

# A New Segmented-Scan Helical Broadcast Video Recorder

*The following three papers describe a new broadcast video recorder using a new segmented helical-scan format. Reasons are presented for the choice of format; economic factors are mentioned along with certain special features. The recorder's servo system and timing-reference system are described.*

## The Recorder's Design and Economic Factors

By B. E. GUISINGER

A new broadcast recorder (Fig. 1) is described with the technical reasoning leading to the choice of a 180°-wrap, two-head, segmented video format and the practical and economic benefits derived therefrom. The choice of segmentation schedule clearly demonstrates a subjective integration of saturation and hue variation between heads. Carrier frequency selection as well as writing speed are discussed in terms of performance objectives. Special problems arising from the use of ferrite heads are presented along with the solutions. Special features and descriptions of some of the circuits employed are included.

INCREASED sophistication and the higher performance requirements of the television industry have pointed out the need for a new generation videotape recorder. Such a design was undertaken with the following goals in mind:

- (1) improved picture performance on all television standards;
- (2) increased editing flexibility and simplicity;
- (3) improved tape economy;
- (4) increased head life; and
- (5) high reliability and reduced maintenance costs.

In addition, the design must be consistent with all factors involving interchangeability.

Currently, the most difficult television standard to faithfully reproduce on a VTR is the 625/50 PAL system (the higher subcarrier frequency and wider baseband width being considerably more demanding than NTSC). This being the case, PAL was chosen as the system upon which to base the initial design.

### Choice of Scanning Method

At present, ferrite is the longest wearing material suitable for fabrication of video heads. Unfortunately, it has not proved reliable on transverse scanning equipment due to its brittle nature and the high impact force encountered with that scanning method. However, ferrites have been used successfully for many years on helical-scan recorders due to their inherent shallow entrance and exit angle

and nonrestriction of the tape by any "female guide" type of device. Therefore, transverse scan was eliminated as a practical scanning method as not consistent with the requirement of increased head life.

Helical-scan formats can be broken down into three main categories:

- (1) 360° wrap, one-head, one field/pass, alpha or omega wrap;
- (2) 180° wrap, two-head, one field/pass, omega wrap; and
- (3) 180° wrap, two-head, segmented field, omega wrap.

The decision of which of these scanning formats to use is not a simple one. The one field/pass systems offer the distinct advantage that no visible hue or saturation errors can occur during a single field. However, when weighed against the track length required for a suitable head-to-tape speed to attain the video performance goals, the interchange factors dismiss the practicality of a one field/pass system. As will be discussed later, with the chosen writing speed, a one field/pass



Fig. 1. The IVC-9000 broadcast recorder.

Presented on 18 October 1973 at the Society's Technical Conference in New York by Barrett E. Guisinger, International Video Corp., 990 Almanor Ave., Sunnyvale, CA 94086. (Portions of this material dealing with operational and economic aspects of the IVC-9000 were presented at the Conference by Joseph Roizen, Consultant.) (This paper was first received on 18 October 1973 and in final form on 24 January 1974.)

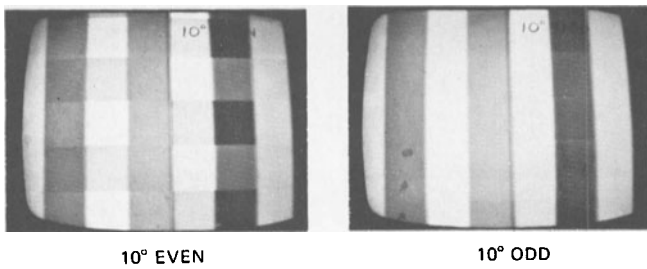


Fig. 2. Odd and even segmentation of scanning format.

system would require a 30-in (76.2-cm) track length. The choice is then a two-head, 180° wrap, segmented helical format.

#### Choice of Scanning Format

It should be noted that all of the mechanical and electrical parameters involved in the design of a VTR are interacting and the final choice is arrived at after a number of iterations. Therefore, it is difficult to write a step-by-step procedure. However, the choice must be made as to how many segments/field and to whether the number is odd or even (i.e., does Head 1 play the same portion each field, or do Heads 1 and 2 alternate on adjacent fields). Since "banding" is inherently possible in a segmented-image format, considerable effort was put into investigating ways to minimize this effect. If odd segmentation is employed, in NTSC, a hue error between heads is visually integrated at a 30-Hz rate such that the eye sees the average between the two colors. In fact, hue errors between heads of up to 20° can be tolerated before visual defects are perceived (see Fig. 2). However, because of the nature of PAL, odd segmentation produces a 12.5-Hz saturation flicker, which is very annoying, at the head switch points. The final decision was odd segmentation for NTSC and even segmentation for PAL.

#### Selection of Carrier Frequencies

Previously mentioned was the decision to design the recorder for the more stringent requirements of PAL. PAL has a subcarrier frequency of 4.43 MHz and a base bandwidth of 6 MHz. Principal causes of signal degradation are the moiré components caused by the FM modulation techniques that are current practice. These are:

Where:

- $f_s$  = spurious frequency
- $f_c$  = instantaneous carrier frequency
- $f_{sc}$  = color subcarrier frequency

(1) Folded 3rd order sideband (inherent)

$$f_s = 2f_c - 3f_{sc}$$

(2) Folded 4th order sideband (inherent)

$$f_s = 2f_c - 4f_{sc}$$

(3) Third lower sideband of 3rd harmonic (inherent)

$$f_s = 2f_c - 3f_{sc}$$

(4) Video feedthrough (man-made)

$$f_s = f_c = f_{sc}$$

(5) First L.S.B. or 2nd harmonic distortion (man-made)

$$f_s = f_c - f_{sc}$$

Since the higher the carrier frequency the more of these spurious components disappear, the blanking-level carrier is chosen for the worst-case calculation. Gaining an improvement in PAL moiré performance over current systems requires raising the carrier frequencies to a point that the third order folded sideband does not demodulate within the base bandwidth. Choosing 9.9 MHz as a blanking frequency, then (1) above becomes  $f_s = 19.8 - 13.29 = 6.51$  MHz which is down on the skirts of the demodulator lowpass filter and thus outside the baseband width. However, extreme care must be taken in the design of the entire RF system as the man-made components of (4) and (5) above will demodulate as  $f_s = 9.9 - 4.43 = 5.47$  MHz. The existing design will produce a 75% saturated color bar pattern with the moiré down in excess of 40 dB.

Through experimentation, it was determined that a significant improvement in signal-to-noise ratio could not be obtained by lowering the carrier frequency for NTSC (although this was perfectly feasible due to the lower subcarrier and base bandwidth). This was mainly due to the extremely high output obtained by use of ferrite heads. However, by leaving the carriers the same for both standards in addition to the advantage obtained by requiring fewer changes between PAL and NTSC recorders, a second advantage is gained. The previously mentioned man-made spurious components of (4) and (5) also demodulate outside the base bandwidth. This is,  $f_s = 9.9 - 3.58 = 6.32$  MHz, as compared to the NTSC baseband of 4.5 MHz. In a practical sense, this allows further misadjustment of the recorder before visual defects are seen. A still further, though small, advantage is to be gained in that the NTSC operation is now fifth-shelf moiré instead of the present equipment's fourth shelf. That is, in (2) above,  $f_s = 19.8 - 14.32 = 5.48$  MHz.

The carrier deviation and pre-emphasis was initially selected in accordance with

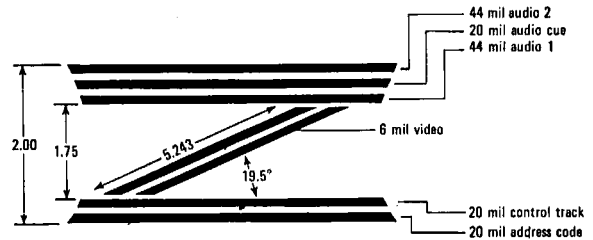


Fig. 3. Format of the physical parameters of the IVC-9000 system.

the current "high band" practice, the only deviation being the raising of the absolute frequencies. However, experimentation showed that on PAL and NTSC, an increase of pre-emphasis from 8 dB to 10 dB would still produce pictures with the specified moiré level with an attendant signal-to-noise ratio improvement of about 2 dB. The final carrier frequencies are:

NTSC: Sync tip . . . . .	8.92 MHz
Blanking . . . . .	9.9 MHz
Peak white . . . . .	12.35 MHz

PAL: Sync tip . . . . .	8.87 MHz
Blanking . . . . .	9.9 MHz
Peak white . . . . .	12.3 MHz

Pre-emphasis—10 dB all systems

#### Selection of Writing Speed

The determination of writing speed is essentially a question of recorded wavelength where:

$$\text{Wavelength } (\mu\text{in}) = \frac{\text{Writing speed (in/s or m/s)}}{\text{Frequency (MHz)}}$$

It has been determined experimentally that a magnetic tape system begins to suffer rapidly as the recorded wavelength of peak-white carrier approaches 100  $\mu\text{in}$ . Therefore, allowing a safety margin, the writing speed was selected as 1500 in/s (3810 cm). This produces a peak-white wavelength of 125  $\mu\text{in}$  (12 MHz). The aforementioned carriers and writing speeds have produced signal-to-noise ratios, on laboratory machines, of 47–48 dB PAL and 49–50 dB in NTSC. These tests were conducted using standard gamma ferric oxide tape which is longitudinally oriented.

#### Final Format Determination

Through extensive discussions with television broadcasters throughout the world, it was determined that the optimum configuration consisted of two high-quality audiotracks, a separate medium-quality cue track and a separate address code track in addition to the control track. These tracks are arranged as shown in Fig. 3. Note that the cue track separates the two main audiotracks to achieve maximum separation and that the two saturating tracks are on the opposite side of the video pattern eliminating crosstalk. Audiotracks are separately editable.

Computer studies were done analyzing the tolerance buildup of the various

guides as well as environmental changes and their effect on interchange. These show an ability to maintain interchange with the 6-mil videotracks and 3-mil guard bands. Maximum mistracking errors amount to 1 mil under worst-case conditions.

An additional benefit arises from the segmentation choice of odd/NTSC and even/PAL in that 60 fields  $\times$  5 segments/field = 300, and 50 fields  $\times$  6 segments/field = 300, so that the basic transport and servos remain the same for both standards and the writing speed is constant. The scanner spins at 9000 r/min on either standard.

### General Design Philosophy

An overall design philosophy was established early in the program. This comprised the basic idea, that the man servicing the machine was of prime importance. That is, there is one type of line driver, sync stripper, servo loop and restoration system, etc. Through the enforcement of this philosophy, the service engineer should experience a reduced number of subsystems to learn before becoming adequately familiar with the equipment.

The same consideration was applied to the equipment operator. Where possible, all setup controls were eliminated or supplemented with automatic systems.

This discourse, while deviating from purely technical, is intended to emphasize the fact that the engineer's duty is not one of a purely technical nature, but one of an optimum man/machine interface.

### RF System

Implementation of the RF system is probably the single most critical area in the electrical design of a VTR. The requirement for flat, equalized amplitude response and linear phase response from approximately 4 MHz to 18 MHz is extremely difficult to obtain. If classical, constant-current record amps and voltage mode preamps are used, then any stray capacity associated with the heads gives rise to resonance effects and associated nonlinear phase response. At least some equipments used antiresonance circuits to cope with this effect. However, if this method is used, constant adjustment is required as the head wears and its inductance changes. A preferred method is to use a low output impedance record driver with electronic shaping ahead in order to effect the desired 6-dB/octave rise in response required to attain constant current. On the reproduce side, a current mode (low input  $Z$ ) preamp is used followed by electronic shaping to replace the 6-dB/octave loss, as opposed to using a voltage mode preamp. This technique has the advantage of "swamping" head resonance effects in both record and reproduce and reducing the number of setup controls.

Ferrite heads, as well as possessing long-wear characteristics, have extremely flat, unequalized, playback response when compared to metal heads (Fig. 4). Existing systems utilize "cosine equalizers" to equalize the playback response to attain a flat amplitude response prior to limiting and demodulation. These equalizers have the unique feature of allowing amplitude response to be varied without an attendant change in phase response. Since the playback of the RF signal from a VTR suffers only amplitude degradation without an attendant degradation of phase response, this circuit has very desirable characteristics. The configuration of a conventional "cosine equalizer" is shown in Fig. 5. Notice that, while the general shape is the inverse of the head response in Fig. 4, the conventional cosine equalizer is curving in the 4- to 6-MHz region while the head response is not. If this system were used as is, the demodulated RF would exhibit a differential gain problem. This is due to the fact that while attaining sufficient

boost to equalize the high frequencies, the low frequencies would become unequalized due to the low-end curvature of the equalizer. Fortunately, a solution to this problem exists.\* This is in the form of a "double tapped" configuration shown in Fig. 6. Where A is the point of the arrival of the 0 and 4T echo pair, B is the T and 3T echo pair and C is the 2T signal, T being the section delay. Figure 7 depicts the amplitude of the echo pairs and the 2T signal at each point. Notice that, if only the T and 3T echo pair are subtracted from the 2T signal, the response is that shown in Fig. 5 or a conventional cosine equalizer. However, if some of the 0 and 4T echo pair is added to the resulting response, it has the tendency to flatten the low end response while increasing the high end boost (Fig. 8). This characteristic is in the desired direction. The actual proportion of the 0 and 4T echo pair added

\* A. N. Thiele, "Horizontal aperture equalization," *Radio and Electronic Eng.*, 40: p. 193, Oct. 1970.

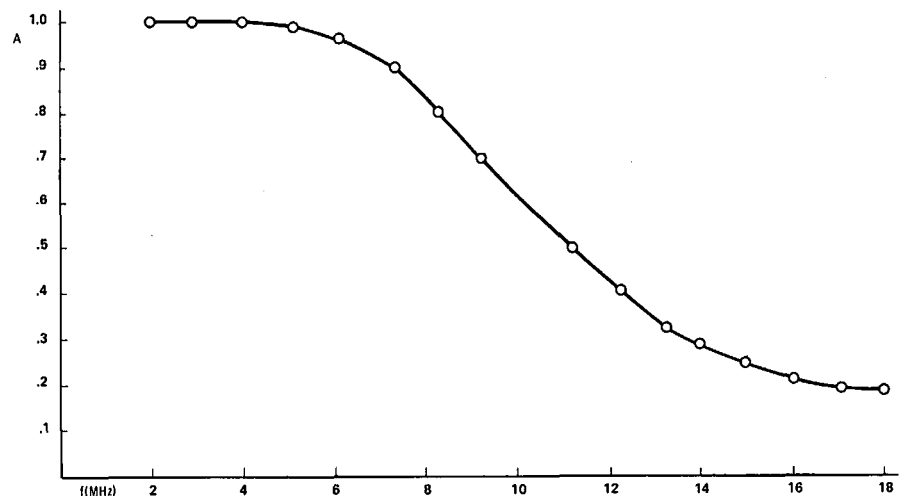


Fig. 4. Unequalized RF playback response.

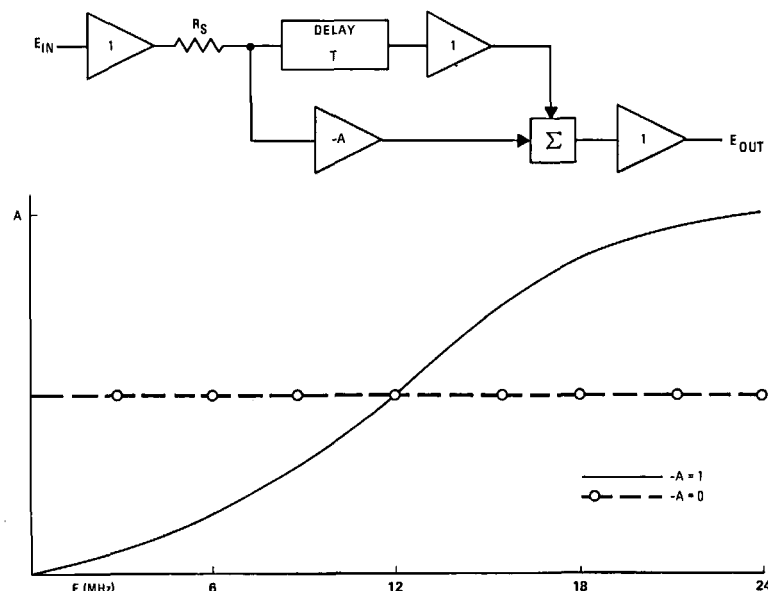


Fig. 5. Configuration of standard cosine equalizer response.

is determined empirically on the recorder to attain best differential gain characteristics over the range of head gap lengths and depths used.

The foregoing description is the method used to attain the equalization of the two heads used in the recorder. The procedure is to match the two heads to each other while obtaining best differential gain characteristics. Unfortunately, this does not always result in best overall frequency response. Therefore, the two-head, or "channel" equalizers are followed by a common, or "master," equalizer which is used to set overall response. Ideally, this equalizer should not affect

the differential gain response. This is accomplished by using a conventional cosine equalizer with a very short time delay, i.e.,  $T/2$ . This has the effect of moving the whole curve of Fig. 5 out in frequency and reducing the sloping characteristic in the low-frequency region. This equalizer is used for the final adjustment of baseband frequency response.

#### Special Features

Several special features of the recorder are worth noting. In addition to an "absolute auto chroma" system, the recorder contains a "chroma match" system which automatically matches

the color burst from Head 2 to that of Head 1. This insures that color saturation differences between heads will be eliminated regardless of the absolute level of the burst recorded. Thus, if it is known that the burst has been recorded at the wrong level, the "absolute auto chroma" may be switched off and an automatic system is still operating without fear of under- or over-saturating the picture portion of the chroma.

The unique input sync processing system of the recorder allows a switch-over to an internal crystal, for playback, in the absence of external synchronizing signals. In this mode, the monochrome time-base corrector is still operative. By locking a two-loop crystal oscillator to the burst from signal emerging from the mono corrector, it is possible to derive an artificial subcarrier at the average burst phase. This subcarrier is used in the color corrector to further reduce the timing errors to a level acceptable for full-color playback on an internally synchronized monitor. This feature can be especially useful for "quick lock" verification on remote location.

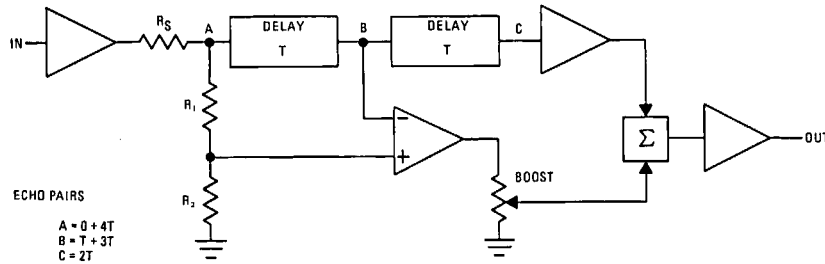


Fig. 6. Double tapped configuration of echo pairs.

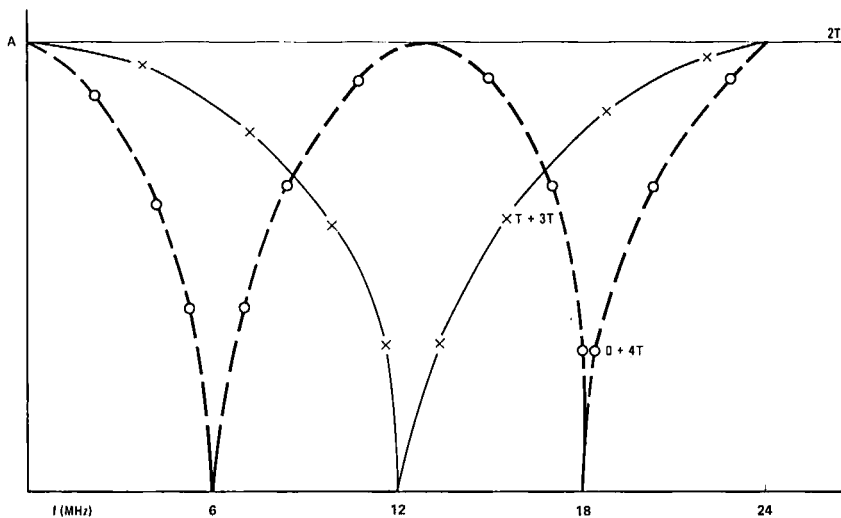


Fig. 7. Double tapped amplitude of echo pairs.

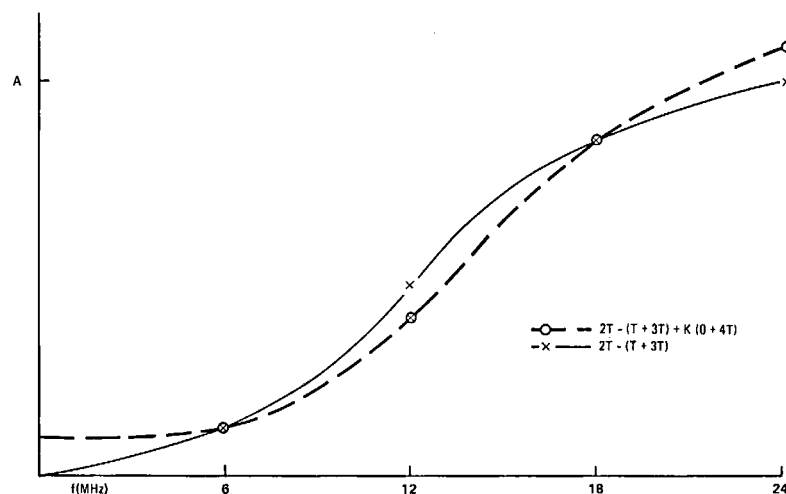


Fig. 8. Double tapped response of echo pairs.

#### Video Line Driver

Figure 9 depicts the basic video line driver used throughout the recorder. Note that an output is provided for assessment of the dc level and an input provided for restoration control. Transistors Q1 and Q2 comprise what has been referred to as a "super alpha" pair or a 100% feedback pair. This configuration can be viewed as a single transistor where the emitter of Q2 is the equivalent collector and the base and emitter of Q1 is the equivalent base and emitter. This connection has the advantage of reducing the familiar  $r_e = 27/I_e$  (ma) to approximately one tenth that value in the configuration shown. This means that in the differential amplifier shown, the gain modulation due to  $r_e$  variation with APL change is significantly reduced. Thus, differential gain through this stage is virtually immeasurable. The R/C combinations of C2/R6 and C4/R13 are internal compensation of the super alpha to prevent oscillation. Resistor R8 and inductor L1 are overall feedback compensation of the entire amplifier stage including the emitter follower output. The main advantage of inductive compensation as opposed to the conventional R/C compensation is that it is not necessary to know where electrical ground is located.

The complementary emitter follower output, consisting of Q5, Q6, Q7 and Q8, is unique in that the standing current automatically increases as the number of outputs is increased. Therefore, the same configuration can be used throughout the machine regardless of whether 1 to 4 outputs are required without wasting the same standing current in each one. This allows another degree of uniformity

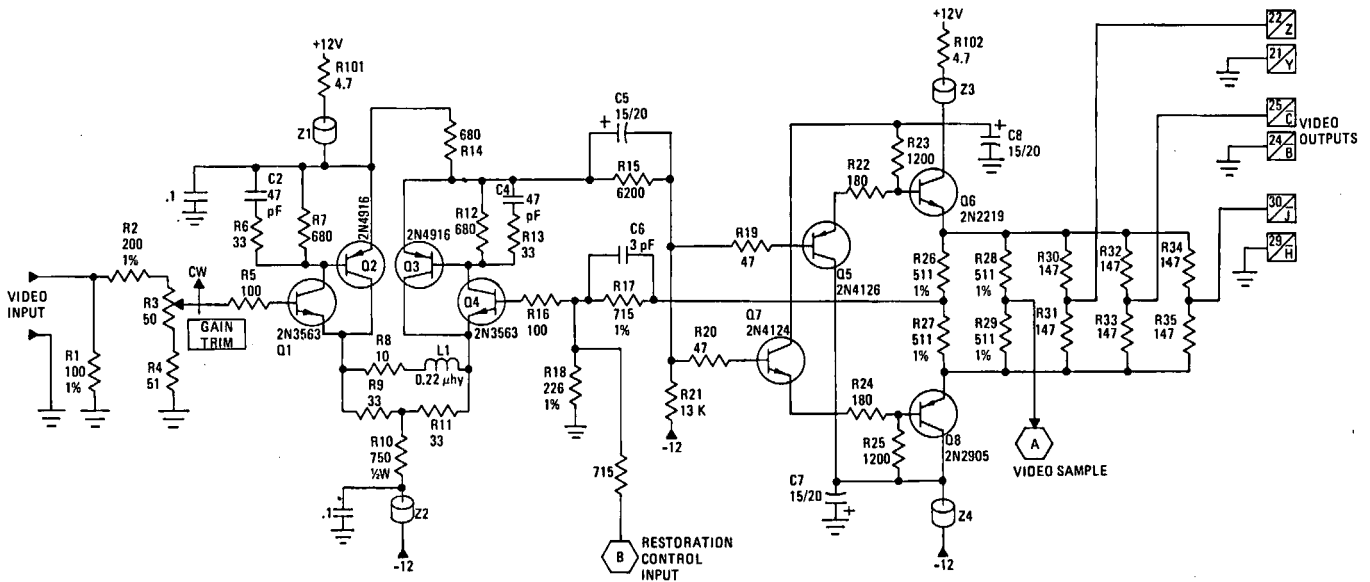


Fig. 9. Basic video line driver used throughout the recorder.

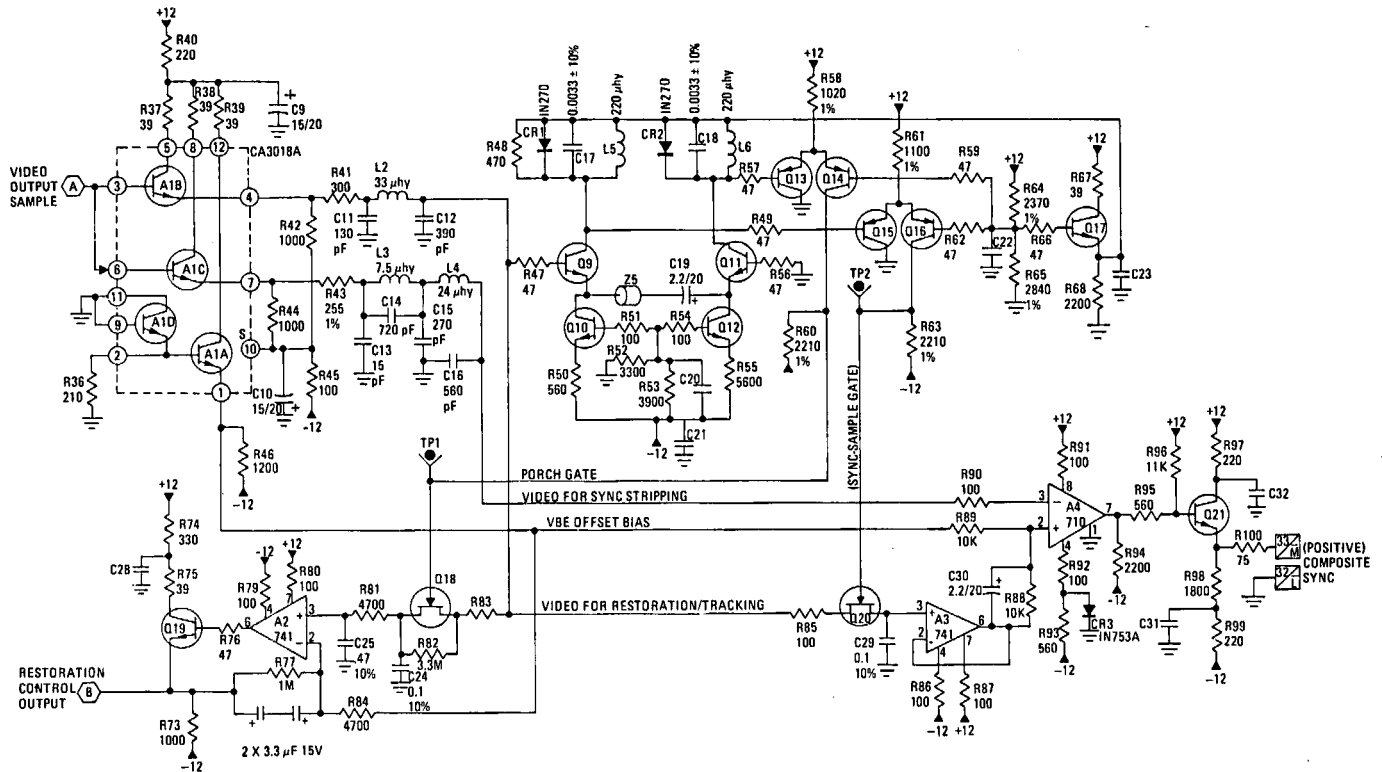


Fig. 10. Schematic of the restoration control and sync stripper.

between circuits. The amplifier, as shown, is flat within 0.025 dB to 9 MHz.

#### Restoration Loop and Sync Stripper

Figure 10 is a schematic of the restoration control and sync stripper which is used in conjunction with the line driver of Fig. 9. Transistors A1B and A1C buffer the two lowpass filters from the video line driver output. Transistor A1A is used as a bias reference in the system, to duplicate the offset introduced by A1B and A1C. The video from the lowpass filter (C11, C12 and L2) is applied to the sample pulse generator consisting of Q9, Q10, Q11 and Q12. Transistor Q9 produces a sample pulse

which occurs at mid-sync tip and transistor Q11 produces a sample pulse occurring at the middle of back porch. These pulses are squared and level shifted by transistors Q13/14 and Q15/16. The video back porch is sampled by FET Q18 and compared to the bias reference. Since both the video back porch and bias reference are shifted negative by a  $V_{be}$ , this level corresponds to ground potential at the line driver output. Any deviation of the back porch from ground is amplified by the amplifier A2 and applied back to the base of line driver transistor Q4, thus restoring the output of the line driver to produce back porch at ground.

Video from the above lowpass filter is also applied to sync sample switch Q20 and the dc voltage is stored on capacitor C29. After buffering by A3, the dc component of this voltage is divided by two and applied to the positive input of comparator A4. The video from the second lowpass filter (C13, C14, C15 and C16 and L3 and L4), which is optimized for signal-to-noise in sync, is applied to the negative input of the comparator. This arrangement insures that sync is always stripped at the 50% point regardless of the sync amplitude or hum content and guarantees that the sync edge received by the monochrome error detector maintains maximum fidelity.

## Format Advantages

The format described above provides a number of inherent advantages over the quad approach. Some of these are:

(1) There are only two heads, instead of four, which reduces the likelihood of banding differential by that factor.

(2) The ratio of lines per segment between the quad and the segmented helical is approximately 3 to 1, diminishing the number of first-line errors or other switching effects that can occur by the same ratio.

(3) Hot pressed ferrite heads have much smoother overall response characteristics which minimize banding effects that are due to head resonance and frequency response characteristics.

(4) A head entering a half helical 180° wrap tape path does so at a small angle, thereby eliminating the shock effect typical of transverse tape scanning by quad heads. This reduces signal perturbations at the start of each scan.

(5) The segmented helical system using two heads also employs alternate segment scanning (NTSC) so that residual small errors are integrated in the output signal. This particular aspect has already been described in detail.

These conditions permit the segmented helical recorder to replay color tapes without the need for individual tape adjustment. The machine should only require checking out at the start of a shift with a test tape, then should be able to be left alone for the rest of the daily operation. This could be particularly important where the VTR is controlled by a station automation system and the only operator function would be to thread up the correct tape at the prescribed time.

## Control Track Head Placement

The control track head has been placed in the scanning assembly in such a way that it maintains an absolute position with regard to the record heads. As a result, control track phase is precisely maintained with relation to the video signal that it is derived from in the record mode. In playback there can be no shift in the control track and video signal relationship and therefore no operational tracking adjustment is required. (The present recorder does have a tracking knob, although such an adjustment is provided as a maintenance or special purpose control in case a situation arises where a nonstandard control track is encountered, such as in contact-duplicated tapes.)

## Economic Factors

The major consumable in any VTR operation is the tape medium itself.

Virtually all quad machines operating in full color pull tape at 15 in/s (38.10 cm). At this rate the cost per hour of the tape is about \$200. Prices vary due to many factors, such as quantity purchased, quality of tape, normal or high energy, source of supply, etc. The segmented helical recorder described here consumes tape at 8 in/s (20.32 cm), and the tape the machine is designed for is a normal energy, longitudinally oriented tape that is made in very large quantities by tape suppliers. This results in a very uniform tape, inherently optimized for the soundtracks and being used up at a rate almost 50% less than the quad.

The machine achieves full specs in audio and video with normal energy tape. This means less drive power for recording or erasure, lower abrasivity on the heads, and non-premium material cost. The combined benefit of lower tape consumption and a greater number of tape cycles due to gentler handling by the transport and scanning system leads to tape economics of better than 60% over the equivalent quadruplex operation.

The next major consumable on a quad VTR is the four-head motor assembly. This head assembly consists of a rigid metal baseplate, an air bearing high-speed motor, a precision female guide assembly with its actuating mechanism, a head drum with four transducers which must very closely match rotating transformers, a control track head and a tachometer mechanism. The entire assembly must be periodically removed, returned to the factory for rework, and then reinstalled. Most TV studios carry a considerable inventory of head assemblies in order to circumvent long rework cycles, shipment delays and premature failures of this complex assembly.

A survey conducted recently both in North America and Europe showed that the average life of such heads in the USA is 493 or 413 hours, depending upon some anomalies in the sampling that related to certain studio operations. In Europe, where wider bandwidths, a higher color subcarrier and more critical technical operations exist, the average was closer to 350 hours.

The segmented helical recorder has a completely different approach to head assembly replacement. The motor tachometer, guides and lower scanning section containing the control track head remain with the machine. Only the rotating upper drum section is removed (by a single screw) and is replaced with a new one containing the two video heads and the flying erase head.

The longevity of this video head assembly is in the order of six times that of the best average of quad heads or approximately 3,000 hours; as a matter

of fact, the warranty is at a 10:1 ratio of 1500 hours versus 150 for the quad head assembly. Even during the active life of the helical head assembly, there are further advantages of an operational nature, since the wear rate of the transducers is so much lower that the need for periodic optimization is greatly reduced. Of course, the paperwork, shipping charges, and incoming inspection connected with these heads are also appropriately diminished.

The last major economic factor with regard to a change of format from quad to segmented helical is in relation to the tape libraries that now fill large vaults at major studios and take up a lot of space even in smaller TV facilities. Large or small, a tape library represents a sizable investment in quad tape. This tape remains as overhead because it cannot be cycled into use, since the program material is of archival value. The same studio purchases an annual stock of quad tapes to feed the machines they are using. At the point in time where the IVC-9000 format is adopted and a few machines are installed, the studio can save a substantial amount by the following procedure.

All library tapes are transferred from the quad format to the segmented helical format during quiet periods when the machines are not normally in use. This renders the following benefits:

(1) Program material occupying a tape worth approximately \$195 per hour is transferred to tape stock worth about \$90 per hour. This is a substantial reduction in archival storage costs, even with the transfer costs taken into account.

(2) Storage space is reduced appreciably because the new recordings are on tape that occupies a smaller reel and container than that of quad tape.

(3) The new IVC-9000 storage format will permit the addition of an extra soundtrack, cue instructions or an address code for future editing. If the studio is contemplating automation or automated editing, they can plan to incorporate these extra tracks during the transfer from quad to the IVC-9000.

(4) Quad tapes released from archival use can be cycled through normal studio operation on quadruplex recorders, reducing the amount of new tape that must be purchased by the studio.

## Summary

Obviously, all of the decision points and judgments involved in the design of a segmented-scan, helical broadcast recorder cannot be presented here. However, some of the major decisions, and the reasoning behind them, have been shown. The recorder is presently operational and all of the design goals have been met.