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Audio Recording on Magnetic Tape

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The material presented in this chapter was gathered from the many available sources for a general guide to the installation, maintenance, and operating engineer. It is intended for use as a supplement to the instruction manuals for specific tape machines in the station and to explain some of the basic principles.

MAGNETIC TAPE

Audio magnetic recording tape consists of a backing or base material, typically polyester ("Mylar") or acetate, and finely divided magnetic particles suspended in a strong binder (oxide coating) that is deposited on the plastic backing. Tapes used in NAB Cartridges have an additional dry lubricant deposited on the plastic backing opposite to the oxide coating side, generally in a dot pattern. This lubricant permits the tape to slide on the adjacent layer, on through to the center of the tape pack, and out past the heads again in a continuous loop.

Some audio tapes have a highly polished oxide coating side and even some open reel (nonlubricated) types have an etched or rough coated base side that may cause confusion as to which side to put in contact with the tape head. If such tape is used intermixed with tape having a dull oxide coating surface and polished base side, a positive identification of the oxide coating side of both types is desired.

Audio tapes of interest in ¼ in. to 2 in. widths are "½ Mil" to "1½ Mil" thick as commonly referenced. Actually, these dimensions are for the backing or base film thickness. Total thickness includes one or more coatings:

Nonlubricated Tape

Thickness in mils (0.001 in.)	Scotch #111	1 Mil	½ Mil
Backing (base)	1.42	0.92	0.50
Oxide coating	0.44	0.40	0.40
Total	1.86	1.32	0.90
Static tensile, lbs/¼/in.			
Yield strength	5.0	4.0	3.0
Breaking strength	6.5	6.0	5.3

Lubricated Tape

Thickness in mils	1 Mil	1 Mil	¾ Mil	¾ Mil
Backing (base)	0.92	0.92	0.75	0.75
Oxide coating	0.37	0.27	0.38	0.38
Backing lubricant	0.11	0.11	0.10	0.04
Total	1.40	1.30	1.23	1.17
Static tensile, lbs/¼/ in.				
Yield strength	4.0	4.0	3.1	3.9
Breaking strength	6.0	6.0	4.9	5.9

Scotch #111 is listed because many other tapes are referenced to it, especially the peak bias reference. It is acetate base, while all of the others listed are polyester. The ½ mil example has a tensilized polyester base, which gives it proportionally more strength per unit thickness of the base.

Oxide coating thickness has some effect on peak bias requirements, even more on the maximum undistorted output level. The intrinsic magnetic properties have much more effect on the peak bias requirements, but are difficult to interpret as to the amount of peak bias change since no single parameter is the controlling factor. If it is desired to keep the peak bias requirements within a narrow range to prevent the necessity of changing machine bias adjustment for consistently optimum results, tape of the same type and manufacture or a closely matched alternate is all that should be used. Manufacturers typically have their own peak bias reference, which is not easily matched to another manufacturer's reference, so tests should be conducted to assure an acceptable match.

There are many factors to consider in selecting the tape desired for general use in your plant, in addition to cost and playing time per reel size. High output, low noise, low print through, output uniformity, and the way they interrelate should be weighed against overall requirements for your operation. A tape applications engineer for one of the tape manufacturers can be of great assistance in the selection process.

If the selected tape has appreciably different characteristics than tape currently used, intermixing them for recording can present a problem. Consider dedicating separate machines for recording the two types of tape in order to optimize the bias current for each type. The method of adjusting bias may be covered for tapes having medium biasing requirements only. If the frequency response of one of the tape types rises or falls more than the machine specification in the instruction manual, refer to the section on optimum biasing later in this chapter. After a period of time most of the older tape will be phased out of the rerecording process and a single bias setting can be used for all recordings.

With the bias properly adjusted, a new tape under consideration should be checked for headroom, or the level differential between the NAB Standard Reference Level and the 3 percent 3rd harmonic distortion point at 400 Hz. If only total harmonic distortion can be measured with test equipment available, this will give a sufficiently close approximation. Professional tape recorders should have no more than 2 percent total harmonic distortion in the record/play process with good tape having medium bias requirements at a level a few dB above normal, where the tape and machine noise level is more than 46 dB down. If the machine will not reach the 2 percent distortion point, check the bias waveform distortion, flutter, etc., to find and correct the cause.

After finding a distortion reading of 2 percent or less, increase the input level to the recording amplifier at 400 Hz until the distortion reads 3 percent THD and note the output level of the playback amplifier. This level should be approximately 8 dB above the normal operating level of the machine, which should be set to agree with the level derived from an NAB Test Tape Standard Reference Level, or some traceable standard, if interchangeability with most prerecorded tapes is desired.

If the new tape under consideration does not have the 8-dB minimum headroom, it should not be adopted unless some special parameter is desired such as extended play that will justify a nonstandard operating level or insufficient headroom. Many other factors should be considered in selecting a new tape (Spratt, 1964) in addition to those covered. The surface characteristics of each side, the degree of stiffness, tape width tolerance, and erasing requirements are among them.

The magnetic material is typically in the form of long needle-shaped particles (Lowman, 1972), some of them are bound to project from the surface of the tape. Quite naturally, this would cause unwanted head wear. Several methods of reducing this form of surface roughness are employed; one of the better is rolling the particles back into the heat softened binder with a highly polished roller surface. The quality of the surface is important to prevent excessive shedding of the oxide and binder, which rapidly builds up on the tape machine heads, pinch roller, etc., which it contacts. Also, a smooth surface permits a more intimate contact between the tape and the head to prevent additional high frequency losses.

MAGNETIC RECORDING THEORY

All sound recording processes are essentially techniques for the storage of information where acoustic signals are transformed into some form of permanent or semipermanent record (Spratt, 1964) from which they can subsequently be converted back into sound. In magnetic recording, the sound information is stored in the form of elemental permanent magnets corresponding in length and strength to the signals to be recorded; these permanent magnets being formed in a continuous strip of some suitable magnetic material.

During the recording process, the magnetic medium is moved through the magnetic field of the gap in the recording head and the resulting flux pattern on the tape is a function of instantaneous magnitude of the recording signal at the moment the tape leaves the head gap. Ignoring the various losses in the heads, etc., which are fairly small in the 200 Hz to 2 kHz region on professional audio tape recorders, flux density on the tape is directly proportional to the recording current.

The heads normally take the form of rings of low coercivity, high permeability laminations split at one point at least with a narrow airgap and wound with one or more coils of fine wire. The length of the airgap ranges from 0.020 to 0.003 in. for an erase head (Spratt, 1964), to 0.0001 in. for a reproducing head. In its travel past these heads, the tape always moves perpendicularly to the line of the airgap. Currents corresponding to the recorded signal are fed into the coil(s) of the recording head and as a result, a flux, also varying in accordance with the recording signals, is produced in the magnetic circuit of this head. The greater part of this flux passes straight across the airgap, but a small portion appears as fringing or leakage flux in front of and behind the airgap. As the tape coating passes across the face of the head, that portion of it in the immediate vicinity of the airgap is magnetized by the magnetic field there. Since the magnetic particles in the coating are of high coercivity, some of this magnetization is retained after the tape has left the gap as the actual recorded signal.

ERASURE

One of the several advantages of magnetic recording lies in the ability to erase the signals which have been previously recorded on the magnetic tape, making it ready to accept a new set of recorded signals. Although permanent magnet erasure is used in a few specialized applications such as delay cartridges, the spacing of the several sections for minimum acceptable operation is very critical.

Bulk erasure gives the most complete erasure of any method employed to date, and will reduce the residual noise level of an audio tape of medium characteristics to approximately 1 dB above that of virgin tape, when carefully done. The bulk eraser must have sufficient power to completely saturate the tape, then the flux field must be slowly reduced on the tape to gradually reduce the remanent flux to zero. The field of the bulk eraser may be reduced by pulling the tape out of it, or by gradually reducing the current to it. The power to the bulk eraser must be a sine wave of relatively low distortion, such as most commercial utilities provide. Any asymmetry of the positive versus the negative waveform will leave a higher residual noise on the tape.

Where only one of two or more tracks on a tape, or a segment rather than the entire reel of tape is to be erased, bulk erasure is impractical. To accomplish demagnetization of just part of a tape, an erasing head with the proper track configuration is required. Of course, a full track head may be used to erase the entire tape instead of a bulk eraser. The erase head is usually similar in general construction and appearance to the recording head. The basic difference lies in the length of the gap (Haynes, 1957). In order to produce a diffuse field, the erase gap length may be as much as 200 times as long as in the associated reproducing head, or approximately 0.020 in. long.

If a normal erase head is employed, it is more than likely that the first erasure will be found imperfect and that a second run past the erase head is found necessary to achieve anything approaching virgin tape conditions (Spratt, 1964). This is due to the fact that the "erased" tape, when leaving the head and still subjected to the diminishing erase field, is likely to be affected by the recorded field not yet erased from the tape on the other side of the head, so that the original recording is recorded, but at a very much lower level, on the tape. Hence the need for a second run past the erase head, which will almost certainly prove effective. This rerecording effect is less likely to occur when the erase head gap is made large, i.e., 0.20 in. in length, so as to give a correspondingly wide spread of the erase field.

Like the bulk eraser, the erase head must have sufficient power to completely saturate the tape, then the field is slowly reduced by tape moving away from the erase head gap. The feed to the erase head must also be a sine wave of relatively low distortion without even-order harmonics of any significance that would cause asymmetry of the positive versus the negative waveform and a higher than necessary residual noise on the tape.

High Frequency Bias

If recording is attempted without bias, operation would have to be confined to the immediate neighborhood of the origin of the B-H curve; otherwise, the amount of distortion would prove intolerable (Spratt, 1964). This restriction on the maximum operating level inevitably results in poor signal-to-noise ratio. The oldest method of obtaining a linear recording with magnetic media is through the use of a permanent, or dc bias, added to the signal (Stewart, 1958). If the medium is first completely demagnetized, the transfer characteristic can be arranged to operate on a comparatively linear portion of the B-H curve of that medium by adding a dc component to the signal. However, only a portion of one-half of the B-H curve is used, with a resultant low signal output.

This was greatly improved upon by the introduction of hf bias, which increased sensitivity as well as maximum undistorted output level, while absence of a dc component in the magnetizing force assures a low noise level. Bias frequencies of five to ten times the highest signal frequency are preferred. This is usually called supersonic bias and is in the 75 kHz to 150 kHz range. The bias current through the recording head coil is always many times as great as that of the signal being recorded. Using the correct value of bias current is very important, for this affects the frequency response, distortion and signal-to-noise characteristics of the recording.

A bias value that is too low for the type of tape being recorded results in a "boost" in high frequency response, high distortion, and a poor signal-to-noise ratio. A value that is too high will cause a loss of high frequency response, due to partial erasure as the signal leaves the recording head airgap. It would be expected that there exists some value or range of values of hf bias current to optimize performance in sensitivity, maximum distortionless output level, frequency response, or all of them (Spratt, 1964). This value could be set to the prescribed point on a meter of the tape machine. This is largely the case but optimum conditions are somewhat different for each parameter and one should not be favored at the expense of the others.

A better method of bias adjustment is to select a tape that has average characteristics for the type used. Reduce the bias current well below the normal level, then slowly increase it for a peak in the 400 Hz output level at full operating level. Note the current or the position of the control. Increase the bias further, closely watching for a rather sharp decrease in output level which is characteristic with some types of tape (Spratt, 1964). A further increase in bias with this type of tape should soon cause the output level to rise again to a gentle peak. An optimum setting for the bias will be for about 1 dB of output level reduction caused by a further increase in bias current. Other types of tape will rise smoothly to a gentle peak without any intermediate dip, and can also be set for optimum bias by further increasing it for a 1 dB reduction in output level beyond the peak.

Frequencies above 400 Hz should then be checked to see that none fall outside the frequency response limits. Some machines have auxiliary peaking controls or suggested changes of fixed component values to make small adjustments in frequency response. If they cannot be used to correct the response, the bias current should be dropped slightly to raise the high frequency levels, or raised to lower the high frequency levels even more. If the results are far from the specified limits in the instruction manual, check for defective components in the equalization circuits or signal path, replace them, and repeat the bias adjusting procedure.

The bias adjustment should not be set on the steep slope of the bias current versus output level curve since small changes in tape characteristics, even those found on the same reel, will cause considerable variation in frequency response, output level and distortion. The only penalty of slight overbiasing, assuming the frequency response is acceptable, is a small reduction in headroom at the shorter wavelengths.

MAGNETIC REPRODUCTION

During the reproducing or playback process, the recorded tape is moved past the airgap of the reproducing head, which may be similar to or even the same head used for recording. The movement of the tape and the magnetic flux patterns it contains induces a voltage in the winding(s) of the reproducing head, which is proportional to the amplitude of the recorded signal and to the frequency of the recorded signal (Stewart, 1958). As the frequency increases, the output signal increases at a rate of 6 dB/octave, assuming the recorded signal is constant in amplitude. Doubling the reproduced frequency by doubling the tape speed will produce the same 6 dB/octave increase in output as doubling the recorded frequency, again assuming the recorded signal is constant in amplitude and that the head losses, etc., are negligible over the frequency range under consideration. When the tape is stopped and there is no relative movement between it and the reproducing head, the flux is fixed in value in the airgap and no signal is generated in the coil.

High Frequency Response

The length of the airgap and the relative tape speed across the airgap are key factors in the high frequency limit of the reproducing process. With typical airgap lengths of 0.0001 in. to 0.0002 in. that are difficult to measure within 10 percent accuracy, an additional hardening of the head surfaces near the gap, due to the final lapping and polishing, reduces the permeability of the iron in that critical area. This, along with other factors (Spratt, 1964), led to the accepted practice of referring to the physical airgap length, i.e., the dimensional length specified in the design and the effective airgap length, estimated from the first head-induced null frequency. This null is caused by cancellation of the flux in the airgap when the signal wavelength is comparable to the length of the airgap. This effective airgap length is nearly always at least 15 percent larger than the physical gap length.

During the recording process, the tape coating assumes a permanent state of magnetization at the instant it leaves the recording head airgap, so the gap length or dimension across the gap is relatively uncritical. It must be large enough to permit the magnetic flux to fringe or leak far enough away from the gap to provide deep penetration into the oxide coating or the magnetic tape (Lowman, 1972). On the other hand, the gap must be small enough so that sharp changes or gradients of the flux may be generated. Thus, the recording head airgap length is a compromise between a large gap, for strong recorded signals, and a narrow one, for definition of small increments of change. A typical recording gap length is 500 μ in.

However, in reproducing, the magnetic flux emanating from the moving tape must induce a voltage differential across the reproducing head coil if the current is to flow in that coil, which is proportional to the sum of the positive and negative flux patterns in the gap at any given instant. When the wavelength of the recorded frequency is equal to the effective airgap length, the sum of the positive and negative flux patterns in the gap at that instant is zero, as is the voltage induced in the head coil. Except for those using very low tape speeds, i.e. below 3.75 ips, the typical 100 μ in. airgap used in the reproduce heads of professional tape machines places the frequency subject to gap cancellation well above the highest signal frequency of interest.

The resonant frequency of the reproducing head inductance and the actual or distributed capacitance of the head and associated circuit should also be well above the highest signal frequency of interest. The head and circuit capacitance, especially in the head cables, must be kept to a minimum because reducing the inductance to raise the resonant frequency reduces the head output over the entire passband, and will particularly diminish low frequency signals.

Low Frequency Response

As previously stated with some qualification, flux density in the tape coating is directly proportional to the recording current. Below approximately 2 kHz on a typical reproduce head at a tape speed of 7.5 ips, there is a 6 dB/octave loss for the longer wavelengths. Consequently, the recorded lower frequencies in the neighborhood of 50 Hz will be approximately 24 dB below the 1,000 Hz level (Haynes, 1957). During playback, therefore, a considerable amount of postequalization is required to attain a nearly flat overall response. The unusual amount of low frequency "boost" required will result in raising all low frequency noise and hum components as well. This procedure usually results in an overall marked reduction in dynamic range.

The long wavelength signals cannot be correspondingly increased in recorded level to compensate for the 6 dB/octave loss in playback because of tape overload and saturation with higher levels. The NAB reproducing characteristic and associated compensating recording requirements have been optimized for tape overload versus other parameters of interest with tapes of medium characteristics. It is essentially the only equalization standard used for professional audio tapes in the US.

The lowest frequency which can be reproduced in any tape system is determined by the signal-to-noise ratio which can be tolerated. As noted, the voltage developed across the coil(s) of the reproducing head decreases with frequency until a level is reached which is insufficiently above the noise threshold of the system and, therefore, considered unusable. The maximum effective bandwidth of most audio tape recorders/reproducers is around nine octaves, i.e., 30 Hz to 15,360 Hz.

Print-through

If a tape is recorded and stored for a period of time, there is a phenomenon occasionally encountered called print-through. It occurs because a strongly magnetized tape section is wound next to a low level or unmagnetized portion, and the strong fields transfer the signal to the adjacent layer. Since the transfer is through the polyester or acetate base, the effect is quite small, but often objectionable. This is not a linear effect, it becomes more serious as the recording level increases and will decrease about 2 dB for a 1 dB decrease in recording level.

The effect increases with time of storage, higher temperatures and exposure to stray magnetic fields. Most of the effect is in the mid-frequency range, where the ear is most sensitive, with high and low-frequency print-through virtually unnoticeable. The use of thinner base tapes will slightly increase the effect.

If a tape is to be stored for some time, the following precautions will help in eliminating print-through: Program peaks should be held to a level not exceeding 0 VU on the recording meter. The storage temperature should be kept below 75° F, and the reel should be stored in a steel can to protect against stray magnetic fields. To protect valuable recordings, it would be well to use a special tape rated for up to 8 dB lower print-through effect than general purpose types. Occasional playing or rewinding of the tape will redistribute the signals on adjacent layers, thereby reducing the effect. Most machines wind the tape more tightly when rewinding than when playing. Therefore, it is best to store tapes "tails out," or before rewinding to take advantage of the slightly increased spacing between adjacent layers.

TAPE HEAD

The individual tape recorder/reproducer is designed for a set of tape heads of certain characteristics, and the user should not attempt to replace them with heads of other characteristics. The physical configuration, mounting style, track configuration, and head contour as well as the

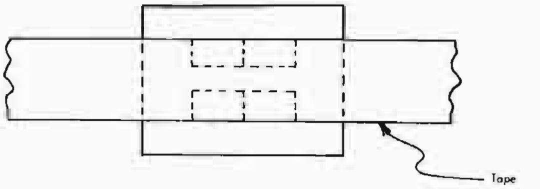

Fig. 1. Correct height adjustment (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

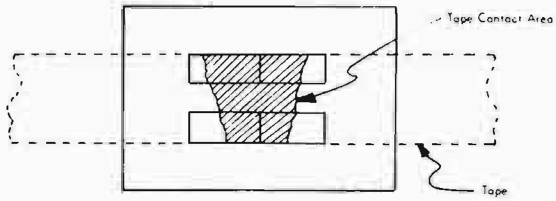

Fig. 3. Keystone Wear pattern (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

electrical characteristics must be matched in replacement heads. More popular types are available from several manufacturers and may be selected from cross-reference charts or by matching the important parameters.

Correct height adjustment of the tape to the heads, or in most tape machines the heads to the tape path, is important for single track heads as well as multitrack heads. Maladjustment of a single track head to tape height adjustment will reduce the amount of signal output from the tape and may cause uneven wear of both tape and head. Proper alignment is even more important on multitrack heads to maintain maximum guard-band width between tracks for minimum crosstalk.

All of the line drawings which follow utilize a 2-track stereo head for illustration (Zeman, 1974). Fig. 1 shows the correct height adjustment for a head of this type. The head should be adjusted so the top edge of the stack in Channel 1, and the bottom edge of the stack in Channel 2 are even with the edges of the tape. On reel-to-reel machines this is usually accomplished by two small Allen head set screws which are located on the center line of the head mounting plate, but are sometimes placed to one side of this plate. If these screws are on one side, the opposite side has wells containing two compression springs to supply the pivot action necessary to azimuth the head gap. Regardless of where these two set scews are located, they serve a dual function, adjusting for zenith or tilt as well as height. Cartridge machines may use regular machine screws instead of Allen head screws, but they serve the same purpose. In addition, there is typically a locking screw in the center of the head adjustment screws that is used to hold the head mounting very securely after it is adjusted. This is desirable because the heads on a cartridge machine may be struck with the cartridge when it is inserted for play.

Head Alignment

Fig. 2 is an exaggerated view of a head incorrectly aligned for zenith. The head face should be at a 90° angle to the transport base plate or deck. Any appreciable deviation from this angle will result in marginal tape contact which will become much more noticeable as head wear progresses.

Fig. 3 shows the result of incorrect zenith alignment. In this case, the head was tilted downward toward the transport base plate at the time it was installed. The keystone wear pattern indicates excessive tape contact at the top of the head and insufficient contact at the bottom. Had this head been tilted away from the base plate, the keystone effect would have been reversed.

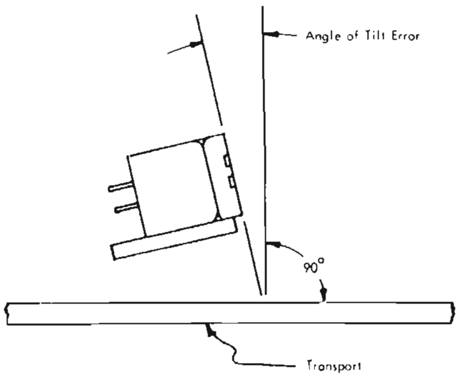

Fig. 2. Misaligned zenith adjustment (inside view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

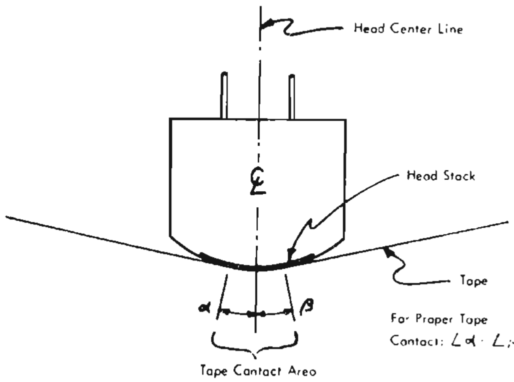

Fig. 4. Proper tape contact adjustment (top view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

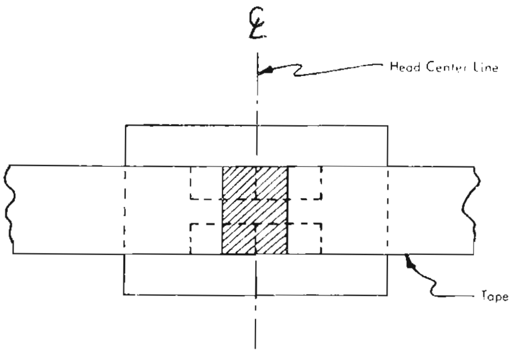

Fig. 5. Proper tape contact area (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

Any adjustment made on the head height is likely to also change the zenith, and vice-versa. When either is adjusted, the other should be checked and, if necessary, readjusted and then cross-checked until both are correct.

Fig. 4 is a top view of the adjustment for head to tape contact. As indicated, using the centerline of the head as a reference, the contact is correct when angle alpha = angle beta, or when the tape contacts the head an equal amount on either side of the airgap as shown in Fig. 5. This is a front view of the proper head to tape adjustment. Contact alignment is accomplished by rotating the head cup or assembly mounting block until the head face is positioned properly.

In factory installation and replacement, tape heads are typically adjusted with gauges and fixtures which are seldom available in the field. A good field method of checking for correct adjustment of the parameters covered so far is to use a black marking pen with a soft felt tip to coat the head face from top to bottom and about ¼ in. on either side of the gap. Run some tape through the machine in the play mode; five or six ft. should suffice. Stop the machine and check the head. The tape will have removed the ink from the head face and this clear area will show area of contact. If it shows the least amount of keystone effect, recheck the zenith. The clear area on the head should look like the shaded area in Fig. 5. When it does, the machine may be considered acceptably adjusted for height, zenith, and contact.

The ink can be removed with a damp (not wet) cotton-tipped applicator. Most head cleaners will dissolve the ink. If the one used will not, use lighter fluid. Be sure to clean the head between each adjustment and position check. Do not coat the face too heavily with the ink. The tape used for making the adjustments should not be a valuable recording, but it must be in good condition and from a reel that runs true. The marking pen should be new and the felt tip not contaminated with foreign particles that could scratch the head face.

Fig. 6 shows the final mechanical adjustment required by a new head - azimuth. The reproduce head gap must be perpendicular to the tape so that all tape equipment in the station conforms to a standard setting to permit interchangeability of tapes between all machines in use.

A preliminary visual alignment of all head airgaps at a 90° angle to the plane of the tape travel, which is almost always parallel to the deck or base plate, is very helpful. A 90° gauge block, small toolmaker's square, or any small plastic lettering guide, etc., with a 90° angle between two adjacent sides may be used. The accuracy of the angle may be confirmed by comparison with the inside angle of a good combination square. With the edge of the gauge-block firmly against the deck or base plate and the adjacent vertical edge just in front of the head airgap(s), adjust the azimuth to align the gaps in parallel with this vertical edge. Use a magnifier (Fidelipac Division of Telepro Industries, Inc.). Careful alignment can result in a surprisingly good preliminary azimuth setting. Also, there are several small optical devices available on the market for a quick mechanical check of the azimuth on cartridge machines.

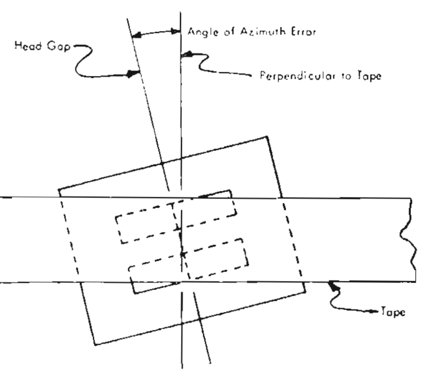

Fig. 6. Improper azimuth adjustment (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

Although azimuth is adjusted mechanically, it must be done while playing a standard alignment tape. At a speed of 7.5 ips, a frequency of at least 12 kHz should be used, with 15 kHz preferred.

As the head is slowly rocked from side to side, the head output will increase and will reach its maximum level when the head gap is directly lined up with the recorded high frequency on the azimuth alignment tape. When the head is perpendicular to the tape path, the upper and lower airgap edges will experience the same phase and there will be no azimuth error. If the gap is tilted in respect to the tape path, however, the upper and lower gap edges see a phase difference. This will result in magnetic flux lines flowing between the upper edge and the center line, and the lower edge and the center line of the gap (Lowman, 1972). These flux patterns will be slightly out of phase and, therefore, will produce an output voltage that will be lower than from a head with no azimuth error. With further tilt so that the upper edge of the gap is crossing the south pole while the lower edge is simultaneously crossing the north pole of the adjacent half wave of the recorded signal, and vice-versa, the total resultant flux is zero. The output voltage from the head will also be zero.

Tilting the gap even further will give an increased output at high signal frequencies, such as used for azimuth adjustment, and will peak when the upper edge of the gap and lower edge of the gap span 1½ wavelengths of the recorded signal. This will give a false indication of correct azimuth alignment, although the peaks on either side will be lower in amplitude than the center peak of true azimuth. Thus, it is important to tilt the head gap back and forth sufficiently to find the true Azimuth peak and adjust it for maximum output level. This establishes the reproduce head as a standard for setting azimuth on the recording head, which is done by removing the alignment tape, threading a blank tape on the machine and recording a 15 kHz signal on it while monitoring it with the reproduce head. Rock the record head slowly from side to side through its arc while recording the signal on the tape until maximum output is obtained from the reproduce head monitoring the recording. Note that the same 1½ wavelength azimuth error may be obtained with the record head as on the reproducing head and true azimuth should be found in the same manner. There will be a slight delay between recording and reproducing the 15 kHz alignment signal because of the tape travel time between the two heads, so a slight pause between adjustments of the record head will be helpful.

Useful Head Life

Electrically, as wear progresses on a reproduce head, the inductance of the head drops and the high frequency response begins to fall off (Zeman, 1974). This can generally be compensated for by readjustment of the high frequency equalization up to a certain point, where the 4 to 6 kHz area rises above machine frequency response specifications, then the head must be replaced to restore the desired response.

As the wear progresses in the record head, the inductance also drops and the head requires less and less bias current for optimum frequency response. This in turn affects the signal current required and also requires readjustment of the recording equalization. If the head is not replaced, the wear/readjustment cycle repeats with increasing frequency until finally the airgap abruptly opens and satisfactory performance is impossible.

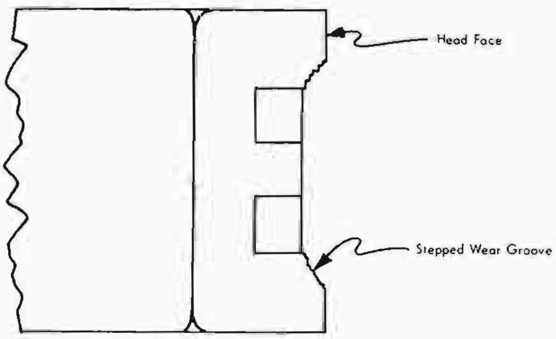

Fig. 7. Wear groove (side view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

In addition to this, there are performance difficulties encountered that are not electrical in nature but show up as electrical malfunctions in the form of dropouts, erratic output (starting first at the high frequency end and working down the audio range as the condition worsens), warbling, and a wide assortment of weird sounds caused by variations in tape contact, and wandering of tape due to wear grooves in the heads.

Fig. 7 shows an exaggerated view of the step effect in a deep wear groove. Originally, the groove was fairly straight, but as wear progressed, the edges of the tape (which are not as rigid as the center portion) tend to cup and become rippled. At the point where the edge curls, and firm contact begins, another groove is started. Tape of varying widths, with different width tolerances or even within the typical ±0.002 in. tolerance range, can also cause this condition.

Fig. 8 shows the flat that is developed in a head face as wear progresses. This flat exists regardless of whether a wear groove is present or not, and spreads the tape contact area over an

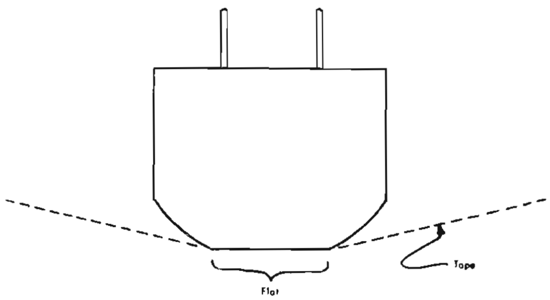

Fig. 8. Wear flat (top view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

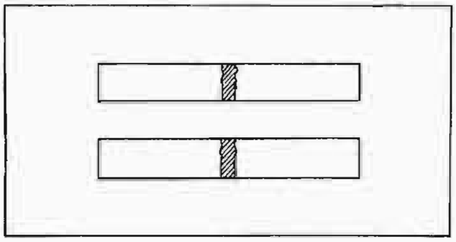

Fig. 9. Open head gap (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine.*)

increasingly wider space, tending to create poor contact at the airgap. Of course, this is where the critical action of the head takes place, so the problem should be corrected before operation is degraded significantly. Once a keystone wear pattern is observed, as shown in Fig. 3, the zenith should not be readjusted on that head, as erratic contact and output will result. If this wear pattern is not excessive on a professional head, it can be relapped and polished by manufacturers specializing in this service, then reinstalled and the zenith error corrected.

Fig. 9 is an illustration of a head with a completely open airgap. Such a head is fit only for the trash can. It may be difficult to believe that anyone could or would use a head until such a condition occurs, but they are not uncommon in stations with a casual inspection/maintenance program. The head face is particularly vulnerable to scratches, nicks, or gouges which can really degrade performance, because good magnetic performance requires annealed metal of high permeability that is physically soft. Before installing any tape head, it is suggested that the head face be covered with a strip of heavy, adhesive-backed plastic tape to protect it during installation. Once installed, the tape should be removed and the head face cleaned prior to making any adjustments.

Cleaning Tape Heads

Isopropyl alcohol is one of the most widely used cleaners for tape heads because of its universal availability. It may also be used for cleaning the pinch roller, which is not true of some commercial head cleaners. Ethyl (grain) and methyl (wood) alcohol serve as well in their almost pure forms, when available. Carbon tetrachloride was once used and is recommended by older reference books, but has been long banned for general purpose cleaning because of its hazard to health.

The record, reproduce, and erase heads are the most critical elements of a tape machine and should be kept immaculately clean. They should be cleaned at regular intervals, not as a maintenance procedure but as an important part of the operating practice. Some suggest daily cleaning, which if properly done will result in consistently superior results. Some clean heads hourly, which indicates an abnormal problem, such as the use of tapes with a poor binder or very poor surface characteristic. This may also be caused by some element in the tape path that is scraping the oxide and binder from the tape, or perhaps the lubricant from tapes used in cartridges. The cause should be determined and corrected if tape heads require hourly cleaning.

Cartridge tape machines typically need cleaning much more often than reel-to-reel machines because of the lubricated backing and the sliding of the tape layers on each other in the cartridge. Yet, some stations have found that "dry" cleaning the heads permits much longer intervals between required cleanings than those using a generous amount of alcohol or commercial head cleaner. With new machines or new heads, more frequent cleaning is required for approximately the first two months, perhaps every other day. At six months and after, the heads are polished sufficiently that a weekly cleaning is reported to be adequate. The heads are simply cleaned with a dry cotton swab or soft cloth. The normal residue does not adhere tightly to the head surfaces and seldom requires any solvent to remove it. An alternate method reported is to use alcohol very sparingly on a swab, followed immediately with a dry swab to remove the cleaner and residue, and then a second dry swab to polish the head surface and remove any traces of cleaner/residue film. This last step is considered very important.

Regardless of the cleaning solvent and method used, it is good practice to avoid putting large numbers of cartridges or open reels with new magnetic tape into a system in a short period of time. This sudden influx of new tape will drastically increase the amount of residue deposited on the head, etc., with most tapes, and pose an excessive cleaning requirement. It is much better to plan a long term or continuous phasing in of a few new tapes at a time for replacement and expansion of the tape library.

TYPICAL MAGNETIC RECORDER/REPRODUCERS

The NAB cartridge machine is used in greater quantities in more US stations than any other type of audio tape machine. Some stations use cartridges for practically every segment of programming broadcasted, while others use them primarily for commercial messages, station IDs and other short nonmusic applications. The cartridge machines are available in several forms

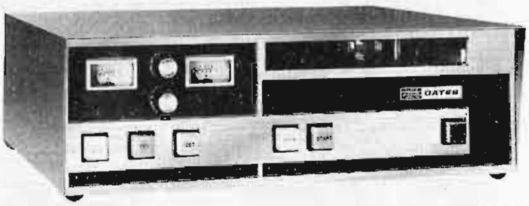

Fig. 10. Single deck record/produce cartridge machine (courtesy of Harris Corporation, Broadcast Equipment Division).

from single deck to multiple deck and magazine units.

Single deck units are available in reproduce only or combination record/reproduce equipments, such as shown in Fig. 10. This unit will accept NAB size A cartridges with up to 10.5 min., size B with up to 16 min., and size C with up to 31 min. of tape @ 7.5 ips. Others will accept only sizes A and B, while some will accept just the A size cartridge. Nearly all can be mounted in standard equipment racks, some being small enough to mount two or three across a standard panel width. Also, most of them can be enclosed in a desk top housing for operator convenience. Mono units use a separate program and cue track, with the program track at the top of the tape. Stereo units with three track heads use the top track for left signal, center track for right signal, and the bottom track for cue signals. Standardization of parameters important in cartridge interchangeability is outlined in the *NAB Standard on Cartridge Tape Recording and Reproducing,* printed in another section of this handbook. Most manufacturers follow this NAB Standard in the design and production of their machines.

Fig. 11 shows a pair of 3-deck cartridge machines that will accept NAB size A and B cartridges in a 19 in. rack housing. Each unit has a common direct drive motor with a long shaft that all three cartridges engage. Except for cleaning of the heads, motor capstan, pinch roller, etc., the top and center decks are removed for adjustment and maintenance. A hinged front panel, quick disconnect deck fasteners and connectors facilitate the maintenance operation.

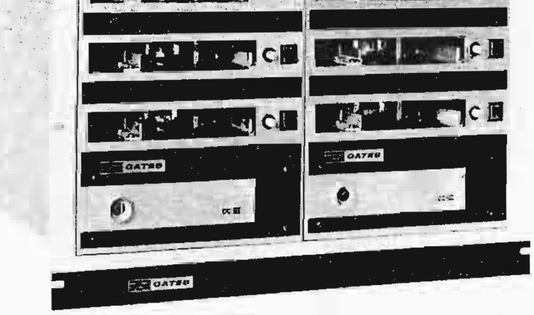

Fig. 11. Three deck cartridge machines (courtesy of Harris Corporation, Broadcast Equipment Division).

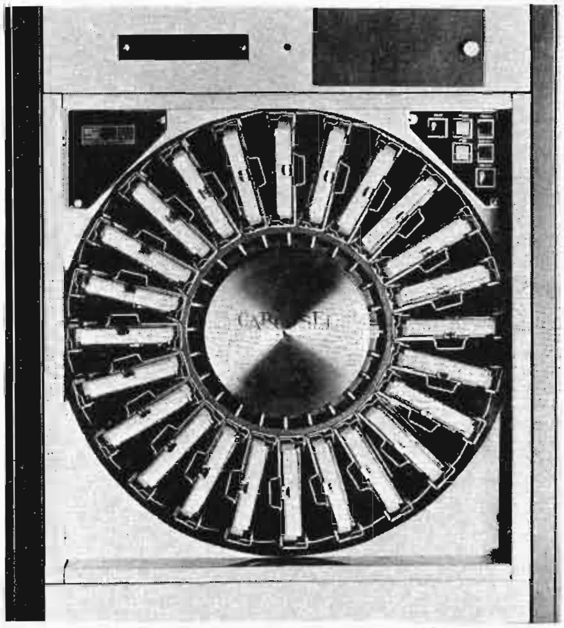

Fig. 12. Single deck/rotary magazine cartridge machine (courtesy of Sono-Mag Corporation).

The multiple cartridge machine shown in Fig. 12 contains up to 24 NAB size A cartridges in a magazine which rotates to align the selected cartridge with the surface of the single playing deck, located at the 3 o'clock position. The cartridge is pulled back into the deck position, played, and returned to the "tray out" magazine position in a typical sequence. The rotation of the drum magazine is relatively slow, taking several seconds even for bidirectional models, making more than one cartridge reproducer necessary if back-to-back operation is desired.

The multiple cartridge machine illustrated in Fig. 13 contains up to 12 NAB size A cartridges in a vertical stack and up to four stacks to an assembly for a total of 48 cartridges. This unit also mounts in a 19 in. rack cabinet. Each stack has a common motor with a long shaft that all 12 cartridges engage. Its principal advantage over the machines as shown in Figs. 12 and 14 is that it provides random instant access to any of the cartridges for back-to-back playing in any sequence. This may be offset by a somewhat more complex loading operation.

The multiple cartridge machine shown in Fig. 14 has a deck behind each stack of 16 cartridges which may be raised or lowered to align with the selected cartridge magazine slot. Up to three of these modules may be fitted into an assembly that mounts in a 19 in. rack cabinet. While it

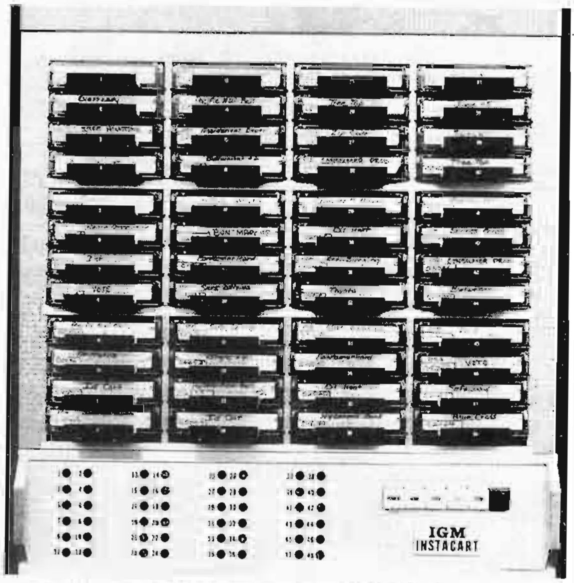

Fig. 13. Forty-eight deck cartridge machine (courtesy of Northwestern Technology, Inc.).

does not give full random instant access, this machine can play a cartridge from a module back-to-back with a cartridge from another module. With some care in loading, the unit shown can play up to three cartridges in a continuous sequence, or even more if the playing time of intermediate selections is sufficient for cueing out and reloading in modules used early in the sequence.

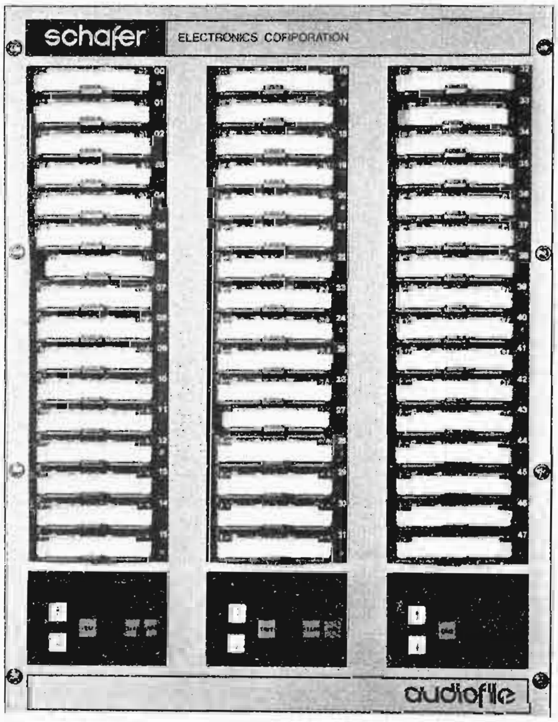

Fig. 14. Three Deck/Fixed Magazine Cartridge Machine (courtesy of Schafer Electronics Corporation).

Fig. 15. Reel-to-reel tape recorder/reproducer (courtesy of International Tapetronics Corporation).

Reel-to-reel machines come in many sizes and are typically used with the larger 7, 10½ or 14 in. reels now that tape cartridges are predominantly used for short segments of programming. Switching logic, motion sensing, dynamic braking and automatic tape lifters are some of the newer features that practically eliminate mishandling of the tape on the machine. Almost all professional reel-to-reel machines use individual motors for the supply and take-up reels, plus a third motor to control the record/reproduce speed. For a fast starting time and almost immediate stability, the capstan motor runs continuously and the solenoid actuated pinch roller moves the tape against the capstan as the brakes are released on the reels.

For the fast-forward and rewind functions, the pinch roller and reel brakes are disengaged, allowing the tape speed to be controlled by the reel torque motors. Power can be varied between the two motors, by either a rheostat or switched resistors. The tape moves in the direction and at the rate of speed determined by the relative power division.

Another form of the reel-to-reel machine, the Philips Cassette machine, is used in news gathering and other portable applications requiring somewhat reduced quality. Comparison of the specifications in the NAB Standard on the Audio Cassette Recording and Reproducing with those for the reel-to-reel or cartridge Standards indi-

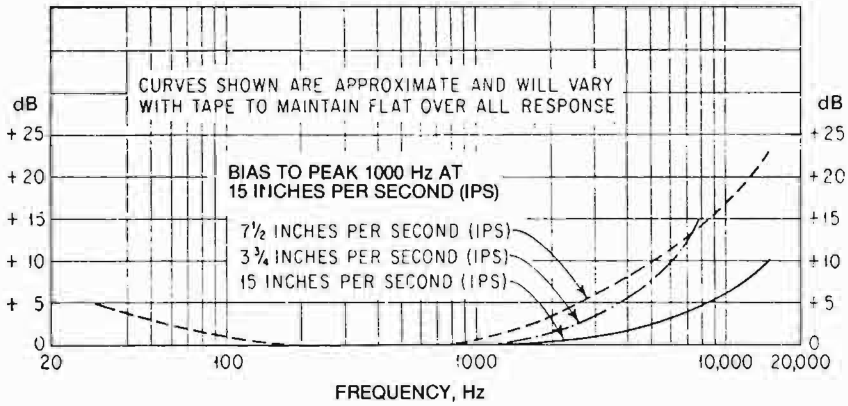

Fig. 16. Standard recording curves (courtesy of Ampex Corporation).

cates the difference in quality in several parameters.

MAINTENANCE

Maintenance instructions in the individual equipment Instruction Manual should be followed on all items covered, unless lengthy experience has proven a variation in some areas will give superior results. For items not covered, the following should be of assistance.

Amplifiers

The recording amplifier is used to raise the output of a microphone to the level necessary to drive the recording head. Since the head airgap length, tape to head velocity, and many other factors determine the frequency response, noise and distortion of the recording/reproducing process, it is advisable to include as much pre-emphasis as possible in the recording amplifier.

The standard recording curves shown in Fig. 16 were derived from the tape distortion characteristics. The tape, when recorded with these curves, will have approximately the same distortion at all frequencies in the audio signal band-pass.

The reproduce or playback amplifier raises the signal generated in the reproduce head to a level suitable for feeding the control console, or next element in the system. This amplifier contains a de-emphasis circuit to adjust for a flat overall response.

Fig. 17 shows standard playback curves, initially derived from the nonlinearities of the record-reproduce process, including the characteristic 6 dB/octave rise in the playback process (until head losses overcome it at the high frequency end). The playback curves are now standardized to provide essentially a flat response from a NAB Frequency Response Test Tape, and the recording amplifier adjusted in the individual equipment for a flat overall response within specified tolerances. The playback amplifier must have an input circuit with exceptionally low inherent noise level. Distortion of any significance is seldom generated within the playback amplifier unless it contains some defective components.

In testing a playback amplifier, it is advisable to adjust the input level to obtain a constant

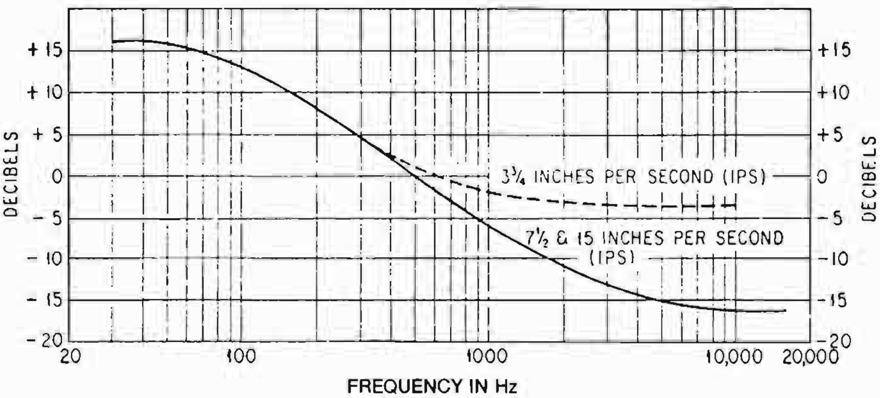

Fig. 17. Standard playback curves (courtesy of Ampex Corporation).

output level for all frequencies. This will prevent overloading the amplifier, which will never occur except on the test bench with a constant input level.

Contour Effect and Fringing

When the length of contact between the tape and the reproduce head pole faces is long with respect to the signal wavelengths, contour effect is insignificant. As long as this is true, the magnetic flux generated in the pole faces by the wavelengths will generally cancel, with no important effect on the flux from pole to pole through the coil (Stewart, 1958). However, as the wavelengths grow longer, the whole head structure, or some part of it in combination with various leakage paths such as through the shield or around the coil to the rear part of the core, may act as a poorly defined gap. Thus, at low frequencies with long wavelengths, a response like that shown in Fig. 18 may be obtained.

This contour effect is especially prevalent in cartridge machines with the narrow heads required to fit within the cartridge windows, and a major peak may be observed in the 120-130 Hz area, with the effect diminishing to insignificance in three to four ripples. Correction is a function of head design primarily, where the contour effects can be reduced by an asymmetrical arrangement so proportioned that the effect of one pole counterbalances the effect of the other.

Fringing is another low frequency effect that occurs when a reproduce head contacts a tape recorded with a track that is wider than the head track. It is generally encountered with multitrack heads on a full-track test tape, and can cause up to 5 dB increase in the extreme

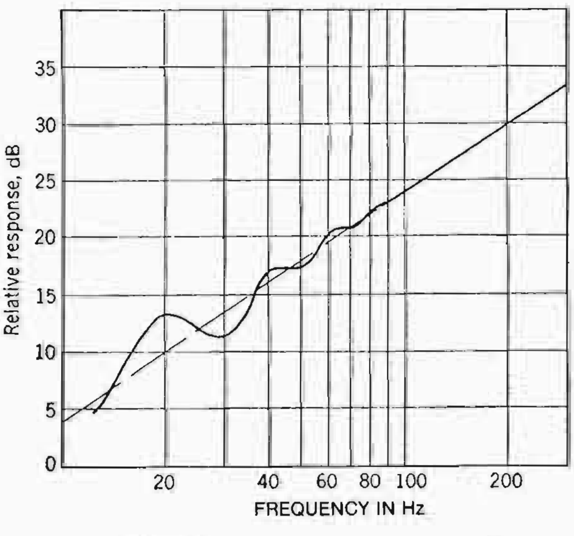

Fig. 18. Contour effects on reproducing-head response.

low frequency signals. If this effect is anticipated and accounted for in the measurements, a full-track test tape is very useful for machines with different track configurations.

Mechanical

All tape recorder/reproducers have precision components that require periodic maintenance and adjustment. Brake tension adjustment should be checked with the methods and equipment prescribed in the instruction manual to maintain optimum performance. No attempt should be made to improve or change the basic design of a tape machine without consulting the manufacturer. Typically the warranty is voided with unauthorized modification, in addition to possible degradation of performance.

Lubrication. If available, the instruction manual on the individual tape machine must be followed for lubrication instructions. If not, older machines typically require lubrication of the capstan drive motor and capstan idler shaft bearings (if indirect drive) about every 3 months or after 1,000 hours of operation with a few drops of SAE 20 oil of good quality. Some reel motors have oil holes and should be lightly oiled after about the same period. If the pinch roller bearings is lubricated, it should be done very sparingly, with any excess carefully removed by blotting with an absorbent cloth or paper and the entire surface subsequently cleaned with alcohol on a soft lint-free cloth.

Cleaning. See the paragraph under Cleaning Tape Heads. The capstan, pinch roller, tape guides, and other elements in the tape path should be cleaned often, sometimes daily with heavy use. Isopropyl, ethyl or methyl alcohol only should be used on the pinch roller, and is generally preferred for the other items. Use a soft cloth or cotton swabs that are lint and contaminant-free, and be sure all surfaces are completely dry before coming in contact with the tape again. It is best to wipe away the residual film with a clean dry cloth or swab after the cleaning operation.

Demagnetize all Heads. All heads should be demagnetized before playing test tapes or other valuable reference recordings, and after every maintenance operation involving the heads. Older machines need head demagnetization at least once a month because of accumulated switching transients and surges due to removal of tubes, etc. Current machines have essentially eliminated demagnetization requirements except when the heads or other items in the tape path are brought in contact with gauges or tools that can be magnetized. Head demagnetizers or hand held bulk erasers should be used on the heads and other tape path elements, being very careful to avoid scratching any of the surfaces. Slowly withdraw the demagnetizer from the items after completely saturating them with the magnetic flux, much in the same manner as used for erasing the tape.

Take-up and Holdback Tensions. These should be checked with a small scale while the machine is running in the normal play mode. NAB hub size reels should produce 6 to 8 oz. tension; the smaller size should produce 3 to 4 oz.

Brake Tensions. These are adjusted with no power applied to the machine, with the scale pulling a string wrapped around the reel hub in the direction of forward tape travel. The tension should be from 12 to 16 oz. In the opposite direction, it should be from 6 to 9 oz.

Capstan Idler (pinch roller) Pressure. The pressure of this idler on the capstan shaft should be sufficient to cause positive drive to the tape, but not so great as to cause the motor to slow down. Ideally, the shaft holding the pinch roller should be parallel to the capstan (assuming the contact surface and bearing surface of the pinch roller are parallel) in the operating position to prevent skewing the tape. This may require several pounds of pressure and may be measured as the point of disengagement between the pinch roller surface and capstan surface when the pinch roller shaft is pulled away with a scale.

Playback Level Adjust. The gain control in the playback channel should be adjusted to give the output level specified by the manufacturer when playing the Standard Reference Level on an NAB Test Tape or equivalent. Depending on the output capability of the playback amplifier and amount of noise reduction versus gain reduction with the amplifier gain control, variations from the specified output level may be acceptable for special applications. However, the amplifier must be capable of at least 10 dB higher output level than the output level read on a standard VU meter for signal peak headroom.

Erase Current. See paragraph under Magnetic Recording Theory.

Bias Current. See paragraph under Magnetic Recording Theory.

Signal-to-Noise Measurements. Terminate the amplifier output in its rated load impedance and connect a high-impedance noise meter across it. Using the Standard Reference Level from the test tape as a reference, measure the noise below this reference level with the tape stopped. This should read well below the noise specified for the machine playing tape with no signal. Replace the test tape with a virgin or well-erased tape and record a section with bias only (no signal), and read the noise from the playback channel with a low-pass filter to remove the bias frequency. A 0.02 MFD capacitor may be placed across the input terminals of the noise meter instead of a low-pass filter. With a simultaneous record/playback machine, adjust the bias balance control for lowest noise (generally a popping or crackling noise). Use the prerecorded tape with bias only for checking playback-only machine noise.

Azimuth Alignment. See the paragraph under Tape Heads.

Playback Response. Terminate the output of the playback amplifier and play the frequency response portion of the test tape. Connect the input terminals of the noise meter to the amplifier output to read the reduced signal level from this portion of the test tape, typically 10 to 20 dB below the Standard Reference Level. Adjust the playback amplifier equalizer(s) for the optimum frequency response specified in the instruction manual. If difficulty is encountered, inspect the heads for defects described in the paragraph under Tape Head.

Record Response. After adjusting the playback response, use a new or erased tape to record test signals from an audio generator over the frequency range of interest. Record the level 10 to 20 dB below Standard Reference Level to prevent any possibility of overloading the tape. With a constant input level to the recording amplifier, adjust the recording equalization to obtain a flat response within rated tolerance from the playback amplifier. If difficulty is encountered, read previous paragraphs to find similar symptoms and the probable causes.

Tension Scales. These are difficult to find in the ranges required for measuring tape machine tensions. They can be purchased from John Chatillon & Sons, 83-30 Kew Gardens Road, Kew Gardens, N.Y. 11415. The following scales are recommended for reel-to-reel machines: LP8 (0-8 oz), LP36 (0-36 oz) and LP72 (0-72 oz).

Care of Test Tapes. Tape intended for repeated use in checking machines must be properly cared for if its full usefulness is to be maintained (Morrison, 1967). Physical deformation of the tape can be a serious problem. Edge damage can be prevented by winding the tape smoothly under moderate tension and evenly spaced between the reel flanges. The tape pack should not be wound in contact with one reel flange, as this will result in irreparable edge damage if it is stored in this condition for long periods of time.

Tapes should not be stored in fields from motors or permanent magnets; i.e., a tape stored in a cabinet next to a loudspeaker or microphone may be affected. Heads and tape guides should be demagnetized before using the test tape. When a reproducer test tape is used for continuous check-out purposes, age and wear as described above often become the primary sources of inaccuracy.

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27

Video Magnetic Recording

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In the early fifties, there was great interest by the television industry in developing magnetic recording devices for television images. By the mid-fifties, several major breakthroughs had been made in the magnetic recording industry that culminated in the display of a quadruplex video tape recorder at the 1956 National Association of Television and Radio Broadcasters Convention. This new device substantially changed the operational aspects of television broadcasting.

The new High Band FM Signal System, pressing the technology even further into its present-day status, has allowed for multiple generations of color television recording to a point where television program syndication and sophisticated teleproduction techniques on video tape have become a reality.

Other developments contributing to the improvement of magnetic video recording have been the *dropout compensation*, minimizing picture defects or short interruptions as a result of small imperfections of the video tape material, *velocity error compensation*, eliminating color hue shift band and *autochroma*, automatic chrominance level control, adding further refinement to the quadruplex recording system.

Further contributions in the development and improvement of video heads and video tape manufacturing have been accomplished. The Society of Motion Picture and Television Engineers has developed standards and recommended practices providing for interchangeability among machines which have been accepted by manufacturers of broadcast television recorders.

Specific devices are used throughout the following text in order to aid in the discussion of various aspects of video tape recording. It should be recognized that the proper names used in the text for devices or functions may be called by other proper names when associated with similar devices of other manufacturers.

Quadruplex Video Tape Recorder

The Ampex VR-2000 as shown in Fig. 1 will be used as an example to describe a current magnetic video tape recorder.

Tape Transport

The dual-speed tape transport closely resembles similar mechanisms found in high quality audio recorders, in that the tape is pulled from the supply reel and across the erase, record, and playback heads by a rotating capstan, and then re-wound by a motor-driven takeup reel as shown in Fig. 2. However, video recording requires precise control of tape positioning and of head drum phase that transcend the requirements imposed on an audio tape transport in many ways. The primary nominal linear video tape transportation speed is 15 ips, the secondary 7.5 ips.

Fig. 1. VR-2000 recorder/reproducer.

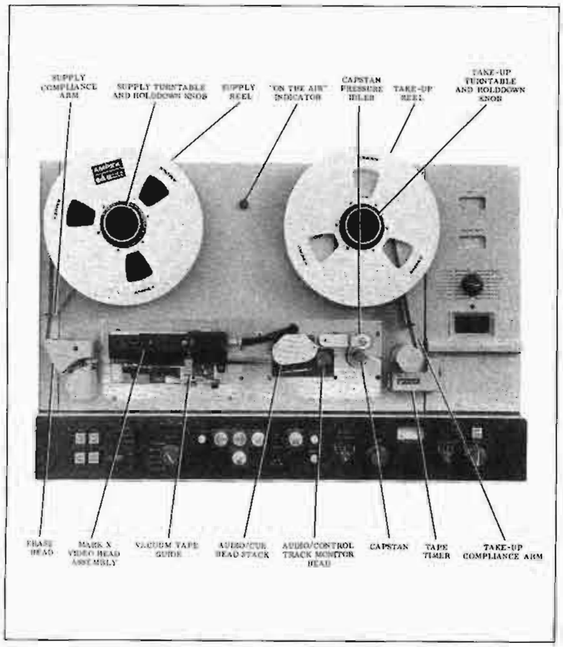

Fig. 2. Overall view of tape transport system.

The tape passes the left tape tension arm, two idlers on the erase head assembly, the full-width erase head, the rotary video head drum and associated vacuum block tape guide, the control track record/reproduce head, and the audio and cue erase record/reproduce heads before passing the capstan and its associated pressure idler. It then passes the tape timer and the right tape tension arm before it is wound onto the takeup reel.

Tape motion in the record and reproduce processes is controlled solely by the capstan, which pulls the tape from the supply reel (on the left), through the tape path and drives the tape toward the takeup reel on the right. Each reel hub is mounted on a torque motor. The supply torque motor opposes the motion imparted to the tape by the capstan, thus providing hold-back tension. The takeup motor supplies just sufficient torque to take up the tape as it is supplied by the capstan. In fast-forward or fast-rewind modes, the capstan idler is removed, the torque of the appropriate turntable motor is reduced allowing the tape to be pulled from that turntable by the greater torque of the other turntable motor.

Servo Control System

The following paragraphs describe the interrelationship between tape position and head drum phase as established during the recording mode, and how it is re-established during the playing mode, as well as the actions of the head drum servo and their relationship to the video signal.

During the recording mode, the video head drum motor rotates at 240 Hz rate (14,400 rpm). At this time the drum tachometer generates a square wave signal whose instantaneous phase and frequency is identical with the instantaneous phase and frequency of head drum rotation. This sine wave signal is recorded longitudinally along the control track at the lower edge of the tape. The rotational rate of the capstan motor is determined by the drive frequency, ¼ that of the drum motor, a 60-Hz rate.

During the playing mode, the video head drum again rotates at the 240-Hz rate and the drum tachometer generates a square wave signal indicative of the instantaneous head drum phase and frequency. The latter signal is phase-compared with the 240-Hz reproduced control track; the resulting error signal is used to establish and maintain the exact relationship between the head drum phase position and the longitudinal position of the tape that existed during recording. Table 1 shows the relationship of recorder system factors depending on the television standard applied.

The head drum servo employs a phase and a velocity servo loop. The phase servo loop locks the head drum synchronous motor to either the video signal being recorded, the station reference sync, or the power line, depending on the mode of operation. The velocity servo loop suppresses the tendency of the synchronous motor to hunt.

During recording, the head drum motor may be locked to the video signal, to the power line frequency, or to an external sync source, e.g., a sync generator; during the playing mode, it may be locked to an external sync source or to the

TABLE 1

The Relationship of Recorder System Factors Depending on the Television Standard Applied

Factor	Television Standard		
	525/30	625/25	405/25
Power line frequency	60 cps	50 cps	50 cps
Frames per second	30	25	25
Vertical rate (fields/sec)	60	50	50
Horizontal rate	15,750 pps	15,625 pps	10,125 pps
Capstan motor power frequency	60 cps	62.5 cps	62.5 cps
Drum motor power frequency	240 cps	250 cps	250 cps
Drum motor revolutions per minute (i.e., the "drum rate")	14,400	15,000	15,000
Nominal tape speed	15 ips	15.625 ips	15.625 ips

power line frequency. In the recording mode, the equipment is normally locked to the video signal; in the playing mode, it may be locked to the power line frequency, or to station reference sync.

For the corrections, the phase servo loop uses the error signal resulting from phase comparison of the drum tachometer signal with the power line frequency or with vertical sync, depending upon whether the operating mode is in record or play. If the phase of the incoming video signal suddenly shifts, which could occur during signal discontinuity or when the program source is switched, the phase comparator generates an error voltage which acts to gradually shift the frequency generated by the voltage-controlled drum oscillator until the drum phase matches the phase of the incoming sync.

The velocity servo loop employs the drum tachometer signal as a trigger for a low Q ringing circuit which is resonant at the drum frequency. The trigger and the output of the ringing circuit are phase compared to detect any changes of the drum tachometer signal frequency caused by drum motor hunting. The resulting error signal is used to control a phasing circuit that shifts the phase of the voltage applied to the drum motor in a direction that opposes the velocity error, thereby reducing or cancelling out the hunting excursions.

The original video tape recorder was designed as a delay device and did not provide synchronous integration with studio operations. The limitation when switching to and from the recorder produced vertical image disturbances and video signal discontinuities at the studio output.

There are two levels to this problem. The first level could be described as frame locking, where the recorder is made sufficiently synchronous so that vertical transfer switching will produce no visible jump in the image. This can be accomplished by drum servo lock, which should not exceed approximately half line accuracy, i.e., ± 30 microseconds. The most complex problem is to achieve full line-lock, wherein the signals recorded on tape are within one-tenth microsecond accuracy of the studio reference signals. This was accomplished by the use of phase modulation of the drum motor, allowing its instantaneous position to be corrected on a line-by-line basis, as shown in Fig. 3.

An early technique used multiphase sine wave signals to drive the capstan and drum motors. There were some inherent defects in the use of this approach. The phase splitting accomplished through Scott-wound transformers did not always produce precise 120° displacement of the three phases needed for the drum motor. Individual amplitudes of these three phases were difficult to maintain in perfect balance and the instantaneous phase correcting circuitry was somewhat limited by the low pass filtering action of the power

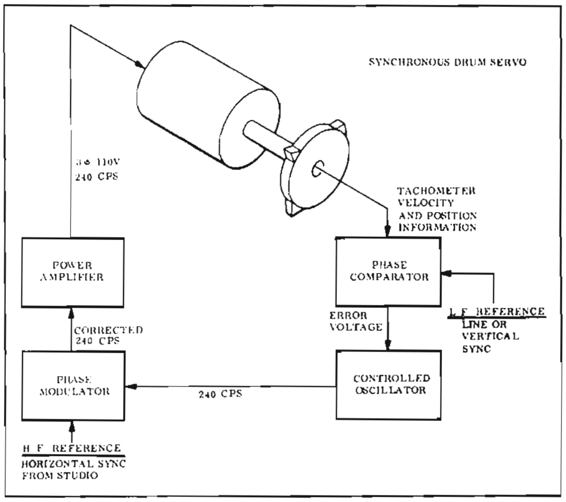

Fig. 3. Block diagram of synchronous servo system.

transformers that acted as the final drive element for the motor windings.

The modern approach to this problem is the use of transistor power switching circuits which gate on a common power supply at the designated times so that phase-to-phase amplitude balance is near perfect. The 120° phase displacement is accurately maintained by logic circuitry and binary count downs. Holding response to phase modulation is virtually instantaneous (Fig. 4).

Phase shifts can be accomplished by altering the switching time of the binaries. The drum motor windings are driven by square waves which add algebraically between any two terminals and result in a staircase waveform with almost complete attenuation of the odd harmonics. This is a particularly desirable condition since the smoothness of angular velocity is dependent upon precise equality of the angularity of pulses applied to the rotor on whose shaft the video head drum is mounted.

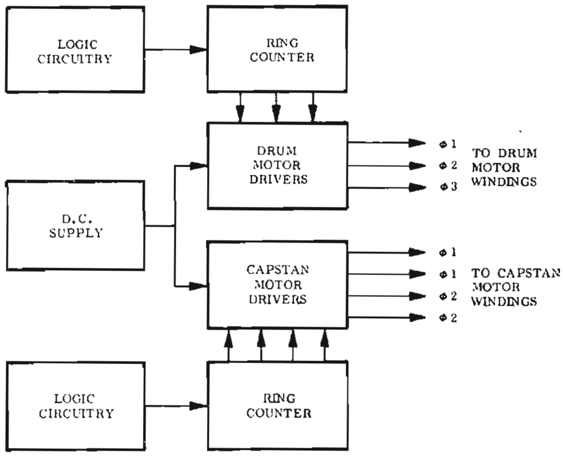

Fig. 4. Block diagram of 2 and 3 phase power switching circuits.

The use of these methods in driving the rotary head assembly has resulted in a long time-base stability in the order of 200 nanoseconds or better when the signals from video tape playbacks are referenced to a stable studio source.

Intersync Servo Control System

The magnetic tape recording and reproduction of television signals involve the scanning of a moving tape by four video heads that are mounted in precise quadrature on the periphery of a rapidly rotating head drum. The longitudinal movement of the tape is synchronized with the rotation of the head drum by the action of two mutually synchronized electronic servos. In the basic system, tape speed is controlled by the action of the capstan servo system; head drum rotation is governed by the head drum servo. By precisely controlling both servos, the Intersync servo system provides improved stability of the reproduced video signal.

A better understanding of the Intersync servo functions and circuitry will be gained by a brief review of the television industry standards and how they relate to problems accompanying the achievement of a high degree of servo synchronization and timing stability.

Elements of the Television Signal

To produce a complete frame of a television picture, the raster is completely scanned twice by the electron beam in the camera and in the picture tube. Each scan starts at the top of the picture and ends at the bottom, resulting in a series of closely spaced horizontal lines of which the horizontal paths traced by the electron beam on the second scan are interlaced midway between those horizontal lines traced on the first scan.

The USA television standard (525 lines 30 frame per second, 60 fields) requires 60 scans per second. When each scan is completed, the scanning beam is blanked out and returned to the top of the raster by a vertical synchronizing pulse occurring at the vertical rate, 60 times per second. The vertical synchronizing pulses are recorded midway across the area occupied by the video information, and recur on every sixteenth path of video information recorded across the width of the tape. The vertical pulses that initiate the first scan of a frame coincide in time with a 30 pps frame pulse that is recorded simultaneously on the longitudinal control track at the lower edge of the tape. The frame pulse recorded on the control track will always appear on the tape in the same relative position with respect to the corresponding vertical sync information which is recorded as a part of the composite video signal.

The 525 line/30 frame television standard uses 525 horizontal traverses of the raster by the electron beam for each complete frame. There are, therefore, 15,750 such traverses per second, requiring 15,750 horizontal pulses per second. This is well known as the horizontal rate or 1H. When video information is present during the recording, the space following each horizontal pulse, with one exception, contains a full horizontal line of video information.

The particular vertical synchronizing information that initiates a new frame is always preceded by a half-line of video information; the similar information that appears on the sixteenth path following completes the frame and is always preceded by a full-line of video information. Thus, complete frames are presented 30 times per second. Fig. 5 shows vertical synchronizing information which appears at the middle of every sixteenth transverse path, and may be seen to include (in sequence) six equalizing pulses, six vertical sync pulses, and six equalizing pulses. The recorded 240 Hz control track signal and the superimposed 30 pps control track frame pulses appear at the bottom edge of the tape. Fig. 5 also shows that the stationary control track record/reproduce head is located approximately ¾-in. "downstream" from the plane of the video heads, and is mounted on the video head assembly. It records and reproduces the 30 pps frame pulses in addition to the 240 Hz control track signal. Because of its "downstream" location, the vertical sync information associated with each frame pulse is 45 video tracks "upstream" from it. SMPTE Recommended Practice, RP-16, "Specifications of Tracking Control Record for 2-in. Video Magnetic Recordings," is shown in Fig. 6.

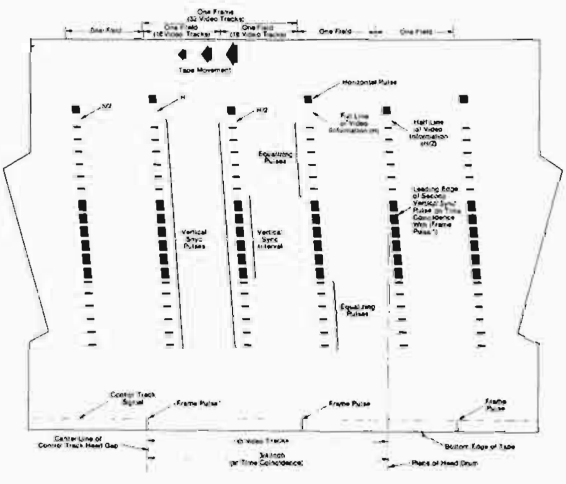

Fig. 5. Positional relationship of video and synchronizing information on the oxide-coated surface of the tape.

APPENDIX

(This Appendix is not a part of SMPTE Recommended Practice RP 16-1964, Specifications of Tracking Control Record for 2-In. Video Magnetic Tape Recordings, but is included to facilitate its use.)

1. The transfer characteristic of magnetic tape is nonlinear. The B_r, I_r curve of the tape as recorded has a shape indicated in Fig. 2a. When a sinusoidal record current (Fig. 2c) is applied to the record head, the resulting recorded flux density is as shown in Fig. 2b. The playback voltage waveform (Fig. 2d) is the first derivative of the recorded flux. Thus, the zero axis crossing region of the playback signal corresponds to the maximum recorded flux region. The verge of saturation is considered to be the condition where the recorded flux waveform is just noticeably flattened on its peaks. This flattening of the flux peaks results in an inflection in the playback signal waveform in the zero axis crossing region. The verge of saturation can thus be determined by increasing the record current until a just perceptible inflection occurs in the zero axis crossing region of the playback signal.
2. Areas to which a compass is attracted (see Section 5.4) do not coincide with point of maximum record current. The compass will be attracted to two areas (X, as shown in Fig. 2) adjacent to the point where the record current crosses the zero axis. The two areas will appear as bars when the track is developed with carbonyl iron or an equivalent material.
3. The location of vertical sync and the frame pulse, as specified herein, will apply only if the recorder video head and capstan servos are referenced to the incoming video signal or its sync generator.

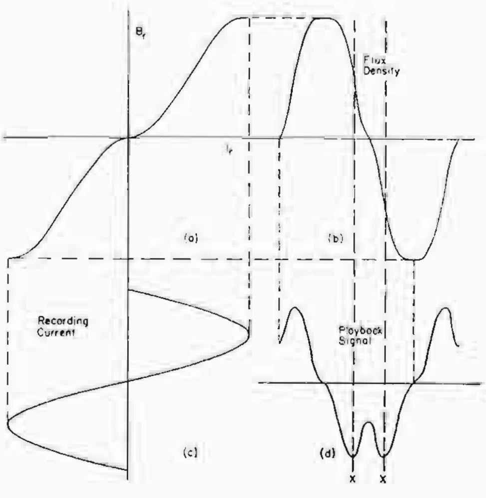

Fig. 6. SMPTE recommended practice RP 16-1964, specifications of tracking control record for 2-in. video magnetic recordings.

Limitation of Timing Errors

There is a minimum degree of inherent timing error in the record/reproduce process. Because of this, any recording will contain a normal amount of timing errors to which the playback process will add more. Timing errors originate from a variety of causes, of which the following are the more frequently encountered:

1. Momentary changes of head drum velocity caused by variations of head drum loading.
2. Momentary phase transients in either the reference signal or the video signal.
3. Momentary loss or degradation of horizontal or vertical sync.
4. Instability of the reference signal caused by a malfunction of the plant sync generator system.

The principal function of the Intersync servo system is the maintenance of synchronization between the reproduced video signal and other video sources to a degree permitting program switching between these sources without interruption of picture continuity. The Intersync servo unit accomplishes this by locking the reproduced signal to the plant sync reference to which the other video signals are locked and by holding the timing errors in the reproduced signal within very narrow limits. Fig. 7 shows the Intersync servo system in a simplified block diagram form.

Servo Record Mode Functions

During the record mode, the Intersync servo unit provides two closed servo loops that control head drum rotation and maintain maximum timing stability of the recorded signal.

The "positional" loop, shown in Fig. 8, determines the average rotational rate of the head drum and the instantaneous angular position (or phase) of the video heads with respect to the reference signal. Its gain and bandwidth are designed to provide a "soft" servo control that resists the reaction of the head drum to high rate-of-change disturbances that may appear in the video or the reference signal. Control is maintained by the phase (i.e., time) comparison of the tachometer signal (representative of head drum phase), with the sync components of the incoming video signal. The resulting measure of timing error is represented by a proportional voltage that controls the frequency of the drum oscillator output. This action places video head number 4 in position to record the vertical sync information at the precise center of the tape width

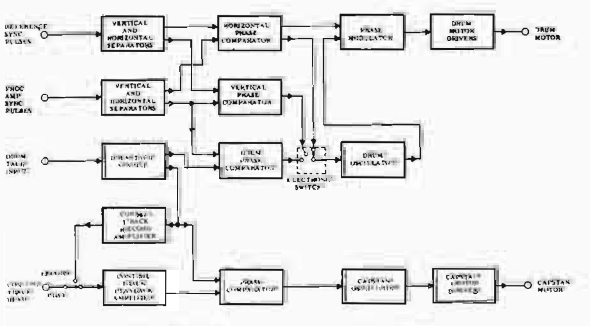

Fig. 7. Intersync servo system.

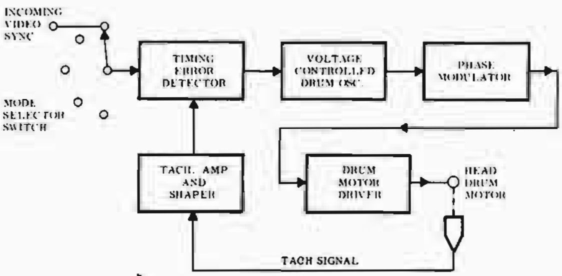

Fig. 8. Block diagram of positional loop.

and in accordance with SMPTE Recommended Practice, RP-16-1964.

If a program transition to a nonsynchronous video signal source is required during the making of a recording, the "positional" servo must correct the angular position of the head drum at a controlled rate, in order to minimize a corresponding instability that will occur during the subsequent reproduction. In the event of severe interruptions of the video sync component, the Intersync servo unit may be switched to the POWER LINE or external as a reference.

The second loop, shown in Fig. 9, provides damping and is used during all modes of operation. Its damping action minimizes high rate-of-change disturbances that affect the instantaneous frequency of head drum rotation, including those resulting from the natural tendency of the drum motor to "hunt" at a 7 to 10 Hz rate, or momentary changes of head-to-tape pressure (drum loading) caused by the passing of a tape splice. The minimizing of these disturbances establishes a flat frequency characteristic within the bandpass of the servo system.

In the damping loop, the tachometer signal is routed to a frequency sensitive detector which derives a signal voltage that is proportional to any instantaneous changes of the tachometer signal frequency. This signal voltage is applied to a phase modulator which also receives the drum oscillator signal. The latter is modulated in terms of corresponding momentary phase shifts to counteract the disturbance and then routed to the drum motor driver.

During the record mode, the capstan servo system maintains constant velocity of the tape in its movement past the rotating video head drum. The frequency of the capstan drive signal is 60 Hz

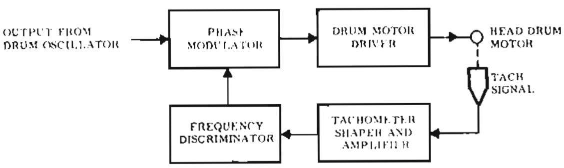

Fig. 9. Block diagram of damping loop.

derived from an oscillator and locked to the drum tachometer signal. The capstan synchronous motor is thus caused to drive the tape at the primary nominal linear rate of 15 ips, but is electronically locked to the rotation of the video head drum.

Using this method to develop the capstan drive signal causes any change in head drum speed to bring about a proportional change in capstan speed. As long as the head drum speed and capstan speed maintain correct relationship, the proper interval between the recorded transverse tracks across the tape is maintained.

Servo Play Mode Functions

At the time of the recording, the tape moves longitudinally at the nominal rate of 15 ips, while the video heads rotate at the rate of 14,400 rpm. The carefully controlled positional relationship between vertical sync information and the 30 pps frame pulse is established at this time, during which the tachometer scans the rotation of the video head drum and generates one complete cycle of a square wave during each revolution. Because the drum turns at 240 rps, the square wave produced by the tachometer has a frequency of 240 Hz and is in exact phase with the drum position.

The tachometer signal is recorded on the control track at normal level together with the 30 pps frame pulse which is recorded at the level of tape saturation. The considerable difference between the record level of the frame pulse compared with that of the control track permits positive identification of both reproduced signals.

Reproduction of the recorded composite video signal requires accurate servo controls that will position the tape longitudinally and phase the video heads transversely to re-establish the positional relationship existing during the recording process.

The tape is positioned longitudinally by the capstan which is controlled by comparison of the reproduced control track signal with a reference signal. Simultaneously the phase of the video head drum is precisely indicated by the phase of the tachometer signal which is compared with that of the reference signal. An error in the longitudinal position of the tape, or in the phase of the head drum results in an error correcting voltage that acts on the respective servo system to cancel the error.

Intersync Servo Control Modes

The Intersync servo unit allows manual selection of five operating modes, providing great flexibility in every operational situation both color and monochrome. The modes are as follows:

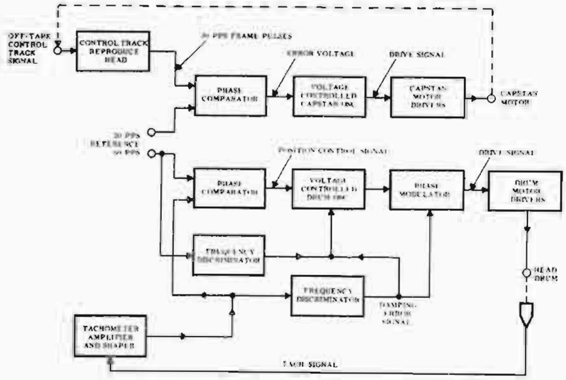

Fig. 10. Automatic mode—initial condition.

Automatic mode. This mode locks the recorder to the incoming video vertical sync signals in record and permits full Intersync operation which tightly locks the recorder to reference horizontal and vertical sync in playback mode.

Intersync servo unit performs its major function during the recovery of signal information from a tape recording. To do this, in the automatic mode it provides servo controls that identify the particular transverse tracks in which a frame begins, positions the tape to cause the video heads to scan the exact center of each transverse track, and phases the head drum rotation to cause one particular video head No. 4 to scan the identified track when switched to Track 1. Other heads may be selected to scan the identified track. Fig. 10 shows a block diagram of the Automatic Mode, Initial Condition and Fig. 11 shows a block diagram of the Automatic Mode, Final Condition.

Track identification is derived from the 30 pps frame pulse recorded on the control track, which controls capstan rotation to position the tape longitudinally. During this period, head drum rotation is locked to a reference signal (e.g., station reference sync), but the video heads are not yet in contact with the tape. Thus the longitudinal positioning of the tape is accomplished by relatively large changes of tape speed during a period when recorded vertical and horizontal sync information is not being reproduced. Because the control track record/reproduce head is in contact with the tape at all times, frame pulses are reproduced as soon as tape movement begins. It should be recalled that each frame pulse coincides, in time, with the vertical sync information that initiates a new frame, and that the frame pulse is recorded on the control track, while the vertical sync information is recorded on a transverse video track. See Fig. 12.

After 1 or 3.8 sec., depending on the type of start up used (head override on) and after capstan rotation has stabilized or nearly stabilized the longitudinal position of the tape, the vacuum tape guide brings the tape into contact with the video heads which then begin reproduction of the recorded video information. If for any reason the control track frame pulses are not present and framing is not accomplished as described previously, duplicate framing information is derived from the reproduce video tracks and used to control the capstan in the same manner as the control track frame pulses. When framing is completed and video is being satisfactorily reproduced, the capstan servo and head drum servo switch to the same condition as the horizontal mode final condition.

Horizontal Mode

This mode locks the recorder to the incoming video vertical sync signal in record and tightly locks to external reference horizontal sync in playback. Use of the horizontal mode minimizes effects from signal discontinuity and permits improved quality when playing back physically spliced color and monochrome tapes. The reproduced video will not necessarily be vertically framed with respect to reference sync.

In this mode, capstan rotation is controlled by phase comparison of the reproduced control track signal with the tachometer signal. There is no other correction of the longitudinal position of the tape. Fig. 13 shows the horizontal mode in the

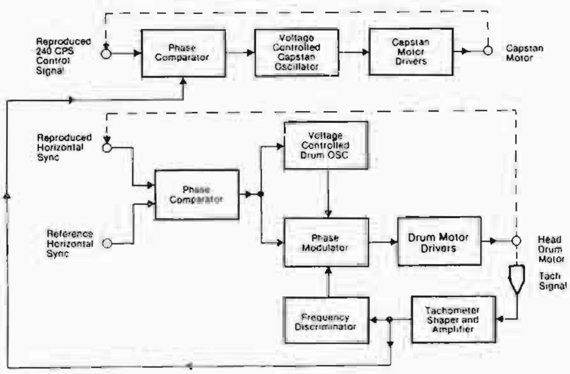

Fig. 11. Automatic mode—final condition.

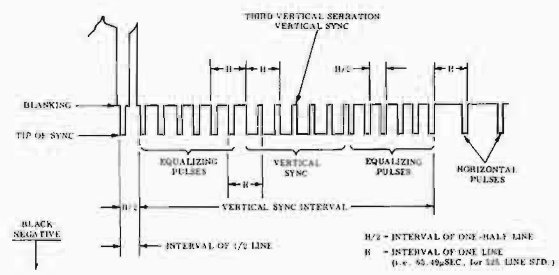

Fig. 12. Elements of the television waveform including the vertical sync interval associated with the generation of a frame pulse (525/30 television standard).

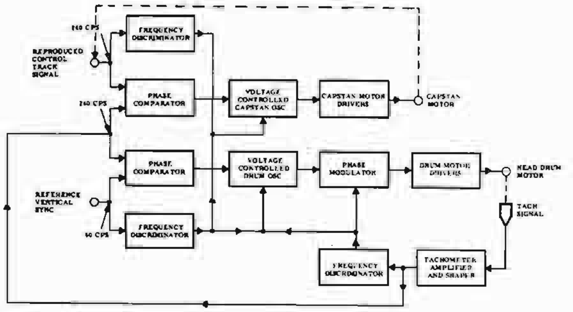

Fig. 13. Horizontal mode, initial condition.

initial condition and Fig. 14 shows the horizontal mode in the final condition.

During the few seconds following the appearance of the reproduced control track signal and before the vacuum guide engages the tape with the video heads, head drum rotation is stabilized by phase comparison of the tachometer signal with reference vertical sync. At the conclusion of this interval, if reproduced video sync pulses are being received, the control of head drum phase is transferred to the output of the horizontal comparator. It remains under this control unless the tachometer phase comparison shows a slipping condition of the tachometer phase with respect to reference vertical sync or the reproduced video sync completely disappears.

Whenever resynchronization is required by the appearance of momentary phase transients, or by the momentary loss of reproduced horizontal sync, it is accomplished by again locking the reproduced horizontal sync to the nearest reference horizontal sync pulse.

The horizontal mode is particularly designed for use with Colortec which is the direct color process. Because this mode provides rapid recovery of lock-in, the interval during which timing errors in the reproduced signal exceed the Colortec correction range is minimized. However, horizontal mode does not provide frame or field synchronization either initially or in the restoration of lock-in following momentary loss of sync. Consequently program switching between reproduced video and other video sources will produce brief disturbances in the picture presentation.

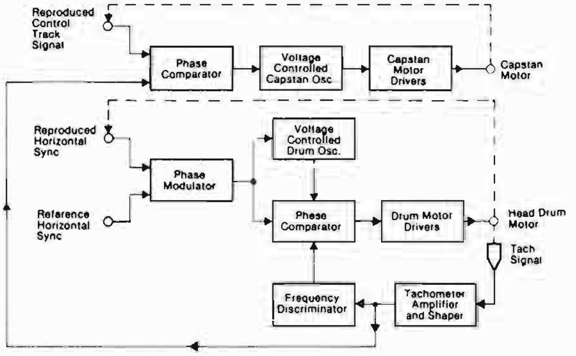

Fig. 14. Horizontal mode, final condition.

Vertical Mode

This mode locks the recorder to the incoming video vertical sync signal in record and to vertical reference sync in playback and maintains accurate frame lock when no-roll switching is desired.

Frame synchronism within ±10 microseconds of the reference is achieved rapidly in two sequential operations. Initially, the capstan positions the tape to place the beginning of a frame, in the recorded signal, in line with the head drum coincidentally with the beginning of a frame of information in the reference signal. This is accomplished by phase comparison of a reproduced frame pulse with a reference frame pulse and is normally completed within 3 to 4 sec. following the appearance of the reproduced control track information. During this period head drum phase is corrected to place Video Head 4 at the center of the tape width coincidentally with the occurrence of reference vertical sync. This is accomplished by phase comparison at the tachometer signal. Fig. 15 shows the vertical mode in the initial condition.

At the conclusion of this period, capstan control is transferred to a control voltage derived by phase comparison of the reproduced control track signal with the tachometer signal. Tape movement is then locked to head drum rotation. Control of head drum rotation is transferred to a control voltage derived by phase comparison of the reproduced vertical sync with reference vertical sync. The occurrence of a phase transient or an imperfect tape splice may cause loss of lock. If this occurs, the capstan will accomplish reframing. Fig. 16 shows the vertical mode in the final condition.

Normal Mode

For monochrome use, this mode locks the recorder to the incoming video signal vertical sync in record and to the power line in playback.

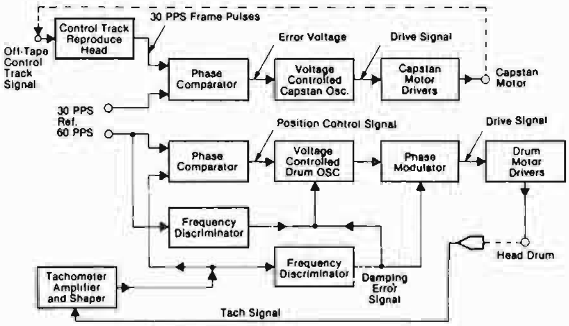

Fig. 15. Vertical mode, initial condition.

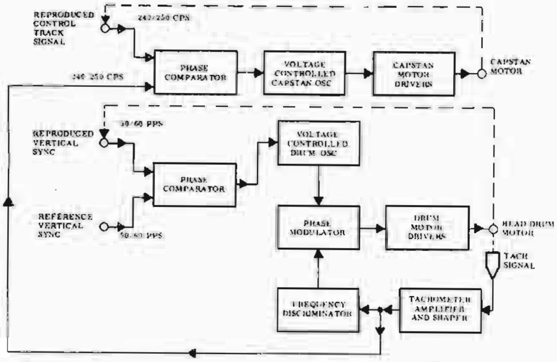

Fig. 16. Vertical mode, final condition.

The normal mode is recommended for monochrome reproduction when the recording is known to contain sync timing discontinuities such as when a tape is improperly spliced. Reproduced video is "soft-locked" to the power line frequency. However, reproduced sync timing is totally ambiguous with the station sync generator reference. Tape reproduction results without regard to framing and is based on phase comparison of the 240 Hz control track signal with the drum tachometer signal, which in turn is phase-locked to the power line. Fig. 17 shows the Intersync servo when operated in normal mode.

Preset Mode

In the preset mode the controls of the Intersync servo unit may be set to any desired record and/or reproduce reference. This mode is used mainly for checking various areas of the circuitry and to meet unusual requirements of the user. Preset mode is similar to normal mode except that its timing reference source is chosen by means of two selector switches.

The Video Head Assembly

The Video Head Assembly includes four video heads that are mounted 90° apart on the periphery of the video head drum. The drum is approximately 2-in. (50.8 mm) in diameter, and rotates during record, play, or ready modes at 14,400 rpm (240 rps).

At the rotational rate of 240 rps, and with tape movement at 15 ips, the actual head-to-tape velocity is approximately 1,500 in./sec., caused by the fact that each video head traverses the (2-in.) width of the tape once during each revolution of the video head drum.

The width of the recorded video track across the tape is that of the video head tips of the video head assembly. At 15 ips tape speed, while using the 10-mil assembly, the guard band separation between recorded tracks is 5.6 mils; while using the 5-mil assembly, the guard band becomes 10.6 mils. In either case the center-to-center track spacing is 15.6 mils. At 7½ ips (using the 5-mil video head assembly) the center-to-center track spacing is 7.8 mils, and the guard band between tracks is 2.8 mils. The 5 mil assembly is required for 7½ ips operation; it may as well be used to reproduce 15 ips recordings to reproduce recordings made with a 10 mil assembly. Generally, the 5 mil assembly is not used when recording at 15 ips.

Under the 525/30 TV standard as each head sweeps across the tape, 16 to 17 horizontal lines of picture information are recorded. The 525 lines that constitute one frame are contained in 32 successive parallel tracks that occupy ½-in. (12.7 mm) of tape length when the tape speed is 15 ips.

Over the past ten years there have been major design refinements in precision-rotating video recording heads. New approaches in construction of unitized transducers as well as new innovations in head drum design have eliminated to a great extent time-consuming and complicated mechanical quadrature maintenance adjustments. The need for electronic quadrature delay lines previously required to compensate for electronic quadrature adjustment and positioning of transducer on the head drum have as well been eliminated.

Improved head tip materials have provided high efficiency performance and markedly im-

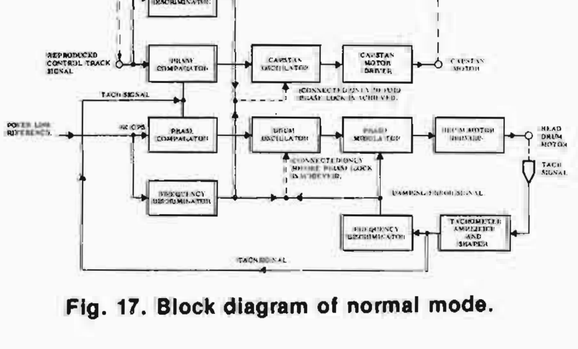

Fig. 17. Block diagram of normal mode.

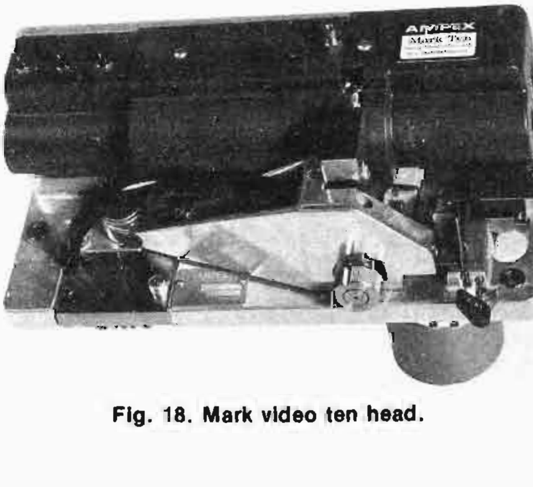

Fig. 18. Mark video ten head.

proved signal-to-noise ratio, and improved appreciably head tip life.

Air Bearings

The air-bearing system for rotary heads was developed mainly for color television signal recording. Air bearings provide for much improved rotational stability with a reduction of mechanical friction, and as a result at the outset the time base stability is superior requiring a lesser degree of electrical correction as well as minimizing the accumulative effect of time base error, particularly in multiple generation recordings. Geometric distortion (water fall), (jitter), inherent in the early ball bearing counterpart head assemblies has been for all practical purposes eliminated with air-bearing improvements. Again, video head assembly reliability in broadcasting has been substantially improved, and there is no lubrication concern, or mechanical ball bearing wear-out while in service providing the supply of clean, dry, oil-free air is maintained at the proper pressure level.

Rotary Transformers

Modern rotary transformer development provide for low-noise coupling of the video head tip transducer to the preamplifier input, and at the same time increase signal-to-noise ratio as well as minimize crosstalk from channel-to-channel of the RF signal.

In addition there has been a substantial reduction in operational maintenance with the elimination of slip rings or mechanical commutation, relieving considerable difficulty. This rotary transformer has proven and enhanced the reliability of "on-air" performance as well as simplified operations and head assembly maintenance. Generally, manufacturing tolerances have been tightened in the construction and refurbishing programs of video head assemblies—yielding to improved quality, matching of electrical characteristics, and overall improved performance from assembly to assembly.

Preamplification

New developments in nuvistor and transistor preamplification electronics provide the first stage of a cascade low-noise circuit. The preamplifiers are designed and located in close proximity to the video head rotary transformer further improving signal-to-noise ratio as well as individual piston capacitors for accurate matching of electrical characteristics to further equalize performance in each head channel system. New head assemblies provide a nonambiguous tachometer disc for more precise timing control of head drum velocity.

Video Head Testing

New head alignment systems have been developed to perform accurate checkout of video head assemblies with nuvistor preamplifiers prior to operational recording. Sweep test modules are designed to plug in line standard module sockets when alignment is performed. The sweep modules generate a saw tooth test signal that modulates the recorder's built-in modulator. A head test loop assembly provides an RF coupling device that is mounted on the vacuum guide of the video head assembly. This induces a sweep test signal through the individual head tips under test while the head drum motor is off and the drum is stationary, allowing separate head checkout. In operation, the RF coupling device is connected to a detector and the output is presented to an oscilloscope for adjustment of the recorder's "Q compensation and frequency compensation" controls. This system allows for accurate compensation of video head resonance.

Another new system developed to reduce video head optimization time has proved most satisfactory and efficient in setting the video record drive levels of the video tape recorder.

The tape transportation speed is reduced 75 percent, i.e., at 15 ips operation the tape speed is reduced to 3.75 ips.[1] The first head is allowed to go into the record mode while the other three heads reproduce. The following head immediately plays back approximately 66 percent of the first head's recorded track. There is sufficient playback to allow for immediate determination of head drive optimization, or the point where the record drive excitation voltage or current to the transducer is selected to an optimum, at the verge of saturation producing the greatest RF output with minimum background noise in the channel. The same procedure is repeated by the "A" track selector switch for heads two, three, and four. This procedure is convenient to implement and requires only a few seconds from what was a 5-to 15-minute task and a most important one in maintaining high-quality video recording, particularly color.

Video Head Tips

With development of high-band color video recording considerable additional engineering has been required to provide for more efficient video head transducers and at the same time achieve a higher frequency record capability. In order to provide higher output level and to improve signal-to-noise ratio, new transducer designs have been developed. The length of the video tip gap has been reduced from roughly 100 microinches

[1]At 7.5 ips operation, the tape transported at 1.78 ips.

SMPTE Recommended Practice RP 11

This Recommended Practice originated in the Video Tape Recording Committee. The proposal, approved by the initiating committee and the Standards Committee, was published for trial and comment in the October 1961 Journal. The recommendation received final approval by the Society's Board of Governors on February 16, 1962.

Tape Vacuum Guide Radius and Position for Recording Standard Video Records on 2-in. Magnetic Tape

1. *Scope*

This recommended practice specifies the tape vacuum guide radius and position for recording standard video records on 2-in. magnetic tape.

2. *Mechanical Dimensions*

2.1 The radius of the tape vacuum guide shall be 1.0334, +0.0000, −0.0005 in. (26.248, +0.000, −0.013mm).

2.2 The position of the vacuum guide shall be set so that the eccentricity of its center of curvature with respect to the axis of rotation of the video heads is as indicated in the table. The eccentricity shall be such that the extension of a line joining the center of curvature of the vacuum guide and the axis of rotation of the heads intersects the tape at the midpoint of its width. The center of curvature of the vacuum guide shall lie between the axis of rotation of the heads and the vacuum guide.

Vacuum Guide Radius		Eccentricity	
Inches	Millimeters	Inches	Millimeters
1.0334	26.248	0.0000	0.000
1.0333	26.246	0.0001	0.003
1.0332	26.243	0.0002	0.005
1.0331	26.241	0.0003	0.008
1.0330	26.238	0.0004	0.010
1.0329	26.236	0.0005	0.013

Note: These dimensions are based on a nominal tape thickness of 0.0014 inch (0.0356mm) and a radius of rotation of the magnetic head pole tips of 1.0329 inch min. to 1.0356 inch max.

APPENDIX

The achievement of tape playback interchangeability requires, among other things, that means be provided to accommodate variations of (a) the radius of rotation of the magnetic head pole tips, (b) the radius of the vacuum guide and (c) tape thickness. These effects are compensated by the stretching of the tape into a slot cavity in the vacuum guide by virtue of the radius of rotation of the magnetic head pole tips projecting beyond the unstretched oxide surface of the tape as held in the vacuum guide. Over the limits normally encountered, the stretching provides automatic compensation if the vacuum guide is positioned to give the minimum geometric distortion in the reproduced picture.

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Fig. 19. SMPTE RP-11, Tape vacuum guide radius and position for recording standard video records on 2-in. magnetic tape.

to a nominal 50 microinches, in order to accommodate the higher frequency associated with high-band recording.

The engineering improvements in signal-to-noise ratio and increasing frequency response of the transducer tip have been major achievements, not to mention that at the same time there has been an improvement in head tip life. These three advances in video recording are in part the reasons for today's state of the art, the ability to make several multiple generation recordings, half speed, 7.5 ips operation, and maintain high-quality broadcast pictures.

The Society of Motion Pictures and Television Engineers has provided a recommended practice, RP-11 "Tape Vacuum Guide Radius and Position for Recording Standard Video Records on 2 in. Magnetic Tape." All video tapes should be recorded to a standard *Tip Engagement* as specified in SMPTE RP-11, see Fig. 19.

This, from a practical point of view, can be done through the use of a standard alignment tape supplied by the equipment manufacturer. In the case of Ampex, their alignment tape is designated as 50262-07 and RCA as MI-41699-A. Both tapes conform to this standard. The key to keeping the total required adjustment range of the tape vacuum guide block as small as possible lies in the regular use in the field of these alignment tapes, enabling operators to regularly position the vacuum guide with respect to the video tips and maintain it. The actual adjustment

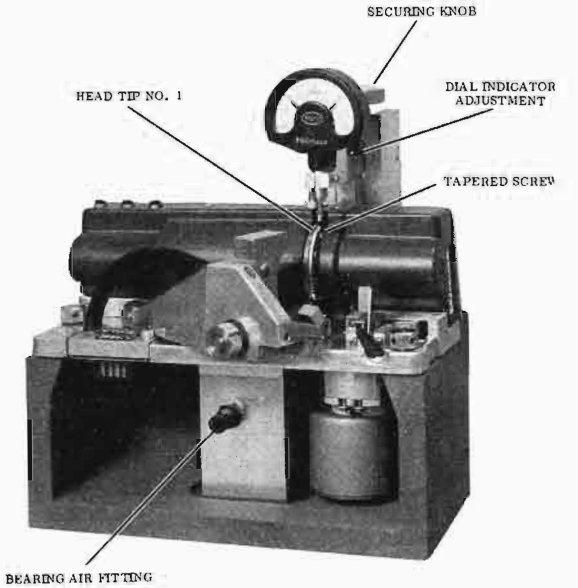


Fig. 20. Video head tip measurement setup.

range needed for the guide is quite small, under normal studio variation of temperature and humidity. The adjustment to compensate for head tip wear is negligible since there is a *self-compensating* change in the amount of tape stretching. Proper alignment of vertical positioning of the *guide height* can as well be made by use of the alignment tape. It is important to head life and picture quality to maintain proper tip engagement. With excessive tip engagement into the tape, it can be expected to have a serious reduction of head tip life, not to mention excessive wear and damage to the video tape. On the other hand, insufficient tip engagement will bring about a degradation in the television playback signal particularly excessive signal drop-out activity, recorded in drop-out activity, and reduction of signal-to-noise ratio. Aside from the extreme of poor head tip life to the other extreme of poor quality picture, it is of paramount importance to maintain interchangeability of video tape recording from one machine to another and one organization to another. Regularly align the vacuum guide block with a standard alignment tape to achieve best possible head tip life consistent with best picture quality and to maintain standardization for interchangeability and interspliceability.

Drum Diameter

In the design of the Ampex television recorder the video head drum is based upon a nominal diameter of 2.06405 in. *All measurements are referenced to this diameter.* Because of machining tolerances, individual drums may differ slightly from the reference diameter.

Tip Projection

The tips of the four video heads on each drum assembly extend out from the drum a maximum of 3.3 mils (.0033 in.) past the reference diameter. This yields a maximum tip-to-tip diameter of 2.06405 in. + .0066 in. or 2.07065 in. The common method of using a dial indicator to measure projection of the tips is valid as a standard measurement under two conditions only:

1. If the diameter of the drum is exactly equal to the reference diameter, or
2. If the dial indicator reading is corrected by the amount the drum is above or below the reference diameter.

As an example, a drum is measured and found to have a diameter 0.2 mil under the reference diameter. Suppose further that the measured tip projections with an indicator are tabulated as follows:

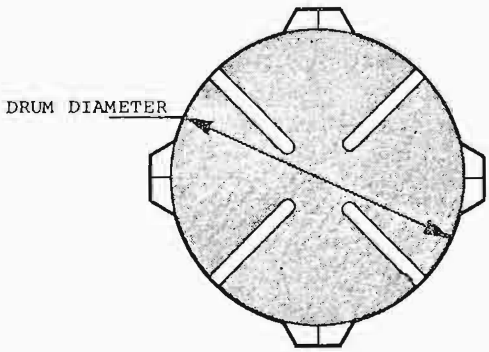


Fig. 21. Head drum diameter.

HEAD	MEASURED PROJECTION	CORRECTED PROJECTION
#1	3.2 mils	3.1 mils
#2	3.3 mils	3.2 mils
#3	3.1 mils	3.0 mils
#4	3.1 mils	3.0 mils

Fig. 22. Measured and corrected tip projection.

To find the corrected or actual projection, half the excess diameter or .1 mil must be subtracted from the measured projection.

Tip Engagement

To assure tight contact between the video heads and the tape, there is negative clearance between the head tips and the tape in the guide. The tape guide is relieved in line with the tips so the tape may stretch as the tip travels across it. *The negative clearance is the tip engagement.*

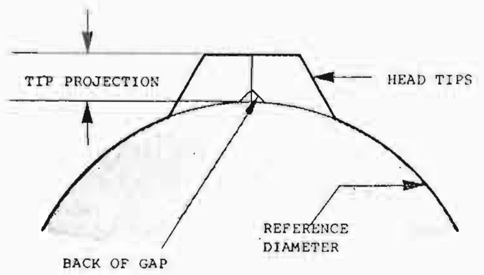


Fig. 23. Tip projection.

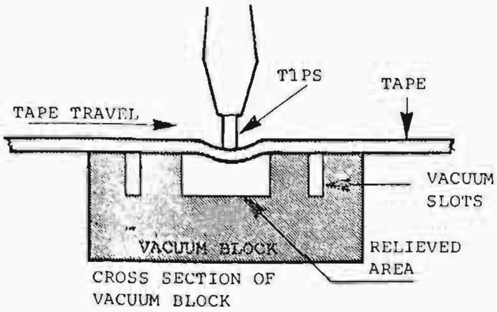


Fig. 24. Head tip engagement.

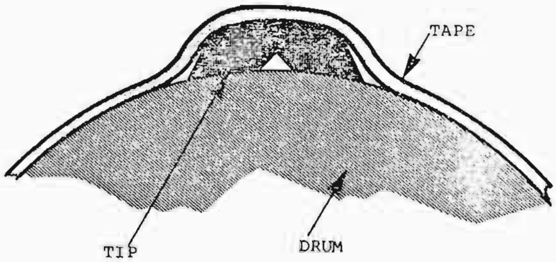


Fig. 25. Head-to-tape contact.

Departure Point

As negative clearance is decreased by moving the guide away from the head drum, signal output will remain relatively unchanged until only a small amount of negative clearance (engagement) is left and intimate contact between head and tape starts to be lost. At this point output will start to fall and finally reach zero. Because horizontal movement of the guide away from the drum destroys concentricity between the two, intimate contact will be lost first at the mid-point of the head's travel across the tape, and a dip will be introduced at the center of the RF envelope of the head's output, as viewed on an oscilloscope, see Fig. 26.

Complete loss of contact between tape and tip is indicated when the envelope dips to zero, see Fig. 27. This point in the guide's movement is called the "Departure Point." To adjust *approximately* for a desired tip engagement, it is only necessary to locate the "departure point" and move the guide towards the drum the distance equal to the desired engagement, the corrected tip projection valve.

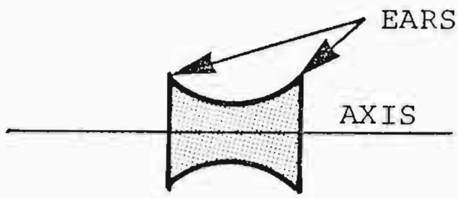


Fig. 26. RF-envelope—partial disengagement.

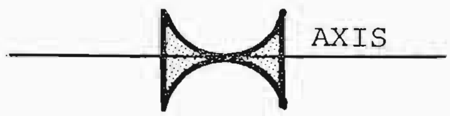


Fig. 27. RF envelope—departure point.

Self-Compensation

At first glance it would seem that a tape recorded with a given tip engagement must always be played back using the same tip engagement. *This is not true.* To understand why, examine what will happen when a tape recorded with a head having 3 mils tip projection is reproduced using a head which has only 2 mils tip projection. When the tape is played back by the 2 mils head, it is found that the tip engagement (when the guide is adjusted to remove skewing) is now only 2 mils. The explanation is this: since the *angular* velocity (video drum rpm) is held the same during record and reproduce, it follows that the tip velocity (ips) must have been greater during the record process due to the longer tip radius. If correct timing is to be maintained, the length of tape traversed by the shorter reproduce tip radius must be less or, in other words, *less tape stretch* has occurred. The reduction in tape stretch due to decreased tip pentration is complementary to the reduced velocity due to decreased tip radius.

The significance of this self-compensation principle can be appreciated by understanding the following experiment. Record a tape with the four heads which has a tip projection of 3.0 mils all

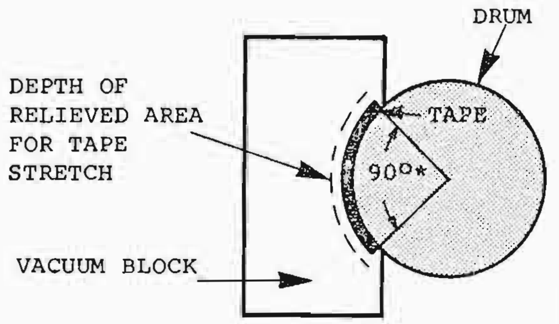


Fig. 28. Video head drum and guide block.

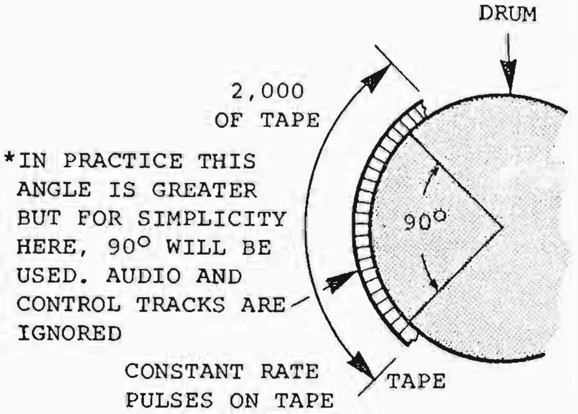


Fig. 29. Video head drum.

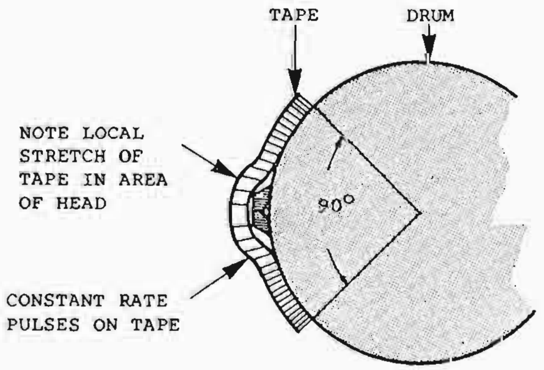


Fig. 30. Tape stretch.

equal, and use 3 mils of tip engagement. Now simply grind one of the four head tips down to 1 mil tip projection prior to reproduce. If you now reproduce the tape which was recorded when all the tips were equal, *you will see no visible defect in the picture:* The reduced velocity of the short tip has been compensated by the reduction in stretch due to reduced tip penetration.

One important idea to be kept in mind is that the stretching will be a localized affair. The effect of stretching is shown in the exaggerated figures that follow. The position of equally spaced recorded pulses on the tape is indicated by black bars on the cross section of the tape.

Facts to Note:

1. The head will sweep the same angle in the same time regardless of amount of tip projection.
2. The peripheral speed of the tip is greater with more projection, but the local stretch of the tape balances out the increased speed by increasing the separation of the pulses on tape.
3. The horizontal position of the guide relative to the chrome surface of the drum remains constant throughout the life of a head and tip engagement decreases as the tips wear down.

Guide Radius and Position

The vacuum guide radius of curvature is specified in SMPTE RP-11 as ranging from 1.0329 to 1.0334 in.

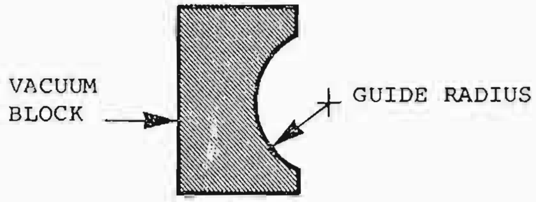


Fig. 31. Guide block radius.

To a first approximation, the variations in guide radius can be accommodated by varying guide position slightly so that the same length of track is always recorded or reproduced regardless of guide radius. Only when the guide radius is 1.0334 are the center of curvature of the guide and the axis of rotation of the drum coincident; for all other values a slight eccentricity exists.

Because guide radius is controlled by the manufacturer, the only variable under the control of the recorder operator is the guide position which determines eccentricity. In practice there are two ways for an operator to set up the proper eccentricity. The most accurate method is to play back a standard tape designed for the purpose and adjust guide position both horizontally and vertically for minimum geometric errors in the reproduced picture. A less accurate method which can be used if a standard tape is not available is the one described previously in the subsection entitled "Departure Point."

Guide Height

SMPTE RP-11 states that the eccentricity shall be such that the extension of a line joining the center of curvature of the vacuum guide and the axis of rotation of the heads intersects the tape at the midpoint of its width. This statement defines what most of us know as guide height, and this positioning of the guide is also under the control of the operator.

The best way for the operator to set guide height is to use the same standard tape used for setting eccentricity, and as in the former case, guide height should be adjusted for minimum geometric distortions in the reproduced test pattern.

When the vacuum guide block is properly adjusted, with reference to a standard tape, various guide engagement errors can be quickly seen and evaluated in the picture monitor. Examples of error configuration displacements are shown in Figs. 32 through 37.

If a standard tape is not available, there are two other less accurate ways available for setting guide height which can be used in an emergency. The simplest way is to make a short recording and then observe the RF output of the switcher during playback while moving the guide away from the head. The RF pattern from the heads will dip as in Fig. 26, and if the guide height is correct, the

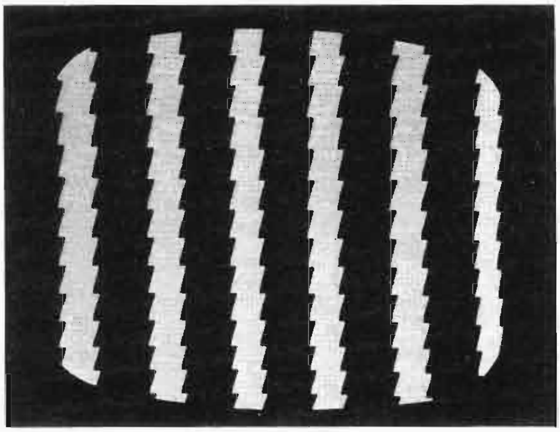


Fig. 32. Guide block too far back tip engagement shallow.

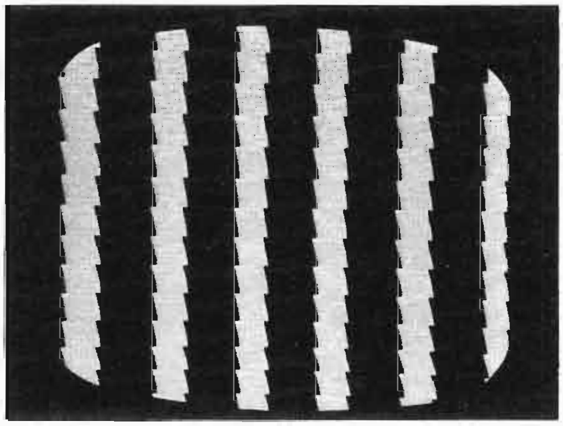


Fig. 33. Guide block too far in tip engagement deep.

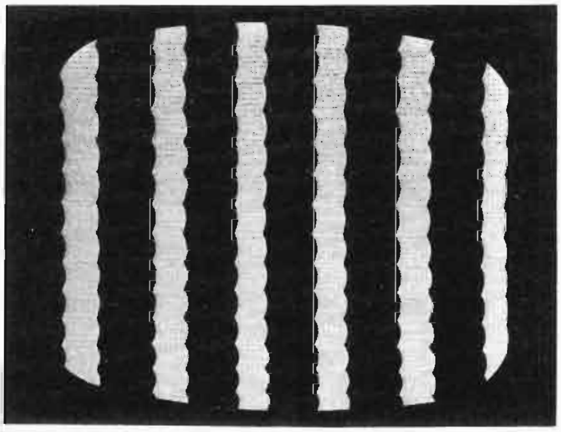


Fig. 34. Guide block too low.

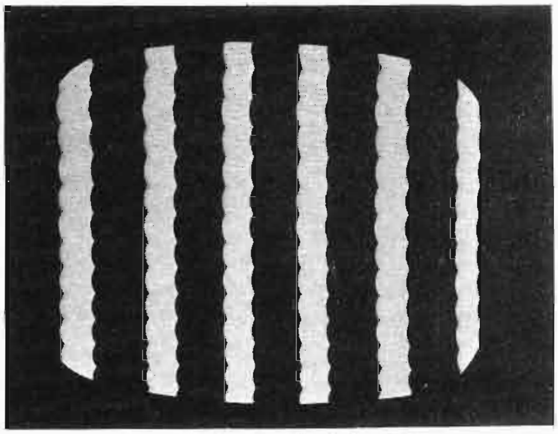


Fig. 35. Guide block too high.

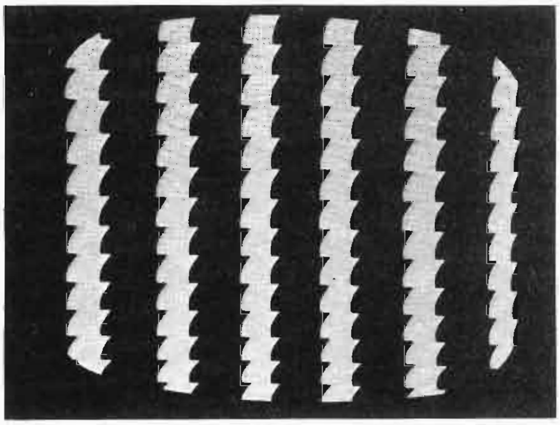


Fig. 36. Guide block too high tip engagement shallow.

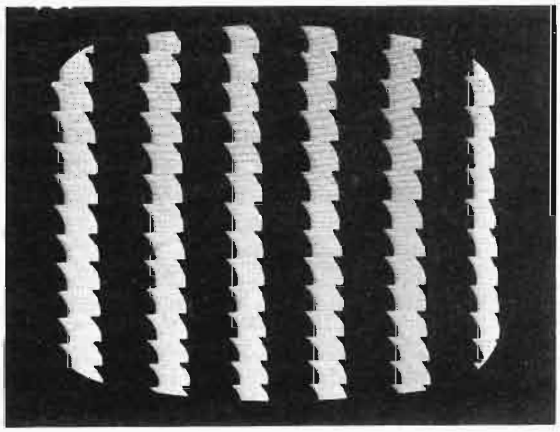


Fig. 37. Guide block too low tip engagement deep.

ears at both ends of the RF burst will remain equal in height as the guide is backed away. The process of recording and playing back must be repeated several times to zero-in the correct setting. In addition, it must be determined that the transport, panel and tape combination is not producing an RF tilt.

A second method is to make a recording with the control track signal also recorded on the Audio I track and then play the tape back upside down. The guide height should be adjusted to remove half of the geometric error observed. The record-playback process should be repeated several times to zero-in the correct guide setting. A certain amount of experimentation with control track level will be necessary to obtain proper playback levels.

Video Head Life

The wear rate of new heads with tips at or near maximum will be relatively high, but will decrease exponentially as the head tip wears down; the head wear rate simply decreases as the tip projection declines. General video tape operating experience has shown that the head wear *rate* during the first 50 operating hours, when a new head is initially installed, may decrease as much as twice during the second 50 operating hours under normal conditions. In the third increment of 50 hours use (up to approximately 150 hours) an additional 25 percent reduction in head wear rate may be expected and finally a point is reached where a minimum descending value of tip wear continues until the final normal failure of a head tip occurs. This point is near or when the "back-of-gap" is reached. The point is clearly seen when finally there is no signal output from a given head tip or when noise banding, chroma level flutter, or difficulty in optimizing the drive to a head tip occurs. Another point is as well-considered failure when the signal drop-out activity rises rapidly around 1 mil of tip engagement. An idealized head wear characteristic curve is shown in Fig. 38.

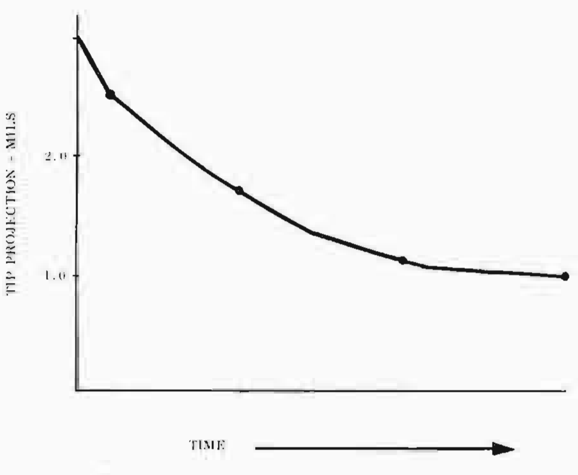


Fig. 38. Idealized head wear curve.

Measurement of Wear Rates

The wear rate per hour equals the difference between the initial tip projection and the remaining tip projection divided by the operating time in hours. If .000050 in. is worn from each tip over an operating time of two hours and 30 minutes, the wear rate is 20 microinches per hour. This can be simply done as follows:

VTR Elapsed Time Indicator Readings:

	Time VTR Head Removed	________
minus	Time VTR Head Installed	________
=	VTR Head Hours Used	________

and finally

Head Wear Rate:

Total Head Tip Wear ________

÷ ____________________________

VTR Head Hours Used ________

= ________ Average wear rate microinches/hour.

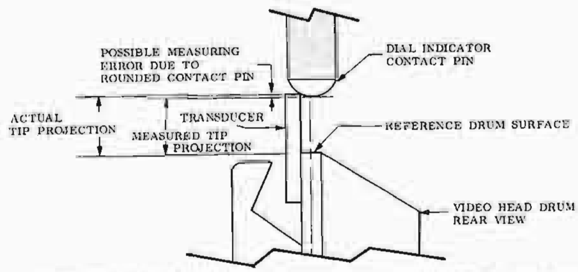


Fig. 39. Dial indicator improper positioning, using rounded contact pin.

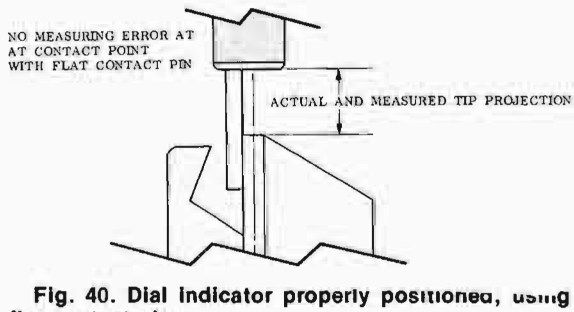


Fig. 40. Dial indicator properly positioned, using flat contact pin.

It is important to maintain accurate records on the time VTR heads are in actual use, particularly if the heads are moved from machine to machine. Dial indicator readings as well should be made with extreme care to provide accurate drum reference and tip projection readings, as shown in Figs. 39 and 40. Further, special care should be taken so as not to damage or abuse the head tip during the time dial indicator readings are being taken.

Factors Affecting Video Head and Tape Life

Video recorder head life and video tape life are directly related. Video head tip wear is affected by the condition of the tape in use, cleanliness of the tape, the abrasive characteristics of the tape, cleanliness of equipment, environment of the VTR operational area, adherence to recording standards, adjustment of the VTR tape transportation system, and the general operational handling procedures of the VTR and video tape. Likewise, the video tape material life is affected by the condition of the video head tip, the tape path surfaces of the video recorder, and many of the factors just mentioned relating to video head life—in addition, the condition of reels, reel hubs, circumstances of packaging, shipping, and storage, and mainly the video tape handling procedures, as well as the tender loving care given by the video tape operator.

Factors Affecting Video Head Tip Life

Video recorder head tip wear is of great concern in relation to the cost of operation as well as providing high quality performance of the video tape recordings and the proper handling of video tape materials. Factors concerning video head life as well affect the "on-air" picture quality and wear of video tape stocks in use.

Factors concerning video head tip life are directly related with that of the video tape material utilized, their care, and the handling procedures used in general operations. The overall "on-the-air" quality, cost of operation, and care of video tape and heads are vital.

All magnetic recording tapes present an abrasive (oxide-coated) surface to the video head tips in the recorder reproducing equipment. Thus, head wear begins the moment the first tape is recorded or reproduced. The rate of wear produced by undamaged tape of good quality is relatively low, but it has a finite value. Tape that has been mechanically damaged in a way that distorts its oxide-coated surface is quite another matter. Head wear is directly related to moisture content in the tape binder system. The higher the moisture content, the higher the head material wear rate. The moisture content level is related to

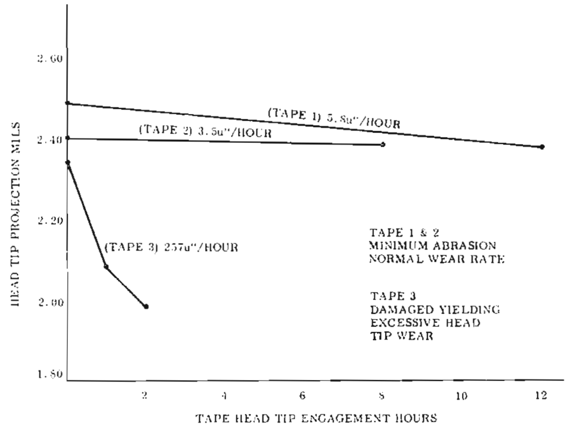


Fig. 41. Comparison head tip wear rate using damaged tape.

relative humidity that the tape is either stored or run in the recorder system. The ideal RH % to store or operate for maximum head life is 30 to 40% RH.

In the case of video head tips which traverse the tape at high writing speeds (e.g., 1,500 in./sec.), undamaged tape allows a useful head life in excess of 100 hours. On the other hand, damaged tape may cause rates of wear ranging up to 400 microinches per hour, thereby reducing useful head life to only a few hours. Fig. 41 compares head tip wear rate using damaged video tape.

Damaged Tape

Tape that has been physically damaged by creasing, crumpling, or scratching is the prime cause of the high wear rates approaching 400 microinches per hour mentioned earlier. Any sharp deformation or scratching of the oxide coating interrupts its continuity and uniformity, resulting in a cutting action somewhat akin to that of a file. It also loosens individual particles of oxide, which may be picked up and retained by the head tips or the head drum. When physically damaged tape passes the head tips, the tips are scratched by this cutting action as shown in Fig. 42. Then, as more tape passes the scratched tips, it is damaged in turn by the milling action of the tips. For this reason, severely scratched head tips must be polished before further use.

Fig. 43 illustrates typical damage to tape caused by creasing or folding. When creased sections of tape pass the head tips, the rate of wear increases drastically, and loosened particles of oxide are picked up and retained by the head tips and the drum.

Fig. 44 shows the random redeposit of oxide particles near the edge of the tape. The appearance of these streaks reveal the end of useful tape

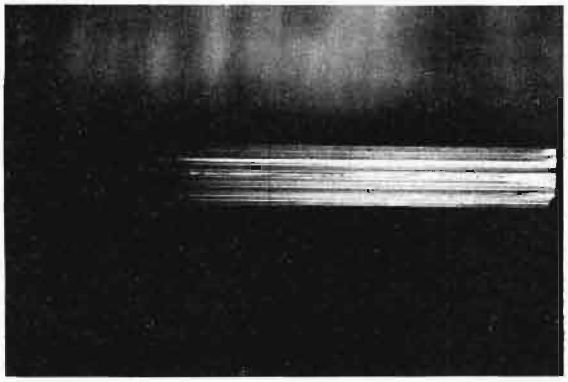


Fig. 42. Damaged video head tip.

Fig. 43. Creases cause oxide buildup, high tip-wear rates.

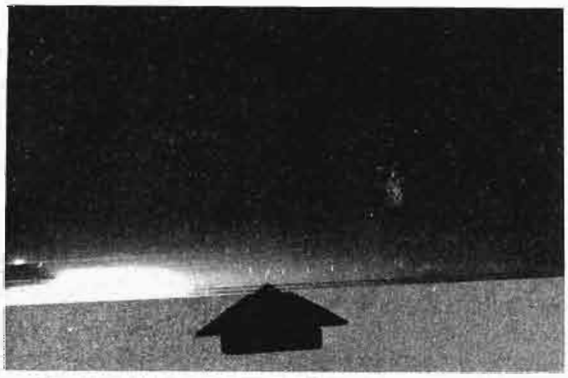


Fig. 44. Oxide redeposits signal end of useful tape life.

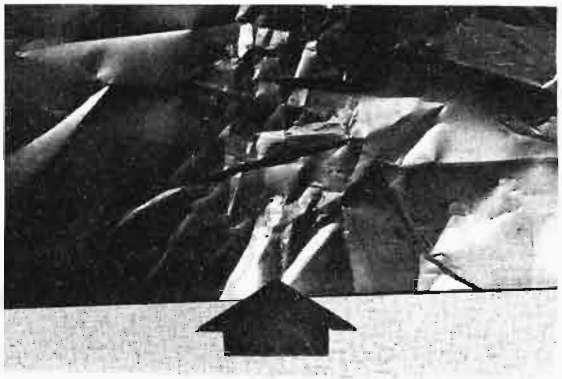


Fig. 45. Crumpled tape scratches tips, causes oxide buildup and rapid wear.

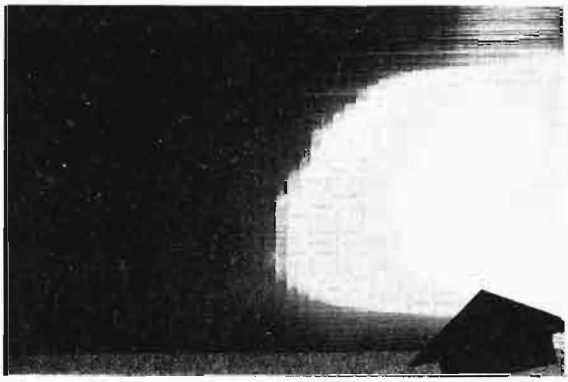


Fig. 46. Transverse burns from passing over a damaged tape cause wear.

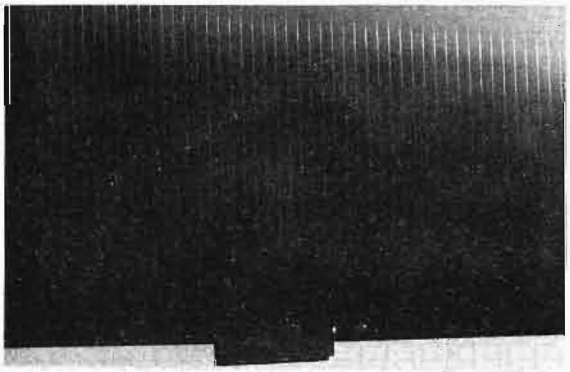


Fig. 47. Opposite side of tape; backing permanently deformed.

life, because it indicates a general breakdown of the oxide binder.

Fig. 45 illustrates a typical random crumpling of the tape from edge to edge. Crumpled tape represents the greatest danger that the head tips may encounter. There is a virtual certainty of tip damage in the form of long, deep scratches, and the subsequent damage of good tape by the damaged tips. Also, a rapid buildup of loose oxide may accumulate on the drum surfaces to aid in the destruction of the tape.

Fig. 46 shows the repeated transverse burns or scratches across the width of the tape caused by damaged head tips or by an oxide-loaded head drum. The deformation of the backing over the same tape section is illustrated in Fig. 47.

Before each day of use, closely inspect all metal surfaces (including tape guides, idlers, compliance arms, head tips, and drum) that touch the oxide-coated surface of the tape for an accumulation of oxide. If any is present, remove it immediately, using a cotton-tipped swab moistened with head cleaner. Be alert for sections of tape that are crumpled, creased, or scratched. These sections appear most often near the beginning of the tape. But wherever they appear, they must be removed before the tape is used to avoid needless head-tip damage.

Examine the head tips regularly by means of a tool-post-mounted microscope equipped with a diffused light source, as shown in Fig. 48. The condition of the tapes being used may be determined by the appearance of the head tips. If severe scratches are detected, polish the tips by running the head for a short period with tape that produces a polished condition. If any head tips are found to be broken, do not use the video- head assembly until it has been repaired or exchanged.

While tape is being manipulated by hand, use care to avoid situations that may lead to creasing or crumpling. In order to avoid severe dropout on tape, gloves should be worn when handling tape. The preferred type are rubber gloves, although cotton gloves do offer some protection from getting the skin oil on the oxide of the tape.

Remember that degradation of the reproduced picture, caused by a buildup of oxide on the head tips, is usually accompanied by a buildup of oxide on the drum surfaces as well. Make it a practice to clean the head tips and the head drum as soon as possible after such degradation first appears.

Environment of Videotape Operational Areas

The environment in which the location of the tape is actually used should approach, as closely as is realistically and practicably, a "clean-room." By definition, then, this area is characterized by the absence of normally expected airborne dust and lint. Various air-conditioning filtration systems are available to accomplish this cleaning.

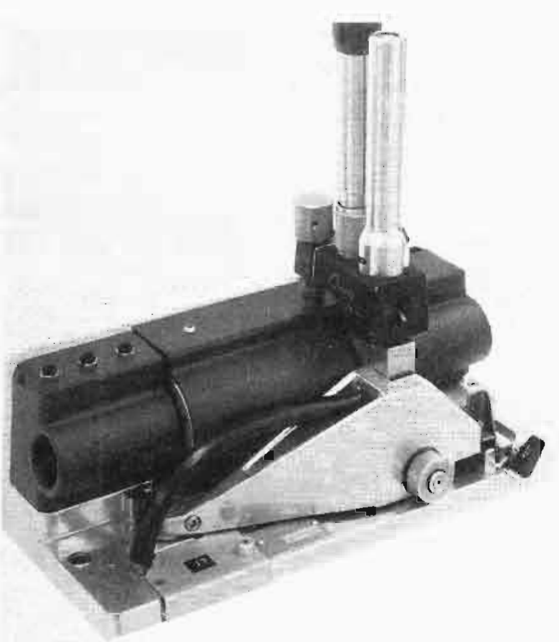


Fig. 48. Head tip inspection microscope.

Whenever possible, the air pressure in the room should be maintained so as to be somewhat higher than the surrounding area. This positive internal pressure will prevent the infiltration of dust through doors and windows that are not absolutely airtight and, of course, is most important in preventing dust from entering when a door is opened.

The surrounding walls and ceilings should be painted. *Air intakes should be well filtered to eliminate outside dust and dirt from entering, even to the point of electrostatic air cleansing when possible.* Carpets or rugs should not be used, but a hard surface such as vinyl, properly waxed, proves best for keeping clean floors. Daily accumulation of dust can easily and frequently be sponge mopped. Video tape recording equipment, racks, shelfs, and video tape reels must be kept clean. The practice of bringing video tape boxes and packaging materials into operation areas is considered to be a source of contamination. A room adjacent to video tape operations, but isolated, is a good place to leave empty boxes for storage, handling, and packaging.

The design of the equipment area should be such that reasonable control of temperature and relative humidity can be exercised. Variations of temperature should be held to within $\pm$ 5° F., of a preselected value and the relative humidity should be kept constant to within $\pm$10 percent. The general recommendation would be an environment that is comfortable for the operating personnel, as this is also ideal for the tape. In broad terms, this would be a temperature in the 70's and a relative humity of about 35 percent. It is doubtful if smoke will contaminate the tape, but ashes can; therefore, great care should be taken when smoking. Food and drink should also be restricted. Minute food particles can easily be transmitted to the video tape and recorders from the operator's hands, resulting in unnecessary collection of debris and ultimately excessive dropout activity as shown in Fig. 49.

Aside from the direct benefits gained from a well-maintained, clean, temperature and humidity controlled environment, the psychological effect upon the employees is of great importance. It is found that operators exercise more care and are more concerned with *quality* when working in an environment such as just described. Cleanliness in video tape operational areas is *absolutely essential* to the long-term life of video tape material stocks and subsequently as well to video head tip life.

Proper Machine Transport Adjustment and Inspection

Supply and take-up holdback torque brake tension adjustments are most important and

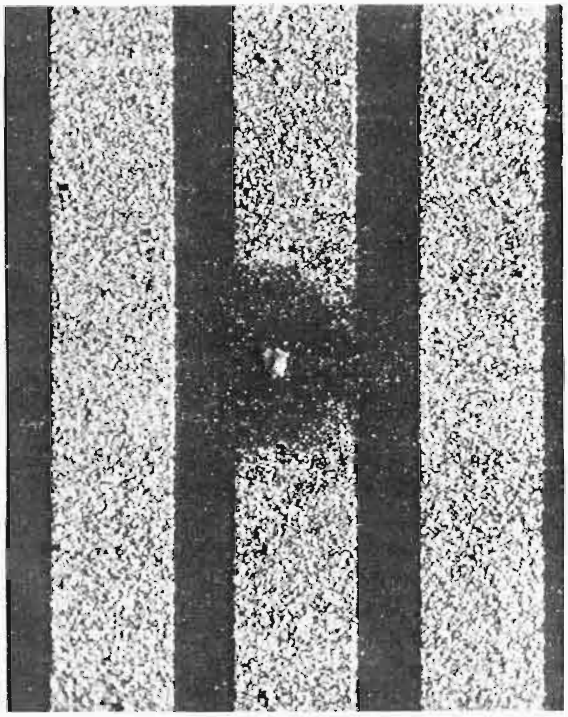


Fig. 49. Dropout.

should be maintained at regular intervals, particularly for the supply reel to minimize geometric imperfections or time base errors, both during record and playback operations. The take-up reel is isolated by the capstan and pinch roller; however, the proper pressure is important at this point to minimize tape slippage and provide stable tape transportation. Bent reel flanges, eccentric reel hubs, and defective supply and take-up motor bearings can be a cause of severe instability problems.

Excessive or nonuniform guide block vacuum levels can further add to geometric distortions and degrade picture stability. Both torque and guide block vacuum fluctuation appear as variable tip engagement errors. Motor tension adjustment and the degree of vacuum in the guide block can contribute to excessive video head tip wear if they are not properly adjusted or are in difficulty.

Regular inspection of tape transport tape path should be accomplished to determine that all surfaces coming into contact with the tape are clean and/or there are no mechanical surface irregularities damaging tape. The vacuum guide, erase head, audio head, tape path guides, and tension arms should be cleaned at regular intervals with a cleaning solvent such as Freon TF[2] and a soft applicator.

Extra care should be given in cleaning the rubber capstan pinch roller, particularly when using solvents. Alcohol has been found best and the pinch roller should be cleaned regularly as well so that the rubber surface does not take on a shine.

Video Tape Operational Handling

The hub is the strongest and most stable part of the reel. This fact is the reason why operators should always handle the reel by the hub and not the flanges. If this single fact is recognized, operators will not squeeze the reel flanges together or apart when picking up a roll of tape and, at the outset, minimize flange damage and subsequently tape damage.

When handling tapes, operators should use utmost caution to insure that the tape does not become contaminated by fingerprints. Simply stated, fingerprints are nothing more than deposits of body oils and salts. These oils will not attack the oxide-binder system, but will form excellent "holding-areas" for dust and lint. The same condition will exist if the tape is contaminated by marking with soft grease or wax pencils.

Fingerprints or grease pencil marks on the backing are just as serious as on the coating because dirt deposits will transfer from the backing of one wrap to the coating of the next wrap on the reel. When a reel that has been contaminated in this manner is put into use, the video recorder itself can be affected and will spread this contamination to other clean reels of tape that are used after the dirty reel.

This is one of the reasons why the stress of importance in visually inspecting the recording equipment after each roll of tape is run to determine where cleaning is necessary. If the recorder becomes contaminated with dust, complete contamination of an entire roll of tape can easily be the result. Debris can collect on heads and guides and be dumped along the backing or coating surface of the tape. This debris will then be wound into the reel under pressure causing it to adhere firmly to the surface. These deposits could appear as a dropout or group of dropouts the next time the tape is used.

Tape contamination caused by fingerprints can be reduced by remembering not to touch the tape unnecessarily. Frequent cleaning of the recorder will reduce the chance of spreading contamination from one reel of tape to others in a library. A cotton swab or lint-free pad moistened with Genesolve-D (an Allied Chemical Trademark), or Freon TF, or similar cleaner is recommended for cleaning all elements of the tape path on the recorder. If other types of cleaning agents are used, they should be given time to thoroughly dry before loading the tape. This will prevent damage to the tape should the cleaner have any tendency to attack the coating of the magnetic tape.

[2]TM, E.I. du Pont de Nemours & Co., Inc.

Empty reels should be thoroughly inspected and cleaned before winding tape on them for storage. Reels with hub damage, or with dirt on the hub winding surface can cause tape distortion. The effect of hub nonuniformity is evidenced by a "spoked" appearance of the tape layers wound upon the hub. This is caused by the pressure of the discontinuity being reflected up through each tape wrap. Maintaining reel integrity cannot be overemphasized as recorded information can be lost not because of tape failure, but because the tape was distorted by a damaged or dirty hub.

One of the most serious and more common forms of tape failure is generally categorized as edge damage. Damaged edges can be caused by the reel, the recorder, or the operator. A damaged or bent reel flange can quickly mutilate the edge of the tape.

Since the tape will probably be damaged with each revolution of the reel, the result of this series of damaged edges will often appear as a bump on the otherwise smooth surface of the wound tape. A similar situation could result if the reel were not mounted evenly. If the reel pedestal height is improper, a guide is misaligned, or the audio "stack" is excessively worn, the resulting edge damage may appear as a "lip" on one side of the tape around the entire reel circumference.

Any of these faults can result in serious damage to a roll of tape. The debris generated from edge damage could be redeposited back onto the surface of the tape across the entire width. An examination of the edges of a tape that has been damaged in this manner probably would disclose an accumulation of loose polyester fibers and loose oxide, as well as damaging to the video head tips.

While this type of damage is serious, it is sometimes difficult to ascertain its cause or even to notice the effect until the damage is severe. Operators should acquire the habit of physically inspecting the recorder in the area of the guides and head for an excessive build-up of oxide, or backing debris. This is generally the first clue that something is wrong.

It is also good practice to continually observe the physical condition of the tape. A sure sign of developing edge damage would be the lip or distortion that was mentioned earlier. When wound on the reel, the effect of this lip will be cumulative and can stretch the backing. The stretched backing will be rippled and will not conform to the heads the next time the reel is used.

Operating personnel should use care in handling the reels of tape. It is important that the reel be picked up in a manner that will not cause the flanges to be squeezed together, or pulled apart. If the flanges are forced against the tape, this could result in edge damage. This is particularly true if the roll has a scattered wind, as the exposed edges of the misaligned strands can be folded over and creased. It is strongly recommended that operators be constantly on the alert for signs of potential trouble. This can best be accomplished by understanding what to look for, and by making continuing inspections of both tape and the recorder tape path. *Know your recorder.*

Video Tape Shipping

Since the widespread use of recorded video tape material requires that the tape be sent from one station to another, certain precautions that apply to the shipment of magnetic tapes should be followed to insure safety in transit.

Logically, the first consideration would be the physical protection of the tape while being transported. The shipping container into which the tape is placed must afford the necessary strength and rigidity to protect the roll from damage caused by dropping or crushing. The ideal container should have provisions within the case to allow a rotational movement of the tape reel. This reel movement minimizes the possibility of tape cinching due to sudden torque created if the case is dropped or roughly handled. The case should also provide protection for the reel flanges.

While a container that is 100 percent watertight may not be necessary, it must, nevertheless, provide a reasonable degree of water resistance. It should, for example, be capable of protecting the contents from being damaged, if, during shipping, it is left on a loading dock in the rain. While it is good practice to always secure the free end of a reel of tape, it is particularly important when preparing reels for shipping. This tabbing-down can be easily accomplished by securing the end to the next wrap on the reel with pressure sensitive tape. The tape chosen should be one that has an adhesive that will leave no residue when removed. Even though the purely physical shipping precautions are not unique to magnetic tape, but are considered good practice in preparing any item of value for transport, there is another consideration that is of prime importance. Since the tape is a carrier of magnetic information, measures must be taken to protect the reels from accidental erasure.

Tests conducted at 3M Laboratories to determine what would constitute adequate protection from stray magnetic fields of a magnitude that might possibly be encountered in transit, found that field strengths within the tape of 50 oersteds or less caused no discernible erasure.

The typical bulk degausser, purposely designed to produce a maximum external field that is used to erase tape while still on the reel, produces a field of about 1,500 oersteds. Sources of magnetic energy to which tape being shipped might be subjected would be motors, generators, transformers, etc. These devices are designed to contain their magnetic fields to accomplish some type of work. It is felt safe to assume that field strengths of more than 1,500 oersteds would not be encountered in ordinary shipping situations. Because field intensity decreases rapidly with distance from the source, the 50-oersteds point (mentioned earlier as not affecting the tape) is reached at a distance of 2.7 in. from a 1,500-oersted source. From this it can be seen that the easiest and least costly method of obtaining erasure protection is by insuring a degree of physical spacing from the magnetic source.

The shipping experience data of NET-National Educational Television over the past ten years representing well over one million individual shipments proved the losses of program to be only three or four video tape reels through possible accidental erasure from stray magnetic fields during shipments. Most accidental erasure comes from poor VTR maintenance practices, where the tape transport or head tips become magnetized. These components should be degaussed on a regular basis. A shipping container such as the "Scotch" Brand Shock-shield plastic case gives adequate protection and minimizes the potential for accidental erasure. This highly protective container can provide excellent protection against physical damage to the contents, as well.

Tape in transit may be subjected to temperature extremes. Temperatures as low as -40° F might be encountered on a loading dock in the far north or in jet flight. A temperature of 120°F could easily be encountered in a motor vehicle in the summer sun. If a reel of tape that has been subjected to extremely low temperature is put into use before it is given the time to return to normal environmental conditions, it may become physically distorted when used. When the roll is subjected to the start-stop action in use, the individual tape layers can shift due to momentum and result in severe "cinching." This can also happen if a very cold tape is dropped or handled roughly. It is recommended that incoming tape be allowed to stabilize in the operating environment for 24 hours before being put into use. Artificial means to hasten this stabilization period is not suggested.

Video Tape Storage

The temperature and humidity of the storage area should approach, as closely as possible, that of the work area. The smaller the environmental change experienced by the tape, the better will be its operation and reliability. As a general rule, the temperature should be maintained between 60° and 80°F., and relative humidity between 30 percent and 50 percent.

Protection from accidental erasure while in the storage area is easily accomplished and is, ironically, of little concern. There are two reasons why this is true. First of all, fields strong enough to cause erasure are not usually or normally found in an office storage atmosphere. Secondly, if the tape is kept as little as 3 in. away from even a strong magnetic source, this spacing should be sufficient to offer adequate protection.

The hub is the strongest and most stable part of the reel. Not only should the reels always be handled by the hub, but, in storage, they should be supported by their hubs. This is one of the two basic reasons why the reel should be returned to its container (a cardboard box, or plastic shipping case) before being placed into storage. Most storage containers are designed so that the reel actually hangs by the hub with little or no weight on the flanges. The other reason for using the storage container is obviously protection of the reel from dust and dirt.

The closed containers should be placed into storage on edge, so that the reel is in an upright position. During storage, additional protection from dust and moisture can be gained by enclosing the tape in a plastic bag. It is generally considered good practice to clean the container before bringing it out of storage so dust that has accumulated during storage will not contaminate the tape as it is being removed.

Of primary importance is the way the tape is wound on the reel, as poor winding can result in distortion of the tape's backing. It is recommended that a wind tension of four to five ounces per ½ in. of tape width as sufficient to render a firm, stable wind. This tension, while great enough, does not result in high pressures within the roll that could permanently distort the polyester backing. Backing distortion, caused by extreme pressures within the tapepack, may result if a roll of tape wound too tightly was subjected to an increase in temperature while in storage.

Just as there is the possibility of problems if the tape tension is too great, too low a wind tension can cause difficulty as well. If the wind is too loose, slippage can occur between the tape layers on the reel. This "cinching" as it is called can permanently damage the tape by causing a series of transverse creases or folds in the area that has slipped. When the roll is unwound, the surface will be wrinkled. When an attempt is made to use the tape again, the wrinkles and creases will disrupt the necessary intimate contact between the tape and the head, resulting in a series of dropouts. If, immediately after an occurrence of cinching, the tape is properly rewound, there is a possibility that the recording may be saved.

Fig. 50. Video tape "cinching."

Along with proper tension, another important consideration is wind "quality." The successive layers of tape should be placed on the reel so that they form a smooth wind with no individual tape strands exposed. A smooth wind offers the advantage of built-in edge protection. A scattered wind will allow individual tape edges to protrude above the others. Since there is no support for these exposed strands, they are vulnerable to damage.

Again, if recommendations as to the storage environment and the actual preparation for storage are followed, no serious problems should be encountered even in long term storage.

Winding and storing magnetic tape properly will lessen the possibility of damage in the event of fire as tape is a poor conductor of heat. It is sometimes possible to recover information from a tape receiving slight fire damage by carefully rewinding it at minimum tension. The information it contains should be transferred immediately to another reel of undamaged tape.

It is recommended that CO_2-type fire extinguisher for combating burning magnetic tape be used. CO_2 is clean and this type of extinguisher contains no chemicals that could harm the tape. If water reaches the tape, it will probably not cause complete failure but there may be some evidence of "cupping" or transverse curvature. The amount of "cupping" would depend on the quality of the wind and the length of time the roll was exposed. If the wind is loose or uneven, the water can more easily reach the oxide surface and the cupping would be more pronounced. The tape, of course, should be removed from the water as soon as possible.

After removal, the rolls should be allowed to dry on the outside at normal room temperature and then slowly rewound most carefully, as well provisions taken to protect the recorder equipment. This will aid the drying and will also help the rolls to return to equilibrium faster.

If a temperature increase is also incurred while the tape is water soaked, steam or at least high humidity will be present. This is likely to cause more damage than water alone. A temperature in excess of 130° F with a relative humidity above 85 percent may cause layer-to-layer adhesion as well as some physical distortion.

Plastic containers and inner plastic bags will provide better protection from water and moisture than will a cardboard box. They are more effective in keeping the water spray from a sprinkler system from reaching the tape. These containers also will offer the tape more protection from the radiant heat of a nearby fire.

To prevent fire involving magnetic tape, store tape in a noncombustible area and make sure that no combustible materials are stored in the vicinity. For maximum fire security, store magnetic tape in a fireproof vault that is capable of maintaining a desirable internal temperature and relative humidity for a reasonable length of time. Under proper storage conditions, magnetic tape has the ability to retain intelligence for an indefinite period of time. Of greatest importance is the physical perservation of the medium so that adequate head to tape contact can be maintained when the tape is again put into use, as well as the

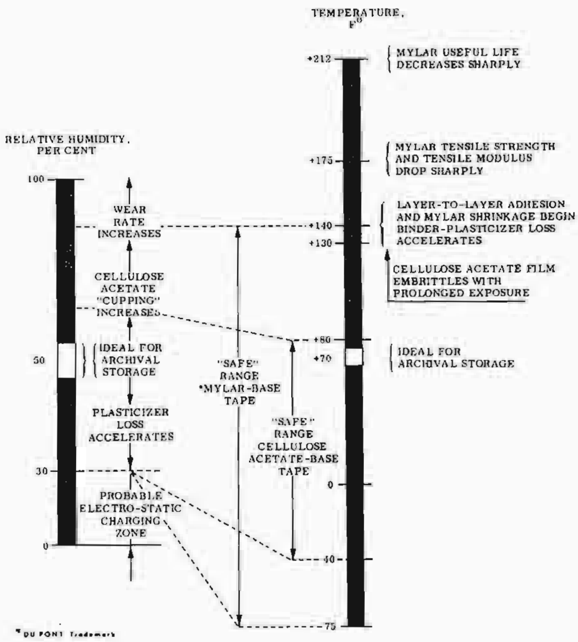


Fig. 51. The effect of environment on magnetic recording tape.

protection to the recording/reproducing equipment and video head tip life.

Signal System

All video recorders use essentially the same type of signal system since the function is identical, i.e., the varying amplitude video signal is converted into a constant-amplitude frequency-modulated signal for impression on the recording medium.

Each recording channel output is coupled by a rotary transformer to its associated video head in the video head assembly. The relative signal level applied to each video head may be selected for measurement by the RECORD CURRENT meter. Each video head thus receives the RF signal continuously from its associated record amplifier, and records that signal during the time it is moving across the tape.

Because the heads are positioned 90° apart on the head drum, and the tape is curved (by the vacuum tape guide) to contact 120° of the drum periphery, there is an interval when one head makes contact with the top edge of the tape before the preceding head loses contact with the bottom edge. During this overlap interval, identical information is recorded simultaneously by both heads. Some of this redundant information is removed in subsequent erasing and recording operations. The remainder provides an overlap period that includes approximately 2 lines of video information. This redundant information is eliminated by the switcher during subsequent reproduction. Thus, either 16 or 17 horizontal television lines of video information are reproduced from each tranverse track.

Since longitudinal tape transportation is at a velocity of 15 ips, head rotational rate is 14,400 rpm, or 240 rps, and since four tracks are traced transverse to the direction of longitudinal tape motion during each revolution of the head drum, 960 tracks are laid down at 90°33 min. during each second of recording or reproduction along 15 in. of tape. The tracks are 10 mils (0.010 in.) in width, with a center-to-center spacing of 15.6 mils. Each frame occupies ½ in. of tape; one field occupies ¼ in.

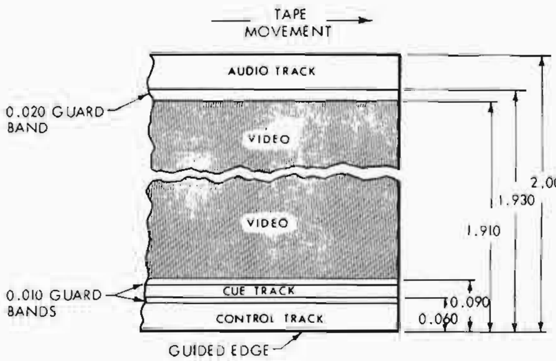


Fig. 52. Recorded track positions and widths in inches. (Width dimensions shown are maximum and tolerance of 5-Mils; guard band dimensions are fixed.)

The recorded track position and dimension are shown in Fig. 52; further reference should be made to the USA Standard published by the United States of America Standards Institute, Standard Number C-98.6.

Coincident with the beginning of each new frame of the recorded video signal, a frame pulse is recorded on the control track, and this is superimposed on the recorded control track signal. During subsequent playback, the servo system uses the reproduced frame pulses for fast framing the picture as the initial step of locking onto the tape recorded signal.

The signal system in the record mode consists of a modulator, record driver, and record amplifier, all of which serve to shape the input video signal into its final form for magnetic impression on the tape.

The frequency modulated signal is amplified by the record driver and fed simultaneously to four identical 75 ohms impedance output paths through separate coaxial cables to individual video record amplifiers in the head channel assembly. Each of these recording channels includes a pad level control.

During playback, the RF signal is recovered, and is passed through a playback network having a straight-line slope characteristic. The region of interest in the sidebands extends from the carrier frequency minus the highest modulation frequency, to the carrier frequency plus the highest

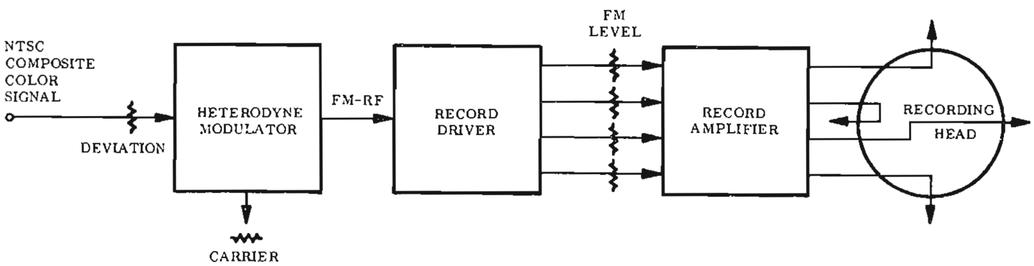


Fig. 53. Block diagram of VTR record mode.

modulation frequency. More specifically, the region of interest when operating under a high-band recording, extends from approximately 2 MHz through 15 MHz.

Modulation

There are basically three types of modulators that are presently in use, each of which has specific advantages and the selection of which is dependent upon the end use involved. All modulators have certain common features. The video input signal is usually limited by a low pass filter, so that frequencies above those that normally are encountered in that particular television standard are adequately attenuated so they do not affect the modulator. The filtered signal is then clamped to eliminate any unwanted distortion (hum, tilt, etc.).

To allow for ease in adjustment of the video recorder to exact frequencies, peak white calibration pulses are also obtained from reference crystals. The crystal output at the designated "white" frequency for the recommended practice in use is applied to the demodulator and deviation may then be adjusted in the modulator so that the calibration pulse and peak white of the picture are equal.

The improvement in video head design has made it possible to elevate the carrier frequencies at which the FM system operates. The new head assemblies permit the maximum carrier deviation frequency to extend to over 10 MHz, refer to Figs. 54, 55A, and 55B. The specific frequencies of the recommended practice have been very carefully selected to minimize interference from the harmonics of the carrier frequencies and give optimum overall signal-to-noise ratio.

Operation at high band frequencies (HB) provide greatly improved specifications of performance. Further, a better appreciation has been obtained from the theoretical considerations of the FM system employed that allow selection of

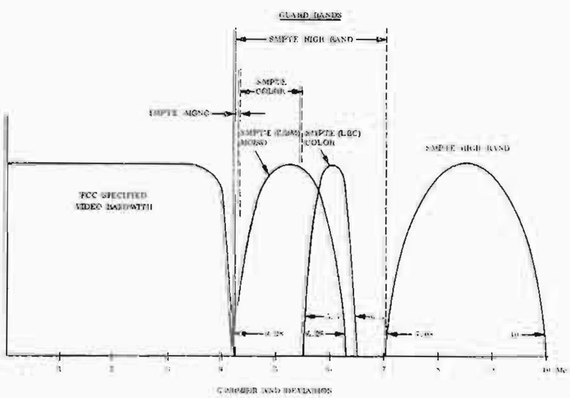


Fig. 54. High band frequency spectrum 525 line.

operating parameters in which the results can better be predicted in advance and which will permit the attaining of a high level of performance in new equipment design.

The three reference carrier frequencies utilized in video tape recording FM systems are generally known as low band monochrome (LBM), low band color (LBC), and high band (HB), the latter, the most recent, provides a single system suitable for monochrome or NTSC color signal recording. The Society of Motion Picture and Television Engineers Recommended Practice RP-6 specifies the reference frequencies of the carrier deviation and the de-emphasis characteristic, as shown in Figs. 55A and 55B.

The Modulator

There are three major categories of modulators, which operate to varying levels of proficiency. The simplest modulator consists of a multivibrator (Fig. 56) whose rest frequency is set to blanking level with deviation frequencies extending from sync tip to peak white. Present day multivibrators using transistors with very rapid switching times and carefully designed for symmetrical cancellation of video feed-through and unwanted harmonics are able to provide accurate long-time operation with very little frequency drift. The advantage of the multivibrator modulator lies in its inherent simplicity. It has few controls and requires very little adjustment. The heterodyne modulator (Fig. 57) uses a fixed oscillator, which is beat against a reactance controlling oscillator whose frequency is determined by the amplitude of the video signal. This circuit may have certain inherent advantages over the multivibrator, since the frequencies of operation are many times that of the actual carrier and deviation desired and filters may be used to eliminate unwanted spurious signals.

The most advanced modulator utilizes the dual-heterodyne principle (Fig. 58) in which two oscillators are driven in opposite directions by the video signal applied to them. The dual-heterodyne modulator takes advantage of the fact that the unwanted signals are 180° out of phase at the mixer and cancel each other out, leaving only the desired component to be amplified and applied to the tape. The mixing circuit is designed so as to obtain extreme linearity of response and very little amplitude modulation of the FM envelope.

Most modulators also have input filters to eliminate spurious signal components that lie above their acceptable frequency spectrum and pre-emphasis filters to properly shape the response characteristics. The output of the modulator is amplified and divided into four adjustable channels to permit head record current optimization. The final amplifier, which provides the

SMPTE RECOMMENDED PRACTICE RP 6–1967

Reference Carrier Frequencies and De-Emphasis Characteristics for 2-In. Quadruplex Video Magnetic Tape Recording

Introduction

In quadruplex television magnetic recording systems, the level of the reproduced signal is controlled by three factors, viz., (a) adjustment of the playback video amplifier gain setting, (b) the reference frequencies to which the video signal deviates the carrier (at frequencies not affected by pre-emphasis), and (c) the combination of the video pre-emphasis used in recording and the video de-emphasis used in reproduction. In order to achieve uniformity in playback, it is essential that video tape recordings be made in accordance with the practices defined herein. It is also essential that all signals contained in a composite recording made by electronic editing or physical splicing of the recorded tape be recorded in accordance with the same one of the practices defined herein.

1. *Scope*

1.1 This recommended practice specifies the reference frequencies to which the carrier is deviated and the associated video de-emphasis, for each of the recommended modulation practices used in 2-in. quadruplex video magnetic tape recording of U.S. standard color and monochrome television signals. (The video pre-emphasis to be used in recording is specified indirectly by requiring a flat input-to-output video response along with a specified de-emphasis in reproduction.)

2. *Practice HB*

2.1 This practice is suitable for color and monochrome signals.

2.2 Recorded carrier frequencies:

(a)	Reference white level	10.0 ± 0.05 MHz
(b)	Blanking level	7.9 ± 0.05 MHz
(c)	Sync tip level	7.06 ± 0.05 MHz

2.3 The general de-emphasis characteristic is defined in Section 5 below.

2.3.1 Values:

(a) T = 0.600 microsecond
(b) X = 1.5

3. *Practice LBM*

3.1 This practice is suitable only for monochrome signals.

3.2 Recorded carrier frequencies:

(a)	Reference white level	6.8 ± 0.05 MHz
(b)	Blanking level	5.0 ± 0.05 MHz
(c)	Sync tip level	4.28 ± 0.05 MHz

3.3 The general de-emphasis characteristic is defined in Section 5 below.

3.3.1 Values:

(a) T = 0.132 microsecond
(b) X = 4.0

4. *Practice LBC*

4.1 This practice is used for color signals.

4.2 Recorded carrier frequencies:

(a)	Reference white level	6.5 ± 0.05 MHz
(b)	Blanking level	5.79 ± 0.05 MHz
(c)	Sync tip level	5.5 ± 0.05 MHz

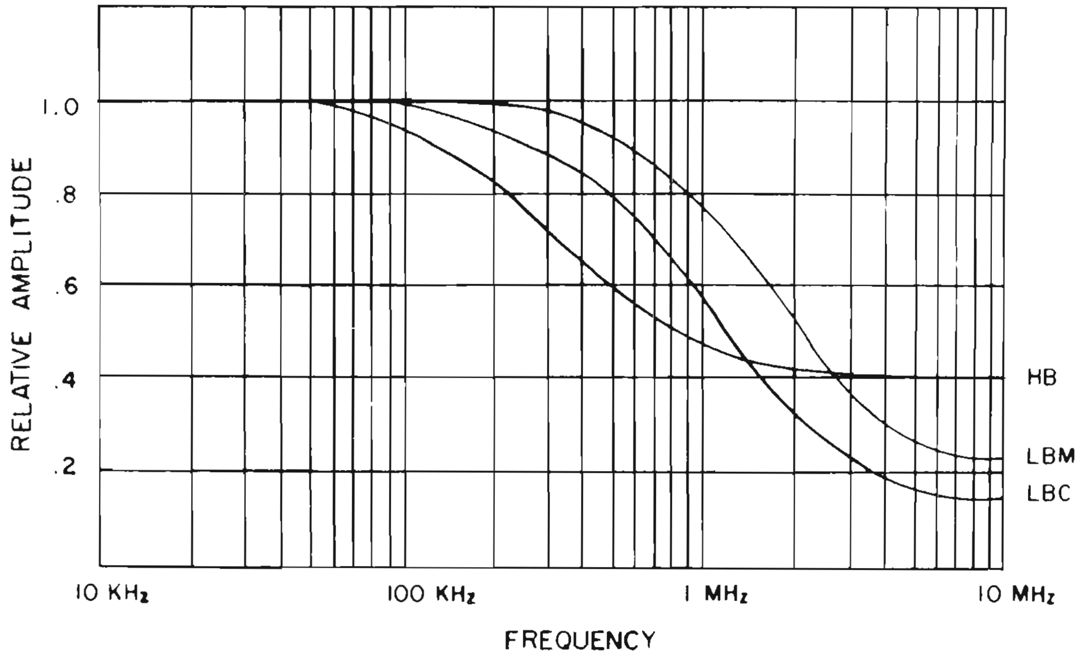
4.3 The general de-emphasis characteristic is defined in Section 5 below.

4.3.1 Values:

(a) T = 0.240 microsecond
(b) X = 6.56

Revision of RP 6–1960
Approved March 1967

Fig. 55A. SMPTE Recommended Practice RP 6-1967, Reference carrier frequencies and de-emphasis characteristics for 2-in. quadruplex video magnetic tape recording.



Graph A. Video De-emphasis Curves.

5. *De-emphasis Characteristic*

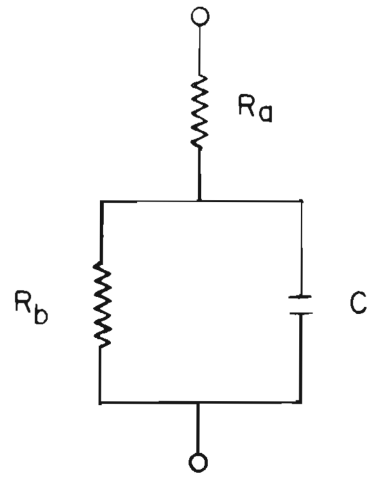
5.1 The video de-emphasis characteristic curves are described in Graph A.

5.2 The video de-emphasis curves are defined as the normalized impedance of the following two-terminal network:

$R_b = XR_a$
$T = R_bC$

where T is time constant, R is resistance in ohms, and C the capacitance in microfarads.

5.3 The de-emphasis characteristic is introduced following the demodulator in the signal playback circuitry. (To obtain a flat input-to-output video response over the passband of interest, a complementary video pre-emphasis characteristic is introduced ahead of the frequency modulator stage during recording.)



Appendix

(This Appendix is not a part of SMPTE Recommended Practice RP 6-1967, Reference Carrier Frequencies and De-Emphasis Characteristics for 2-In. Quadruplex Video Magnetic Tape Recording, but is included to facilitate its use.)

This recommended practice assumes that all pre-emphasis and de-emphasis is placed in the video portion of the signal path and that the response of the RF portion of the signal path is flat over the passband of interest. Ideally, the magnitude of the remanent flux on a recorded tape should be independent of frequency over the passband of interest, but since there is no practical way of measuring it, the most practical approach is to ensure that record current in the video heads is independent of frequency over the passband of interest.

Fig. 55B. SMPTE Recommended Practice RP-6 1967, Reference carrier frequencies and de-emphasis characteristics for 2-in. quadruplex video magnetic tape recording.

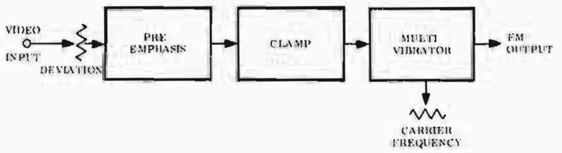


Fig. 56. Block diagram of multivibrator modulator.

current pulses to the head transducer, is also designed to give a flat current versus frequency result so that no distortion of the signal occurs as it is transferred to the tape. Any nonlinearity in this process produces unwanted modulation which is difficult to eliminate in the playback process.

Common to all modulators is the requirement that carrier frequencies remain stable so that the recovered blanking level will be of the

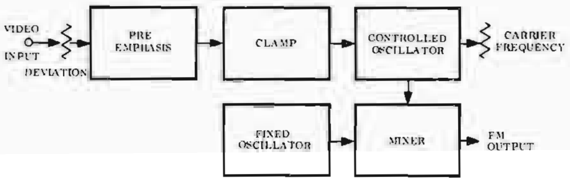
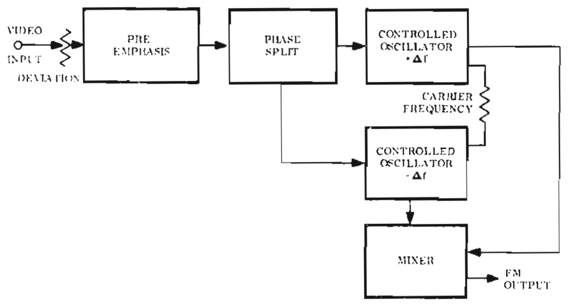


Fig. 57. Block diagram of heterodyne modulator.

same frequency on any recorded video tape. Special circuitry is usually included in the modulator, which uses a crystal reference as a source of AFC control. Blanking level frequency is compared with the crystal source and any error signal derived serves to keep the modulator at the correct frequency.

Carrier and deviation frequencies are recommended by the SMPTE VTR standards committees and when adhered to produce fully interchangeable tapes with regard to reference carrier frequencies.



Fib. 58. Blcok diagram of dual heterodyne modulator.

In determining recommended recording practices for professional broadcast usage, there are three basic considerations that must be kept in mind:

1. The recommended practice should result in as high as possible an order of performance with equipment that can be built today.

2. Its theoretical limitations should be such that future improvements in equipment and in the tape medium itself may be taken advantage of.

3. It must be capable of being accurately specified, allowing good interchangeability between tapes made on differing designs of recorders.

There are two areas to be decided in the determination of a new recommended practice: the choice of the type of pre-emphasis to be used, and the selection of carrier frequencies and deviation.

Choice of Pre-emphasis Method

It is customary in video tape recording practice to apply some degree of pre-emphasis to the signal before it is recorded on tape, followed by a like amount of de-emphasis during playback, in order to improve the signal/noise ratio of the playback signal. The process is comparable to that employed in FM sound broadcasting, in which higher modulation frequencies, containing a small portion of the total signal energy but a large portion of the total bandwidth, produce a greater amount of deviation of the carrier than that produced by low frequencies. Similarly, in video tape recording, high video frequencies, which in a monochrome picture contain only a small portion of the total signal energy, are recorded with a greater deviation than they would have had in the non-pre-emphasized case.

An obvious problem occurs with a color television signal, in that a large amount of signal energy is concentrated at the frequency of the color subcarrier which is located fairly high in the video band. The maximum level of the subcarrier determines the limit of pre-emphasis that can be employed with a color signal.

As is well known, the sensitivity of the human eye to noise in a television picture varies as a function of frequency, being in general more sensitive at low video frequencies than at high. It is important that a pre-emphasis scheme give as much improvement in signal/noise as possible at frequencies that have both a high visibility factor and are present in substantial amount in the output of a video tape recorder. Because of the triangulation effect of FM, very low video noise frequencies are not encountered and the region centered broadly around 1 MHz is the area where signal/noise improvement is most needed.

Types of Pre-emphasis

Two basic schemes of pre- and de-emphasis have been used. Video pre-emphasis in which a boost of high frequencies is applied to the video signal before modulation, and a complementary reduction of highs is applied after demodulation, while RF current (or flux) in the recording head is kept constant as a function of frequency, has been the type in most common use.

An alternate system, called RF pre-emphasis, in which the video signal before the modulator and after demodulation is unaltered but the recording head current is increased for sideband frequencies away from the carrier region, has also been used. In this method, an equalizing network in the RF playback signal path is used to reduce gain at the sideband frequencies which have been pre-emphasized. Both single-sided (in which sidebands on one side of the carrier region are boosted) and symmetrical (both sides boosted relative to the carrier) types have been proposed.

The result of boosting the amplitude of certain sidebands relative to the carrier is to increase the amount of phase deviation of the crossovers of magnetic information for modulation frequencies represented by these sidebands. A similar result would have been achieved by increasing the deviation for these frequencies directly in the modulator's output. In either case, the result is to increase the modulation index of the tape crossovers.

The information on the tape is no longer the same for the two methods when the carrier moves about, as occurs from the lower frequency portion of the video signal. With video pre-emphasis, the increase of modulation index for high video frequencies is independent of the position of the carrier. With RF pre-emphasis, the amount of increase depends on the carrier's position relative to the boost network and upon the slope of the network.

A brief comparison of the two methods follows with an eye towards determining which method would be most suitable in a newly recommended practice for the recording of both color and monochrome signals at a high level of performance. The assumption is made that the VTR to be used already has excellent performance characteristics in all respects except that of signal/noise ratio, and employs "straight-line" playback equalization.

Overall Noise Performance

The maximum amount of deviation of tape crossovers at high video frequencies is determined by the unavoidable spurious outputs, or moire, that will be produced by the color subcarrier on highly saturated colors. This in turn is determined by the spurious output "shelf" that has been selected, as will be explained later.

Certain monochrome test signals, such as the "multiburst" signal, produce similar amounts of spurious output to that produced by color signals, and are subject to the same limitation. The principal source of this spurious output from tape is in lower sidebands of the third harmonic of the carrier, which is generated by the tape's limiting action.

Therefore, the limits of the amount of pre-emphasis for any given modulation frequency, and consequently the signal/noise improvement at that frequency become the same for both video and RF pre-emphasis. For differences in signal/noise performance between the two, we must look at the way the amounts of pre- and de-emphasis vary with modulation frequency and with picture brightness level.

Noise versus Frequency

It is essential that RF pre-emphasis network does not significantly alter the record current characteristic in the carrier deviation region. It should boost sideband frequencies as near to the deviation region as possible, in order to achieve noise reduction for the more visible frequencies. This requires a sharp step in the network response, which is difficult to design and even more difficult to match in the playback path. In practice, not much improvement can be made in the critical 1 MHz region by this method.

There is little difficulty in designing video pre-emphasis networks to boost the region of 1 MHz and above, but limitations of another sort are encountered here. If the boost occurs at too low a frequency, the spikes and overshoots on transitions in the video signal applied to the modulator, which are a normal result of video pre-emphasis, will become relatively wide and will result in considerable carrier energy lying outside the normal deviation range. In addition, head switching transients and tape dropouts will develop long "tails" from the de-emphasis network. It has been found in practice that a time constant of 0-6 μsec in the network is a reasonable compromise. In a network in which an 8 dB boost is applied to the highest frequencies, this time constant gives a 6.7 dB boost at 1 MHz.

Noise versus Brightness Level

Practical networks for RF pre-emphasis methods result in a considerable variation in signal/noise ratio with picture brightness level, some 8 dB being reported in one case. The networks were chosen in this case so that the greatest improvement in signal/noise occurred at a grey level. It being argued that the eye's sensitivity is greatest at this level and with worsening results at white and black. It should be noted that the sync pulse and burst regions, which are used for control of timebase-correcting devices, do not get the most favorable signal/noise ratio.

Video pre-emphasis, when applied to a properly equalized VTR, particularly when using straight-line equalization, results in a nearly flat curve of noise versus brightness. Variations are typically under 1 dB.

Frequency and Transient Response

When the carrier is perfectly centered on a symmetrical RF pre-emphasis network, the boost of each sideband of a pair is equal, and we could expect the phase response to be symmetrical as well. Under these conditions a limiting action applied to the signal (as in the tape) will not alter the relative amplitude or phase of the sidebands and an exactly complementary network will return the signal to its original condition without distortion. When the carrier is located at some other position, however, the sidebands will be altered by limiting and the complementary network cannot return the signal to its original state. This effect causes a variation to occur in frequency and transient response as a function of brightness level. RF de-emphasis networks have usually been chosen on an empirical best-overall-result basis to minimize this effect.

As the effects of video pre-emphasis are not a function of carrier frequency, the networks employed here may be made exactly complementary to each other. It is a requirement that the modulator and demodulator be able to handle the increased deviation without incurring nonlinearities, in order for frequency and transient response to be unaffected.

Differential Gain and Differential Phase

Varying frequency and phase response with brightness level will show up as differential gain and differential phase when color signals are used. For the same reason as discussed above, good results with these parameters are more easily achieved with video pre-emphasis.

Moire in E-E Condition

RF pre-emphasis clearly has the advantage here because of the lower amount of deviation present in the modulator at the color subcarrier frequency.

Moire Off-Tape

As explained earlier, the modulation index of tape crossovers at the subcarrier frequency is the same for both systems. Spurious components caused by the tape's limiting action will, at least to a first approximation, be the same as well. There is some evidence that limiting an RF pre-emphasized signal will produce a greater increase of third and higher order sidebands than limiting a wave employing an equal amount of video pre-emphasis. If a frequency "shelf" is selected which permits these sidebands to be the major source of spurious interference, then lower moire off-tape should result from video pre-emphasis. Calculations indicate that for a modulation index of 0.2 and with 10 dB of pre-emphasis, third order sidebands are approximately 29 dB below the first order ones in the case of RF pre-emphasis, and 36 dB in the case of video pre-emphasis. In the same example, second order sidebands are treated nearly equally at a level of -16 dB relative to the first. Older recording systems, in which moire is caused by folded second order sidebands, would therefore be affected equally by either method.

Problems of Equipment Design

Because of the wider deviation of high frequencies with video pre-emphasis that must be handled by the modulator and demodulator, the achievement of adequate linearity in these units is more difficult. On the other hand, the design of the networks required in RF pre-emphasis is quite a problem, especially that of the de-emphasis network when attempting to minimize response variations with carrier position.

The exact specification of pre-emphasis is simpler with the video method because the networks involved are generally simple resistor-capacitor combinations which can be accurately described.

Considering all of the above comparisons between the two methods, it is apparent that the video pre-emphasis technique allows the highest performance level to be achieved and can be more accurately specified. The greater linearity requirements in modulator-demodulator design, it is felt, are well within the range of achievement with present-day techniques.

Choice of Carrier Frequencies and Deviation

There are a number of conflicting and interlocking requirements that are considered when choosing frequency and deviation parameters for color video tape recording, necessitating the making of many compromises. In order to sort the various considerations, the procedure for arriving at a set of frequencies is presented as a series of steps. It is to be expected that after going through the procedure, it will be necessary to return to some early steps and make trades of one parameter for another, to achieve a well-balanced recommended practice. The procedure is based on the use of video pre-emphasis.

1. *Determine the bandwidth required.* This is based on the requirements of the particular television standard being accommodated.

2. *Locate the null frequency for this bandwidth.* The overall video bandwidth of the system is determined by the output low-pass filter following the demodulator. Its rejection characteristics, beginning at the first null, are employed to eliminate spurious signals.

Consideration should be given here to the use of both complex and somewhat simpler filters. In a typical Bode-type design having four critical frequencies in the pass-band, the ratio of flat response: 3 dB down; first null frequencies is 1.0 : 1.875 : 1.375. This seems a reasonable minimum complexity of filter to require for a broadcast recorder. A filter with a somewhat more complex design, of course, may achieve a wider flat response with the same null frequency. An example of this is the filter employed in the Ampex VR-2000 recorder, in which the ratio of those frequencies is approximately 1.0 : 1.10 : 1.25.

3. *Select the "shelf" of operation.* It was seen that the higher order sidebands produced by heavy deviation at a single high modulating frequency (the color subcarrier frequency in our case) can produce spurious signals in the output, depending on the carrier frequency used. These spurious outputs arise from: (a) "negative" or folded frequencies due to the spacing between the sideband and the carrier being greater than the carrier's frequency and (b) lower sidebands (of the same order) of the carriers' third harmonic, resulting from limiting (as in the tape) at the carrier frequency, followed by filtering. Both sources produce the same spurious frequency and respond to moving the carrier in the same way.

When the carrier frequency is increased, the reduction of spurious outputs does not occur smoothly, but rather in discrete steps. This happens when an interfering sideband, producing a video output that increases in frequency at twice the rate that the carrier is moved upwards, moves into the rejection band of the low-pass filter. After this happens, the next higher order sideband will be the controlling factor, and since this sideband has a lower amplitude, the spurious output will be less. The "shelf" in the spurious output curve thus formed is not level since the output from a sideband is a function of its distance from the carrier. The lowest spurious level on a given shelf occurs when the rejected sideband has just passed into the rejection area.

Since the selection of a shelf determines which order of sideband will produce interference, it therefore determines the amount of deviation that will produce a given level of interference, and this deviation in turn controls the signal/noise ratio. While higher order shelves allow greater amounts of deviation, they also require higher operating frequencies. One must weigh, therefore, the effect of the generally lower efficiency of the head-to-tape process at shorter wavelengths, with resulting lower playback signal levels, against the signal/noise improvement of increased deviation.

Recording recommended practices for 525 line color recording in the past have used a second order shelf, that is, second order sidebands produce interference. To avoid impossibly large amounts of spurious moire in the picture, the amount of deviation had to be kept low, at a cost in signal/noise ratio.

Ability to operate at higher frequencies has led to the "high band" recommended practices, which are intended for both color and monochrome operation at improved levels of performance. The 625 line version employs a third-order shelf, and the 525 line "high band" standard, due to the narrower bandwidth and lower subcarrier frequency of 525 line signals, is able to use a fourth-order shelf.

4. *Determine the lowest carrier frequency permissible for this shelf.* This is calculated using the filter null frequency and the rejected subcarrier sideband. The lowest-swinging carrier frequency that can contain superimposed color information is placed at this frequency. For standard white-upwards deviation polarity, the blanking level of the signal, where the color synchronizing burst is located, is placed here.

5. *Calculate the high frequency (subcarrier) deviation which will produce the specified level of interference.* Several approaches to this calculation are possible. A conservative method is to add the contribution of the folded sideband of the carrier to the contribution of the (same order) lower sideband of the third harmonic, assuming limiting to a square wave and subsequent filtering out of the third harmonic itself. This represents a "worst case" simulation of the recording process.

6. *Decide on the amount of low frequency deviation.* If the deviation of the lower frequency (unpre-emphasized) portion of the signal is too large, differential gain and differential phase effects, particularly in playback, will be difficult to minimize. Too small a deviation will result in excessive sensitivity to tape dropouts and switching transients and in poor low frequency signal/noise ratio. A compromise is definitely required here. Experience has shown that a ratio of about 8 dB between high and low frequency deviation is practical. This results in low frequency deviation from blanking to white of the order of 1½ to 2 MHz in high-band practice.

7. *Select the pre-emphasis time constant.* With the ratio between deviation at low frequencies and

at the subcarrier frequency previously determined, the time constant of the video pre-emphasis network will determine the slope of the curve. A short time constant produces a sloping curve throughout the video band and minimizes the "tails" on transients. A larger time constant gives a curve that climbs quickly at relatively low and mid-frequencies and levels out at high. It will give a better weighted signal/noise ratio due to lower playback gain in the more visible frequencies. Recent choices have tended in this direction. As mentioned earlier, a time constant of 0.6 μsec has been found to be feasible.

The Playback System

The magnetic flux recorded on the tape induces a voltage in each video head as it traverses the tape during PLAY mode. This output of each head is coupled through a rotary transformer and preamplifier to its associated playback amplifier, which also provides equalization of the signal response.

Following additional amplification, the individual channels are sequentially gated by a switcher to re-form a continuous FM signal. Switching from the output of one head to that of its successor is performed during the blanking interval. In modern equipment this switching is performed on the front porch of horizontal blanking, and is triggered by a front porch switching pulse derived within the switcher. The re-formed FM signal from the output of the switcher is de-emphasized, limited in the demodulator to remove unwanted amplitude modulation, and demodulated to the form of the original composite video signal by the demodulator.

Demodulators

The most common method of demodulating utilizes the pulse count principle. There are several approaches to providing constant width pulses. Two commonly used methods are with delay lines or the use of a one shot multivibrator, to convert the FM modulated signal into its video component. The reflection of the delay line, or precisely calibrated length, provides a round-trip period for the incoming pulses, generating fixed width pulses whose repetition rate carries the wanted video intelligence. The one-shot multivibrator system varies only in that a trigger for the multivibrator is used to generate the fixed width pulse. In the case of the delay line, pulses are rectified and applied to an integrating filter. In both cases the filter attenuates the carrier and multiple carrier components and yields the video signal ready for processing. Limiters are necessary to accommodate variations in signal amplitude from the video head (Fig. 59).

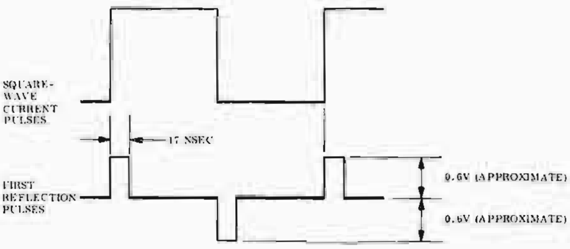


Fig. 59. Waveform of delay line constant with pulse generation.

Time Element Compensation (Amtec)

The Time Element Compensation provides for line-by-line compensation of timing errors in the composite video signal by sampling the timing accuracy of the signal once each 4 times 63.5 μsec, relative to a stable time reference. In normal operation, an internal AFC controlled oscillator is used as the reference signal. When the intersync servo system is in use, external station sync is applied. The instantaneous time difference between the sampled and reference signals is converted to a proportional voltage which in turn controls the delay time of a voltage controlled delay line in the video signal path (Fig. 60). The unit is normally inserted between the demodulator output and the processing amplifier input of the video tape recorder. The line-by-line time element compensation eliminates picture geometric distortion problems, such as skewing, scalloping, quadrature, single band essing and waterfall effects, as well as extends the tolerance from effects at physical splice points with different tapes from different sources that have minor guide block alignment differences. Time Element Compensation was not intended to eliminate the need of vacuum guide block alignment and careful attention should always be given to assure that proper guide block alignment is accomplished at the outset of all video tape recordings. The uncorrected composite video signal is shown

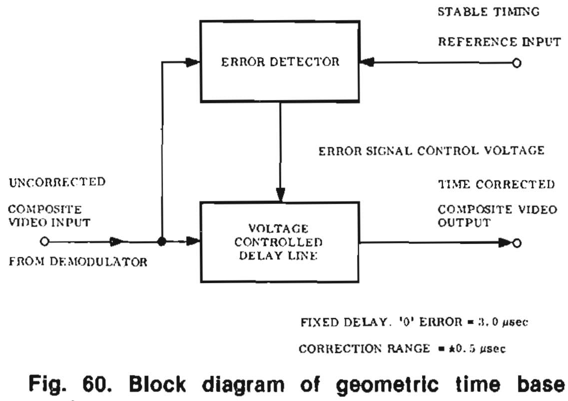


Fig. 60. Block diagram of geometric time base corrector.

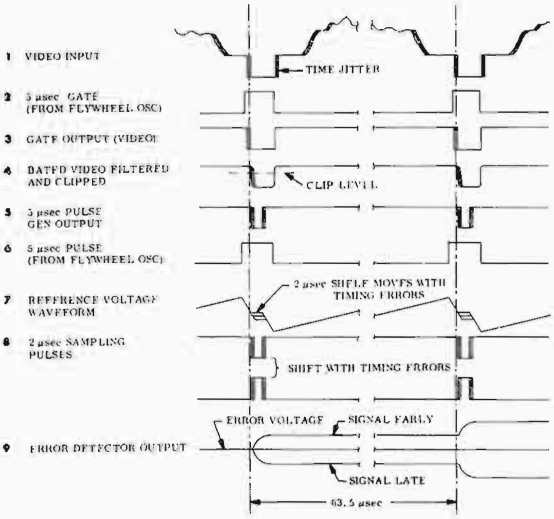


Fig. 61. Amtec waveform timing diagram.

in Fig. 61, the waveform timing diagram. The noncorrected composite video signal from the demodulator passes through a voltage controlled delay line. The noncorrected incoming sync information is routed to the error detector (Waveform 5) where it is time compared with a stable timing reference signal (Waveform 7).

The error detector produces a bias voltage that is approximately proportional to the fourth power of the timing difference between the compared signals (Waveform 9). This bias voltage becomes a control voltage that is applied to the voltage controlled delay line, causing the latter to insert a varying delay affecting the lines of video information and partially correcting the horizontal sync pulses. The inserted delay is the precise opposite of the original timing error in the reproduced signal and thus causes error cancellation. The time corrected composite video signal is then delivered to the processor.

Fig. 62 shows the functional diagram. The error detector is primarily concerned with the time (or leading) edge of the horizontal sync pulses contained in the incoming composite video signal. For this reason the horizontal sync pulses are clamped to a reference voltage and routed to a 5 μsec gate (Waveform 2) while enroute to the error detector. The gate allows approximately the last 0.75 μsec at the front porch and approximately 4.25 μsec of the sync pulse to pass (Waveform 3) to the 2 μsec pulse generator.

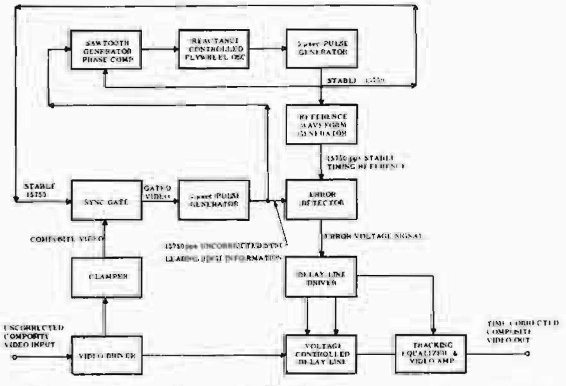


Fig. 62. Time element compensator functional block diagram.

The pulse generator produces a rectangular pulse of 2 μsec duration (Waveform 5). It is formed by the leading edge of the sync pulse and the output is therefore timed by sync. This is the signal that the error detector time compares with a stable timing reference for the derivation of the error (or bias) voltage.

The error voltage is developed during the interval of each pulse, at the horizontal rate, and is the bias that is ultimately applied to the voltage controlled delay line. During the interval between sampling pulses, the bias voltage is held constant by the charge on a capacitor. In this way the line of picture information following each sync pulse is held at the corrected time until the next sampling pulse occurs (Waveform 9). No additional sampling or correction takes place during the visible portion of the picture.

During the "picture straightening" mode the error signal contains only the ac, or high rate-of-change timing error information. The dc or low rate-of-change components are not required for the correction of picture geometry.

As previously stated, the timing coincidence gate and relay driver receive the noncorrected incoming horizontal sync information from the sampler/driver. It also receives the *long-term average* of the rate of incoming horizontal sync from the 5 μsec pulse generator. When the two signals are in coincidence, the timing coincidence gate and relay driver energize the relay. Under this condition the connected circuit time constant will be the one selected by the manual switch position, and the correction rate will be either "normal" or "fast." The timing coincidence gate also recognizes the condition of noncoincidence of the two signals by causing the relay driver output to fall to the minimum, deenergizing the relay. This causes the insertion of the "very fast" time constant correction rate in the circuit, and disables the gate.

The 5 μsec time averaged pulse (Waveform 2) is routed through a switch to the reference waveform generator whose action was described above. The shaped sawtooth (Waveform 7) is routed to the error detector, where it is phase compared with the 2 μsec noncorrected sync pulse sample (Waveform 8). It is here that the primary error signal is derived, that ultimately biases the voltage controlled delay line (Waveform 9).

The output from the error detector is routed to the control voltage amplifier (Board 5) which provides push-pull outputs. This output is applied to the control voltage driver on Board 4. The signal is then routed to a voltage controlled delay line. The delay line is controlled by the error bias from the error detector which is amplified by the control voltage amplifier and control voltage driver. This output from the control voltage driver is applied to silicon junction capacitors that serve as the delay control elements. The total delay is 3 μsec, variable through a range of approximately ± 20 percent.

The driver amplifier causes the error bias to vary approximately as the fourth power at the output voltage from the error detector. At the output from the driver amplifier, the error bias is converted to a control voltage whose amplitude overcomes the nonlinear characteristic of the voltage controlled delay line, and whose polarity precisely coincides with that of the error detector output.

The video bandpass characteristics of the voltage controlled delay line vary with changes in delay and must be compensated. The tracking equalizer provides the required compensation. Its balanced input is connected to the push-pull bias voltage output from the control voltage driver, and its single-ended input is received from the output of the voltage controlled delay line.

The tracking equalizer exhibits variable response characteristics that are the mirror image of those exhibited by the delay line, and thus cause the overall bandpass of AMTEC to be flat to 6.0 MHz/sec throughout its range. This signal passes through the video output stage to the phase comparator from which it is routed to the processor in the videotape television recorder system.

During the Inter-sync mode, the pulse advancer produces a 5 μsec pulse that is derived from the leading edge of reference sync, but is advanced in time, by the same interval, that tape read-out is advanced by the action of Inter-sync. This pulse is applied to the reference waveform generator, and replaces the *long-term average* sync pulse that is used during the picture straightening mode. Under either mode the gate driver (and the gate) continue under the control at the 5 μsec long-term average at the rate of incoming horizontal sync. The output of the reference waveform generator is used to correct the sync timing errors contained in the incoming video signal, but corrects them to coincide with the external reference instead of the long-term average of incoming horizontal sync.

The reproduced picture elements must remain stable with respect to the corresponding picture elements of another video signal during the "Inter-sync" mode. Under these conditions, the reproduced signal is time compared with an external timing reference instead of with an average of the horizontal sync contained in the uncorrected composite video. The external timing reference is normally the local station sync generator.

Overall System Description

Fig. 63 shows the System Block Diagram. The incoming noncorrected composite video signal from the demodulator is routed to the video amplifier, which adjusts the signal level and impedance to the requirements of the voltage controlled delay line.

The signal is also routed by two converging paths through a clamped video stage to the sync gate. By the way of the first path, the signal passes through a video amplifier to the clamped stage. By the second path horizontal sync is stripped from the composite video signal and passed to the clamp pulse generator which produces push-pull clamp pulses that are applied to the clamped stage.

The 5 μsec pulse generator (horizontal rate) controls the action of the sync gate, which allows a 5 μsec sample of the noncorrected sync pulse, and its timing edge, to pass through the low-pass filter and a clipper stage en route to the 2 μsec pulse generator whose output is formed by the sample.

The 2 μsec (non-time corrected) pulse is routed to one input of the error detector and to the reference waveform generator. The latter generates a stable sawtooth waveform at the average horizontal rate, and adds the voltage received in the 2 μsec pulse to form a 2 μsec step on the slope (Waveform 7). Because the peak-to-peak descending slope time is 5 μsec, the 2 μsec step appears at a higher voltage level when the pulse is early, than when it is late.

The noncorrected 2 μsec pulse is also routed to the sampler/driver. The latter provides two out-

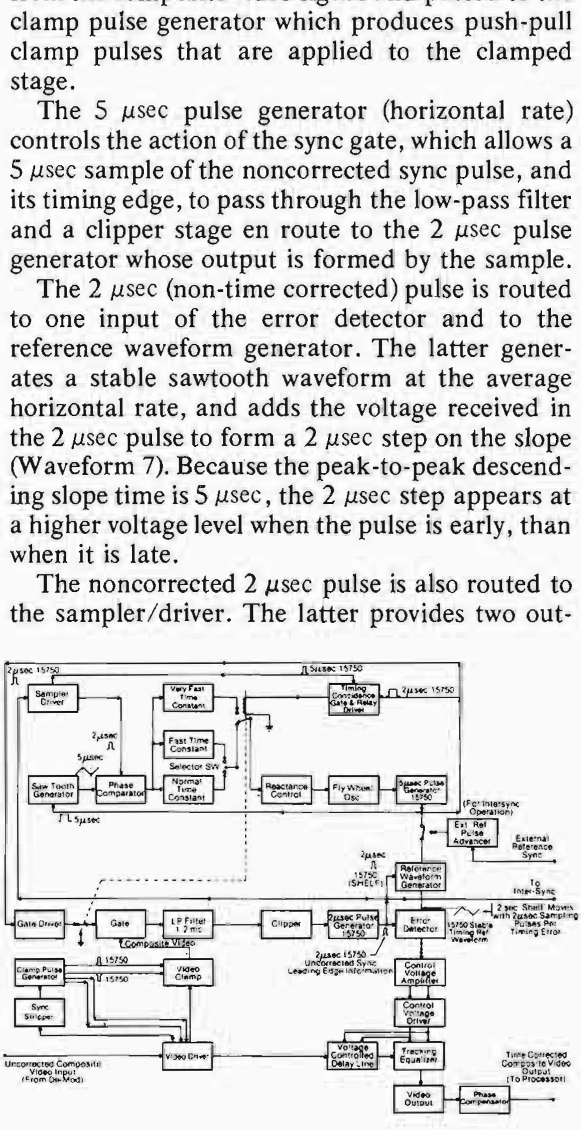


Fig. 63. Amtec system block diagram.

puts, one of which is routed to the timing coincidence gate and relay driver, the other to the phase comparator. The latter also receives a 5 μsec sawtooth waveform from the sawtooth generator which is triggered by the signal from the 5 μsec pulse generator. This signal is the long-term average of the rate of incoming horizontal sync, and is established in the reactance-controlled flywheel oscillator loop. The resulting phase comparator output voltage is routed to the inputs of 3 selectable time constant circuits, that are graded "normal," "fast," and "very fast." Manual switch selection offers the choice between "normal," and "fast;" supplementary relay switch selection adds the choice of "very fast" to the particular time constant selected by the manual switch position. One of the time constants is always in the circuit, and modifies the comparator output to the reactance control circuit of the flywheel oscillator.

The filtering action of the time constant circuits eliminates high rate-of-change components in the reactance control voltage, which causes the oscillator to remain locked in frequency and phase to the long-term average of the incoming horizontal sync rate. Because the output of the 5 μsec pulse generator is formed from the output of the flywheel oscillator, the pulse is timed at the long-term average rate.

Direct Color Recovery Process

The chrominance portion of the NTSC color television signal is modulated on a 3.579545 MHz subcarrier that has a frequency tolerance of ±10 Hz, a maximum rate-of-change of 0.1 Hz, and a phase tolerance of ±10 electrical degrees.

Analysis of these factors, together with the standard (nominal) relative head-to-tape velocity of 1,500 ips used in the television recorder/reproducer, will show that during reproduction the equivalent instantaneous position of the video heads relative to the tape must be maintained within ±11.7 microinches of their equivalent instantaneous positions during the making of the recording.

The first step toward this precision of head phase control is taken by Inter-sync which can achieve an accuracy of ±150 microinches. The second step is taken by Amtec, which can achieve an equivalent accuracy of ±75 microinches. The direct color process reduces the residual error to an equivalent time error of 0.005 μsec (5.0 nanoseconds) or less.

The recovery of color signals from magnetic tape began with typical timing errors of 10 μsec, and an equivalent head position error of 0.015 in. The reproduced chrominance signal required separate processing to stabilize the subcarrier.

While domestic color receivers could reproduce color pictures from the signal, certain of the principal properties of NTSC color were lost. For example, there was no frame interlace of luminance with chrominance components, and instead of the use of a band sharing principle, it was necessary to assign the lower part of the band to luminance, and the upper to chrominance information.

Colortec takes over in the reduction of head-to-tape timing errors where the successive processes of Intersync and Amtec terminate. While the circuit of Colortec bears some resemblance to that of Amtec, there are important and significant differences.

Colortec uses an electronically controlled variable delay line, as does Amtec, but its control signal is the result of phase comparison of the reproduced 3.58 MHz color burst with the 3.58 MHz reference subcarrier. The video input signal is received from the Amtec output which may typically contain residual timing errors of 0.05 μsec referred to the subcarrier. This is equivalent to a head position error of approximately 75 microinches.

Occasional reference to the accompanying block diagrams, Figs. 65, 66, and 67 will be an aid to clarification of the discussion of the Colortec Direct Color Process that follows.

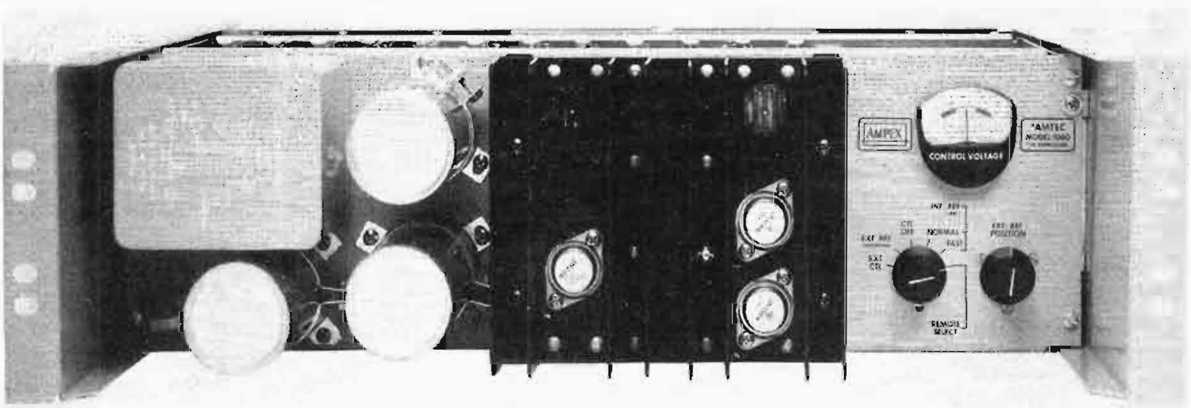


Fig. 64. Amtec time element compensator.

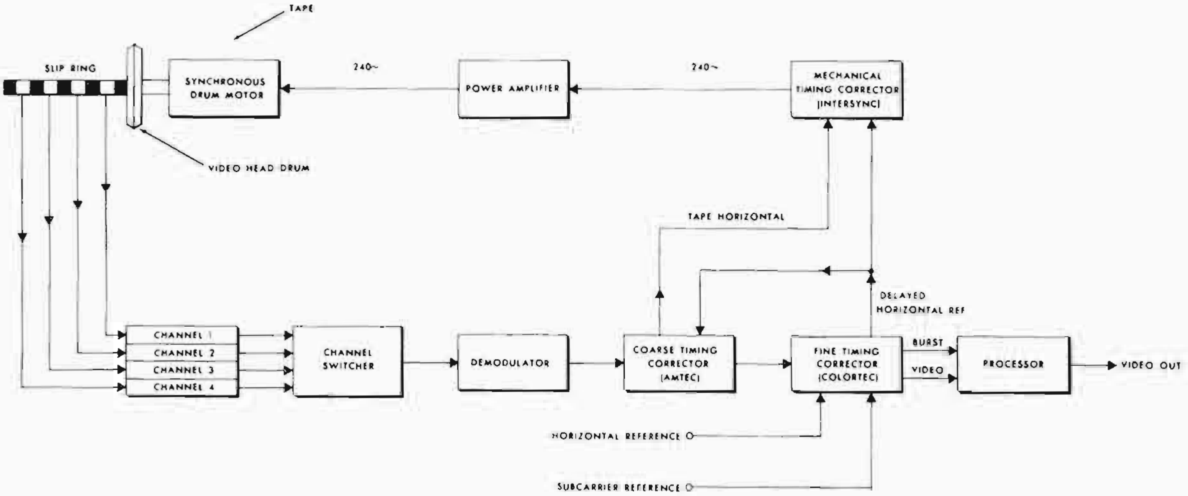


Fig. 65. Simplified reproduce mode.

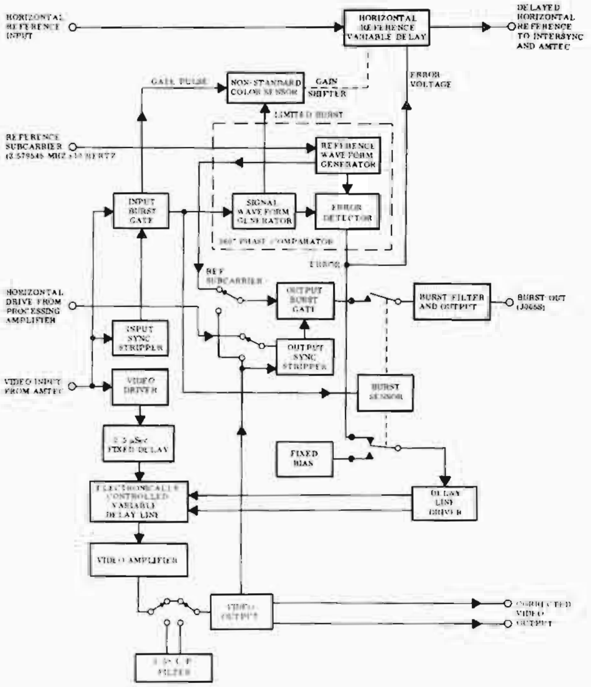


Fig. 66. Colortec simplified block diagram.

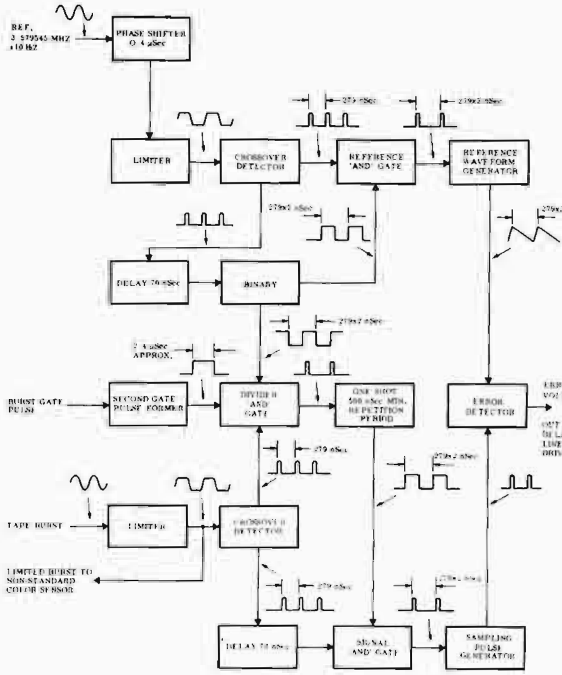


Fig. 67. 360° phase comparator.

Horizontal sync is stripped from the reproduced composite video color signal, and its trailing edge used as the timing reference for the operation of the burst gate. The burst gating pulse begins 0.5 μsec following the trailing edge of sync and has a duration of 2.4 μsec. Thus, the burst gate allows only the burst portion of the blanking interval to pass through to the signal waveform generator. The latter produces pulses from the negative-going crossovers of reproduced burst. The repetition rate of the pulses from the output of the signal waveform generator is one-half the burst frequency. These pulses are applied to one input of the error detector.

The 3.579545 MHz ($\pm$10 Hz) reference subcarrier signal is applied to the reference waveform generator, which produces a linear sawtooth waveform that is in-phase with the reference, but whose repetition rate is one-half of its frequency. This sawtooth is applied to the second input of the error detector.

The pulses received from the signal waveform generator sample the slope of the sawtooth signal received from the reference waveform generator, thus deriving an error voltage whose amplitude is proportional to the phase difference of the compared signals.

This phase comparison is repeated during each burst period; the successive error voltages thus derived are maintained until the next burst interval occurs. The error signal output therefore has continuity, but is corrected during each successive burst interval.

The error detector functions as a 360° comparator, referring to Fig. 68. This unusual attribute is made possible by causing the reference sawtooth waveform to occur at one-half the subcarrier rate, which in turn permits the occurrence of two crossover pulses during one reference waveform period. Binary logic insures that the selected sampling pulses are within the limits of the reference sawtooth slope.

By virtue of this sampling range, the comparator action permits stabilization of chrominance in the reproduced color signal despite the presence of system mechanical timing errors that exceed the correction range of Amtec. Thus, the corrected video signal that appears at the output of Colortec is held in phase with the reference, and home receiver will not lose color lock during the passage of a tape splice, vertical roll, or a large timing error, such as those that might be present in a non-standard color signal.

Following push-pull amplification by the delay line driver, the error output signals are applied to the + and − inputs of the electronically controlled variable delay line.

The video input signal, from Amtec, is also applied to the video driver which in turn drives the 2.4 μsec fixed delay line. This fixed delay permits reproduced burst to be phase-corrected by the control voltage that is derived from its phase comparison with the reference. The output of the fixed delay line is applied to the remaining input of the electronically controlled variable delay line, where the final time correction required by the direct color process is made.

Following amplification by the video amplifier, the time-corrected video signal is normally routed directly to the Colortec output stage. However, a 3.58 MHz low pass filter may be inserted by means of a switch if a nonstandard color signal departs beyond the corrective capability of the system. This filter removes all color subcarrier components from the color signal.

Because the processing amplifier removes burst from the back porch of sync, it is necessary to reinsert burst in its composite video output. Colortec provides for this by stripping burst from its corrected video output by means of a process that is identical with that applied initially to incoming video. This recovered burst is filtered to remove some of the unwanted noise, and remains fully representative of the original recorded burst in terms of amplitude and phase. It is this reconstituted burst that is routed to the processing amplifier.

If preferred, Colortec also offers the alternative of inserting totally new burst that is derived from the reference subcarrier. This new burst will contain less residual noise, and have a more symmetrical form but may not be truly representative of the original tape signal-to-burst relationship.

The incoming horizontal reference signal is applied to one input of the horizontal reference variable delay; the control voltage applied to the other input is the previously mentioned error signal derived by the error detector which controls the delay of the output sync. Delayed horizontal reference sync is routed to and used to govern the Intersync and Amtec units in the television recorder system.

Delayed horizontal reference sync makes it possible to operate the electronically controlled variable delay line near the middle of its range. The delayed sync, delays the timing of the video signal received to Colortec, and tends to maintain midrange operation regardless of the phase relationship of subcarrier-to-sync.

The scanning frequency of the NTSC color signal is 2/455 of the burst frequency. The record/reproduce systems that preceded NTSC color could not preserve this relationship, which resulted in timing difference between reproduced burst and reproduced sync amounting to as much as $\pm 20 \mu$sec.

In order to reproduce such nonstandard color signals, the horizontal reference timing of Colortec is switched to another mode wherein feedback gain is increased, the normal reference horizontal delay is changed from 2.5 μsec to 30 μsec, and the higher frequency components of the timing error are allowed to modify the reference timing. These modifications of playback mode permit the successful reproduction of second generation nonstandard color recordings that meet the rate-of-change of sync specified by the FCC for monochrome signals.

In the automatic modes Colortec senses the type of video signal that is present, i.e., whether it is monochrome, standard NTSC color, or nonstandard color.

When a monochrome signal is present, a fixed voltage is applied to the electronically controlled variable signal delay line, and Colortec then functions as a unity gain amplifier.

The incoming 3.579545 MHz (± 10 Hz) subcarrier is routed through a variable phase shifter, a limiter, and to a crossover detector. The latter passes only the negative-going axis crossovers of the subcarrier, resulting in a train of pulses whose leading edges are spaced at 279 nanosecond intervals.

The crossover detector output is routed by two paths. By one path it is applied to an input of the reference AND gate; by the other it is routed

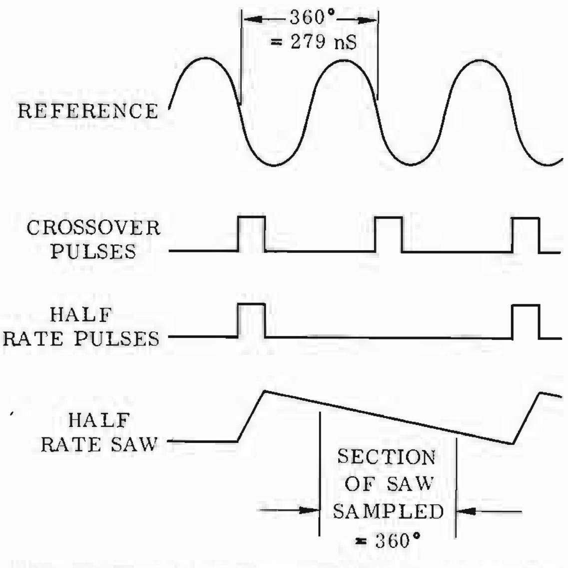


Fig. 68. Waveform diagram half-rate 360° comparator.

through a 70 nanosecond delay and then to a binary frequency divider.

The binary output is a symmetrical square wave whose repetition rate is one-half that of the subcarrier. Thus its leading edges are separated in time by 558 nanoseconds (279 nanoseconds x 2). This output is applied to the other input of the reference AND gate, and to the divider AND gate. The reference AND gate opens only when there is coincidence of the gating pulses from the crossover detector with the square wave from the binary. Its output is thus a series of pulses whose leading edges are separated in time by 558 nanoseconds, and whose widths are those of the gating pulses from the crossover detector.

The reference AND gate output pulses are applied to the reference waveform generator, which forms them into a linear sawtooth waveform whose wavelength is 558 nanoseconds. This sawtooth is applied to one input of the error detector.

Burst gated from the tape video signal is filtered, limited, and applied to a second crossover detector. The output of the latter is a series of pulses whose leading edges are separated in time by 279 nanoseconds. These pulses are routed through a 70 nanoseconds delay to the signal AND gate.

The crossover detector output is also routed to the divider AND gate. The divider AND gate requires the coincidence of three signals to open. The third signal is the burst gate pulse which is shaped to a pulse of 2.4 μsec duration by the second gate pulse former.

The output of the divider AND gate is a series of pulses whose leading edges are separated 558 nanoseconds in time, and which continue to occur for a 2.4 μsec period. These pulses trigger a 500 nanoseconds (minimum repetition period) one-shot multivibrator whose output is a series of 200 nanoseconds, pulses whose leading edges occur 558 nanoseconds apart.

Automatic Chroma Control

Automatic chroma provides for automatic playback equalization, functions more rapidly and accurately than can be performed manually, and eliminates the need for constant operator attention during playback.

Color saturation errors can occur in several forms: there are fixed saturation errors, differential gain, and nonuniformity of chroma level within a head band during playback due to variation in head-to-tape contact pressure.

The autochroma functions by measuring the amplitude of the color burst from a given head channel, and electronically adjusting the playback equalization of that channel to provide compensation. This is accomplished simultaneously and continuously over all four channels, controlling the response to provide a constant burst level in the signal output and ultimately therefore a constant chroma level. Additional manual adjustment is provided to compensate for cases where the ratio of burst to picture chroma was recorded incorrectly.

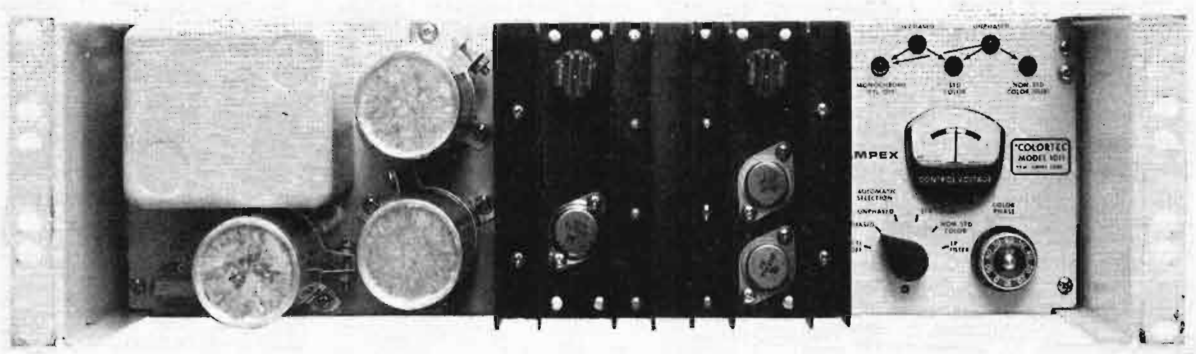


Fig. 69. Colortec.

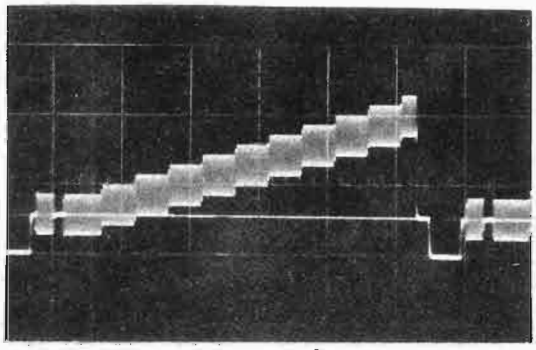


Fig. 70A. Differential gain test signal.

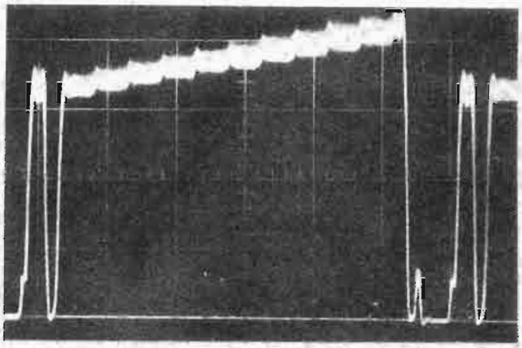


Fig. 71A. Off-tape, differential gain present.

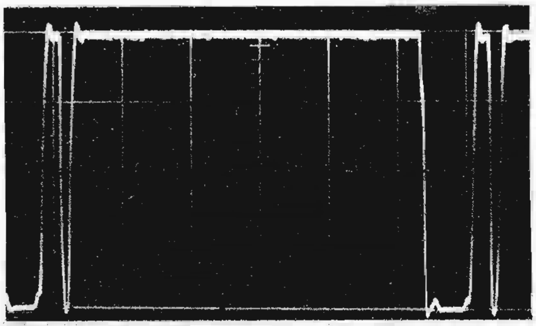


Fig. 70B. Detected subcarrier of test signal.

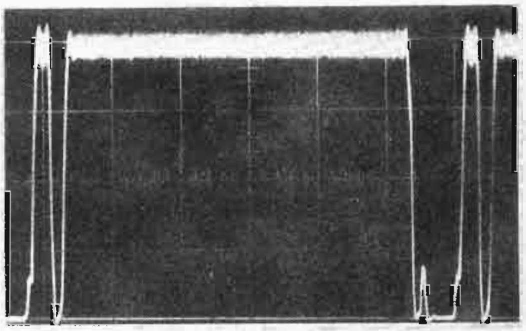


Fig. 71B. Off-tape, correctly adjusted.

Differential gain, or the dependency of chroma gain upon luminance level, could be caused by deficiencies in the modulator, demodulator, and various amplifiers in the video signal path. Fortunately, improvements in design with transistor circuitry have largely eliminated this problem. A far more important cause of differential gain is in the incorrect equalization of playback response. There are usually several combinations of settings of the various playback equalizing adjustment that will result in an apparently correct chroma level, but not all of these combinations will give a constant chroma gain throughout the brightness range. It is important that the adjustment settings providing the lowest differential gain be obtained.

The simplest and most accurate way to determine these settings involves the recording of a standard stairstep-plus-subcarrier test signal such as is shown in Figs. 70A and 70B. Deviation is adjusted so that the steps without subcarrier cover the full range of blanking to white. The subcarrier level is then made to be approximately equal to the standard burst level. On playback, the signal is fed first to a low pass filter to remove all but subcarrier components, followed by a detector, where the output is observed on an oscilloscope synchronized at horizontal rate.

The playback equalizers are adjusted for a flat waveform whose height is equal to that produced by the signal before recording, as in Fig. 71A and 71B. If differences between head channels are seen, the head resonance compensating controls may be adjusted slightly to trim out the differences. It should be kept in mind that the adjustments described are primarily to deal with effects in the playback machine itself. Any properly optimized recording should produce identical results, and therefore it is not required to repeat this test more frequently than on a routine maintenance basis, preferably when heads are optimized and resonance compensation is checked.

Automatic Velocity Compensation

The velocity compensator, in conjunction with the Colortec and Amtec, compensates for minor variances in head-to-tape velocity during playback of tapes and enhances to a large degree interchangeability by eliminating color hue shift banding effects. The automatic velocity compensator's function is to make corrections in the output signal of the VTR playback which corrects for the effects of minor difference of vertical guide block alignment, small differences in radius of the guide, differences in the contour of the guide as a result of accumulation of oxide particles, and to some degree in the amount of guide vacuum. Velocity error is a result of differences between the relative head-to-tape velocity during record

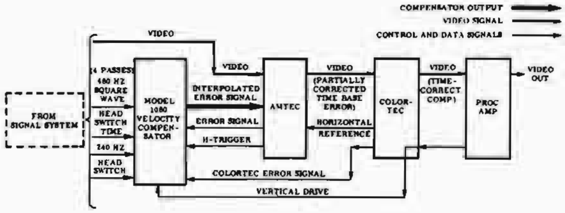


Fig. 72. Overall system functional block diagram.

and that during playback. Excessive velocity error results in a noticeable shift of hue progressing from left to right in the picture. The overall system functional diagram is shown in Fig. 72.

The compensation process adds a corrective velocity-error component to the Amtec waveform. However, the video signal is not affected since it does not pass through the compensator.

One complete rotation of the head drum covers 64 horizontal video lines, with each of the four heads covering 16 lines during its excursion across the tape. The velocity compensator is based on the assumption that the velocity error in each line is generally repetitive during successive head rotations.

The Amtec and Colortec accessories supply the compensator with time-base error indications (as voltage levels) for each line of video. The compensator algebraically adds these error indications, then stores each sum in a specific memory capacitor as a voltage level.

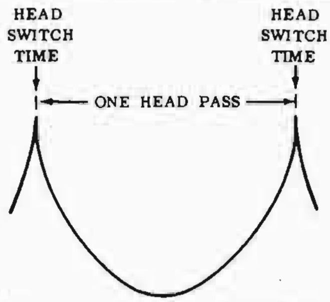
Capacitor loading proceeds repetitively for 500 μsec, building up in each capacitor a voltage level analogous to the time-base error changes occurring throughout write time. For readout, the stored voltage levels are sequentially timed into a temporary storage capacitor, which then drives a ramp generator. The generator provides a ramp proportionate to the voltage level previously stored in the capacitors.

The proportionate ramp is added to the Amtec error signal and returned to the Amtec delay line, which then provides a corrected velocity error signal to the Colortec accessory. The final Colortec output is then a time-corrected, composite video signal which is applied to the processing amplifier.

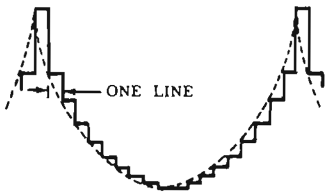
Because the proportionate ramp must begin as the Amtec starts to process a line of video, a horizontal (h) trigger signal is brought into the velocity compensator. Eight other signals are also supplied to the velocity compensator from external sources. The processing amplifier supplies one, a vertical signal which is extended and then used to inhibit the write function of the compensator during the vertical interval.

The seven other signals are parts of the head decoder timing: a 480 hertz square wave from the signal system and four 240 pulse-per-second signals from the signal system (tach, tach +90°, inverted tach, and inverted tach +90°). The signal system also provides head-switching time and head-switching information for the line-decoding function of the velocity compensator.

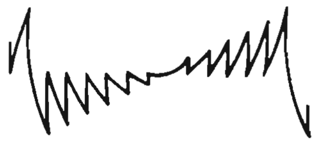
Fig. 73 shows a representation of the actual time-base error caused by guide-height misadjustment (Detail A) during one head pass, the line-by-line correction waveform of the Amtec and Colortec (Detail B), and algebraic resultant of these waveforms (Detail C). Ideally, these signals should cancel; however, since the Amtec and Colortec correct on a line-by-line basis, and not continuously, an error component is still left. This residual error component is velocity error.



Detail A. Actual Time-base Error Waveform (Error caused by misadjustment of vaccum guide height)

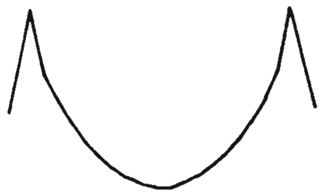


Detail B. Combined Amtec and Colortec Error Waveforms showing line-by-line correction



Detail C. Velocity error component remaining (A - B)

Detail D. Simulated velocity error signal generated by velocity compensator



Detail E. Output of velocity compensator (D + B)

Fig. 73. Derivation of Amtec delay line driving signal.

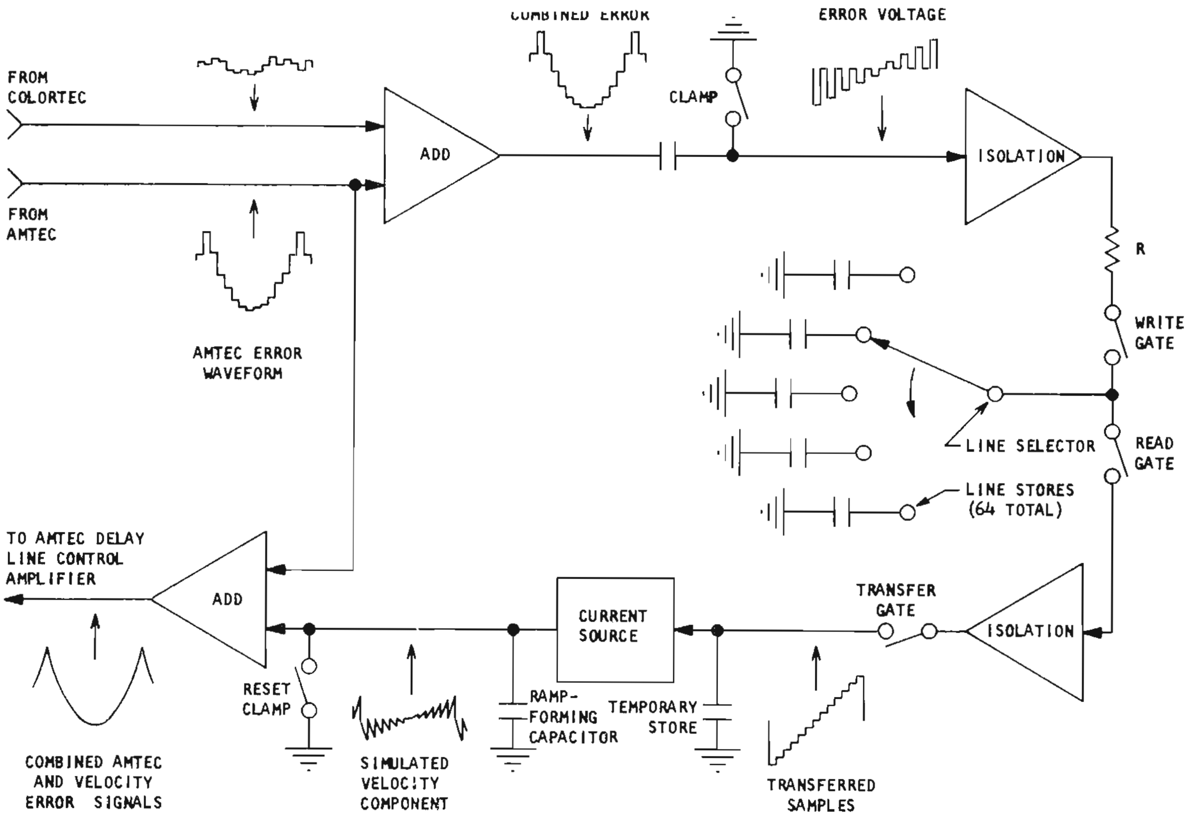


Fig. 74. Basic block diagram—velocity compensator.

The velocity compensator generates a simulated velocity error waveform (Detail D), and adds it to the actual Amtec error waveform. When algebraically added, these signals result in an error signal which very closely approximates the actual error waveform (Detail E). This signal is used to drive the delay lines in the Amtec accessory, and allows the Amtec to pass on a video signal virtually free of geometric and velocity errors. The basic block diagram of the velocity compensator is shown in Fig. 74.

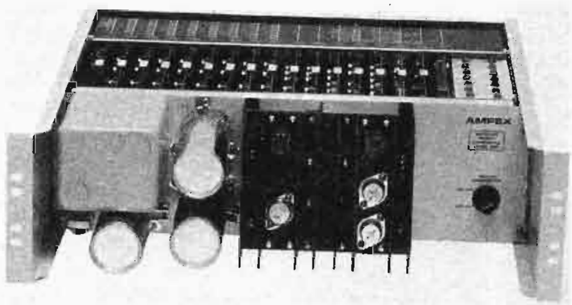


Fig. 75. Automatic velocity compensator.

Video Processing Amplifier

The processing amplifier provides for seven operating controls as shown in Fig. 76.

The primary purpose of the processing amplifier is that of providing a noise-free composite video output signal that is suitable for broadcast purposes. This purpose is accomplished by two principal groups of functions. The first group includes those common to the requirements of monochrome or color operation; the second group includes those specifically required for color operation.

In the first group, the processing amplifier clips noise and switching transients from incoming sync, reshapes the pulse form, and recombines it with video and blanking to produce a composite video signal of broadcast quality. If noise content is excessive or pulse width is incorrect, the operator has the option of replacing incoming horizontal sync with new sync generated within the unit.

The processing amplifier derives and provides switching pulses which cause video head switch-

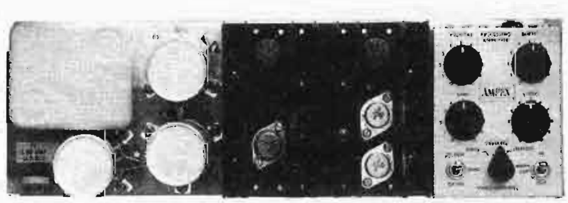


Fig. 76. Processing amplifier.

Fig. 77. Processing amplifier control panel.

ing to take place on the front porch of sync, thus avoiding any ambiguity in the timing edge of horizontal sync.

During monochrome operation the processing amplifier limits noise to a fixed level in the video portion of the signal by preventing negative noise peaks from extending below the blanking level. During color operation the signal is similarly processed, but the 3.58 MHz burst frequency, on the back porch of sync, is allowed to pass without change.

The processing amplifier eliminates all noise that occurs during the vertical and horizontal blanking intervals.

The video, blanking, and sync levels controlled by the processing amplifier are adjustable at the unit, or from a remote location.

In the second group, for color operation, the processing amplifier places color burst on the back porch of sync. In the Colortec-equipped system, the operator has the choice of retaining the original burst, or of replacing it with new burst derived from the 3.58 MHz reference, and provisions are made for a vertical drive signal required to operate the burst gate in the Colortec unit.

SIGNAL DROPOUT COMPENSATION[3]

Physical Nature of Dropouts

The discussion of full-color substitution starts properly with an analysis of what a dropout actually is. When a particle in the videotape coating interferes with head-to-tape contact, or a void exists in the oxide due to a scratch, a reduction in the recorded or reproduced signal can be caused. As a result, the normally constant FM signal used for video recording becomes amplitude modulated to a degree which depends on the signal loss produced by the particle or scratch. When this degree of amplitude modulation cannot be accommodated by the playback limiter circuits of a recorder, a momentary streak appears in the reproduced picture.

Most dropouts caused by scratches result from handling at the user level and produce diagonally organized groups on the television screen. Multiple-generation tape copies contain defects originated in previous recordings and thus multiply the incidence of visible dropouts.

High-band recording, by its very nature, increases the incidence of dropouts over that for low-band operation. Over half of the recorded energy is in the first 1/10 wavelength of penetration into the recording medium. Since the wavelength is shorter in high-band recording, the energy is closer to the surface of the tape and therefore the recording is more susceptible to the surface contamination effects which produce dropout.

Dropout streaks in a reproduced picture may be either light or dark, or any color, depending on the exact transient nature of the video signal as well as other instantaneous machine factors. Furthermore, should defects occur during the period of video clamping or color burst, polarity of the resulting effect becomes unpredictable.

In general, dropouts are most annoying when they appear as bright streaks on a predominantly dark or low-key background. It should be kept in mind that more defects may be apparent to the viewer's eye as picture composition varies, even

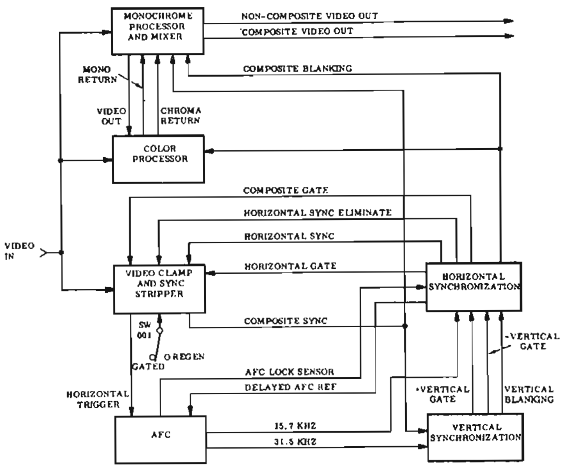


Fig. 78. Processing amplifier, simplified block diagram.

[3]The following material is from "Dropout Compensation for High-Band Color" by Fred J. Hodge, Video Projects Manager, Mincom Div., 3M Co., Camarillo; in Broadcast Engineering Feb. 1968.

though tape quality and machine constants remain unchanged.

Electrical Nature of Dropouts

A signal dropout in a video recording system consists of an abrupt negative amplitude-modulated notch in the carrier. The effectiveness of limiter circuitry in the demodulator can have marked effects on how clearly this AM component is reproduced through the FM system.

An examination of the playback carrier prior to its introduction into the limiter stages discloses that, with most samples of tape, the signal contains an entire family of dropouts of different amplitudes and durations. The change in amplitude of the carrier during these momentary events may range from a reduction of only a few percentage to a complete failure. A majority of these dropouts are never seen, as their effects are absorbed by the action of the limiters in the demodulator.

Head wear or circuit changes can cause partial loss of total limiting gain. If this occurs, an increasing number of the carrier depressions reach the discriminator and become visible on the television screen. Furthermore, improper transient response in the RF amplifying system can exaggerate the durations and amplitudes of the carrier dropouts, making their effects more pronounced.

Excessive noise also can reduce dropout immunity, since the carrier cannot be recovered by the limiter when momentarily reduced to a value less than the noise level.

Use of Redundant Signal

The principle of redundancy was applied to a standard video recorder system to compensate for the visual effects of signal dropouts. In this system, an artificial and essentially redundant signal was obtained through a delay line of requisite signal characteristics and a time delay corresponding to one television line (approximately 63.5 μsec). This selection was based on the following factors:

1. The inherently high redundancy existing between signal profiles in most time-adjacent line periods (two successive lines as displayed on a kinescope screen) comprising a television signal.
2. General inability to detect minor geometric distortions of pictorial detail which exist for short time durations.
3. The increasing availability of economically feasible delay devices of requisite bandwidths and duration.

Ideally, the one-line delay system for compensator use should retard the television signal 63.5 μsec (63.55 μsec for color) and display a conventional video frequency response and rise time. A full-bandwidth system was developed and evaluated, but until the new generation of high-band color video tape recorders became popular, a 63.5 μsec delay line with a frequency response of 500 kHz was used to store the highly redundant components of the video and sync signals.

Full-Color Compensation

To obtain accurate color replacement information, it is necessary to overcome three basic problems: (1) time-base stability of 4° phase, or about three nanoseconds; (2) differential phase and gain of 3° and 3%; and (3) allowance must be made for dot interlace of the 3.58 MHz chroma subcarrier information.

There are several ways to produce delayed substitution material for dropout compensation, and a number of circuit variations have been tested. All involve detection of the signal defect in the radio-frequency portion of a magnetic video recorder; they differ as to the location in the playback circuit where information is stored and re-inserted, and as to the sequence and duration of these insertion periods.

FM Compensation

One possible method employs an FM dropout compensator in which detection and substitution are accomplished in the RF signal portion of the reproduce electronics. In such a system, the FM signal is delayed and used directly for substitution. This is the simplest method for wideband monochrome information since the FM carrier can be transmitted directly through a high-frequency glass or quartz ultransonic delay line. However, FM substitution in the RF signal produces the same sort of discontinuity as an FM head-switch transient at the beginning and end of the dropout pulse, due to the introduction of a considerable phase discontinuity. This method cannot properly compensate the first and last portion of the dropout.

Video Compensation

In a second basic system, the principal delay and switching operations are accomplished in the video-signal portion of the recorder/playback system, after demodulation of the RF carrier. This usually is called a video-substitution compensator. It has the advantage that the inherent delay of the filter and demodulator can be used to insure that the dropout substitution starts before the actual disturbance. Video switching can also be done with no transients, and the fill-in match in luminance and chrominance can be made nearly perfect.

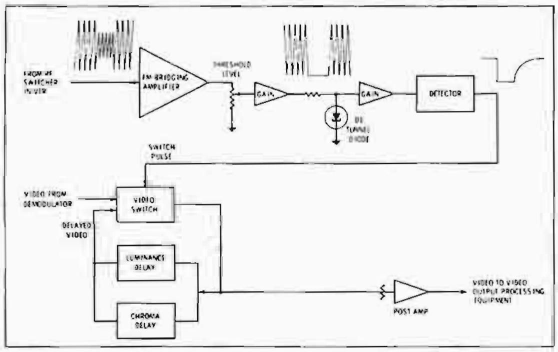


Fig. 79. Dropout compensator routes luminance, chrominance through separate delay lines, also uses demodulator delay.

Color Video Compensator Design

A block diagram of a complete compensator is shown in Fig. 79. The detector actually is a double-acting device. First, a constant-current source applies the RF signal to the level-detector stage, tunnel diode D1. The RF drive causes D1 to change state on the peaks of the RF pulses, resulting in a square wave. The threshold-level control adjusts the gain of the amplifier stages to determine the lowest RF level which will cause D1 to fire. The square wave from the dropout detector is used to reset repeatedly a ramp generator. If the generator is not reset (as is the case if loss of RF interrupts the square wave output from D1), the ramp continues to rise and eventually triggers the dropout pulse generator. This double process correlates the depth and duration of the RF amplitude disturbance for faster and more accurate dropout detection.

The delay caused by the ramp generator is just long enough to permit the activation of dropout substitution before the beginning of the dropout, which occurs in the video at a time delayed from the FM by the demodulator and filter in the recorder.

A detector timing adjustment controls the time lapse between loss of RF and dropout pulse generation. This adjustment is set to delay triggering just long enough so that the detector

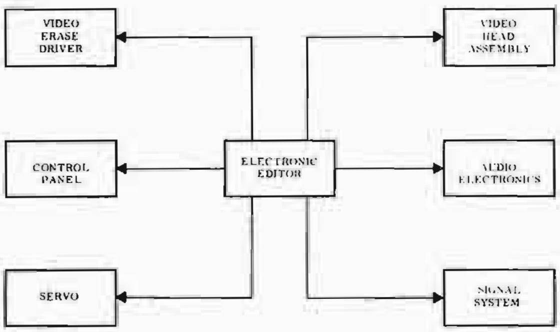


Fig. 80. Recorder system block diagram.

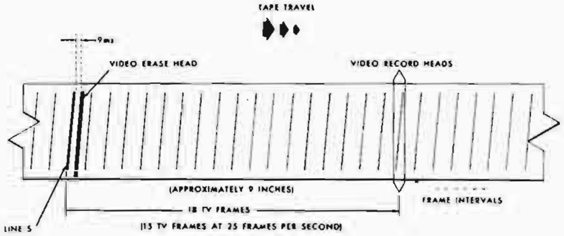


Fig. 81. Head separation measurement.

ignores spikes in the RF caused by such defects as noise and pre-emphasis in the video-recorder system for black-to-white transition.

The pulse circuitry extends the dropout signal for a short duration in case any limiter disturbance follows the dropout interval. The negative-going dropout pulse is routed to the video switch. The video switch is placed in the output of the recorder demodulator after filtering but before any sync separation or signal division. If this cannot be done, separate dropout protection must be devised for tape signal paths not routed through the switch.

The heart of the storage system is a pair of special glass memories. One of the two glass memories is designed to handle the 3.58 MHz chrominance information directly. It provides necessary response plus freedom from spurious reflections over the chroma bandwidth of 2 MHz to 4.2 MHz, as required for NTSC color. The other memory delays the luminance information at a carrier frequency of 10 MHz.

Adequate sync and blanking response to preserve timing relationships is the criterion for the luminance-channel response. Above 2.5 MHz, all energy must be removed from the luminance signal processed by the color channel. Otherwise, edge interference between the phase-corrected color and the luminance is apparent in the delay material.

The chroma signals (2.3 to 4.2 MHz) can be delayed directly. The total delay time for the chroma signal is trimmed by a variable delay line. Incorrect total delay time of the chroma signal shows as a change in the hue of the fill-in material. The chroma signal, inverted 180° in phase, is added to the delayed luminance signal

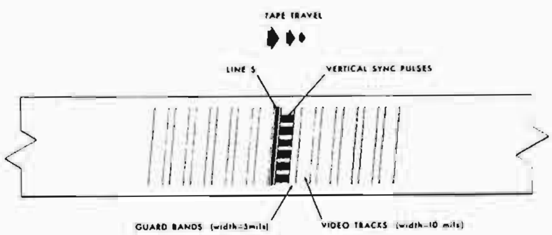


Fig. 82. Detail of splicing point.

and applied to the delayed-video input of the video switch.

System Performance

A properly designed and operated dropout compensator detects and compensates not only the gross dropouts producing the high-contrast flashes, but also the dropouts of lesser amplitude that appear in high-saturation color signals due to changes in recorder equalization. The speed of switching action is such that the switching transients are past the response limits of standard television systems. These factors, together with the relatively wide-bandwidth luminance and full-bandwidth color fill-in material, produce a system that makes it virtually impossible to see compensated dropouts on a random basis. In addition, full compensation during the sync interval eliminates time-correction errors and servo instability caused by dropouts. When such compensation is achieved, useful tape life is extended and program quality is improved.

Electronic Video Tape Editing

The electronic editor provides a sure and convenient method of editing television tape recordings without physically cutting the tape. The editor makes it possible to start and stop the recording system at any time for costume or scenery changes, insertion of commercials or new scenes, correction of production errors, or assembly of a single tape from many separate segments. The extreme difficulty of maintaining frame sync and control track signal continuity required something more than the operator's greatest skill and care together with the most ingenious splicing equipment available. This problem is eliminated by the electronic editor which permits the editing of tape with complete continuity of signals and without physically cutting and splicing. Original tape segments are not disturbed in any way during the electronic splicing process and may be reused many times. The entire splicing procedure is accomplished with the tape in motion at normal speed.

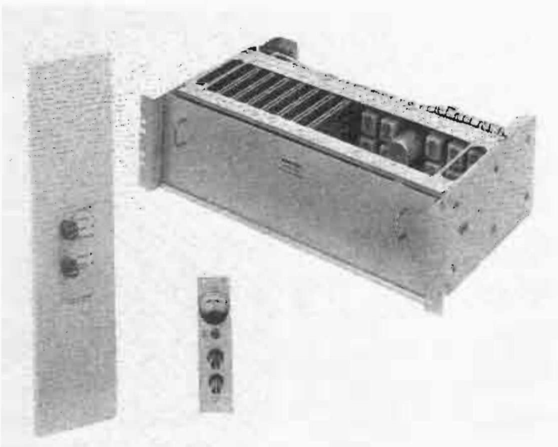


Fig. 83. Electronic editor.

The electronic editor accomplishes this by modifying and controlling signals from the various systems and subsystems of the recorder (see Fig. 80). It eliminates disturbances that arise from the cut and splice process, and, by controlling the Intersync servos, maintains the correct phase relationship between the master tape signals and the incoming new video signal. The finished splice appears the same as a change in picture content caused by camera switching.

In addition, the editor automatically makes allowance for the distance between the planes of the erase head gap and video heads by precisely synchronizing the application of erase current and video record signals. This permits the first new frame of an insertion to follow its immediate predecessor on the tape and maintains the complete continuity of video, blanking, and synchronizing signals.

The distance between the erase head gap and the video heads may be considered equivalent to time. The time value of this distance is that interval required for the tape to travel from the erase head to the video heads at the primary nominal rate of 15 ips tape speed (the tape space occupied by approximately 18 television frames). Fig. 81 illustrates the physical relationship between the erase head and the video heads. The line "S" marks the point on the tape where the insert splice will be made and where the erasure must start.

The electronic editor establishes the position of line "S" by means of a gating circuit that is triggered by the first frame pulse that follows the initiation of a random cue signal for the insertion. Line "S" is within the guard band immediately following the recorded video track that includes the vertical synchronizing pulses (Fig. 82). Since there are two groups of vertical sync pulses per frame, it follows that the correct group must be chosen to precede erasure turn-on. This is established by a framing pulse from the control track.

The electronic editor control panel (Fig. 83) has two controls that provide the operator with a choice of any four operating combinations. The selector on the right is a four-position switch from which normal, insert, assemble, or remote modes may be chosen. In Normal the editor is removed from the recorder system. With the selector set at Insert, the editor is programmed for an insert recording. When the selector is at Assemble, the editor is programmed for an assembly of prerecorded material. With the selector set at REMOTE, the editor modes may be selected by a remotely mounted editor control panel. The selector on the left is a two-position switch which provides a choice between audio-video and video. With the selector at audio-video, both audio and video are recorded. When the selector is at video, only video is recorded.

During either operating mode, the time-controlled sequential switching of erase current and video signal is initiated by pressing the Record pushbutton, producing the ingoing electronic splice. When an insertion is made, it must be terminated at a particular time, which requires a second, or outgoing splice, initiated by pressing the Stop pushbutton. The electronic editor switches off the incoming video information and the erase current on an automatically controlled time schedule that is the opposite of the ingoing splice time schedule. Both splices are timed and controlled by the editor electronics and the editor accessory panel, as shown in Fig. 83.

Editing—Time Element Control (EDITEC)

The Editec system (Time Element Control) allows for programming of the electronic editor in a wide variety of television production situations, editing, tape positioning, and provides for timing facilities by providing automatic control in editing and related studio equipment. Programs may be assembled, on a scene-by-scene basis, into a first generation master edited tape. The scenes may be recorded in any order that is convenient to the scheduling of personnel, artists, or equipment. The beginning and end of each scene can be precisely located by Editec to a one-frame accuracy, and each scene may be lengthened or shortened as required, by one or more frames. The effect of any particular splice may be previewed on the monitor before the splice is made. A scene may be inserted into an existing tape for correction or other reasons. The beginning and end of the new scenes may be precisely located, adjusted and previewed on a one-frame accuracy basis. Where performer, lighting, camera, or technical and production errors occur in a scene being inserted into a video tape, the action may be repeated as often as required and re-inserted into the video tape. The Editec control allows new scenes to be spliced in at exactly the same frame on every "take." Audio splicing as well is accomplished in time synchronism with the video splicing. The frame-by-frame accuracy allows for precision splicing of prerecorded music on the audio track with respect to video splices made to the rhythm of music.

Time base errors at splices are automatically reduced to less than a microsecond providing "jitterless splicing" or "picture whips" in the finished program. Edit points may be accurately spaced and as close together as desired relieving restriction on the frequency in the number of edits and at intervals of one frame and up. This provides for animation and allows the video recorder to automatically record any preselected number of frames onto the end of a previous recording. Edit points may be adjusted forward and backwards as required, down to one frame increments. The Editec Program Unit is shown in Fig. 84.

Video tape life is extended by means of a nonscratch erase head mechanism and special control of the tape vacuum guide, allowing rehearsal of edit points several times without damage to the master video tape. The erase head mechanism is shown in Fig. 87.

The primary function of Editec is to provide control signals that start and stop the electronic editor at the precise time a new scene is to begin and end on the program master tape. These control signals are derived from cue tones that are recorded on the cue track of the program tape. The cue tones used differ only in their frequency. One of them serves as the remote cue signal which controls remote equipment, e.g., a second television recorder; the other is the edit cue signal which controls the editing operation.

The Editec operator prepares the program master tape in advance of actual shooting, by marking an edit cue at the beginning of each successive scene as timed by the script, or a separate scene timing schedule. In some cases, this is accomplished by simultaneously recording a continuous control track signal for the full dura-

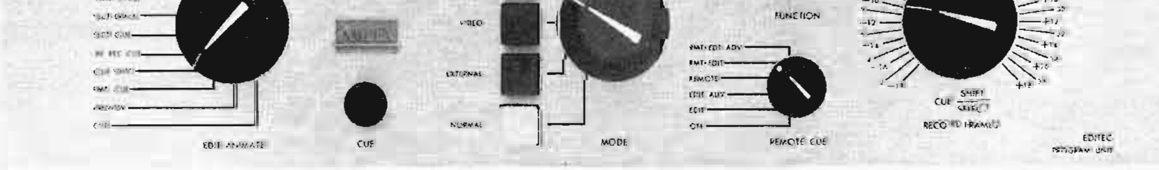


Fig. 84. Editec program unit.

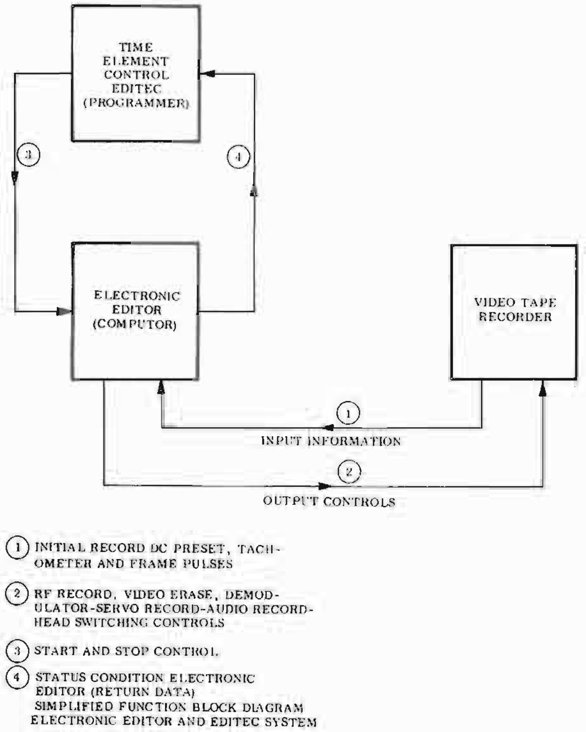


Fig. 85. Functional electronic editing system.

tion of the projected program. If external equipment is to be turned on at a desired time, the operator records a remote cue for each such occasion.

All functional elements of the basis electronic editing system are shown in Fig. 85. The connections through the demodulator relay and the record driver gates are made through electromechanical relays in the basic system. The basic system includes the electronic editor, the erase switch, the RF switch, and Intersync.

The Inter-Sync controls rotation of the recorder head drum to synchronize recording and playback with external reference signals. During play operation of the recorder, with Intersync set for automatic mode, reproduced vertical and horizontal sync are compared with reference vertical and horizontal sync signals. A position error output proportional to the phase error between these signals is generated. The position error output is applied to the head drum drive system, causing the head drum to rotate faster or slower to reduce the phase error, synchronizing the signals. When the recorder is switched to record operation, the reproduced signals are, of course, not available for synchronization. Instead, the tachometer sync signal produced by the rotary head assembly is compared with reference vertical

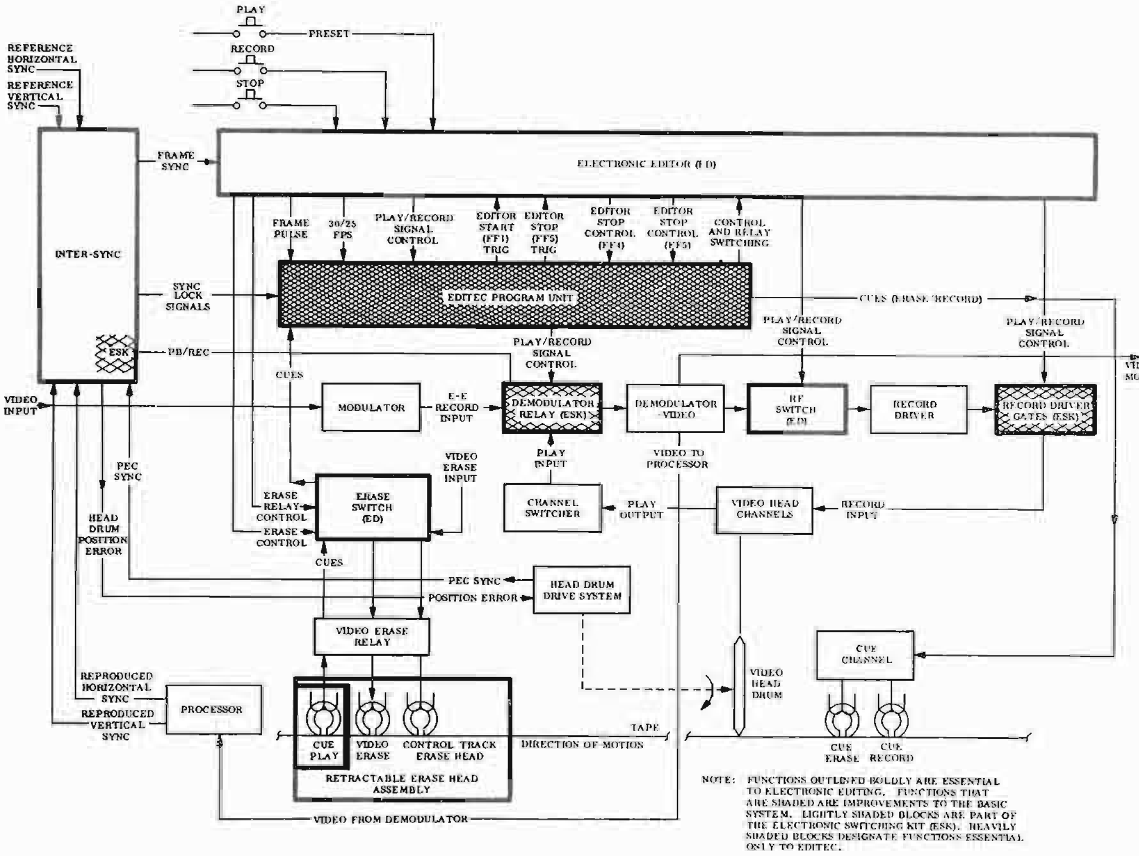


Fig. 86. Editec—controlled editing system, simplified diagram.

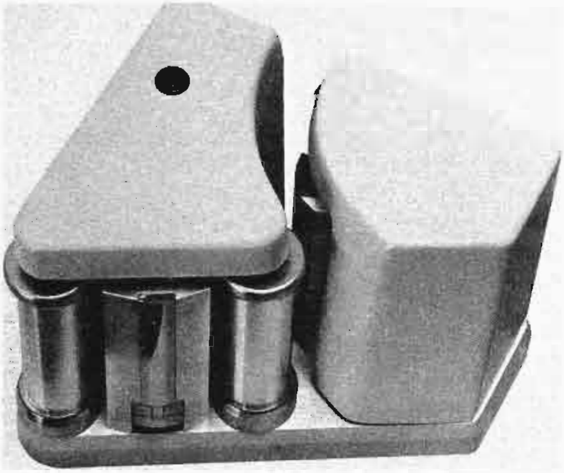


Fig. 87. Back of tape erase head showing cue playback head mechanism.

sync. The position error output produced by Intersync in this mode is used to place recorded vertical sync information at the precise center of the video tape.

The electronic editor times the making of an electronic splice so that there is no blank tape and no overlapping of recordings. This is accomplished in assemble or insert mode. During normal mode, all recorder functions operate normally, bypassing the control afforded by the electronic editor. The editor makes an electronic splice as follows:

1. The recorder is first started in play mode, which presets the timing and logic circuits of the editor. During this mode, the signals being played from tape are taken from the video heads on the head drum, preamplified in the video head channels, combined in the channel switcher, connected to the demodulator, demodulated, and displayed on the external monitor.

2. At the desired point, the splice is initiated by depressing the record pushbutton. This allows the video erase, RF record, Inter-Sync, and audio erase to be programmed by the electronic editor logic. In addition, a pulse is generated which initiates the editor programming cycle. Inter-Sync places vertical sync in the center of the tape and the play/record relay connects the outputs of the record driver to the video heads on the head drum.

3. After a brief settling period that allows the first transverse track of the next frame to move into position for erasure, the editor turns-on the erase switch. If insert mode is being used, erase energy is not switched to the control track erase head by the video erase relay. In assemble mode, the control track is erased.

4. Coincidentally with the start of erasure, the editor starts counting frame pulses received from Intersync. At the count of 18 frames, the editor turns on the RF switch, audio record, and the Intersync is switched to the record mode. This connects the new video information to the record drivers coincidentally with video head scanning of the first transverse track that was erased 18 frames earlier and also switches the modulator E-E output to the demodulator, causing the record input to be displayed on the monitor. Because Intersync position error signals keep recorded frame sync centered on the tape, the first and subsequent vertical (frame) sync pulses are lined up with the sync pulses on the previous section of the recording.

5. Recording is terminated by depressing the stop pushbutton. At the correct instant, when a complete frame has been erased, the editor turns off the erase switch, stopping erasure of the video track. At the count of 18 frames, the editor turns off the RF switch, stopping the recording of new video information on the tape. The editor turns off audio erase and record signals. Two seconds later the recorder has stopped completely.

Electronic switching of Intersync from play to record concurrently with the start of the electronic "splice" improves continuity of recorded sync. When Intersync is kept operating in automatic mode until the precise instant of the "splice," the higher sample rate of this mode reduces drift from synchronism with the reference signals almost to the vanishing point. As a result, the maximum discontinuity between the sync of the last frame preceding the "splice" and the first frame of the "spliced-in" recording is 0.2 μsec.

Editec System Functions

Cue recording and playback is the key to the functioning of the Editec system. Edit cues recorded on the audio 2 track of the tape are used to represent splices. Once recorded, edit cues have a fixed physical relationship to the splices they represent. From the reference thus established, the responses to the cues or the cues themselves can be shifted in a controlled manner, frame-by-frame, to improve placement of the splice. The reproduced edit cues are used to trigger recorder switchover from play to record or vice versa.

There are two types of cues, edit and remote. The edit cues are bursts of 4 kHz audio signal; the remote cues are bursts of 1 kHz audio signal. Both are recorded on the same track. The remote cues are also used for programming but, unlike the edit cues, they trigger the turn-on of external equipment.

When the mode switch on the Editec program unit is set at any position but normal, turning Editec on, a relay makes circuit changes in the cue channel. This relay disconnects some normal control functions and causes the cue record/play head to operate only as a record head. Each cue, whether edit or remote, is recorded individually by actuating the cue button on the program unit front panel.

Cues are thus recorded on the tape by a head that is about 18 frames "downstream" from the video heads on the head drum. The cue play head used by the Editec system is mounted on the retractable erase head assembly. This head is about 23 frames "upstream" from the video heads. Thus, when Editec is on, cues are recorded at their usual position on the tape but are reproduced 41 frames earlier. This is necessary in order that the reproduced cue signal may precede the arrival of the splice point on the tape at the plane of the video heads. It also allows the 3/5 second lead time that is required for the electronic editor to turn-on and make the "splice" at the splice point. In addition, this lead of reproduced cues with respect to recorded cues permits shifting the time position at which a reproduced cue will act, on a calibrated basis. As shown in Fig. 88, there is actually more than a second of tape movement time at 15 ips between the positions of the cue playback head and the cue record head, 41 frames at 30 fps. Cue recordings and cue responses are timed by Editec logic in response to frame pulses that are received from Inter-Sync via the electronic editor.

Editec starts the editing process by applying a start trigger to the electronic editor in response to a reproduced edit cue. After a brief, timed delay, the editor turns-on video erase energy through the agency of the erase switch and starts counting frame pulses toward the scheduled turn-on of video record energy. At the count of 18, the editor triggers record-on output voltages from Editec to the demodulator relay. The demodulator relay switches from play to record, disconnecting the playback signal from the monitor and connecting the incoming record signal to the monitor. These same control voltages are routed through the demodulator delay to Inter-Sync, which they also switch from play to record operation. At the same time, other control voltages from the electronic editor switch the RF switch and the record driver gates to record operation. All of these editor-controlled operations act to connect record energy to the video heads on the head drum.

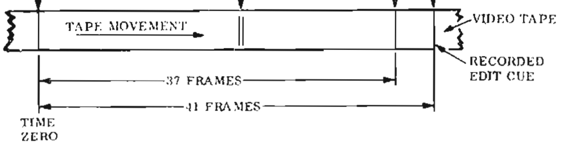


Fig. 88. Physical relationship of cue record, reproduce, erase and the video heads.

The electronic editor continues erasing and recording the video tracks on the tape until it receives a stop trigger from Editec. After a brief, timed delay, the editor turns-off erase energy and starts counting frames to the scheduled turn-off of record energy. At the count of 19, the editor turns off video record energy and switches the demodulator relay from record to play operation via Editec. This stops recording and switches the playback signal to the monitor. Intersync is also switched back to play mode.

Control of Recording and Rehearsal

To permit rehearsal of a program tape without actually recording it, overriding control of recording is given to the operator. When the mode switch on the program unit control panel is set at Record in auto or manual mode, or when the Record button on the recorder is actuated after the recorder has started in play mode, the record relay in the system control unit is energized. Splices are then recorded in response to reproduced edit cues.

Although final signal switchover from play to record is accomplished electronically when a splice is made, the record relay retains a power switching function that gives it control over whether the tape is actually erased and recorded to make a splice. The result is a rehearsal for any pass of the tape during which the record relay is not energized. During a rehearsal, the monitor is switched between the play and record inputs in response to edit cues. Except that splices are not actually made, the system operates exactly as it would if splices were being made.

Editec exchanges several other control functions with the electronic editor and with the control circuits of the recorder. One of these is the play bus which is received from the recorder circuits. Others are the rewind and stop functions, commanded from Editec during the programming of various phases of recorder operation. The details of these control functions are described later in this section. When Editec and the electronic editor are set for normal operation, control of the recorder reverts entirely to its normal control circuits.

Editec Operating Modes

The Editec has 11 basic modes of operation which are divided into two main categories, the cue record modes and the cue response modes.

There are three cue record modes used exclusively for recording edit or remote cues.

1. *Preview mode.* The purposes provided by the preview mode are varied. In some applications, such as the replacement of a commercial, it is usual to retain the display of the tape playback in

order to establish the precise placement of the edit cues that mark its beginning and its end. Under other circumstances, preview mode permits marking the exact point at which a recorded scene is to be terminated and followed by a new scene supplied by the camera. The edit cue recorded to mark the end of the recorded scene causes the picture monitor to be switched synchronously to the new scene from the camera, thus presenting a preview of the transition to the new scene. Such a preview may show that the cue should be placed earlier or later to locate the transition correctly. The judgment concerning the necessary shift of the cue position can be noted for use at the time the new scene is recorded.

2. *Remote cue mode.* Essentially the remote cue mode is the edit cue recording function of the preview mode, except that the function translator applies a 1 kHz control signal to a cue burst oscillator. The only function accomplished in the remote cue mode is the recording of remote cues on the cue track (audio 2 track) of the tape.

3. *Preview and erase mode.* This mode is the same as the preview mode, but with the added feature that all previously recorded remote and edit cues are erased before new edit cues are recorded.

There are eight cue response modes in which Editec responds to cue information recorded on the tape.

4. *Cue mode.* In the cue mode new edit cues may be recorded as described in the Preview Mode, but without previewing. In addition, previously recorded edit and remote cues are reproduced and used to initiate various control functions internal and external to the Editec system. All of the cues recorded on the cue track (audio track 2) of the tape are reproduced by the cue playback head on the erase head assembly as shown in Figs. 86 and 87. The output from the cue playback head is amplified by a preamplifier and the output of the preamplifier is applied simultaneously to the inputs of a 1 kHz and 4 kHz bandpass filter. Each of these filters reject all frequencies that are not within its passband. Thus, the output of the 4 kHz filter includes only reproduced 4 kHz edit cue signal bursts and the output of the 1 kHz filter includes only reproduced 1 kHz remote cue signal bursts.

Rejection of noise on the edit cue signal line is accomplished in cue mode and in all other modes by two methods. The first is filtering, which also separates the remote and edit cues. The second is integration, which rejects noise pulses of brief duration that may happen to pass the 4 kHz filter. The filtered reproduced signals are applied to individual r-c time constants that establish a specific runup time for the edit cue signal to reach the amplitude that is required to trigger the cue pulse generator, which is a Schmitt trigger. Thus, the triggering signal must be of the correct frequency to pass through the 4 kHz filter and must have a specific minimum duration in order to reach the level required to trigger the cue pulse generator. This prevents triggering of the cue pulse generator and subsequent Editec logic circuits by random noise.

5. *Cue shift mode.* The cue shift mode is used when the time location on the tape of a recorded edit cue is not to be disturbed but its action is to take place earlier or later. Reproduced edit cues follow the previously described cue mode path through the preamplifier, 4 kHz filter and logic circuitry. Because the time at which the reproduced edit cue takes effect is to be other than its recorded time position, the logic circuitry is linked to a matrix gate by which its action is determined by the setting of the front panel record frame selector. This switch may be set at any number of frames from minus 18 to plus 18 with respect to the exact recorded edit cue.

When the record frames selector is set at zero (mid-range), the matrix gate produces an output at the count of 19. This is the same count that is programmed into the programmed gate, as in the cue mode just described, and thus at this setting both gates produce an output simultaneously, resulting in no cue shift.

If the Record Frames selector is set at some minus number of frames, the matrix gate will produce an output at an earlier time than the programmed gate.

For example, if the selector is set at -3, the matrix gate will produce an output at the count of 16 (19-3) frame pulses (or 15 frames). If the setting is +4, the matrix gate will produce an output at the count of 23 (19 + 4) frame pulses (or 22 frames). From this point on, cue shift mode essentially parallels the processes of the cue mode.

6. *Rerecord cue mode.* Rerecord cue mode parallels cue shift mode in shifting the time at which a recorded edit cue will act. However, in rerecord cue position of the Edit-Animate selector, the cue originally recorded is erased and rerecorded at a new time position on the tape. As in cue shift mode, the cue to be given special treatment is selected by actuating the cue button just before that cue reaches the cue reproduce head.

Recording the original cue at a new position eliminates the necessity of keeping a cue sheet that shows the position of each edit cue. Since cues are rerecorded where they will act, there is no need to keep a record of cue shifts for one or more of the cues.

Extension of cue shift range by rerecording of cues can be used to extend the range of the cue shift dial, permitting the movement of a given cue any distance on the tape. For example, if cue placement is in error by 24 frames, the cue can be shifted only 18 frames using cue shift mode. In rerecord cue mode, the cue can be shifted 18 frames with one pass of the tape and another six frames with another pass of the tape.

The use of frame cutting (flash cuts or quick cuts) technique requires the recording of an edit cue to mark the beginning of a tape segment on which are to be recorded flash cuts or quick cuts. Then, with the record frames selector set at the positive number of frames to be recorded of each cut in rerecord cue mode, a new edit cue marking the start of the cut to follow is laid down as each cut is made. Successive flash cuts may have any frame duration from 1 to 18 frames. All may have the same duration, or may be at differing rates to accelerate or retard the appearance of transitions. In essence, this process is similar to animation with cue shift, which is an invaluable facility at times. When animation is required, however, it is preferable to use the manual or auto position of the Edit-Animate selector to avoid excessive wear of tape and heads.

7. *Select cue mode.* Select cue mode is used to select a particular edit cue from a closely spaced series of edit cues, to initiate an editing operation. The logic circuitry initially counts the reproduced edit cues until the selected cue is reproduced. The Editec operation then reverts to that of *cue mode* previously described.

8. *Select and erase mode.* Select and erase mode permits the selection of any one of a closely spaced series of edit cues for erasure. For example, it is desired to erase the sixth edit cue in a series of 12, the record frame selector is set at 6.

9. *Manual erase mode.* The manual erase mode permits the manual selection of an edit cue for erasure. Just before reproduction of the edit cue that is to be erased, the cue button is depressed and held down. When the cue talley flashes, the cue button is immediately released to avoid erasure of desired cues.

10. *Animate mode.* The Edit-Animate selector provides the choice of manual and auto animate. The manual animate mode requires restarting the system manually for each new take of an animation sequence; the automatic animate mode provides an automatic start for successive takes. In automatic mode, successive takes are separated by an interval of 15 to 20 seconds. The configuration of successive takes is illustrated in Fig. 89.

When Editec is to be operated in manual or automatic animate mode, an initial edit cue is recorded to mark the starting point of the animation. When this cue is reproduced it places in operation an electronic mechanism that senses the first "missing" cue. When the initial edit cue is reproduced the mechanism is alerted to find a second edit cue 1 frame later, see Fig. 89. When the second cue turns out to be missing, Take 1 is

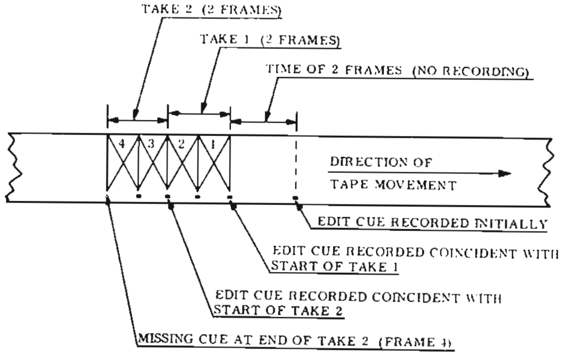


Fig. 89. Animation production in 2-frame takes (record frames selector set at 2).

initiated and an edit cue is recorded coincidentally with the start of Frame 1 and each frame that follows in Take 1. At the completion of each take, the machine recycles the tape to the starting point and stops.

The duration of each take is controlled on a calibrated basis by the setting of the record frames selector. Duration may be extended to any greater duration by holding down the record button on the program unit.

If the record frames selector is set for 2-frame takes (on its outer scale), takes and cues will be arranged on tape as shown in Fig. 89. At the completion of Take 1 (2 frames), the recorded edit cues on the tape include the initial cue and the cues that mark the beginning of Frames 1 and 2 only. There is no recorded cue that marks the end of Frame 2, which is also the beginning of Frame 3. At the completion of Take 2, there are additional recorded cues that mark the beginning of Frames 3 and 4, but as shown in Fig. 89, there is no cue marking the end of Frame 4 (and start of Frame 5). This is the "missing" cue.

11. *Animate erase mode.* Animate erase mode provides a means for precisely controlled erasure of unwanted frames at the end of an animation sequence.

The beginning of each frame in an animation is marked by a recorded cue. To achieve erasure of animation frames, it is necessary only to erase the cues that accompany them and to enter either animate mode with no record input applied. In animate erase mode, the erasure of cues that accompany undesired frames is accomplished by counting "backward" from the first "missing" cue. Erasure of cues is terminated by actuating the recorder stop button.

As in the animate mode, the indexing logic is the key to the detection of the first missing cue. It is the same in animate erase mode. When the first missing cue is detected, its location on the tape is momentarily opposite the cue playback head. As indicated in Fig. 87, the first missing cue point will be opposite the cue erase head 37 frames later.

Since the time interval between the cue playback and erase heads is known in terms of frames, it is only necessary to count back from this interval the number of frames it is desired to erase.

The timing of cue erasure in animate erase mode is derived automatically from the setting of the record frames selector. The record frames selector is set at the number of frames that are to be erased, which can be any number up to 37. The difference between the number of frames that are to be erased and the number of frames that are between the cue play and erase heads is derived automatically. A number of frames greater than 37 can be erased by repeating the animate erase procedure.

At this point, only edit cues are erased. The video frames are erased and replaced during animate mode retakes that will start with the new "first missing cue."

In the overall system the location of major equipment components described previously is shown in Fig. 90.

Fig. 91. Overall view RA-4000.

Random Access Programmer

The Random Access Programmer provides for the first time precise synchronized operation of two or more video tape recorders. The programmer allows operation to the extent of automatic search and tape cueing down to an accuracy of 1/30th of a second when running from high speed tape winding modes of the video recorders to frame-by-frame running synchronization at normal playing and record rates. This, combined with the recorder Intersync servo system, provides exact signal synchronization allowing editing capability similar to that of film double system frame-by-frame or A/B roll mixing and program editing. Electronic splices may be made precisely and by predetermining selected points, for rerecording into a master edited video tape program. A separate audio recorder may as well be controlled by the Random Access Programmer providing that provisions for transport control, capstan servo, a spare audio track and channel, and the necessary electronics and interface are provided.

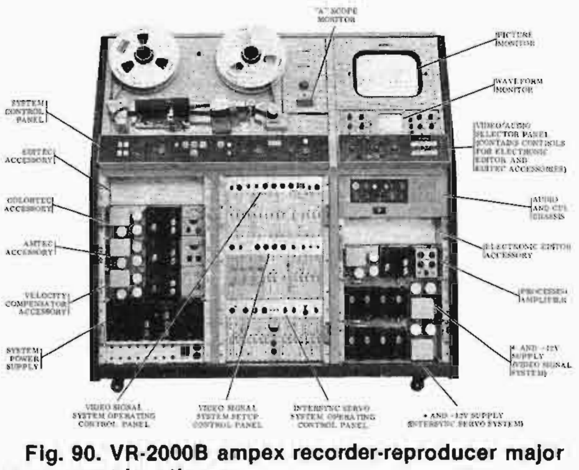


Fig. 90. VR-2000B ampex recorder-reproducer major component location.

Five control modes are provided for editing, program switching and general random access programming of video tape recorders.

Mode One. The most complex of the system provides full synchronization of two or more video tape recorders and is the primary operating mode utilized in editing.

Mode Two. Allows for "A" roll and "B" roll mixing of signals from two video recorders in synchronism to a third video recorder providing a composite program re-recorded inter master.

Mode Three. Operates one video recorder in the assemblage of scenes or sequences from a studio or single camera and other video sources. The recorder cues to a point 10 sec prior to the time set into the memory register providing precise commencement of the record function and at the exact frame time.

Mode Four. Operates one video recorder primarily for random access in playback. Scenes or short segments may be quickly located, precisely timed, cued up and integrated into live studio operation or switched directly on air from the recorder by external command.

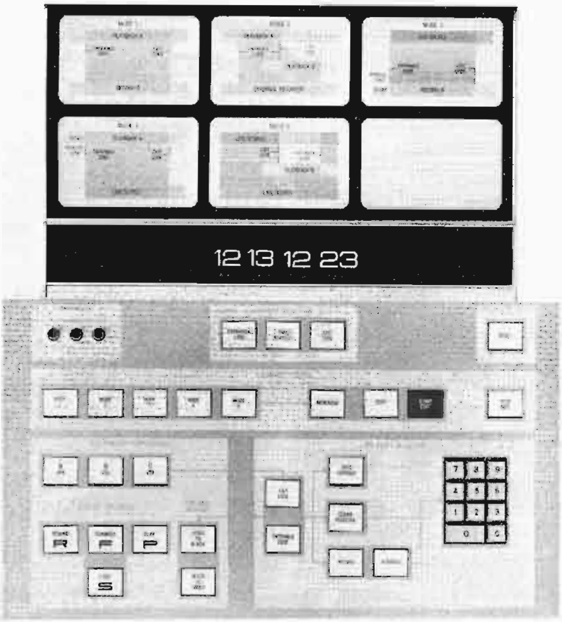


Fig. 92. Modes one to five and control panel.

Mode Five. Is primarily a variation of Mode Two, where the capability of "A"/"B" roll mixing is accomplished. However, the difference is that the "A" roll is a video signal source lacking time code data. In this case, the time code generator is providing timing data to accomplish an automatic pre-roll into full synchronization of the "B" video tape recorder, along with the foreign video signal source. This provides a composite synchronized output signal to a third recorder or directly to the air.

As with film, the accurately spaced sprocket holes provide a convenient mechanical method for exact metering of film footage, in conjunction with film edge number printing systems for identification of each picture frame. In the case of magnetic video recording, this method has been developed to identify each and every television frame on the video tape.

This system provides for the recording of a precise magnetic address code on the cue track (audio track two) in the form of a digital signal. In that the television signal scanning frequencies are closely controlled by the station synchronizing generator, it is convenient to express the address in terms of *hours, minutes, seconds,* and frame number (0 through 29). Addressing each and every frame allows a degree of redundancy that provides for greater noise immunity and as we reach the higher sample rate (one per frame), promotes faster search and synchronization. The digital code is known as Manchester Bi-Phase-Level and is useful over a wide range of tape transportation speeds from approximately 4 ips to 300 ips allowing readability in either direction of tape motion, rewind, fast forward, and at nominal linear running rates of the recorder.

A time code generator produces the necessary digital time code to be applied to the cue track (audio track two). The time code recording may operationally be recorded either from the "time of day" clock time or "elapsed time" (television time controlled from the station synchronizing generator), from the beginning zero time on each subject video recording or rerecording session. The time code may be recorded simultaneously with the video and audio program and on a start and stop basis, and or may be post recorded should this time prove convenient in the assemblage of program material for editing.

The code frame format is made up of a thirteen-bit synchronizing section together with a 65-bit addressable group. The synchronizing section performs three basic functions: a burst of uninterrupted clock transitions to enable the decoder to lock to the bit clock, a repetitive pattern to enable an address synchronizing pulse to be derived, and tape transportation direction to be defined by examination of the direction of a predetermined transition. The addressable group is divided into blocks of five, with the fourth data bit repeated to form the fifth bit. This reduces the effective data bits to four per block (or fifty-two in all). This insertion of two adjacent identical bits in each block of five addressable bits preserves the unique feature of the synchronizing section in its capability of defining address sync and tape direction. One-half of the available data bits per frame are used to form the consecutive time code, while the other half is available for identifying data that can be maintained over successive edits and generations.

When the code is recorded on the cue track, the video tape can be automatically searched for a required frame address. The desired video tape address is retrieved by placing the exact time and frame into the memory register from the keyboard

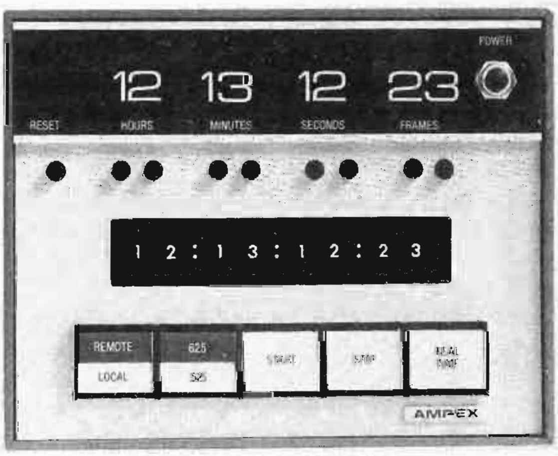


Fig. 93. Time code generator.

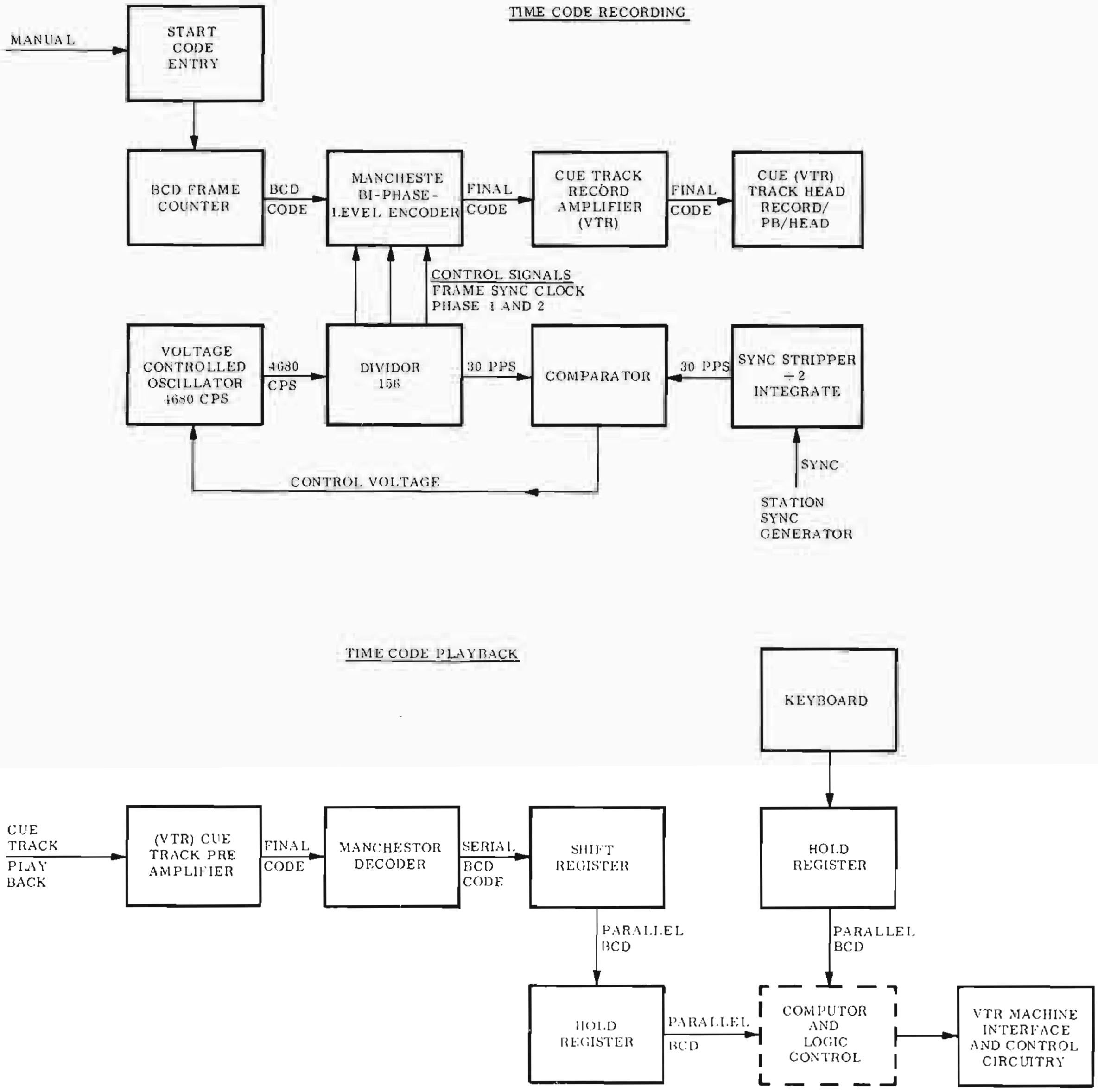


Fig. 94. Time code recording and playback functional block diagram.

control. When the recorder is activated the comparison of the code address on the tape is made with the desired code time held in the memory register. The random access programmer will continuously search by electronically subtracting the two address and, from the difference, the direction of search is determined as well as the search speed (fast forward or rewind) is regulated. As the difference decreases, the rate of search decreases until the video tape recorder transport brings the tape smoothly into position at the required address picture frame. Fig. 94 shows a simplified record and playback functional diagram of the Random Access Programmer Code System.

Magnetic Disc Video Recorder

The Ampex HS-100 Slow Motion Magnetic Disc Video Recorder and Reproducer is a fully transportable, instant replay television recorder/reproducer manufactured for use in studio, mobile vans, or indoor remote broadcast sites. It is capable of recording standard NTSC color or monochrome video signals and then immediately replaying the recorded material, either forward or in reverse, at normal speed, twice normal speed, one-half normal speed, one-fifth normal speed, or in manually controlled, continuously variable speeds ranging from stop-action, freeze, to normal. The disc recorder as well permits opera-

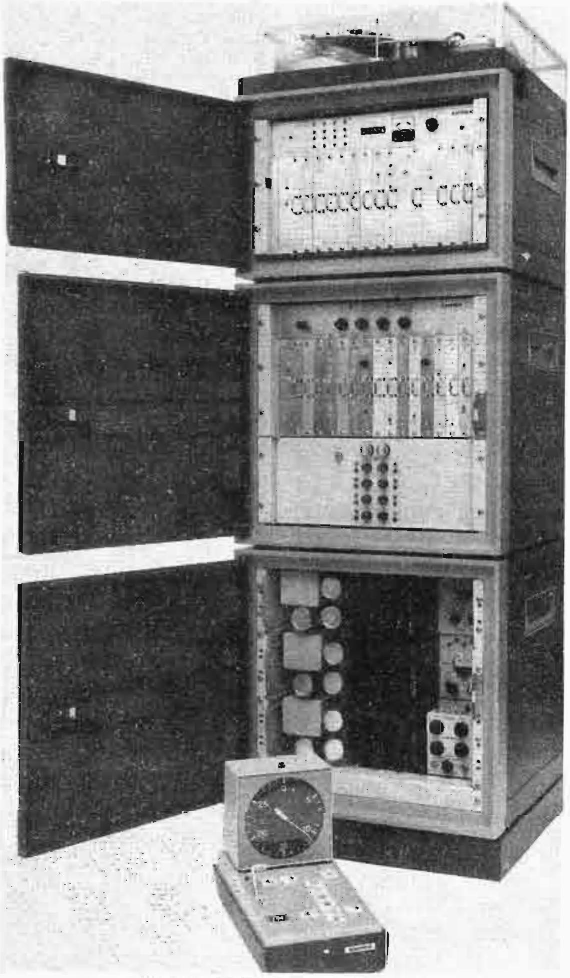


Fig. 95. HS-100 video disc recorder.

Fig. 96. Video disc recorder control unit.

tor-controlled, single-frame video advance, either forward or in reverse, whenever playback is in the freeze mode. The video output of the disc recorder fully complies with NTSC and FCC standards regardless of speed or direction changes. Storage capacity of the recorder is 1800 television fields, corresponding to 30 seconds of video material in the normal record mode, or 60 seconds of material in the alternate field record mode, i.e., recording only every other television field.

The disc recorder is packaged in four units: the disc servo unit, the electronics signal unit, the output processing unit, and the control unit. Each unit is enclosed in a weather-resistant metal cabinet.

Disc Servo Unit

The disc servo unit, Fig. 95, contains the electromechanical components of the disc recorder and their associated electronics. Electromechanical components include a disc drive assembly with its associated circuitry and four stepper assemblies. The disc drive assembly controls the rotation of two magnetic recording discs, each of which provides two recording surfaces, i.e., top and bottom side of each disc. Each of the four stepper assemblies controls the movement of one carriage assembly, with its record/reproduce head, across one of the four disc surfaces. The disc drive assembly and the four stepper assemblies are mounted on a machined aluminum top plate which is in turn shock mounted.

The electronic signal unit, Fig. 96, contains most of the signal system electronics, the control logic, and the major parts of the power supply system. The output processing unit, Fig. 96, contains a standard Amtec, Colortec, and a Processing Amplifier. The control unit, Fig. 96, contains all the primary controls used to operate the disc recorder. Mounted above the control panel is an illuminated clock type dial, calibrated from 0 to 30. A white pointer on this dial indicates the head location relative to the 30 seconds storage capacitor of the system. A red pointer tracks with the white pointer. This pointer can be stopped and then reset to its tracking position at the option of the operator to provide a cue marking.

Video recording in the magnetic disc recorder is accomplished by using high band (HB) systems to provide highest picture quality. The video system has two modulation systems, FM for recording and playback, and AM for the half-line delay function. The frequencies of the FM modulator are: 7.06 MHz tip of sync, 7.90 MHz for

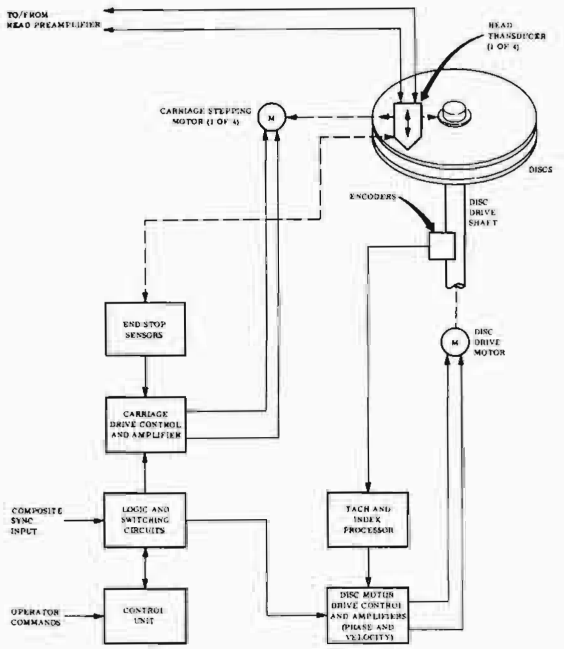


Fig. 97. Disc drive and carriage stepping motors control circuits simplified block diagram.

blanking and 10 MHz for peak white, the same as HB in SMPTE RP-6. The video system consists of four head preamplifier assemblies, each located on a carriage drive assembly, an RF switching logic module and record amplifier module and eight signal processing modules.

The modulated video signals are recorded on the four surfaces of two metal discs rotating about a common vertical shaft. Recording is continuous until the operator overrides the record mode by selecting a reproduce or fast search mode. As long as recording continues, the latest 30 seconds, 60 seconds for alternate field recording, of recorded video is maintained in storage, ready for instant playback. Material recorded prior to the 30-second storage limit is progressively erased to permit recording of new material.

Rotation speed of the two recording discs is 60 revolutions per second (3600 rpm). This speed is precisely controlled by a disc drive servo system which instantly detects and corrects disc drive motor speed variations as shown in Fig. 97. The primary purpose of the disc drive servo is to lock the rotation of the discs in phase with the external reference vertical sync. This phase lock ensures that each complete revolution of the discs corresponds exactly to one television field, beginning and ending during the vertical blanking period. The disc drive servo comprises an optical tachometer, driven by encoders on the disc drive shaft; the electronic circuits associated with the tachometer are a velocity discriminator, a phase comparator, the motor drive amplifiers and the disc drive motor.

Each of the four head assemblies used in the disc recorder is moved by an independent stepper assembly that steps the head radially across the surface of the disc. For purposes of identification the heads and their associated signal paths are referred to as head (or channel) A, head (or channel) B, head (or channel) C and head (or channel) D. In addition to recording, each head also functions as a playback and erase head. During operation, Head A steps radially across the top of the top disc, Head B steps across the bottom of the top disc, Head C steps across the top of the bottom disc, and Head D steps across the bottom of the bottom disc.

Each head assembly consists of a ferrite head transducer and two ferrite pads mounted so that the head and the two pads extend perpendicularly from the corners of a triangular platform. The head and the two pads provide a stable three point contact with the disc surface, and are held against the disc by a cantilever spring which bears against the rear of the platform. The head carriage assembly, which moves the head assembly, is mounted on guide rails extending radially across the disc surface. As the head carriage is moved a given distance along the rails, the head transducer is carried across the disc in the same direction and the same distance.

Driving power for the carriage assembly is provided by a stepping motor controlled by logic circuits and by end stop sensors, which provide reversing commands as well. The carriage assembly is coupled to the shaft of the stepping motor through a pinned stainless steel belt. The manner in which the stepping motors move (or step)their associated carriage assemblies is determined by the track format for the mode of operation being used.

Track Format, Normal Record Mode

Each field is recorded on the disc as a circular track; the head is held stationary while the disc makes one complete revolution. When Head A completes recording a single field, Head B starts recording the next field. While Head B is recording, Head A is being stepped to a new position. When Head B has recorded its field, Head C records the next field. While Head C is recording, Heads A and B are both being stepped to new positions. When Head C has completed recording one field, Head D starts recording, Head A erases the track in which it is now positioned, and Heads B and C are stepped to new positions. When Head D completes recording one field, Head A starts recording in the track it just erased, Head B erases, and Heads C and D step to new track locations. In this manner each head records every fourth field, and successive fields are recorded by Heads A, B, C, and D in sequence. Heads A and C record odd numbered fields; Heads B and D record the even numbered fields.

Recording, moving, and erasing follows a definite sequence for each head. For example, during Field 1, Head A records. During Field 2, the stepper assembly moves Head A 0.010 inch radially across the disc (tracks are 0.007-inch wide, 0.010-inch center-to-center). During Field 3, Head A is moved an additional 0.010-inch radially, placing it a distance of two tracks away from where it recorded (during Field 1). During Field 4, Head A erases, with a dc current, any signal previously recorded on the track in which it is now positioned. At the start of Field 5, the erase current to Head A is switched off and Head A is fed the FM signal output of the record amplifier.

Carriage Reversing

During any given field, one head is always recording, one head is erasing, and the remaining two heads are being stepped to new track positions. The heads move in this manner toward the center of the discs until Head A eventually reaches its innermost track. This position of Head A is sensed by a lamp and photocell arrangement positioned so that the photocell detects Head A as it makes its first step from its last record track position. The photocell output, acting through the carriage control logic circuits, prevents Head A from making the second stepping movement. During the two subsequent fields, Heads B and C also reach their innermost point of travel and are similarly prevented from making their second stepping motion. On the next field, Head A records on the track where it was stopped, and Head D steps one track. On the following field, the direction of rotation of all four stepping motors is reversed. The heads then begin stepping toward the outer edge of the disc, following the normal sequence, and recording between the tracks used when the head movement was toward the center of the discs.

At the outer edge of the discs, head travel is again inhibited and reversed by a second lamp and photocell arrangement. Thus, the heads travel continuously until stopped by an operator command. If a stepping error occurs, the head carriage logic circuits detect it and correct at the end stops before allowing the carriages to reverse direction.

Alternate Field Recording

In the alternate field recording mode of operation, head sequencing is the same as for the normal recording mode, except that it is triggered at half the rate. The rotation speed of the discs, the track width, and the track spacing is unchanged and only the odd numbered fields are recorded. During even numbered fields, no steps are triggered and the record amplifier is turned off. Erase current, however, is permitted to flow during the even numbered field intervals.

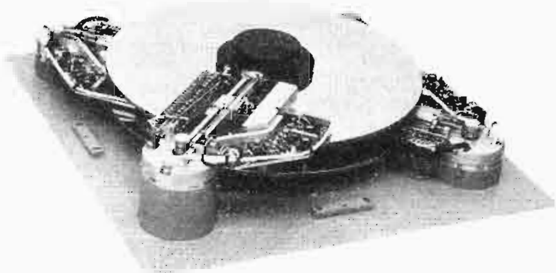


Fig. 98. Disc drive and stepper assemblies.

The record signal path, shown in Fig. 99 contains a modulator located in the electronics signal unit, a record amplifier, and four preamplifiers located in the disc servo unit. The modulator module contains a preamplifier circuit which amplifies the composite video input, a preemphasis network, and a modulator which converts the composite video to an FM signal (RF).

In the record amplifier module, the RF is amplified and divided into four sequentially gated outputs, each of which is applied to a different one of the four preamplifiers. Each preamplifier contains a relay which is energized during the record mode and de-energized during playback. During recording, signals gated out of the record amplifier are applied directly to the head transducer by way of a record current level adjustment potentiometer in the preamplifier and the preamplifier relay contacts. An erase circuit in each preamplifier supplies a dc erase signal to its associated head transducer when commanded to do so by a gating pulse. The same pulses that gate the FM signals out of the record amplifier supply the erase commands for the preamplifiers. The lines carrying the gating pulses are connected in such a way that the pulse that gates the channel A signal out of the record amplifier turns on the erase function in the channel B preamplifier. Similarly, the pulse that gates the channel B signal out of the record amplifier simultaneously turns on the erase function in the channel C preamplifier. This sequence, applied to all four channels, ensures that when one head is recording, the head that will record next is erasing previously recorded material.

In the normal speed forward direction playback mode, the sequence of carriage movement is identical to that used in record. The head connections are transferred, by means of relays, from the record and erase amplifiers to the reproduce preamplifiers. The outputs of the reproduce preamplifiers are sequentially gated through the rest

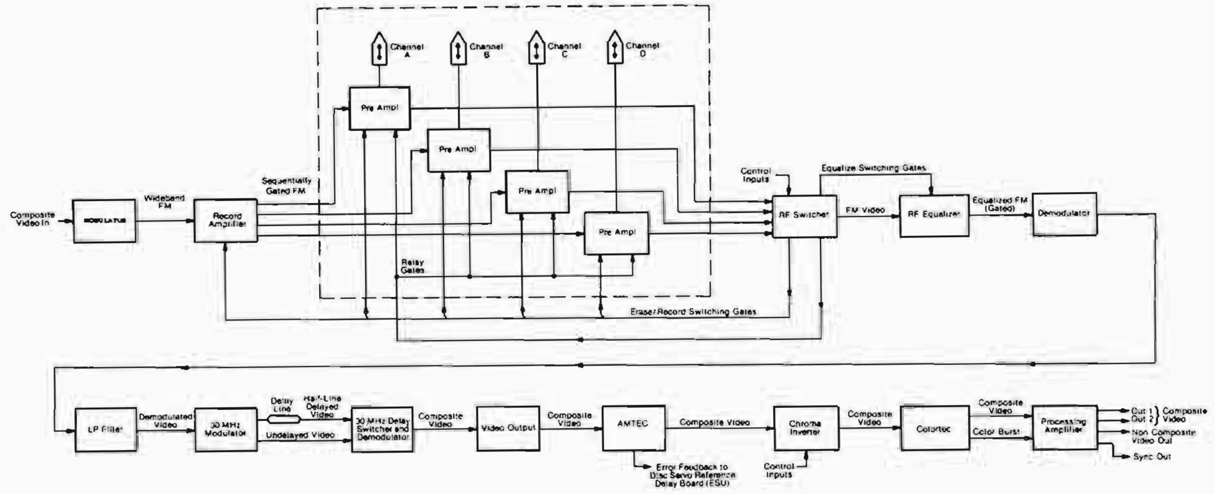


Fig. 99. HS-100 disc record/reproduce signal path simplified block diagram.

of the reproduce electronics in the same manner that the record current was gated to the heads in the record mode. Each field is reproduced in the exact sequence in which it was recorded, so that the demodulated video output is a standard NTSC signal.

In the still frame or freeze mode, the playback sequence is stopped on a particular field, and the system video output is derived from the continuously repeated playback of a single track. In this mode, line interlace and chroma phase are restored by special techniques to produce a standard television signal.

Line Interlace

The normal television video signal is a succession of odd and even fields characterized by a half-line shift of horizontal sync (with respect to vertical) in each field, Fig. 100.

This half-line shift produces line interlace of the two fields, constituting a frame, when displayed on a picture monitor. When, as in the case of still framing, each successive field is derived from the same recorded track, and is therefore identical to the one preceding it, interlace must be restored artificially.

The phasing of the record switcher on the disc recorder is such that each recorded field begins and ends just after the last equalizing pulse of the vertical interval (point A or B' of Fig. 105). Odd

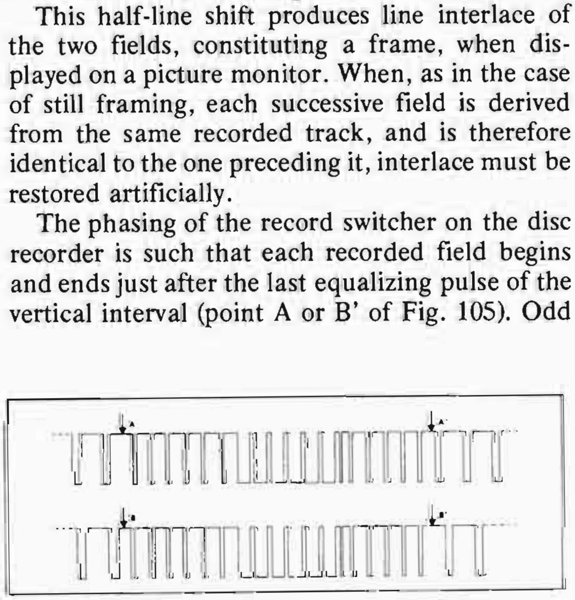


Fig. 100. Odd and even vertical field intervals.

fields, as recorded on the disc by Heads A and C, begin at A' and end at B'; even fields, as recorded by Heads B and D, begin at B' and end at A'.

To produce line interlace artificially, odd fields are changed to even fields, or even fields are changed to odd fields, by insertion of a half-line delay in the video signal during the horizontal scanning interval of each field (i.e., from A to B, or from B to A). The half-line delay insertion is controlled by the system logic. By knowing what type of field is required, by examining reference sync, and knowing what type of field is being reproduced by each head, the logic controls the insertion of the half-line delay as required, always removing the half-line delay during the vertical interval A to A and B to B. Accordingly, when still framing, the half-line delay is inserted during the horizontal interval of alternate fields.

Chroma Phase

In the NTSC color system the frequency relationship between the 3.58 MHz chroma subcarrier and the horizontal and vertical scanning rates are such that the chroma phase advances 180° each line and each frame, dot interlace. This minimizes chroma-luminance crosstalk since the effects are reversed on successive scans.

In still framing, a chroma-phase problem arises from attempts to generate a continuous signal from a single recorded field. In scanning a complete field, the chroma phase at the end of the field is advanced 90° with respect to its phase at the beginning of the field. If the field is then rescanned from the beginning, 90° phase discontinuity appears in the chroma signal at the beginning of the scan. This would not only destroy dot interlace, but in a normal receiver would seriously disrupt the color demodulation process.

The chroma phase shift is further influenced by the insertion or removal of the half-line delay.

Insertion of the half-line delay retards the chroma phase 90°; removal of the delay advances the chroma phase 90°. Thus when the half-line delay is inserted at the beginning of a rescan, its 90° phase-shift adds to the 90° shift caused by rescanning, producing a total chroma phase shift of 180°. Conversely, if at the beginning of a rescan the half-line delay is switched out, its phase shift cancels out the 90° shift caused by rescanning. The combined result when still framing, therefore, is that a 180° phase shift occurs in the chroma phase at the beginning of every second field. This effect is compensated for by a chroma inverter which extracts the chroma signal, including burst, from the composite video playback signal, reverses its phase each time the half-line delay is inserted, and recombines it with the luminance portion of the signal.

Slow Motion

Slow motion is essentially a combination of normal motion and still framing. To produce the effect of slow motion, each recorded track is scanned not once but several times, depending on the slow-motion rate selected, after which the playback signal is taken from the next track. Selection of a particular speed determines the average number of scans per track, even though some tracks may be scanned more often than others. For example, if a speed reduction of 2:1 is selected, each track is scanned twice; at a 3:1 reduction, each track is scanned three times. At a 2.5:1 speed reduction, half the tracks are scanned twice and half are scanned three times. Thus speed control is continuously variable from normal to freeze.

During the time a particular track is being rescanned, the system operates exactly as described for still framing (freeze mode). Carriage motion stops, the signal is derived from one particular head, the half-line delay is switched in or out at the beginning of each rescan, and the chroma phase is reversed each time the half-line delay is switched in. When the playback signal is advanced from one track to the next, carriage movement and head switching progress from one field to the next as in normal motion. Since switching from one track to the next produces a normal transition from one field to the next, the state of the half-line delay and chroma inverter remains unchanged during the transition. That is, if the half-line delay was in the signal path before the switch, it remains in after; if it was bypassed before the switch, it remains bypassed after. Similarly, no inversion of the chroma phase is carried out at this time.

In reverse motion playback, the sequence of carriage motion and head switching is reversed and the carriages are made to move in the opposite direction. Thus,, the fields are played back in opposite sequence to that in which they were recorded.

The head switching sequence, D, C, B, A, preserves the normal progression of fields from odd to even, but loses the track-to-track continuity of the chroma signal. In switching, for example, from Head D to Head C, switching is from the end of one field to the beginning of the one which preceded it in the original recording. This constitutes a 180° chroma-phase reversal, which must be corrected by reversing chroma phase in the chroma inverter. Thus, when switching from track to track in the reverse motion direction, the half-line delay is not altered but the chroma phase is reversed by the chroma inverter.

When rescanning a track in slow motion reverse, the action of the half-line delay and chroma inverter is identical to rescanning in the forward direction.

Recordings made in the alternate field record mode differ from those made in the normal mode in that only odd fields are recorded, the first field of each frame. Since all fields are odd, it is necessary to change the state of the half-line delay, i.e., either insert it or remove it, as the case may be, each time the signal is switched from one track to the next, both in the forward and reverse motion directions. In going from track to track in either the forward or reverse direction, the chroma phase is retarded 90°, which is cancelled out when the half-line delay is removed, and increased to 180° when the half-line delay is inserted. Therefore, in the alternate field record mode, it is necessary to reverse chroma phase by means of the chroma inverter each time the tracks are changed, and at the same time insert the half-line delay. When rescanning a track in the alternate field record mode, either in forward or reverse motion, the half-line delay and chroma inverter are controlled in exactly the same manner as in normal still framing.

Recording of only half the fields otherwise affects the system in the following ways:

a. The storage capacity of the system is doubled, from 30 to 60 seconds.

b. Speed-up of motion is available as well as slow motion. Speed is continuously variable from twice normal speed to freeze action (still frame).

c. Increments of motion from field-to-field are doubled in the reproduced picture. This becomes noticeable as jerkiness in fast-action sequences when played back at very slow speed.

The reproduce signal path, Fig. 99, contains the four head transducers, the four head preamplifiers, and RF switcher module, an RF equalizer module, a demodulator module, a low pass filter, a 30 MHz modulator module, a delay line, a delay switcher and demodulator module, a video output (amplifier) module, an Amtec assembly, a chroma inverter module, a Colortec assembly, and a processing amplifier assembly. The particular functions of these modules and assemblies are discussed in the following paragraphs.

During playback, the relay in each of the preamplifiers is de-energized so that the low level signals picked up from the discs by the head transducers are routed through the preamplifier circuits.

In the RF switcher module, the outputs from the preamplifiers are sequentially gated to the RF equalizer module in accordance with the playback mode, i.e., normal, slow motion, freeze, selected by the operator. The RF switcher also converts the control inputs from the system logic circuits into the gating pulses that control the record, erase, and equalizer switching functions.

The RF equalizer contains a master equalization circuit and four channel equalization circuits. The gating, switching, pulses applied to the RF equalizer select the applicable channel equalization circuit for the signals being gated out of the RF switcher. For example, when the RF switcher applies the channel A signal to the RF equalizer, it also applies a command signal to the equalizer module which routes the signal through the channel A equalizer circuit.

The outputs from the RF equalizer are applied to the demodulator. The circuits in this module convert the FM output of the RF equalizer to a series of identical, in both width and amplitude, pulses with a pulse recurrence frequency twice that of the FM signal.

The pulse outputs from the demodulator module are applied through a low pass filter to a 30 MHz modulator. The low pass filter integrates the pulses from the demodulator and attenuates the FM carrier. The resulting output from the filter is a carrier-free video signal which varies in amplitude in accordance with the pulse recurrence frequency of the demodulator output.

The 30-MHz modulator generates a 30-MHz carrier which is amplitude modulated by the demodulated video output of the low pass filter. The 30 MHz signal is then split into two paths. One path goes directly to the 30-MHz delay switcher and demodulator; the other path is through a delay line to the 30-MHz delay switcher and demodulator.

The 30-MHz delay switcher and demodulator contains a diode switching circuit which selects either the delayed video or the undelayed video, depending on the playback mode. In normal speed playback operation, the undelayed 30-MHz signal is selected; and in slow motion or freeze action operations the delayed and undelayed 30-MHz signals are selected alternately. The purpose of the delay line is to delay the signal by one-half line, approximately 31.4 μsec, to synthetically restore the interlace to the TV picture when repeating fields, i.e., it changes fields into frames. Switching between delayed and undelayed video is controlled by a timing signal originating in the signal switching logic.

The demodulator circuit in the 30-MHz delay switcher and demodulator module demodulates the selected 30-MHz input, delayed or undelayed, to produce a replica, composite video, of the video input that was applied earlier to the 30-MHz modulator module.

In the video output module the composite video signal is amplified and filtered, and the sync pulses are clamped to the required level. A de-emphasis network connected to the video output module compensates for the pre-emphasis applied during the recording process in the modulator module.

The composite video output is fed to the Amtec and reduces signal timing errors and also provides a timing error feedback to the disc servo reference delay. From the Amtec, the video is applied to the chroma inverter and separates the chroma from the composite video, electronically inverts the chroma in accordance with the operating mode, and then recombines the luminance and chroma to form an NTSC color signal. Chroma inversion does not occur during normal playback, or record, modes of operations.

The output of the chroma inverter is applied to the Colortec, which corrects residual signal timing errors. The Colortec output consists of two signals: one, the composite video and two, a time-corrected color burst signal. These signals are fed to the processing amplifier which combines the composite video and the time-corrected burst, added to back porch of composite video, to provide a time-corrected composite video signal.

Fast Search

Fast search is used to move the head rapidly, at about four times normal speed, from one point on the discs to another. In fast search, as in normal operation, the heads must remain precisely in step, otherwise loss of field-to-field continuity would result in subsequent playback. Therefore the sequence of motion is kept the same as in normal speed operation. Because of the inertia of the carriage drive system moving at search speed, it is not convenient to reverse the direction of travel of the carriages at the inner and outer limits of travel. Therefore a lamp and photocell arrangement, located on carriage drive A detects the approach of the heads to the inner and outer limits and briefly slows the carriage speed to normal while carriage direction is being reversed.

The HS-200 computer control console combined with the magnetic disc recorder provides a complete teleproduction and editing system. The

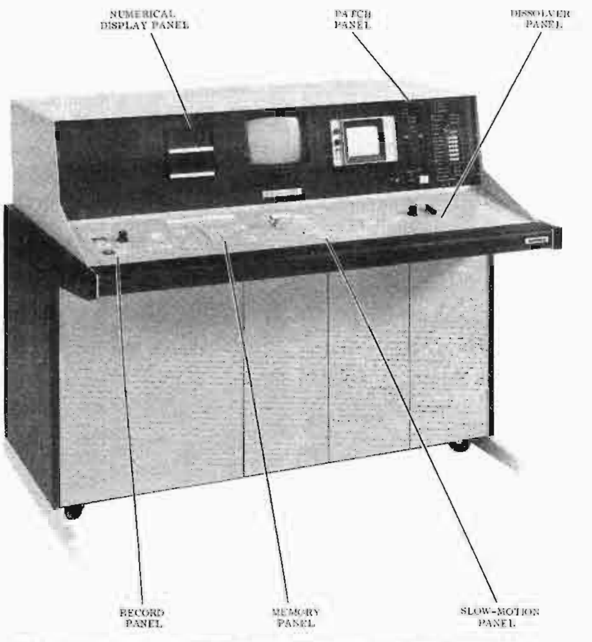


Fig. 101. HS-200 computer system control console.

combined system may now be used for complex electronic editing under the control of computer type logic, permitting automatic editing of complete programs, such as commercial spot advertising and animation sequences. The system can be controlled from the cue track of a quadruplex video recorder, allowing the transferring of video tape programming as desired to the magnetic disc medium for playback, instant replay, freeze frame, time-controlled freeze frame, double speed playback, slow motion, and variable animation assembly.

The main advantage in television production over video tape recorders is in its ability to repeat the same track for hundreds of passes without wearing the magnetic disc surface, and to play back frames in any predetermined order. The two video recording systems, magnetic video tape and magnetic video disc, combine the functions best performed by each and are entirely complementary.

Summary of Magnetic Disc and Computer Control Console Capabilities

Animation. The system has a total capacity of 900 frames. These may be all recorded in one operation or in short passages by alternately pressing the start and stop record buttons. Also, the system can be programmed to record any number of frames from one through 900 each time the start record button is pressed.

Animation can be preprogrammed and requires only two passes of the video tape on the VTR. On the first pass, cues can be recorded at appropriate places on the video tape. On the second pass, the computer control console will automatically compile the animation sequence using cues from the VTR to place the magnetic disc in record for a preset number of frames.

Manual or automatic time lapse. This is an extension of animation. As mentioned previously, the system will record a preset number of frames each time the start record button is pressed. The lapse-timer unit can be preset to perform this function automatically.

Random access to any frame. The machine has a frame counter which gives every frame an address. Using the keyboard numerical entry system, any number from 1 to 900 can be entered into store. When pressing search, the equipment will search out the desired frame and display it in freeze. This frame could be considered as an individual frame or the first frame of a sequence.

Variable-speed playback in forward or reverse. As on the magnetic disc recorder a choice of three speeds is selectable by push buttons. Slow motion 3 position provides continuously variable speed from normal all the way to freeze under the control of a lever. On the computer control console all of these functions are accessible through the patch panel which also enables preprogramming of these functions.

Freeze frame or field. On the magnetic disc recorder a freeze picture is obtained by repeating one recorded field. A half-line delay is used to turn odd fields into even fields and vice versa to produce a frame. Because we are repeating fields, there is a loss of vertical resolution which is subjectively acceptable on most program material.

On the computer control console a freeze picture can also be produced by repeating two adjacently recorded fields to make up the frame. In this way full definition is obtained. These two modes are called the field and frame modes, respectively.

If a freeze picture of some recorded fast action is required, then the field mode must be used because the frame mode would produce a blurred picture due to the fact that it was made of two pictures recorded 1/60th of a second apart.

Stop motion is produced by repeating fields or frames. The same choice of repeating frames or fields is available in slow motion.

Time-controlled freeze frame. Any frame can be accessed and held in freeze for any time period between two frames and 900 frames before another mode such as a switch or forward or reverse motion is actuated.

Automated dissolves of variable length. The computer control console includes a digital dissolver. The dissolve rate can be preset to be any one of the following: Cut, 4, 8, 11, 16, 22, 32, 43, 64, 86, 128, and 256 frames. A dissolve between any two channels (one of which could be the output of the magnetic disc) will take place at the push of a button, at the receipt of a remote cue, or at any frame address in the memory store.

Matting and keying. The matting and keying amplifier in the computer control console allows adjustments of luminance, chrominance, and saturation of the matting signal. This device will key or matt at the push of a button from a remote cue, or from any stored frame address. The time duration of the key or matt can also be controlled. One very useful application is the animation of special keying patterns which can be stored on tape for future use.

Computer logic for sequential preprogramming. A solid-state memory unit stores up to eight switching, mixing, editing, timing, and slow-motion commands and holds them until cued. Once the preprogramming is completely set using the patch panel, an entire sequence can be assembled automatically.

Two-way remote control. The equipment will receive cues from a VTR in the form of logic commands or tone bursts and will act upon them through the patch panel. It will also send signals to another magnetic disc recorder system or VTR. This, for example, permits preprogramming of an A-B roll consisting of cuts, dissolves, and slow-motion effects between the two machines.

Random access slide store. The magnetic disc recording system can be used as a buffer store for a sequence of color slides. Up to 900 slides can be recorded on the discs. The memory store can be programmed to search for up to eight slides, displaying each one for a predetermined period.

Concept of Editing and Special Effects Utilizing the HS-200 Teleproduction and Editing System

The simplest concept of motion picture editing (either film or tape) is that of "assembly": the putting together, in sequence, of various scenes available from prerecorded material, or the production of scenes in the required order at the time of editing. The process of assembly from prerecorded material involves locating the desired sequence and attaching it to the preceding one either physically, photographically or electronically. This is actually the only way it can be done with film with any degree of precision or artistic flexibility. With either tape or disc, however, assembly and recording can be accomplished concurrently by producing the scenes in order and recording each one to its desired timing and making the desired transitions. The HS-200 magnetic disc recorder and computer console adds an order of magnitude to the ease, speed and precision with which this can be done, and progress may be reviewed as the operation is carried out.

Insertion of new material into previously recorded material is a common requirement. Accurate placement of the insertion with regard to preceding and following material requires the ability to determine the "in" and "out" edit points of both the new material and the material into which it is to be inserted. There are two possibilities for carrying out such an operation: (1) the material to be inserted is recorded on the magnetic disc and cued with extreme accuracy to the desired "in" point and then electronically edited into the prerecorded sequence on tape from cues previously placed and precisely adjusted. (2) The original material is recorded on the magnetic disc and the new material inserted at the desired points from any other source, once again with one-frame accuracy of placement.

The "cut" (an instantaneous change of scene) is the simplest of video transitions both physically and subjectively, timing being the only variable. With film, proper timing is accomplished by selecting the frame at which the cut is desired. The magnetic disc control console offers this facility by allowing leisurely study of material at a frame-by-frame rate, and also allows realistic preview of the cut before it is accomplished.

The "dissolve" is a more complex transition requiring the fading out of the first picture simultaneously with the fading in of the second one. Timing again is the critical point, not only as to when the dissolve occurs, but in how long it will last. With film this is done in the optical printer with precise control of the number of frames involved, and is an operation that must be entrusted to the lab technician. With the computer control console and an accompanying video source, dissolves may be achieved with the same accuracy and automatically controlled as to the length. Again the major advantage offered by this system is the ability to preview or rehearse the effect with the possibility of desired adjustments before actually performing the final transition.

The "fade" involves simply fading from picture to "black" or vice versa. It is easily accomplished in a number of ways. It can be done at the time of recording or during the editing process. The advantage offered by the computer control console in this operation is accuracy of timing.

The "A-B roll" technique, commonly used in film production, involves dividing the production into "odd" and "even" scenes. The "odd" scenes are placed in sequence on one video source and the "even" ones on another. With proper timing between the two sources, "odd" and "even" scenes are then combined into the desired final form. With the precision of control available, this is easily accomplished within the computer control console and a second video source.

In keying process, one picture signal is inserted into another, e.g., a title into a background scene.

In film this is a laboratory process requiring time and expense. In television it is achieved electronically by combining two video signals. The main use of the computer control console in this process is as the source of the signal to be keyed. Because of its frame-at-a-time capability in playback, material to be keyed may be recorded on succeeding frames and keyed into the background as desired and changed on cue. Animated titles or products can be recorded on the magnetic disc and keyed into other material with full control of movement and timing.

The time lapse technique, which might also be called "time compression," allows the reproduction of lengthy events to be condensed as much as desired. This effect is accomplished by taking picture frames at selected intervals during the event being recorded, rather than recording it continuously. When the reproduction is played back in a continuous manner, time compression is achieved. In other words, if one frame is recorded every five seconds during a 15-minute process, we will finish with a total of 180 frames. If these frames are played back at the normal rate, 30 fps, the whole event can be viewed in 6 seconds. This is done on film by exposing one frame, either manually or by a timer, at every selected interval. The same technique is possible on magnetic recordings with the magnetic disc recorder. Two advantages accrue: (1) The reproduction is immediately reviewable. (2) Playback is not locked to any particular frame rate (as it is in film), allowing the length of the event to be manipulated to fit any time segment.

Simulated time lapse, which produces the effect of time lapse, is achieved by combining the backward motion and single frame recording capabilities of the magnetic disc. For example, a potted plant may be placed on camera, a series of frames recorded, and between each "take" a little of the plant snipped off until the plant has been cut entirely away. If this sequence is played in reverse, the plant seems to grow before the camera. This can be applied to a number of different subjects.

Slow and fast forward motion have long been available on film. They are achieved by photographing at either a faster or slower frame rate than normal, and playing back at normal speed. The desired speed of replay must be determined at the time of photographing as there is usually little or no flexibility in the speed of film playback. The magnetic disc recorder, however, allows complete control of the speed of playback from stop to normal speed, and these speeds may be varied as desired. For faster-than-normal motion two different techniques are available with the disc recorder. The first is "time lapse," explained previously. The second is a technique in which every other field or frame is recorded. Playback at normal speed then provides double speed action, once again with variable speed down to full stop.

Stop action is an often-used effect in which a normally moving scene suddenly "freezes," and, if desired, subsequently returns to normal motion. In film this can be accomplished in the laboratory printing process. This effect is easily achieved with the magnetic disc recorder and action can be programmed to stop at a pre-selected point and to continue at a pre-determined time. All the flexibility of direction and speed of playback are also available in conjunction with this effect.

Animated titles are created by moving and manipulating the elements of the title. In film this is the job of the "animator" who uses a special camera and associated equipment. With the magnetic disc computer control console, many if not all of the desired title effects can be accomplished in the studio using normal television equipment. Again the frame-at-a-time and reverse playback capabilities of the magnetic disc are useful. The effect of a title "writing itself" is achieved by shooting a complete title, and then on subsequent "takes" blacking out a portion between each frame. This material, once recorded on the magnetic disc, can then be "keyed" through a background.

With the magnetic disc and computer control console, anything that can be animated on film can be animated on tape. The process of taking animated pictures is merely that of one-frame-at-a-time photography, for which the recorder is exceptionally well suited. The important advantages of the system allow the material to be viewed, and if necessary manipulated, before it is photographed, and provides results that can be instantly reviewed after production. These features apply equally to animated "cells," live or static models, and printed art work.

The flash cut technique results in a series of very rapid changes of scene, possibly as many as three or four per second. At a slightly slower rate of scene change it is sometimes referred to as "squeeze action" and gives the effect of jerky animation. In film this can be handled on the animation stand if the picture material is static, or in the printing process if movement is required within each short sequence. With the magnetic disc recorder control the effect is achieved for either kind of subject by simply recording the required number of frames of the first subject, and then repeating the process in sequence for each following subject; this can be done as rapidly as the subjects can be changed. A variation of this technique, which gives an almost subliminal effect, calls for the repeated brief insertion of other material into a continuous scene. This effect is accomplished on the system with only the need to determine in advance the

Fig. 102. VR-3000 portable quadruplex video tape recorder.

intervals at which the insertion is desired. The number of insertions, or flash cuts, and the times at which they occur can be precisely controlled and programmed with an accuracy of 1/30th of a second.

Quadruplex Portable Video Tape Recorded

The Ampex VR-3000 Portable Video Tape Recorder provides for the first time a rotary head quadruplex recording system in a miniaturized light weight, battery operated, portable configuration. The compact unit is switchable between low band monochrome (LBM) and high band (HB) NTSC color or monochrome. Video tapes recorded on the portable video tape recorder are interchangeable with all other quadruplex VTR equipment.

Fig. 103. VR-3000 portable recorder and companion camera.

The compatibility with other broadcast VTR equipment is of paramount importance to accomplish a free flow of video tape interchange in television program productions, remote news programs, on-location features and on-site commercial advertising productions.

Video tape path dimensions cannot be changed without compromising interchangeability; therefore, this recorder meets and complies with all SMPTE recommended practices and USASI standards and at the same time is packaged in a unique fashion and the permissible weight is only a small fraction of that of the smallest existing broadcast VTR machine. As well, hand-held companion cameras have been designed to complement the portable video tape recorder. An overall portable recording system is shown in Fig. 103.

The recorder and the associated camera is portable by a man. There is obviously a limit to the weight that he can carry, particularly if he is asked to exercise an artistic appreciation of the picture he is recording. This limit of weight influences greatly the design of every component of the system, electrical or mechanical. The power consumption of each circuit is optimized very carefully, the size and weight of the battery pack is to be kept within reasonable limits. This equipment must also operate with the variable environment in which recording may be performed. The range of temperature must be at least from that of a skiing resort to that of a mid-summer sun (minus 20C to plus 55C).

More difficult than the temperature problems are those created by all the possible accelerations the equipment may be submitted to, such as operation on back-pack, aboard a car, an airplane or a helicopter. These produce spurious inputs into the various servo mechanism loops, thus creating entirely different problems from those of fixed machines.

The determination of what constitutes a reasonable use of this equipment is in itself a problem. The spectrum envelope of vibrations aboard helicopters, heavy airplanes, and automobiles is well known. A subjective criterion can be established for TV use by saying that the portable recorder should perform for all movements of the camera producing a usable picture.

The tape transport is conceived in such a way that, apart from the transducers, no fixed element is in contact with the oxide of the tape, so that the generation of scratches are minimized. The capstan operates according to the principle of "minimum work" and does not require a pinch roller. The tape path is relatively unconventional, but the critical dimensions determining the position of the recorded information on the tape are exact, conforming to the established recommended practices. The tape transport design for

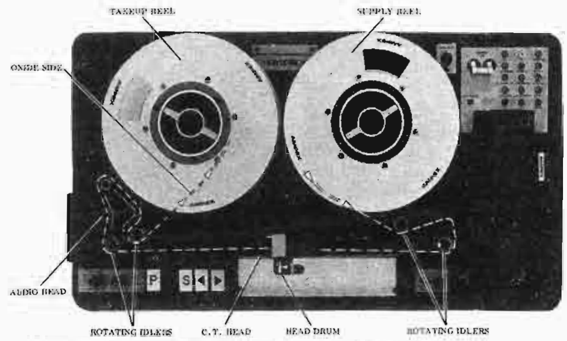


Fig. 104. Portable quadruplex video recorder tape threading path.

the portable recorder shows the tape path and major element of the portable video tape recorder in Fig. 104. The tape is wound "oxide in" on a standard 8-in. reel, permitting about 72 minutes of video recording tape to be accommodated. The tape path used causes the oxide side of the tape to be exposed to a minimum number of path surfaces and elements.

The unusual feature of this transport is the absence of a capstan pinch roller. The capstan without a pressure device depends solely upon the tension of the tape wrapped around it for its grip on the tape. A large tape wrap angle is provided by the transport design. This provides adequate "grip" to permit the capstan motor to remove disturbances in the tape transportation process.

The greatest of these is caused by angular acceleration of the entire package in the plane of the reels. The average work done by the capstan motor (in the absence of disturbances) is held to a minimum by maintaining constant tension at the output of the supply reel. Supply reel holdback tensioning is provided by a magnetic particle brake, where the torque drag is electrically controlled by a tape tension arm near the supply reel. This brake is more efficient than a motor system.

The supply brake is also used for "parking" the supply reel during movement of the machine prior to use. While parked, the take-up motor supplies a slight torque to maintain a tight tape path, and will even restore a tight tape path, if a severe lurch during transportation of the machine should loosen the tape.

Since the capstan motor does minimum work and a brake can do none, it is clear that all tape motion is powered by the take-up motor. The proper choice of this motor is paramount in achieving good overall electro-mechanical efficiency.

A dc motor is most efficient when operating near its maximum speed, and of course has zero efficiency when stalled. Since reels turn rather slowly at 15 in/s, a motor is needed whose unloaded maximum speed is low.

While a dc motor is a logical choice for a high efficiency head drum drive, at high speeds an ordinary dc motor can easily waste 15W or so in brush-commutator friction. To save the 15W is well worth the few ounces of electronics necessary to make what is called a "brushless" dc motor; a motor in which the switching, instead of being done by mechanical sliding contacts, is done by transistor switches using timing information derived from the rotation of the shaft. Since a drum motor tachometer is necessary for servo purposes, timing information is readily available without any weight penalty.

The vacuum guide is engaged and retracted by a tiny dc motor controlled by limit switches so that power is consumed only during movement. This motor, incidentally, is not part of the video head assembly but is affixed to the transport.

A small brushless dc motor drives a diaphragm-type vacuum pump. It is surprising how little air leaks past the seal formed by the tape and the vacuum guide vacuum slots. Such air flow capacity provided is needed to accommodate the occasional wrinkled piece of tape which will not seal properly at the female guide, and to pump away the air contained within the vacuum system in a reasonably short time.

The capstan motor is a small and higher-speed version of the take-up motor. Since it does a minimum of work, the average motor current is small. The motor is servo-controlled, being locked to the drum rotation. A tachometer on the back shaft provides speed information, while damping is provided by a servo loop electrically performing the same function as a flywheel. A flywheel large enough to absorb tape disturbances is too heavy and will not work in a machine subject to angular acceleration because of its great moment of inertia.

Where the power savings justify the extra circuit weight, switching-type voltage changers are used to obtain an efficient dc-to-dc voltage transformation. They are most useful when the voltage ratio is large as in power supply for some of the integrated circuits which operate at low voltage. Four main servo mechanisms are included in this machine: capstan loop, drum loop, and tape-tension loops.

The capstan servo differs from the usual in many ways. Most of the existing fixed machines use a capstan coupled to a heavy flywheel and a low-cutoff frequency loop. No tachometer information is collected in the record mode, and high frequency disturbances are absorbed by the large inertia. Such a solution is not possible in the case of a portable machine for several reasons. First, the inertia of the flywheel would prevent the capstan from following the rotational movement of the transport. Second, the starting time would be longer, an important factor in recording of quick action news events. Third, the weight and volume would be prohibitive. The adopted solution is a low-inertia high-cutoff frequency loop capstan. A high rate of tachometer information is collected by measuring the speed of the capstan with respect to the transport, and by supplying the error to the high frequency loop. A problem associated with such a scheme is that it is difficult to realize an error-free tachometer. Very tight mechanical tolerances and an optical electrical compensation device are used. The cutoff frequency of the capstan servo-loop is at least 100 times that of previously designed VTR equipment.

The head drum servo mechanism function is to drive the heads at a very precise speed and to position them with respect to the tape. The problem is compounded by the movements of the transport with respect to the rotor of the drum motor. Certain applications, helicopter or car, produce vibrations at relatively high frequencies. Some vibrations may have direct rotational components, or their application in certain directions, with respect to the center of gravity of the transport, may transform them into rotation in the plane of the drum. These vibrations would produce timebase and velocity errors that must be eliminated. It is necessary to have a much higher cutoff frequency than is usually required in a fixed machine while in the record mode. High rate tachometer information is again necessary, thus presenting the same problem as with the capstan servo, which is solved by different means, but identical in principle. An electronic tachometer eccentricity cancellation device is as well utilized.

The power consumption is a most important factor in a portable unit. The head drum motor, which requires the largest share of the available power, must be as efficient as possible. The necessary high frequency response of the servo loop is more easily obtainable with a motor having a dc motor transfer characteristic. A brushless dc motor especially designed for this application is used.

The function of the tension-servo mechanism is to maintain the tape tension at a nearly constant value, from beginning to end of the reel of tape, and under any condition of tape friction or guide vacuum variation.

It was mentioned earlier that the capstan operates under the principle of "minimum work." This means that the power to move the tape is supplied by the take-up reel motor that works against the braking action of all frictions in the tape path plus that of a magnetic particle brake attached to the supply reel shaft. Ideally, the capstan does not supply any work when the tape is going at the proper speed, and only addition and subtraction of torque is needed when the tape speed differs from normal. The tension differential between the two sides of the capstan is maintained within limits by the tension-servo loop. The advantage of this scheme is that it leaves a large reserve of torque available to take care of the perturbations.

The only readily available batteries which meet the weight and size requirements are silver-cadmium units. The batteries chosen supply about 3W per ounce of battery over 60-minute operational periods without risking damage due to overdischarge. A battery having a nominal voltage of 33 v was chosen, and a center-tape is provided. This permits an adequate voltage for 12 v regulators even when the battery is at the end of its discharge cycle, at which time its voltage will fall to plus and minus 14 v.

Taking wattage, voltage, age factor, and reserve into account indicates a battery having a capacity of four ampere-hours. The battery in use consists of 10 three-cell units of 3.3 v each. When interconnected and packaged in an insulated container with connector, the completed battery weights seven pounds. Where ac power is available the portable video recorder can be operated from a battery eliminator ac power pack in place of the battery pack. The portable quadruplex video recorder, and companion camera, serve as excellent examples of the weight and size economies to be gained by careful selection of energy convertors and careful matching of those convertors to the work load. The weight of the recorder is 55 pounds including the back pack rack, an additional approximate weight in the hand-held camera is 15 lbs.

The signal system function is to supply the recording heads with the proper frequency modulated current to drive the tape. The recording capability of the portable video recorder signal system produces a final recording equal to that previously described in the VR-2000 video tape recorder/reproducer and with a power consumption of only a fraction of what is required. It uses the technique of square-wave recording signals, presenting the advantage of a less critical optimization of the head current, and less sensitivity to stray magnetic fields. The advantages of integrated circuits have been fully taken, as well as the power consumed per circuit function is generally less.

Verification of recorder performance is provided and playback is accomplished from the demodulator output. This, of course, does not provide for the regular signal processing amplifier. The composite uncorrected video output is of sufficient quality level for audition of recorded takes and good verification in field operations. Video tapes recorded on the VR-3000 portable recorder will provide the same high quality playback level as though they were originally recorded on the VR-2000 recorder/reproducer.

The portable recorder is designed to accommodate European television recording standards by simply replacing a single circuit board in the recorder electronics.

Beyond the fact of compatibility with other broadcast recorders and the interchangeability of video tape recordings, it is essential to preserve the final stability of the recording within a wide range of environmental and motion conditions; such as in flight and mobile field operations. In quadruplex recorders, longitudinal tape flutter is not translated as much into video time base instability since the primary head-to-tape velocity component is transverse to the tape motion. This, and the advantage of the lighter mass, and low inertia of the quadruplex rotary head drum format is most favorable to the realization of the necessary high performance servo system providing better angular error correction and acceptable time base stability particularly critical in color television broadcasting application.

THE STANDARDIZATION OF VIDEO TAPE RECORDING

Before discussing the standardization of video tape recording, it might be useful to review the overall program of standardization handled by SMPTE. Basically, all American standardization goes through the United States of America Standards Institute (USASI), formerly the American Standards Association (ASA). The ASA has since been reorganized and is now a new corporation, the USASI. This organization holds the responsibility in the United States for all national standards which are often generated in many places and through many channels. The SMPTE generates through its engineering committees all of the standards in the motion picture field, and currently many of the standards in the operational phase of the television field.

One may consider that USASI Standards are formed by a seven-link chain. The first link is the origin. Standards do not necessarily originate within SMPTE engineering committees, although this is generally the case. They can originate anywhere.

Once the need for a standard has been established, the video tape recording engineering committee formally takes it under study. If the proposal needs work, it is turned over to a small subcommittee appointed by the main committee, which prepares the first document and circulates it to the full engineering committee for a letter ballot. Once approved, the proposal is then reviewed by the SMPTE Standards Committee, which consists of the chairmen of all SMPTE engineering committees. At this level the committee takes a look at the standard with respect to the overall field. For example, if a standard is generated in the Video Tape Recording Committee, the Sound Committee chairman then looks at it in terms of that committee's responsibility.

Once a draft standard is approved by the SMPTE Standards Committee, it is published in the SMPTE's Journal for a trial period during which time criticism is invited. All comments are reviewed by the chairman of the Reviewing Committee as well as the chairman of the USASI Standards Committee which review the document concurrent with publication. This committee operates under USASI regulations and belongs to the organizations which make up the membership. Here, the voting members speak for their companies and examine the proposal in terms of industrial acceptance. The SMPTE, as the administrative sponsor of the USASI Standards Committee C-98, carries the responsibility for insuring that a balance of membership is maintained by the producers, distributors, retailers and consumers. It further assures that the views of all parties substantially concerned have been considered in the preparation of the standards. As sponsor, the SMPTE also acts as a secretariat for all committee functions and responsibilities.

With the approval of the USA Standards Committee, the SMPTE Board of Governors, as the official voice of the society, gives the society's approval. The document then proceeds to the USASI Standards Board. Once this approval is received, the standard becomes a USA Standard, and is published in the Journal for public information and there first utilized for reference purposes.

Although the society generates standards, it does not provide the document for sale. Once a standard is approved by the USASI, it becomes their property and is published and distributed by the institute.

Another document that the society generates is the Recommended Practices. There is a philosophical difference between the Recommended Practices, and the Standard. They are both generated by the same people but the Recommended Practices are considered more as for good engineering practices to the industry than as basic standards.

A serious area of misunderstanding involves the difference between a standard and specification. Many people come to the society asking for a standard when in reality they want a specification. For many reasons a scientific organization such as the SMPTE cannot write specifications. This is done by trade organizations. For instance, there are many associations in the television field—the Electronic Industries Association (EIA), the National Association of Broadcasters (NAB), and many others. One can say that the difference between the two types of organizations is that the technical society generates the numbers and then the trade association writes these numbers into specifications.

The rapid growth of the field of Electrical Standards has resulted in the problem of borderline responsibilities. These problems are dealt with through a group called the Joint Committee for Inter-Society Coordination, which has representatives from the NAB, the Institute of Electrical and Electronic Engineers (IEEE), the Electrical Industries Association (EIA) and the SMPTE. If a proposal is submitted, which appears to fall under more than one organization, the JCIC decides which of these four should undertake the task.

The SMPTE also works on the International level. Quite recently, a technical committee was organized for the standardization of video tape recording through the International Electrotechnical Committee (IEC). The first meeting of this committee (SC60B) was held in March of 1968 in Paris.

The Video Tape Recording Committee has been functioning for over 18 years. The first meeting was held in June of 1958 under the chairmanship of Howard Chinn of CBS. It has been meeting regularly since then.

Throughout the history of the committee the emphasis, of course, has been on quadruplex recording for broadcast uses. The main assumption underlying this effort is the concern for interchangeability. When a video tape recording has been sent to a user in another location, it should play back on their machine as well as it does on the equipment providing the original recording. In order to illustrate the kind of guidance that the committee has received from the SMPTE Board of Directors, we may examine the charge of the committee. "To propose standards and good engineering practices for the construction, adjustment, operation and measurement of video tape recording and reproducing equipment and for those video tape dimensions or other characteristics which affect performance and interchangeability."

This, of course, is a reasonably general charge, and out of the whole spectrum of problems that arise in the process of developing a technology as complex as video tape, it has been necessary to study certain priority items before others.

The membership in the committee consists of experts—people who operate and manufacture equipment and are most concerned with video tape recording. In terms of their participation in the work of the committee, the members vote as individual experts and not as spokesmen for their companies.

The turnover in membership from year to year has not been great, but the committee has been expanded as the need for entry into various areas of this technology has arisen. Normally VTR Committee meetings are held about every two months in New York City at SMPTE Headquarters. The meetings are open to visitors.

It is worth noting that Recommended Practices are usually less menable to being locked up, so the Recommended Practices technique of expressing a consensus on the way to do something is useful. It allows a more rapid consolidation of information and dissemination of it into the field.

There is a good example of this in the case of RP11. This is the Recommended Practices dealing with the radius of the tape vacuum guide and its position for producing a standard video tape recording. This may seem like a relatively simple document when read, but the variables that were considered in drafting it are quite numerous. One has to compromise head wear and tape wear with dropout activity, for example. The whole question of friction between the rotating head and the tape as it affects servo-stability and tape life had to be evaluated. Data was gathered on both head wear and tape wear. This illustrates what may go into a document that ends up being less than a full page of typewritten material.

The committee is constantly revising or considering revision of existing documents. Automatic review is built into both the USASI Standards program and the SMPTE Recommended Practices program. The documents are reexamined at least every five years.

So far as future committee work is concerned, this depends on the rate of progress that the industry exhibits, and on the problems that are communicated to the committee. International activities will also dictate activity at home. The IEC, the International Electrotechnical Commission, and other groups—CCIR, the Consultative Committee for International Radio, and the EBU, the European Broadcasting Union—are at work on video tape recording standards. In general these reflect our USA documents, but are, of course, adapted where necessary to the fifty-field television systems used in Europe.

VIDEO TAPE RECORDING

"USA Standards"

C98.1	Dimensions of 2-In. Video Magnetic Tape
C98.2	Monochrome Video Magnetic Tape Leader
C98.3	Audio Records for 2-In. Video Magnetic Tape Recordings
C98.4	Speed of 2-In. Video Magnetic Tape
C98.5	2-In. Video Magnetic Tape Reels
C98.6	Video, Audio and Tracking Control Records on 2-In. Video Magnetic Tape
C98.7	Primary Audio Reference Level Recording for Quadruplex Video Magnetic Tape Recorders Operating at 15 In./s
C98.8	Audio Level and Multifrequency Test Tape for Quadruplex Video Magnetic Tape Recorders Operating at 15 In./s
C98.9	Color Video Magnetic Tape Leader
C98.10	Primary Audio Reference Level Recording for Quadruplex Video Magnetic Tape Recorders Operating at 7.5 In./s
C98.11	Audio Level and Multifrequency Test Tape for Quadruplex Video Magnetic Tape Recorders Operating at 7.5 In./s

Note: The above listed "USA Standards" (USASI) may be obtained from the:

United States of America Standards Institute
10 East 40th Street
New York, N.Y. 10016

VIDEO TAPE RECORDING

"SMPTE Recommended Practices"

RP 5	Dimensions of Patch Splices in 2-In. Video Magnetic Tape
RP 6	Reference Carrier Frequencies and De-Emphasis Characteristics for 2-In. Quadruplex Video Magnetic Tape Recording
RP 10	Video Alignment Signal Specifications for Quadruplex Video Magnetic Tape Recording
RP 11	Tape Vacuum Guide Radius and position for 2-In. Quadruplex Video Magnetic Tape Recording
RP 16	Specifications of Tracking Control Record for 2-In. Quadruplex Video Magnetic Tape Recordings
RP 26	Label Specifications for 2-In. Quadruplex Video Magnetic Tape Recordings
RP 29	Video Test Tape for Quadruplex Video Frequency Mag. Tape Recorders Operating at 15 In./s and Practice LBM of SMPTE RP 6
RP 30	Video Test Tape for Quadruplex Video Frequency Mag. Tape Recorders Operating at 7.5 In./s and Practice LBM of SMPTE RP 6
RP 31	Video Test Tape for Quadruplex Video Frequency Mag. Tape Recorders Operating at 15 In./s and Practice LBC of SMPTE RP 6

Note: The above listed "SMPTE Recommended Practices" may be obtained from the:

Society of Motion Picture and Television Engineers
862 Scarsdale Ave.
Scarsdale, N.Y. 10583

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