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tech tips

How VCR Servos Work

This Tech Tip gives a basic explanation of how VCR servos operate. Use the information in this Tech Tip with the troubleshooting procedures covered in Tech Tip 132 to quickly isolate problems using the Sencore VA62A Universal Video Analyzer, the SC61 Waveform Analyzer, and a test tape recorded on a known-good VCR with VA62A video patterns.

How to Simplify Servo Troubleshooting

Many technicians comment that VCR servo problems are tougher to troubleshoot than problems in other VCR circuits. They don't need to be tough, however, if you have a good understanding of how they work, have adequate test equipment, and use organized troubleshooting methods. Before discussing the circuits, let's list the facts about servos which can complicate troubleshooting without a good plan:

1) Servos have both electrical and mechanical components. Electrical or mechanical defects cause nearly the same symptoms.

2) Servos are self-correcting feedback loops. A problem in any part of the loop causes all the signals to be wrong, because the circuits try to correct for the problem. This makes it tough to find problems with only a meter or scope.

3) Most servos use a feedback loop inside another feedback loop. A defect in either loop causes the signals in both loops to be wrong, making signal measurments confusing.

4) There are two separate sets of servos; the capstan servo controls tape movement, and the drum (or cylinder) servo controls the spinning video heads. Problems in one may cause symptoms similar to the other, without a good way to identify symptoms.

5) The servos interact with the system control circuits. Servo problems often look like system control problems and vice versa. Well defined procedures isolate the problem to its real cause.

6) Servo problems may look like a luminince circuit defect, or vice versa.

These factors won't seem as serious once you understand how the servos control the VCR mechanisms. We'll start by explaining why servos are needed.

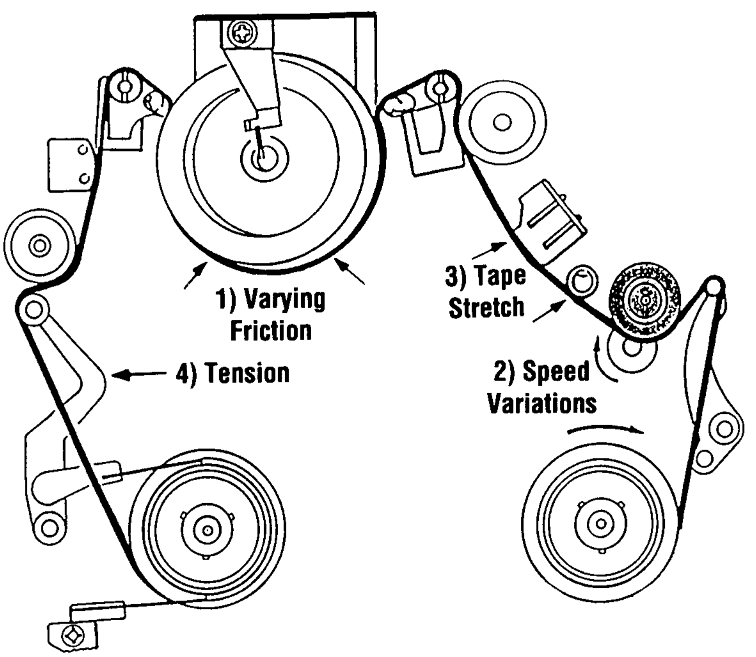


Fig. 1: The servos correct for: 1) Varying friction between the heads and tape, 2) Variations in tape speed, 3) Stretching of the tape, and 4) Variations in power supply voltages, tape tension, motor bearings and mechanical wear.

What the Servos Do

When the VCR plays a tape, the spinning video heads must travel over the exact tape path the heads traveled during recording. The servos correct for many mechanical factors during playback. Some of these are:

1) Varying friction between the heads and the tape, which causes the speed of the heads to change.

2) Variations in the exact tape speed from one VCR to the next.

3) Stretching of the tape, which changes the tiny physical spacing between the stripes of video information.

4) Miscellaneous variations, such as power supply regulation, tape tension wear in motor bearings, and changes in mechanical parts.

In order to correct for all of these variables, the servos need a way to measure the tape's progress through the VCR. This is the purpose of the control track.

The Control Track

A special signal, called the "control track," lets the VCR detect variation in tape movement. The control track is recorded along the edge of the tape by a stationary head to mark the spot where the spinning video head begins recording a vertical frame of video information.

The control track signal is a 30 Hz signal synchronized to the video head rotation. Some VCRs, such as Beta and U-Matic, use a signal with a 50% duty cycle. Conventional VHS decks use a signal with a duty cycle of approximately 60/40. Decks with time indexing, such as Super-VHS, change the control track's duty cycle as the tape plays to encode the elapsed time onto the tape, In any case, one of the signal transitions marks the beginning of a video frame of information, (The second transition isn't used, so the exact duty cycle is not important.)

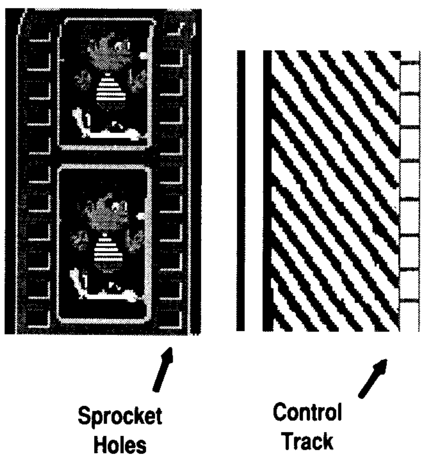


Fig. 2: The control track marks the position of video information on the tape, just like the sprocket holes mark the position of the picture frames on a movie film.

Because the video heads use an azimuth shift to reduce interference, the same video head must play back the signal track it recorded. The servos compare the timing of the control track transition and a signal coming from the head to keep the correct head in contact with the correct signal path at all time.

The control track serves the same purpose as sprocket holes on a movie film. Sprocket holes mark the position of each picture on the film. As the projector moves the film past the lens, toothed wheels engage with the holes to place each picture frame in front of the lens before the shutter opens to shine light through it. The movie projector uses mechanical control to ensure the film plays exactly the same on any projector.

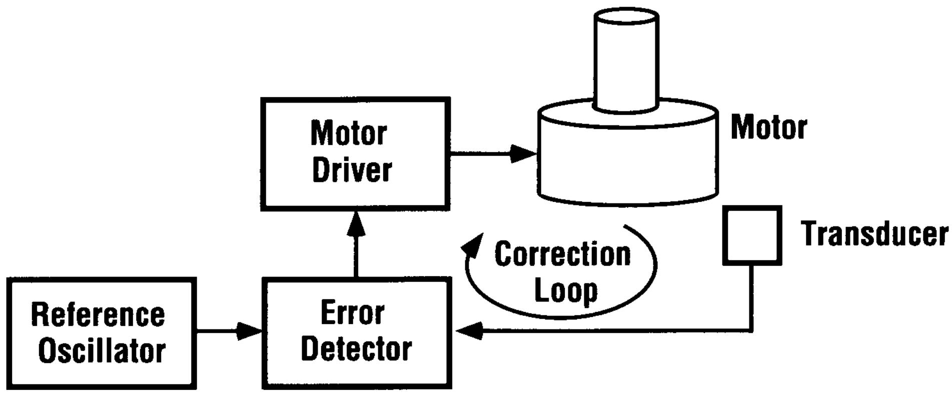


Fig. 3: A basic servo consists of a motor, transducer, reference oscillator, error detector, and motor driver. The circuits control the speed of the motor to keep the transducer output in step with the reference signal.

The difference between film and video tape is that the servos don't mechanically lock to the moving tape. Instead, they electrically sense the placement of the control track pulses and adjust the speed of the tape to correct for errors.

The Basic Servo

Early VCRs used a relatively simple single-loop, single-servo design. While these circuits did the job, they had lower performance than today's circuits. We will look at the single-loop systems first, because they are easier to understand than the multi-loop circuits used today.

Servos control the speed of a motor by comparing its rotation with a stable electronic reference signal. Fig. 3 shows that a simple servo has five parts:

1. The motor
2. A transducer driven by the motor
3. A reference oscillator
4. An error detector
5. The motor driver.

The Motor: The motor's speed must be controllable. Various schemes are used, but all have a way to adjust speed by varying a DC voltage. Nearly all VCRs use "direct drive" motors for the drum servo, meaning the motor connects directly to the head drum through a solid shaft, rather than through belts or pulleys. Some capstan motors are also direct-drive, while others drive the capstan through a belt and pulley arrangement. The advantage of the indirect, belt drive is that the motor can turn at a higher speed, and then be reduced to the correct speed through the pulleys. The higher speed motor makes corrections in motor speed less noticeable, for improved audio quality.

The Transducer: A transducer converts the mechanical motion into an electrical signal that the circuits process. The transducer might be inside the motor, or externally connected to a shaft or pulley. Typical transducers are magnets moving past coils or hall-effect ICs, light and photo transistor combinations, or toothed wheels moving past a coil. In some cases, the transducer is a signal picked up from the tape by a magnetic head.

Transducers fall into two general types: pulse generators and frequency generators. A pulse generator (often called "PG" on the schematic) produces one or two electrical pulses for each revolution of the motor. A frequency generator (often called "FG") produces a signal with a higher repetition rate, which varies in frequency as the motor's speed changes. The frequency of the FG signal represents the motor's speed, but cannot be used to determine the exact position of the motor's shaft, like the PG signal can.

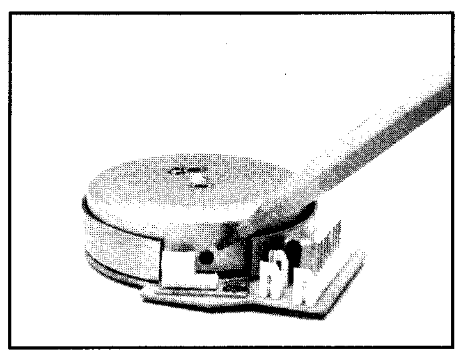


Fig. 4: The two magnets on the head assembly pass a coil or hall-effect IC to produce the PG (pulse generator) signal needed to control the heads' position during playback.

The Reference Oscillator: The only way to tell if the transducer output represents an error is to compare it to a known good signal. VCRs use a stable 30 Hz reference signal for comparison. During recording, this signal is generated by dividing the frequency of the 60 Hz vertical sync in half. During playback, the signal usually comes through a digital divider from the 3.58 MHz crystal color oscillator.

The Error Detector: The error detector compares the phase or frequency of a transducer output with the reference signal. The varying DC then corrects the motor speed through the motor driver.

The Motor Driver: The motor driver converts the DC voltage from the error detector to the form needed to control the motor's speed. Most VCRs use an AC motor (sometimes called a "brushless DC" motor), so the motor driver must also convert the DC control voltage into a 2 or 3 phase signal, which controls the motor's speed. More details on this process are covered later.

Fig. 6 shows how the five parts of a simple servo controlled older VCRs. The transducer is a pulse generator made of two permanent magnets attached to the head drum. A signal is induced as each magnet passes the pickup coil. One magnet has its north pole facing the coil, and the other has its south pole facing the coil, so the servos can keep track of which video head is in contact with the tape.

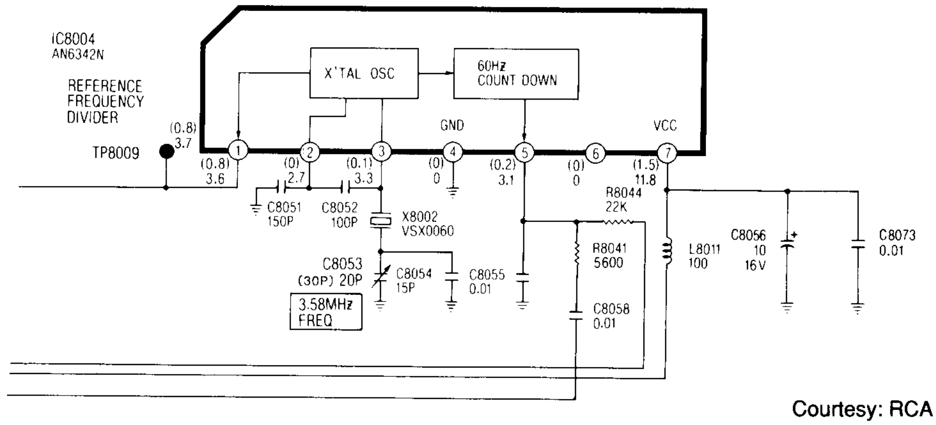
If the pulses arrive from the transducer and the reference at different times, the error detector produces a DC correction voltage to speed up or slow down the motor. When the pulses arrive at the proper time, the correction voltage drops to its "zero correction" level.

The Dual-Loop Servo

As Fig. 6 indicates, early VCR servos used a single correction loop. A single loop offers the advantage of low cost, but has the disadvantage of slow correction, such as occurs when you change channels while recording, causing the timing of the incoming sync to change. The response time was improved by adding a second loop.

Most VCR servos now use both a speed loop and a phase loop. The speed loop's job is to quickly get the motor to a speed near the normal operating speed. This loop can be very fast, but does not have to be too accurate, because it provides coarse control of the motor speed.

The phase loop, then "fine tunes" the actions



Courtesy: RCA

Fig. 5: This schematic shows how most VCRs digitally divide the 3.58 MHz color signal to produce the 30 Hz reference needed by the servo.

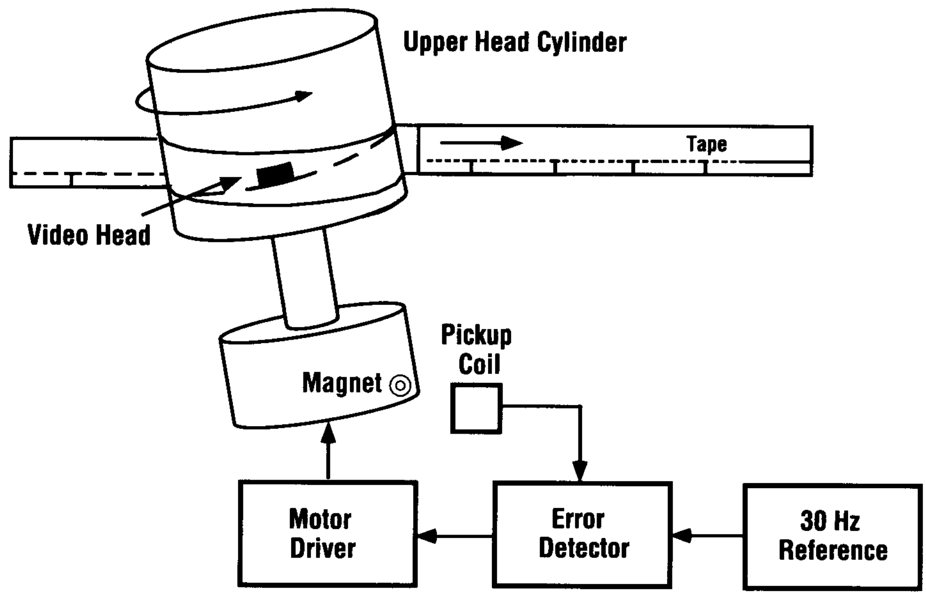


Fig. 6: The simple servos used in early VCRs had the same 5 key parts explained in Fig. 3.

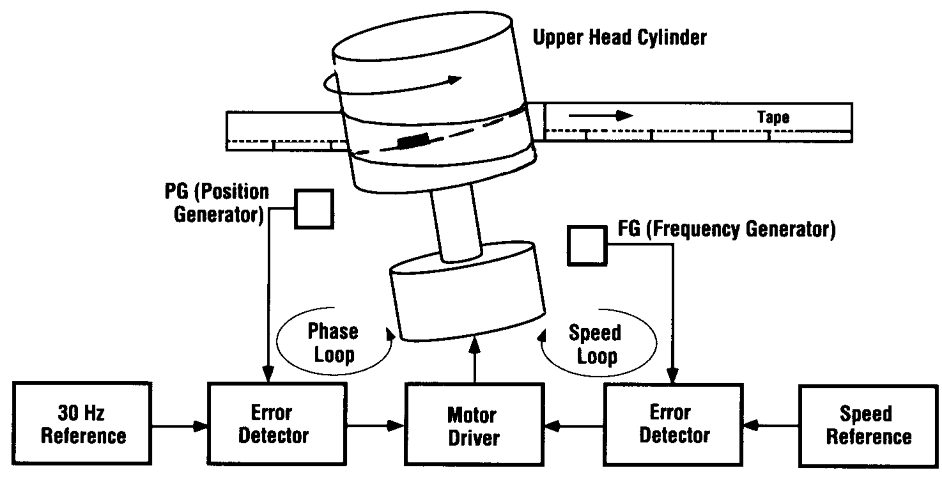


Fig. 7: Modern VCRs add a second loop to provide faster response to changing conditions. The "phase" loop is like the old single-loop system, and provides fine adjustment to the motor. The "speed" loop gets the motor close to the correct speed quickly.

of the first loop. The phase loop compares the phase of the control track or a pulse generator to the 30 Hz reference signal, just as the single-loop servos did. However, since it only has to make minor adjustments to the correction supplied by the speed loop, it can do so quickly. By combining the two loops, we get both speed and precision.

Troubles in a dual-loop system cause all the signals in both circuits to try to correct for the error. Tech Tip 132 explains how to isolate problems to the correct loop.

The Capstan Servo

Early VCRs only applied servo correction to the spinning video heads. The heads needed to compensate for all tape motion errors. They did not need a capstan servo, because they

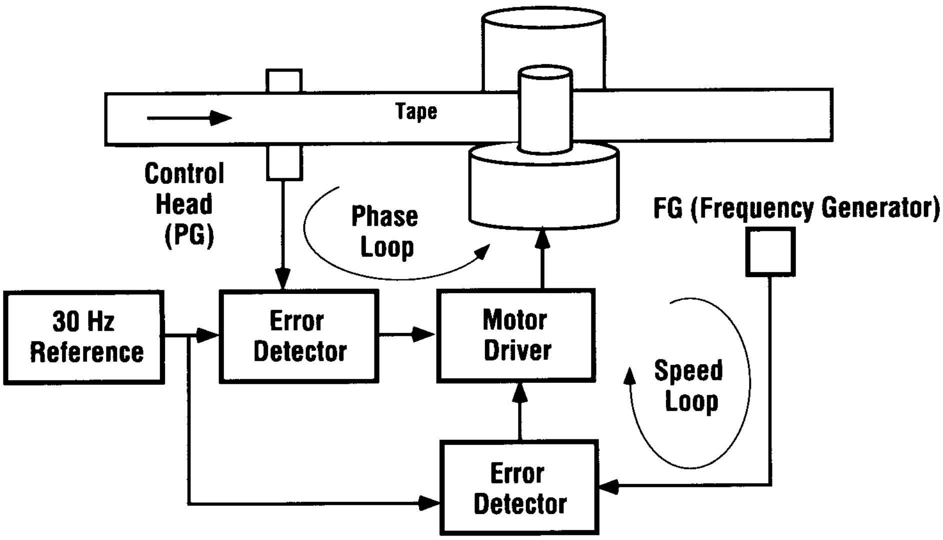


Fig. 8: Modern VCRs also have a servo to control the tape motion through the capstan motor. It, too, uses a dual-loop correction system for speed and accuracy.

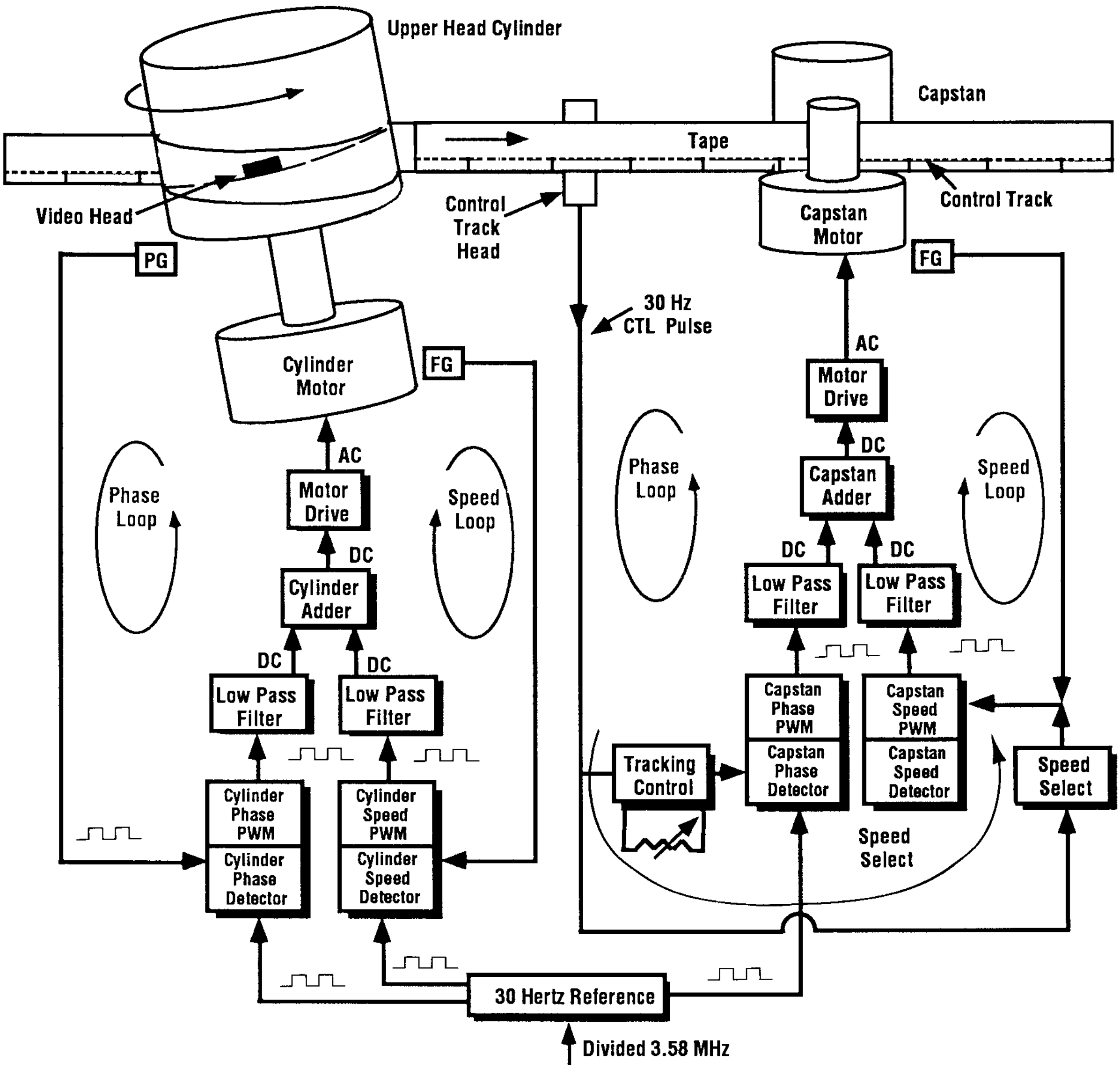


Fig. 9: The capstan servo actually has a third correction loop which senses which speed was used to record the tape. If the frequency detector notices the control track at 15 or 60 Hz (instead of the normal 30 Hz), it quickly moves the motor to the next speed.

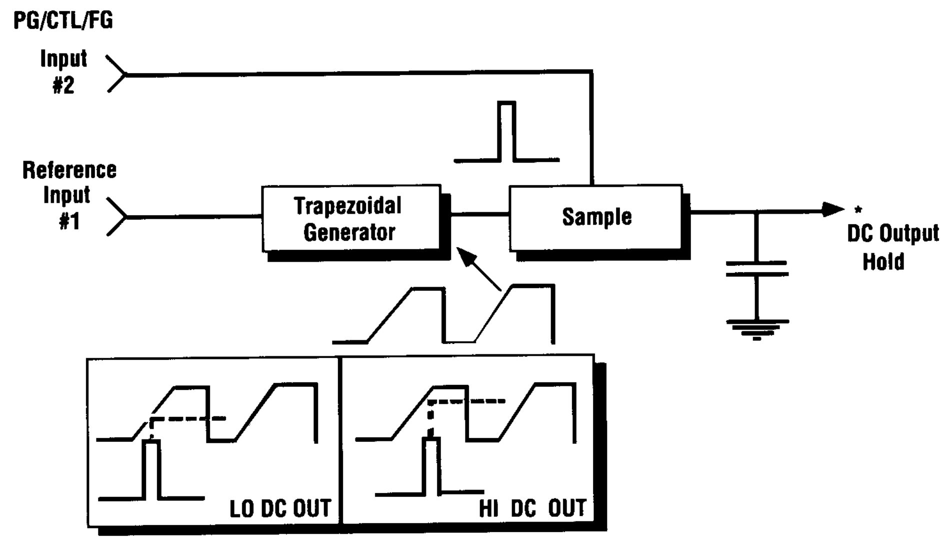


Fig. 10: Many older VCRs use a trapezoidal generator as an error detector. If the pulse arrives late, it triggers a voltage higher on the voltage ramp, which translates to a higher DC error voltage.

only recorded and played tapes at a single speed. Multi-speed VCRs added a second set of servos to automatically choose the correct speed during playback. As an added benefit, the capstan servo makes adjustments for tapes that were recorded at a slightly different speed, or that have been stretched through repeated playing.

Where the drum servo normally makes phase corrections by comparing a pulse generator to the 30 Hz reference signal, the capstan servo uses the control track. The control track head becomes the servo's transducer. When the error detector notes that the control track and 30 Hz reference do not agree, the servo changes the capstan motor's speed.

In addition to the phase and speed correction circuits, the capstan servos need another detector to sense which tape speed was used to record the tape. The speed detector is a frequency sensor, set for 30 Hz. If the speed detector finds the frequency is near 30 Hz, it does nothing, and lets the speed and phase loops control the capstan motor. If the speed detector senses a 15 or 60 Hz control track signal, it instructs the capstan motor to double or halve its speed. After this large speed correction, the normal speed and phase loops bring the control track signal into exact timing with the 30 Hz reference.

Improvements in Error Detectors

Early VCRs used analog comparators as error detectors. The pulse from a transducer fed one input, while the 30 Hz reference controlled a trapezoid generator. The point at which the PG pulse crossed the rising edge of the trapezoid translates to the DC correction voltage. If the pulse arrived later, the ramp was at a higher level, creating a higher DC output. A sample and hold stage then stored this voltage in a capacitor to feed the motor driver.

The biggest problem with these circuits is that they drift as components age. Several internal adjustments are needed to compensate for this drift, and any stage which is out of alignment can cause the servos to stop working.

Newer VCRs use "pulse width modulators" (PWMs) as error detectors. These are sometimes called "digital" servos, because correction is based on square waves of constant amplitude.

When no correction is needed, the PWM produces a signal with a 50% duty cycle (the "on" time is the same as the "off" time). Feeding this signal through a low-pass filter (LPF) results in a DC voltage with a level 50% of the peak-to-peak value of the PWM, which becomes the "zero correction" level.

If the reference and feedback signals are not in proper timing with each other, the PWM IC changes the ratio between the on and off time which, in turn, changes the DC at the LPF output. For example, holding the voltage high for a longer time causes the DC correction voltage to increase. Feeding this higher DC to the motor driver, causes the motor to change speeds. When the speed is correct, the pulse width returns to the 50% duty cycle.

Because the IC must constantly make corrections, the pulse width is constantly changing. Watching the PWM output on an oscilloscope, shows this correction. It might look like the scope trigger circuits are unstable, but the variations in the waveform are the normal corrections produced by the PWM.

When there is a servo problem, the pulses may either be abnormally steady, or may vary quickly from maximum to minimum width. See Tech Tip 132 for details.

Motor Drivers

Whether analog or digital, the output of the error detector is DC. Most servo motors, however, use AC drives. The motor driver converts the DC control signal to the needed AC motor drive.

By concentrating on the DC point in troubleshooting, it doesn't matter if the VCR uses a 3-phase, 2-phase, or direct-drive DC motor; the servo operation is always the same.

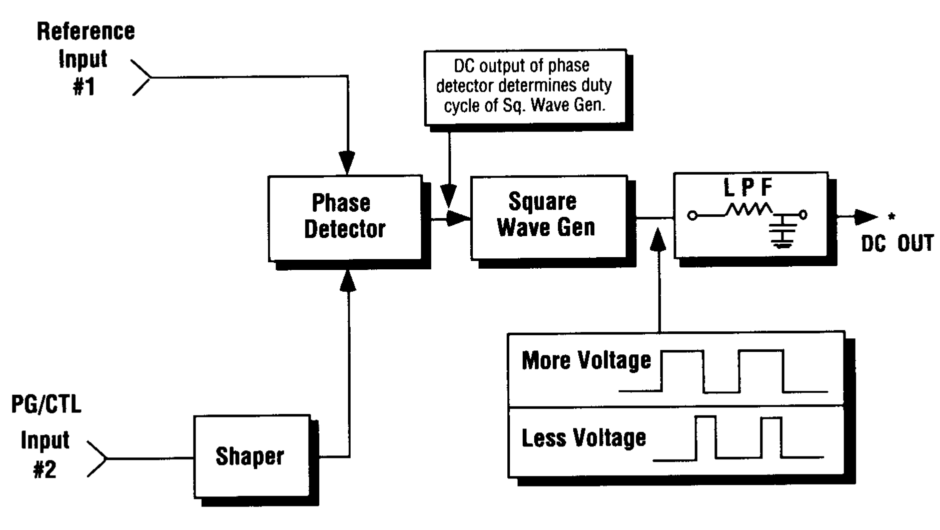
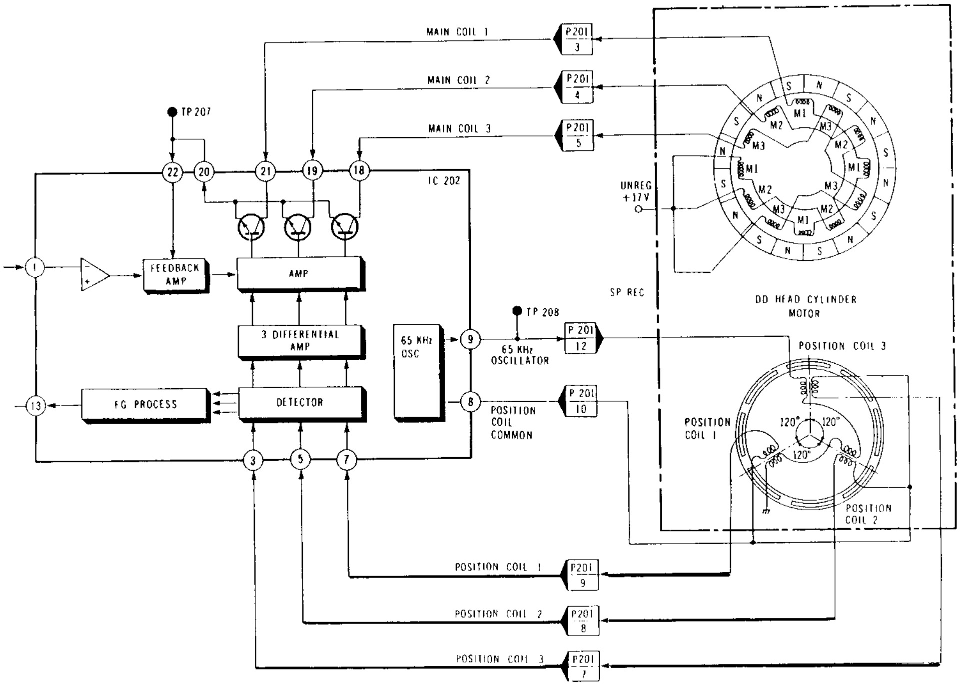
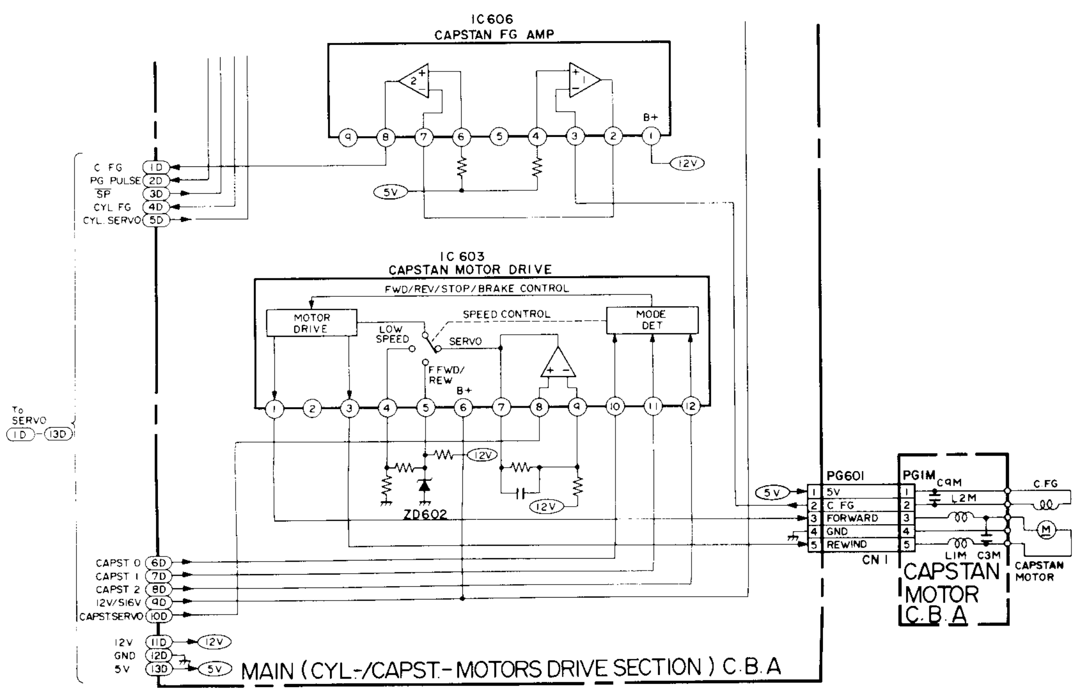


Fig. 11: Most VCRs use a form of PWM (pulse width modulation). When the duty cycle is low (less "on-time"), the DC output is less than when the duty cycle is high (longer "on-time").



Courtesy: Panasonic

Fig. 12: Many VCRs use 3-phase motors. The driver converts the DC correction voltage to drive signals of different frequencies to keep the motor turning at the required speed.



Courtesy: RCA

Fig. 13: A 2-phase motor uses a flip-flop which applies current to either of two drive coils. The speed is controlled by varying the coil current, and the frequency is self-determined by the position of the motor shaft as it rotates past hall-effect detectors.

(NOTE: Most "DC servo" motors are actually AC motors. The motor driver circuits are simply inside the motor enclosure instead of on the main circuit board.)

The two most common servo drivers feed a 3-phase or a 2-phase AC motor. The motor driver's integrated circuit and motor driving transistors are usually on the main servo board, and then feed to the motor through multiple conductors.

The 3-phase system produces three driving signals, each shifted by 120 degrees from the next. The speed of the motor is controlled by the rate of change (frequency) of these three signals. There are often three other motor windings, called "position" coils, which feed signals from the motor back to the motor drive IC. These feedback signals confirm the motor is rotating correctly and may also serve as the frequency generator (FG) for the speed loop.

A 2-phase motor operates on a flip-flop princi-pal. The motor has two sets of windings which alternately energize to move the shaft. After one winding receives current, and causes the motor shaft to move, a sensor inside the motor detects when the shaft has turned to the position needing power from the other winding. The driver then removes the current from the first winding and applies it to the other. Then, as the shaft turns farther, the signals reverse.

The speed of this type of motor is controlled by varying the amount of DC current supplied to the drive coils. Increased current causes the shaft to turn faster. The rate (frequency) at which the driver alternates current to each drive coil is solely dependent on how far the shaft has turned, and unlike the 3-phase system, is not controlled as a way to regulate the motor's speed.

In either case, feeding a variable DC voltage into the motor speed control test point should allow you to manually control the motor's speed, if the motor and driver are good. Tech Tip 132 gives details on using this information when troubleshooting.

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