The Servo System for a Helical Broadcast Recorder

By DONALD E. MORGAN

The IVC-9000 Servo System is designed to control tape motion and tension through all modes of operation. The reel controller, capstan, scanner, and tension systems are all position servos interacting to control precise transducers capable of accurate performance. Digital techniques have been applied throughout the system, providing such features as controlled lock-up and error memories for edit mode operation. Compact modular packaging provides convenience, and reliable, long-life design provides assurance of good performance.

Introduction

The IVC-9000 Servo System provides a new level of performance for videotape recorders. New developments in the areas of tape deck design, motor design, air bearing techniques, and servo philosophy have been applied throughout the machine.

Precise control of tape motion and tension is the purpose of the servo system. Tape (Fig. 1) moves from the supply reel through a vacuum chamber to the scanner area, then around the capstan and through a second vacuum chamber to the take-up reel. The tape is air lubricated throughout the guide path and at the scanner, with longitudinal heads being the only friction contact.

The servo is made operational in the following sequence: first, the reel servos are activated; second, the scanner servo accelerates the drum to develop air film; and third, the capstan is allowed to move tape as the vacuum collar releases tape onto the scanner. The capstan can then use the control track, the scanner can refer to video information, and, finally, tension can be established according to video head scan information. The features of each of these servos will be discussed in that order.

Reel Servo

The supply and take-up reel control systems operate in conjunction with the vacuum chambers (see Fig. 1 in the paper by Guisinger, the first paper in this group). The servo has two modes of operation: (1) to load tape into the chamber with velocity as the control variable, and (2) once in the loaded zone, to maintain that operating condition with position as the control variable. Tape position in the chambers is sensed continuously over a distance of 5 in (127 mm) using a photodiode solar cell mounted in the side wall, illuminated by an array of lamps in the opposite side wall. The solar-cell preamplifier output determines the firing angle for SCRs (silicon controlled rectifiers) in the motor drive amplifier. The servo is compensated in such a way that empty reel bandwidth is 10 Hz and full reel bandwidth is 2 Hz. The power available can accelerate the reels so that tape position in the chambers is maintained with ± 0.25 in (6.35 mm) through all modes of operation transients.

The vacuum chambers are used in the classical sense as tension disturbances attenuators (isolators) and do have some transmittance. Further, reduction of tension disturbances is accomplished by smoothing the reel drive current during normal play/record mode, while maintaining the efficiency of SCR motor drive. The stored energy in motor winding inductance is used by enabling a flywheel SCR, after the primary drive SCR has turned off, in such a way as to keep current flowing in the motor in the same direction. This application of the flywheel diode results in average reduced current transients and associated instantaneous tension disturbances.

Capstan Servo

Tape motion is position-controlled by the capstan servo in all modes of operation: record/play, shuttle, and stop. The rubber-coated capstan, friction-coupled to the tape, determines all tape motion and is driven by a low inertia motor. The 1500-line tachometer disc giving position information to the inner loop, is located between the motor and capstan. Power is applied with a current mode motor drive amplifier (MDA), thus reducing torque disturbances due to brush/armature impedance variations. Position error is derived in the capstan inner loop, which compares tach as a control variable to an appropriate reference determined by mode selection (Fig. 2).

In record mode the 4-kHz reference is derived from the scanner tachometer output. Thus, during record, the longitudinal tape motion is forced to follow scanner disturbances so that during reproduce tracking errors do not result. The capstan inner loop bandwidth is wide enough to follow scanner gyrations.

In video head optimize (VHO) mode this same reference derived from the scanner is divided by two, pulling tape at half-speed, providing simultaneous read-after-write. Inner loop compensation is switched to maintain stability in this mode.

In play mode the 4-kHz reference is derived from outer loop (control track loop) position error. Derivation of this error will be discussed in subsequent paragraphs.

In shuttle mode the reference for the inner loop is from a voltage-controlled oscillator (VCO). The VCO in local shuttle mode is controlled from a potentiometer on the control panel and is capable of forcing the inner loop to drive tape from less than 2 in/s (5.08 cm/s) up to 300 in/s (7.62 m/s). The inner loop stability is maintained throughout this wide range by changing phase comparator modes when the speed, and therefore the carrier, is high; the phase comparator is simply a flip-flop type and the loop gain will be independent of speed. At lower speeds carrier feedthrough is eliminated by reverting to the sample-and-hold phase comparator. This shuttle mode is remote controllable for search operations where address track is used as a control variable to an external controller. Very

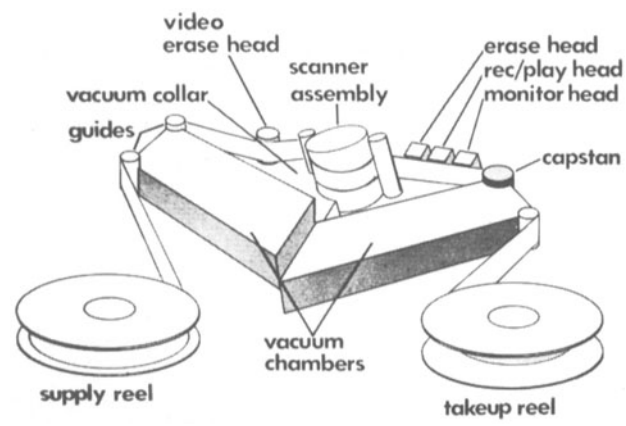

Fig. 1. IVC-9000 top plate configuration.

Presented on 18 October 1973 at the Society's Technical Conference in New York by Donald E. Morgan, International Video Corp., 990 Almanor Ave., Sunnyvale, CA 94086.

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rapid but accurate control can be maintained during these search operations. Once final position is reached, the stop mode will maintain position with no slippage.

In stop mode the capstan inner loop is switched to a mode with zero dc as a reference, so the tachometer is forced to seek the nearest cycle of the 1500-line disc. This mode of operation is called active stop and is assumed whenever the speed drops below 2 in/s (5.08 cm/s), if stop mode (Fig. 3) has been requested. Active stop can be defeated when the operator wishes to manually cue the machine or spot erase material from either audio track. Spot erasing is done by placing the machine in the ready mode and depressing the capstan manual control panel pushbutton with the righthand, while rotating the capstan with the left. This defeats the inner loop control. When the button and capstan are released, the capstan will revert to active stop.

Returning to the control track loop, the most interesting portion of the capstan servo is required to position tape to the proper frame and maintain tape in motion just as it moved during record with control track (300-Hz square wave) as the control variable.

The control track head is mounted in the scanner housing and thus provides an ideal location for recording 300-Hz square wave derived from the scanner tachometer directly under the scanner drum. The position of the control track gap is very precisely controlled during fabrication of each scanner. This assures proper tape format control for proper performance of tapes recorded on one machine and reproduced on another (interchange). Secondly, the control track loop is capable of achieving vertical framing for the scanner servo loop, thus allowing the scanner horizontal loop to achieve fully synchronous lock on the proper line. Framing information is recorded on the control track in the form of a small pulse derived from reference frame, added to the 300-Hz square wave. In reproduce (Fig. 4), the reference frame pulse is extracted and compared in time position digitally with reference frame. Improper line-up of the two signals operates on the velocity/phase comparator of the control track loop through the use of miscount logic. When the two-

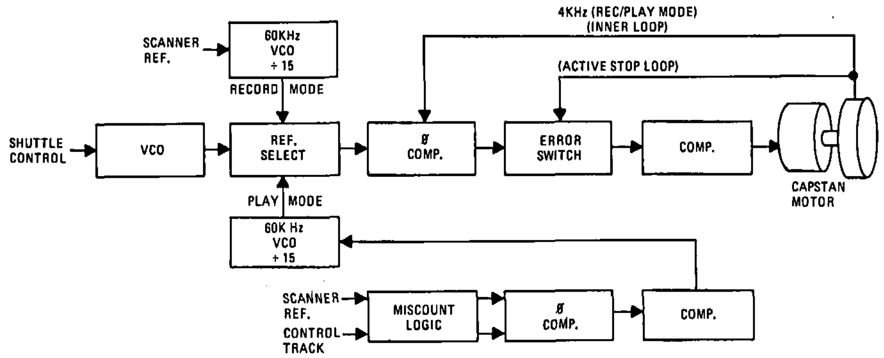

Fig. 2. Capstan servo block diagram.

frame signals are lined up, miscount stops, the control track loop locks onto the nearest 300-Hz cycle and the tape is longitudinally positioned as it was during record mode.

The 300-Hz control track signal is phase compared with a 300-Hz reference derived from the scanner in a ramp sample-and-hold circuit; the analog signal is then conventionally amplified and compensated for loop stability providing a 10-Hz bandwidth (Fig. 5). During the miscount or framing operation the compensation is switched to give a 25-Hz bandwidth and rapid relock performance. The steady state 10 Hz provides an optimum performance when the horizontal loop is enabled with a 30-Hz bandwidth. This assures that the horizontal loop can follow the residual error of the control track loop. The analog control track signal then modulates a 60-kHz voltage controlled oscillator which is divided to give 4-kHz for the inner loop reference.

The miscount logic, as referred to previously, is a network of logic circuitry (Fig. 6) designed to assess the position of the control track frame pulse with respect to reference frame and to take appropriate action. The three possible courses of action are to advance the tape, retard the tape, or hold the same position. Subtracting or miscounting control track pulses will advance the tape one cycle of 300-Hz each time a miscount action is taken. Subtracting a 300-Hz reference pulse will retard the tape one cycle per miscount. Reference frame is a 12.5-Hz square wave in PAL and 15-Hz square wave in NTSC. The negative going edge lined up inside control track frame pulse is proper framing.

Lockup time is very predictable since the control track frame pulse can be no more than 12 300-Hz cycles away from the nearest reference frame edge (PAL: 10 cycles in NTSC).

$$12 \text{ max} \times 80\ \mu s = 960\ \mu s \text{ PAL}$$

$$10 \text{ max} \times 66.7\ \mu s = 667\ \mu s \text{ NTSC}$$

This is so since miscounts can only occur at the frame rate, and the servo relocks between subsequent miscounts and is ready for the next until framing is complete. This miscount logic is applied when the operator wishes to lip sync two machines together to the same frame. The control panel pushbuttons (capstan override fast, slow) will advance or retard the tape. The rate at which lip sync miscount occurs is varied by the shuttle speed control knob, from 0.1 Hz to 1 Hz. When the override buttons are released, the normal framing logic will frame the tape to the nearest reference frame.

If the fully synchronous framing function must be defeated, placing the servo in tach mode only, or horizontal mode only, will put the control track loop in a condition where it will not frame the system upon request of play. The function of the control track in this mode is to assure that Scanner Head 1 is playing Tape Track 1. This allows the operator with a prior knowledge to play a tape with hot switches restored. The resulting performance will be a monitor relock (vertical roll) during the video source switchover.

The final feature of the control track loop is for the maintenance people. A momentary switch is provided to intentionally move the tape so that Head 1

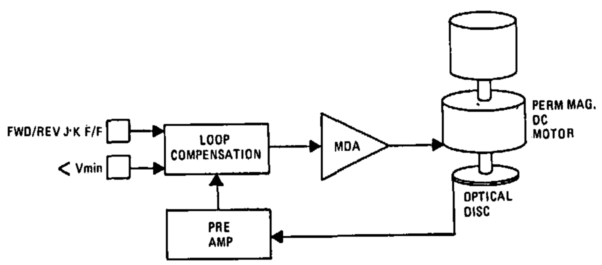

Fig. 3. Capstan active stop loop.

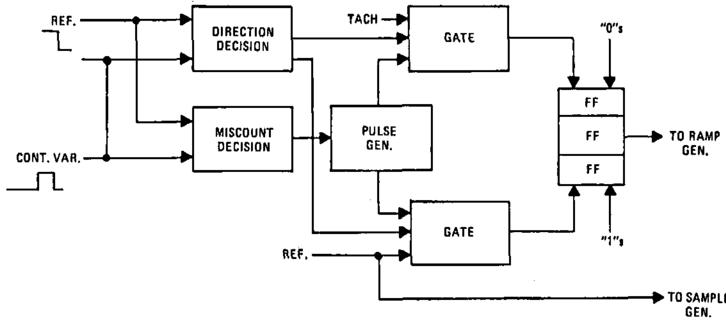

Fig. 4. Miscount logic and velocity/phase detector.

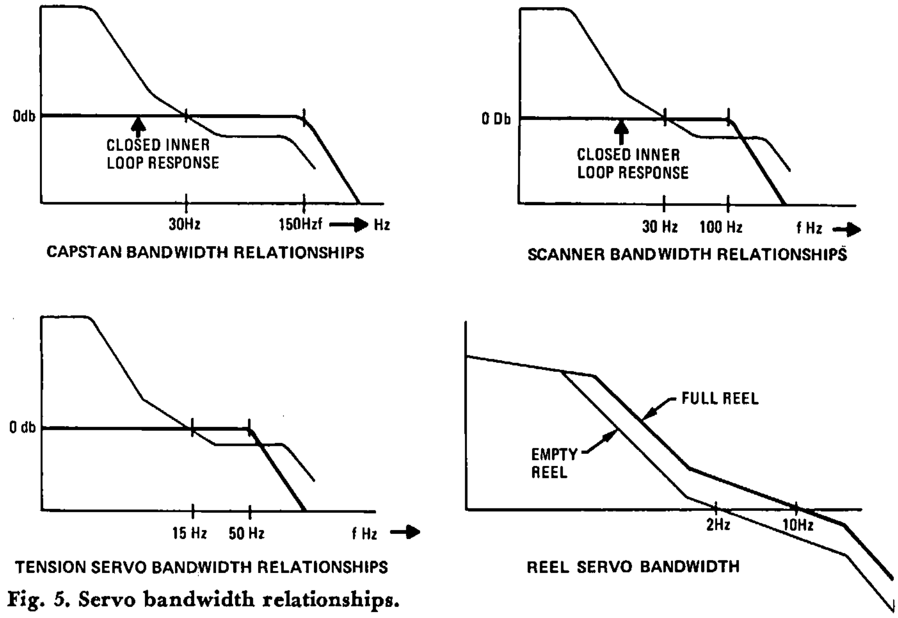

Fig. 5. Servo bandwidth relationships.

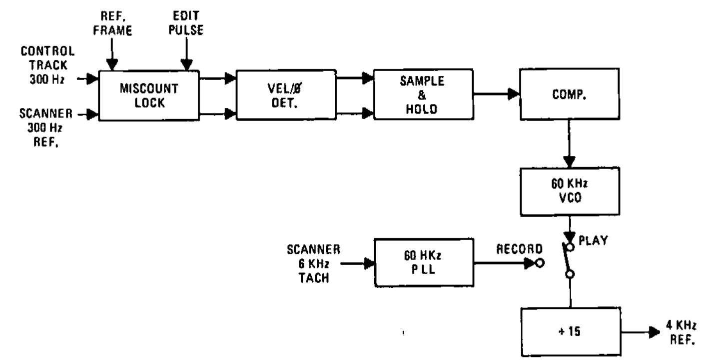

Fig. 6. Capstan record/play mode.

will play on Track 2. When a signal loss occurs on one channel, it is desirable to ascertain whether the malfunction is a record or reproduce function. The Head 1/Track 2 switch provides a quick check.

Scanner Servo

The scanner assembly (Fig. 7) is composed of the following: drum cylinder in which there are mounted three heads (two video R/P and one scanning erase head); a rotating transformer assembly; a brushless dc motor (8-pole, 2-phase); and a tachometer disc. Considerable effort over the last two years was spent developing the groove design to provide the desired air-flotation of tape over the drum under all required environmental tape and tension conditions. Considerable effort was also put into applying brushless dc motor techniques, thus increasing the life of the scanner unit. The efficiency of the motor was increased over brushless dc motor techniques by removing any Hall effect sensors and reducing the magnetic air gap. The sine/cosine waveforms required to drive the two phases are derived from a track on a uniquely designed tachometer disc (Fig. 8). Four cycles of sinusoidal waveform are derived from a track with clear and opaque line widths proportional to the value of the sine wave at that point.

The other tracks on the tach disc are a once-around track which is used to electronically locate the drum position with respect to reference frame, and a 40-line track which provides a 6-kHz carrier for the scanner inner loop. When the scanner is rotating at normal speed, 9000 r/min, the 150-Hz basic rate must be eliminated, since it occurs just outside the band-edge of the inner loop servo (see Fig. 5). The 40-line track is read with two sensors geometrically 180° apart. This produces a triangular waveform from each sensor, one high when the other is low. When these waveforms are differentially compared, the output of the comparator shows no time modulation due to disc concentricity error. Thus, no 150-Hz component is present in the scanner error. Figure 9 shows that the analog signal representing positional error of the scanner is derived by comparing 6-kHz tach with 6-kHz reference in a ramp sample-and-hold controlled by a velocity/phase detector with miscount logic for framing tach Head 1 pulse.

The sampled voltage is conventionally amplified and compensated to give a bandwidth of 100-Hz with a critically damped stability (Fig. 5). This error signal is used to amplitude-modulate the 600-Hz sine and cosine waveforms for driving each winding of the motor. The scanner, therefore, will move as the reference moves. In record mode, the inner loop reference is derived from the input sync references. In reproduce fully synchronous mode, the reference is derived from a 6-kHz waveform which has been time modulated with an error signal from the horizontal loop. This process occurs in a delay modulator formed by intercepting a 6-kHz reference ramp with the compensated analog horizontal error in a differential comparator. The ramp is generated with a double slope, steep near the final lock position and 10-dB less steep near the ends of the ramp. This approach maintains the requirement for a full 167-μs lock range, and also provides good signal-to-noise ratio in the final value region for the horizontal error memory to work with (Fig. 10).

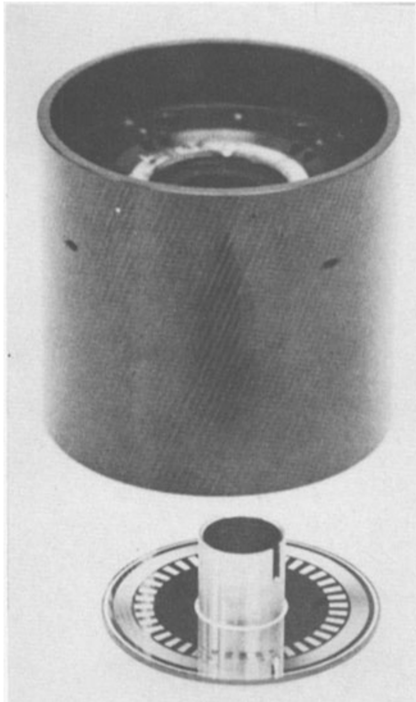

Fig. 7. Scanner assembly and tachometer disc.

When the operator desires to edit tapes previously recorded, it is necessary for the servos to hold throughout the edit the tension and horizontal error conditions last experienced during fully synchronous playback just prior to entering the edit mode. With these parameters frozen, the deriving references for the tension servo inner loop and scanner inner loop, the servo is in tach mode, and the edit recording is being made so that the format on tape is precisely the same as the original recorded material.

Tension Servo

It is a well-known fact that the tape

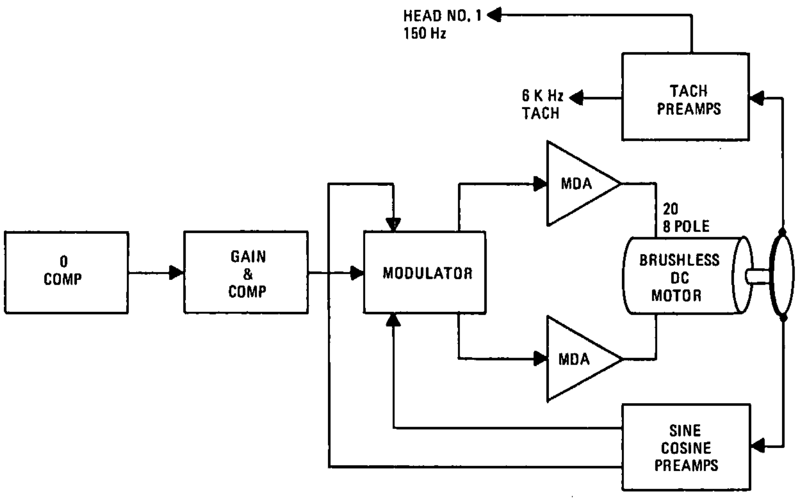

Fig. 8. Scanner drive.

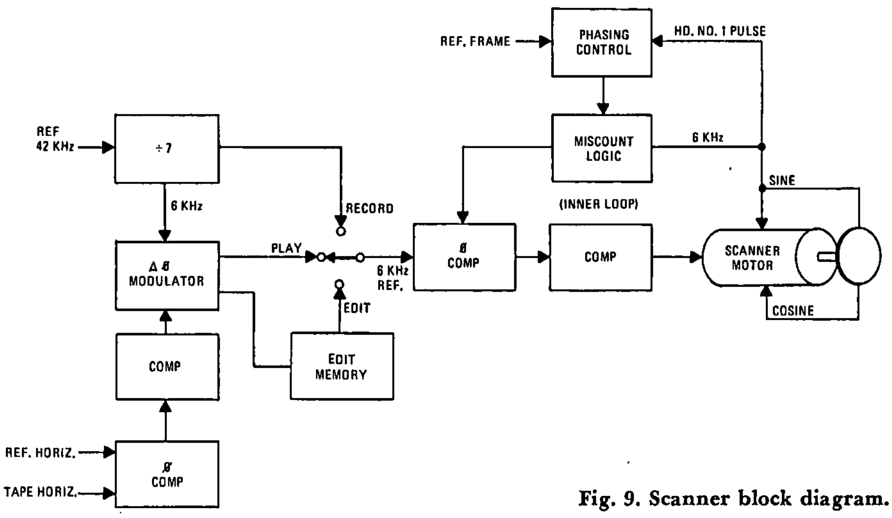

Fig. 9. Scanner block diagram.

medium is elastic and that its length varies with environmental parameter changes in humidity and temperature.

The design approach applied in the IVC-9000 is to apply constant tension during record mode regardless of environment, then servo the tape to proper length by controlling tape tension on reproduce. Tape tension is established by the vacuum level in the chambers; vacuum level is controlled by the vacuum modulator which, in turn, is supplied by a high vacuum supply.

The key element in this system is the vacuum modulator, which is an enclosed chamber with a vacuum input port and two variable output ports (one to each chamber), and an output port connecting the vacuum collar. The port opening cam is directly connected to the shaft of a brushless dc motor. Applying brushless dc motor techniques in this application assures long life and friction-free operation with higher efficiency.

The tension servo block diagram, Fig. 11, shows the modulator driven with an inner position loop. A cam disc on the motor shaft develops control variable position information. This analog voltage is in the form of a ramp as the motor rotates the modulator from closed to open position. The ramp is converted to sine and cosine drive voltages amplitude modulated with the compensated loop error voltage. The references for positioning the control variable are switched from mode to mode, thus positioning the modulator to provide proper vacuum. In play mode, the reference is derived from the error voltage of the horizontal sync circuit in the off-tape sync processor. This allows for scan length determination in the tension error detector and correction through varying tension to change tape length. The tension error after compensation is routed through digital memory for edit freeze, since tension is one of the variable parameters fixed in edit mode. The memory is an analog-to-digital converter followed by a latch driving a digital-to-analog output. Feedback from output to input comparator makes the memory operate as a voltage follower in normal mode and, if the strobe clock is inhibited (as during edit freeze), the output assumes the last value voltage.

The operating range of tension control is 25 oz (625 grams). This large range allows the servo to re-establish tape length over an environmental temperature range of 0°C to 40°C and a relative humidity range of 20% to 80%.

Since the tension servo affects length only and the tape also changes in width due to environmental changes, the question arises, how does the tension servo correct for this? The Poisson's ratio effect in conjunction with the 19° track angle causes a slight mistracking effect. It turns out that if 25 oz were required to correct track length, the off-track figure is 1.9 mils peak-to-peak. In light of the 6-mil track width, this represents a small loss of signal.

The tension control servo of the IVC-

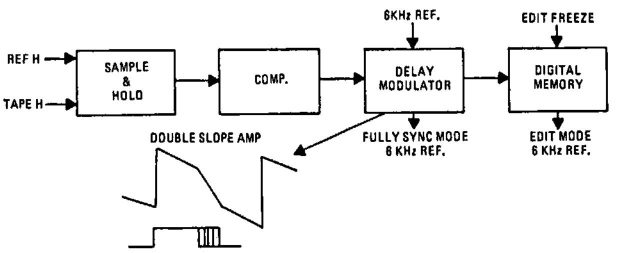

Fig. 10. Scanner horizontal.

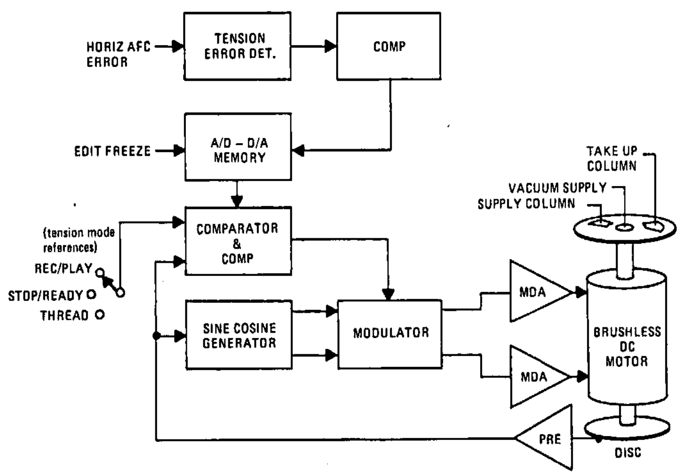

Fig. 11. Tension servo block diagram.

9000 has evolved over two years of design effort and epitomizes the sophistication of design effort applied by the engineering team.

Summary

The purpose of the servo system in any tape recorder is to control precisely all moving elements, including tape, as control references require. Designing a precision control system begins with basic mechanical elements capable of operating precisely. Operating parameters of the servo loops must then be chosen to optimize the signal-to-noise ratio of loop error signals, and at the same time, to keep carrier frequencies high enough to support the required loop bandwidths (Fig. 5). This was done on the IVC-9000 transport and servo system. The final performance of these various servos is reflected in the time-base stability of the demodulator output. The peak-to-peak time base error of 0.2 μs is well within the 1-μs window of the time-base corrector.

An Analysis of Quadruplex and Helical-Scan Video Recording

By JEROME L. GREVER

In recent years, there have been a number of changes in the field of videotape recording — in the technology and in user requirements. In view of these changes, an RCA engineering team was assigned the task of evaluating whether future high-quality video recorder designs should be quadruplex or helical scan. This paper reports on the results of that investigation and gives some thoughts on video recording in the future.

NEARLY 18 years ago, the quadruplex videotape recorder was introduced to the broadcasting industry. Today, 7,000 quad machines are in use around the world — about 4,000 are in the U.S.A. And these machines are compatible — a tape recorded on an Ampex VR-1200 in Miami will play very well on an RCA TR-70 in Chicago. Or, a tape recorded in Hamburg, Germany, can be played to-air in Sydney, Australia.

Since 1956, quadruplex machines have undergone many improvements and the quality of today's video recording is quite high. However, during the last several years, many users have indicated a need for video recorders that are simpler to operate and that are more cost-effective — equipment that costs less to purchase and to operate. We at RCA recognized it was necessary to fully address these considerations and to make a scientific and objective judgement as to the optimum video recorder configuration in light of present and anticipated future requirements. Accordingly, we engaged in development work in areas that impact the cost and the complexity of the equipment. Many parameters were studied and trade-offs were evaluated. Following is a summary of what was learned during the course of that investigation.

Quadruplex vs Helical Scan

The first major question was whether our future high quality video recorders should be quadruplex or helical scan. Putting it another way, RCA management asked the Engineering Department, "Should we embark on the design of a high quality helical scan VTR?" In order to answer that question, a comprehensive evaluation of the key design parameters of both types of recorders was initiated.

In the design of a videotape recorder, a great many areas must be considered including reliability, maintainability and a host of operating features. In the course of the study it was decided that these items, although important, can be specified in overall design objectives and are not closely related to whether the recorder is quadruplex or helical scan. Other items, however, could be dependent upon the type of scanning and the investigation was focused on them. They are:

- Video Signal-to-Noise ratio
- Operating cost
- Manufacturing cost (purchase price)
- Head-to-tape interface
- Segmentation error
- Interchangeability
- Compatibility

In these areas, trade-offs can be readily made. For example, the designer can elect to improve the characteristic of interchangeability by suffering an increase in manufacturing cost. Or, he could decide to reduce operating cost at some sacrifice in signal-to-noise ratio. Let us review each of these areas.

Video Signal-to-Noise and Operating Cost

Signal-to-noise ratio is probably the most important performance parameter of a videotape recorder. It is also closely related to operating cost by virtue of track width and head scanning speed. Therefore SNR and operating cost will be treated together.

As shown in Fig. 1, the signal is recorded on the magnetic tape in a track whose width is equal to one dimension of the magnetic head. As the head scans the tape, the signal is recorded as a varying intensity of magnetic flux on the tape. The wavelength is proportional to the head scanning speed and the signal frequency being recorded. Analysis will show that the playback signal output is proportional to the track width and that the signal output increases with increasing wavelength. For short wavelength recording, as in video recording, the signal output increases with an increase in head scanning speed, but not linearly. Further, the tape noise increases as the square root of the track width. The combination of these factors causes the video SNR to increase approximately as the square root of the amount of tape used per unit of time.

The level of signal playback or SNR is also governed by characteristics of the tape. Figure 2 is the familiar hysteresis or B-H curve of a magnetic material. The amount of excitation required (H) and

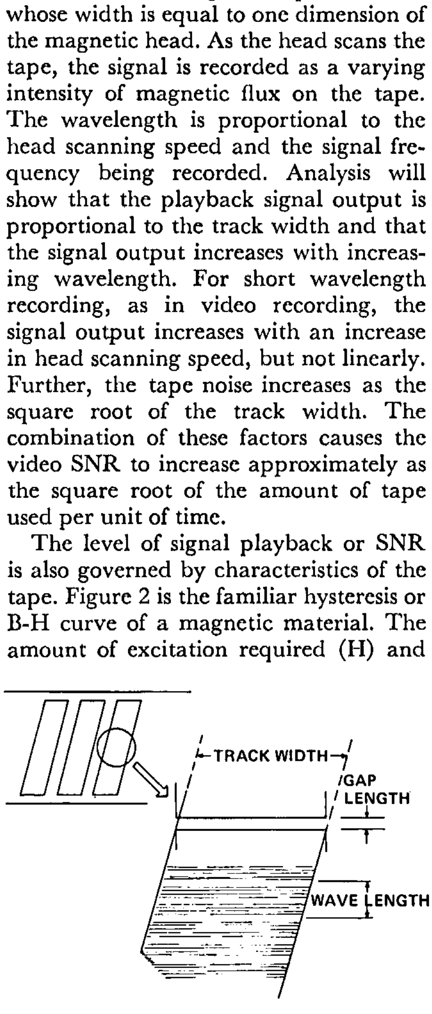

Fig. 1. Recording the video signal.

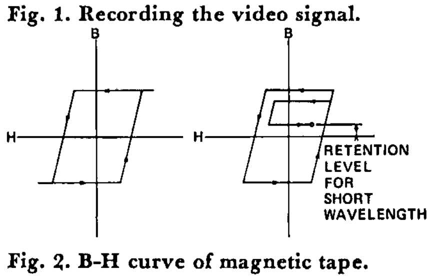

Fig. 2. B-H curve of magnetic tape.

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