FINAL REPORT

For

ENDLESS LOOP MAGNETIC TAPE RECORDER

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CONTRACT NAS5-3914

prepared for

Goddard Space Flight Center
Greenbelt, Maryland

prepared by

LEC · Lockheed · Electronics · Company

Industrial Technology Division
Edison, New Jersey

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February, 1966

SUMMARY

This document, the final report of NASA contract NAS5-3914, is submitted to Goddard Space Flight Center by Lockheed Electronics Company (LEC). Described herein is the overall project history, the equipment produced, techniques employed, tests conducted, technical knowledge gained, and program results.

The scope of the program involved the development of an Endless Loop Magnetic Tape Recorder. Only one prototype unit was produced. This recorder utilized 1000 feet of 1/2 inch wide tape, on which 5 data tracks are recorded. The frequency range of the recorded signal is from 20 kc to 130 kc at a tape speed of 33 ips.

A key feature of this recorder is its compact size. The diameter of the tape pack, when fully loaded to 1000 feet, is less than 6 inches, and the total recorder package is 312 cubic inches. The dimensions of the rectangular case are 6" x 6-1/2" x 8".

In addition to the compact size, the use of a brushless dc motor coupled with an integrated circuit phase lock speed control servo has contributed significantly to the excellent acceleration and flutter characteristics of the recorder. However, the torque characteristic of the motor proved to be a disadvantage also.

Installing a tape load of 1000 feet in the compact size imposed severe constraints on the tape path. To minimize the number of components in the drive mechanism, it appeared desirable to use the motor as one of the capstans. Since the motor is able to accelerate and decelerate quickly upon application and removal of power, the inertia of the center hub of the reel cartridge was great enough to override the start-stop characteristic of the motor. This caused the tape to bind at the point of exit from the cartridge. To counteract the tendency of the motor or stop abrubtly, a circuit was added to the servo that gradually decreased the power to the motor. This technique allowed the entire system to come to rest without binding the cartridge.

A second problem that was not corrected was a tendency of the tape pack to jam depending on the recorder's axial orientation. This tendency was found to be related to the tension in the tape pack also. A parallel effort at GSFC, with a similar tape cartridge, did not encounter the binding problem related to orientation. Several comparisons of the LEC model and the GSFC model failed to show any difference in basic design which could be traced to the ultimate cause of the problem. At that point in the program, the contracting agency decided not to increase the budget for further study because of the lack of immediate need for the device. Consequently, the remainder of the contract effort was directed at carefully documenting the combined performance of the servo and the brushless dc motor. This data is shown in Table I.

The remainder of this document summarizes the entire program activity and is divided into the following major areas:

- System Design
- Phase Lock Servo
- Brushless dc Motor
- Magnetic Heads
- Vibration Isolation and Momentum Compensation Systems

For a chronological review of this program, the reader is directed to the reports which were generated during the program.

- Design Study Report
- Quarterly Progress Reports
- Monthly Progress Reports

Table I lists the pertinent recorder characteristics.

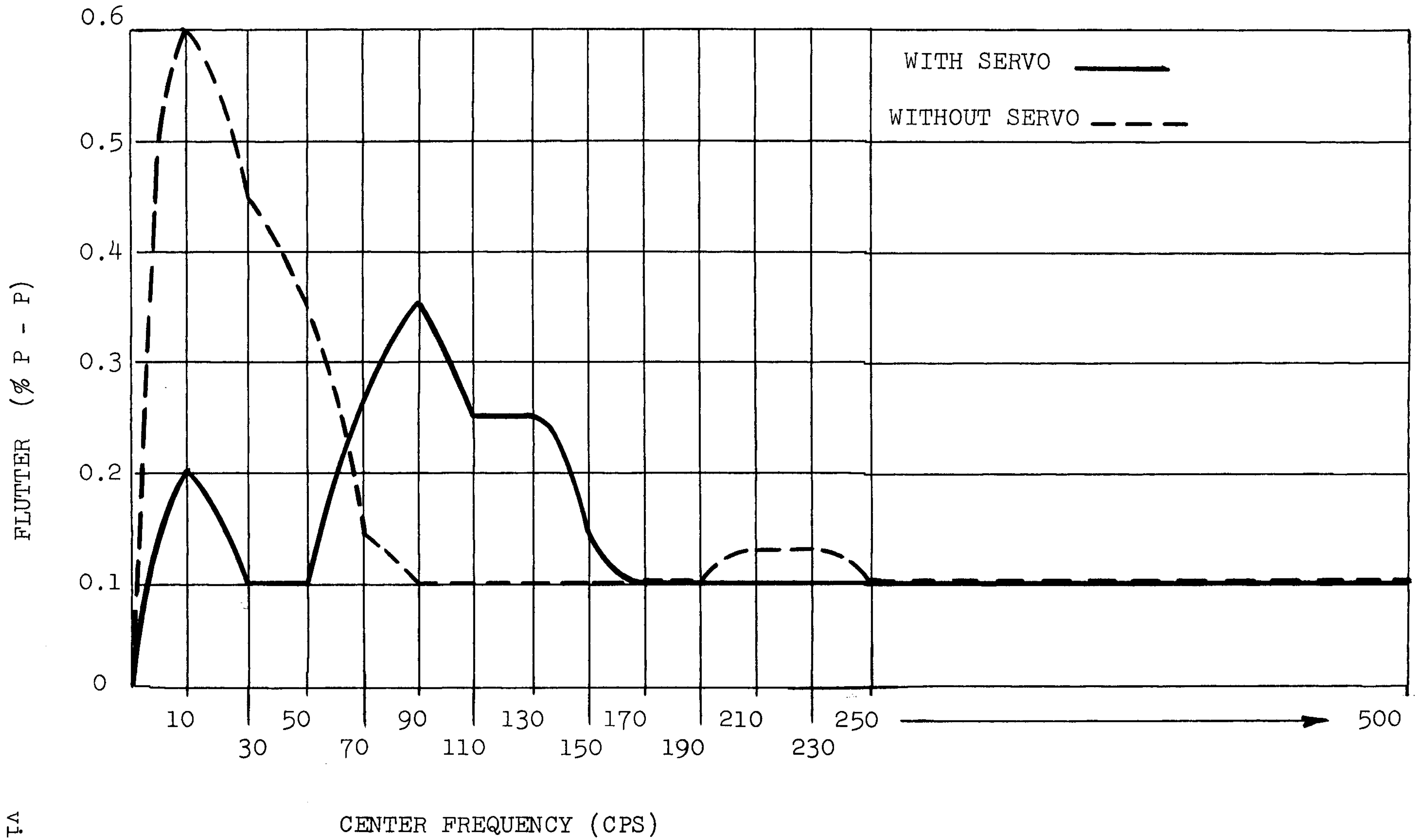
TABLE I

SUMMARY OF RECORDER CHARACTERISTICS

Weight	9 pounds
Case Size	6 x 6-1/2 x 8"
Number of Tracks	5
Length of Tape	1000 feet
Frequency Response	120 kc
Flutter (dc to 2.5 kc)	0.75% peak-to-peak
Recoding Method	Saturation
Signal Type	FM
Tape Speed	
Record	33 ips
Reproduce	33 ips
Power	
Record	1.5 watts
Reproduce	1.5 watts

TABLE I CONTINUED

FLUTTER RECORD



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LIST OF ILLUSTRATIONS

INTRODUCTION

This final report defines Lockheed Electronics Company's efforts in the fulfillment of NASA contract NAS5-3914 for the Goddard Space Flight Center. The period of contract performance is from July, 1964 to October, 1965.

The objective of the program is to design, develop, fabricate, test, and deliver a 1000 foot compact, endless loop magnetic recorder, which utilizes 1/2 inch wide tape. The tape contains 5 tracks with associated head parameters to enable recording and reproducing a signal at a frequency range of from 20 kc to 130 kc. Record and reproduce is performed at a tape speed of 33 ips.

Photographs of the equipment produced, one which shows the unit in the case and one showing the unit outside the case, are depicted in Figures 1 and 2, respectively.

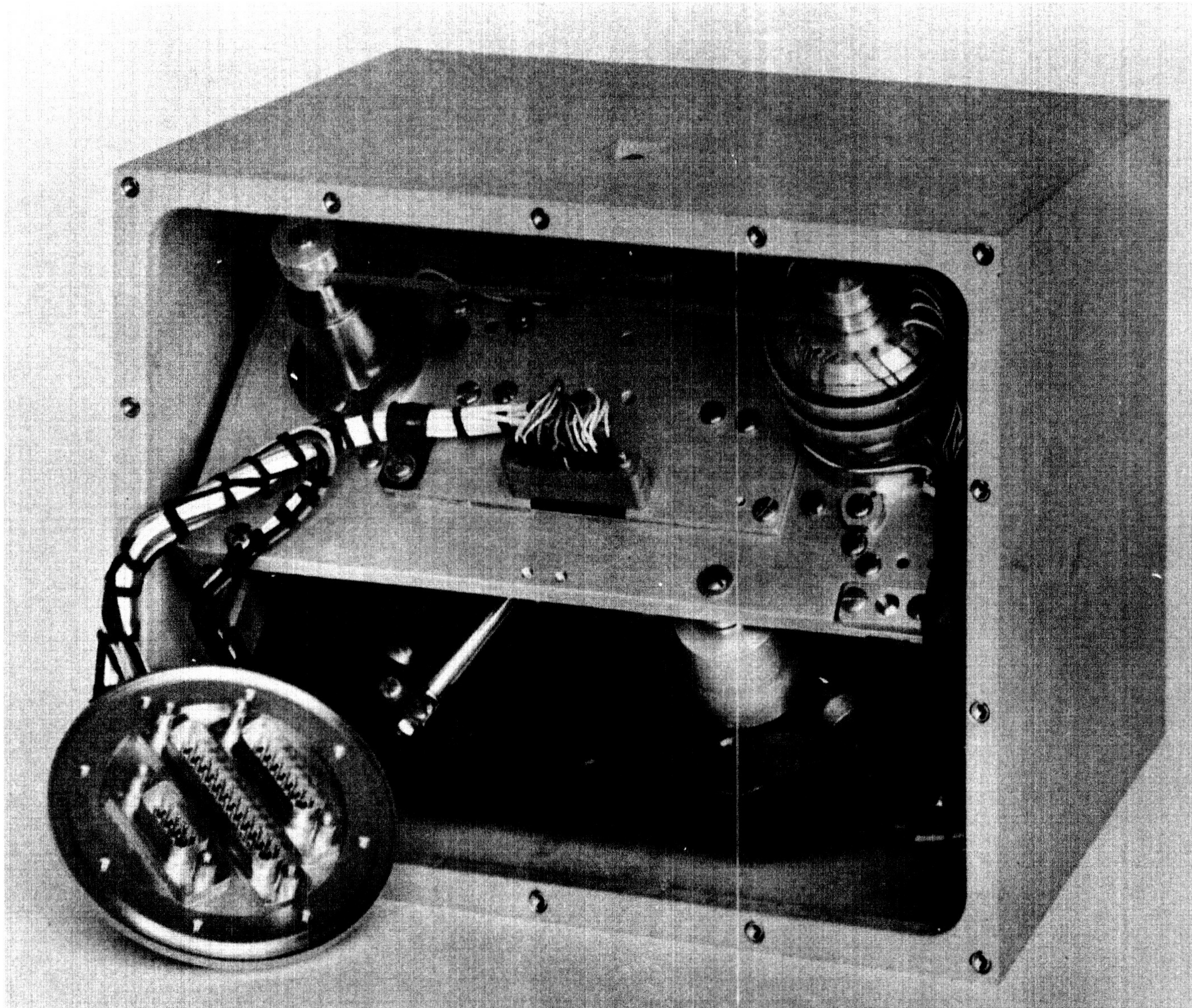


FIGURE 1

1000 FOOT ENDLESS LOOP MAGNETIC TAPE RECORDER (WITH CASE)

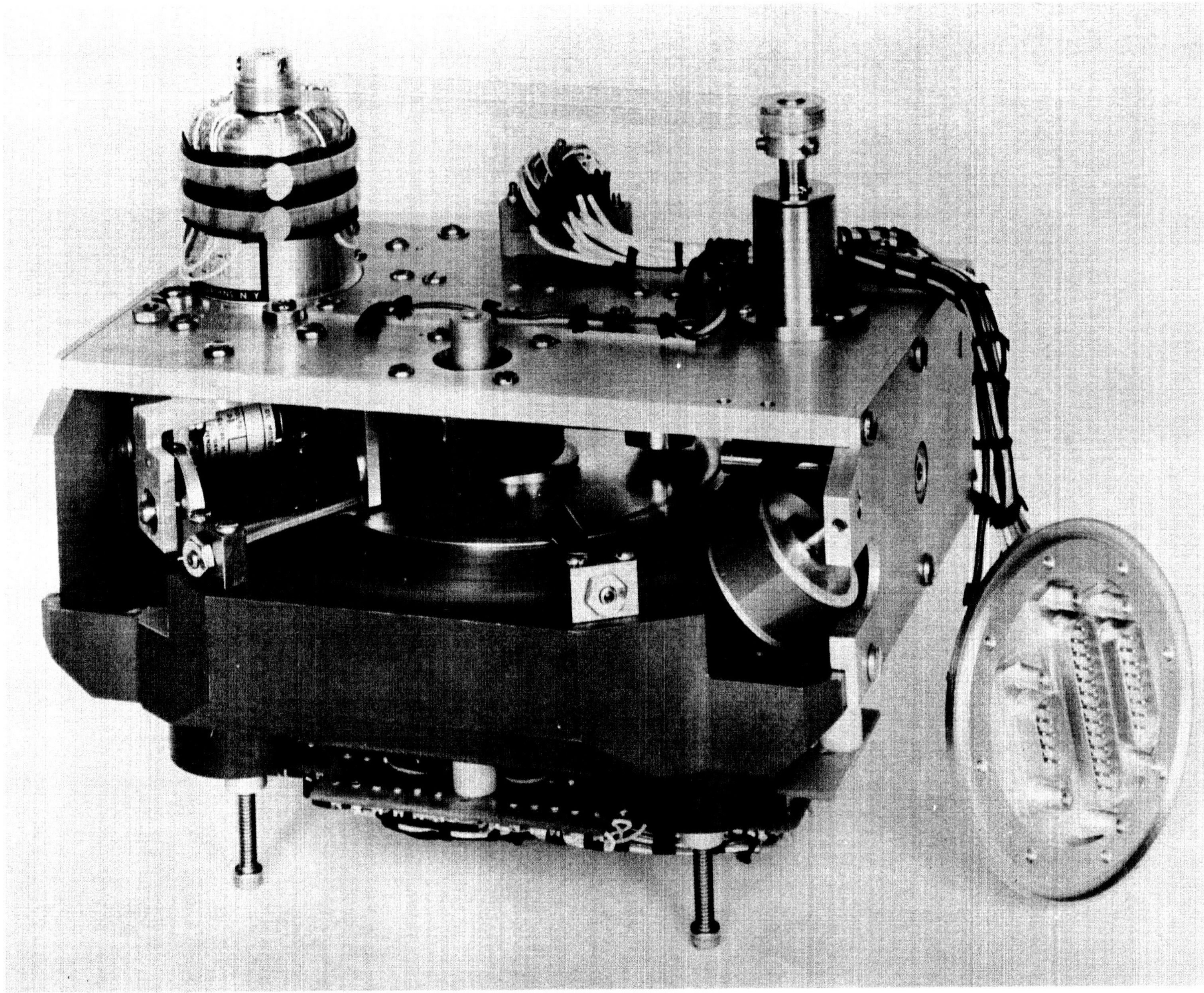


FIGURE 2

1000 FOOT ENDLESS LOOP MAGNETIC TAPE RECORDER

SYSTEM DESIGN

The primary requirement placed on this recorder is to store up to 8 minutes of television data on 5 tracks of 1/2 inch wide tape. The bandwidth of this data is from 70 kc to 120 kc with record and reproduce at the speed of 30 ips.

Since there are no signal electronics used in the system, the record/reproduce head system must be compatible for use with the intended data. Based upon the Nimbus television specifications, the television data varies from dc to 60 kc. This analog signal is converted to a frequency modulated wave with a center frequency of 96 kc and 24 kc deviation. The modulation index (mf), at an information frequency of 60 kc, is 0.4. A quantitive analysis and definition of the side-band spectrum for this index can be found in the Design Study Report prepared under this contract.

As will be discussed in the Transport section of this document, the mechanical system has a low starting inertia. This characteristic, aided by the excellent starting torque of the brushless dc motor, brings the unit up to speed in less than one second. Since the storage of television pictures will be performed by numerous start-stop operations, this feature represents a considerable savings in tape "dead time" resulting in increased data storage.

Speed control will be maintained within 0.1% by the phase lock servo system. All of these features are contained in an integrated package 6" x 6-1/2" x 8" which weighs less than six pounds. A system block diagram is shown in Figure 3.

The design considerations of the brushless dc motor, heads, servo, transport and vibration isolation system are discussed in detail under the appropriate sections of this report.

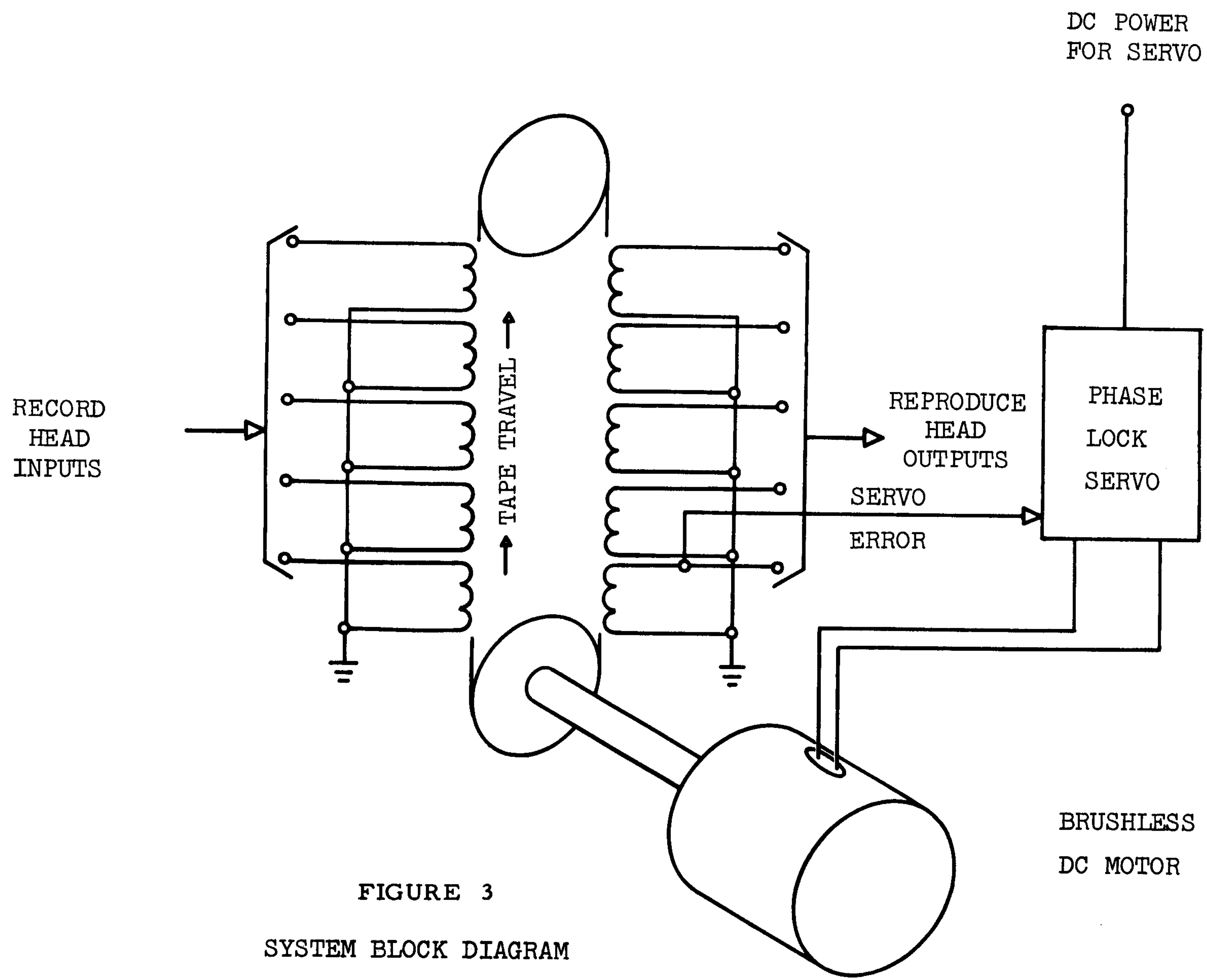


FIGURE 3

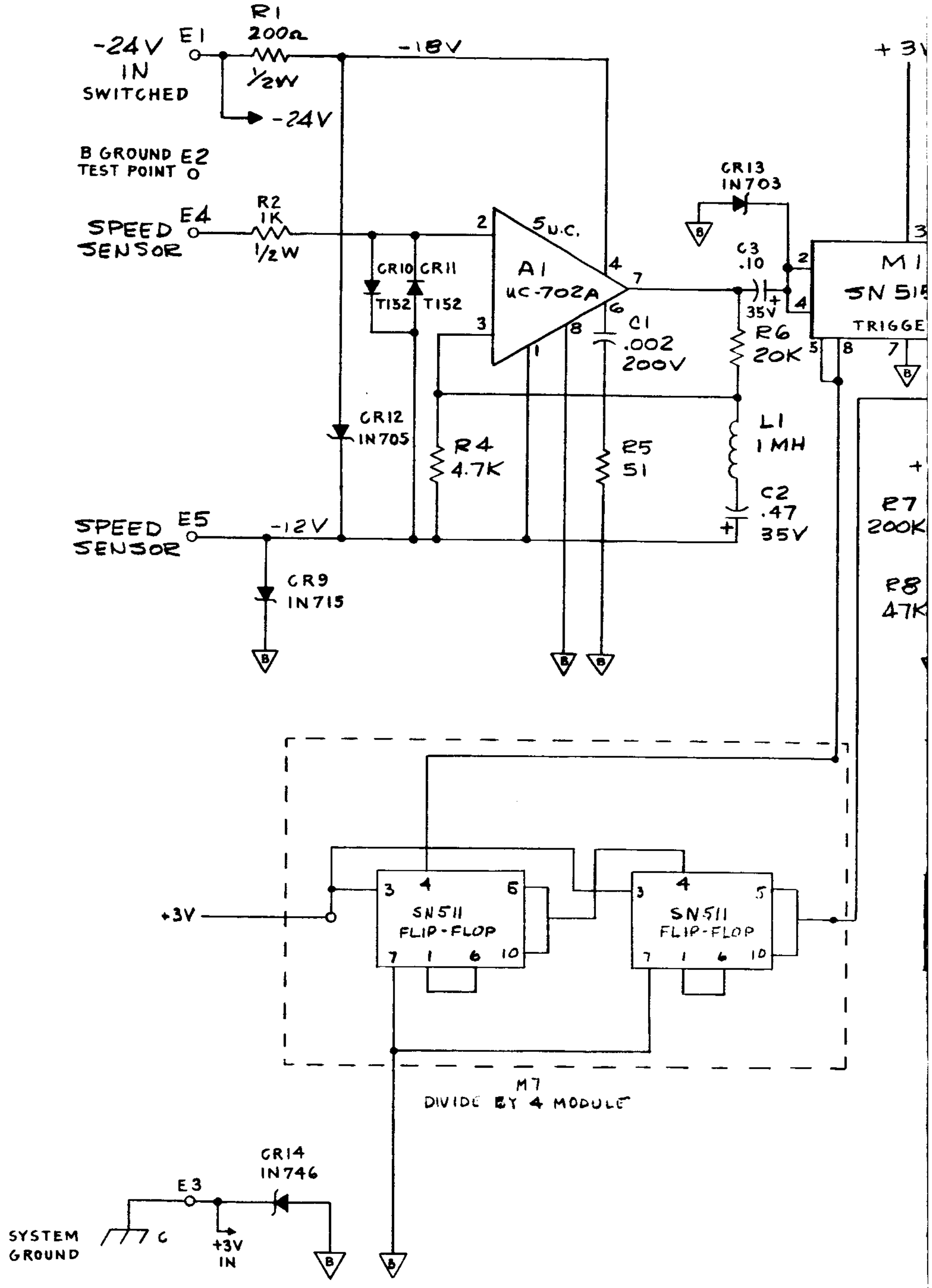
SYSTEM BLOCK DIAGRAM

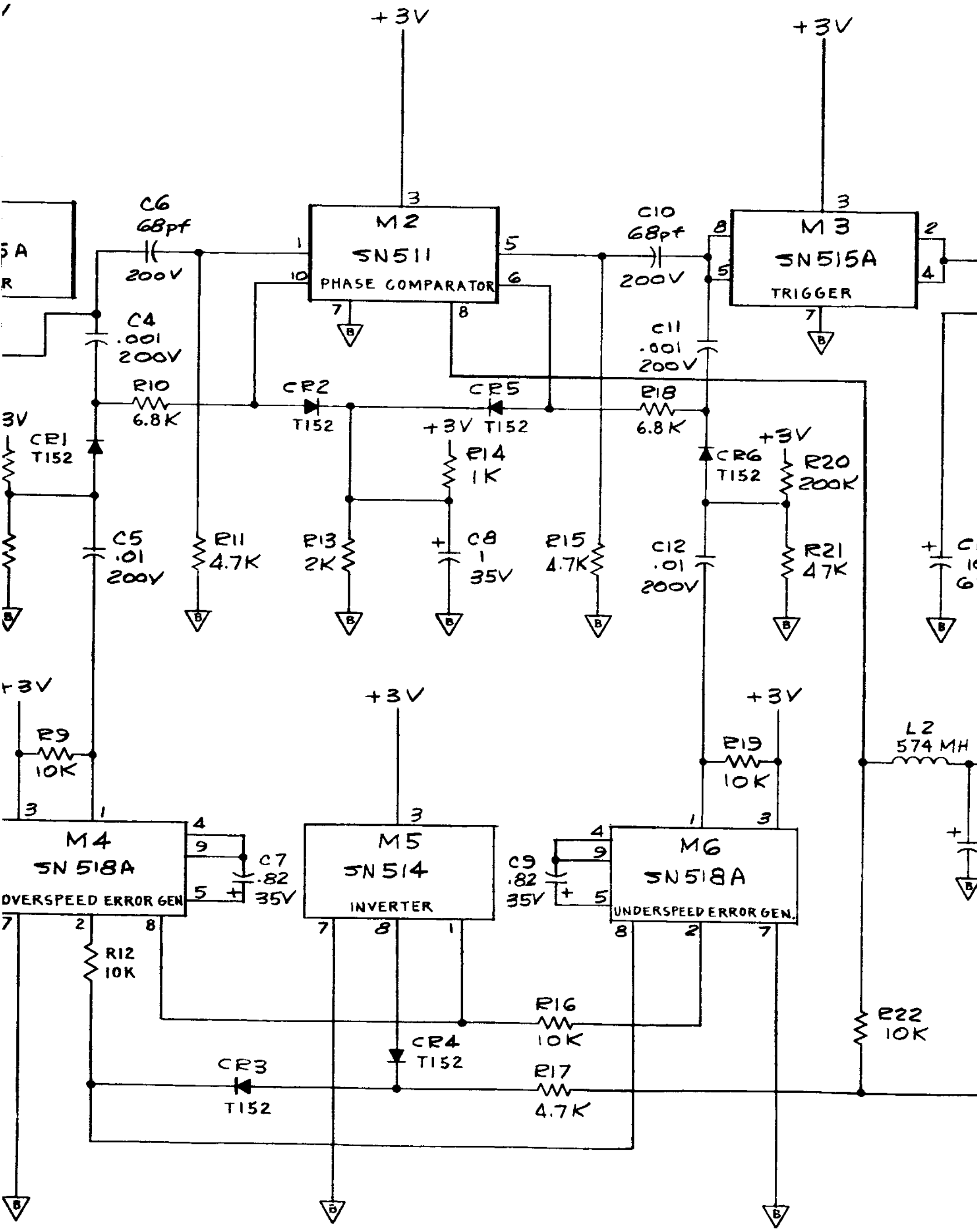
PHASE LOCK SERVO

The phase-locked speed control servo is a hybrid of both analog and digital circuitry. Low power and accuracy considerations dictate digital logic in the so-called "front end" of the servo; that is, those circuits dealing with speed sensing, reference frequency generation, phase comparison and digital course loop error generation. Once synchronization has been achieved between capstan motor and reference signal, linear techniques are applied. Derivative compensation employed to achieve the proper degree of system damping cannot be accomplished even by the application of complex digital processes. A Schematic and Block Diagram appear in Figures 4 and 5, respectively.

The servo, then, is a combination of linear and non-linear devices which function in the following manner:

The capstans are driven by a brushless dc motor whose speed


-24V IN SWITCHED
E1
R1 200Ω ½W
-18V
-24V
B GROUND TEST POINT E2
SPEED SENSOR E4
R2 1K ½W
CR10 CR11 T152 T152
A1 uC-702A
5 U.C.
C1 .002 200V
CR13 IN703
C3 .10 35V
R6 20K
M1 SN 51
TRIGGE
+3V
CR12 IN705
R4 4.7K
R5 51
L1 1MH
C2 .47 35V
R7 200K
R8 47K
SPEED SENSOR E5
-12V
CR9 IN715
+3V
SN511 FLIP-FLOP
SN511 FLIP-FLOP
M7
DIVIDE BY 4 MODULE
CR14 IN746
E3
SYSTEM GROUND
+3V IN



+3V
M2
SN511
PHASE COMPARATOR
M3
SN515A
TRIGGER
C6
68pf
200V
C10
68pf
200V
C4
.001
200V
C11
.001
200V
R10
6.8K
CR2
T152
CR5
T152
R18
6.8K
CR1
T152
CR6
T152
R14
1K
R20
200K
C5
.01
200V
R11
4.7K
R13
2K
C8
1
35V
R15
4.7K
C12
.01
200V
R21
47K
R9
10K
R19
10K
L2
574 MH
M4
SN 518A
OVERSPEED ERROR GEN
M5
SN 514
INVERTER
M6
SN 518A
UNDERSPEED ERROR GEN.
C7
.82
35V
C9
.82
35V
R12
10K
R16
10K
CR4
T152
CR3
T152
R17
4.7K
R22
10K

82

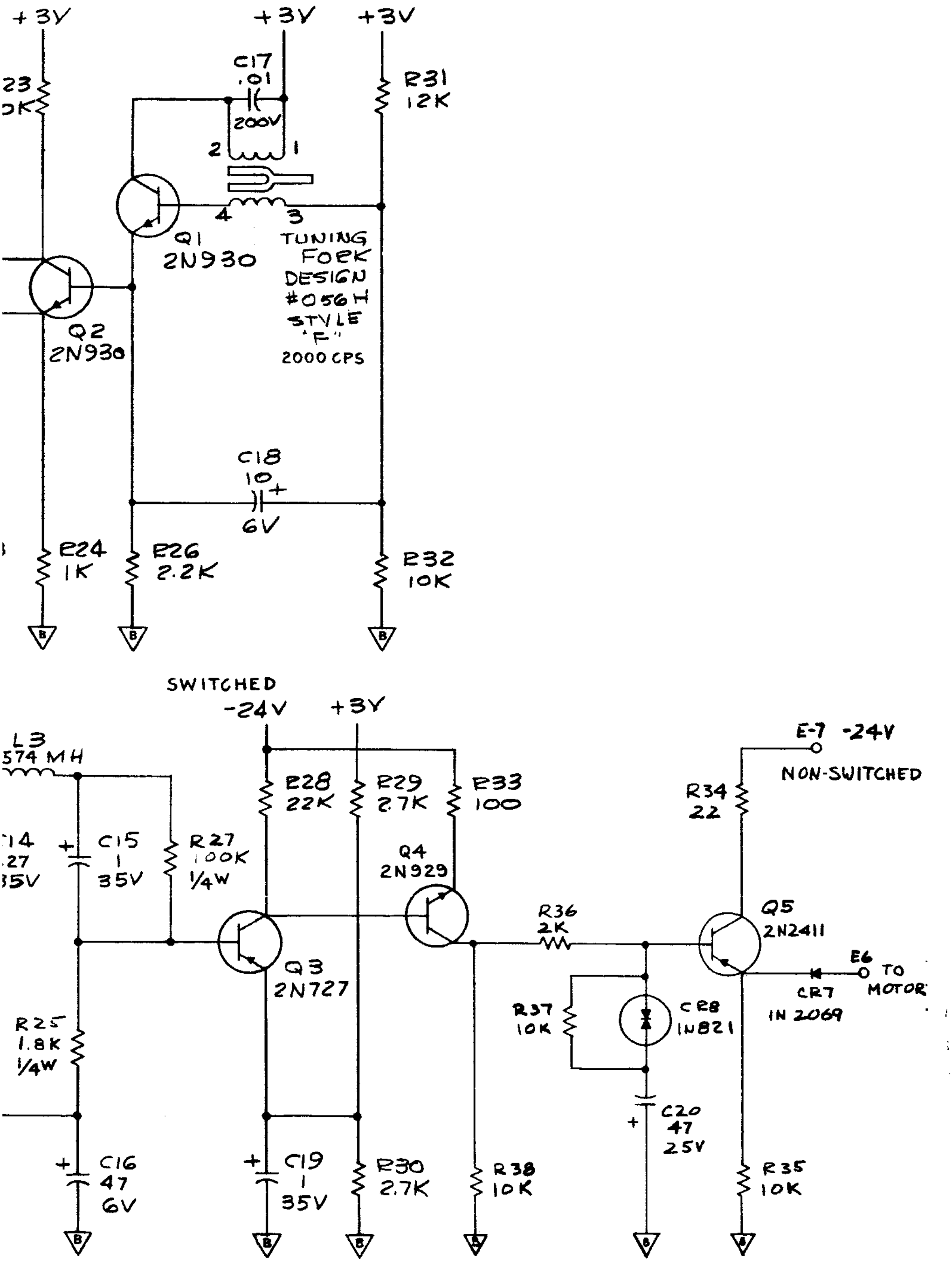


FIGURE 4

SCHEMATIC, PHASE LOCK SERVO

3

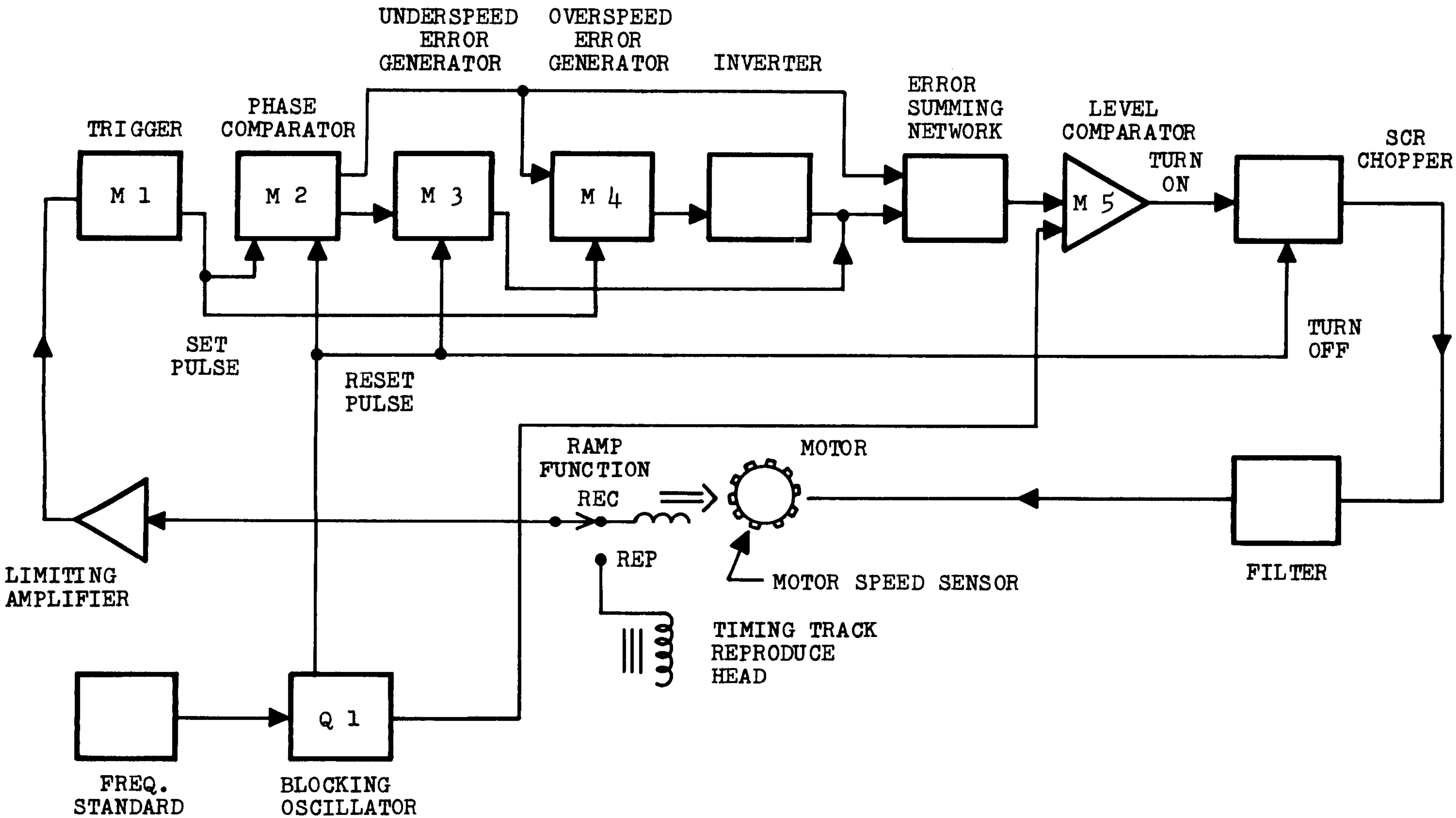


FIGURE 5

CAPSTAN MOTOR SERVO BLOCK DIAGRAM

can be made to vary over a considerable range. The speed of the motor is controlled by the effective voltage impressed across it by the output of the servo.

Recorded on the tape is a fixed reference signal whose frequency is directly proportional to the rotational speed of the motor. At a motor speed of 2100 rpm corresponding to a tape velocity of 33 ips, the frequency of this signal is 8000 cps. Since the frequency reference in the servo is 2000 cps, the tape signal, after amplification, is counted by four so that it may then be compared directly with the reference. The resultant signal is henceforth defined as the speed pickoff signal.

The speed pickoff signal is fed to the speed servo circuit where it is amplified, limited, and compared on a pulse-to-pulse basis with a reference frequency generated by a high accuracy frequency source (the sole speed determining component). If a frequency difference between the two signals exists, as is the case before the transport has reached speed during startup or after a severe loading has been introduced into the mechanical system, this difference is sensed by digital subtraction methods in an underspeed or overspeed error generator. Each underspeed or overspeed pulse will charge or discharge a storage capacitor in measured increments correcting the motor speed until the frequency difference goes to zero.

At this time the phase comparator takes control. The capstan motor will maintain a speed accuracy precisely that of the reference oscillator, since the two are phase locked in digital fashion. Any tendency for the phasing between the two to vary will be corrected for linearly in the summing network and level comparator, with appropriate system damping taking place in the former. Correction signals are applied to the motor in the form of a varied duty cycle output from the SCR motor driver-chopper. Chopping techniques reduce the power dissipation in the driver to a minimum and is in accord with high efficiency control techniques.

Reference Oscillator

The reference signal is generated by a tuning fork oscillator, which is directly synchronized with the tape pickoff signal through a trigger circuit.

For the sake of standardization, the negative going edge of the trigger output pulse will be defined as the "set" pulse and that of the reference oscillator output pulse will be defined as the "reset" pulse.

Input Amplifier

The input amplifier is a Fairchild μC-702 differential operational amplifier, with a non-linear feedback network to provide a high impedance as well. Waveforms can be seen in Figure 6 revealing the limiting action plus gain exhibited by the stage.

Trigger

The trigger circuit takes the output of the input amplifier (Figure 6B), squares it, and presents it to the clock inputs of the phase comparator flip-flop module and two error gates. This signal is a square wave with a negatively going rise time of 1 microsecond as required by the RCTL logic employed, (Figure 6C). This is accomplished by taking the 3 volt P-P squared output of the input amplifier and applying it to a Tl 515 "exclusive or" gate, whose outputs and inputs are connected in a regenerative fashion. This regenerative circuit duplicates the performance of a schmitt trigger, and can be considered as such for the purpose of this analysis.

Phase Comparator

The set pulse is applied to one side of the phase comparator stage (Figure 7C). The phase comparator is a bistable TI SN 511 integrated circuit with two independent triggering input lines. The set pulse will drive the circuit into one of the stable modes. A reset pulse introduced at the other input (Figure 7D) causes the circuit to revert to the other condition of stability. Since the negative going edges of the input pulses contain the set and reset information, differentiation capacitors are present in both input lines. When the capstan motor is operating at the proper speed, the output of the phase comparator will be a sqaure wave. The voltage present at the Q and Q' outputs (Figure 7E and 7F), acts to inhibit the underspeed and overspeed error circuits.

Error Gates

During the condition in which the capstan motor is rotating at the proper speed, the reset pulse will be applied to the underspeed error gate input in coincidence with a positive condition of the Q' output. (See Figure 8). Under these conditions no triggering will take place.

If, however, the capstan motor is operating at a speed lower than normal, the reset pulse, occurring at the reference frequency, may arrive at the input of the underspeed error gate prior to the time the set pulse has caused the phase comparator to change states. As a consequence, the reset pulse amplitude is added to the amplitude of the collector voltage. The sum of the two voltages is adequate to overcome the trigger threshold and causes the underspeed error generator to produce a pulse. An underspeed error pulse will be generated by each reset pulse that has not been preceded by a set pulse. See Figures 10 through 12. Figure 13 reveals that an overspeed condition results in no pulses passing the underspeed gate, since all reset pulses are preceded by set pulses.

In the overspeed error gate, the same procedure occurs. The set pulse is applied to the input of the overspeed generator, and, under at-speed conditions, will be coincident with a positive condition at the Q phase comparator output (see Figure 9). In Figures 14 through 17 it can be seen that pulses exceeding the gating level are produced, increasing in repetition rates, as 10 kc is exceeded.

This is caused by the appearance at the gate of set pulses which have not been preceded by reset pulses.

Error Generators

The error generators are a pair of TI 518A single shot multivibrators whose pulse duration is set by an external capacitor at approximately 5 milliseconds. The generators take the pulse output of the overspeed and underspeed error gates (a few microseconds in width) and stretch them (Figure 18 and 19) into milliseconds. They also perform a second duty, that of mutually excluding each other from being false triggered during periods where the gates do not have time to be conditioned as lock-in is approached. As the pickoff frequency approaches the 10 kc reference, the repetition rates of the error generators go to zero.

The underspeed and overspeed error generators produce pulses of identical width and amplitude and opposite polarities which are summed by the coarse-loop integrating capacitor. In this manner, a train of underspeed pulses will result in a negative net change in charge on the capacitor whereas a train of overspeed error pulses will develop a positive net change of charge on the capacitor.

The output of the overspeed error generator is diode coupled directly to the coarse-loop integrating capacitor C9, while the output of the underspeed error generator is first inverted. Figures 20 and 21 show the circuit waveforms at underspeed and overspeed conditions. The bottom trace, in both cases, reveals the dc level on the integrating capacitor.

Summing Network

The phase comparator output is integrated and the resultant analog dc output is summed with the coarse-loop error signal at one input of the level comparator. In order to provide a faster response path for the error signal (derivative compensation), a high pass filter bypasses one leg of the summing network.

Level Comparator

The level comparator is a Fairchild μA702 integrated operational amplifier. The analog servo error signal present at one input of the level comparator is compared with a time generated ramp function (generated by the blocking oscillator) at the other input. The analog level is thus converted into a change of state at the level comparator output, whose delay time after conduction of the blocking oscillator is a linear function of the analog dc level. This delay time, divided by the time between conduction periods, yields the duty cycle of the turn-on and turn-off pulses to the motor driver chopper. This duty cycle determines the rotational speed of the motor.

Motor Drive Chopper

This circuit, made up of discrete components not available in integrated form, consists of a gate controlled switch rectifier and other components to aid in turn-on and turn-off. Turn-on is accomplished by the application of the differentiated level comparator output to the gate terminal of the SCR. Gain exhibited by the SCR allows turn-on from a medium impedance source. Turn-off is affected by the back-biasing of the SCR conduction path for 10 microseconds. The low impedance high peak-power characteristic of the blocking oscillator is used to perform this operation.

The use of a filter in the line between the outputs of the chopper and the drive motor depends on the inertia and electrical characteristics of the motor chosen. The addition of a filter at a later date will not affect the operation of the system.

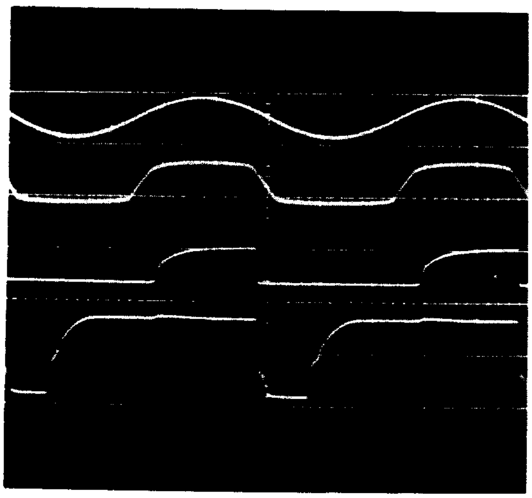


FIGURE 6

INPUT AMPLIFIER AND TRIGGER-
PICKOFF FREQ. 2000 CPS

SWEEP RATE 100 μ sec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	.1V/cm	A	Speed Pickoff
2	5V/cm	B	Squared Amplifier Output
3	5V/cm	C	Set Pulse
4	2V/cm	F	Q' Output (Ø Comparator)

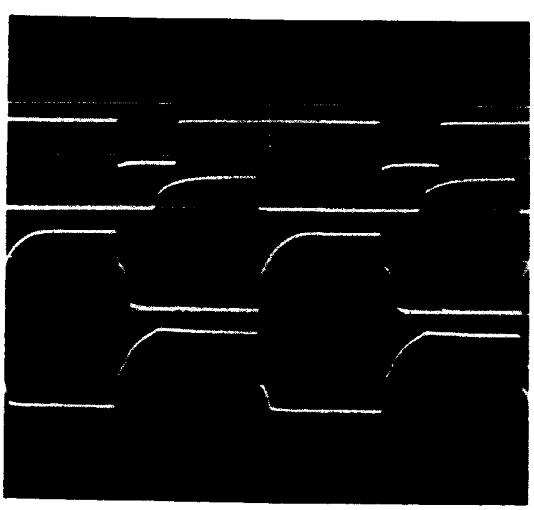


FIGURE 7

PHASE COMPARATOR-PICKOFF FREQ 2000 CPS

SWEEP RATE 100 μ sec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	D	Reset Pulse
2	5V/cm	C	Set Pulse
3	2V/cm	E	Q Output (Ø Comparator)
4	2V/cm	F	Q' Output (Ø Comparator

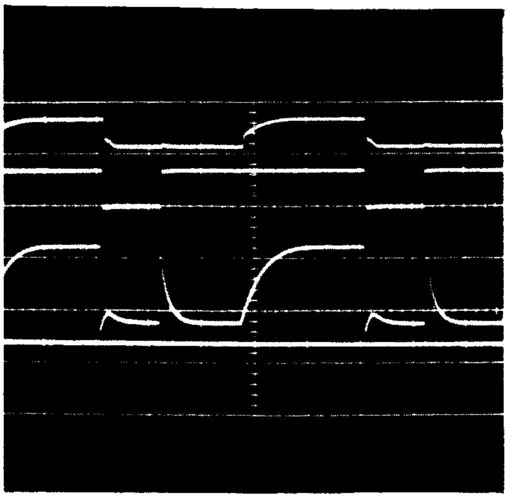


FIGURE 8

UNDERSPEED GATE-PICKOFF FREQ 2000 CPS

SWEEP RATE 100μ sec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	E	Q Output (Ø Detector)
2	5V/cm	D	Reset
3	2V/cm	G	Underspeed Gate Input
4	DC	I	Underspeed Gating Level Ref. to 3

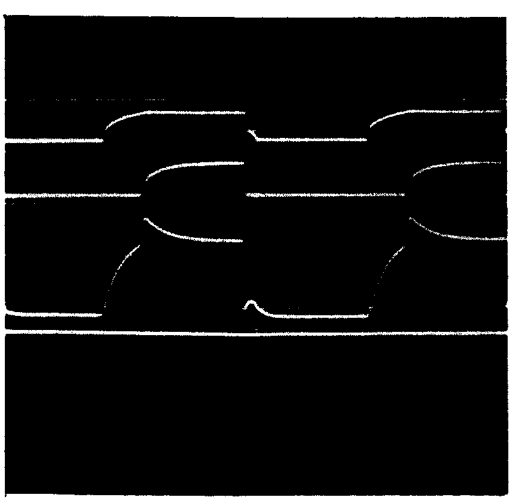


FIGURE 9

OVERSPEED GATE-PICKOFF FREQ 2000 CPS

SWEEP RATE 100μ sec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	E	Q Output (Ø Comparator)
2	5V/cm	C	Set Pulse
3	2V/cm	H	Overspeed Gate Input
4	DC	J	Overspeed Gating Level Ref. to 3

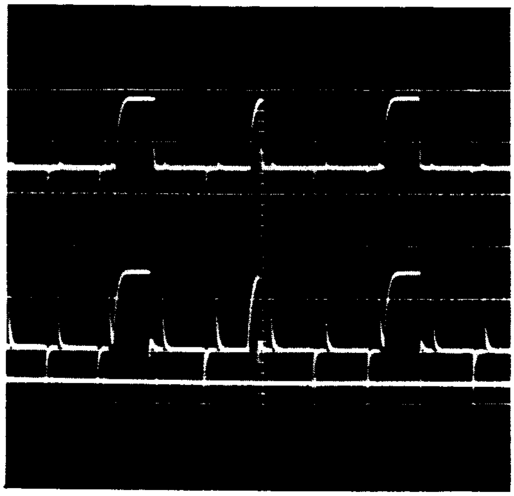


FIGURE 10

UNDERSPEED GATE-PICKOFF FREQ 800 CPS

SWEEP RATE 500µ sec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	2V/cm	E	Q (Ø Comparator)
2	2V/cm	G	Underspeed Gate Input
3	DC	I	DC Gating Level Ref. to 2

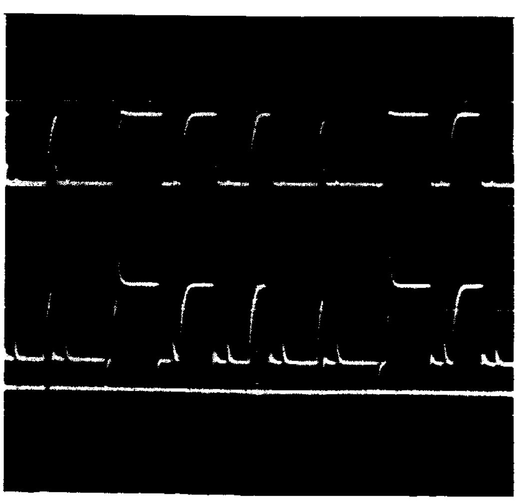


FIGURE 11

UNDERSPEED GATE-PICKOFF FREQ 1600 CPS

SWEEP RATE 500µ sec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	2V/cm	E	Q Output (Ø Comparator)
2	2V/cm	G	Underspeed Gate Input
3	DC	I	DC Gating Level Ref. to 2

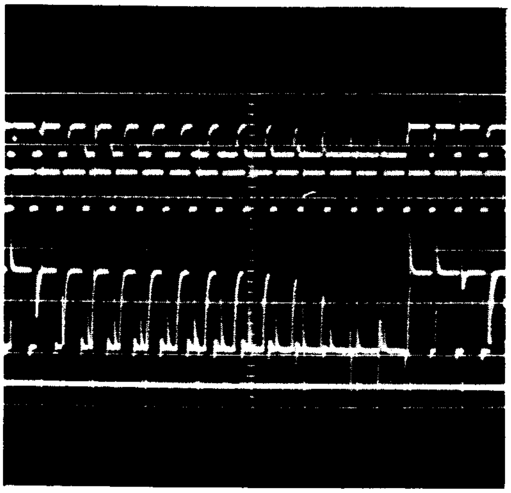


FIGURE 12

UNDERSPEED GATE-PICKOFF FREQ 1900 CPS

SWEEP RATE 1 ms/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	E	Q Output (Ø Comparator)
2	5V/cm	D	Reset Pulse
3	2V/cm	G	Underspeed Gate Input
4	DC	I	DC Gating Level Ref. to 3

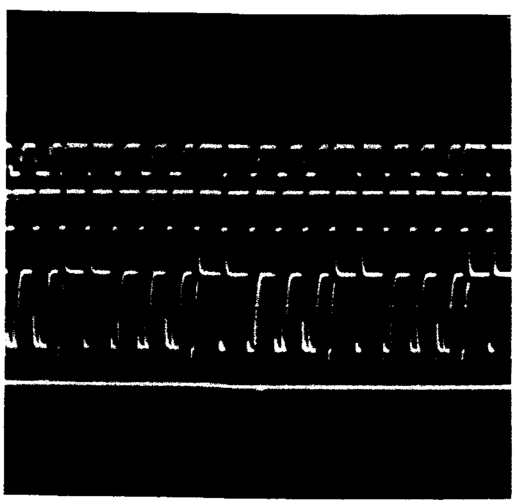


FIGURE 13

UNDERSPEED GATE-PICKOFF FREQ 3600 CPS

SWEEP RATE 1 ms/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	E	Q (Ø Comparator
2	5V/cm	D	Reset Pulse
3	2V/cm	G	Underspeed Gate Input
4	DC	I	DC Gating Level Ref. to 3

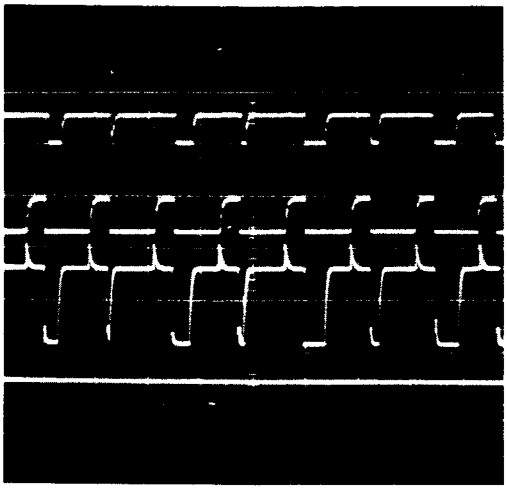


FIGURE 14

OVERSPEED GATE-PICKOFF FREQ 800 CPS

SWEEP RATE 1 ms/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	F	Q' Output (Ø Comparator)
2	5V/cm	C	Set Pulse
3	2V/cm	H	Overspeed Gate Input
4	DC	J	Overspeed Gating Level Ref. to 3

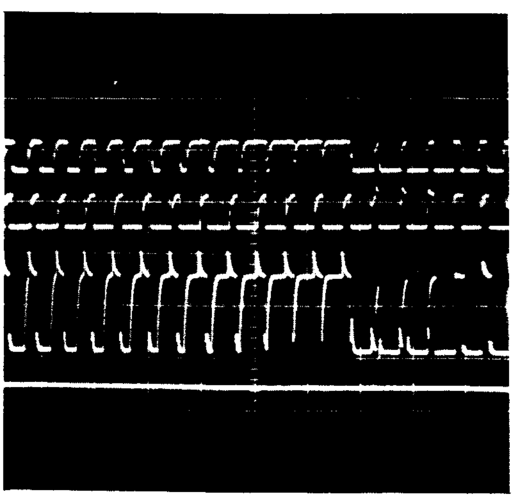


FIGURE 15

OVERSPEED GATE-PICKOFF FREQ 1900 CPS

SWEEP RATE 1 ms/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	F	Q' Output (Ø Comparator)
2	5V/cm	C	Set Pulse
3	2V/cm	H	Overspeed Gate Input
4	DC	J	Overspeed Gating Level Ref. to 3

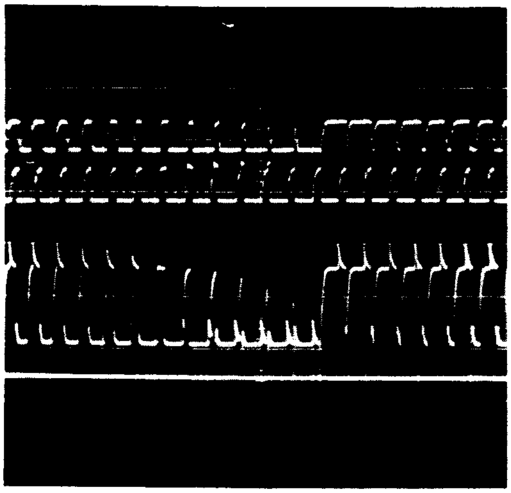


FIGURE 16

OVERSPEED GATE-PICKOFF FREQ 2100 CPS

SWEEP RATE 1 ms/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	F	Q' Output (Ø Comparator)
2	5V/cm	C	Set Pulse
3	2V/cm	H	Overspeed Gate Input
4	DC	J	Overspeed Gating Level Ref. to 3

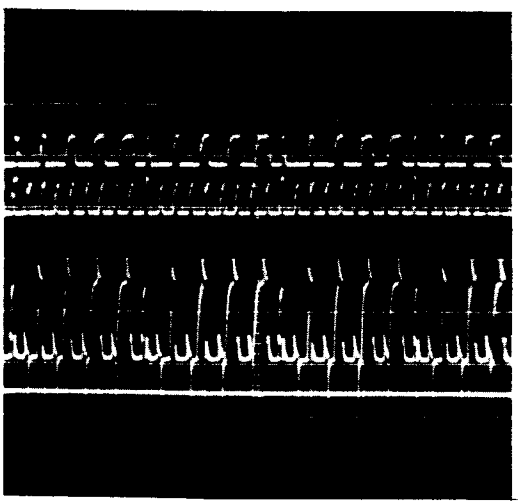


FIGURE 17

OVERSPEED GATE-PICKOFF FREQ 3600 CPS

SWEEP RATE 1 ms/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	2V/cm	F	Q Output (Ø Comparator)
2	2V/cm	C	Set Pulse
3	5V/cm	H	Overspeed Gate Input
4	DC	J	Overspeed Gating Level Ref. to 3

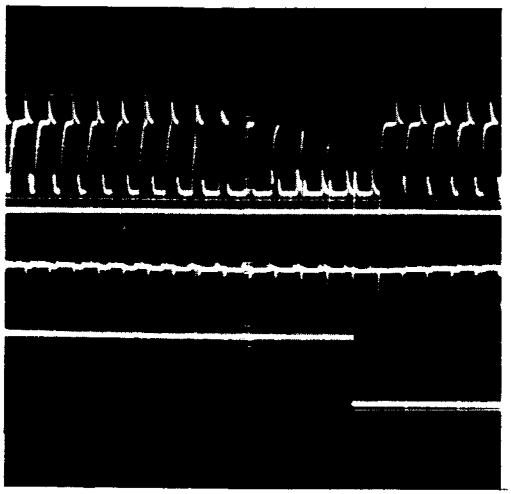


FIGURE 18

OVERSPEED ERROR GENERATOR
PICKOFF FREQ 2100 CPS

SWEEP RATE 200 sec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	2V/cm	H	Overspeed Gate Input
2	DC	J	Overspeed Gating Level Ref. to 7
3	2V/cm	L	Overspeed Gate Output
4	2V/cm	N	Overspeed Error Generator Output

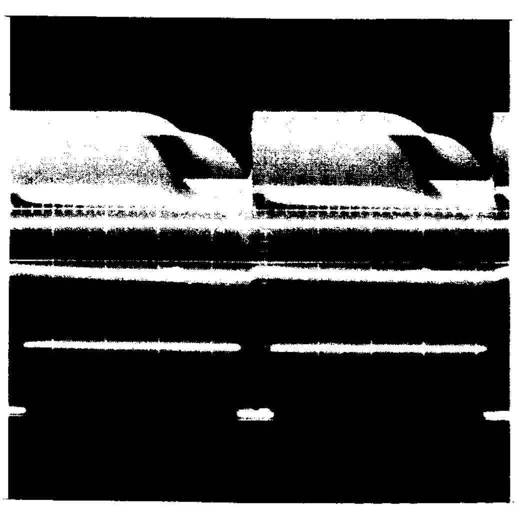


FIGURE 19

OVERSPEED ERROR GENERATOR
PICKOFF FREQ. 2004 CPS

SWEEP RATE 50 m sec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	2V/cm	H	Overspeed Gate Input
2	DC	J	Overspeed Gating Level Ref. to 1
3	2V/cm	L	Overspeed Gate Output
4	2V/cm	N	Overspeed Error Generator Output

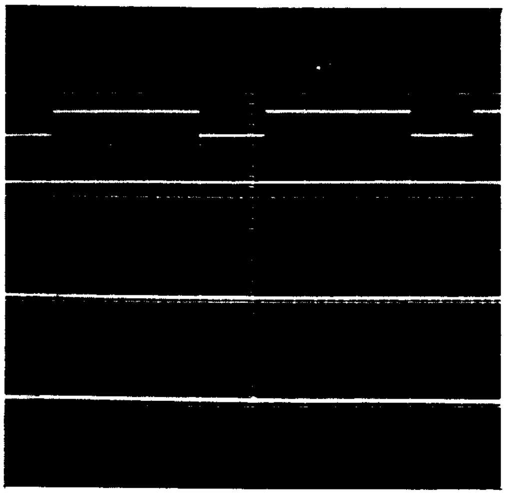


FIGURE 20

OUTPUT ERROR GENERATORS
PICKOFF FREQ. 2004 CPS

SWEEP RATE 25 m sec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	N	Overspeed Error Generator Output
2	5V/cm	M	Underspeed Error Generator Output
3	5V/cm	O	Inverted Under-speed Error Generator Output
4	2V/cm	P	DC Level on Integrating Capacitor

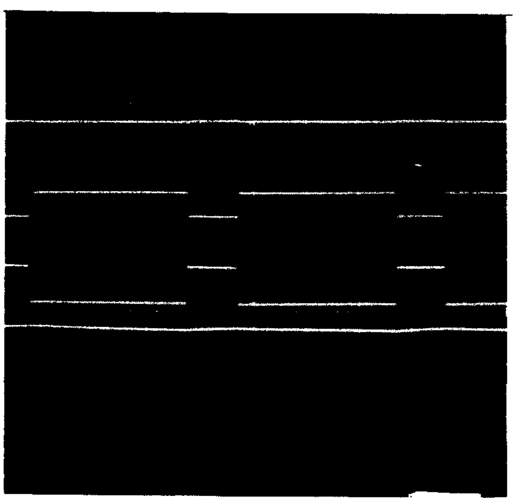


FIGURE 21

ERROR GENERATOR-PICKOFF FREQ 1990 CPS

SWEEP RATE 25 msec/cm

TRACE	SCALE	SCHEMATIC LOCATION	DESCRIPTION
1	5V/cm	N	Overspeed Error Generator Output
2	5V/cm	M	Underspeed Error Generator Output
3	5V/cm	O	Inverted Under-speed Error Generator Output

TRANSPORT

The initial design considerations of the tape transport were heavily dependent on the limited area available and the requirement to maintain a minimum number of tape wraps on the cartridge. Consideration was given to a conventional design that could be contained in the maximum plan area of 6" x 8", as indicated in the specification. However, this design would not fit into the plan area, once allowances for case walls and vibration isolator system clearances were made. This design further limited total plan area to approximately 5-1/4" x 7-1/4" and would require an extremely compact endless loop cartridge, which was further complicated by the use of 1/2 inch wide tape.

Cartridge designs that were a radical departure from the type of cartridge commonly used on endless loop machines at Goddard were also considered; i.e., oval cartridges, sharply conical cartridges, and multiple stacked cartridges. These approaches were discarded because of the low probability of a truly successful design being generated within the framework and time scale defined in the work statement.

The design shown in Figure 22 was selected after the other approaches were eliminated due to their shortcomings. The following major advantages are realized from this design:

A. Tape cartridge size approaches that of the existing GSFC standard 1/2" design and thus keeps the number of tape wraps to a minimum.

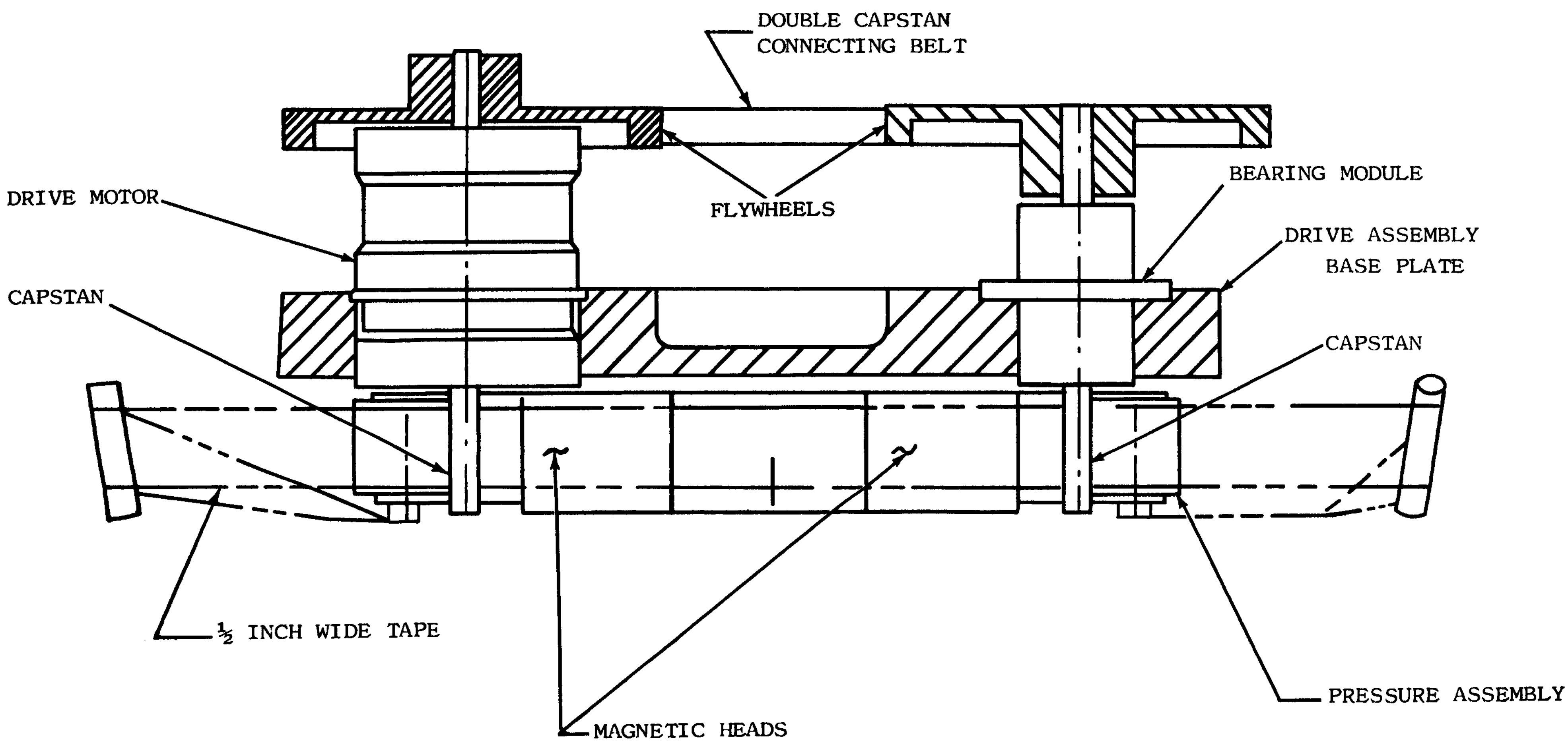


FIGURE 22

TAPE CARTRIDGE CROSS SECTION

B. Most of the detailed elements of the existing designs were utilized.

C. Good tape entrance and exit characteristics including minimal rise and fall angles were retained.

D. Compact base plates are retained for low weight and maximum stiffness.

E. Basic mechanical design was fairly straight-forward and did not require an excessive number of rotating elements (thus enhancing basic reliability).

F. A liberal and convenient space was available for mounting electronic assemblies.

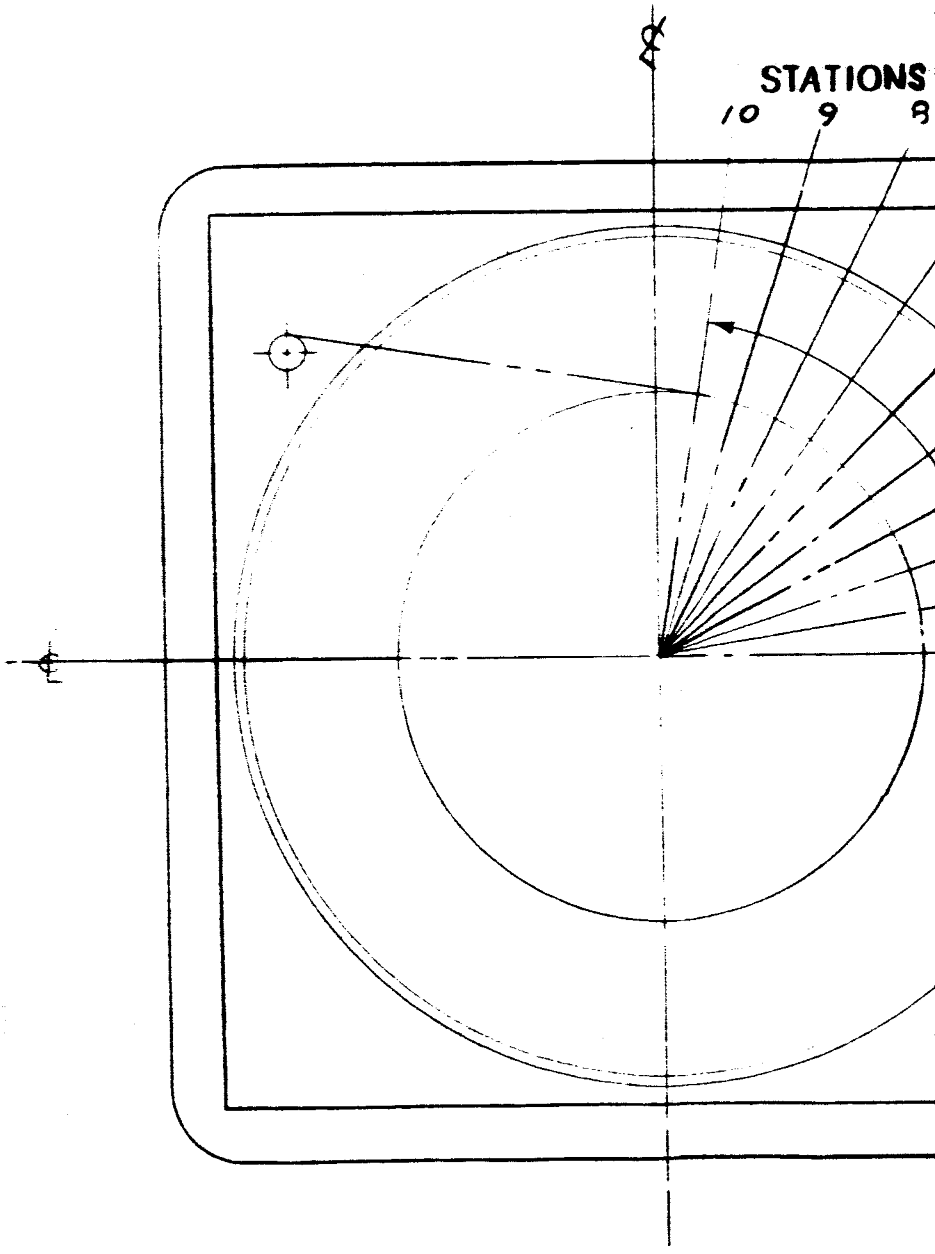
The key elements in the design are the transposition of the mechanism from its normal position adjacent to the cartridge, to an inverted, over-the-top position and the skew mounting of the cartridge. An added advantage of this arrangement provides a separate tape cartridge and drive assembly without the need for concentric ring mounting of the cartridge. Three distinct and easily separable packages result; the transport mechanism, the cartridge, and the drive electronics.

The tape drive assembly consists of a double capstan drive, a record/reproduce magnetic head subassembly and the brushless dc drive motor, all arranged in a compact over-the-top configuration on a subcasting fastened to the tape cartridge.

Since the tape speed in both record and reproduce is sufficiently high to retain a capstan speed at which brushless dc motors provide reasonable efficiency, the motor shaft is used for one of the capstans. The use of this capstan as the metering capstan (capstan with no slip at 1% speed ratio between capstans) results in maximum stiffness between tape and motor. This is an important characteristic when applying the phase lock servo. A secondary advantage is the elimination of another drive belt and second bearing module.

The tape cartridge in this unit was based largely on an existing design developed on a previous GSFC contract. Some modifications were necessary and included (1) reduction in overall plan area to accommodate a 6.092" D. tape pack rather than 8.58" D. tape pack, (2) reduction of the number of lower guide rollers from 12 to 8 because of the reduced area available and the shorter distance between rollers, (3) revision of the details to allow use of 1/2" tape, (4) modification of tape entrance and exit paths to accomodate the over-the-top placement of the transport drive mechanism.

The cartridge hub detail and lower rollers are critical to flutter performance as well as reliable operation of the recorder mechanism. A graphic representation of the tape exit transition is shown in Figure 23. This diagram depicts both an ideal and the actual transitions, which are presently in use in LEC recorders. First consideration was given to a lower roller-reel hub profile which would provide the ideal transition. This profile would be achieved simply by bending the tape at its upper edge to allow for direction change.



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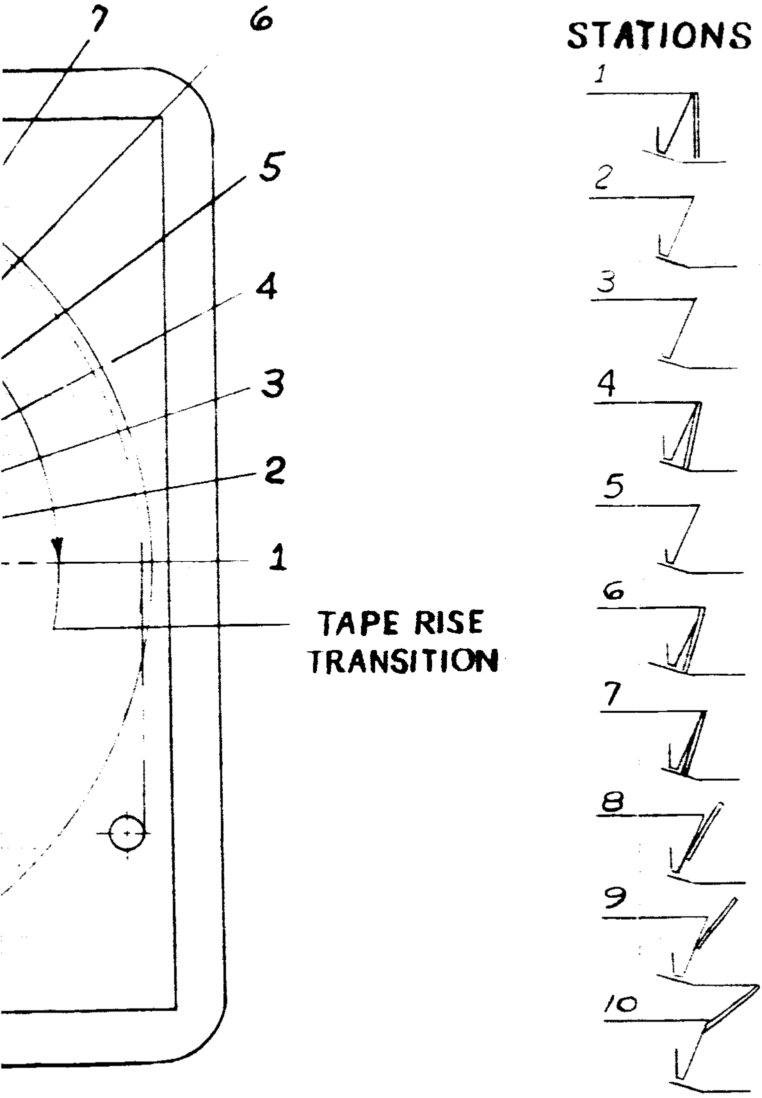

FIRST APPROXIMATIO
OF TAPE POSITIONS
DURING ACTUAL RIS
CONDITIONS

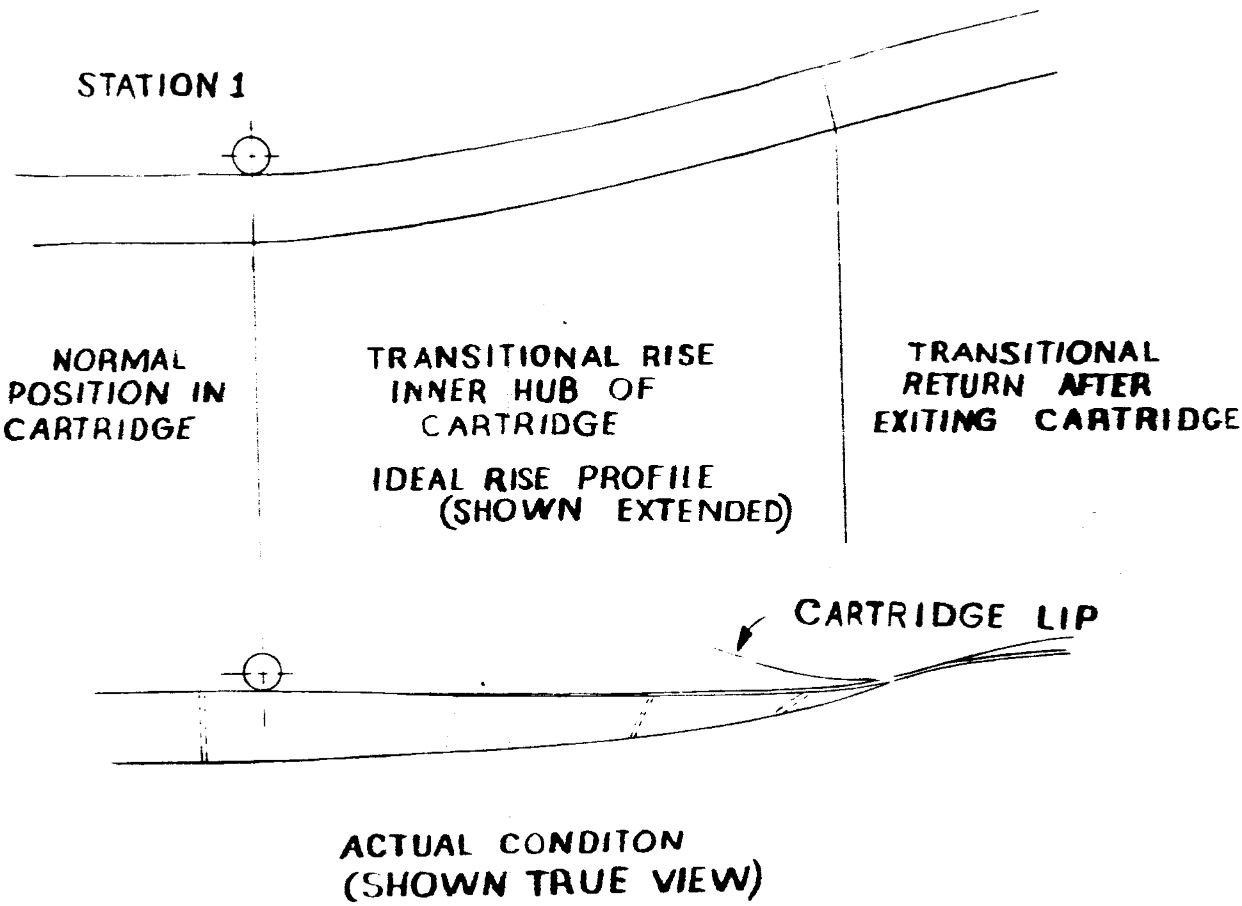

FIGURE 23
TAPE PATH TRANSITIONS

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However, further investigation indicated that in order to accomplish this, the reel hub surface must be tilted in the exact opposite sense to the present reel hub angle. This characteristic precludes this profile since the tape would tend to unravel from the pack when so mounted.

The tape exit condition in the final unit is shown as "actual" in Figure 23. Here, the tape twists and bows to set a direction for an abrupt exit between the reel hub and the rest of the tape pack. The figure indicates some typical positions of tape cross sections at stations 1 to 10 for the conventional path. The stations are designated from start of exit rise to completion to provide a convenient method of describing the reel hub-roller profiles.

BRUSHLESS DC MOTOR

A key component of the recorder is the brushless dc motor. Motor design specifications are based upon the transport design and the characteristics necessary for high efficiency and low flutter.

Some considerations which affect the choice of motor are:

a. motor efficiency
b. flutter due to capstan runout
c. bearing reliability as a function of motor speed
d. relative torque losses in capstan bearings.

Motor efficiency is shown in Figure 24 and is based upon peak efficiency associated with the particular speeds for this class of motor.

The effect of capstan diameter on motor speed selection and flutter is as listed in Figure 25. The speed data is for a 33 ips tape speed and flutter is based on simple radius variations as a function of nominal capstan radius (1/2D) with a conservative .0001" runout.

The effect of speed on reliability is more difficult to define; it will suffice to say that speeds in the area of 2000 rpm have proven totally satisfactory in a number of other spacecraft recorder programs and are considered conservative.

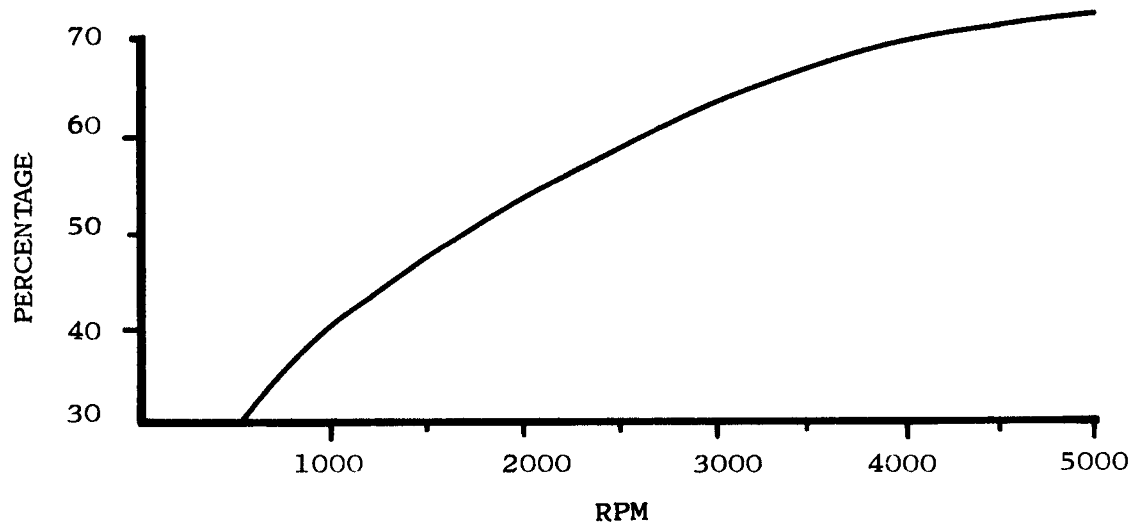

FIGURE 24

MOTOR EFFICIENCY

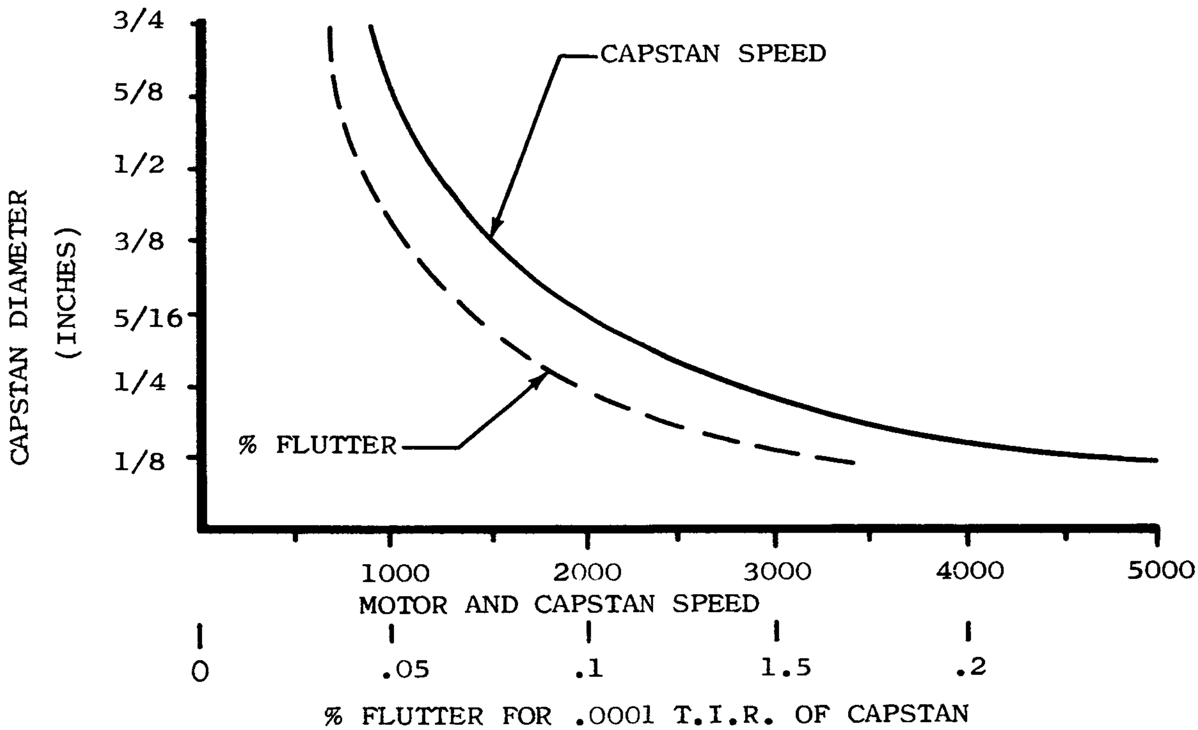

FIGURE 25

CAPSTAN DIAMETER VS. MOTOR SPEED

Since the motor used will require one watt of operating power, the effect of bearing power losses on motor speed selection is negligible. (At 0.02 in-oz and 2000 rpm only 0.03 watts of mechanical power is lost).

By using the criterion that the flutter introduced by the capstan should be at least an order of magnitude below the total flutter specification (0.6%), a motor speed of 2100 rpm and a capstan diameter of 5/16 will provide an efficiency above 50%. The slight increase in capstan-caused flutter, from 0.06 to 0.07%, has little effect on overall flutter performance. These figures can be verified by cross checking efficiency in Figure 25.

The specifications of the motor are as follows:

Motor Speed - 2100 RPM

Torque - Based upon measurements in the present 1200 foot unit with allowance for the larger tape width, a required torque of 0.23 in-oz has been specified. The basic characteristics of the motor will allow a wide range of operating mean torques.

Operating Voltage - Based upon the 24 VDC available and a 30% allowance for control across the servo output, -17V has been specified as the mean operating point. This will allow for variations of operating points from motor to motor; flexibility in changing tape speeds over a small range; fast transport acceleration and response.

Number of Commutating Points - The minimum number of commutating points of three, will increase cogging and overall co-efficient of fluctuation. Excessive points will decrease reliability and increase complexity because of the additional switching transistors and circuitry. Present design incorporates 5 points (10 transistors).

An additional design feature introduced here is the selection of a permanent magnet field material that will reduce cogging effects and allow operation at a liberal rotor to stator gap.

Efficiency - 60% at 2 watts input. Motor is useful over a wide range of power inputs (1/2 watt to 5 watts).

Mechanical Construction - In order to retain reliability and smooth operating characteristics as demonstrated on present LEC 113 modular hysteresis synchronous motors, the same case and bearing construction has been used. The case outline is shown in Figure 26.

It should be noted that although the motor will normally consume the small amount of power indicated, the inherent characteristic of the dc motor to draw only as much current as required will provide a considerable factor of safety in available torques. This factor of safety is approximately 3 to 1.

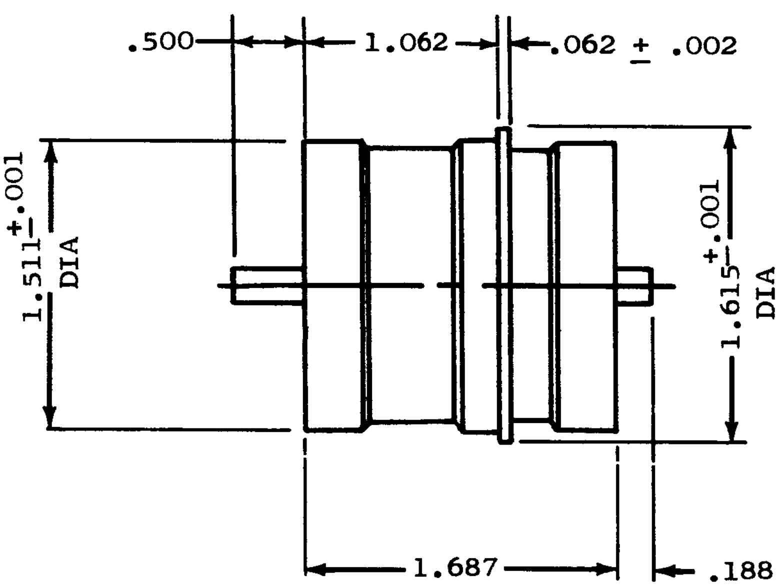

FIGURE 26

MOTOR OUTLINE

MAGNETIC HEADS

Design parameters for the record and reproduce heads may be divided into the following three categories:

1. Mechanical
2. Electrical
3. Interacting electrical and mechanical

Design considerations of these categories are directed toward the achievement of high reliability in service. Rigidity of the head block and cores is insured by construction techniques that are carefully controlled at every step. Potting material, method of screwing heads together, gapping techniques, core preparation, coil winding and insulation, lapping, and final test are integrated into an electromechanical design which insures integrity and reliability in the environment in which the heads are utilized. The number of parts used in the construction is kept to an absolute minimum so as to obtain high predicted reliability.

The mechanical design parameters consist of the head block configuration and materials, the number of tracks, the location of coils and shielding, the potting material, the size, and weight.

The head configuration is shown in outline form in Figure 27.

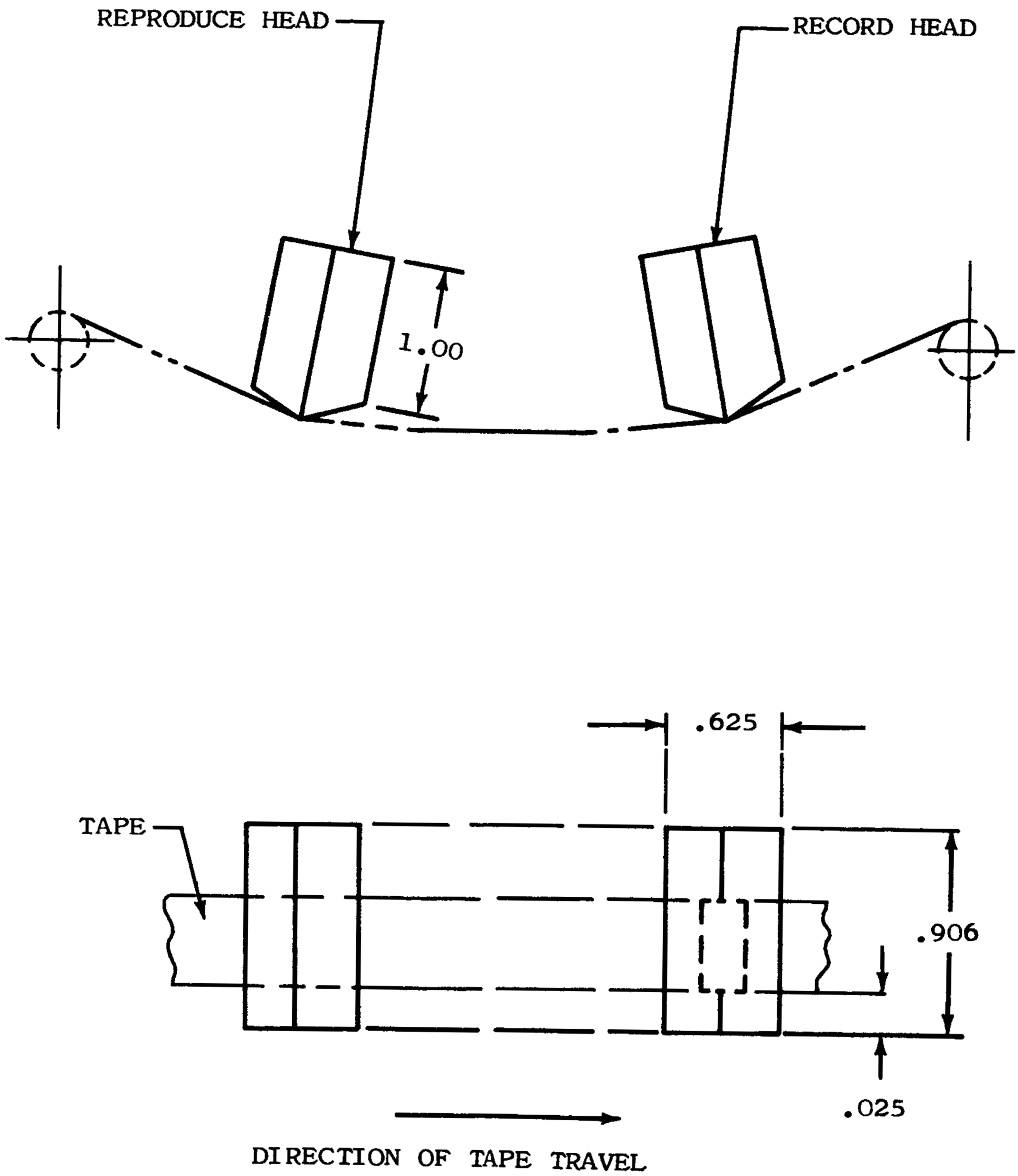

FIGURE 27

HEAD CONFIGURATION

The major record head electrical design parameters consist of the record inductance, number of turns, magnetic circuit, core cross sectional area, front gap and interface area, rear gap area, and operating currents.

The record inductance is determined by :

a. The available voltage (24 volts) used to supply drive current at the record frequencies of 70 to 120 kc.
b. The ratio of the coil impedance to the source impedance of the driver.
c. The number of turns required to supply the ampere-turns needed to record the signal on tape.
d. The desirability of omitting a transformer.

The above considerations resulted in preliminary design parameters:

Inductance (L) = 1 mh

The magnetic core size is based on the requirement for ample winding space and efficient magnetic design. The cross sectional area of core is sized to prevent flux saturation of the core. This insures that the record head gap contains the bulk of the ampere-turns supplied to the magnetic circuit.

A five track configuration has been selected in order to reduce the tape wear. The use of a five track head on a

1/2" format results in some crowding of the cores. In order to provide the required space in the head for the coils and maintain low crosstalk levels, two adjacent wound coils are located in opposite halves of the head block. The magnetic circuit is returned by a straight length of laminated core material. The tracks are decoupled from one another by shields which extend beyond the over-all dimensions of the core.

The air gap between two sections of the heads is rigidly controlled by a vacuum-deposited film for the reproduce head and beryllium copper spacers also serve as eddy current shields and thus tend to divert the flux to the tape rather than directly across the gap area.

The block is filled with suitable potting material to mechanically secure the laminations and coils in place during vibration, and protect the electrical windings from humidity, etc..

The record gap is dependent on the quantity of record current available and the requirement for adequate fringing at the record tips to cause the flux to penetrate the tape. An 80 microinch gap is used to satisfy both requirements.

The front gap interface cross sectional area is sized to permit the record flux to penetrate the tape. The rear gap is introduced into the magnetic circuit in order to facilitate assembly and prevent distortion due to the non-linear

BH characteristics of the magnetic core material. The introduction of the rear air gap reduces the effect of the non-linear characteristic because the magnetomotive-force drop across the air gap is considerably greater than the magnetomotive-force drop across the magnetic core material.

The reproduce head electrical design parameters are similar to the record head. The inductance is based on the requirement for sufficient output voltage and the requirement for an appropriate resonant frequency of the reproduce head. This resonant frequency arises as a result of the inductance and distributed capacitance of the reproduce head. The resonant frequency is selected so as to be outside the frequency band of the head. If the resonant frequency were less than the upper frequency limit, then attenuation or amplification (depends on circuit "Q") would occur.

The choice of a reproduce air gap dimension is influenced by the packing density of the information recorded on tape. The gap width must be sized so that it is smaller than the wave length of the highest frequency recorded on tape. This is equivalent to 250 inches. 80 μ inches is used in order to obtain a maximum of 12 db signal reduction at 120,000 cps when related to the peak output signal of the reproduce head.

The front gap interface area is sized to prevent the bulk of the flux on tape from being shunted. With a small front gap interface area, the flux on tape is not shunted appreciably; thus, it travels through the core to link with the coils, permitting acceptable signal/noise ratios on playback.

A summary of specifications based upon the initial design is as follows:

RECORD HEAD

Number of Tracks:	5
Track Width:	.060"
Inductance:	1 mh
Gap:	80×10^{-6} inches
Frequency (record):	70 KC - 120 KC @ 33 ips
Crosstalk:	42 db

REPRODUCE HEAD

Number of Tracks:	5
Track Width:	.055"
Inductance:	70 mh
Gap:	80×10^{-6} inches
Frequency:	70-120 KC
Reproduce Voltage	25 mv rms

VIBRATION ISOLATION

The transport is mounted on five vibration isolators within the case which filter the higher frequency components of vibration that are transmitted through the spacecraft structure. The sinusoidal vibration level to which the transport will be subject is 10 g's, 5 to 2000 cps (see Figure 28). Since most of the resonant frequencies of the transport subassemblies occur at higher frequencies, the transport-isolator natural frequency of 50 cycles per second has been chosen.

One isolator is located at each corner of the recorder base. The weight of the recorder (9 pounds) being equally distributed on the four mounting points. The recorder is mounted on the four isolators in a manner that placed the transport center of gravity above the plane defined by the isolator centers of gravity. Since this is not a recommended manner in which to use the isolators, a fifth mount was added on the top side of the transport to negate the previously existent cantilever system. A scale mockup of the transport was fabricated and vibrated using this isolator format. The results proved conclusively and soundness of the design and defined the stiffness of the individual mounts. The Lord HTO Series, BTR (Broad Temperature Range) isolators have proven to be satisfactory in past spacecraft recorder programs and will be applied here.

Figure 29 is a plot of the load vs. natural frequency of a typical 7-pound isolator. This curve indicates a natural frequency of 55 cps for a load of 1-1/4 pounds at a prototype

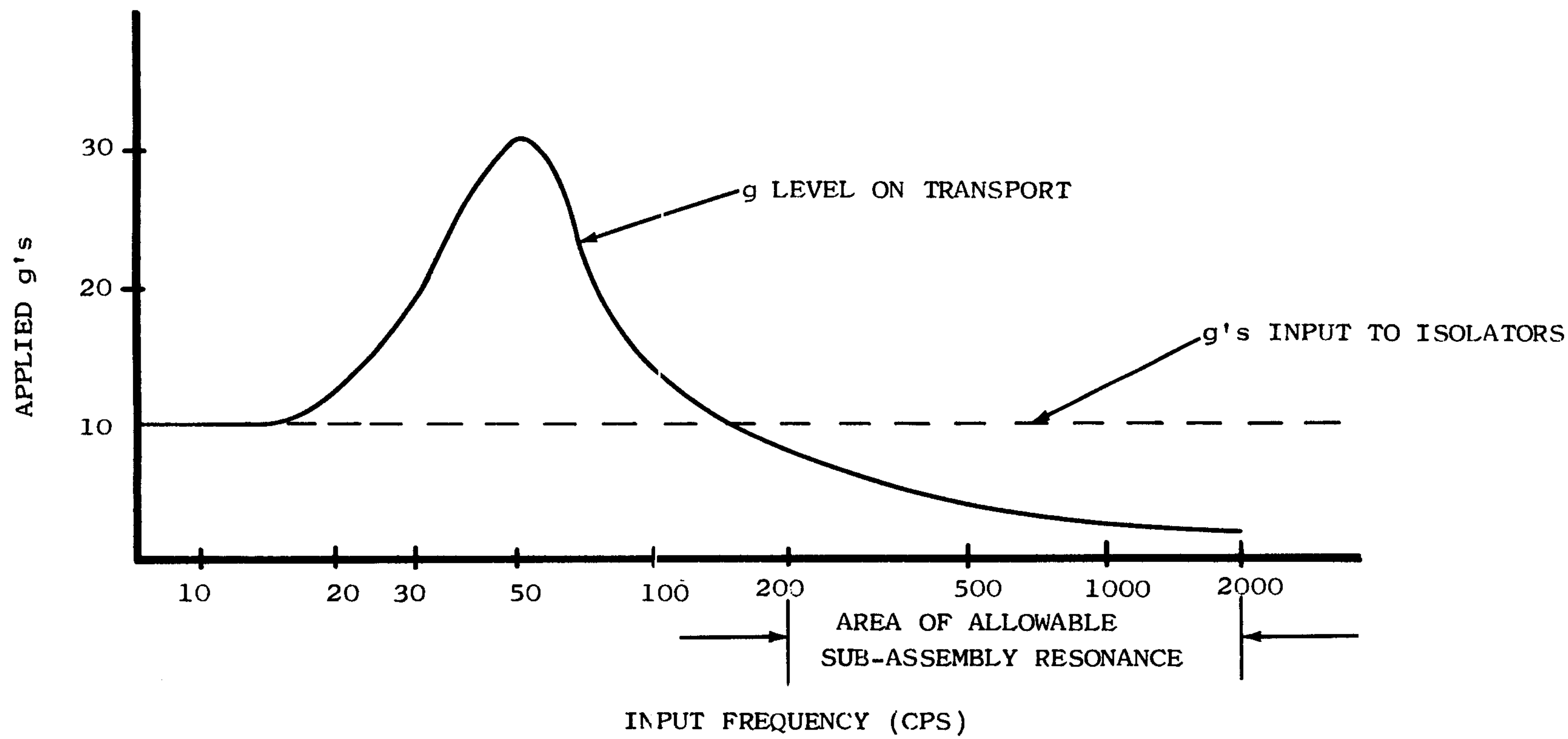

FIGURE 28

VIBRATION ISOLATION CURVE

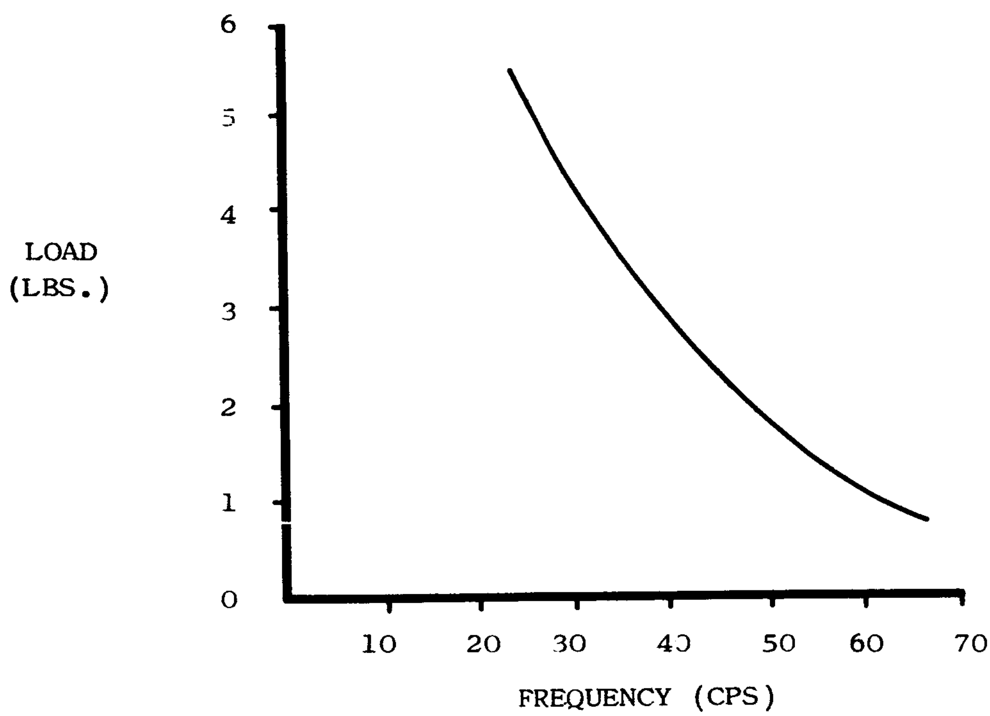

FIGURE 29

LOAD VS. NATURAL FREQUENCY

vibration level of 10 g's, 5-2000 cps. The input amplitude of 10 g's at 55 cps is .065 inches, peak-to-peak. The isolator amplitude, with an expected transmissibility of 3 at resonance, is (3) (.065) = .195 inches peak-to-peak. The maximum allowable amplitude of the isolator is .32 peak-to-peak yielding a safety factor of 1.6. At the anticipated flight acceptance level of 5 g's, the isolator amplitude at resonance is .096, yielding a safety factor of 3.3.

Since the transport is mounted diagonally in the case, the thrust and transverse axes of vibration are oblique rather than parallel to normal axial and transverse axes of the isolators. In addition, these isolators have approximately equal spring rates in all directions assuring all-attitude protection for the transport.

NEW TECHNOLOGY

In accordance with the New Technology clause of the contract, this data has been assembled and submitted to GSFC under separate cover. One area, which was developed under this contract, was considered new technology. This is the phase lock speed control servo, which is completely described in this report on pages 7 through 24.