pulses are added and controlled either remotely or locally. Output from the machine is obtained through two identical feedback amplifiers with independent gain and output impedance controls.

Synchronizing pulses are obtained from a point near the clamp, after which they are sent through a 500-kc low-pass filter which removes carrier components in the signal as well as very short transient noises. The pulses then go to the sync separator, consisting of several triode amplifiers, all of which have been designed to provide very dependable operation under noisy sync conditions.

The raw synchronizing pulses, including noise, are then exposed to the selective action of the 6BN6 sync gate. The clean synchronizing pulses, which are the original pulses amplified and clipped in several stages, are then fed to the sync adder and to the two sync outputs. The clean pulses also energize the keyed clamper.

The horizontal gating generator is a sync controlled AFC circuit which generates pulses just slightly wider than the sync pulses themselves.

Also utilizing the raw synchronizing pulses, the vertical gating generator separates vertical information from the remainder with an integrator. The pulse delay delays timing information in the vertical synchronizing pulse for about 680 μsec, forming the end of the vertical gating pulse. But the leading edge of the vertical gating pulse is derived in a special sawtooth generator which delays time information in the previous vertical synchronizing pulse for almost one field. The horizontal and vertical gating pulses are combined in the gating adder and are fed to the suppressor grid of the 6BN6 sync gate. In addition, these gating pulses are sent to the reblanking former, which delays the trailing edges a few microseconds, forming the composite blanking signal, as described earlier. Blanking itself is accomplished by a diode clamp circuit.

Performance

To test the efficacy of the processing amplifier in treatment of signals much more noisy than it would be required to handle from the Videotape Recorder, an extremely bad air signal was taken from a tuner and fed to the input. Figures 6 and 7 show "before and after" examples. Figure 6 is an oscillogram of vertical waveforms corresponding to the input and output of the processing amplifier. The input signal is seen to contain practically all the noise ills that could possibly exist, the output corresponding to what would be expected from previous discussions. The view shown in Fig. 6 is a magnified portion of the vertical period.

Figure 7 shows the horizontal waveforms under the same conditions. Here again, the gating of the synchronizing pulses and the reblanking operation reconstruct the video signal into an acceptable form. The processing amplifier can be easily set up to match the output signal to either standard levels of pedestal and

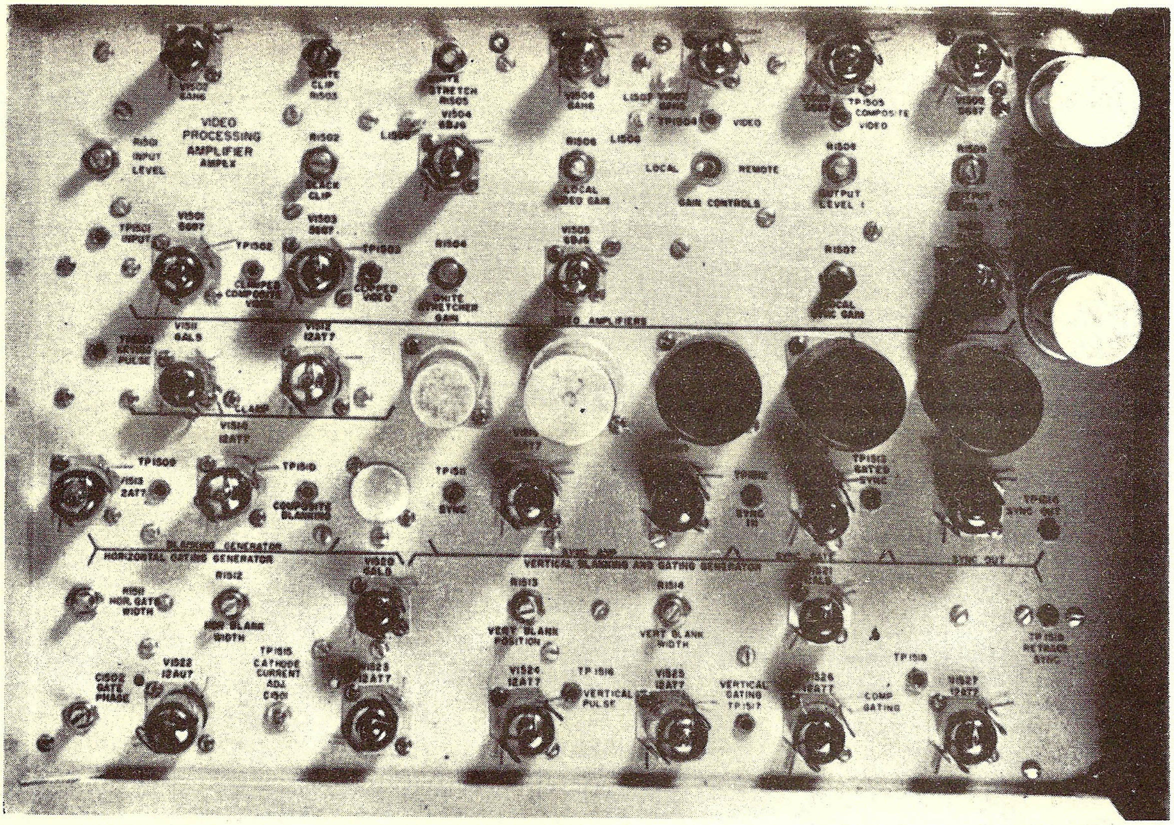

Fig. 10. The video processing amplifier.

sync or to the levels existing in the input signal.

Figures 6 and 7 are intended only to demonstrate the maximum capabilities of the processing amplifier; Fig. 8 is an indication of actual performance with video-tape signal as input. While they are fewer than in the previous illustrations, faults in the VTR waveform are easily noticed. There is the characteristic carrier "grass" (noise) on the front porch, synchronizing pulse, and back porch, and, although they may not be seen in this picture, noise transients do exist. The output synchronizing pulses are clean and well defined, yielding a signal completely compatible with network practices.

In practical use of the new unit as a stabilizing amplifier, another virtue in addition to signal clean-up is realized. Figure 9 is an illustration of the ability of the device to restore setup to a video signal with insufficient setup. A composite video signal will, after repeated subjection to stabilizing amplifiers, lose the normal setup. Furthermore, the usual stabilizing amplifier loses its ability to clean up the back porch after setup has been destroyed, for if the black clipper cuts deeper into the blanking pulse, the black tips of the video signal also will be distorted. Provided with a local and remote pedestal height control, on the other hand, the processing amplifier will recreate any desired amount of setup. The bottom half of the figure gives an idea of what is possible.

The New Unit in Use

The processing amplifier (Fig. 10) has been in commercial use in the Ampex Videotape Recorders since November 1956, when Television City (CBS), Hollywood, began the first regular programming with magnetic tape.

While the unit was designed specifically for the Ampex Videotape Recorder, its adaptability to other uses has become obvious. Suitable applications for the processing amplifier can be inferred from its performance in relation to the video-tape signal. As a stabilizing amplifier, the unit probably would find its greatest value on the receiving end of a network broadcast for re-formation of blanking pedestals and general cleaning up of the synchronizing pulses. In addition to usual studio applications for conventional stabilizing amplifiers, the new unit might also have value as a device to restore noisy air signals for isolated communities which rely only on air relay of television for local redistribution.

It is expected that, eventually, as video-tape production demands become less pressing, attention can be turned to making the processing amplifier available as an entity.

It seems reasonable enough to restore a noisy signal by reblanking and sync gating through the use of appropriate pulses derived from the signal itself, but it had never before been necessary to produce such a device. The advent of the Videotape Recorder precipitated the design of the necessary circuits; the processing amplifier emerged as the consequence of the given requirements.

Techniques in Editing and Splicing Video-Tape Recordings

Editorial Note: Shortly after the Ampex VR-1000 Videotape Recorder was made commercially available, it became apparent that, because of special problems, development of a satisfactory method for editing and splicing video tape was of immediate importance. The two following papers (each slightly condensed) describe the steps leading to the development of the Ampex splicing method. The first paper, presented at the 1957 Spring Convention in Washington, D.C., outlines early experiments and problems encountered. The second paper discusses in detail the method finally adopted.

Factors Affecting the Splicing of Video Tape

By KURT R. MACHEIN

Video tape can be spliced, but techniques applicable to photographic film or recorded audio tape are not suitable for video tape. Splicing and editing of video tape are possible and practical but are a special process quite unlike the splicing of photographic film or audio tape.

AUDIO-TAPE RECORDING consists of one longitudinal recording and the only conditions which must be observed in splicing are tape speed and head alignment, but the factors involved in splicing video tape are much more complex and the requirements much more stringent. Video-tape recording consists of three different recordings: (1) transverse picture information; (2) longitudinal audio recording; (3) longitudinal control track. The spatial relationship existing among the three recordings is of great importance and must remain constant within certain tolerances if the recorded program is to be properly reproduced.

In cutting and splicing video tape, certain conditions are necessary: (1) At the transition of the splice, the head which starts to play back the first track after the splice must find this track sufficiently well positioned in the lateral direction to allow the machine to recognize the vertical interval without confusion. (2) The spatial relationship between the control track on the first tape and that on the tape to which splicing is to be done must be such that the capstan servo amplifier is not subjected to sudden phase shifts which might throw the servo out of control. (3) The tracking error generated at the moment the splice passes the video head must be small enough so that the new tape tracks smoothly and excessive noise will not appear in the picture.

Figure 1 is an enlargement of the upper 0.7 in. of a video tape showing the composite signal. The unrecorded audio track, erased by the audio erase head, appears as a wide longitudinal stripe along the upper edge. Vertical synchronization pulses appear at intervals of 16 video tracks. In splicing, the cut must be made inside a 5-mil space next to a vertical synchronization pulse.

If, at the moment a splice passes the rotating head during reproduction, a tracking error of not more than 20% is to be permitted, the accuracy of splicing must be ±2 mils, since one track is 10 mils wide. Tracking is accomplished, during reproduction, by observation of the phase of the 240-cycle control-track signal. Plus or minus 2 mils corresponds to a peak-to-peak error of 23° for the 240-cycle signal. In other words, each tape splice must display a phasing error not exceeding 11.5° on the control track.

An examination of the problem indicated that the most suitable point at which to cut the tape would be the transverse track which carries the vertical blanking interval. This occurs on the tape at $\frac{1}{4}$-in. intervals and is slightly longer than one scan of a transverse track. The recording is not normally visible on the tape so it was necessary to devise a method by which the required track can be identified.

One approach investigated for this purpose involved the electromagnetic detection of a prerecorded editing pulse by means of a reproducing head whose output was dependent only on amplitude of magnetic flux, and independent of the rate of change of flux. An editing pulse

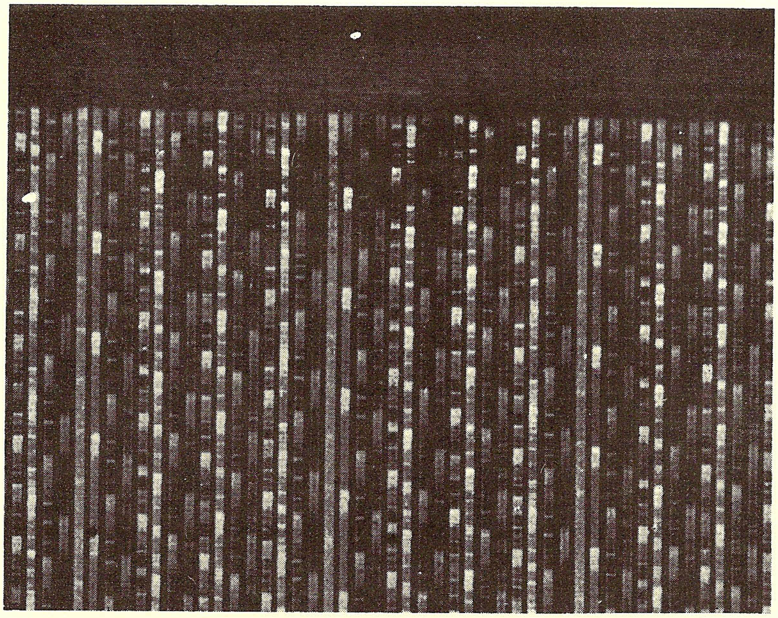

Fig. 1. Upper 0.7 in. of a "developed" video tape. The recording contains the entire composite video signal.

Presented on April 29, 1957, at the Society's Convention in Washington, D.C., by Kurt Machein, Ampex Corp., 934 Charter St., Redwood City, Calif.
(Revised paper received on September 29, 1958.)

derived from the incoming video signal and recorded on the control track, and thus bearing an exact and clearly defined relation to the picture information on the transverse video tracks, could then be detected, independently of tape motion, by the flux sensitive head mounted on an editing device. For very accurate indication of the edit pulse position, the rise time and duration of the pulse must be short, and it was in this connection that the flux-sensitive head approach lost its appeal. The magnetic field of the short pulses was not large in comparison with the earth's magnetic field, and consequently the use of flux-sensitive heads would have required a very careful adjusting process in order to achieve a null with respect to the noise source. Magnetic fields generated by the recorder would also have to be taken into consideration.

Other experiments were conducted to determine which of several methods would be the most satisfactory in developing the magnetic tracks into contrasting, easily visible images.

In working out the method which was later adopted, experiments were conducted using various liquids containing carbonyl iron in suspension. These were the requirements: (1) the liquids used must in no way affect the Mylar backing or the oxide binder on the tape; (2) the liquids must be of a volatile nature; and (3) after splicing, the image produced must be easy to remove, wet or dry, by a simple "wipe" process.

With this method, when the tape is immersed in the liquid, iron particles precipitate on the tape in a selective manner, the density of the deposit being approximately proportional to the magnetization of the tape at this point. After the tape dries, an optical image, which shows the signal path and the impressed variations on it, becomes visible.

Figure 2 is a photomicrograph of the lower 0.7 in. of a video tape showing carbonyl iron particles tracing magnetic patterns. This pattern displays only synchronization pulses in the absence of video information. The recorded 240-cycle control track is seen at the lower edge and horizontal synchronization pulses are seen as small square markings along the video tracks. Three vertical bars define two complete fields, or one complete frame of picture.

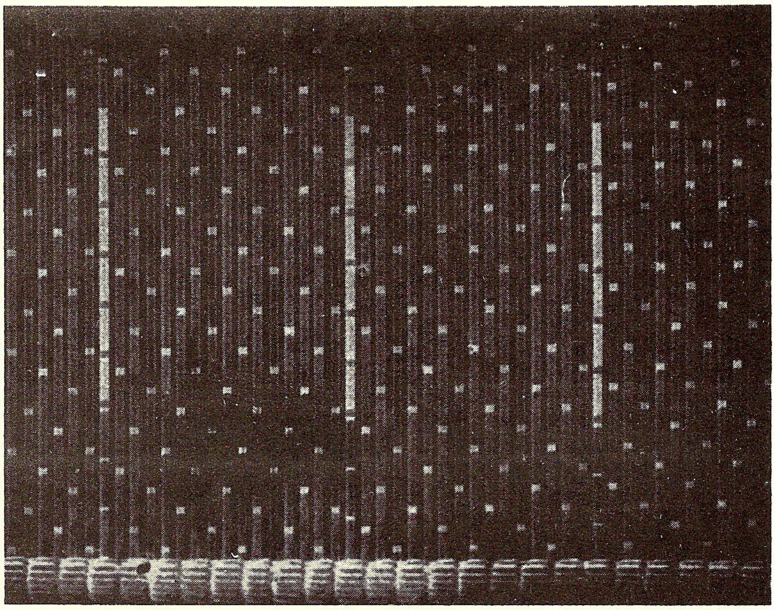

Fig. 2. Photomicrograph of a "developed" video tape. Carbonyl iron particles trace the magnetic pattern. The image was developed and completely dried in less than 3 sec.

With an optical device of approximately 10 powers, the vertical blanking interval can be distinguished from the horizontal pulses and the rest of the video information. The vertical blanking interval appears on the tape as a solid track, starting in the lower third of a single transverse track and lasting for approximately the length of one track. Since the position-servo of the recorder keeps the beginning of the blanking period within very close tolerances to plus-or-minus one horizontal line, a cut between the two tracks carrying the vertical interval can be made if accuracy of ±1 mil is maintained. The second tape, which is spliced to the first, is cut in a similar manner.

Further experiments have demonstrated the soundness of this approach. In the laboratory, a number of splices were produced in this manner, using conventional thin, high-strength splicing tape. The splices passed the video head without disturbing the picture on the screen. The slight increase of the thickness and stiffness acts as a small additional load on the head drum, momentarily slowing down the speed. This speed variation is quickly corrected by the servo amplifier after the splice has passed. There is a slight tendency for the picture to rock a little horizontally for a half second or less.

Other splicing methods under consideration at various times included the use of a ferric compound solution which would be swabbed on the tape and a reagent added which would allow a selective plating process to occur. The precipitated ferric particles thus released would trace out the magnetic impressions. Another method involved the use of a dye with a high ionic affinity which would leave a deposit in proportion to the tape signal amplitude.

The goal during all this experimentation was to achieve a simple, accurate, practical splicing method which would meet industry requirements arising with the expanding use of video-tape recording.

Electronic Marking and Control for Rapid Location of Vertical Blanking Area for Editing Video-Tape Recordings

By JOSEPH ROIZEN

A relatively simple and inexpensive method for splicing video tape has been developed. Three problems were investigated: (1) visual "development" of the video track; (2) accurate positioning of the splice; (3) joining tapes to achieve maximum mechanical strength. Electronics have been included in production machines to provide accurately spaced "edit" pulses to position the splice. Simplified tray spray "development" methods have been attained.

A PRELIMINARY STEP toward developing a method for accurately editing and splicing video tape was that of interviewing network engineers on their day-to-day problems. Data gathered in this manner provided a basis for experimental and testing work. Three basic problems were dealt with in early research and experiments: (1) the visual "development" of the magnetic image on the tape; (2) the accurate positioning of the splice in relation to the small mechanical tolerances within which the transition must be placed; (3) the method of joining tape ends to achieve maximum mechanical strength and minimum effect on the head drum assembly. Following extensive study and testing, a basic method of utilizing magnetically influenced particles in a high vapor pressure liquid suspension was adopted.

Tests were conducted to determine optimum particle size (ranging from 1 to 20 μ) which would give sharply defined read-outs on short duration, fast-rise time pulses. Particles in the 3- to 5-μ range proved ideal for this application. All magnetic metals obtainable in fine powders including iron, nickel, cobalt and stainless steel were checked for availability, ease of handling and reflectivity. Both carbonyl iron and stainless steel proved to be usable, each having specific advantages depending on the application.

The selection of a liquid carrier for the particles was limited to materials meeting these specifications: (1) low toxicity; (2) high vapor pressure for rapid readout; (3) safety for use with the Mylar backing; (4) ease of cleaning so as to leave no residue on the tape and; (5) low viscosity to permit good mobility of the particles as they settle.

Several liquids proved to be acceptable. The two most common and easily available are lacquer diluent which is an industrial cleaning fluid; and Freon TF, a film cleaner. A commercially available package, called Ampex Edivue, consists of a suspension of carbonyl iron and diluent in a wide-mouth jar that can be used to "visualize" the video tape without needing a separate tray. As the diluent evaporates with the resulting increase in suspension density, a replenishing supply of liquid should be provided to maintain the original concentration.

The problem of positioning the splices required careful examination. The logical location for a splice is during vertical blanking time and after vertical synchronization has occurred. Under these conditions the home viewer will not see the splice going by because both video and sync continuity will be maintained and the transition will occur at a time when the vertical oscillator has just been fired and cannot be triggered again. The video at this point is blanked or out of sight at the top of the picture. Figure 1 shows a visualized tape using a stainless-steel developer. A regular monoscope pattern is recorded on the tape. The pulses along the bottom edge of the tape are spaced under the vertical blanking area on a monoscope recording. A video signal that may contain low brightness levels with all the information near blanking level would make it impossible to differentiate the blanking area from the rest of the video scans. Experimental data also showed that to maintain stability during a splice, it was of the utmost importance that the 240-cycle control track phase shift at the splice be kept under 15°. These two conditions made explicit the need of electronically marking the tape in such a way that the exact splice point would invariably be readily visible.

The circuitry to generate a high-amplitude, short-duration pulse, which is referenced to the vertical sync of the incoming video signal and the 240-cycle control-track signal was then developed (Fig. 2). This pulse is superimposed during record mode on the control-track signal and appears as a sharp blip on the bottom edge of the video tape when it is "visualized." The servo control unit includes a coincidence gate which is open for approximately 300 μsec by vertical sync and allows the differentiated rise-time pulse (approximately 100 μsec) of the 240-cycle signal from the photocell on the head assembly to be superimposed on the control-track recording. This assures that edit pulses will only be laid down when the recorder is in stable operation and that, when recorded, they will be at some fixed phase of the control-track signal. The edit pulses can then be positioned accurately in the proper relationship to the video signal by manual adjustment of the control-track record head. Figure 3 shows the waveforms of this circuitry.

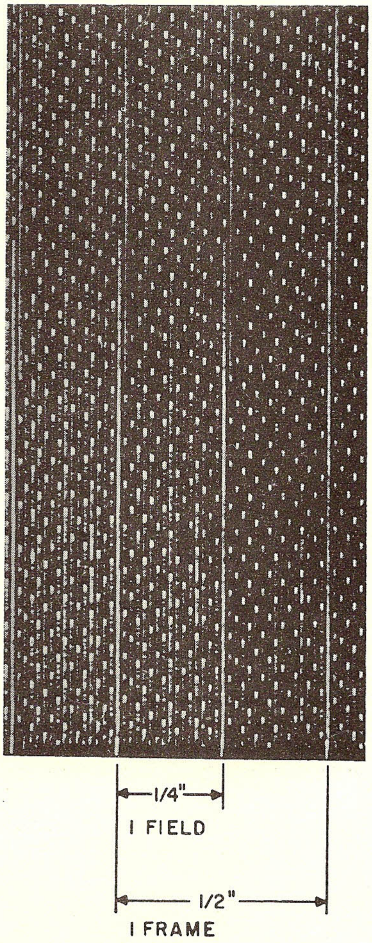

Fig. 1. Monoscope pattern recorded on tape. The vertical blanking intervals appear as long lines and horizontal sync pulses show as the pattern of dots between them.

Presented on April 24, 1958, at the Society's Convention in Los Angeles by Joseph Roizen, Ampex Corp., 934 Charter St., Redwood City, Calif.
(Revised paper received on September 29, 1958.)

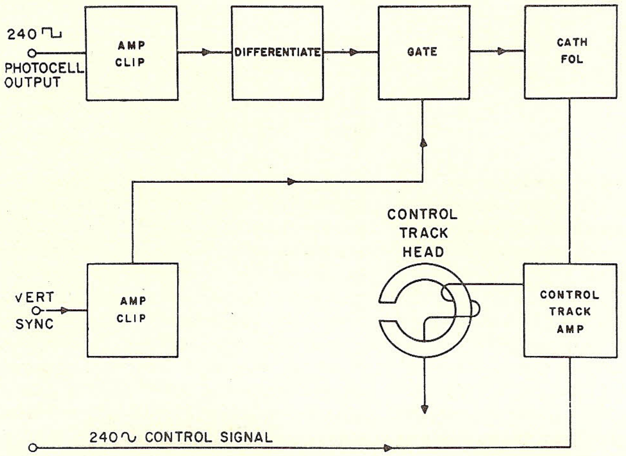

Fig. 2. Block diagram of system for edit pulses applied to the control track record head through the control track amplifier.

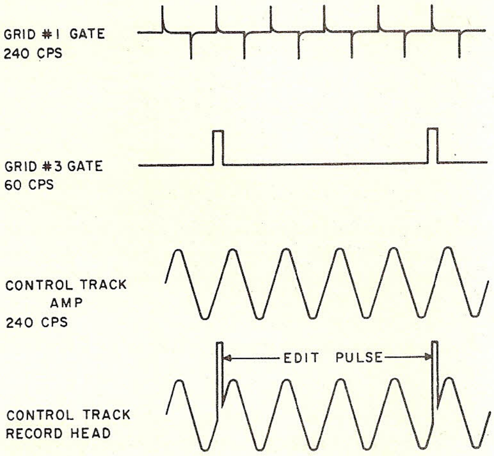

Fig. 3. The action of coincidence gate which allows the vertical sync at Grid 3 to gate through edit pulses phased to control track.

Joining the Tapes

The problem of how to join the tapes required careful consideration. There are four methods by which Mylar tapes can be spliced: (1) welding by controlled heat and pressure; (2) welding by dielectric heating; (3) overlapping an adhesive joint; (4) butt-jointing with pressure-sensitive backing tape.

The overlap adhesive joint and the heat and pressure methods were discarded, the first because of the limitation of a 5-mil overlap, and the second because the area around the splice becomes brittle and breaks at 10 to 15 lb.

A butt joint made with extra thin (under 1-mil) splicing tape, $\frac{1}{4}$-in. wide, was adopted as the best available method, and the project of developing a precision splicer was launched.

Before the precision splicer was complete a small manual splicing jig was made available. With this device, two tapes are held in good longitudinal alignment and a milled-out slot, angled correctly, against which a 6-in. straight-edge is laid is the cutting guide for an Exacto knife or razor blade. The edit pulse is lined up against the straight edge and two similarly cut tapes can be butted together and spliced with thin backing tape.

The precision splicer (Fig. 4), developed later, simultaneously cuts two tapes that have been properly positioned in it with the edit pulses lined up under hair lines of the glass cutting guide. A three-position knob allows excess ends of video tape to be cleared away and the splicing tape to be pulled forward. The video tape then drops down on the adhesive side of the pressure-sensitive backing and a squeegee-type pressure pad is applied to seal on the backing. The excess backing tape is trimmed off and the splice is finished. Since edit pulses appear at every field, a defective splice can be corrected by cutting out two fields, which results in a loss of only $\frac{1}{30}$ sec of picture information.

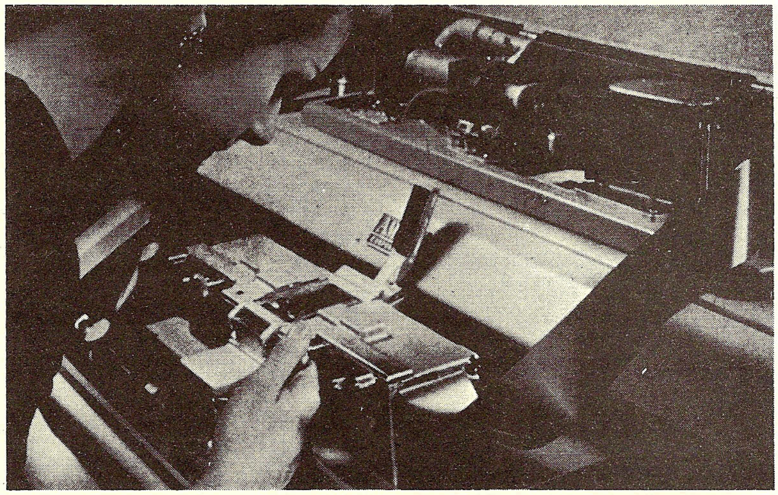

Fig. 4. Splicing device in use.

Editing of the video-tape recording must be done on a video-tape recorder. As the tape is played back, either sound or picture can be used for selecting stop and start points. The precise braking characteristics of the video-tape recorder allow a predictable amount of tape to go by the head drum after the stop button is pressed. The mark on the back of the tape and a paper marker insert serve to locate the spot again. Cutting out or splicing in a section of tape can then be accomplished. Since the edit pulses appear at every field, 60 splicing points at $\frac{1}{4}$-in. intervals in every second of picture information are provided.

Since it is possible to erase and record audio without affecting the picture, sound dubbing is no more difficult than with standard audio recorders using present-day studio techniques.

The method of splicing video tapes, described above, seems entirely practical as a means of meeting immediate needs. Continuing research will undoubtedly lead to improvements and to new developments for recording and duplication of video tapes.

Magnetic Tape for Video Recording

By ROBERT A. von BEHREN

The new video-tape recording systems now in commercial and experimental use require special magnetic tapes differing in design from standard types, and manufactured to a standard of perfection which a short time ago it was believed impossible to achieve. This paper discusses some of the unique features of video-recording tapes and the problems encountered in their development.

THE ANNOUNCEMENT in March 1956 that the three major television networks had placed orders for Ampex video recorders precipitated a large and concentrated effort to perfect a magnetic tape for use on these machines. Actually, no completely new concepts were introduced into magnetic-tape technology by the Ampex machines. Except for a few obvious peculiarities due to the rotating-head scanning method, the requirements for tape were essentially the same as for other TV recorders. The real challenge arose out of the fact that these machines were moving rapidly out of the laboratory and into the commercial world where *quantities* of high-quality and reliable tape would be needed to sustain TV network operations. It is of interest here to examine some of the problems encountered in the development of video-recording tape for this critical application.

Special Requirements

One obvious requirement for a video recorder is the ability to record a wide spectrum extending from a few cycles per second to about 4 megacycles.[1] If one were to try to meet this requirement by merely increasing the speed of the tape past the head, a number of serious problems would be encountered. Many of these, such as the difficulty in recording low frequencies (as well as high) and the severe requirements of amplitude and phase equalization have been obviated in the Ampex recorder by the use of a FM carrier.

An additional innovation in the Ampex machine is the method of scanning the tape transversely with a set of rotating heads. This effectively chops the active video track in short segments and arranges them side by side instead of end to end on the tape, permitting some half million lineal feet of recorded track to be carried on a 5000-ft roll of tape.

Necessary Compromises

On the negative side of the ledger, these gains have not been achieved without making some compromises in other areas. In the Ampex machines, the track width has been reduced to only 0.010 in. and the minimum recorded wavelength to something like 0.2 mil. Both of these factors tend to reduce the signal-to-noise ratio of the system. It is interesting to note that the Ampex video recorder utilizes only about $\frac{1}{16}$ as much tape area per unit of bandwidth as conventional audio recorders. That is, the video recording channel occupies some 250 times the spectrum of audio channel, but the rate of tape consumption is only 16 times as great.

In addition, the FM carrier method introduces a further complication. Whereas in most recorders, the zero signal noise level is determined by the residual noise of erased (i.e. magnetically neutral) tape, in the Ampex machine the carrier signal is at all times impressed on the tape. The zero signal noise level is therefore comparable to the modulation noise of the tape, which may be 10 to 20 db higher than the erased noise level. It is well known that the usual noise-suppression mechanism associated with the FM carrier transmission does not pertain to the Ampex system because the carrier frequency is only slightly higher than highest video frequency.

The factors just mentioned all conspire to reduce the signal level and increase the system noise to the point where the signal-to-noise ratio of 35 db required for network video transmissions is difficult to obtain. The first problems to be solved, then, were to increase the output of video-recording tape at extremely short wavelengths and to reduce the modulation noise. Fortunately, these problems were related in that the methods used to gain increased output also helped the noise situation.

It became immediately apparent that orienting the particles of the magnetic coating with their easy axes in the direction of recording (i.e. transversely) would help this situation. Orientation is, of course, standard practice for tapes in which the recording is longitudinal, but the usual techniques for accomplishing this do not lend themselves to transverse orientation. This necessitated the development of some completely new manufacturing techniques and considerable revision of production equipment. Needless to say, transverse orientation was accomplished, and is now employed as a routine matter in the production of video recording tape. While this factor alone accounted for perhaps 3- to 5-db improvement in signal-to-noise ratio, further improvement was needed.

It is well known that the efficiency of a magnetic tape for recording and reproducing very short wavelengths is generally related to surface smoothness. However, the importance of this can best be appreciated by reference to some theoretical studies of the reproducing process.

Calculations by Wallace[2] and independently by Westmijke[3] show that for a tape which was originally magnetized uniformly throughout its thickness, and according to a sinusoidal pattern of wavelength (λ) in the recording direction, the effectiveness of the magnetized particles in producing flux in an ideal playback head is given by exp. $[-2\pi d/\lambda]$, where d is the distance of the particle from the reproducing-head surface. The physical significance of the relationship is that for very short recorded wavelengths the magnetic flux contributed by particles situated deep in the tape coating closes upon itself without linking the playback head. Therefore, the relationship provides a means for estimating the depth of the effective portion of the tape coating at short wavelengths.

Values of wavelength appropriate to the FM carrier frequencies of the Ampex system have been inserted in this formula, and the "penetration" curves of Fig. 1

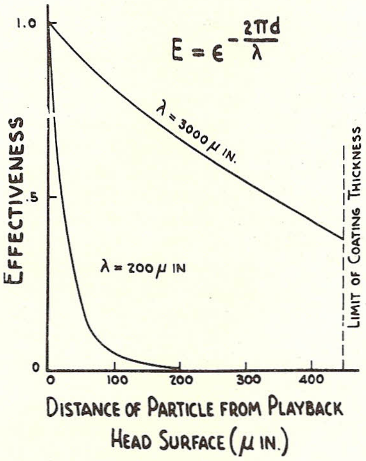

Fig. 1. Theoretical effectiveness of magnetized particles vs. distance from the playback head surface. For short recorded wavelengths only the surface layers of the tape coating contribute to the playback signal.

Presented on October 5, 1957, at the Society's Convention at Philadelphia, by Robert A. von Behren, Minnesota Mining and Manufacturing Co., Magnetic Products Div., 2301 Hudson Rd., St. Paul 6, Minn.

(This paper was received on August 8, 1958.)

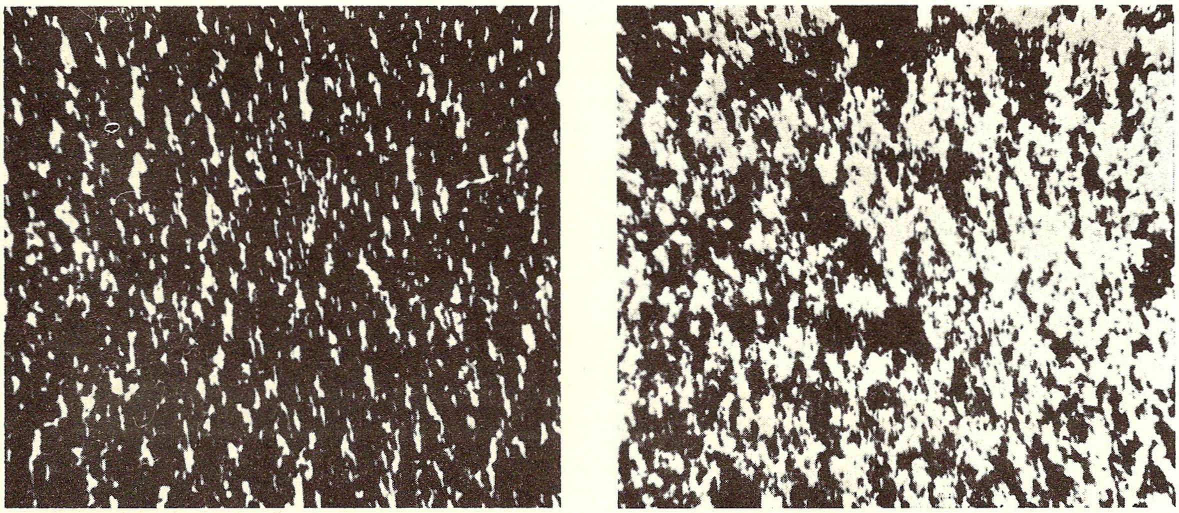

Fig. 2. Photomicrographs (50×) comparing surface characteristics of conventional tape (left) and video recording tape (right). Only the light areas are in close contact with the recording heads and hence effective for video recording.

result. At the lowest carrier frequency of 500 kc corresponding to a 3-mil wavelength, the effectiveness of the coating drops slowly, reaching only 40% at the back of the 450 μin. coating. This situation is not serious, as it is in the case of the lower curve representing the highest carrier frequency of 7.5 mc (0.2-mil wavelength). At this frequency, fully 50% of the signal intensity is contributed by the first 20 μin. of the coating, and almost all of the effective particles are confined within the first quarter of the tape thickness. This means that if there are relatively few magnetic particles within the effective region nearest the reproduce head, for instance, because of surface roughness or dust inclusions, the signal level will be weak. Moreover, if these conditions tend to vary from point to point as the head passes over the tape, the signal will be unsteady and the noise high.

It is easy to appreciate the seriousness of this problem when one realizes that the needle-shaped particles of magnetic oxide are themselves perhaps 10 μin. in diameter and 50 μin. long. Of course, this theoretical treatment is greatly oversimplified, and therefore inaccurate, but it does yield a useful insight into the importance of surface smoothness for video recording. In a general way, good correlation has been obtained between output and noise characteristics of tape samples, and surface smoothness as observed microscopically.

Improvement of Surface Characteristics

It is noted that considerable progress has been made in perfecting the surface characteristics of video recording tape coatings. Accomplishments in this direction are illustrated by the photomicrographs of Fig. 2. These photos were taken

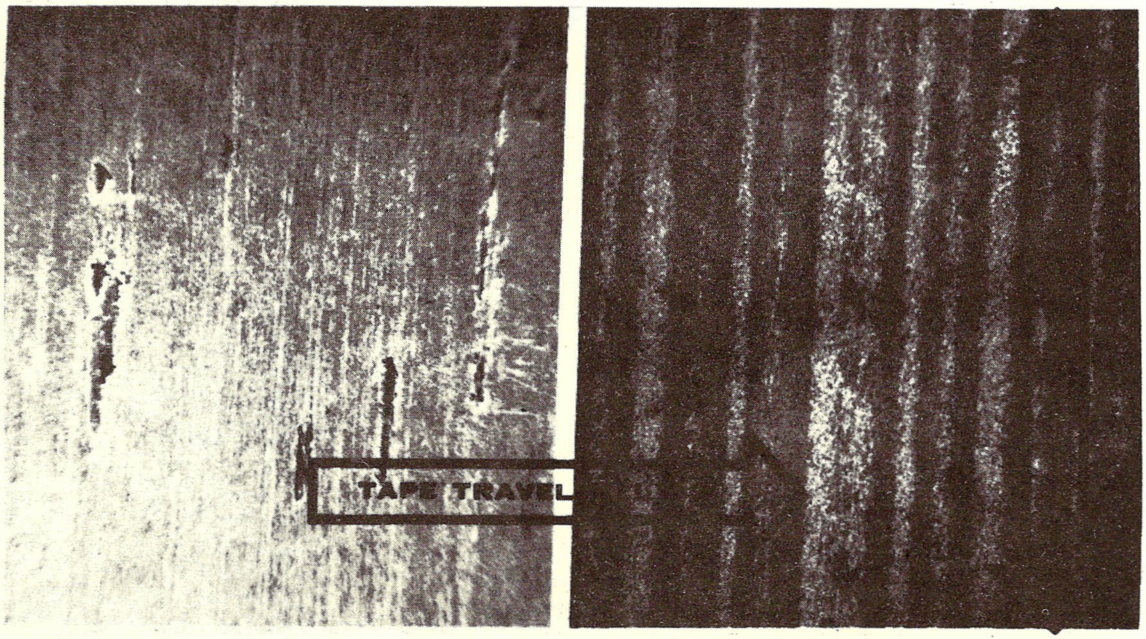

Fig. 3. Photomicrographs (35×) showing wear patterns of conventional, early experimental recording tape (left) and "Scotch" brand video recording tape No. 179 (right). Severe ruboff deposits were present in conventional tape after only 15 passes through the Ampex video recorder, whereas the "Scotch" brand video recording tape was perfectly clean after 320 passes.

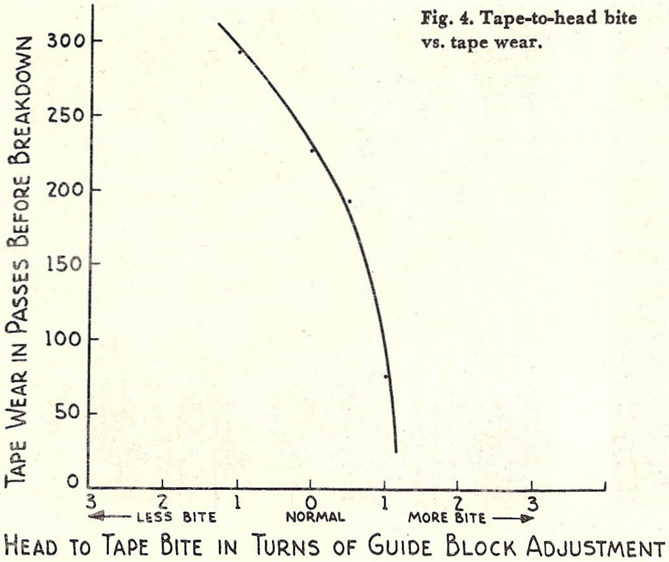

Fig. 4. Tape-to-head bite vs. tape wear.

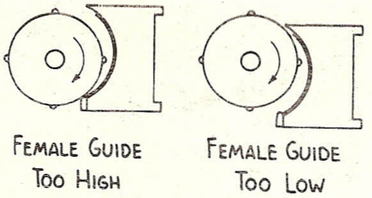

Fig. 5. Misalignment of female tape guide.

by a special technique and reveal as dark areas any valleys or holes in the coating which are deeper than about 10 µin. Note that in the photo on the left, showing the surface irregularities of typical sound-recording tape, only a small portion of the tape area is effective in recording video signals. The photo on the right, showing the surface of production video-recording tape, reveals a surprisingly high proportion of usable tape area. A commensurate improvement in noise level is apparent on the television screen.

Wear and Friction Problems

However, particle orientation and surface smoothness alone do not complete the story. Equally important is the ability of the tape to maintain its smooth surface throughout hundreds of passes through the Ampex recorder. It was soon discovered that the Ampex high-speed rotating head presented more severe wear and friction problems than ever before encountered. Early tape constructions were often gouged and scored to the point of uselessness in only one or two passes through the machine. The high head speed of about 100 miles/hr (in laymen's units) and severe head pressure of several hundred pounds per square inch created havoc with the soft binder resins used in tape coatings. These often melted and collected in hard slivers on the surface of the tape and heads. When lodged on a head, this caused "banding," or loss of every fourth "band" of 16 lines on the TV screen. When the slivers became attached to the tape surface as shown in Fig. 3, the result was a severe dropout or white flash on the television screen. These "dropouts" were then more or less permanent for the life of that particular tape, and when the number of accumulated dropouts became too great, the tape had to be discarded.

Fortunately, a great deal of work had already been done on hard wear-resistant coatings for magnetic tape, and it was possible to develop a formulation which worked. It required, however, that several dozen different runs of experimental tapes be manufactured on production equipment and evaluated on Ampex machines, and without the generous cooperation of CBS network engineers in testing these experimental tapes, this phase of the tape development might have been seriously delayed.

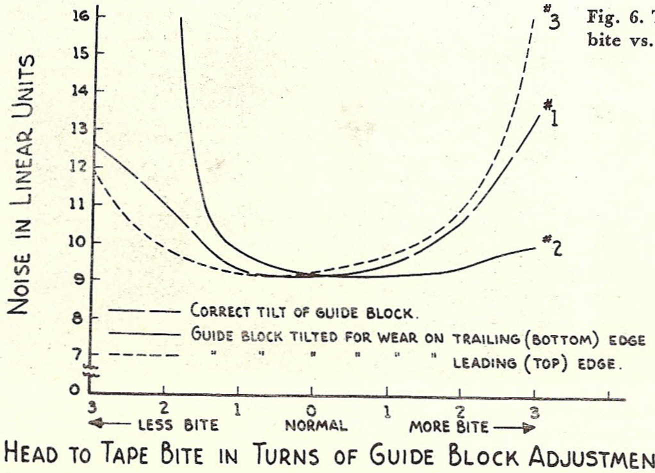

Fig. 6. Tape-to-head bite vs. noise.

While the present production videotape construction is remarkably resistant to wear and friction from the rotating head, it is not completely immune. With repeated use, the tape surface is eventually broken down, after which the number of dropouts increase rapidly with each playing. However, the exact number of passes through the machine before breakdown is influenced greatly by the adjustment of the head "bite" (which controls the pressure of the heads against the tape). In one laboratory-controlled experiment, the wear life of a tape was determined as a function of the head bite with the results as shown in Fig. 4. It can be seen that a change in head bite of only 0.002 in. can make the difference between obtaining about 300 plays and only 65 plays. Tape wear is therefore an important consideration in establishing the correct adjustment of the female tape guide with relation to the rotating head assembly.

Equally important is the adjustment of the female tape guide in vertical plane as illustrated in Fig. 5. If the center of the female guide curvature and the axis of the head drum are not the same height, the head pressure will be greater at one edge of the tape than the other. The head pressure must then be increased until even at the lowest side of the tape it is sufficient to maintain a steady signal. The pressure on the high side is then excessive, and the tape will wear out rapidly along one edge. Tests indicate that the correct head setting determined from the standpoint of tape wear also yields minimum noise. This is illustrated by the curve of Fig. 6.

While the above discussion is applicable to tape wear life under controlled conditions, the situation may be modified by other considerations. Splices and dents in the tape backing create local areas of high head pressure which may result in rapid wear. In almost all cases, the end point in the life of a tape is determined by excessive dropouts.

As has been mentioned earlier, a

smooth-surface magnetic coating is of paramount importance in preserving the quality of the video signal. In addition to average smoothness, one must also be concerned with a host of sporadic disturbances, such as streaks, scratches, nodules, dust, dents, creases and poor splices, any of which, if allowed to occur in the tape, would probably cause a beautiful pyrotechnic display on the TV screen. Unfortunately, the beauty of this is not appreciated by the networks and elaborate quality control methods are practiced in the factory in an effort to eliminate these defects. Considerable progress has been made since the first production runs of video-recording tape, and efforts to increase the already high standards of perfection achieved in video-recording tape are continuing. The difficulty of this problem can be appreciated when one realizes that a single roll of video-recording tape has an area as large as a tennis court and we are looking for flaws much smaller than a grain of sand.

As a bit of diversion from the half-hidden and microscopic problems discussed thus far, one perfectly obvious mechanical problem presented itself. In the Ampex machine an attempt is made to direct the tape through the various head stations and rollers by means of edge guiding. Any slight misalignment in the machine guiding or curvature to the tape causes a tendency for the tape to wander up or down between the guides. The 2-in. wide 1-mil Mylar base tape is not stiff enough to edge guide, but will fold or buckle. This causes loss of signal from the audio or control tracks, and in severe cases the tape creases and bunches in going through the capstan pinch. While everyone agrees that there is a tape-guiding problem, it is often difficult to know where machine alignment leaves off and tape curvature begins. Unfortunately, the factors which contribute to tape curvature are inherent in the Mylar base, and the only solution, for the moment, is to reject rolls which exhibit this tendency. Rigid quality control has all but eliminated this as a problem in the field.

In spite of the considerable number of problems encountered in the development of video tape, manufacture and use of this product are going ahead on a commercial basis. As there is almost zero margin for error in each of several dozen manufacturing steps, over 50% of the output is rejected as not meeting quality standards. However, laboratory and production research are continuing in an effort to improve both the performance and reliability of video-recording tape.

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Discussion on Video-Tape Recording

Chairman and Moderator

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Mr. Harmon: Many in our audience are a great deal more familiar with film than they are with the peculiar waveshapes that the speakers have been discussing this evening, but, speaking as a broadcaster with a little more familiarity with the electrical waveshapes than with film, I should say that Ampex, particularly on this project, has gone far off the beaten path in solving some very substantial problems in a unique way to make a major contribution to the television industry.

(*Anon*): The great tolerance of a television signal in its video portion is amazing, compared with its complete intolerance in its synchronizing portion. Why is it that we don't see more of the apparent degradation of the video part of the signal? Does it have degradation in that area?

Mr. Dolby: There is, of course, degradation of the picture as well as sync, but the effect of raw VTR signal on a stabilizing amplifier is by no means indicative of the real degradation. By comparison, a normal television receiver, which is designed to accept a certain degree of noise in the sync, would give a very fine-looking picture from direct VTR output. However, the integration action of the oscilloscope and film does give an exaggerated appearance to the noise seen in the illustrations. In fact, many picture lines may go by before a single spurious pulse appears in the VTR output.

Mr. Lewin: What success has there been in re-recording of video signals?

Mr. Ginsburg: The re-recording has been very satisfactory. The last one I saw performed in the field was about four months ago and involved a loss of about 50 lines in resolution and very little loss in signal-to-noise ratio. As a matter of fact, I have been told that, in one case, master control at CBS Television City, in selecting the better-looking tape from the output of two machines, selected the one which was actually a dub of the other. This situation occurred as a result of someone forgetting to push the record button when supposedly recording the show in duplicate, after which they made a dub of the original to use for back-up during playback.

Mr. Newmayer: In kinescoping, making a film of the video tape, do you run into any complications other than banding and shutter block which you'd get from an ordinary program? Is there any distortion that would be induced through the equipment or the frequency?

Mr. Ginsburg: No, there are no complications introduced in the process of making a film from video tape.

Mr. Zambuto: With regard to the linearity of the demodulation characteristic, is that curve theoretically derived from the assumption that your pulses, in other words your modulated waves, are actually square waves?

Mr. Anderson: No, that theoretical curve was drawn with or direct from sine-wave operation.

This discussion was held on April 29, 1958, during the Society's Convention in Washington, D.C.

Mr. Zambuto: Did you check what happens if the wave is square?

Mr. Anderson: Well, it usually ends up being a sine-wave anyhow, because of the upper cutoff frequency.

Mr. Zambuto: In the matter of splicing, it is quite evident, of course, that in the region of the butt-weld you are going to exceed the curie point. What happens there?

Mr. Machein: It is very important to determine this point of temperature and, of course, it will largely depend on the backing you are going to use. Up to this point we have been concentrating on basic questions of how to cut and splice so we are not in a position to present a final solution to this question right now. We have a welding machine ordered and in development, but it's a little bit early to give you a final answer backed by numbers at this point.

Mr. Harmon: I believe Mr. Ginsburg said that there is considerable hope that the voltage which could be read off the tape would be greatly increased at some later date because of improvements on the tape or improvements in the heads or some other mechanism. May I ask him to comment?

Mr. Ginsburg: I don't think I mentioned the tape in this connection. The tape manufacturers are doing very well, but there is lots of room for improvement in the efficiency of the heads.

Mr. Lewin: In regard to splicing, what do you do about the displacement between the sound and the picture?

Mr. Machein: The displacement between sound and picture is a constant displacement and it is somewhat similar to the displacement that occurs on film. I must admit I haven't thought of this as very serious because it's an established technique as far as motion pictures are concerned.

Mr. Lewin: If you make a cut at a certain picture frame don't you lose the sound which is in advance of that? You are dealing with a single system here and not the conventional double system.

Mr. Machein: Preferably you will choose a point for cutting your picture which is either on the end of a scene or where the sound is not significant; or you would have to find a way to delay the sound.

Mr. Smith: What physical tolerances are allowable in splicing during the vertical blanking interval? If I understand correctly, you splice between the track where the vertical blanking begins and the track where the vertical blanking ends, is that correct?

Mr. Machein: That's correct.

Mr. Smith: What tolerances do you allow in the actual "cut" between the tracks?

Mr. Machein: We must assume that the front portion of the vertical blanking will be held constant by the positioning servo and that the spacing between two tracks is 5 mils. In relation to the longitudinal motion of the tape, we found that an accuracy of ± 1 mil is sufficient. It may be interesting to note that we have made quite a number of splices, with conditions as severe as possible, making observations with the naked eye and using a razor blade. Five out of seven splices went through very satisfactorily.

Mr. Fine: How much azimuth error is tolerable in the heads of your different machines for optimum reproduction, between two machines?

Mr. Ginsburg: In considering all the tolerances that we have to meet in order to play tapes back interchangeably, it turns out that the azimuth alignment is a minor problem.

Mr. Harmon: What happens if this azimuth alignment is out? I assume that it would first appear as a difference in level coming out of the individual heads, but is there also a phase problem, a timing problem if this is out in that direction also?

Mr. Ginsburg: The phasing problem would not be of significant importance, the primary consideration being visibility of banding noise. This effect would be the result of the azimuth alignment on a given channel on the playback machine being different from the azimuth alignment of the corresponding channel on the record machine.

Mr. Harmon: As I understand it, there is a device which adjusts the gain from each head. You have separate pickup channels so that this might be taken care of if it was constant. On the other hand, if it was random it would be difficult to handle such a problem.

Mr. Ginsburg: The use of an FM system allows us to pass the recovered modulated wave through rather conventional amplifier and limiter stages. Therefore, variations in the amplitude of the r-f signal will not result in variations of the demodulated signal amplitude but merely in variations of the signal-to-noise ratio.

Mr. Hughes: In the recording of a composite NTSC signal, would this azimuth error in position between successive heads become more critical or do I misunderstand some of the physics involved? Is azimuth error allowable between successive heads?

Mr. Ginsburg: "Azimuth alignment" refers to that alignment which makes the gap perpendicular to the plane of rotation.

Mr. Hughes: I perhaps misunderstood the word. I meant the position of the heads on the periphery of the drum, at 90° intervals, 90° plus or minus how much?

Mr. Ginsburg: The positioning you are referring to is what we call angularity, or rotational alignment.

Mr. Harmon: On this delay-line detector, can you give us some information on its sensitivity and its noise level, signal-to-noise and such characteristics? It certainly is admirably simple. What are these characteristics in terms of some of our other types of detectors for FM signals?

Mr. Anderson: I must confess I don't remember all those figures. I do know the conversion sensitivity was quite a bit better than we had found in the slope detector. This made it a very attractive type of translation device, but I don't remember all of the signal-to-noise figures and the conversion factors.

Mr. Harmon: Certainly it's simplicity in itself.

Mr. Anderson: Yes, and nothing to go wrong, very straightforward.

Mr. Zambuto: I can conceive of at least two different types of flutter possible in this machine because of the two different motions. Can you give any idea of the tolerances in that?

Mr. Ginsburg: We can eliminate the factor of longitudinal tape flutter. This has primary bearing only on the audio track performance. Hence, it is simply necessary to conform to high-quality audio-tape recording tolerances.

Mr. Zambuto: Wouldn't that also affect the relative signal level because it would displace the rotating head with respect to its own track, so the head wouldn't read the whole of the track but only a part of it?

Mr. Ginsburg: No, by the time the flutter in the longitudinal direction gets that bad, the audio is so bad that you wouldn't want to use the tape anyway. Errors in the time base characteristic of a program played back from tape are, to a very large extent, a function of the oscillations of the rotating drum about its proper time varying position. For the usual case in which drum displacements take place in a sinusoidal fashion, it is desirable to keep F squared times A equal to or less than 3, where F is the natural hunting frequency and A is the peak amplitude of the displacement expressed in rotational degrees.

Mr. Zambuto: With respect to the future uses of this device, it has been said that possibly it could be mounted on a truck for recording certain events. Exactly how portable do you think this equipment is at the present moment?

Mr. Anderson: The best answer I can give to that is the fact that I said, "a truck." The equipment weighs, if I'm not mistaken, about 1350 lb and it does require a lot of portable space and portable power to move it around.

Mr. Zambuto: I wasn't thinking just in terms of power, I was thinking in terms of what may happen to the equipment during transportation. In other words, what kind of shock isolation should the equipment be given and do you think this would be feasible? What transportation difficulties would you expect?

Mr. Anderson: The original piece of equipment that was shown last year at the NARTB was self-contained in one console. It was taken out of the console to make it more accessible to the broadcaster. As a measure of the reliability and desirability of the equipment, that particular recorder was shipped to Chicago by truck from the airport, bounced on a DC-6 all the way back and I'm sure it was pushed off the DC-6 on to a truck and then back to Redwood City. That same equipment was trucked again to Los Angeles, trucked to Monterey, and I think it's been trucked around the Bay area several times. As far as I know, no damage has ever resulted from any of those operations.

Mr. Solow: Mr. Miner said that he wanted to elicit some comments from the audience, so it is perhaps fitting that I stand up here and let these evil geniuses look upon the kind of human being they're going to render extinct in the near future. In my opinion, the real impact of video-tape recording on television will come through programming, as Mr. Miner suggested, rather than through a straight technological competition with film. In this respect, video tape is different from the introduction of audio tape in radio because in that instance there was a contest between recorded and live radio programs, whereas now video tape represents really the live technique versus a film recorded show. I fear, on behalf of my own welfare, that video tape will change programming to the extent that film will be used less, because live TV is not very popular with actors and actresses. In the half-hour and hour presentations in the live form, all sorts of tensions, frantic costume changes and scene changes are, of course, necessary and, as a result, many actors and actresses refuse to appear on live TV. Of course, the tension arises from the fact that a fluffed line is going to be heard by the entire audience, or some disarray in the dress of a male actor who has just made a quick change may be evident. So, even without any further perfection in the technique of splicing, isn't recording in segments — starting with a fade-in and ending with a fade-out — possible, so that an hour's show can be leisurely performed in front of television cameras, together with a video-tape recorder, in perhaps the space of 6 or 7 hours preceding the broadcast. Then everybody can go home, relax and look at the show on the air and it will, essentially, be a live show. In this way your video tape will enhance the ease of presentation of live TV and render film shows less necessary as time goes on.

Mr. Harmon: One thing that would bother me about this, in what you say, in going to "black" as we call it, in television, this is fine, but suppose you have a fluff in the middle of a television field, how do you splice this?

Mr. Solow: Do it over again. Do it in easy segments.

Mr. Harmon: But you're still going to have to go back to a vertical period somewhere to make the splice?

Mr. Solow: That's right. You'd divide an hour's show perhaps into six 10-min segments.

Mr. Harmon: I thought you might be suggesting to the Ampex gentlemen that here's a neater way to splice, just go to black for a couple of dozen fields and cut anywhere you want and let your picture roll.

Mr. Solow: No, construct the script originally in the form of segments that would start with a fade-in and end with a fade-out, so that each segment is successively put in the can. You could then splice without worrying about revealing the scan lines, and just play the whole show. Of course, as more machines are delivered to the networks, I can also foresee, with added horror, that each television camera can have its own tape recorder connected to it, and then after all of the performance has been completed, the show can be played back over several monitors in the manner that live TV is played back, and a technical director can then punch one tape in following the other, and make lap dissolves and fades and that sort of thing. I suppose that is in the offing, too. So it's a dim future.

Mr. Miner: I think the general area that you're discussing resolves itself, in great measure, to the operating agility of the people who are using the equipment rather than the actual abilities of the equipment itself.

Interchangeability of Videotape Recorders

By CHARLES P. GINSBURG

New requirements are placed on video-tape recorders when tapes are to be recorded on one machine and reproduced on another. The nature and extent of these requirements are discussed for both monochrome and color.

Some of the greatest problems involved in the interchangeability of video tapes, whether in monochrome or color, come from the fact that the pictures from the tape are segmented. An average of a little more than 16 picture lines is read out as each head describes an arc of 90° across the tape. There are 16 of these picture line groups in a field. Because of the segmentation, small variations from one band to another in noise, in frequency response or in time position will be visible and objectionable. If we make the reasonable assumption that the response characteristics of the four r-f electronics channels which carry the signals to and from the heads are matched, the variations mentioned above can be discussed in terms of electrical and magnetic behavior and mechanical positioning of the heads.

Noise Banding and Frequency Banding as a Function of Variations in Head Performance

Let us say that the process of recording a signal on tape and then recovering it constitutes a transmission channel. On the VR-1000 Videotape Recorder, we have four such head-tape transmission channels. These channels vary among themselves in two ways of special interest to the interchangeability problem:

(1) Slight variations exist in the impedance frequency characteristics of the several channels. This is due to very small differences in head circuit resonant frequency, including variations in the source impedance of the amplifier circuits driving the heads during recording, as well as loading impedances presented to the heads during playback.

(2) Attenuation characteristics due to magnetic losses and to gap effect vary slightly from one head to the next. Since we are working with magnetic gaps whose dimensions approach the shortest wavelengths which are recorded on the tape, there may be variations in attenuation resulting from an inability to hold the gaps to exactly equal values for all heads.

Consequently, in comparing the transmission characteristics of the four channels, we will find:

(1) Differences in the amplitude vs. frequency characteristics accompanied by differences in delay distortion. This would be the case for variations caused by differences in the resonant frequencies.

(2) Differences in the amplitude versus frequency characteristics not accompanied by differences in delay distortion. This would be the case for variations caused by differences in the size of the magnetic gaps.

The tendency toward noise banding and frequency banding will increase somewhat when tapes are to be played back interchangeably. The optimizing of the recording current for a given head is, by definition, a process by which the best possible picture is obtained, and results in the best possible current setting in view of the playback as well as the record characteristics of that particular head. Theoretically, there are several reasons why an optimum recording current setting for a given head will not necessarily be the best setting if a different head assembly is to play back the same tape. Fortunately, in practice, this matter is of secondary importance.

The azimuth alignment requirement for the head gaps, i.e. perpendicularity with respect to the transverse magnetic tracks, is considerably tighter for interchangeability than it is for an operation in which a tape is to be played back only with the same head assembly with which it was recorded. Within extremely wide limits of azimuth errors, there is essentilly no decrease in head resolution or head output in the latter case, since the control system is so designed that each of the four heads will play back the particular set of magnetic tracks which it recorded. However, if the azimuth is different in playback than in record,

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Presented on April 24, 1958, at the Society's Convention in Los Angeles by Charles P. Ginsburg, Ampex Corp., 934 Charter St., Redwood City, Calif.
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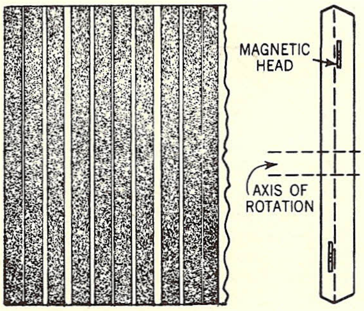

Fig. 1. Irregular track spacing.

Fig. 2. Playback result when female guide is farther from drum than when recording was made.

which would be the case in interchanging tapes, there will be a loss in playback voltage increasing at the shorter wavelengths and causing a decrease in signal-to-noise ratio even for small azimuth errors. Since we are concerned with wavelengths as short as 200 μin., the numerical value of the azimuth tolerance might be very difficult to meet were it not for the fact that the tracks in the Videotape Recorder are only 0.01 in. wide. The displacement of the axis of the gap with respect to the axis of the recorded signal must be kept small with respect to the shortest wavelength which is to be reproduced. It is obvious that this same tolerance can be met at a larger angular difference as the track width is decreased.

Because of the several sources of variation in transmission characteristics from one channel to the next, it might seem desirable to have independent control of the r-f playback response of each of the four channels. However, from an operational standpoint, it is highly desirable to be able to play back a tape recorded on a different machine without adjusting the channel response characteristics. The heads have been sufficiently well controlled in performance to permit the interchange of monochrome tapes without playback equalizing controls, but because the high-frequency components of the NTSC color signal are more important than they are in monochrome such adjustments are usually necessary when interchanging color recordings.

Another source of degradation of signal-to-noise ratio peculiar to the interchangeable use of video-tape recordings lies in the mechanical tolerances affecting the pattern written on the magnetic tape. As shown in Fig. 1, errors in track spacing can be caused by faults in positioning the heads in the axial direction. Somewhat similar troubles can be caused by excessive wobble of the rotating head drum, or by asymmetry with respect to the center line of the tape as the tape is guided from the supply reel to the head drum and then to the take-up reel.

When a tape is played back on the same machine and with the same head assembly with which it was recorded, these track spacing and track curvature problems are of little or no importance, since eccentricities in recording will be followed by the same eccentricities in playback.

For operations in which tapes are used interchangeably, however, a misregistration of as little as 0.002 in. during part or all of the sweep of a given head across the tape will result in a decrease of the amplitude of the recovered modulated wave, a consequent decrease in signal-to-noise ratio for the corresponding portion of the reproduced picture, and an increase in banding noise.

In short, slight tracking errors will merely result in an overall decrease of the signal-to-noise ratio for the non-interchanged tape playback; but these same slight tracking errors will cause banding noise in the tape interchange case if track spacing or track curvature errors exist. For an overall signal-to-noise ratio of 36 db, for example, a difference of 2 db from one band to the next will be more objectionable than an overall degradation of 2 db.

Time-Base Banding

If the timing variations in the reproduced picture which may occur as a result of variations in the rotational motion of the drum are disregarded, the factors which play a role in the variations in time position of the information coming from the rotating heads can then be classified as:

(1) Factors relating to the positioning of the head tips around the circumference of the drum. This positioning is referred to as rotational alignment, or angularity, or quadrature relationship.

(2) Factors involved in the configuration of the drum and the female guide.

Angularity

If the time base of the reproduced information experiences a discontinuity in the transition from the output of one head to the output of the next, there will be a corresponding step in the picture information which appears on the monitor. Figure 2 shows such discontinuities generated when the female guide in playback is farther from the drum than it was when the recording was made. Figure 3 illustrates what happens when a tape is recorded by heads in proper rotational alignment but which is being played back by heads which are not in quadrature.

Although the FCC standards of good engineering practice imply that such discontinuities must not amount to more than 0.5% of the line period, or about 0.3 μsec, an error this large repeated every 16 picture lines is intolerable to the observer. To hold these displacements to an acceptable value, each head gap should be positioned to within one-half the distance on the drum circumference corresponding to 0.05 μsec, since the error will be cumulative when the tapes are used interchangeably. In linear distance on the drum, this amounts to about 38 μin.

Since it would have been impractical to use optical means for rotational alignment of the heads on the periphery of the drum, it was initially planned to use delay lines to compensate for errors

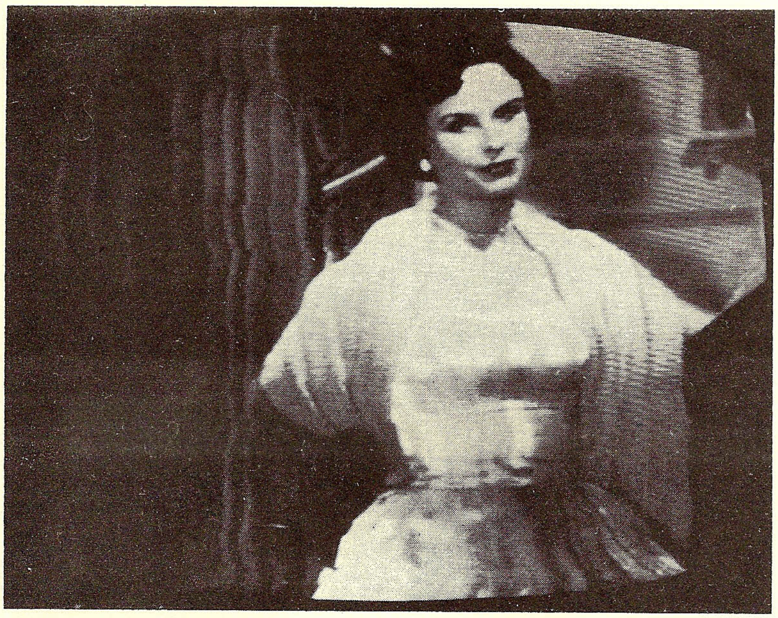

Fig. 3. Result of poor quadrature alignment.

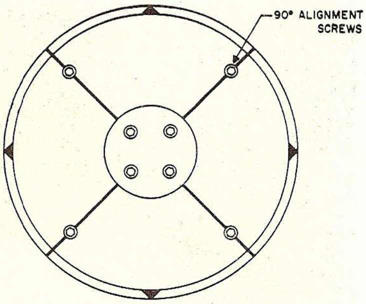

Fig. 4. Arrangement of alignment screws.

in angularity. However, because of problems resulting from interchannel cross-talk during both record and playback, and also because of some possible operational complications, it was decided instead to use an approach in which the heads are first aligned on the drum to within 1 μsec, and are then brought into effectively perfect angularity by means shown in Fig. 4. The tapered alignment screws are used as vernier angular adjustments of the pie-shaped segments of the drum, and angularity of the head gaps can thus be set to a very precise degree.

Head Wear, Tape Stretch, and Nonconcentricity

For color as well as for monochrome, we are concerned with changes which occur as the pole tips of the rotating heads wear down due to abrasion by the tape. The nominal setting of the female guide for a new head drum assembly is approximately that setting which establishes concentricity of guide profile and drum (Fig. 5).

There is sufficient tension exerted on the tape from both lateral directions so that the rotating head tips which project from the periphery of the drum into the slot in the female guide actually stretch the tape temporarily in the region of head contact. It is obvious that as the guide is moved closer to the drum, the extent to which the tape is stretched at any given point in the sweep is increased in accordance with the movement.

Assuming that a recording has been made and then put on the shelf while the heads are worn down 0.001 in. through usage, what happens when an attempt is made to play back the old recording?

Having a smaller sweep radius, each head gap will now describe a shorter path per unit angle of sweep. On the other hand, the tape is now being stretched less, and thus the information that was recorded per microsecond will tend to have a shorter path during the playback process than it occupied during the original recording process. In practice this compensating action is about 90% effective, which means that for 1 mil of tip wear the guide must be backed 0.1 mil away from the drum.

Although there are means by which

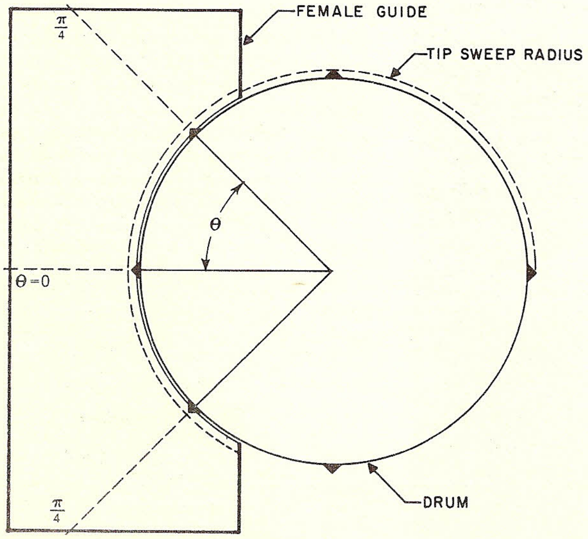

Fig. 5. Profile of drum and guide.

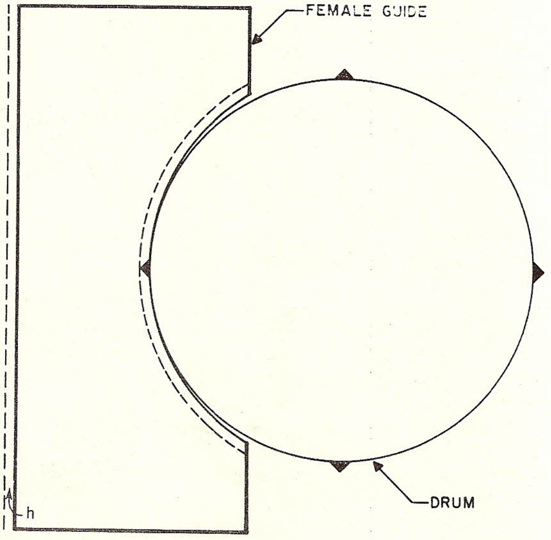

Fig. 6. Nonconcentricity due to movement of guide toward drum.

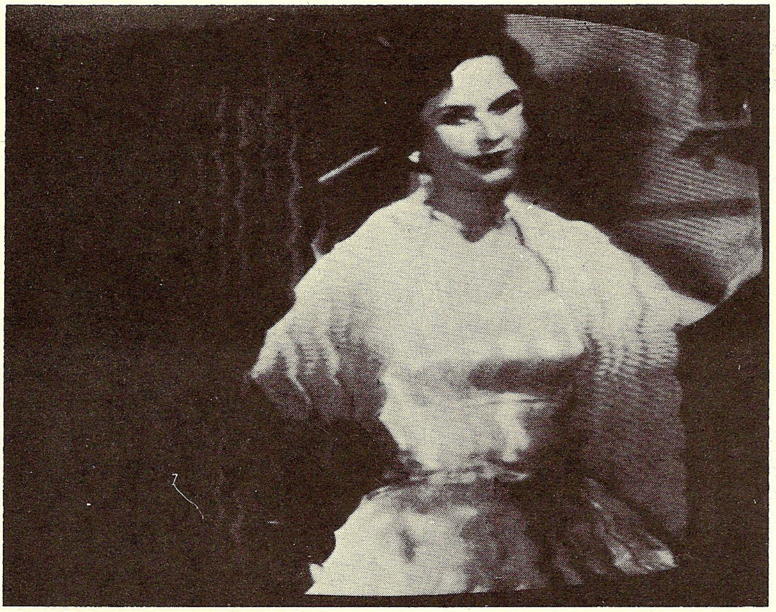

Fig. 7. Scalloping distortion resulting from vertical misadjustment of the guide.

this percentage of compensation might be increased to the point where no adjustment of the guide would be needed, there are other considerations which require that a compensating means be available by which to alter the time base of the playback signal. For example, the temperature and humidity coefficients of the tape itself are large enough to necessitate time-base adjustment even under fairly limited ranges of ambient conditions. The range of compensating movement of the female guide may be expected to be greater under conditions of interchanging tapes from one recorder to another than it would be in the case of recording and playing back on the same machine.

Since the curvature of the guide and the arc of the rotating heads can be concentric at only one horizontal position of the guide with respect to the drum, it is apparent that the geometry will generally display some small nonconcentricities (Fig. 6). Consequently, we can expect variations in the extent to which the tips protrude into the guide slot, with accompanying changes in tape stretching, as a function of the instantaneous angular position of a given head. Therefore, it becomes necessary to ascertain:

(1) What effect on raster structure is generated by these variations?

(2) What effect on color signals is created by these nonconcentricities?

Some simplifications can be effected by assuming that perfect recordings have been made in every case and that any changes in position or dimension are understood to prevail only during playback. Let ΔP be the change in protrusion of the head tips into the guide slot, and consequently into the tape, as a result of a change in the guide position with respect to the drum. Θ is the angle which a given head makes with respect to a horizontal line directed from the drum center toward the guide. The heads sweep down across the tape so that Θ for the active part of the head sweep starts off at $-\pi/4$, progresses to zero and then to $\pi/4$. For a horizontal movement, h, of the guide toward the drum, $\Delta P = h \cos \Theta$.

Let us define a function ΔS as the proportional difference between playback time base and record time base. This might best be explained by the following example: If a given amount of picture information took 10 μsec to record, and then, because of a horizontal movement of the guide, takes 10.5 μsec to play back, ΔS will be equal to 0.05. This means that the playback time base will have a proportional difference of 0.05 with respect to the record time base. Thus ΔS is dimensionless and is merely a correction factor to apply in the case of a misadjustment, misalignment or compensating movement.

We can now set

$$\Delta S = \frac{Kh \cos \Theta}{r}$$

where r is the tip sweep radius and K is the numerical value of the compensating action referred to earlier; i.e., small tip radius changes are 90% compensated for by a decrease in tape stretch.

If we define e as the total accumulated error in time base as the head describes an arc between two values of Θ, then

$$e = \int_{\theta_1}^{\theta_2} \Delta S d\Theta = \frac{Kh}{r} \int_{\theta_1}^{\theta_2} \cos \Theta d\Theta$$

If we want to predict the extent of the discontinuity generated by moving the guide 1 mil closer to the drum, we have merely to integrate e over the limits of $\pi/4$ to $-\pi/4$. Thus,

$$\epsilon = \frac{Kh}{r} \int_{-\pi/4}^{\pi/4} \cos \Theta d\Theta$$

$$= \frac{0.9 \times 0.001 \times 1.414}{1.036}$$

$$= 1.23 \times 10^{-3}$$

Therefore, the amount of information recovered by a head during its 90° arc is less than it should be by a factor of

Fig. 8. An example of successful interchangeability, when components are properly adjusted.

1.23×10^{-3}. Since it takes 1/960th of a second for a head to describe a 90° arc, the accumulated time-base error during the sweep amounts to $1/960 \times 1.23 \times 10^{-3}$ seconds which equals approximately 1.3 μsec.

The type of scalloping distortion shown in Fig. 7 is the result of vertical misadjustment of the guide. The fact that such distortion is accompanied by negligible displacement at the transition points can be shown by integrating the cumulative error e over the range defined by the active portion of the head sweep. For a vertical guide misalignment v, $\Delta S = \frac{Kv}{r} \sin \Theta$, and therefore:

$$e = \frac{Kv}{r} \int_{-\pi/4}^{\pi/4} \sin \Theta d\Theta = 0$$

Thus the total amount of information played back under conditions of vertical mispositioning of the guide is correct, although time-base errors within each head sweep may easily reach an objectionable value. If we define scalloping as the accumulated time error between $\Theta = 0$ and $\Theta = \pi/4$, then scalloping equals:

$$\frac{1}{2 \times 960} \int_{0}^{\pi/4} \Delta S d\Theta = \frac{Kv}{1920} \int_{0}^{\pi/4} \sin \Theta d\Theta$$

For a vertical misalignment $v = 0.1$ mil, the scalloping will thus amount to less than 0.015 μsec within each band. The maximum tolerable amount of scalloping, from the standpoint of subjective picture quality, may be considered to be 0.1 μsec or less. Proper adjustment of vertical positioning of the guide prior to recording can be made by use of a standard alignment tape.

Finally, let us consider the effects, on a color picture, of the nonlinear characteristic induced in the time base by the nonconcentricity which results from guide movement. Since the color system is one in which phase locking is effected at the beginning of each picture line, our principal concern is the extent to which phase shift occurs at the 3.58 mc subcarrier frequency during a single line. We have considered time-base errors caused by nonconcentricity to be sinusoidal. Vertical misalignment of the guide with respect to the drum will cause an expansion of the time base at one extreme of the sweep and a contraction of the time base at the other extreme. This will be accompanied by a maximum rate of change of the time base occurring during that television picture line which is read out at the center of the sweep. A horizontal mispositioning of the guide will result in a maximum stretch error at the center of the sweep and a maximum rate of change of time-base error during the first and last lines of each sweep. The extent of the time-base rate errors will directly determine the amount of hue shift in a burst locked color Videotape Recorder system. Taking into account all of the variables involved in a given playback operation, and even allowing a reasonable degree of operational or setup error, the worst case of phase change within one line will be undetectable to the eye.

Since time-base distortions of the type we have been discussing can be closely controlled, especially as operating and maintenance characteristics of the machines continually become better understood by the users, it seems rather doubtful that these phase changes will ever become objectionable. However, if the expanded use of color video-tape recorders on an interchangeable basis, involving sequential duplication operations, presents detectable hue shift in the picture, the problem can be readily solved by the use of a pilot carrier system of the type which has been developed in the laboratory and which grants complete freedom from the type of defects discussed. The conversion of color machines from burst locked to pilot carrier operation would be a comparatively simple matter. Unless we find that eventual usage warrants the transition to a pilot carrier system, it is best to reserve that portion of the video-tape spectrum for other possible uses.