PREPRINT NO. 891 (E-3)

VACUUM CASSETTE DUPLICATOR

Roger R. Sleger
Robert P. Harshberger, Jr.
Ampex Corporation
Redwood City, California

PRESENTED AT THE

43rd CONVENTION

SEPTEMBER 12-15, 1972

AUDIO

A

E S

Convention Price ....$ .35
By Mail to Members ......$ .75
By Mail to Non-Members...$1.00

AN AUDIO ENGINEERING SOCIETY PREPRINT

This preprint has been reproduced from the author's advance manuscript, without editing, corrections or formal review by the Editorial Board. For this reason there may be changes should this paper be published in the Journal of the Audio Engineering Society.

Additional preprints may be obtained by sending request and remittance to the Audio Engineering Society Room 929, 60 East 42nd Street, New York, N. Y. 10017.

VACUUM CASSETTE DUPLICATOR

ROGER R. SLEGER and ROBERT P. HARSHBERGER Jr.

AUDIO-VIDEO SYSTEM DIVISION
Ampex Corporation
401 Broadway
Redwood City, California 94063

A fully automatic 40:1 "In Cassette Duplicator" has been developed that is based upon a small, servo controlled, vacuum tape transport. The system isolates the cassette mechanics from the duplicating area thereby enabling precise tape control at the heads. The principles of operation of the Ampex CD-200 vacuum duplicating system are presented.

INTRODUCTION

Open reel production tape duplicating equipment can currently operate at up to thirty-two times normal tape speed. In the past duplicating preloaded cassettes or tape duplicating equipment could not be accomplished at that speed. This is no longer true. A 40 times "in cassette" duplicator is being marketed that not only records at a higher rate than ever before, open reel or cassette, but rewinds at tape speeds as fast as most snappy, studio tape recorders and on top of that, is fully automated. Sounds impossible? Consider the reasons that speed is limited in cassette duplicators – flutter, tape tracking, tape stretching, oxide shedding, etc. There are, in fact, many reasons, the most significant of which is tape handling reliability. Why record twice as fast if only half the cassettes make it through the system? Well, at last there *is* a better way.

The finest pieces of digital, instrumentation, and video tape handling equipment all have one thing in common: *pneumatics*. Using air, a designer can effectively isolate tension disturbances from one area of the tape to another and achieve orders of magnitude improvement in many operating parameters. Well, it's time we audio people recognize the capability of this type of tape handling system and apply it to some of the tough situations we've been trying to master using old techniques. The cassette duplicator described in this paper, as you will see, is a very practical audio application of pneumatic transport technology.

BACKGROUND

To record audio tape, using current techniques, every inch of tape must pass the gap of a record head.

It is usual practice to duplicate tapes by reproducing a master tape on one machine while recording onto blank tape on another machine. Typically, both machines operate at some multiple of normal master tape speed. Many recorders or slaves will usually be fed from one reproducer or master. When the final product is to be a cassette, one may choose from two basically different duplicating philosophies.

High production duplicating (over 10,000 copies off the same master) employs a continuous loop master reproducer and reel-to-reel type slaves (Figure 1).

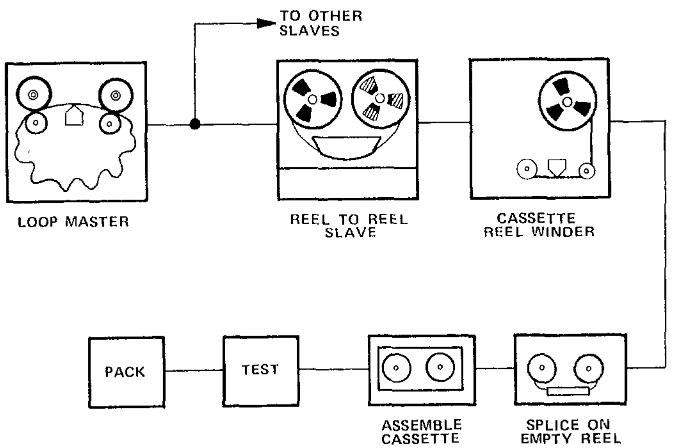


Figure 1. Typical High Production Chain

The master tape runs continuously so that a multitude of copies can be made on one reel or pancake of tape per slave recorder. Cassette reels are then wound with material from the recorded pancake, spliced or attached to another reel and loaded into cassette cases. Labels are applied to the cassette, and it gets checked and packed. This process is impractical for low-quantity duplication due to the number of expensive machines and operators required.

A more practical method to create cassette copies is to record preloaded cassettes (Figure 2). Using this approach one may create copies using only two machines, a master and a slave.

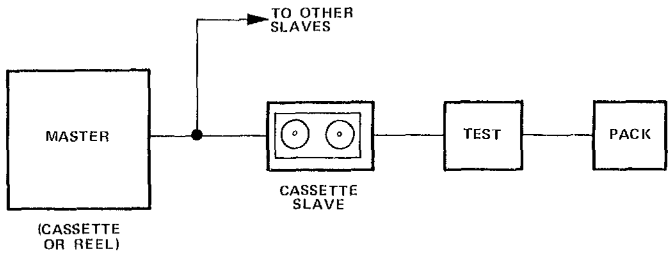


Figure 2. Typical Low Production Chain

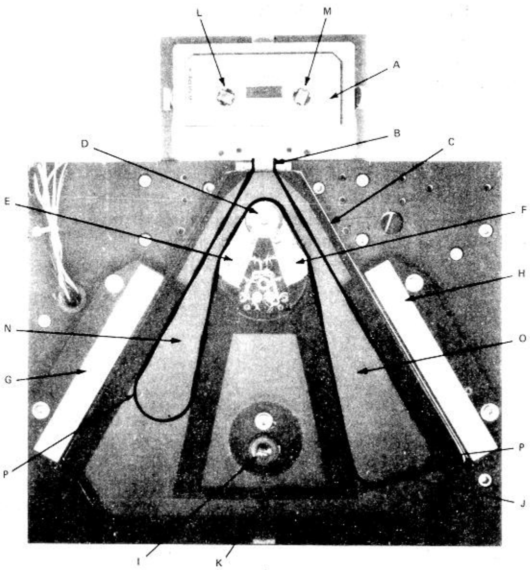
The unit cost of each copy usually is higher than for high-quantity duplicating because cassettes must be preloaded with the proper tape length to match the master length, but the equipment cost is lower. Early duplicators using this approach utilized one master, open reel or cassette, and a number of cassette slaves all running at normal speed for that particular master tape. Since running a machine twice as fast will yield twice the copies per unit time, duplicating speeds have been steadily increasing over the years. High-speed cassette operation, however, creates serious handling and recording problems not encountered in low-speed operation. It is essentially these problems that led to the unusual design of the high-speed duplicator described in this paper.

DESIGN

Transporting tape inside a cassette at high speed is like roller skating on an ice pond. You can become sidetracked with nearly insurmountable secondary problems. The new duplicator design requires use of a very high-speed slave recorder, since it is fully automated and normally operated alone with one master. Using one slave allows use of better quality recording heads and electronics than could be used with multiple slaves, since only one set of each is used per system. Automating one slave for cassette changing is also more practical than for a number of slaves. Clearly, a new, very different tape transport is required in this system.

The duplicator being described uses a cassette master that is reproduced at 75 in/s or forty times normal cassette speed. A separate, fully automatic slave, interconnected with the master, records preloaded cassettes that are stored in chutes on the slave. One copy is recorded per slave for each cycle of the master cassette tape. The slave will store and sequentially record up to 100 cassettes automatically. Mechanically defective cassettes are rejected from the slave through a separate slot from completely recorded cassettes. More than one slave may be operated with the same master.

The master and slave transports are identical in design (Figure 3). Both use a vacuum chambered transport for high-speed tape handling. A loop of tape from the cassette is sucked into this vacuum chamber, which contains a large diameter capstan (D) and two tape heads (E, F). This loop of tape is transported by the capstan.



A – CASSETTE
B - INLET GUIDE
C – VACUUM CHAMBER ASSEMBLY
D – CAPSTAN
E,F - TAPE HEADS
G,H – SERVO AND CONTROL P.E. CELLS
I – LIGHT SOURCES
J – CUE UP BRAKE
K - VACUUM INLET
L – "B" REEL MOTOR
M "A" REEL MOTOR
N – "B" VACUUM CHAMBER
O – "A" VACUUM CHAMBER
P TAPE LOOP

Figure 3. Transport (Shown with tape in the "cued up" mode, ready to record.)

Two reel drive motors (L, M) supply or take up tape as dictated from the servo for that particular motor. Fast starts and stops are permitted because of the buffering action of each of the long vacuum chambers (N, O). Flutter is extremely low since the vacuum chambers very effectively isolate tape reel disturbances from the capstan and head area. The heads themselves are mounted as close as possible to the capstan to further minimize flutter.

Because the vacuum system presents a constant tension to the tape, there is essentially no tape speed variation from the beginning to the end of any cassette. The constant tension wind results in a very smoothly packed cassette take-up reel which minimizes binding within the cassette. Since tape tension is constant, a pinch roller at the capstan is not needed or used. To further ensure against slippage, the transport vacuum chambers are tapered in such a way that, together with the servo, they counteract friction effects at the tape heads which would otherwise unbalance tape tension across the capstan.

The vacuum chamber assembly (C) is a separate easily replaceable unit. The chamber is constructed basically out of plate glass and epoxy. Glass is used because visible paths through the chambers are needed for the servo system optics and because, unlike many clear materials, it does not as readily acquire and hold static charge. The chamber is designed such that the tape oxide surface does not touch the glass surface but is separated from it by a thin film of air. In fact, the only components the tape makes sliding contact with in the entire machine are the tape heads. This greatly reduces wear on tapes as well as minimizes oxide loss due to scraping. Self-acting air films are deliberately formed at the steel inlet guide (B) to the transport.

Each transport has three motors – a capstan motor and one for each cassette reel drive. All the transport motors are direct-drive, so there are no clutches, brakes, or belts to wear out or malfunction.

The reel drive motors are bidirectional, permanent magnet, dc. They have the very high torque-to-inertia ratio required for fast start-up. During rewind, the motor commutator turns at between 4,000 and 11,000 rpm, depending on actual adjusted speed, which provides adequate motion to keep the commutator/brush interface clean. Soft brush material is used together with electronic suppression to isolate RFI transmission into the duplicator electronics.

The capstan motor is used only during the record portion of each cycle. During rewind, an air film is induced across the capstan and the capstan is not rotated at all. For this reason, a single-speed hysteresis-synchronous motor is used which gives very good flutter performance. The heavy capstan motor is stabilized and at full speed before the system will allow a record cycle to begin. As a result, motor start time is not critical.

SERVO SYSTEM

The servo system is shown in block diagram form in Figure 4. It can be seen that there are two essentially identical servos labeled "A" and "B". "A" refers to the left-hand or takeup reel and "B" refers to the right-hand or supply reel. The PEC is a long solar cell whose output is proportional to the amount of light falling on it. This in turn is inversely proportional to the amount of tape in the chamber blocking the light. The signal from the PEC is first amplified by a wideband amplifier. Wide bandwidth is required to minimize time-position errors fed to the comparator. The amplified signal then passes through a solid-state switch to a narrow-band compensation amplifier. This amplifier contains all the necessary compensation to stabilize the servo. The signal then passes through another solid switch ganged with the first, to a wide band motor drive power amplifier. The wide band width is necessary here so that a step input (such as that resulting from the servo being switched off) also results in a step output – required for the stopping operation. The motor drive amplifier has a very low output impedence (<<1 ohm); hence, turning off the input results in a step short circuit across the motor. This will stop the motor from 10,000 rpm in less than one revolution. The input to the motor drive amplifier is a virtual ground, allowing this point to be used as a summing junction for injection of the other signals to the motor. The servo loop is closed mechanically by the tape loop, driven by the motor, regulating the amount of light falling on the PEC.

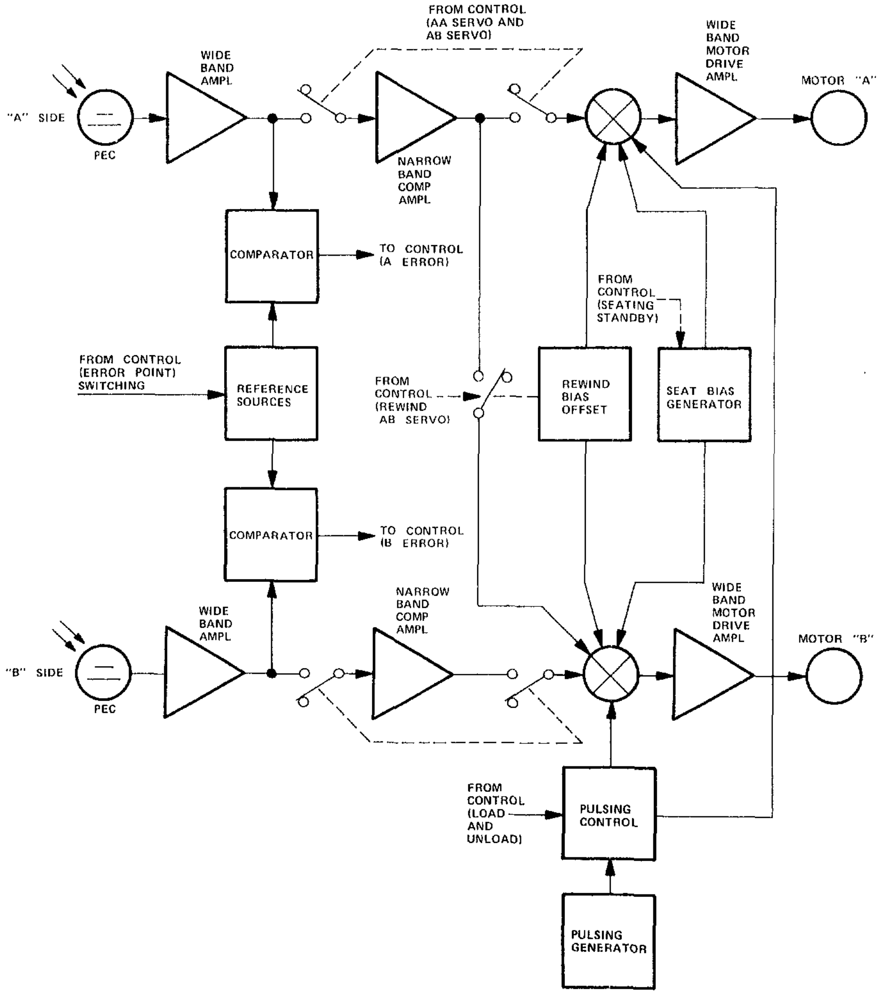


Figure 4. CD-200 Servo Block Diagram

On the block diagram there are several areas not in the servo loop; these will be explained here.

The output of the first wideband amplifier gives a continuous and accurate analog account of the tape loop position in the chamber. This is fed to an analog comparator along with various switchable dc references. The output of this is translated to a digital pulse occurring as the tape loop is passing certain points in the chamber. These signals are used in controlling modes as explained later and are referred to as high, zero, or low error crossings.

The pulsing generator is a 40-Hz, 10% duty cycle multivibrator. The pulsing control can select either positive or negative excursion and apply it to the summing junction of either "A" or "B" motor drive amplifier. This results in the motor being driven by a pulsed dc in either direction. The reason for this is explained later under "Non Servo Motor Control". The rewind bias applies a positive dc voltage to one summing junction and a negative to the other, injecting an error offset in the servos. This will be explained in detail under the section "Rewind Technique".

The seat bias applies a 60 Hz ac voltage superimposed on dc to the summing junctions while the machine is in standby. This allows the reel spindle to easily engage the cassette hubs when the cassette is inserted.

SPECIAL OPERATIONS

Because of either the duplicating speed or inherent cassette weaknesses, a number of special cassette handling techniques have been derived and are explained below.

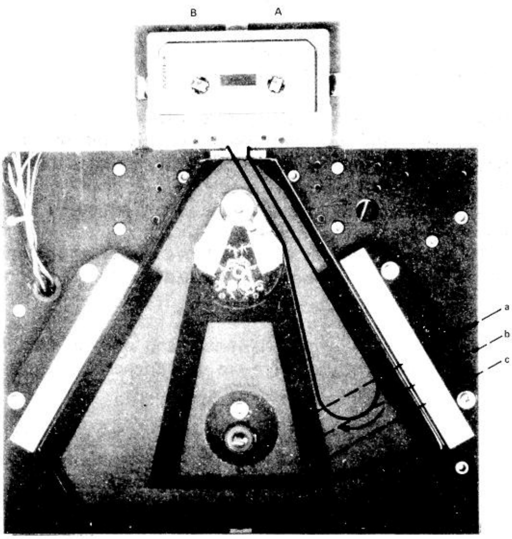
Non Servo Motor Control

Before the tape can be run under servo control, it must be drawn out of the cassette into the chambers. This could be done by switching the servos on, but since, when no tape is in the chambers, the error signal is very high, loading would be extremely fast and rough, possibly damaging the cassette. Instead we choose to slowly pulse the tape down the chambers. The pulsing technique is used to allow the motors to turn slowly while still maintaining high torque. This is not possible with pure dc. When the tape has reached the zero error crossings, the servos are turned on; thus the servos are energized at their zero error or near running position, resulting in a smooth mode change. The same technique is used to unload the chambers by switching servos off and pulsing on at end of tape. The pulsed torques used are strong enough to overcome any cassette or machine friction but not strong enough to damage the cassette upon withdrawal of the tape into the cassette.

Rewind Technique

Both at the start of the cycle and upon completion of record, tape is rewound under servo control in one vacuum chamber. (Refer to Figure 5.)

Both motor drive amplifiers are switched to be controlled from the "A" PEC. This would make the loop seek the zero error position for "A" servo (position B) and neither reel would move, since both servos are satisfied and no disturbance exists. If we now inject an error into the "A" servo such that it seeks position C and into "B" servo such that it seeks position A,



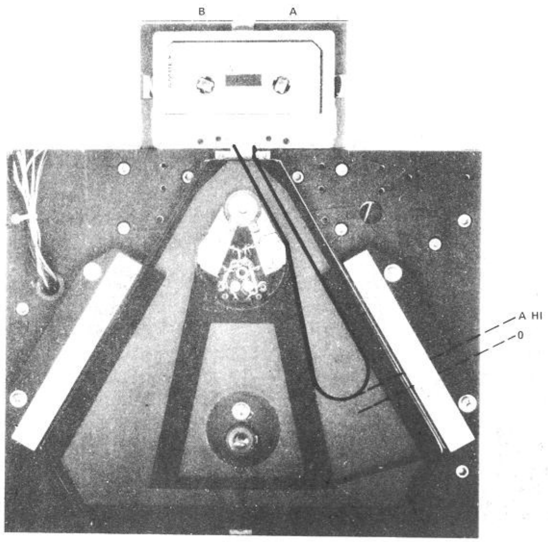
Rewind Mode

Figure 5. Rewind Mode

neither servo can be satisfied; hence the loop will assume an intermediate position and will move from reel "A" to reel "B". The rewind speed is determined by the amount of offset from B that is introduced into each servo and by cassette friction.

End of Tape Sense

(Refer to Figure 6.) The end of tape sensing in this machine does not depend on clear or reflective leader or tones but instead senses true end of tape. As tape is moving under servo control in rewind or record, the supply reel will run out of tape and begin winding tape in the opposite direction. This inverts the phase in the servo mechanical feedback loop; thus the tape tends to pull out of the vacuum chamber. As the tape crosses the high error crossing point in the chamber, it signals the control to turn off the servo. As stated earlier, the motor drive amplifier output impedence is very low so the motor will stop extremely fast; a portion of the loop will still be in the chamber, thus preventing tape damage.



EOT Sensing Position (Note· A reel is partially backwards)

Figure 6. EOT Sensing Position (Note: A reel is partially backwards.)

CUE-UP AND RECORD

Since cassette programs generally start very close to the beginning of a tape, the tape must be accelerated to stable motion or within flutter specification in a minimum of time. With a heavy ac motor plus a flywheel, the motor with the tape cannot be accelerated quickly enough for acceptable performance. Since the cassette handling logic insists that the capstan must be stopped during the "cueing up" mode, this rules out continuous capstan rotation.

Because of these restrictions, a technique was developed that permits use of the ac capstan but does not allow capstan start time to affect machine start time. In effect, the capstan is turned on after the "cue up" mode and is slowly accelerated to speed (Figures 7 and 8). Tape is looped into both vacuum chambers in preparation for duplication (Figure 8); however, no takeup motor torque is provided. Consequently, the capstan drives tape down the takeup reel vacuum chamber until it reaches the pneumatic brake at the bottom of the chamber. At this point, an air film forms between the tape and capstan and the capstan no longer is able to drive the tape. Tension does exist in the tape during the "cued up" mode due to the

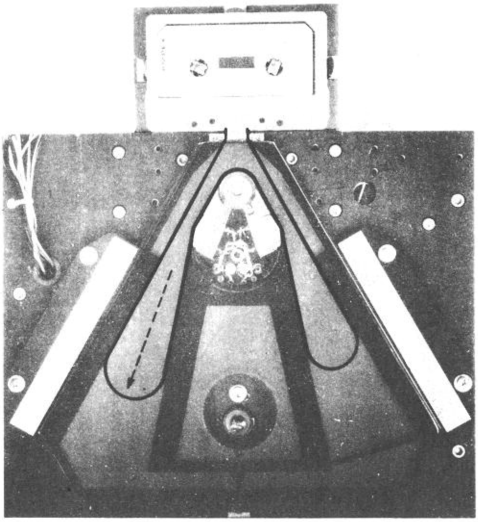


Figure 7. "Cue Up"

vacuum in the supply or "B" vacuum chamber. The counteracting tension is the head friction plus the result of vacuum holding tape against the pneumatic brake.

The machine stays in the "cued up" mode (Figure 8) for approximately 4 seconds to allow the capstan to reach stable speed, after which it is permitted to proceed to record (Figure 9). When a record command is given, the "A" side reel servo is simply turned on, which lifts tape immediately from the vacuum brake, provides take up torque, and breaks the air film between the capstan and tape. Tape motion begins as quickly as the servo motor motion lifts the tape. The motion is stable as soon as the servo has partially settled down from this instantaneous speed change. A typical start from zero to 75 in/s within flutter specification takes 0.07 seconds or 2.8 seconds at playback speed.

TIGHT CASSETTE

If the cassette becomes tight during record due to misassembly of cassette, poor tape slitting, or damaged cassette, the takeup reel will tend to bind against the cassette case. This increase

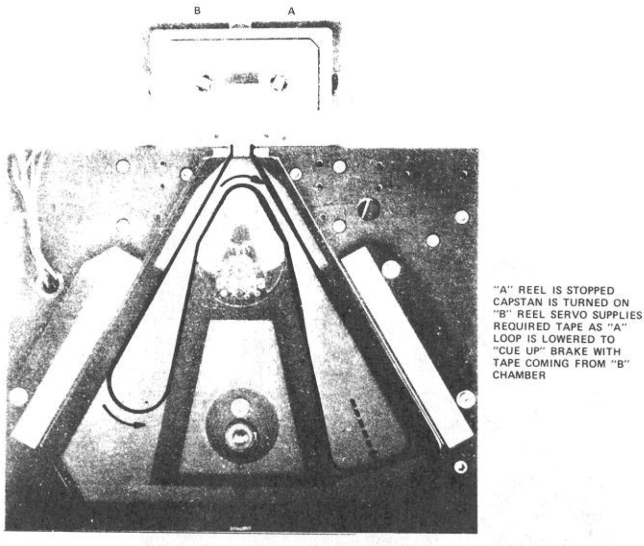


Figure 8. "Cued Up" Mode

in required torque causes the tape to ride further down the chamber, increasing the servo error. When this binding is sufficient for the tape loop to pass the low error crossing, the control is signaled to abort the cassette. An aborted cassette is considered a reject and will generally not operate in any standard cassette tape recorder. Conversely, any cassette not aborted *will* operate in almost any cassette recorder. This built-in test of the cassette is a highly significant portion of the automated duplicating system, since the cassette mechanics need not be tested further.

TRANSPORT CONTROL

A flow chart of the transport control sequence is shown in Figure 10. The main flow paths are shown in heavy lines, while the malfunction flow paths are shown in light lines and are labeled as to what malfunction they represent. Note that at "Is complete off" the main path

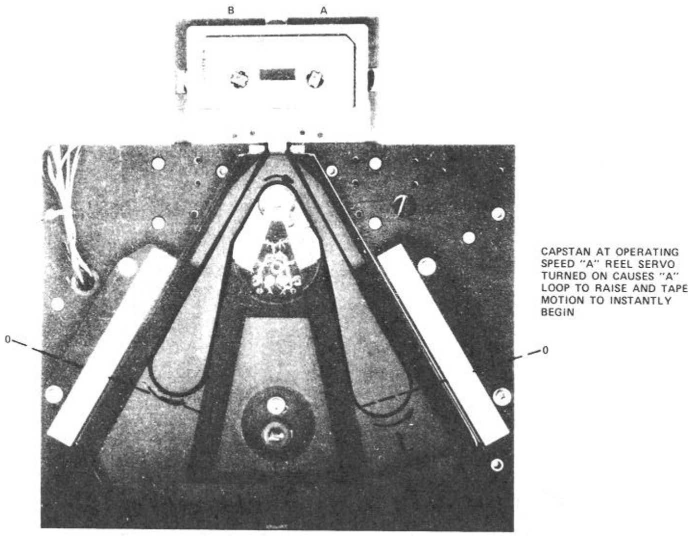
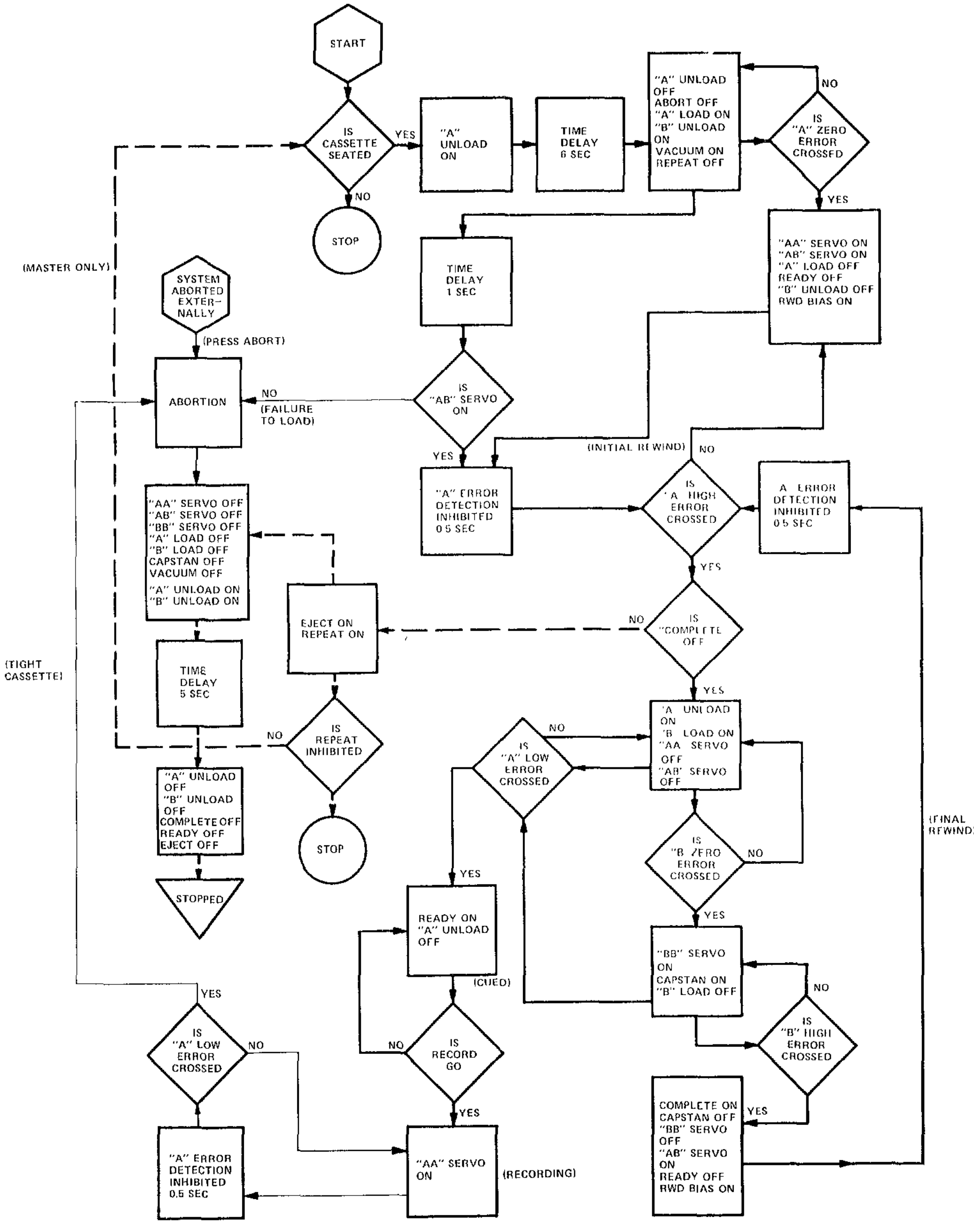


Figure 9. Record Mode

splits. This is due to the requirement to have two rewind cycles, one at the start of the cycle and one at the end. This interrogation determines which rewind it has just completed.

A fail-safe feature which is not shown on the flow chart works as follows:

Separate photo cells high in the chamber determine if any tape is in the chamber. If not, the servos are prevented from turning on, either accidentally or otherwise. This protects against machine malfunctions, and cassette conditions unresolvable by the transport control. If the sensors determine there is no tape in the chambers and any servo is on, it is a runaway condition and the cassette is aborted. If the sensors determine there is no tape in the chambers and no servo is on, this indicates a normal condition and the servos are locked out from being turned on accidentally, by noise or cassette malfunction. In addition, the fail-safe starts a timer at the start of every cycle. If the cycle does not repeat itself within 6 minutes, the cassette is aborted. This indicates a malfunction that is not normally aborted in the



CD-200 Control Logic Sequence

"A"	LEFT SIDE FACING MACHINE
"B"	RIGHT SIDE FACING MACHINE
"AA" SERVO	"A" MOTOR SERVO CONTROLLED FROM A SIDE
"BB" SERVO	"B" MOTOR SERVO CONTROLLED FROM "B" SIDE
"AB" SERVO	"B" MOTOR SERVO CONTROLLED FROM "A" SIDE
LOAD	PULSED DRIVE TO DUMP TAPE
UNLOAD	PULSED DRIVE TO TAKEUP TAPE
HIGH ERROR CROSS	SENSE OF TAPE LOOP NEAR ENTRY GUIDE
LOW ERROR CROSS	SENSE OF TAPE LOOP NEAR DEEP END OF CHAMBER
ZERO ERROR CROSS	SENSE OF TAPE LOOP NEAR RUNNING POSITION
COMPLETE	CASSETTE HAS SUCCESSFULLY RECORDED
EJECT	CASSETTE NOT ABORTED
ABORT	CYCLE STOPPED BEFORE COMPLETION
REPEAT	ON MASTER ALLOWS RECUE AND START OF NEXT CYCLE AUTOMATICALLY
STOPPED	ALL MODES OFF
STOP	NO FURTHER ACTION
READY	CUED UP WAITING FOR RECORD
RWD BIAS	OFFSET SERVO ERROR FOR REWIND
RECORD	GO SIGNAL ALLOWING CONTINUANCE OF CYCLE AFTER READY

——— NORMAL FLOW

— — END OF CYCLE

——— CASSETTE MALFUNCTION FLOW

system or, in the master, it indicates that all slaves have run out of cassettes and the master need not wait any more.

AUDIO

The duplicating speed of 75 in/s represents 40 times real time, hence, a frequency of 12 kHz relates upward to 480 kHz. This means the electronics must be flat to 480 kHz. The bias frequency must be much higher than this. We chose 2 MHz bias as an acceptable frequency.

The reproduce amplifier is fairly straightforward considering the frequencies involved. A separate preamp is located at the heads to minimize head to preamp cable capacitance shunting of the signal. The output of the reproduce amplifier is automatically switched on during record and distributed to the slaves.

Each slave has its own record amplifier and bias buffer for each channel, allowing for individual control of each channel on each slave. The bias oscillator is located in the master and bias is distributed at low level to each slave. The oscillator is switched on automatically during record.

The heads used are not subject to the size and placement restraints associated with normal cassette operation; hence larger, high-quality professional-type duplicator heads are used. The heads for the two different programs are on opposite sides of the capstan; hence inter-program cross-talk is essentially non-existent. All tracks, mono or stereo, are recorded in a single pass, resulting in a minimum duplication time. Side one is recorded forward and side two of the cassette is, at the same time, recorded backward.

CONCLUSIONS

The duplicator described in this paper has effectively eliminated preloaded cassette problems by isolating the cassette itself from the duplicating area. This type of system permits use of production-type duplicating heads, provides excellent tape guiding, and in short gives as good or better tape handling capabilities as any other audio duplicator available today.