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Final Report For
Incremental Magnetic Tape Drive Mechanism
(23 August 1965 - March 1966)
Contract No: JPL 951289

Copy____Of____

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Final Report

for

Incremental Magnetic Tape Drive Mechanism

(23 August 1965 - March 1966)

Contract No: JPL 951289

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ABSTRACT

This is the final report concluding the work on the Incremental Magnetic Tape Drive Mechanism. In this contract, Ampex Corporation designed, fabricated and delivered an engineering model of the Incremental Drive fulfilling all those requirements set forth by the contractor.

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APPENDIX I

1.0 INTRODUCTION

On August 23, 1965, Ampex Corporation undertook a contract with J. P. L. to develop, design and fabricate one experimental model of an Incremental Magnetic Tape Drive Mechanism which is to be capable of moving tape in accordance with the requirement of J. P. L. Design Specification No. GMY-50384-DSN entitled "10^7 Bit Incremental Magnetic Tape Recorder", dated 23 December, 1964. It is the purpose of this report to describe this work fully. The program has provided significant understanding of those objectives set forth in the specification and, additionally, generated a sophisticated piece of laboratory test equipment embodying many of the concepts arising from the study program.

2.0 DESIGN STUDY

2.1 Specification Outline

The program objective is to build a tape drive mechanism which is capable of incrementing tape at Repetition (or Stepping) Rates from 0-375 cycles per second for single track Packing Densities of 100-500 bits per inch on tape. This device must be capable of operating with very low power; the final unit requiring no more than 5 watts average power and 10 watts peak power. The total weight of the recorder to be no more than 5 pounds. Its construction must be simple and robust and its reliability must be high.

2.2 Analysis

The first step in the study was to analytically relate the packing density and repetition rate to power.

2.2.1 Preliminary Calculations

According to the work statement, the recorder must operate in incremental mode for packing densities from 100 to 500 Bits/inch. The initial design goal will be to have a repetition rate up to 400 cycles per second.

If we impose a velocity control system on the capstan, there will be certain restricted combinations of packing density, repetition rate and velocity. In order to develop a graph showing these limitations, the following assumptions are made:

1. That this curve represents the velocity profile for one cycle.

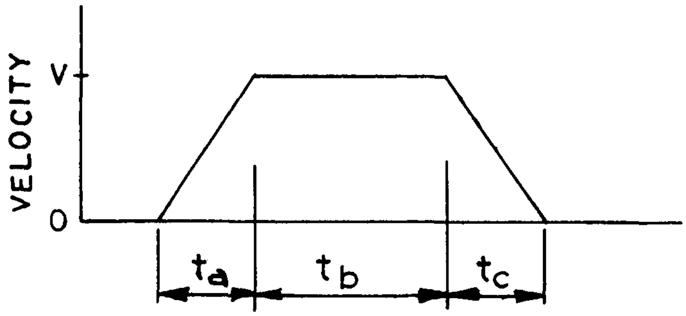


FIGURE 1

That is to say, for one cycle, there is an acceleration period (t_a), a steady state period (t_b) and a deceleration period (t_c).

2. The packing density is defined as D Bits/inch. Therefore, the tape must move 1/D inches/cycle.

For example: $\frac{1}{D} = \frac{V}{2} \cdot t_a + V \cdot t_b + \frac{V}{2} \cdot t_c$

since $t_a = t_c$ then

$$\frac{1}{D} = V(t_a + t_b) \qquad \text{EQUATION I}$$

3. If an arbitrary one millisecond is set for t_a, equation I becomes:

$$\frac{1}{D} = V(10^{-3} + t_b) \qquad \text{Equation IA.}$$

4. The repetition rate is defined as R cycles/second. Then the time allotted for each cycle is I/R which we can set equal to the above cycle time.

$$\frac{1}{R_m} = t_a + t_b + t_c$$

$$\frac{1}{R_m} - 10^{-3} = (10^{-3} + t_b)$$ Where R_m =max. repetition rate.

Substituting this in equation IA, we get,

$$\frac{1}{D} = V\left(\frac{1}{R_m} - 10^{-3}\right)$$

or

$$R_m = \frac{V \cdot D}{(10^{-3} VD + 1)}$$ cycles/sec. Equation 2.

See Graft No I of this equation.

2.2.2 Incrementing Power

It is desirable to calculate the predicted incrementing power (peak and average) for the different bit densities and incrementing rates.

The following assumptions and definitions are important:

1. Bit density D Bits/in
2. Bit rate R Cycles/sec
3. Torque of incrementing motor, $K_1 \quad T^2$ = Power
4. Assume a velocity profile for one cycle.

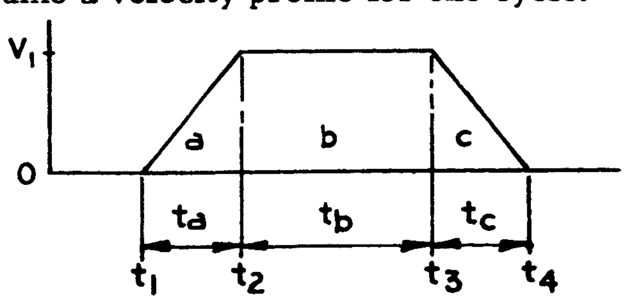


FIGURE 2

a = constant acceleration b = constant velocity
c = constant deceleration

5. The inertia = J = 7×10^{-3} oz-inch-sec^2.
6. Friction torque = T_2 = constant K_2 = 8.5 inch ounces.

As a first approximation, we can assume that the acceleration equals the deceleration.

Equation 3. $d_a = d_c = \dfrac{\dot{V}(t_a)^2}{2} = \dfrac{\dot{V}(t_b)^2}{2}$ $\qquad$ d = distance

and $d_b = V\,t_b$

The distance to be moved per cycle is 1/D in inches.

Equation 4. $\dfrac{1}{D} = d_a + d_b + d_c$

from Eq. 3 $\dfrac{1}{D} = 2d_a + d_b = 2 \cdot \dfrac{\dot{V}(t_a)^2}{2} + V\,t_b$

but $\dot{V} = \dfrac{V}{t_a}$

$\therefore \dfrac{1}{D} = Vt_a + Vt_b = V(t_a + t_b)$

D is known, V + ta are selected, then.

Equation 5. $\boxed{t_b = \dfrac{1}{DV} - t_a}$

From the dynamics.

Equation 6. $T = J\alpha = J\ddot{\phi}$ $\qquad$ $\phi r = x$

Where J = inertia (ounce-in-sec^2)
ϕ = capstan rotation
r = radius of capstan
x = distance along tape

$$T_1 = J\frac{\ddot{x}}{r} = \frac{J\,\dot{x}}{r\,\Delta t_a} = \frac{J\,V}{r\,\Delta t_a} \quad \text{due to acceleration}$$

$$T_2 = K_2 \quad \text{(constant) due to friction}$$

Equation 7. $T_a = T_1 + T_2 = \frac{J\,V}{r\,\Delta t_a} + K_2 = T_{max}$ or peak torque

Equation 8. $T_b = T_2 = K_2$

Equation 9. $T_c = K_2 - T_1 = K_2 - \frac{J\,V}{r\,\Delta t_a}$

Since power $P \approx K_1 T^2$, $T = \sqrt{\frac{P}{K_1}}$

Eliminating T in 7, 8, and 9

$$\sqrt{\frac{P}{K_1}} = \frac{J\,V}{r\,t_a} + K_2$$

Equation 10. $P_a = K_1\left(\frac{J\,V}{r\,t_a} + K_2\right)^2$

Equation 11. $P_b = K_1(K_2)^2$

Equation 12. $P_c = K_1\left(K_2 - \frac{J\,V}{r\,t_a}\right)^2$

And the energy (E) per cycle is equal to:

Equation 13. $E = P_a t_a + P_b t_b + P_c t_c$ from Equation 5.

and $t_a = t_c$

Equation 14. $E = P_a t_a + P_b\left(\frac{1}{DV} - t_a\right) + P_c t_a$

From 10, 11, 12, and 13.

Equation 15. $$\boxed{E = K_1\left(\frac{JV}{r t_a} + K_2\right)^2 t_a + K_1(K_2)^2\left(\frac{1}{DV} - t_a\right) + K_1\left(K_2 - \frac{JV}{r t_a}\right)^2 t_a}$$

Equation 15 then is the energy per cycle expression.

2.2.2 Optimum Power

Although it may not be a realizable system, a little thought allows us to calculate the minimum power for a given set of conditions. The average velocity = R/D = $\overline{V}$

If we let t_b = 0, the velocity profile then changes to a triangle whose height is V.

$V = 2\overline{V} = 2\ R/D$

Equation 16. $\boxed{V = 2\frac{R}{D}}$

and $2\ t_a = 1/R$ SEC/CYCLE
or $t_a = 1/2R$ SEC/CYCLE

With these, equation 15 becomes:

$$E = K_1\left(\frac{J}{r}\frac{2R2R}{D} + K_2\right)^2 \frac{1}{2R} + K_1\left(K_2 - \frac{J}{r}\frac{4R^2}{D}\right)^2 \frac{1}{2R}$$

$$= \frac{K_1}{2R}\left[\frac{J^2}{r^2}\frac{16R^4}{D^2} + 2K^2\frac{J}{r}\frac{4R^2}{D} + K_2^2 + K_2^2 - 2K_2\frac{J}{r}\frac{4R^2}{D} + \frac{J}{r}\frac{16R^4}{D}\right]$$

$$= \frac{K_1}{2R}\left[\frac{2J^2}{r^2}\frac{16R^4}{D^2} + 2K_2^2\right]$$

Equation 17. $E = \frac{K_1}{R}\left[\frac{16J^2}{r^2}\frac{R^4}{D^2} + K_2^2\right]$

Equation 17 is the minimum energy per cycle for the set of parameters K_1, K_2 J, r, R, and D given.

Energy per cycle times cycles/per second = power - then,

$$ER = P = K_1\left(16\frac{J^2}{r^2}\frac{R^4}{D^2} + K_2^2\right) \qquad \text{(IN WATTS)}$$

Equation 18.

$$P = K_1 \left[16 \frac{J^2}{r^2} \frac{R^4}{D^2} + K_2^2 \right] \quad = \text{average power in Watts.}$$

See graph #2 - Average Power versus Stepping Rate

However, if certain realistic physical restraints are put on the system, such as V = 1 inch per second, and t_a = one millisecond, then equation 15 becomes:

$$E = K_1 \left(\frac{JV}{rt_a} + K_2 \right)^2 t_a + K_1 K_2^2 \left(\frac{1}{DV} - t_a \right) + K_1 \left(K_2 - \frac{JV}{rt_a} \right)^2 t_a$$

$$= K_1 \left(2 \frac{J^2 V^2}{r^2 t_a^2} + 2K_2^2 t_a \right) + K_2^2 \left(\frac{1}{DV} - t_a \right) K_1$$

$$= 2K_1 \frac{J^2 V^2}{r^2 t_a^2} \cdot t_a + 2K_1 K_2^2 t_a + \frac{K_1 K_2^2}{DV} - K_1 K_2^2 t_a$$

$$= K_1 \left[\frac{2J^2 V^2}{r^2 t_a^2} + K_2^2 t_a + \frac{K_2^2}{DV} \right]$$

Equation 15a $$E = K_1 \left[\frac{2J^2 V^2}{r^2 t_a^2} + K_2^2 \left(t_a + \frac{1}{DV} \right) \right]$$

$$K_1 = \frac{1}{70} \text{ WATTS / (OZ-IN)}^2$$

$$K_2 = 8.5 \text{ OZ-IN}$$

$$J = 7 \times 10^{-3} \text{ OZ-IN-SEC}^2$$

$$r = 1 \text{ INCH}$$

$$\therefore \quad E = \frac{1}{70} \left[2 \frac{(49 \times 10^{-6}) V^2}{10^{-3}} + 72 \left(10^{-3} + \frac{1}{DV} \right) \right]$$

See Graph #3 Energy/cycle versus packing Density

THEORETICAL MAXIMUM REPETITION RATE FOR
A GIVEN PACKING DENSITY AND VELOCITY

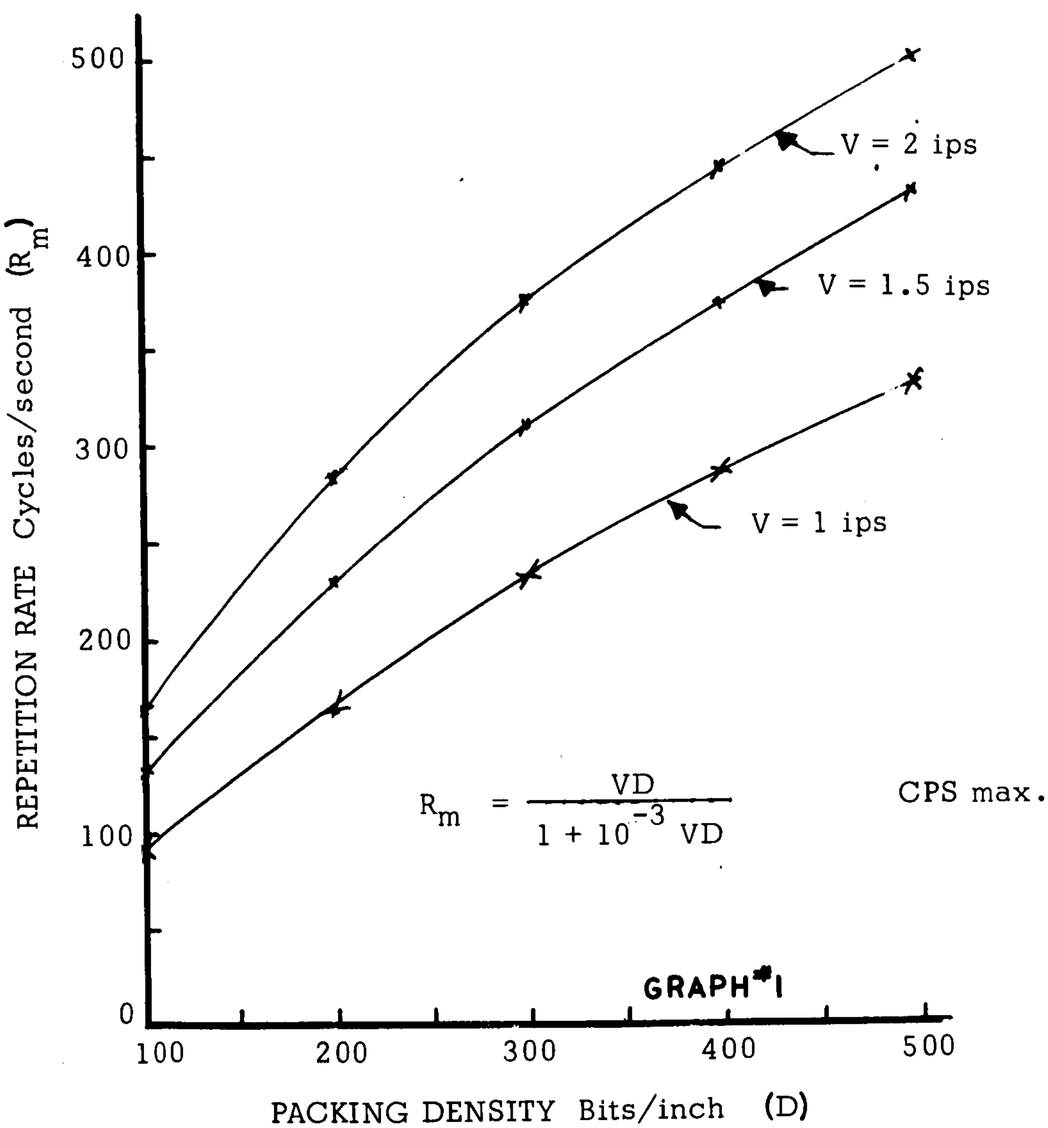


FIG. 3

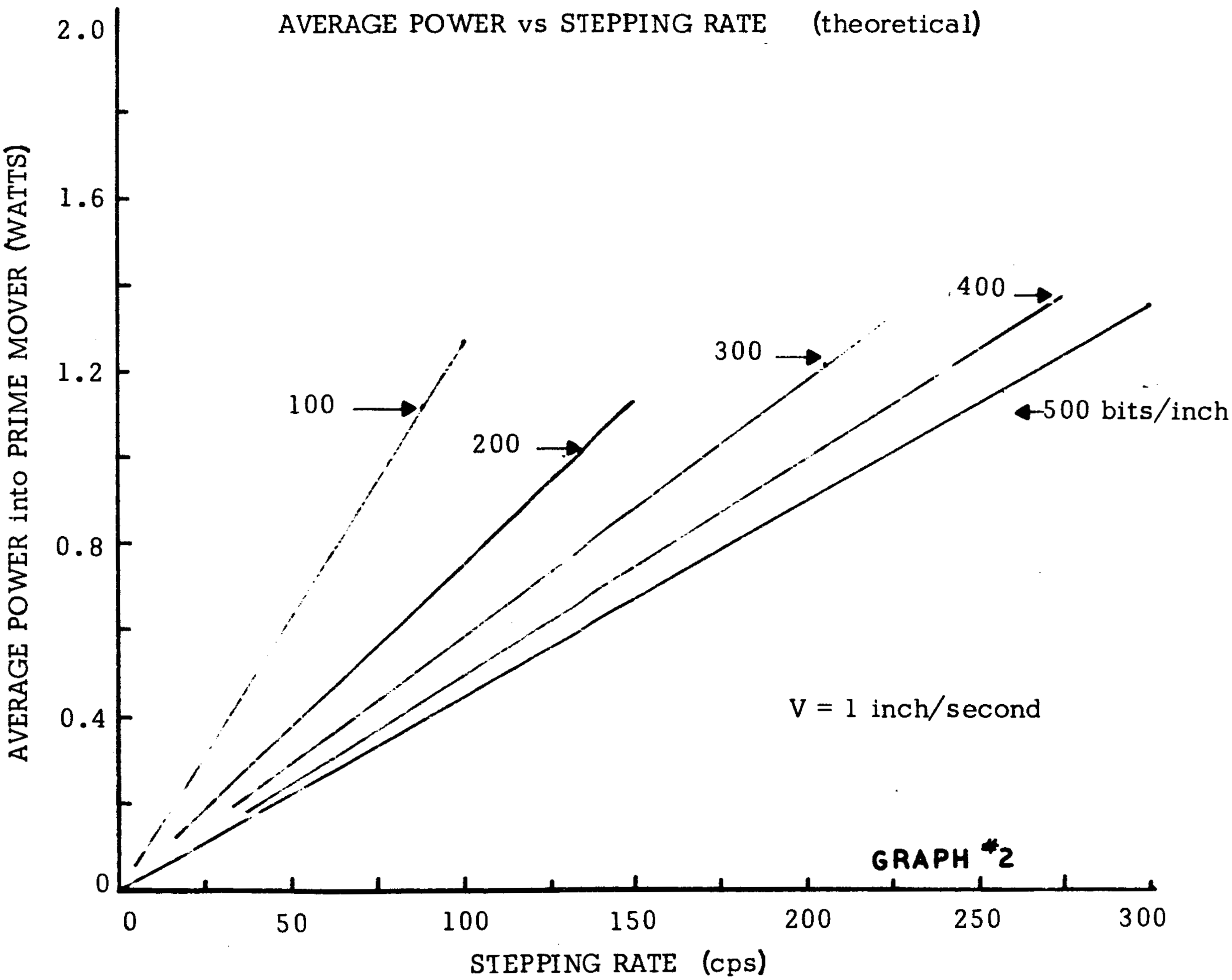

AVERAGE POWER vs STEPPING RATE (theoretical)
AVERAGE POWER into PRIME MOVER (WATTS)
2.0
1.6
1.2
0.8
0.4
0
100
200
300
400
500 bits/inch
V = 1 inch/second
GRAPH #2
0
50
100
150
200
250
300
STEPPING RATE (cps)

FIG. 4

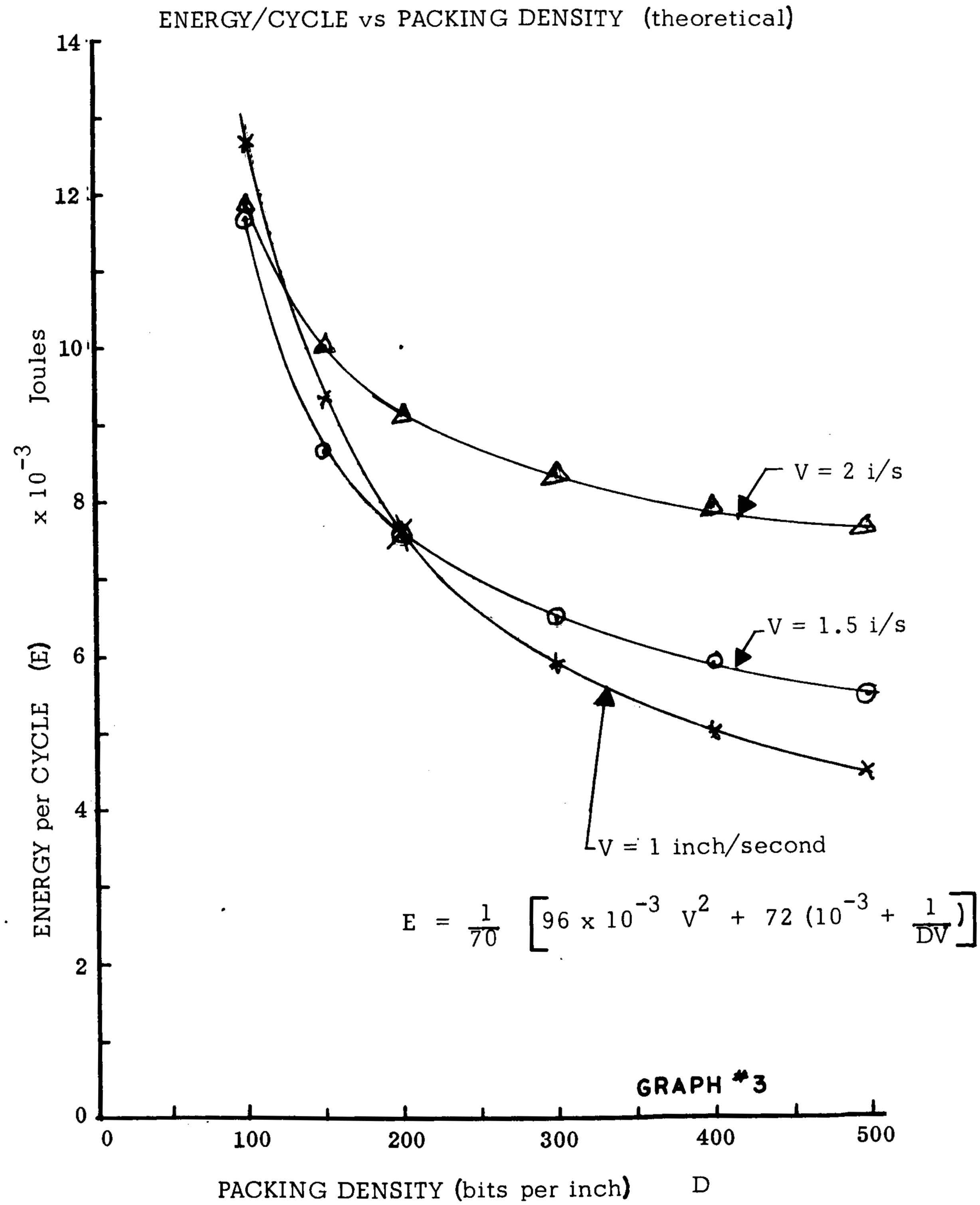

ENERGY/CYCLE vs PACKING DENSITY (theoretical)
ENERGY per CYCLE (E) x 10^-3 Joules
14
12
10
8
6
4
2
0
V = 2 i/s
V = 1.5 i/s
V = 1 inch/second
E = 1/70 [96 x 10^-3 V^2 + 72 (10^-3 + 1/DV)]
GRAPH #3
0
100
200
300
400
500
PACKING DENSITY (bits per inch) D

FIG. 5

2.3 Practical Prime Mover

The most important goal in this program is to select a proper prime mover for the incrementor. Before making any decision it is advisable to take time out and review the characteristics of prime movers. With a little knowledge comments can be made as to what is considered a desirable feature on those parameters open for inspection.

(1) It would appear that what ever type of tape drive system that is chosen it must be compatible to a practical control technique. To achieve a high responsive servo system a high torque-to-inertia ratio (T/J) is required.

(2) It will also mean, electrically speaking, the motor should have a low electrical time constant (L/R ratio) in the sub-millisecond region.

(3) The effect of the motor inertia, J, on the power can be easily seen in the expression relating average power to the inertia.

Equation 18. $P = K_1 \left[16 \frac{J^2}{r^2} \frac{R^2}{D^2} + K_2^2 \right]$

This equation shows a low inertia in the motor which is desirable for low power.

(4) The prime mover is the driving element and must be rigid with no mechanical resonance.

(5) The torque and rest position must be independent of angular position.

(6) The prime mover must be capable of long life and high reliability.

(7) It must be lightweight.

(8) The prime mover must lend itself to practical control system.

The next step in the study was the review of the potential tape-drive and prime mover combinations.

2.4 Capstan/Tape Drive Approaches

In investigating a tape drive system for this incrementor it was necessary to review the overall tape transportation parameters - i.e. the prime mover, driving element, tape path configuration, tape buffer storage and reel system. In this study existing types of tape drive designs were reviewed to determine potential solutions for these specific requirements.

There are three basic tape drive designs: the direct coupled prime mover; the semi-direct drive; and the non-direct drive.

2.4.1 Direct-Coupled Prime Mover

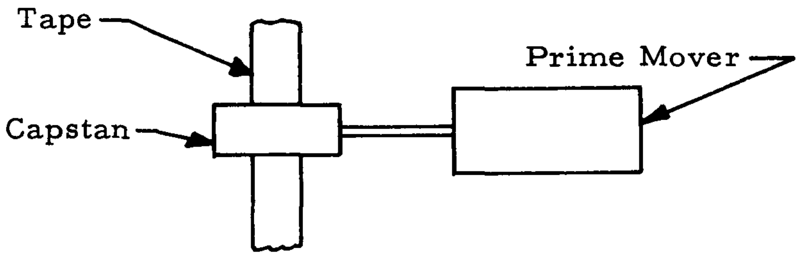


Figure 6

Here the prime mover is directly coupled to the capstan. Tape movement is accomplished by friction drive using either a large wrap around the capstan or using a pinch roller. The tape motion will, therefore, follow the prime mover. There are many types of motors used with this system. A list is made here with their characteristics.

(a) A. C. Motors - Conventional Rotating Magnetic Field. There are two types: Induction and Sychronous. Each have armature of high inertia due to the iron. They also have inductance in the field windings.

(b) D. C. Motors - Conventional Commutated Armature. D. C. Motor fall into the following types: Series, Shunt Compound, Separately excited, and Permanent magnet.

They feature the following characteristics: High inertia of motor due to the iron in the armature. High inductance in the coil windings. Motor has cogging characteristics. There are some commutation problems due to inductances; in one case, for small h. p. motors there are now solid state D. C. brushless motors.

(c) Stepping Motors
These fall into two types: Mechanical detent and Magnetic detent. Each characterized by a fix number of positions. The number of positions, at most, are insufficient to be useable. The Slo-Syn motor noted in the original Ampex proposal has only 200 increments per revolution.

(d) Other Type Motors
There are two other types of motors worth considering. These are D. C. motors with low armature inertia - the Printed Armature and the Minertia motors. Both exhibit a low inertia armature and a large magnetic structure which is a weight problem but not an eliminating condition except for the Minertia motor.

2.4.2 Semi-Direct Drive

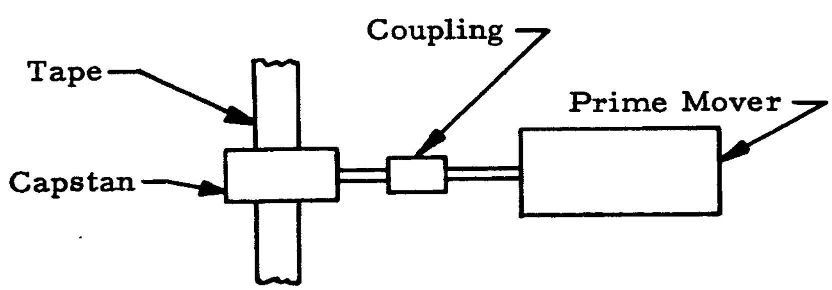


Figure 7

This arrangement uses a clutch-brake coupling between the motor and capstan for starting and stopping the capstan. The clutch-brake devices used in this case fall into two main types: Friction engagement and Magnetic Particle engagement. The friction engagement is generally actuated by one of the following methods: a coil, a crystal, or a magneto strictive device. The magnetic particle engagement uses either wet or dry particles. There are two other minor clutch-brake devices worth mentioning. These are the eddy current and the loudspeaker types. A general characteristic shown of those clutch-brake devices reduce to practical commercial use is they have response time equal or greater than four milliseconds. It is difficult to achieve a response time of less than four milliseconds, life and power becomes a serious consideration.

2.4.3 Non-Direct Drive

In this type of drive the capstan is initially turning at a given speed. The tape is held away from the capstan so there is no contact. When tape movement is desired the tape is brought into contact with the spinning capstan. This can be done either using a pinch roller to press the tape against the capstan, or by using a pneumatic or electrostatic capstan to draw the tape to the capstan. The capstan actuated pinch roller drive is a popular method in computer transport. This type of drive is characterized by the high inertia of the actuator mechanism and the high power required to operate them. The other two type drives, the pneumatic and electrostatic capstan require external power source that is impractical for our use here.

3.0 MOTOR DRIVE DEVELOPMENT

In order to conceive a practical design that can be used in the final unit a review was made of all the work done up to this point. As a first design selection, the following were judged suitable for our purpose.

3.1 Motor Selection

Reviewing the requirements outlined under paragraph 2.3 for practical prime mover the motor that approaches the requirements is the Print Armature motor. A review of the Printed Armature motor (PMI 368) characteristics are as follows:

(a) T/J ratio is quite adequate.

(b) L/R ratio, the electrical time constant is less than 100μsec, (L <100 μh).

(c) The inertia is less than 0.004 in. oz. sec.^{2}

(d) Its construction is rigid in the torque plane.

(e) The motor has no cogging or fixed rest position.

(f) Life is long, in the order of 10^9 revolutions at 3600 RPM which is equivalent to 244 days at 3600 RPM. Life improves with lower speed.

(g) The weight is 3 lbs., with possible reduction by using other magnetic material.

(h) The linear relationship of the motor characteristics makes it an ideal motor for servo analysis.

3.2. Tape Path Considerations

There are two tape path configurations worthwhile mentioning for this application. They are the capstan pinch roller and the rubber capstan approach. The capstan pinch roller approach is complicated by the fact that the pinch roller requires actuation or the rubber may possibly take a compression set. The pinch-roller approach does not lend itself easily to a bidirectional design. An alternate approach is the use of a rubber coated capstan surface where rubber is used to improve the friction coefficient between the drive element and the tape. Maximum wrap angle around the drive element is desirable for maximum tape drive force. The rubber coating on the capstan is compliant,thereby permitting a design where the head can rest directly on the capstan. With this arrangement the head to tape contact pressure is a function of the head force against the rubber capstan and not the tape tension. This allows more freedom in chosing a working tension for the rest of the system.

3.3 Reel System

Since the incrementor must be a low inertia system it is necessary to decouple the inertia of the reel from the capstan. A buffer storage is required to isolate the capstan from the reel. Provisions for maintaining the feed rate into the buffers is necessary in this design. Basically speaking, it would mean some simple regulating system will be required of the reels.

4.0 MOTOR CONTROLLER AND ELECTRONICS

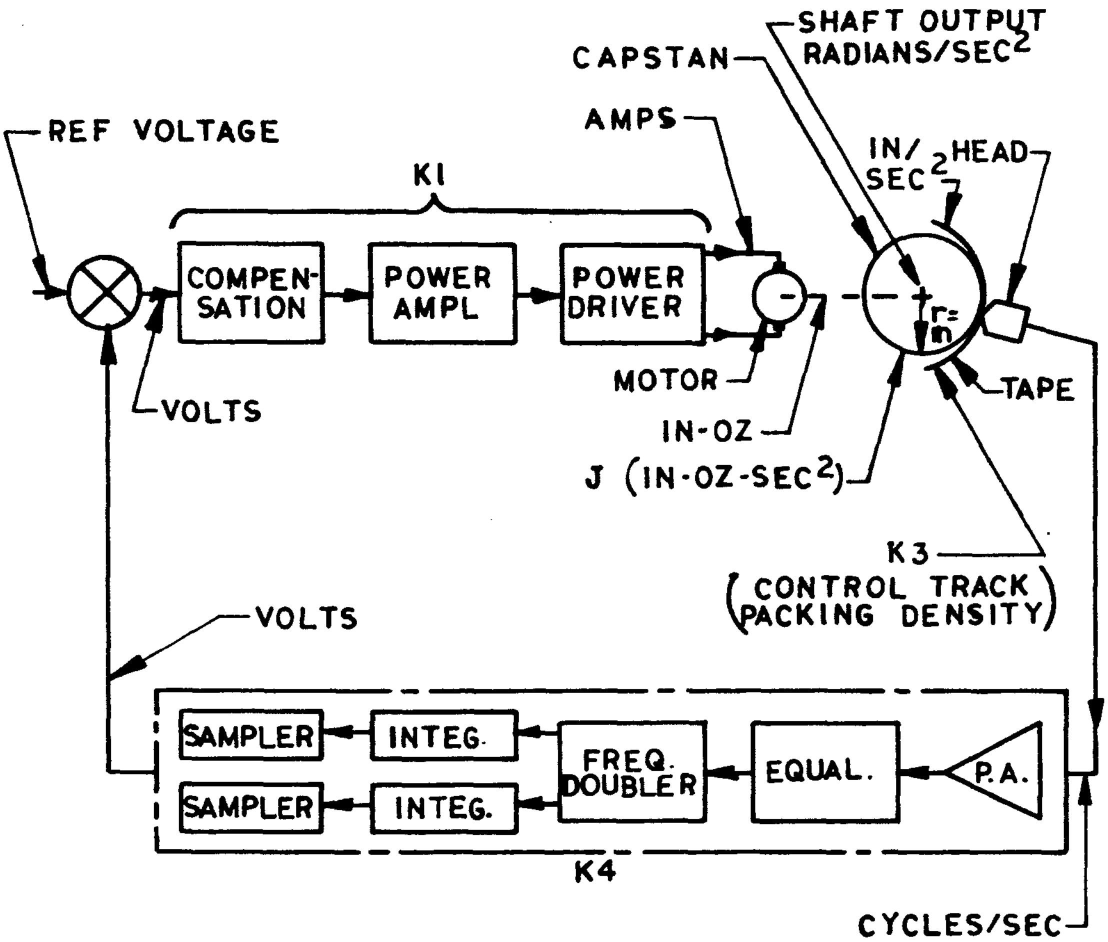
4.1 Incrementing Servo

In this phase of the study, both the position and velocity type were considered for this application. The advantage of the position servo versus the velocity is that the position servo has no error; it locks in one-to-one relation with the reference, and of course, the system is fully in synchronization or non-synchronized. In this incrementor because of two restrictions, i.e. insufficient information rate from control track, and a very low inertia system, a position type servo was difficult to stabilize.

The type of servo finally chosen for the incrementor capstan is a velocity type. That is, the velocity of the tape is detected, and this information is used to drive the capstan motor amplifier and thus the capstan motor at its proper speed. Figure 8 is a diagram of the incrementor servo. To obtain velocity information from the tape drive, one channel on the tape is used exclusively for the capstan servo. A track of 2000 cycles per inch is pre-recorded on the tape before the tape is installed. A conventional audio reproduce head is used to reproduce this signal. A pre-amplifier and equalizer amplify the signal prior to its conversion.

Following the equalizer, the next three stages in the block diagram are called: 1) Frequency doubler, 2) Integrator, 3) Sampler, and are for the purpose of converting the frequency of the signal to a voltage inversely proportional to it. This voltage is converted to a power signal and is applied to the motor. The voltage level out of a flip-flop is used to bias the signal to the power amplifier to an off condition (no current in the motor) when the capstan is com-

4.2 Capstan Servo Block Diagram



Incremental Servo Diagram

Figure 8

manded to stop. The flip-flop is also used to develop feed forward signals for both the start and the stop transient but is out of the circuit in the steady state operating condition.

The state of the flip-flop then determines whether the capstan and tape is moving or stopped. In the normal mode of operation, (the incremental mode) a signal is fed in the start input, squared up, shaped, and used to set the flip-flop. The capstan servo brings the tape up to speed (one inch per second) and remains there until a positive pulse is received at the stop input, at which time, the flip-flop is reset and the tape stops. The stop input may be generated by the clock output, in which case, the tape will stop after reading each character. In this mode of operation, a periodic train of commands (or a sine wave) may be applied to the input, and if the repetition rate is within the capability of the incrementor, then the machine will step at this same rate, on the average, and will move at a distance of one character at a time.

It should be noted that by a proper electronic buffer, the incrementor could be made to step several characters per cycle in which case the data could be clocked out of the buffer serially with almost no jitter. Also, the power requirements would be reduced for a given data rate.

4.2 Capstan Servo Block Diagram

The block diagram (Figure 8) depicts the dynamics of the capstan servo.

The definitions are as follows:

(a) K_1 - This block includes the compensation and a current amplifier. The transfer function of this section is:

$$K_1 = G\left(\frac{j\frac{f}{3.8f_1}+1}{j\frac{f}{f_1}+1}\right) = 0.24 \text{ AMPS/VOLT} \qquad \begin{array}{l} f = 270 \text{ CPS} \\ f_1 = 29 \text{ CPS} \\ G = 0.9 \end{array}$$

(b) K_2 represents the printed circuit motor used on the capstan.

$$K_2 = 8.5 \text{ OZ-IN/AMPS}$$

(c) J represents all the inertia fastened to the motor shaft,

$$\frac{1}{J} = \frac{1}{7\times10^{-3}} \quad \frac{\text{RADIANS/SEC}^2}{\text{OZ-INCHES}}$$

(d) $S = j2\pi f$ where f is cycles/second.

$$\frac{1}{S} = \frac{\text{RADIANS/SEC}}{\text{RADIANS/SEC}^2}$$

(e) r = radius of capstan hub in inches.

r = 1 inch

(f) Control track density on tape K_3 = 2000 cycles/inch

(g) Gain of the frequency to voltage convertor $K_4 = 3x10^{-3}$ volts/CPS

The product of these gives the loop equation:

$$G_L = K_1 K_2 \left(\frac{1}{J}\right)(r)\left(\frac{1}{S}\right)(K_3) K_4$$

Inserting numbers given and setting equal to one gives:

$$G_L = (.24)(8.5)\left(\frac{10^3}{7}\right)(1)\left(\frac{1}{S}\right)(2000)\left(\frac{3}{10^3}\right) = 1$$

$$\frac{1.7 \times 10^3}{S} = 1$$

$$f = \frac{1.7 \times 10^3}{2\pi} = 270 \text{ CYCLES}$$

This gives the approximate natural frequency of the capstan servo.

The difficulty in controlling the speed of the tape at such a low value is mainly because of the low inertia and its associated low stored energy. The requirement to accelerate in a short period of time at low power and the fact that the energy is non-retrievable dictate that the capstan inertia be low. This, coupled with the limited sampling frequency causes the main design problems in the capstan system.

4.3 Signal Electronics

The signal system consists of one record amplifier, a two track record-reproduce head, two toggle switches to select record or reproduce mode, two reproduce preamplifiers, and one detector. Therefore, there is one complete data channel and it is used for a clock channel. The other channel is complete through the preamplifier and is included to check dynamic skew.

4.3.1. Record Amplifier

The record amplifier is a simple saturating amplifier used to convert a sine wave input to a square wave current into the record reproduce heads to simulate an NRZ clock signal.

4.3.2. Reproduce System

4.3.2.a Preamplifier

Differential type preamps are used in order to reduce to minimum noise pickup within the transport. The output of the preamp is greater than a one volt level.

4.3.2. b Detector

A very simple circuit was used for the peak detector. Since the job is to detect a clock (all ones) channel of NRZ data, great sophistication for the detector was not needed. The output of the detector is a positive spike to indicate a "one".

4.4 Power Supply

The power supply is of the conventional type center-tapped transformer with full wave bridges and smoothing capacitors. The $\pm$ 9 Volt supplies are used to feed the $\pm$ 6 V DC regulators while the $\pm$ 5 Volt unregulated power is used to run the two motors.

5.0 DRIVE SYSTEM DESIGN & CONSTRUCTION

5.1 Motor Modification

As a first consideration for a prime mover to be used in a breadboard, the Printed Armature motor seemed most likely to achieve our goal. Once this decision was made the obvious first step was to examine the motor closely to see if any alterations can be made to customize this motor for our specific application knowing these motors are built for the commercial market. Keeping in mind, of course, we were not willing to undergo any major motor development simply from the standpoint that such an adventure is a project in itself. Fortunately, we have accumulated a great deal of knowledge and experience over the years on these motors because of its wide usage in Ampex recorders. Initially, to describe this type motor it is closely analogous to a loudspeaker in its characteristics. It is dependent on a low mass conductor operating in a strong magnetic field. The field is created with a permanent magnet made of an alnico alloy. The weight of this magnet constitutes approximately 85% of the total weight of the motor. The obvious step for reducing weight is to examine alternate materials for the magnet. Time and cost involved did not warrant us to make any weight reducing design changes for the breadboard, but for a flyable unit it would be advantageous to do this work.

The PMI 368 motor was selected for our use. Its weight is three pounds and a torque constant of three inch ounces per amp. One of our major concerns is the power consumption. Since power is a product of EI, these parameters were examined. The voltage, E, across the motor is the voltage drop due to brush resistance, armature conductor resistance, and the back EMF. The back EMF is insignificant since the motor will be operating at a low RPM. The brush and armature resistance is low and there is not much that can be done to lower these values. In reviewing the current, I, in the power equation, means were discovered to improve its relation. The torque constant (or torque to current ratio) can be improved by increasing the number of conductors in the armature. It was easy to make this modification by taking the printed armature of a 9 ZF PMI motor which has four layers of conductors and putting it into the 368 PMI motor that has only two layers of conductors. By doubling the armature segments the torque constant was also double. This was a significant power reducing step.

5 .2 Tape Drive Configuration

Because this is a low speed application it allowed the selection of a tape path configuration where a rubber capstan can be used with the head riding on the capstan. This configuration lends itself to a simple design that will accomplish all functions. The idea of the rubber capstan is to provide the friction to drive the tape and also give a compliant surface for the head to rest against. The rubber is a 60 durometer silicone rubber. Recent development at Ampex showed that polyurethane gave better characteristics in damping and toughness for this compliant material. This type of configuration provides a system where the head to tape contact force is independent of the tape tension. This means low tape tension reeling can be used for lower power in the reeling system. Also, the tape tension variation has little effect on the head to tape speed since the tape is clamped to the capstan.

5.3 Head Mount

The head is mounted on an arm assembly which allows azimuth and tilt adjustments. The head to tape contact force is set with a spring at two ounces normal force. Part of the face of the head was relieved to allow wear so the head will not touch the rubber. The head used is a 250 micro inch gap audio head.

5.4 Buffer Arm

A buffer is required to isolate the capstan from the reel. An arm of low mass is located next to the capstan to provide small storage of tape to take care of short fast transients of tape motion during incrementing. At first the idlers at each end of the arm were made of a closed cellular foam material to give a compliant material to absorb the shock of the short fast transients. Comparison tests of this wheel with an aluminum wheel showed no significant difference, so the foam wheel was replaced by the aluminum one.

5.5 Capstan

5.5.1 Construction

The rubber capstan is attached to the shaft of the prime mover and, therefore, requires it to be a minimum inertia design. Aluminum was selected as the base metal and silicone rubber for the compliant surface. The rubber thickness is .10". There are indications from the test results that this thickness may be reduced. More comments on this will be made later.

5.5.2 Capstan Radius

The general energy equation generated earlier for the assumed velocity profile is:

$$E = K_1\left(\frac{JV}{rt_a} + K_2\right)^2 t_a + K_1 (K_2)^2 \left(\frac{1}{DV} - t_a\right) + K_1\left(K_2 - \frac{JV}{rt_a}\right)^2 t_a \qquad \text{EQ. 15}$$

where "r" is the capstan radius.

It appears that an optimum capstan radius can be determined from this equation to give a minimum energy value. For a given set of operating condition the variables are J and r, the rest being constants. J is the total inertia.

$$J = J_{\text{motor armature}} + J_{\text{capstan}}$$

For a chosen geometric shape for a capstan design an equation relating its inertia as a function of the radius can be derived. This expression is as follows:

$$J \text{ capstan} = (r^3 + .224r^2 + .0217r + .000836)\ 10^{-3} \text{ in. oz. sec.}^2$$

The motor armature inertia is:

$$J \text{ motor armature} = .0038 \text{ in. oz. sec.}^2$$

For minimum energy the partial derivative of E to r is set equal to zero.

$$\frac{\partial E}{\partial r} = 2K_1 t_a\left(\frac{JV}{rt_a} + K_2\right)\frac{\partial\left(\frac{JV}{rt_a}+K_2\right)}{\partial r} + \cancelto{0}{\frac{\partial\left[K_1 K_2^2\left(\frac{1}{DV} - t_a\right)\right]}{\partial r}}$$

$$+ 2K_2 t_a\left(K_2 - \frac{JV}{rt_a}\right)\frac{\partial\left(K_2 - \frac{JV}{rt_a}\right)}{\partial r}$$

$$= 2K_1 t_a\left(\frac{JV}{rt_a}+K_2\right)\left[\frac{\partial JV}{\partial r} + \cancelto{0}{\frac{\partial K_2}{\partial r}}\right] + 2K_2 t_a\left(K_2 - \frac{JV}{rt_a}\right)\left[\cancelto{0}{\frac{\partial K_2}{\partial r}} - \frac{\partial \frac{JV}{rt_a}}{\partial r}\right]$$

set equal to zero

$$\frac{\partial E}{\partial r} = \left(\frac{JV}{rt_a} + K_2\right)\left(\frac{\partial JV}{\partial r}\right) - \left(K_2 - \frac{JV}{rt_a}\right)\left(\frac{\partial \frac{JV}{rt_a}}{\partial r}\right) = 0$$

$$= \frac{JV}{rt_a}\,\frac{\partial \frac{JV}{rt_a}}{\partial r} = 0$$

$$= \frac{J}{r}\,\frac{\partial \frac{J}{r}}{\partial r} = 0$$

The value for J was substituted and data simplified to give the following:

$$(r^3 - .224\,r^2 + .0217r + 2.84)\left(2r - .224 - \frac{2.84}{r^2}\right) = 0$$

Each factor was set equal to zero and resulting r (radius) determined. The first expression failed to give a real positive value. The second has a root at r = 1.16". This is the capstan radius which will give a minimum energy condition.

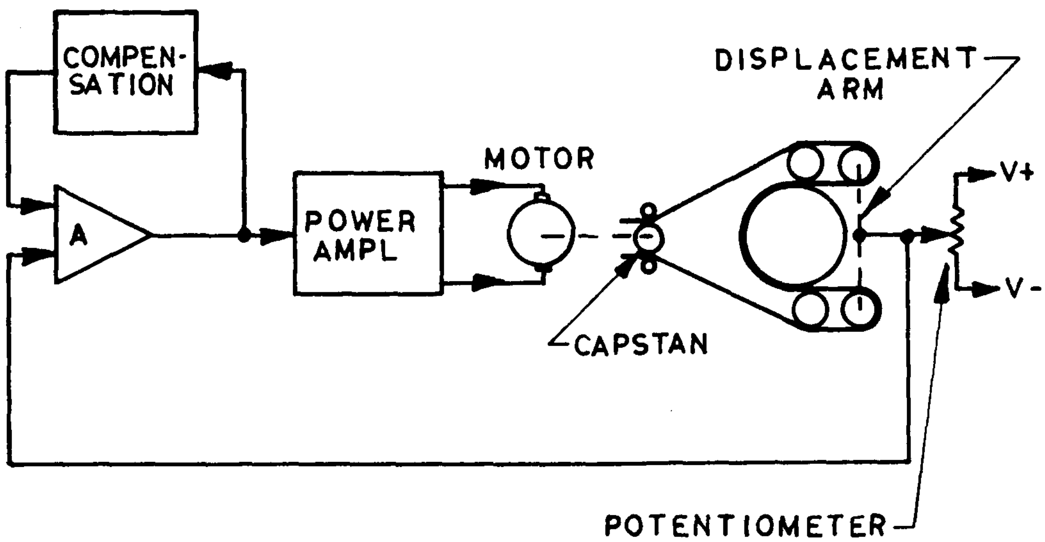
5.6 Reel System Simulation

5.6.1 Loop Capstan

A separate capstan is used to feed the tape into the incrementor. Its purpose is to simulate the reeling system by feeding tape in and out of the rubber capstan. The buffer arm which acts as an isolator is connected to a position senser that provides the loop capstan servo position feedback information.

5.6.2 Loop Servo

The loop servo is a very simple position type servo and its sole purpose is to keep the displacement arm in an approximate neutral position. This is done so that the incrementing capstan always "sees" about the same mechanical load.



Loop Servo Diagram

Figure 9

When the displacement arm is moved from its neutral position by the incrementing capstan moving tape, a potentionmeter which is attached to the displacement arm shaft, puts out an error voltage. The error signal is fed to an amplifier, then to a power amplifier.

The output of the power amplifier is fed to the loop capstan motor which in turn moves the loop of tape to reduce the error of the displacement arm and return it to its neutral position.

Transfer Functions

Displacement arm

$$G_1 = \frac{1}{2\pi} = \frac{1}{2.5} \quad \text{radians/inch}$$

Displacement arm potentionmeter

$$G_2 = \frac{6}{2\pi} = \frac{3}{\pi} \quad \text{volts/radian}$$

Amplifier gain (power amp. and compensation)

$$G_3 = 20\,\frac{\left(j\frac{f}{f_o}+1\right)}{\left(j\frac{f}{2.7f_o}+1\right)} \quad \text{amps/volt}$$

Motor Gain

$$G_4 = 1 \quad \text{oz. in. /amp}$$

Motor shaft radius, inertia, and dynamics.

$$G_5 = \frac{\Omega}{Js^2} = \frac{\frac{1}{8}}{(0.001)s^2} = \frac{125}{s^2} \quad \text{inches/oz. in.}$$

The product of these gives the loop equation,

$$G_L = \left(\frac{1}{2.5}\right)\left(\frac{3}{\pi}\right)\left[20\,\frac{\left(j\frac{f}{f_o}+1\right)}{\left(j\frac{f}{2.7f_o}+1\right)}\right](1)\left(\frac{125}{s^2}\right) = \frac{3000}{\pi s^2}\left[\frac{\left(j\frac{f}{f_o}+1\right)}{\left(j\frac{f}{2.7f_o}+1\right)}\right]$$

If a mean value is taken for the function of f_0 of approximately 1.6

then $$G_L = \frac{3000 \times 1.6}{\pi S^2}$$

If this is set equal to unity, the frequency at which the loop gain is equal to one can be calculated.

$$G_L = 1 = \frac{3000 \times 1.6}{\pi S^2} = \frac{1530}{S^2}$$

$$\text{if} \quad S = 2\pi f$$

$$f = \frac{\sqrt{1530}}{2\pi} = 6.2 \text{ CPS}$$

This way one can calculate the approximate natural frequency. To gain a more accurate description, the loop equation could be plotted on a Nichols chart or any of the other various methods of linear servo analysis.

6.0 TEST & EVALUATION

The test and evaluations were conducted on the experimental model of an incremental tape drive mechanism built for J. P. L. This recorder is capable of reproducing information incrementally up to 500 bpi at stepping rates up to 260 cps. The breadboard contains all necessary electronics for record and reproduce.

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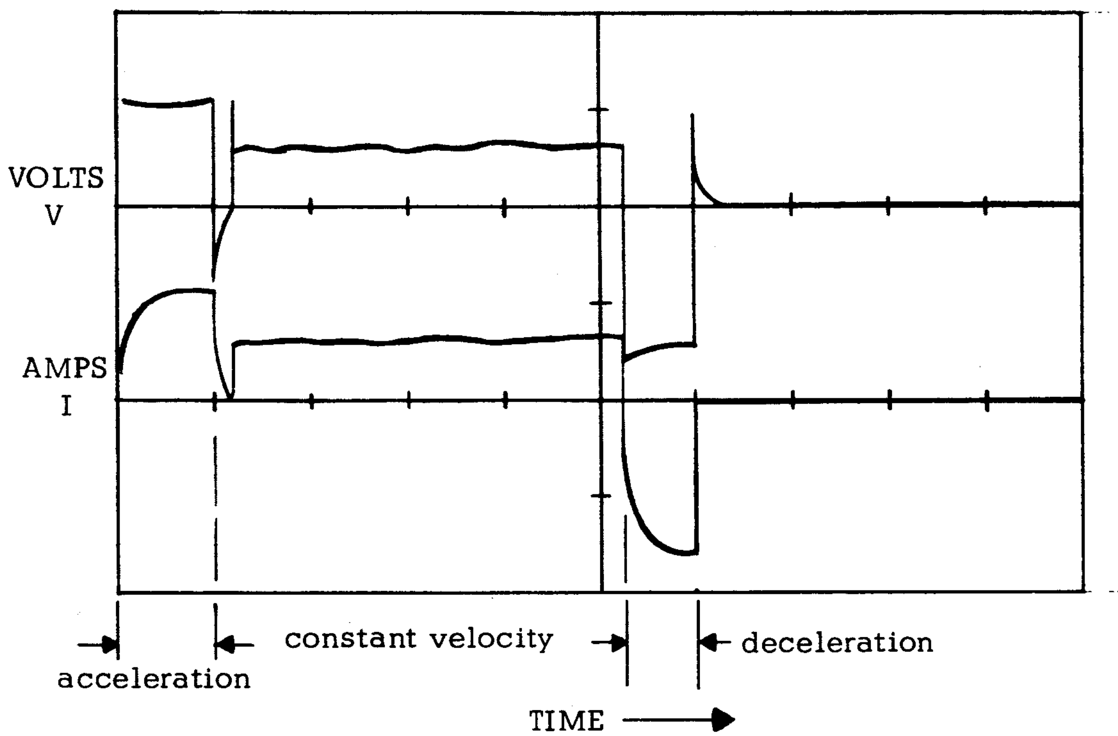
6.1 Power Measurements

The power requirements to the incrementor were evaluated for the different operating modes. The measurements were made on the power consumption as a function of stepping rate for single track packing densities of 100, 200, 300, 400 and 500 bits per inch. The following method was used to determine the power. An 0.1 ohm resistor was placed in series with the motor; and by detecting the voltage drop across this resistor, the current was calculated using ohm's law. Measurements were made using an oscilliscope. A photograph was taken of the wave form of the current and voltage to the prime mover. A typical picture is drawn in the figure below. The top line is the voltage and the bottom is the current. By multiplying the volts and amps the instantaneous power versus time was plotted in a graphical form for one cycle. The area under this curve is the energy per cycle (Joules/cycle). Multiplying this value by the Repetition Rate gave the average power (Joules/cycle x cycle/second = Joules/sec or Watts). The highest point on this curve is the peak power. One comment should be mentioned at this point on the power measurements for the 100 and 200 bpi cases. Looking at the waveform picture there is an absence of the stop command. It was found at the lower bit densities the stop command is not required which conserves power as a result. This also accounts for the dip at 200 bpi of the curve for power shown on the graph Power versus BPI.

POWER MEASUREMENTS

Typical wave form for one cycle.



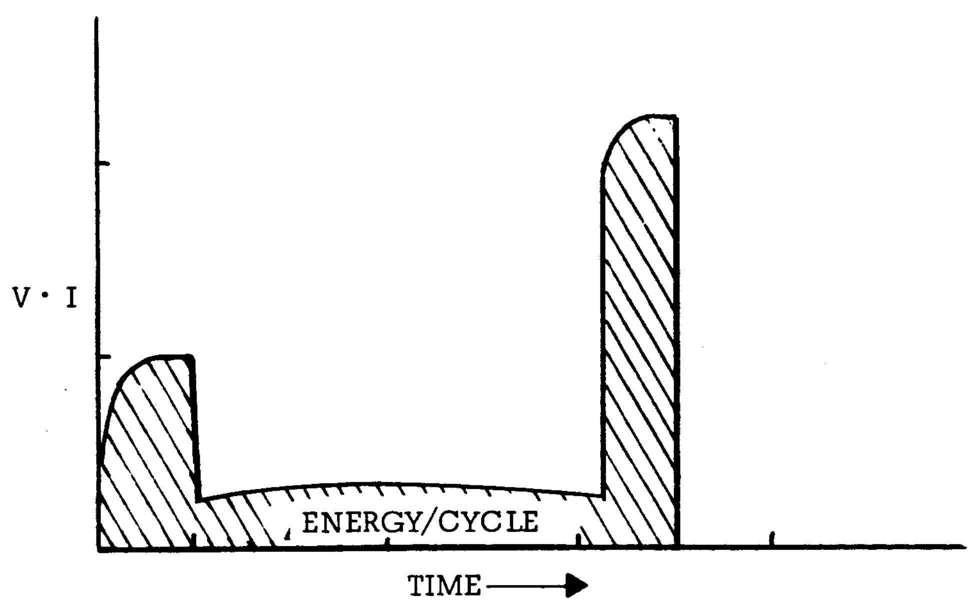
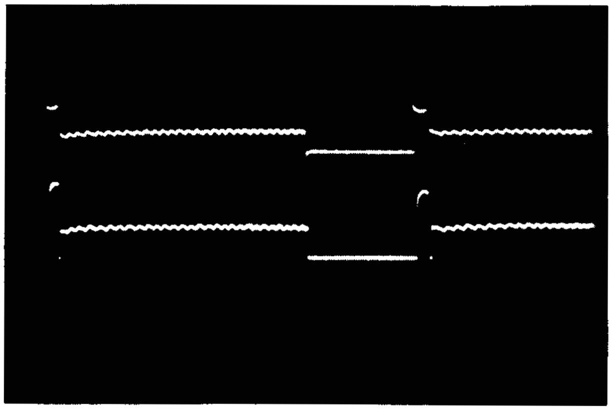
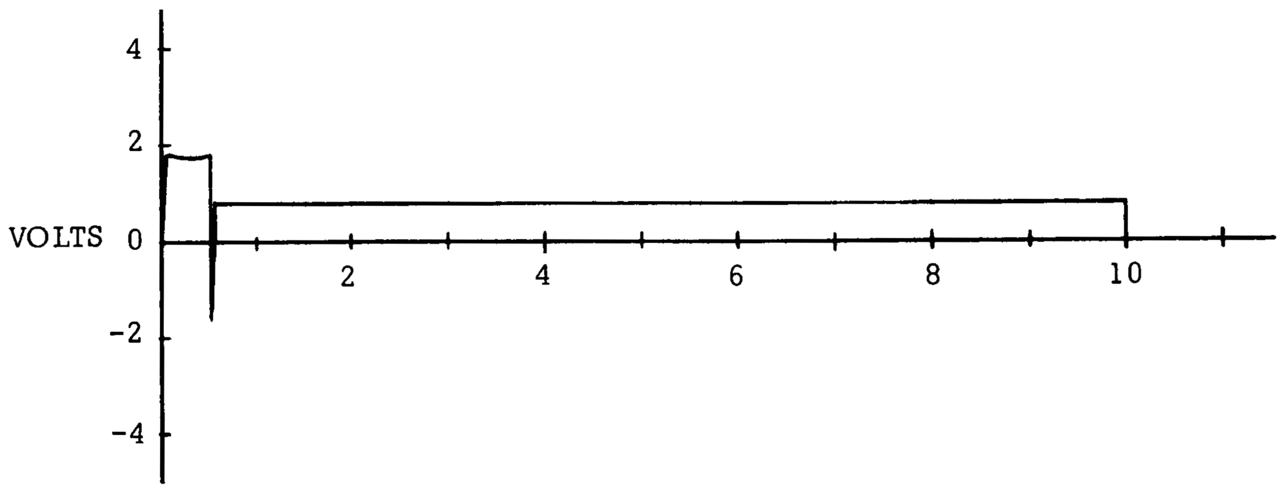


FIGURE 10

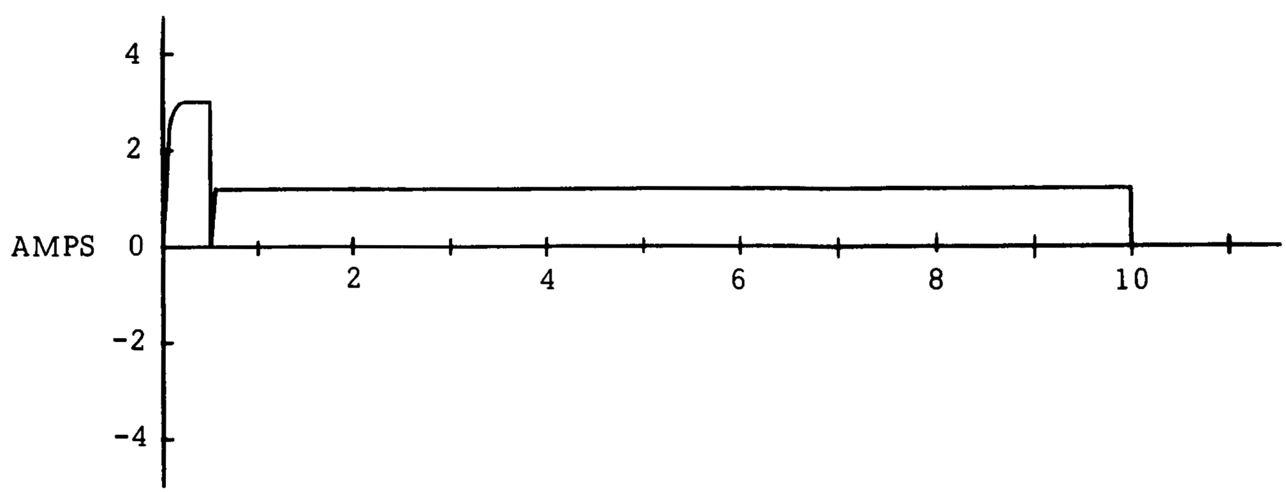
POWER MEASUREMENTS FIGURE 11



Packing Density, D	100 bpi
Repetition Rate, R	70 cps
Horiz. Cal.	2.0 ms/cm
Vert. Cal. (Top)	2.0 v/cm
Vert. Cal. (Bottom)	2.0 A/cm



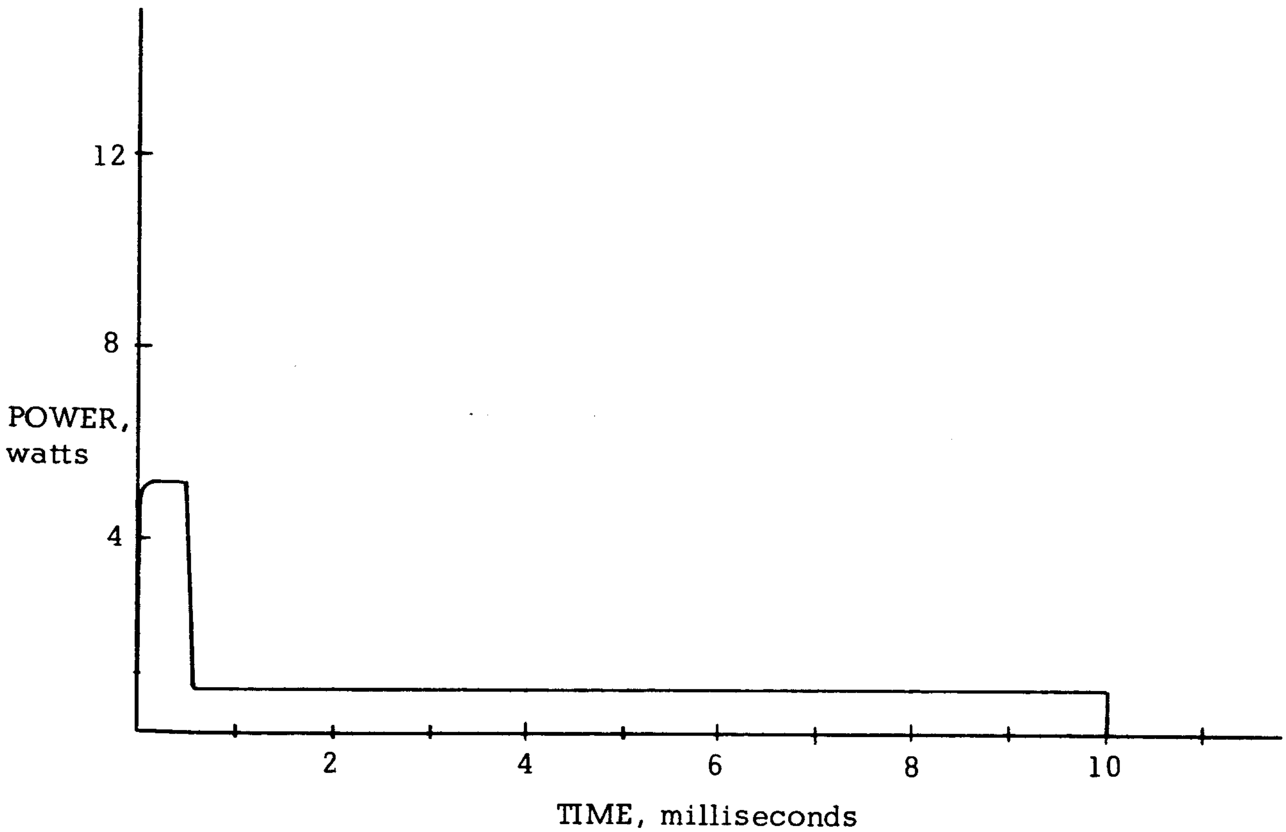
TIME, milliseconds



TIME, milliseconds

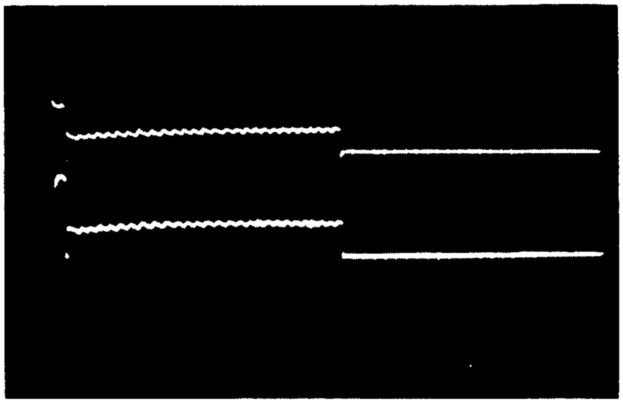
FIGURE 12

POWER MEASUREMENTS

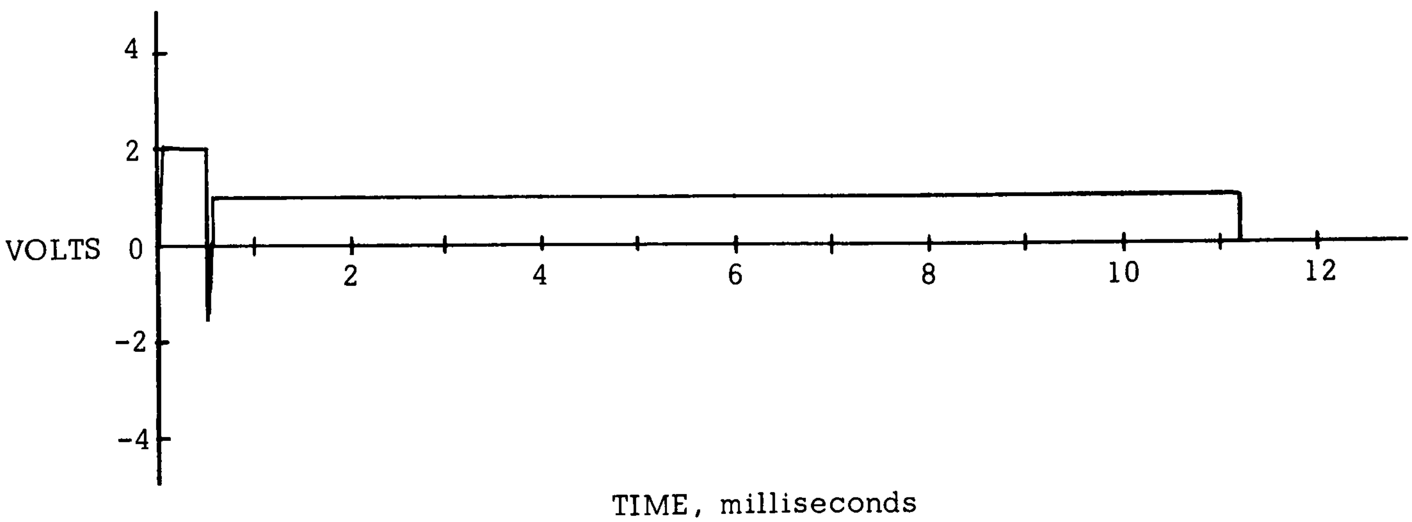


Packing Density, D	100 bpi
Repetition Rate, R	70 cps
Energy/cycle	0.012 joules/cycle
Average Power	0.80 watts
Peak Power	5.2 watts

POWER MEASUREMENTS FIGURE 13



Packing Density, D	100 bpi
Repetition Rate, R	7 cps
Horiz. Cal.	2.0 ms/cm
Vert. Cal. (Top)	2.0 V/cm
Vert. Cal. (Bottom)	2.0 A/cm



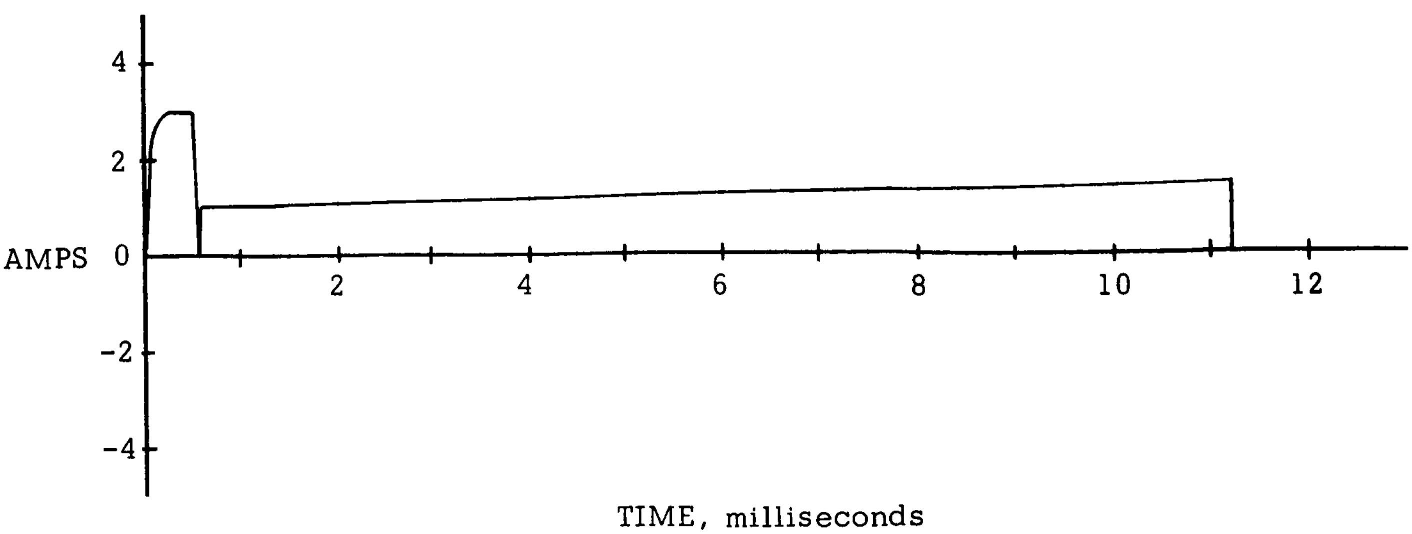
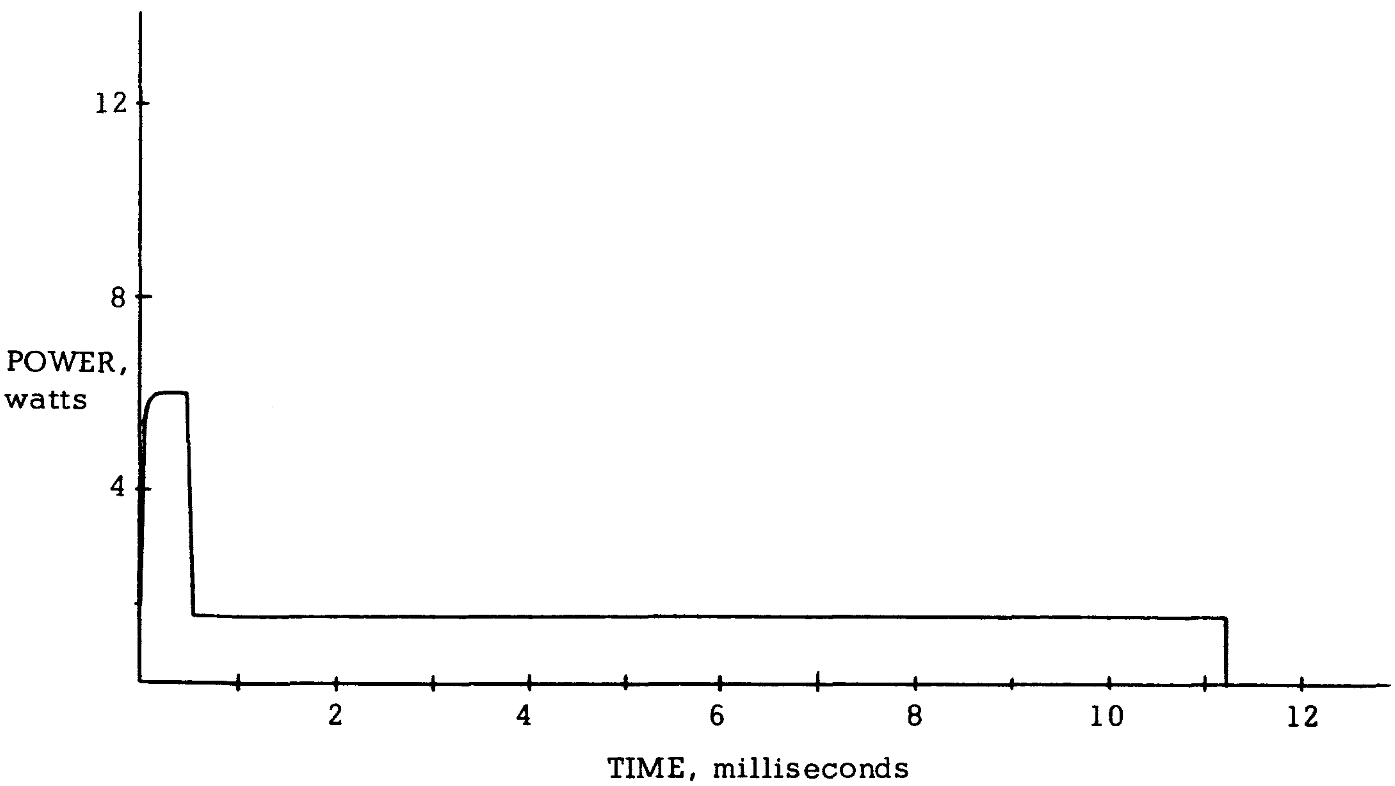


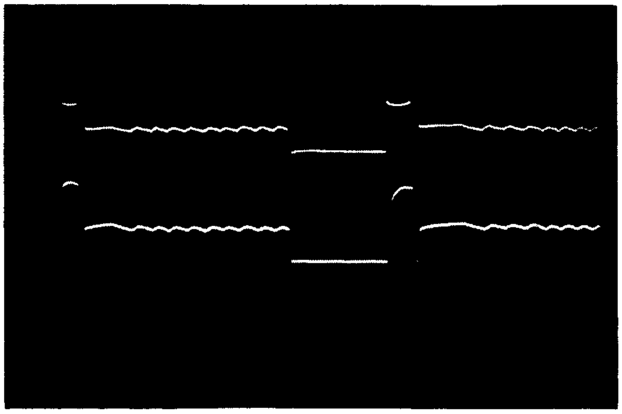
FIGURE 14

POWER MEASUREMENTS

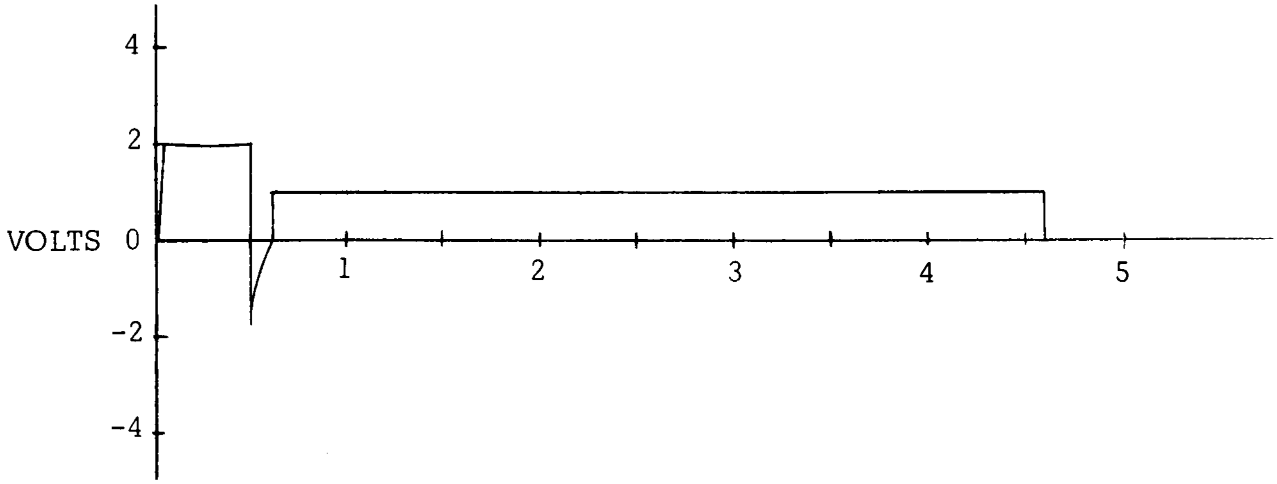


Packing Density, D	100 bpi
Repetition Rate, R	7 cps
Energy/cycle	0.018 joules/cycle
Average Power	0.13 watts
Peak Power	6.0 watts

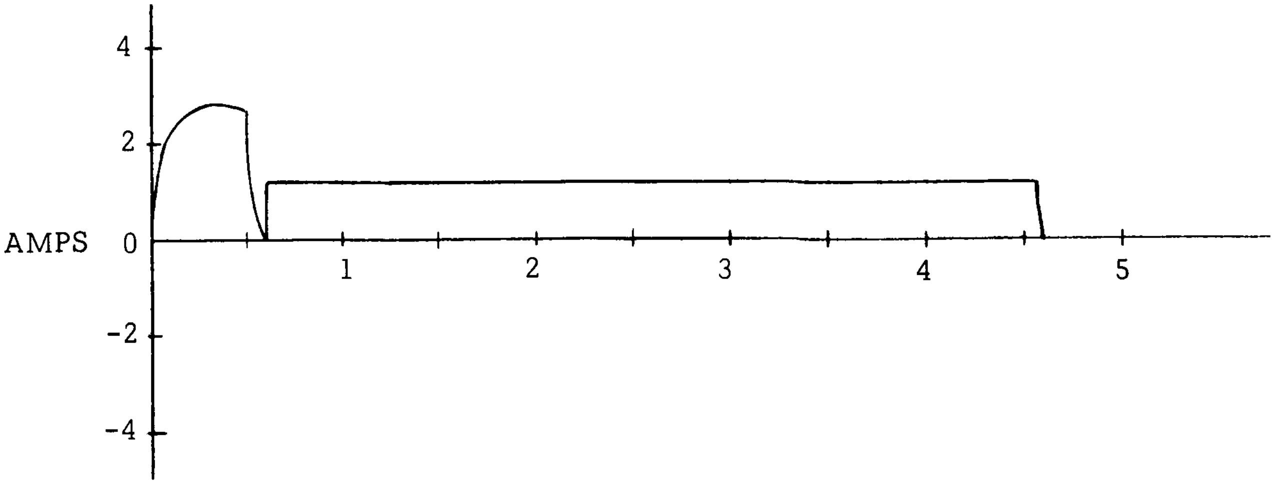
POWER MEASUREMENTS FIGURE 15



Packing Density, D	200 bpi
Repetition Rate, R	150 cps
Horiz. Cal.	1.0 ms/cm
Vert. Cal. (Top)	2.0 V/cm
Vert. Cal. (Bottom)	2.0 A/cm



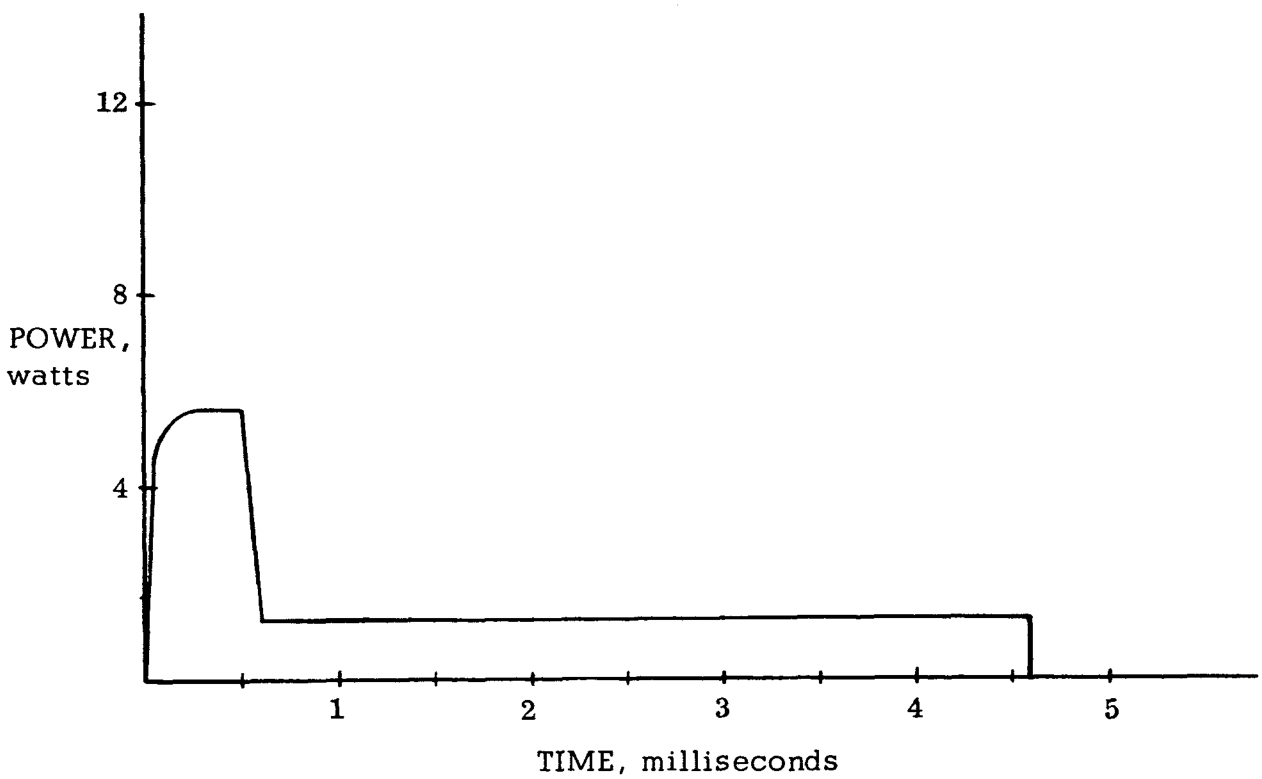
TIME, milliseconds



TIME, milliseconds

FIGURE 16

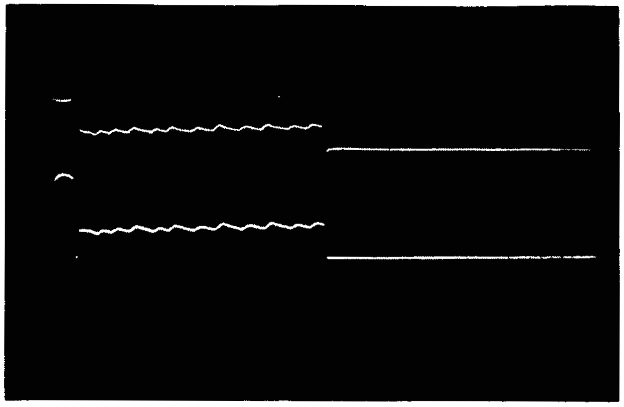
POWER MEASUREMENTS



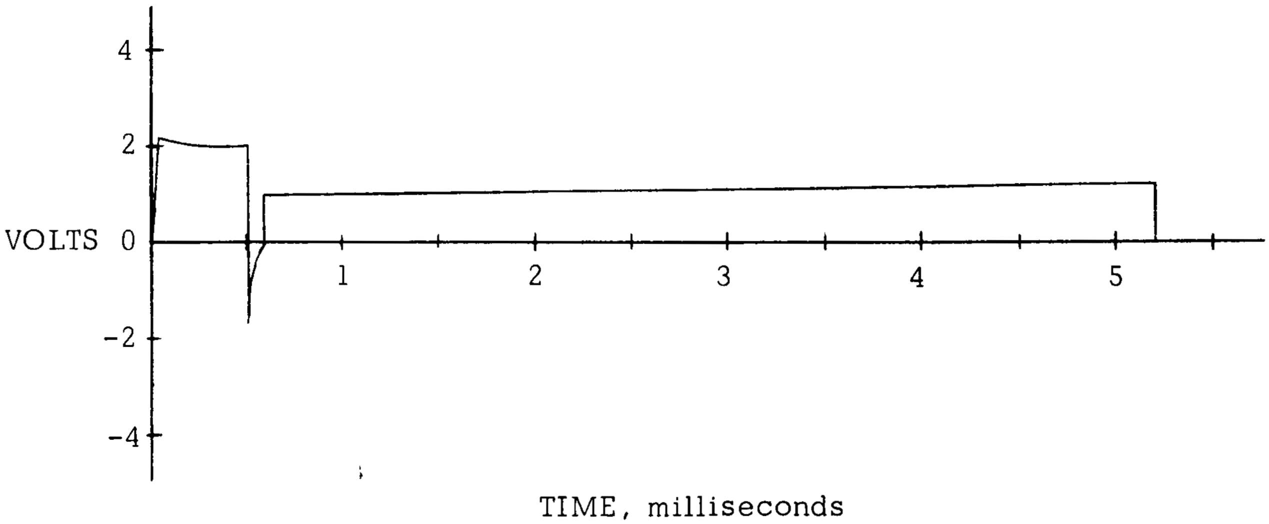
Packing Density, D	200 bpi
Repetition Rate, R	150 cps
Energy/cycle	.008 joules/cycle
Average Power	1.21 watts
Peak Power	5.6 watts

POWER MEASUREMENTS

FIGURE 17



Packing Density, D	200 bpi
Repetition Rate, R	15 cps
Horiz. Cal.	1.0 ms/cm
Vert. Cal. (Top)	2.0 V/cm
Vert. Cal. (Bottom)	2.0 A/cm



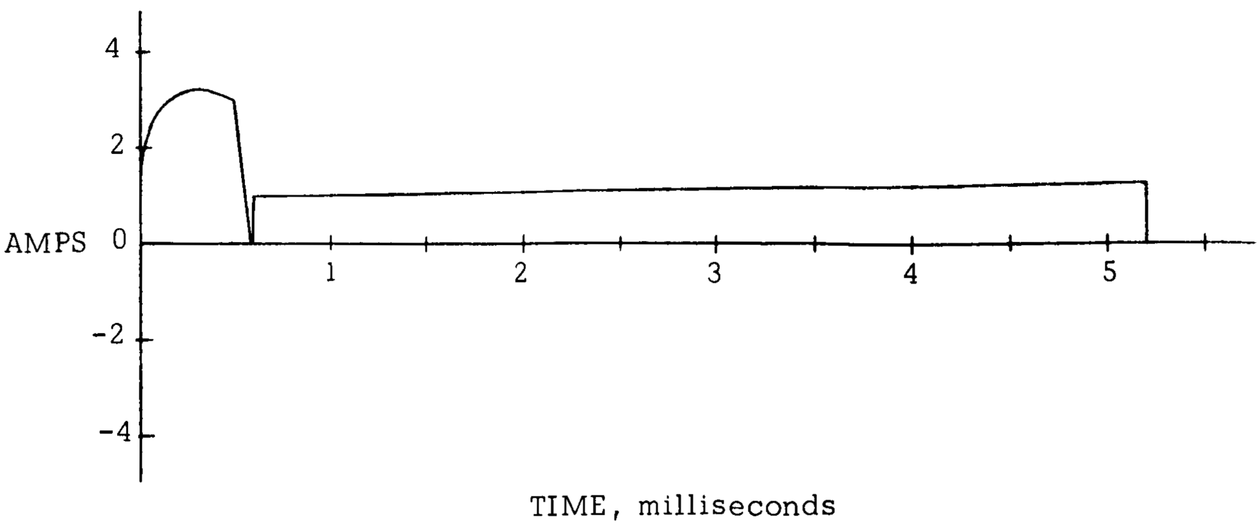
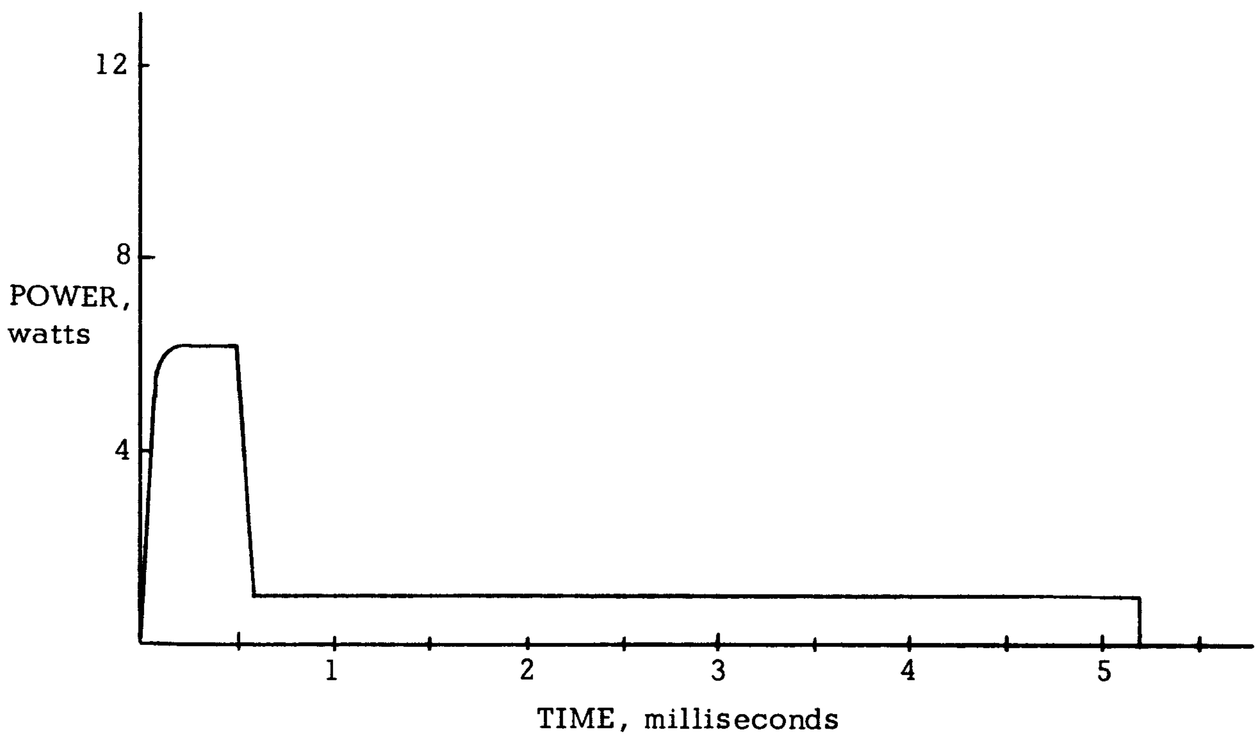


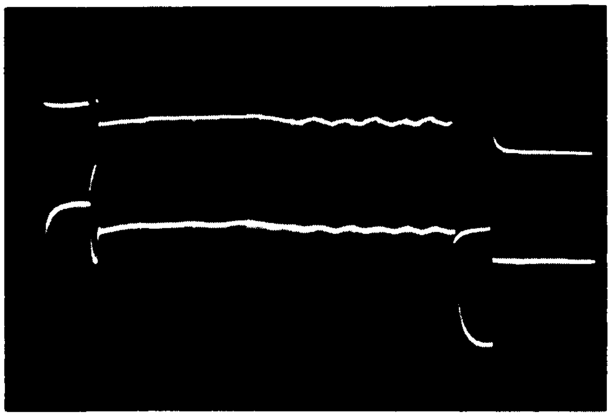
FIGURE 18

POWER MEASUREMENTS

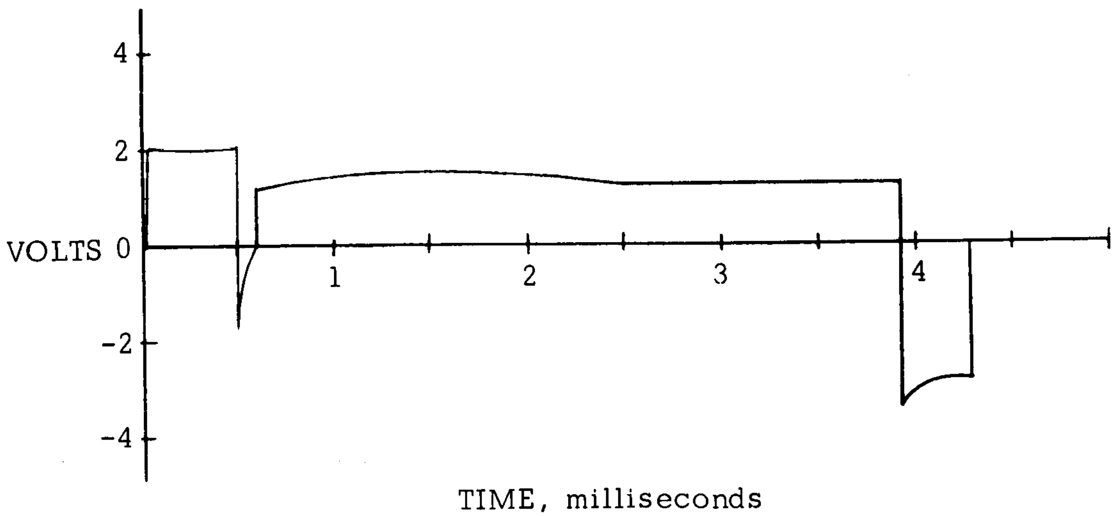


Packing Density, D	200 bpi
Repetition Rate, R	15 cps
Energy/cycle	0.008 joules/cycle
Average Power	0.12 watts
Peak Power	6.2 watts

POWER MEASUREMENTS **Figure 19**



Packing Density, D	300 bpi
Repetition Rate, R	180 cps
Horiz. Cal.	0.5 ms/cm
Vert. Cal. (Top)	2.0 V/cm
Vert. Cal. (Bottom)	2.0 A/cm



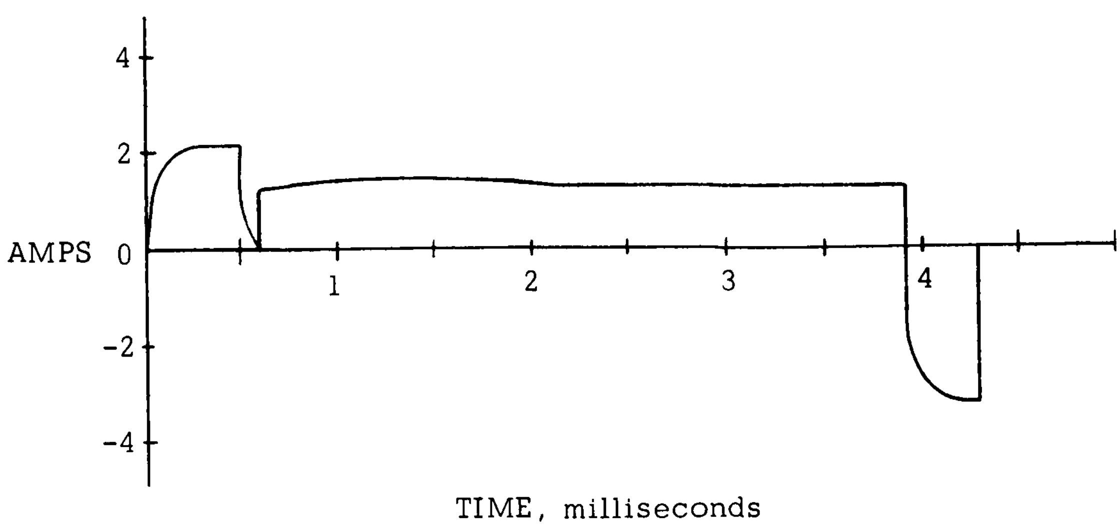
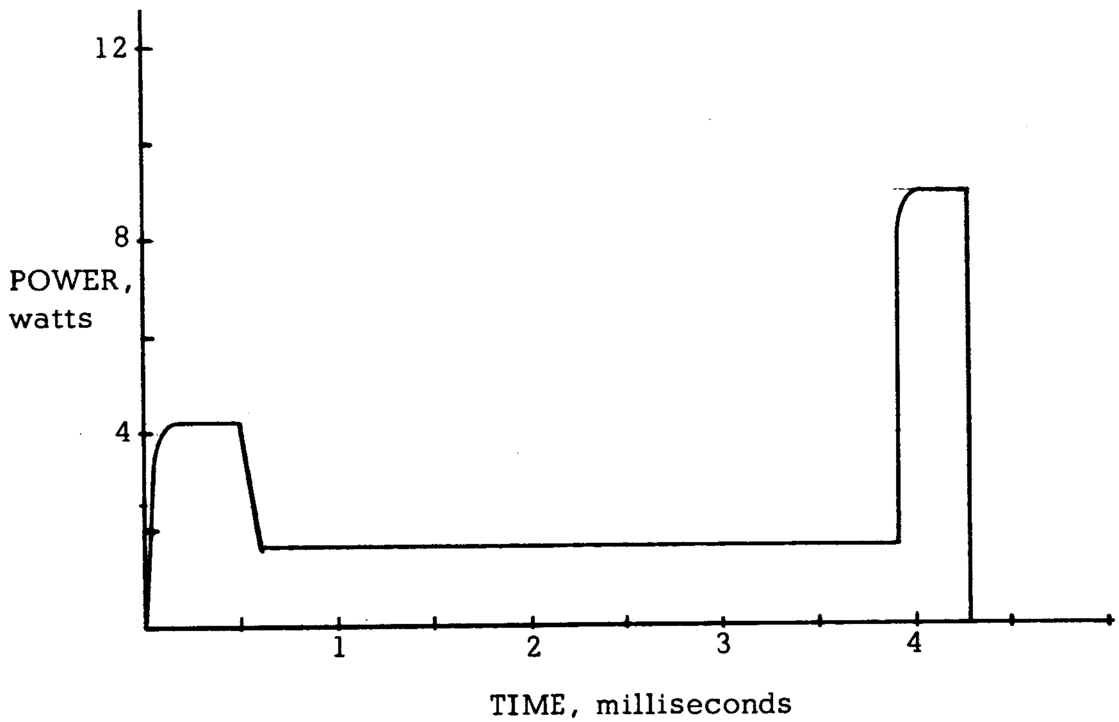


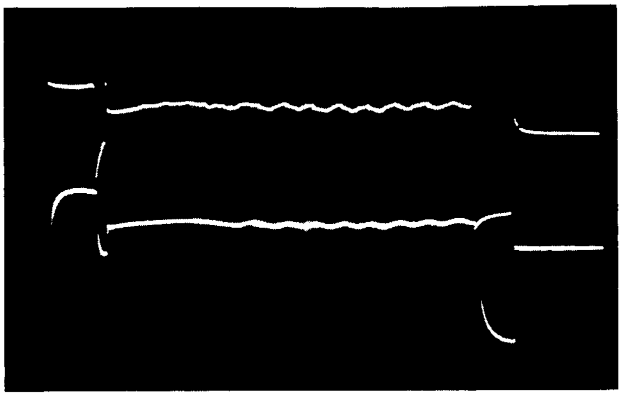
FIGURE 20

POWER MEASUREMENTS

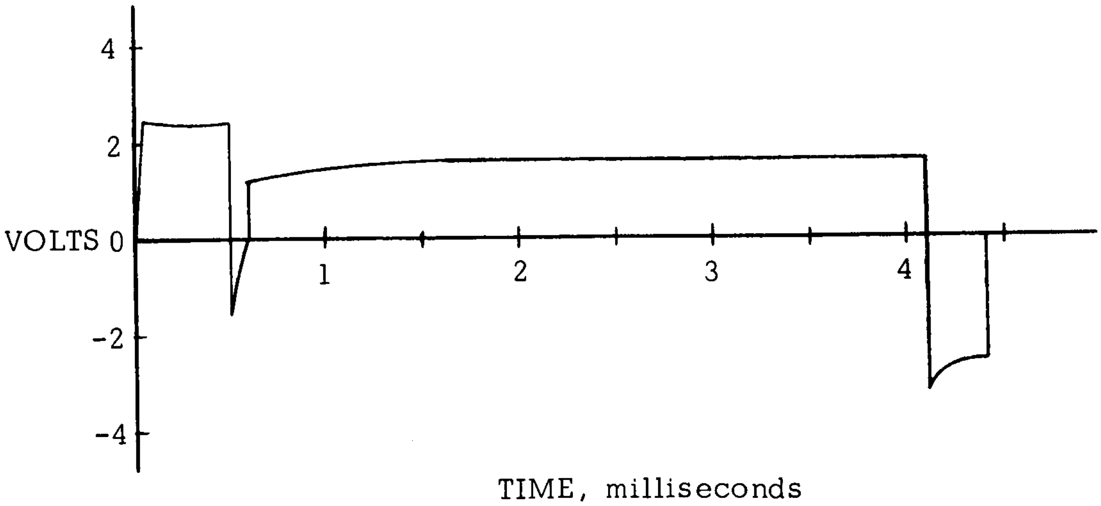


Packing Density, D	300 bpi
Repetition Rate, R	180 cps
Energy/cycle	0.010 joules/cycle
Average Power	1.86 watts
Peak Power	9.0 watts

POWER MEASUREMENTS Figure 21



Packing Density, D	300 bpi
Repetition Rate, R	18 cps
Horiz. Cal.	0.5 ms/cm
Vert. Cal. (Top)	2.0 V/cm
Vert. Cal. (Bottom)	2.0 A/cm



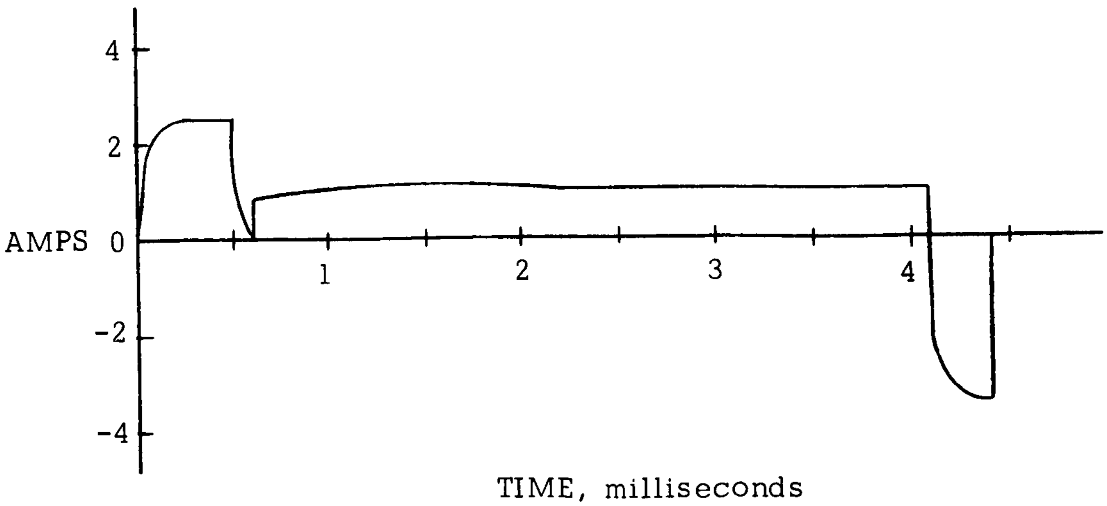
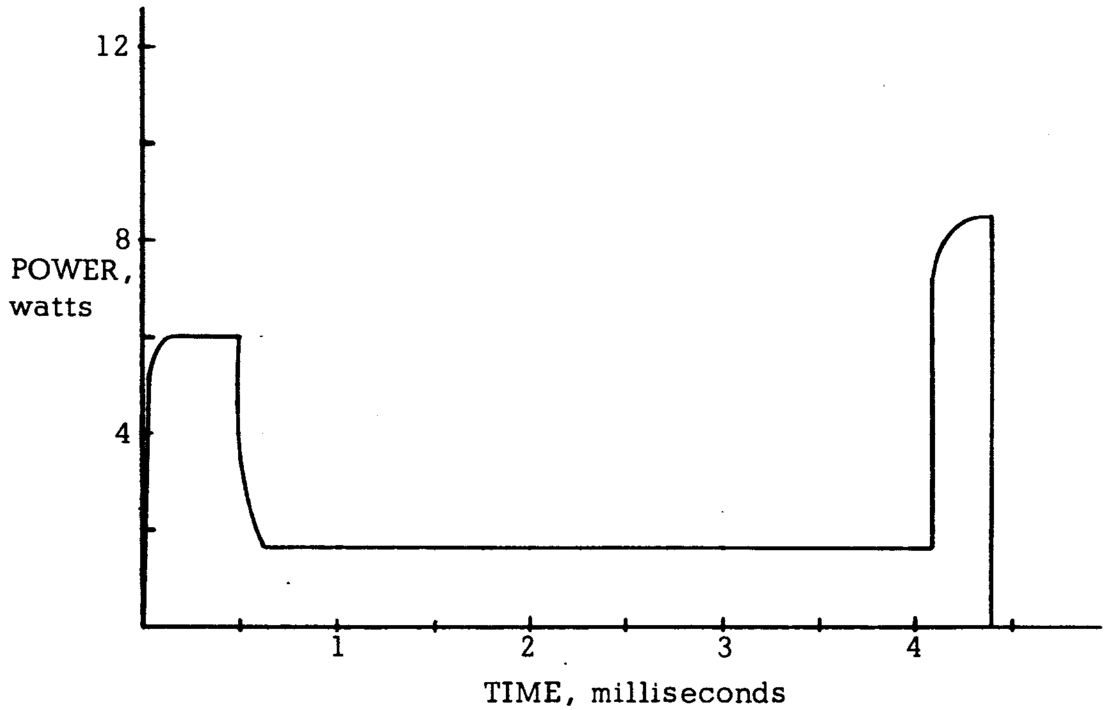


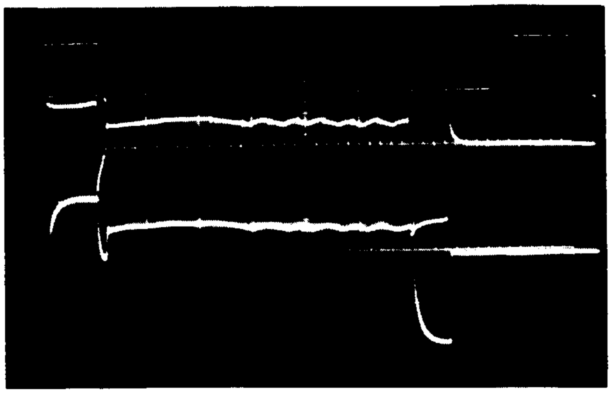
FIGURE 22

POWER MEASUREMENTS

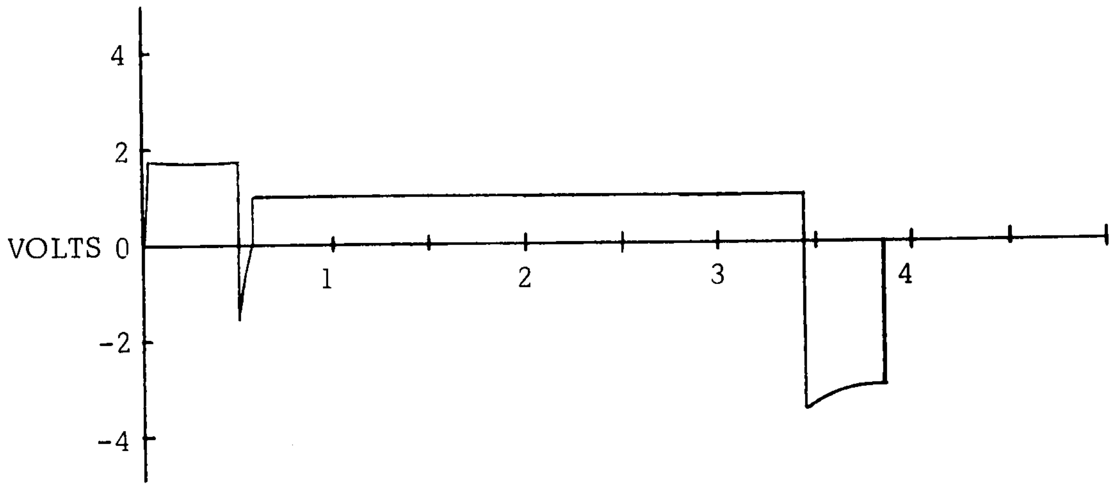


Packing Density, D	300 bpi
Repetition Rate, R	18 cps
Energy/cycle	0.011 joules/cycle
Average Power	.19 watts
Peak Power	8.6 watts

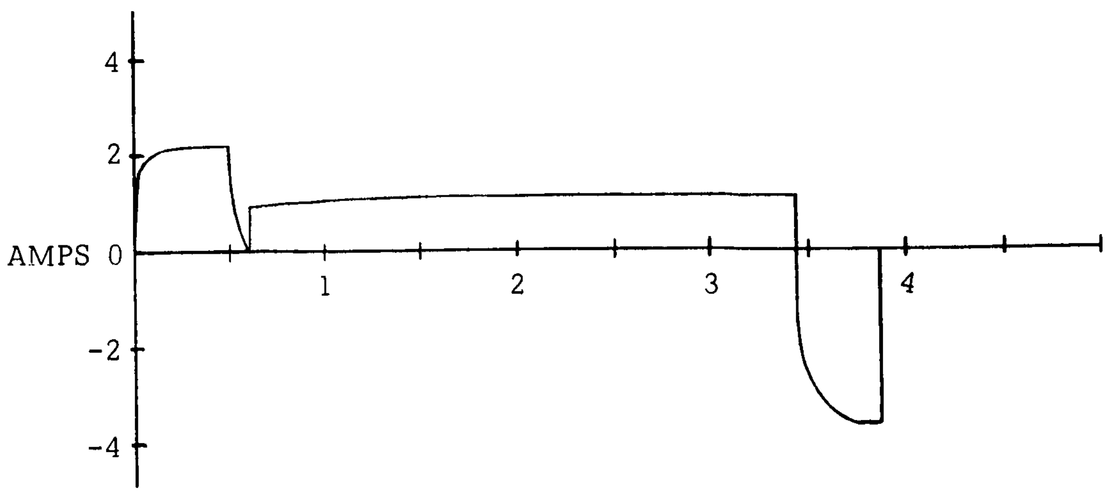
POWER MEASUREMENTS Figure 23



Packing Density, D	400 bpi
Repetition Rate, R	180 cps
Horiz. Cal.	0.5 ms/cm
Vert. Cal. (Top)	2.0 V/cm
Vert. Cal. (Bottom)	2.0 A/cm



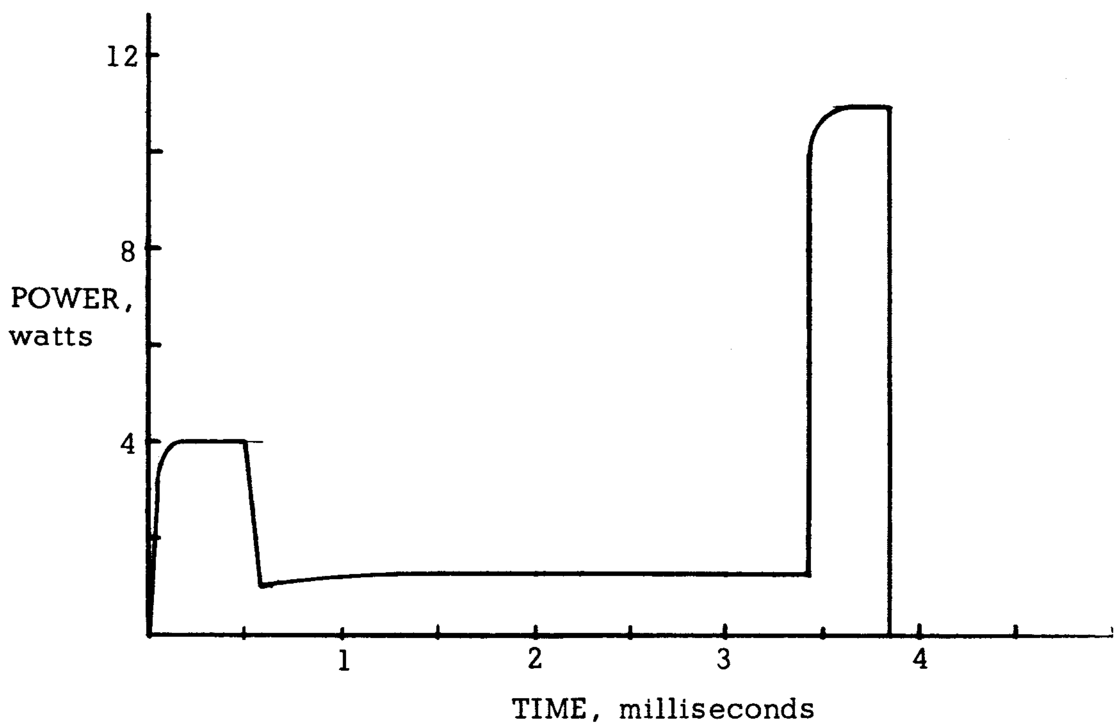
TIME, milliseconds



TIME, milliseconds

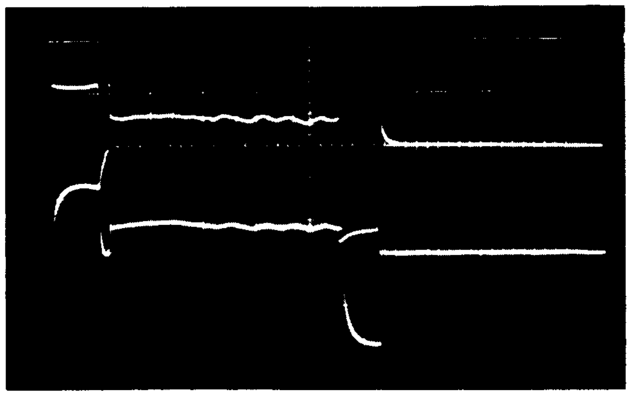
FIGURE 24

POWER MEASUREMENTS

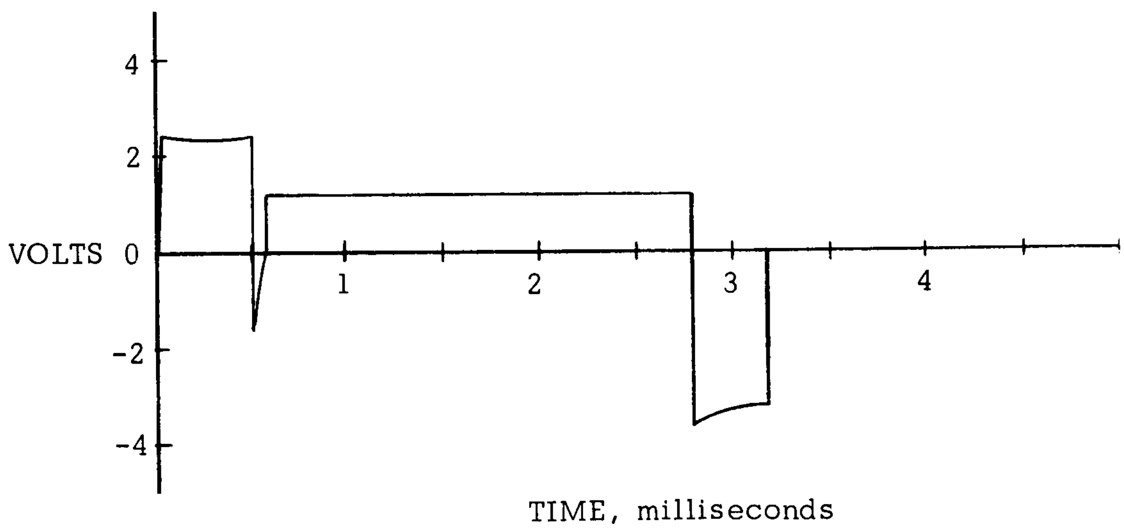


Packing Density, D	400 bpi
Repetition Rate, R	180 cps
Energy/cycle	0.011 joules/cycle
Average Power	1.90 watts
Peak Power	11.0 watts

POWER MEASUREMENTS Figure 25



Packing Density, D	400 bpi
Repetition Rate, R	18 cps
Horiz. Cal.	0.5 ms/cm
Vert. Cal. (Top)	2.0 V/cm
Vert. Cal. (Bottom)	2.0 A/cm



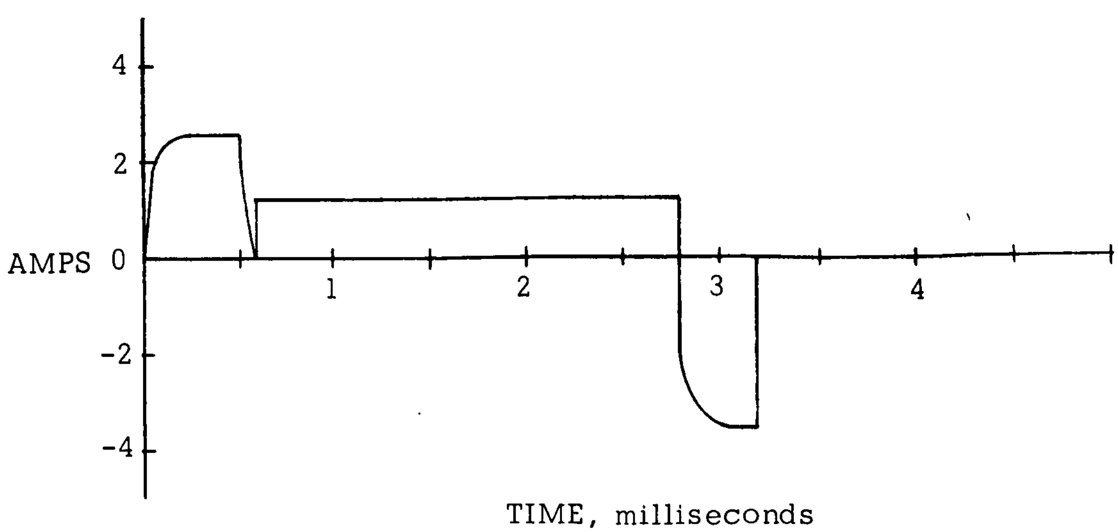
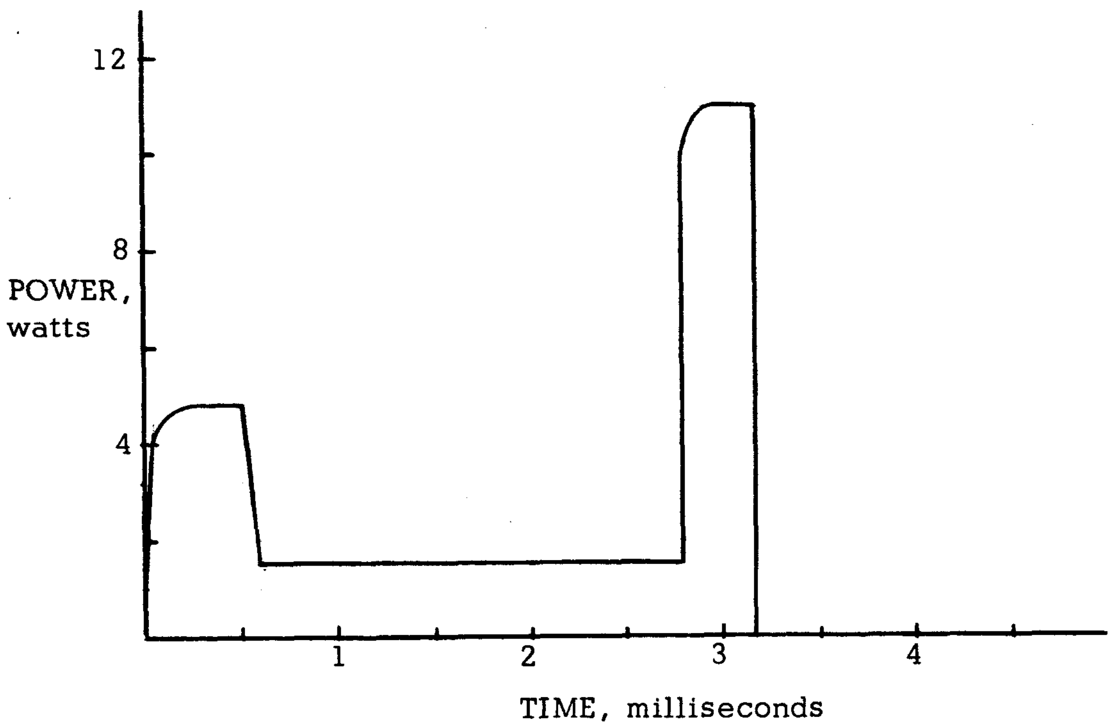


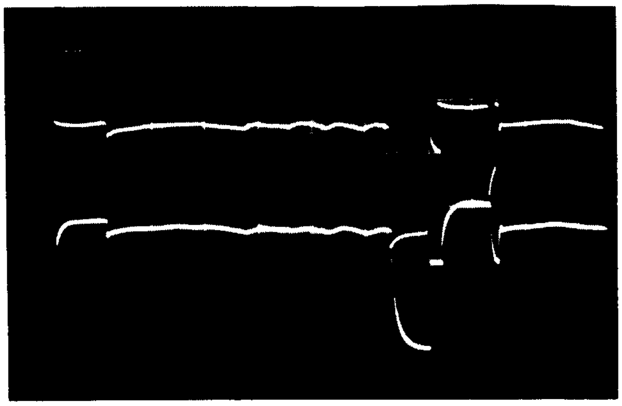
FIGURE 26

POWER MEASUREMENTS

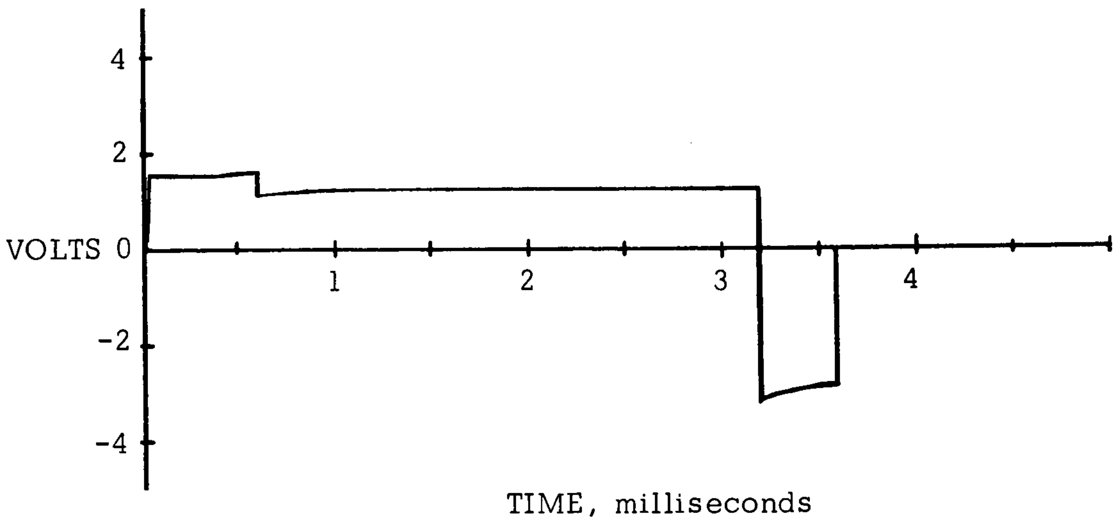


Packing Density, D	400 bpi
Repetition Rate, R	18 cps
Energy/cycle	0.010 joules/cycle
Average Power	0.18 watts
Peak Power	11.0 watts

POWER MEASUREMENTS Figure 27



Packing Density, D	500 bpi
Repetition Rate, R	260 cps
Horiz. Cal.	0.5 ms/cm
Vert. Cal. (Top)	2.0 V/cm
Vert. Cal. (Bottom)	2.0 A/cm



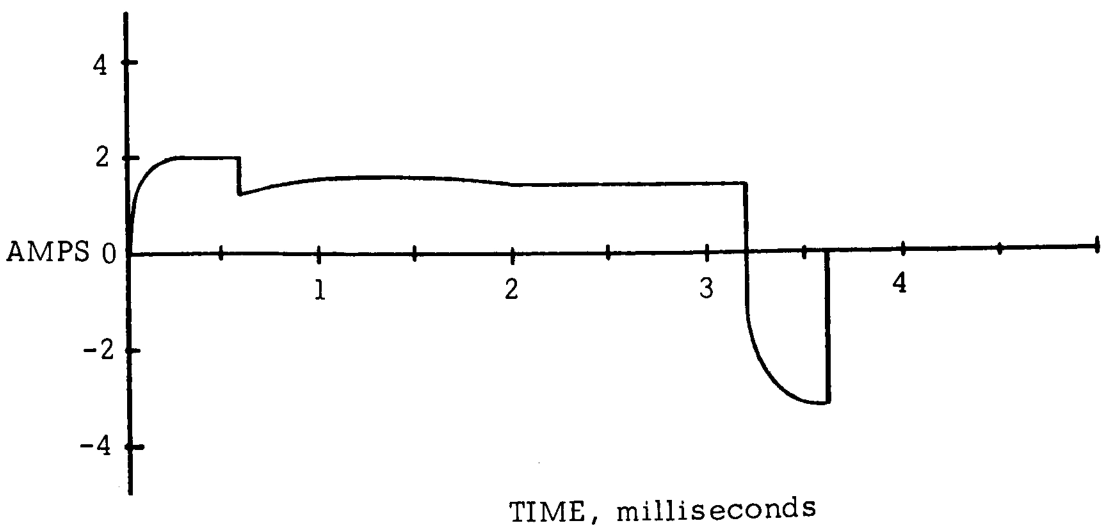
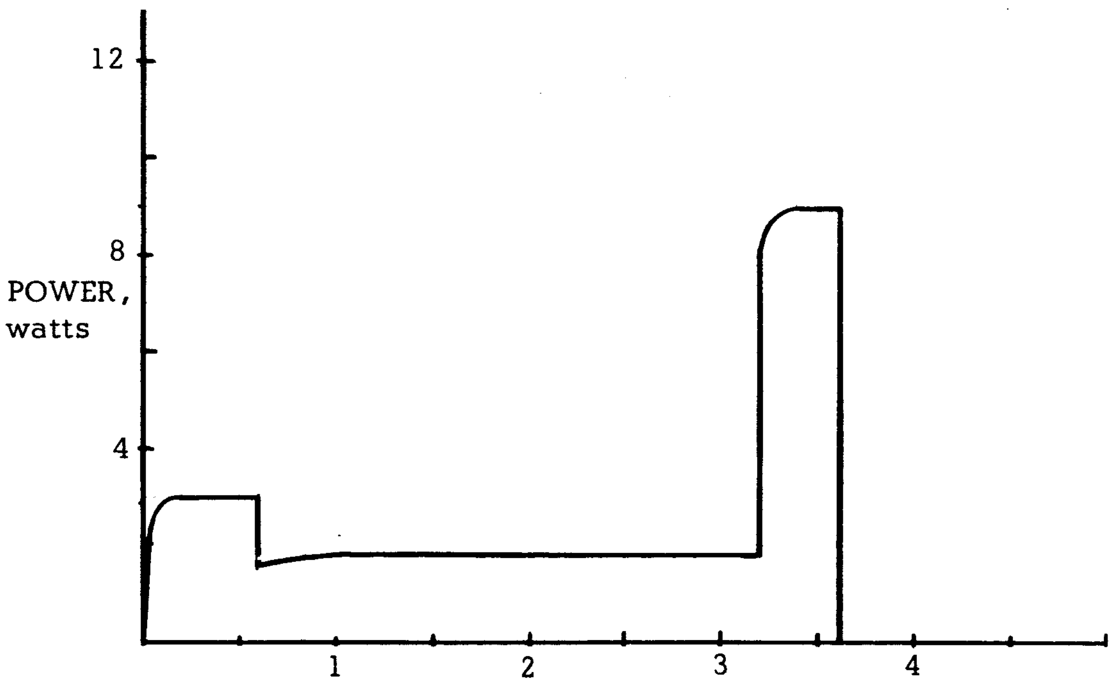


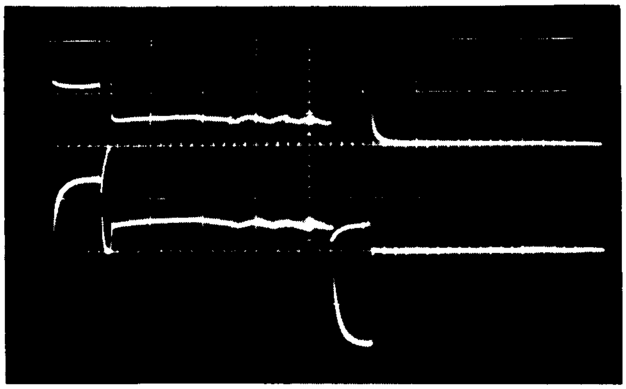
FIGURE 28

POWER MEASUREMENTS

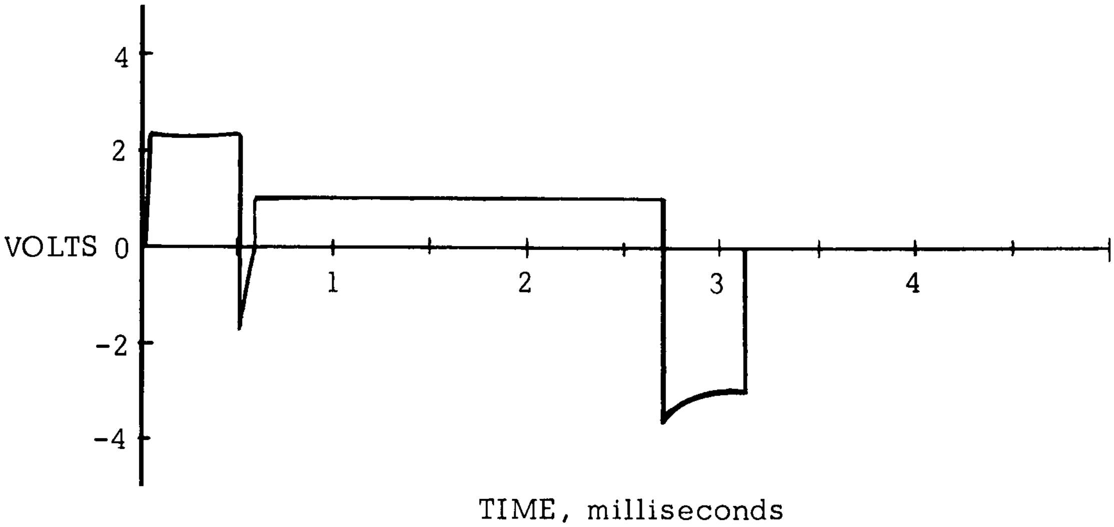


Packing Density, D	500 bpi
Repetition Rate, R	260 cps
Energy/cycle	.010 joules/cycle
Average Power	2.60 watts
Peak Power	9.0 watts

POWER MEASUREMENTS FIGURE 29



Packing Density, D	500 bpi
Repetition Rate, R	10 cps
Horiz. Cal.	0.5 ms/cm
Vert. Cal. (Top)	2.0 V/cm
Vert. Cal. (Bottom)	2.0 A/cm



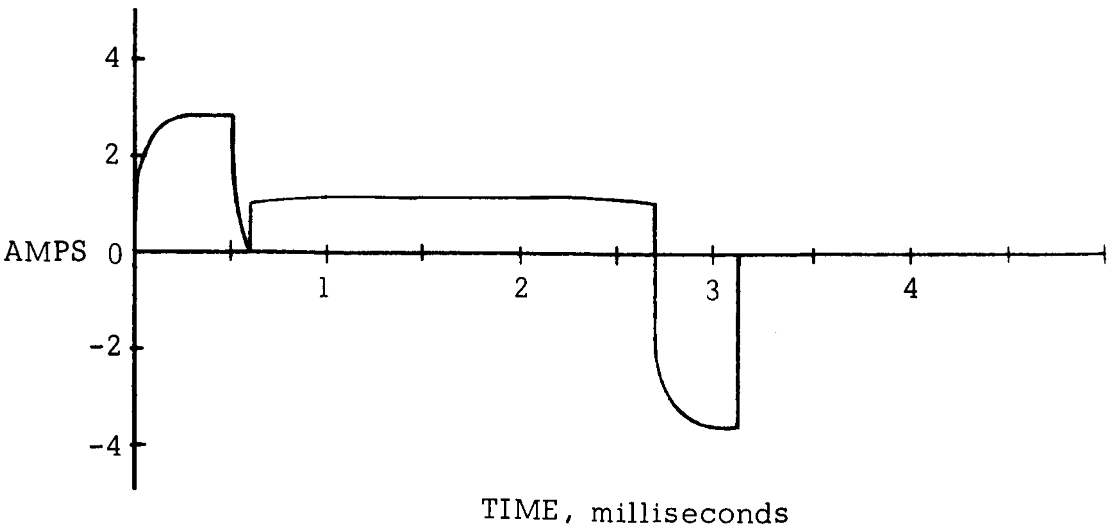
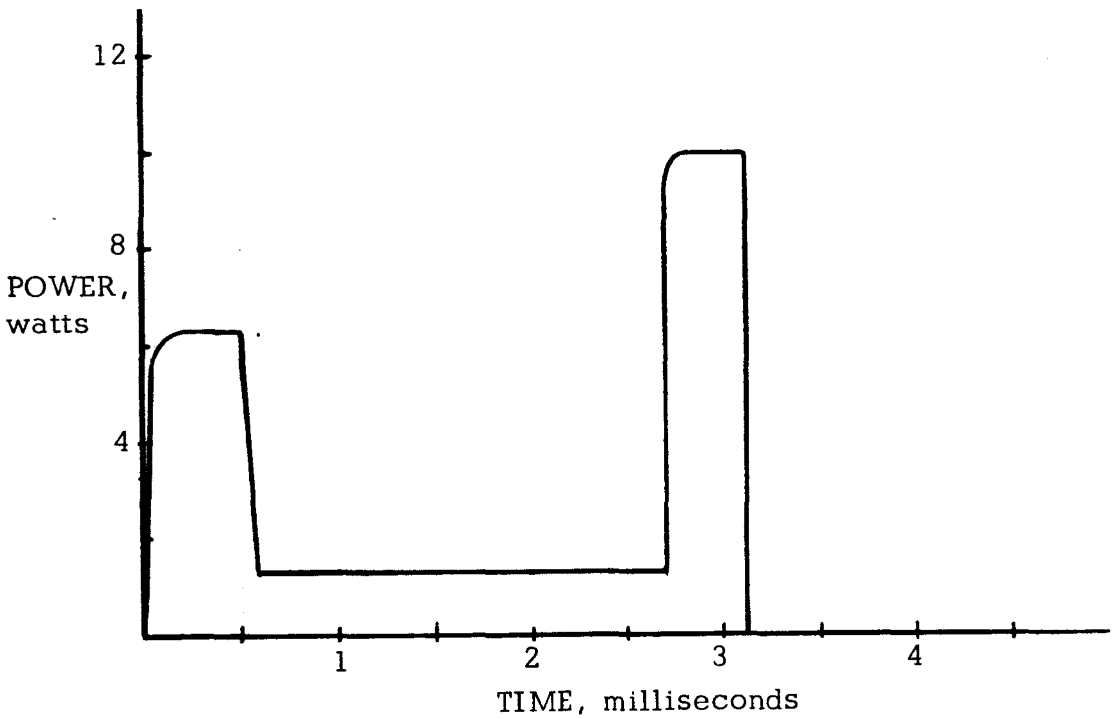


FIGURE 30

POWER MEASUREMENTS

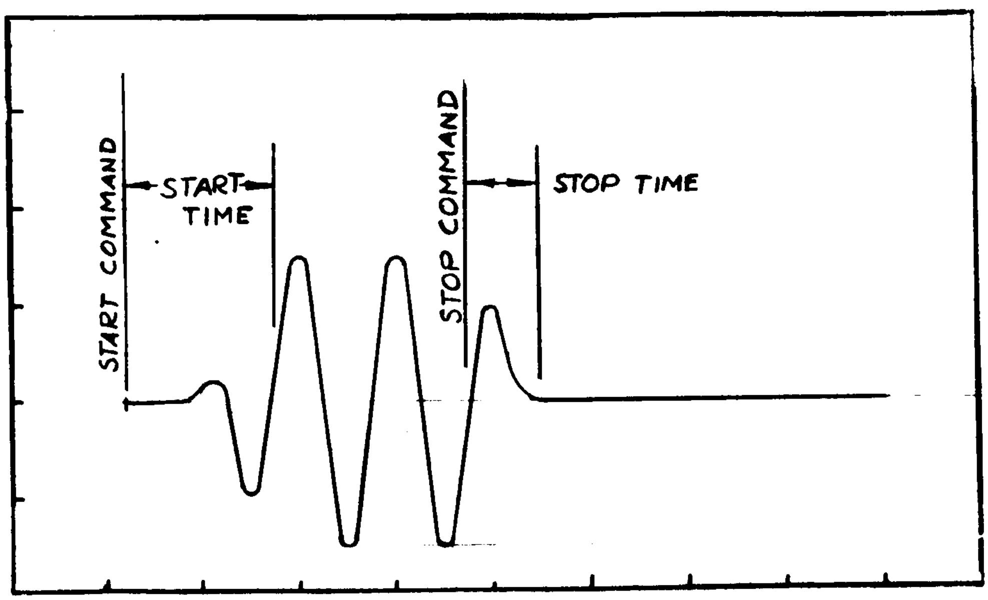


Packing Density, D	500 bpi
Repetition Rate, R	10 cps
Energy/cycle	.010 joules/cycle
Average Power	0.09 watts
Peak Power	10.0 watts

6.2 Start Time

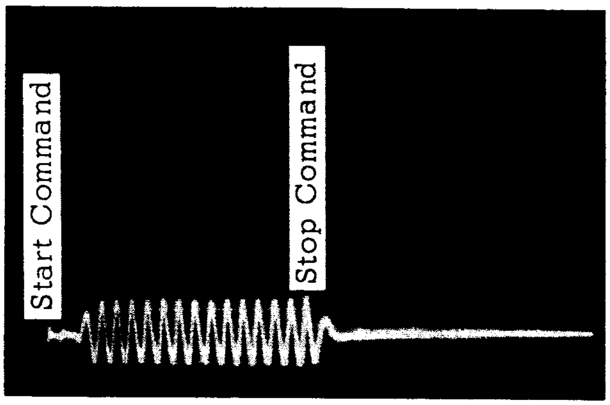
The following pictures show the signal of the control track. There is a 2 K.C. per inch carrier recorded on this track. The tape speed is one inch per second. A typical control track wave form is sketched here to show the different points on the wave form. When the motor is given a start command there is about a 1.0 millisecond delay before the capstan starts to move. It takes another 0.5 millisecond to get up to speed for a total of about 1.5 millisecond start time. The stop time is less than 0.5 millisecond. One of the interesting things is the long delay after the motor receives the start command before the tape starts to move. Although there was no further investigation into this because of the limited time in the contract, it is believed that the delay is caused by a mechanical displacement either in the shaft or the rubber on the capstan, most likely the rubber. The step necessary to investigate this would be to go to a thinner thickness of rubber.

FIGURE 31



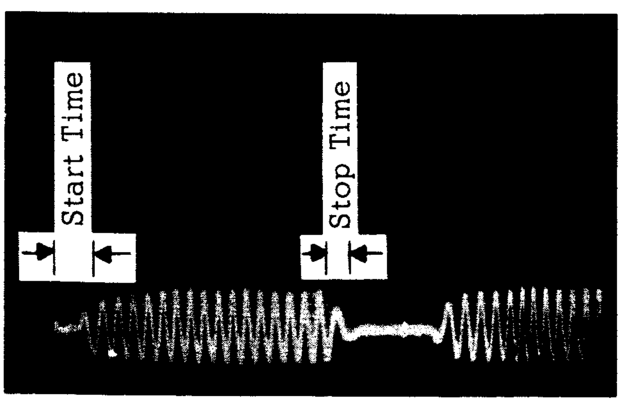
START/STOP PROFILE - for 100 bpi

FIGURE 32



Repetition Rate	7.5 cps
Horiz. Cal.	2.0 ms/cm

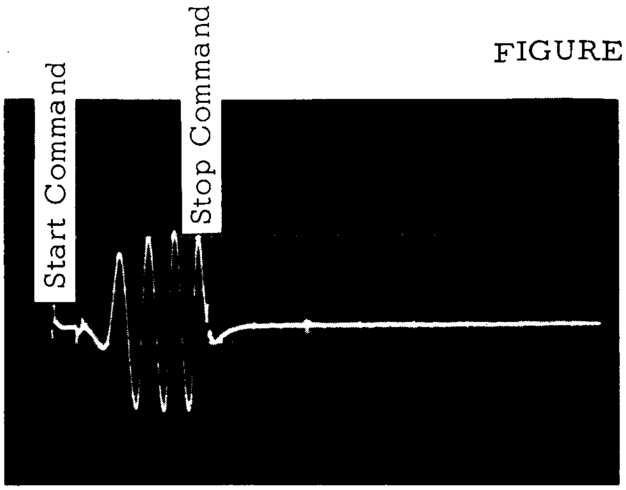
FIGURE 33



Repetition Rate	75 cps
Horiz. Cal.	2.0 ms/cm

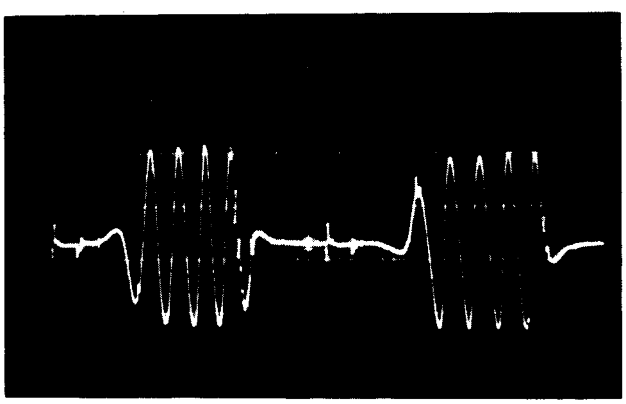
START/STOP PROFILE - for 400 bpi

FIGURE 34



Repetition Rate 18 cps
Horiz. Cal. 1.0 ms/cm

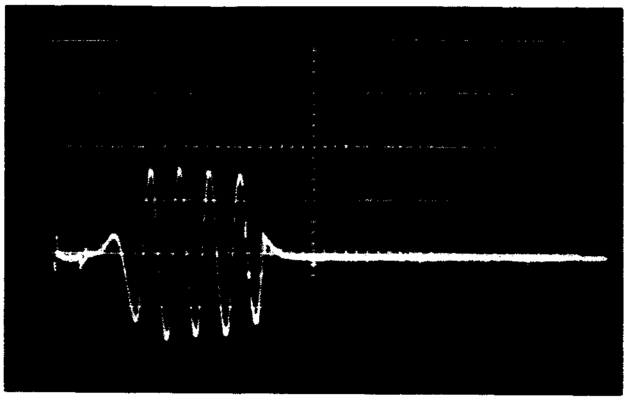
FIGURE 35



Repetition Rate 180 cps
Horiz. Cal. 1.0 ms/cm

START/STOP PROFILE - for 300 bpi

FIGURE 36



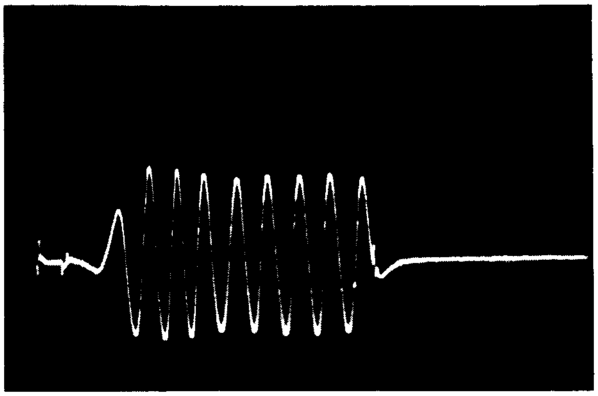
Repetition Rate	18 cps
Horiz. Cal.	1.0 ms/cm

FIGURE 37

Repetition Rate	180 cps
Horiz. Cal.	1.0 ms/cm

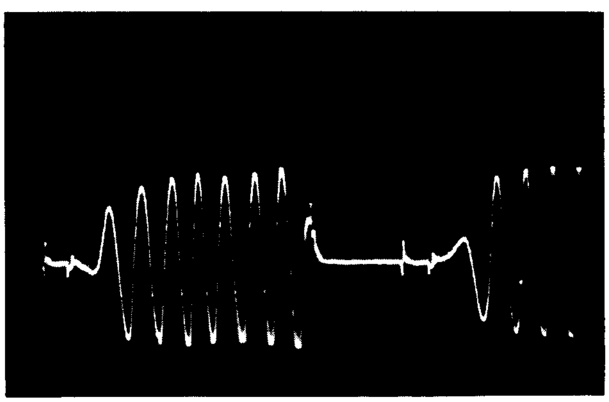
START/STOP PROFILE - for 200 bpi

FIGURE 38



Repetition Rate	14 cps
Horiz. Cal.	1.0 ms/cm

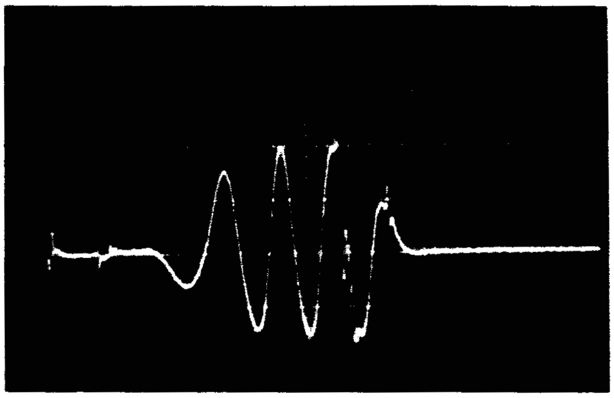
FIGURE 39



Repetition Rate	140 cps
Horiz. Cal.	1.0 ms/cm

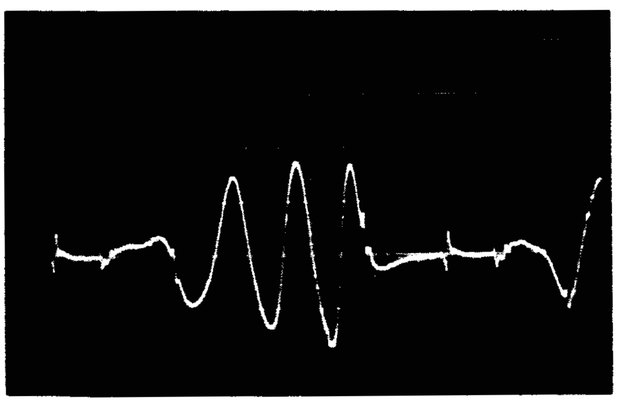
START/STOP PROFILE - for 500 bpi

FIGURE 40



Repetition Rate	26 cps
Horiz. Cal.	0.5 ms/cm

FIGURE 41



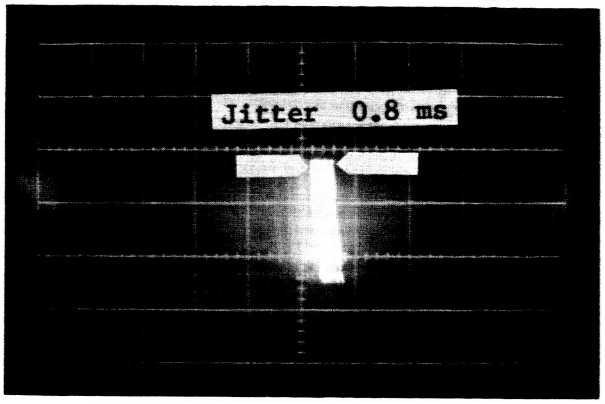
Repetition Rate	260 cps
Horiz. Cal.	0.5 ms/cm

Jitter

The following pictures show the jitter for the different packing density and repetition rate. Jitter being defined as time base uniformity of bit spacing on one data track during reproduce mode at a constant bit rate command. Picture exposure time is five seconds. Scope is synchronized on the command signal. Tape speed is one inch per second.

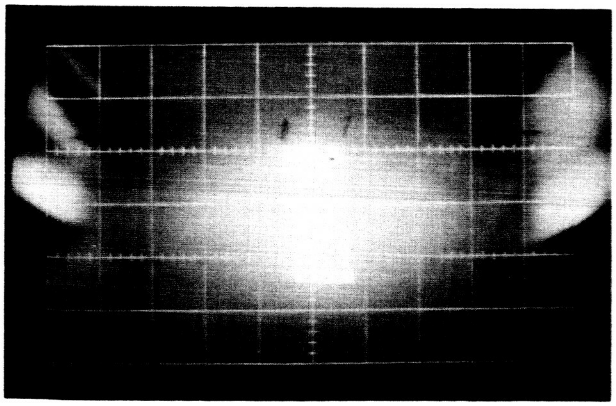
JITTER MEASUREMENTS - for 100 bpi

FIGURE 42



Repetition Rate	7 cps
Horiz. Cal.	2.0 ms/cm
Jitter	0.8 ms

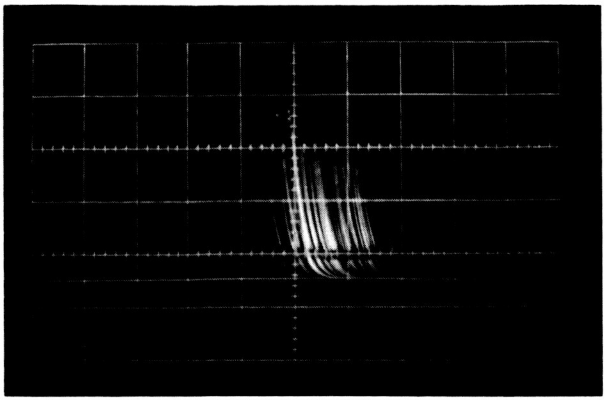
FIGURE 43



Repetition Rate	70 cps
Horiz. Cal.	2.0 ms/cm
Jitter	2.4 ms

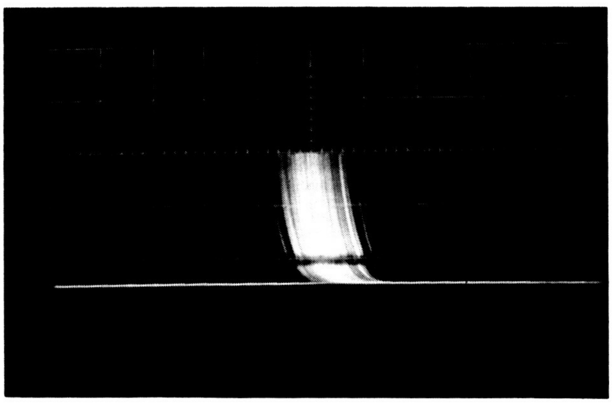
JITTER MEASUREMENTS - for 200 bpi

FIGURE 44



Repetition Rate	15 cps
Horiz. Cal.	1 ms/cm
Jitter	1.6 ms

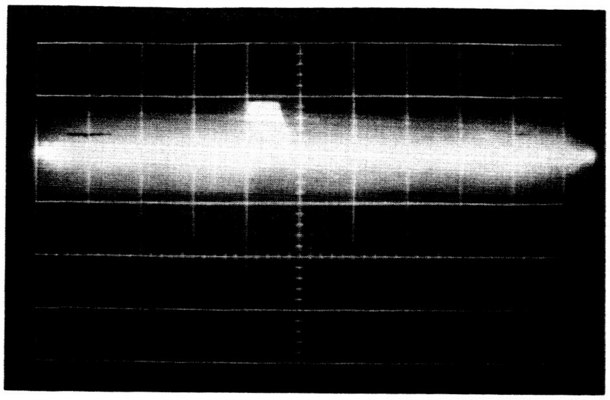
FIGURE 45



Repetition Rate	150 cps
Horiz. Cal.	1 ms/cm
Jitter	1.2 ms

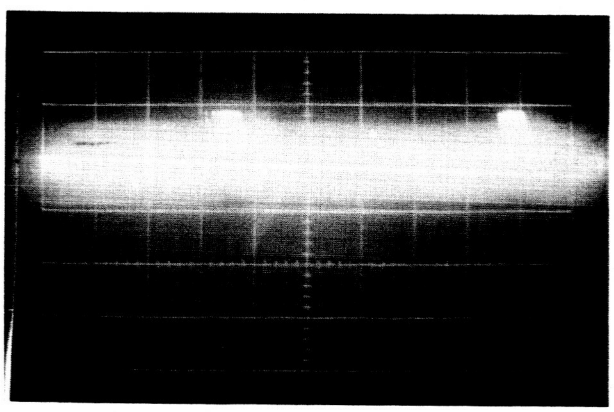
JITTER MEASUREMENTS - for 300 bpi

FIGURE 46



Repetition Rate	18 cps
Horiz. Cal.	1.0 ms/cm
Jitter	0.6 ms

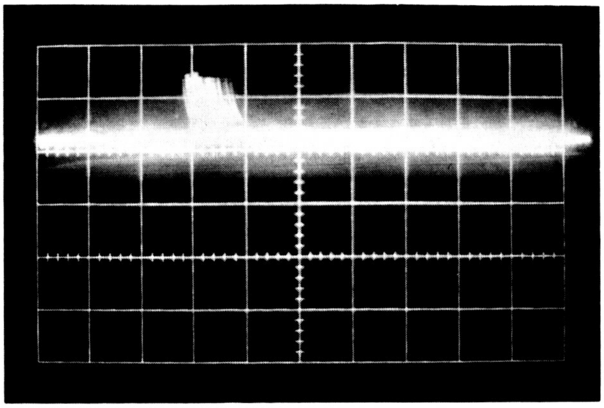
FIGURE 47



Repetition Rate	180 cps
Horiz. Cal.	1.0 ms/cm
Jitter	0.3 ms

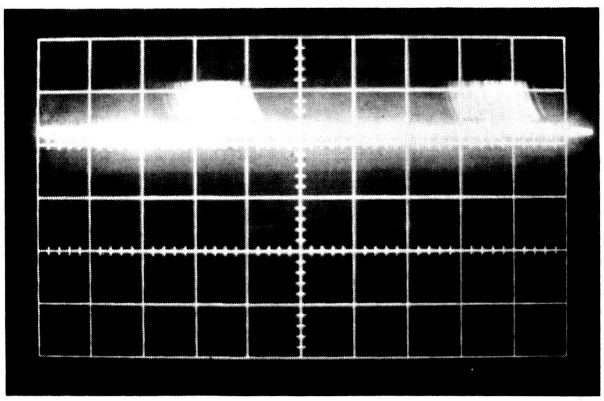
JITTER MEASUREMENTS - for 400 bpi

FIGURE 48



Repetition Rate	26 cps
Horiz. Cal.	1.0 ms/cm
Jitter	1.0 ms

FIGURE 49



Repetition Rate	180 cps
Horiz. Cal.	1.0 ms/cm
Jitter	1.5 ms

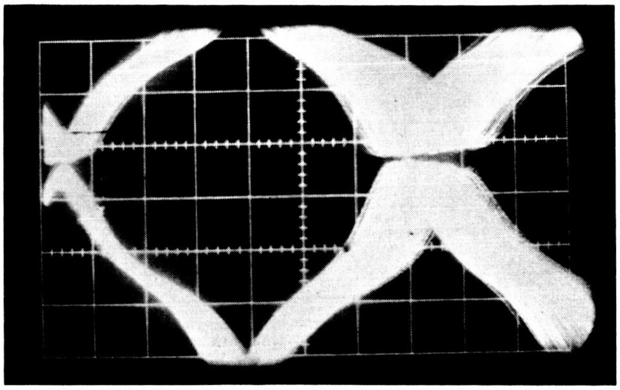
Skew Measurements (Interchannel Time Displacement Error, ITDE)

The following skew measurements were taken between Channel 2 and 3 at a tape speed of one ips, packing density 500 bpi. The channels are identified as follows:

Channel 1 (Top)
" 2
" 3
" 4

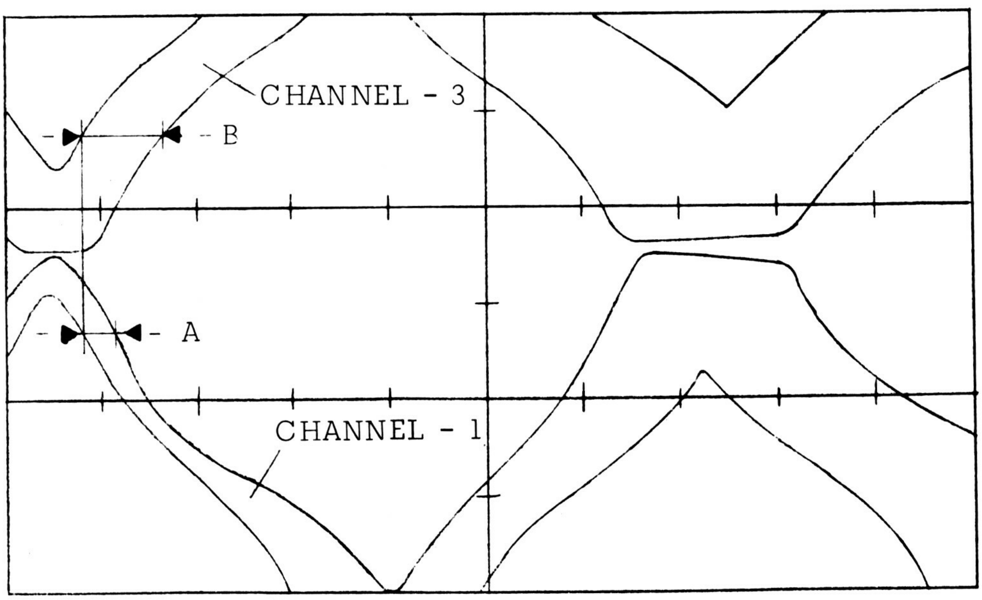
SKEW MEASUREMENTS

FIGURE 50



Horiz. Cal.	0.5 ms/cm
Skew, 1 ips	0.25 ms

FIGURE 51



Scope synched on lower signal. A equals velocity variation of the tape. B minus A equals time difference between channels.

7.0 TABULATED RESULTS & GRAPHS

7.1 Power (at 1 ips)

Packing Density (bpi)	Rep. Rate (cps)	Energy per cycle (J/cycle)	Average Power (Watts)	Peak Power (Watts)	Rep. Rate (cps)	Energy per cycle (J/cycle)	Average Power (Watts)	Peak Power (Watts)
100	70	0.012	0.80	5.2	7	0.018	0.13	6.0
200	150	0.008	1.21	5.6	15	0.008	0.12	6.2
300	180	0.010	1.86	9.0	18	0.011	0.19	8.6
400	180	0.011	1.90	11.0	18	0.010	0.18	11.0
500	260	0.010	2.60	9.0	10	0.010	0.09	10.0

7.2 Skew (at 1 ips) - less than 0.25 ms

7.3 Start Time - less than 1.5 ms

Stop Time - less than 1.0 ms

7.4 Jitter (at 1 ips)

Packing Density (bpi)	Rep. Rate (cps)	Jitter (ms)	Rep. Rate (cps)	Jitter (ms)
100	70	0.8	7	2.4
200	150	1.2	15	1.6
300	180	0.3	18	0.6
400	180	1.5	26	1.0

FIGURE 52

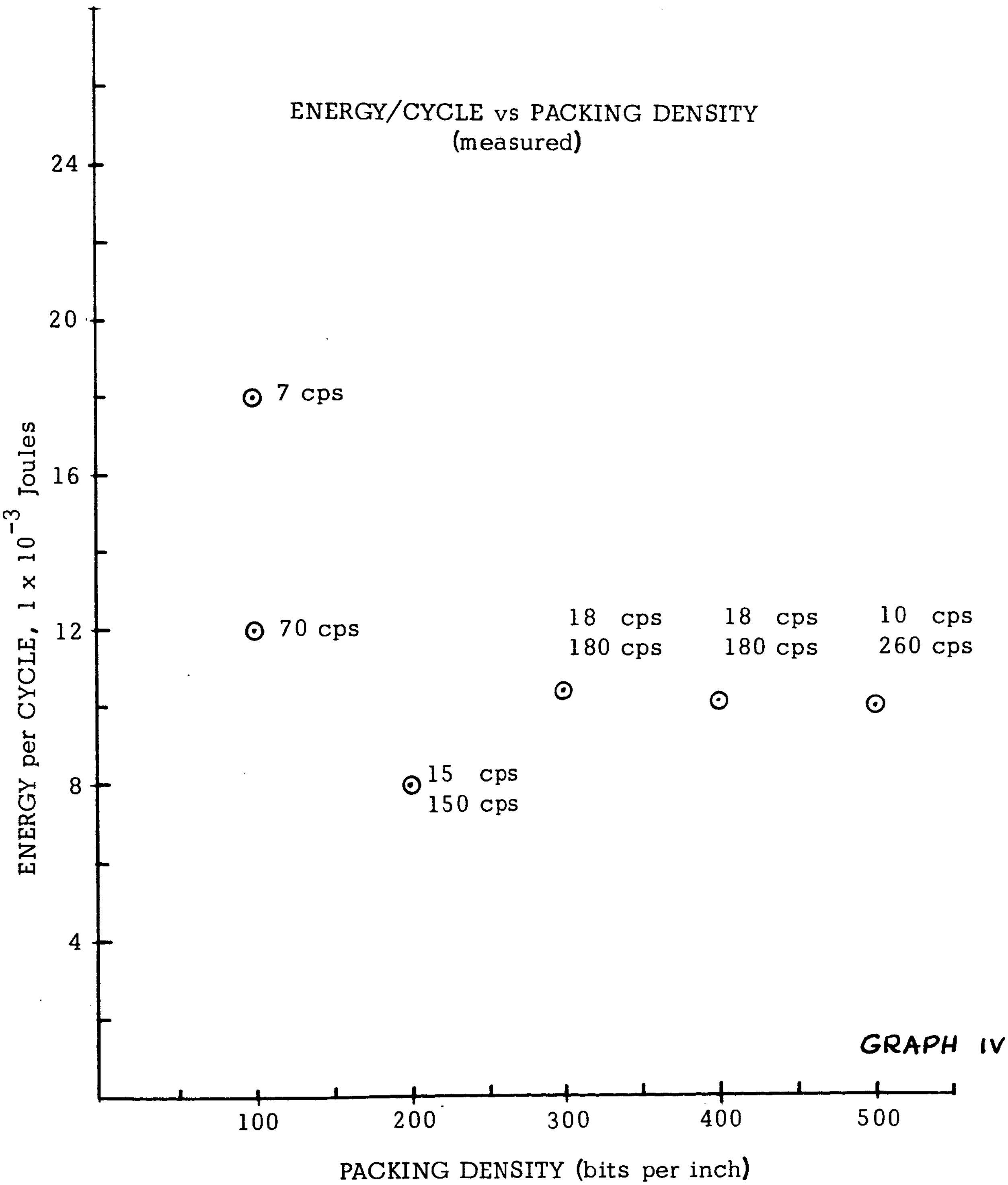

ENERGY/CYCLE vs PACKING DENSITY
(measured)
ENERGY per CYCLE, 1 x 10^-3 Joules
24
20
16
12
8
4
7 cps
70 cps
15 cps
150 cps
18 cps
180 cps
18 cps
180 cps
10 cps
260 cps
GRAPH IV
100
200
300
400
500
PACKING DENSITY (bits per inch)

FIGURE 53

POWER vs STEPPING RATE
(measured)

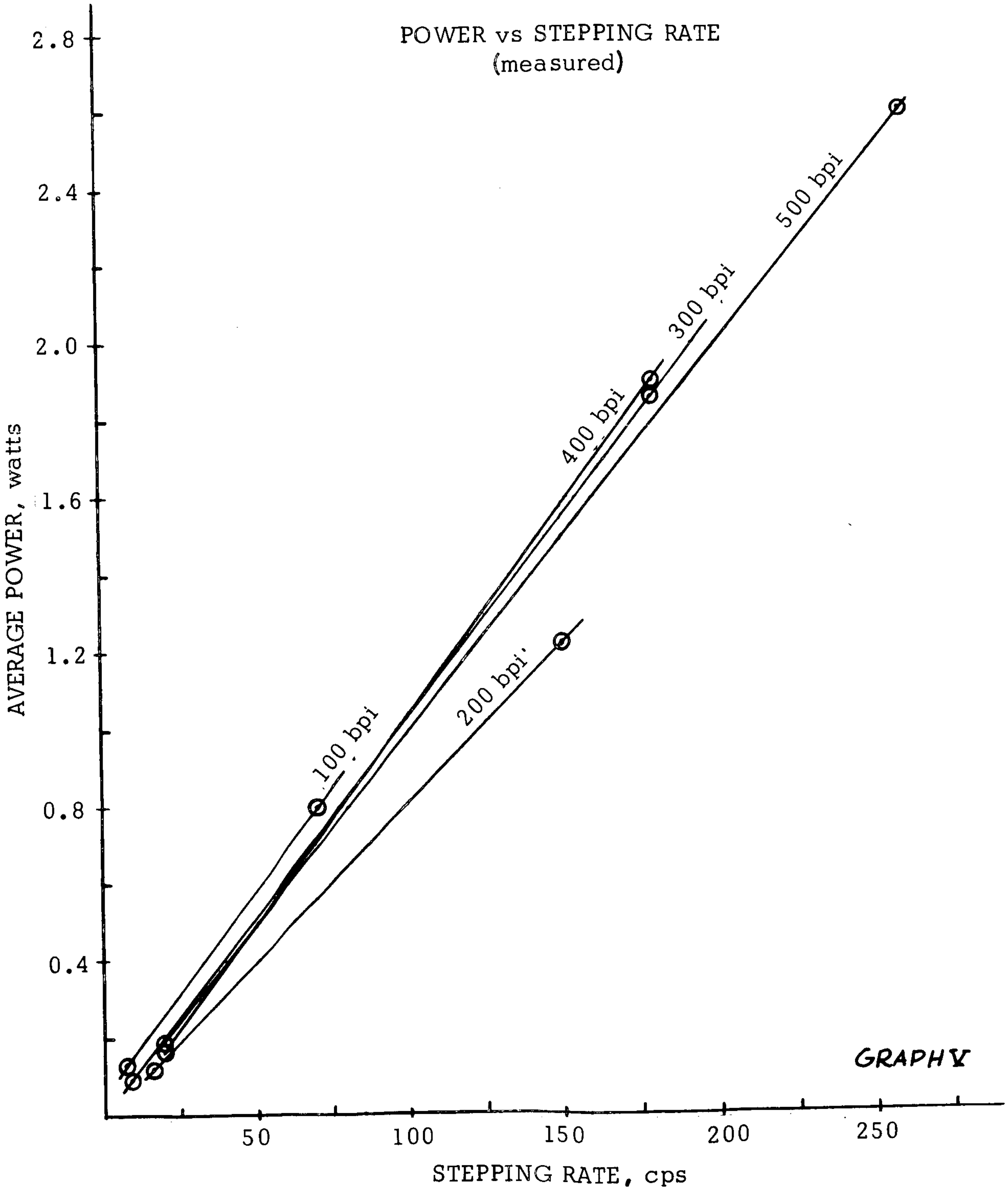
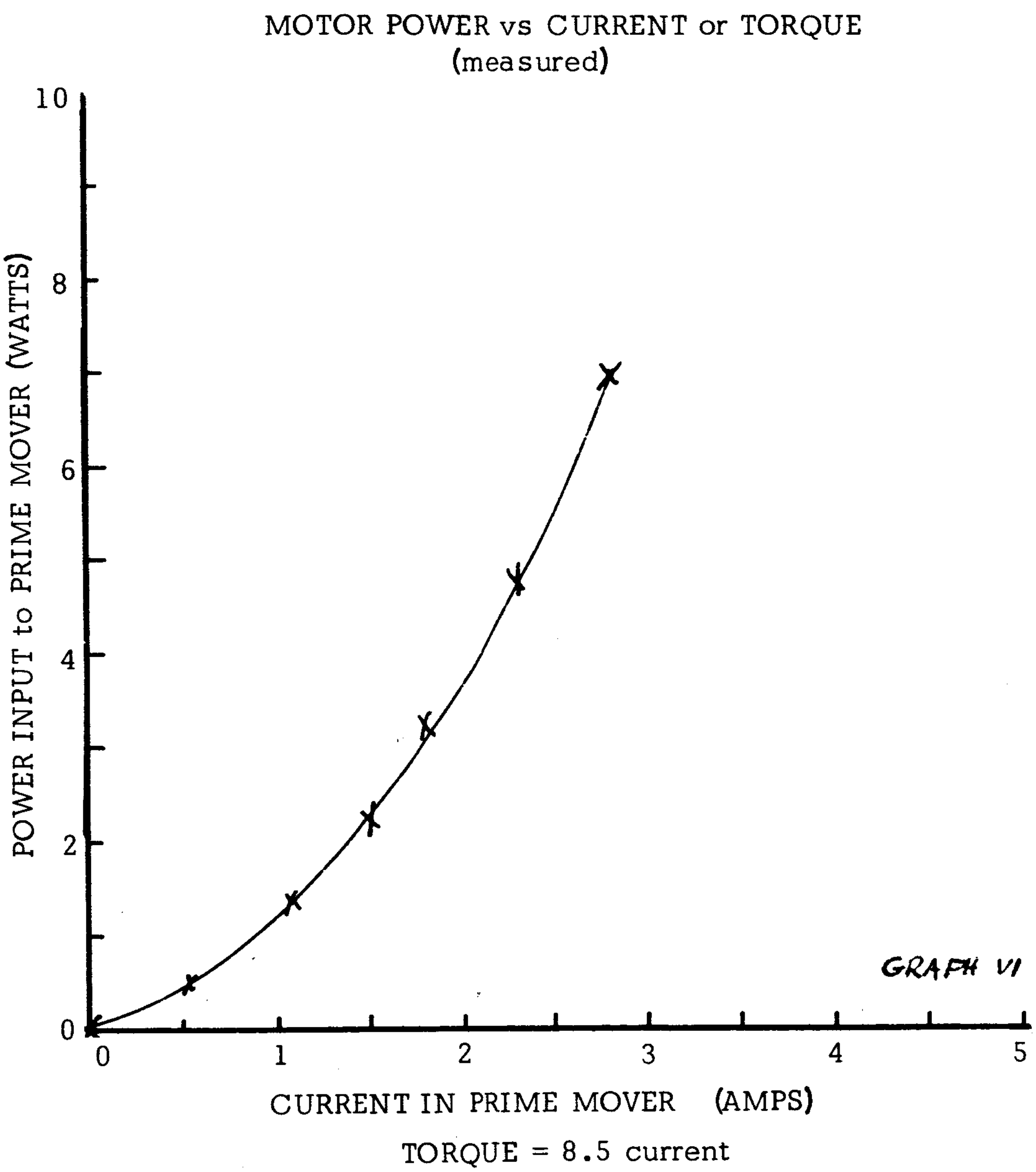


FIGURE 54



modified PC 368 motor

FIGURE 55

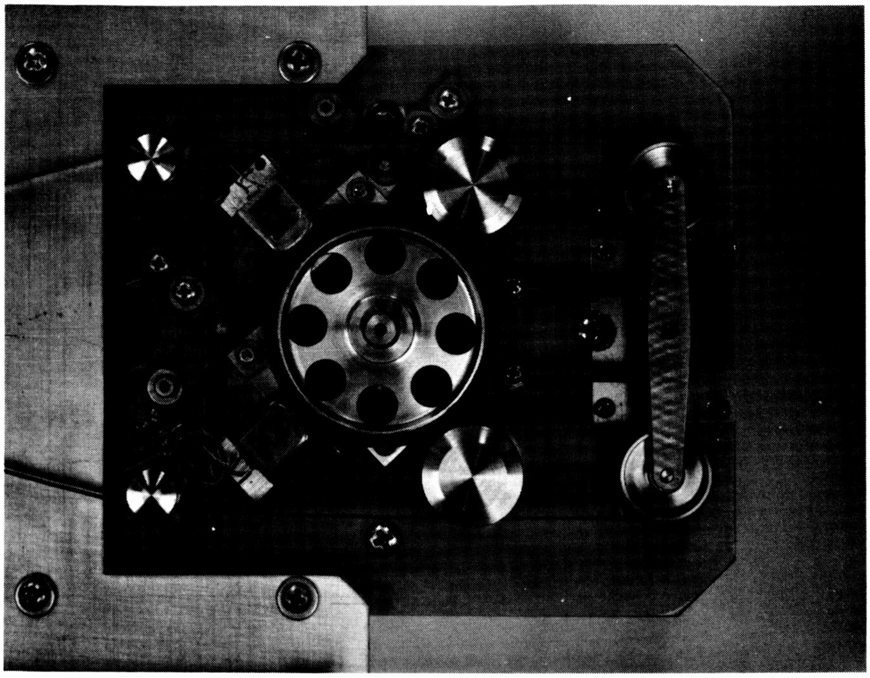


FIGURE 56

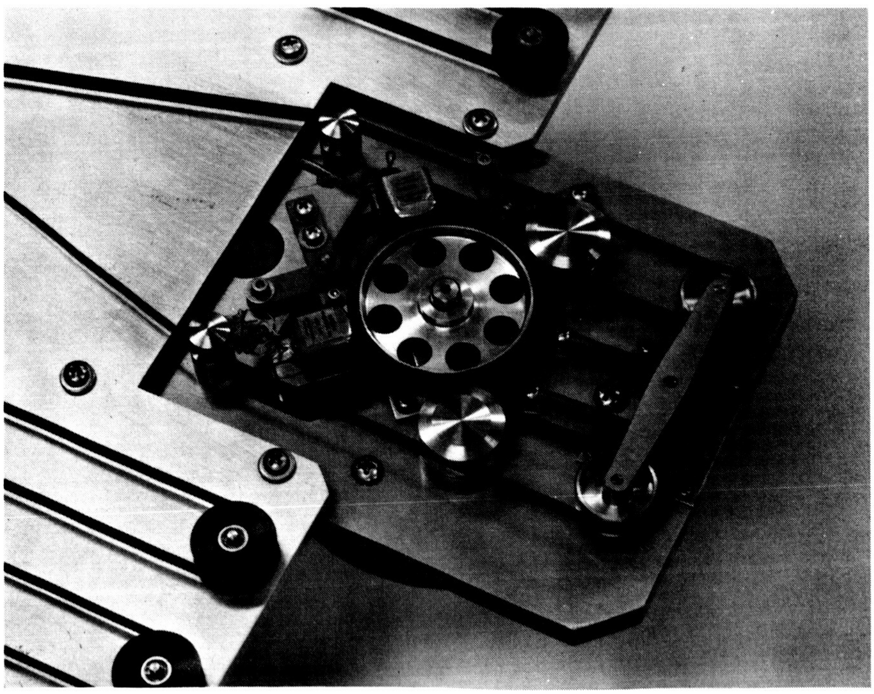


FIGURE 57

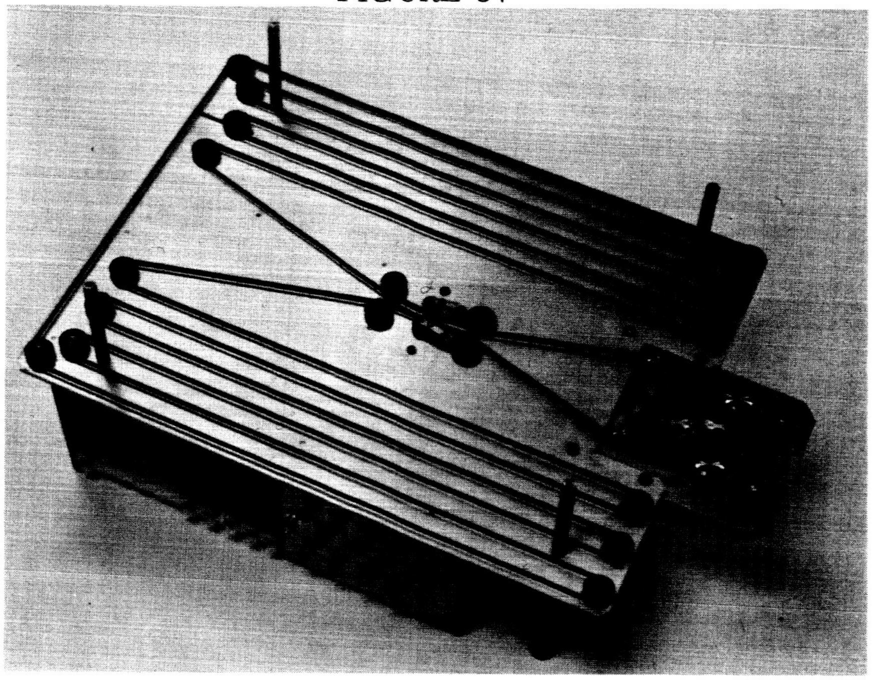
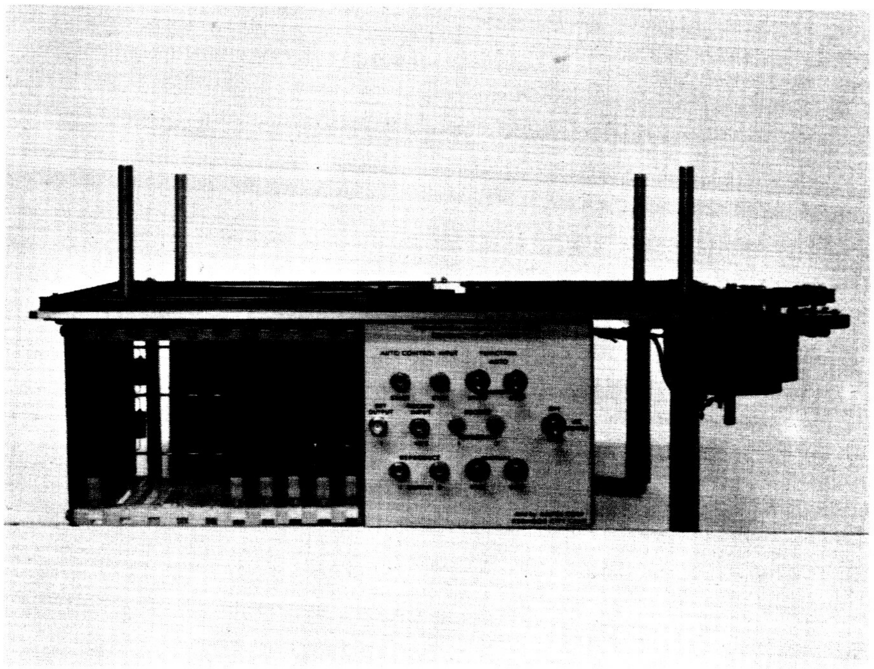


FIGURE 58



SUMMARY

This report concludes the work for J. P. L. to build one experimental model of an Incremental Magnetic Tape Drive Mechanism. In this eight months study contract, Ampex successfully met the specification objectives and developed an incrementor which is capable of incrementing tape of packing densities up to 500 bits per inch at stepping rates of 0-260 cps with low power consumption (less than 5 watts average) into the prime mover. Test results on the incrementor are recorded in this report.

The experimental model is a versatile laboratory unit that contains all the electronics to record and reproduce signal at any combination of packing density and stepping rate so that further experimental studies can be made with no modification.

One of the important results of the tests was the relationship of power versus repetition rate and packing density. Graph **V** shows a plot of this data. Note that all curves fall in the same general area which indicates that the power is more a function of repetition rate and the influence packing density on power is small in comparison in the range of 100 - 500 bpi. The reason for this discrepancy of these experimental results with the analytical result can be explained by the fact that the power is consumed mostly in the starting and stopping of the incrementor. The steady state power is very small. This is easily seen in the graphs on power measurements.

The present breadboard power supply is power limited. This limits the power available to the motor in the start/stop periods. Slight modifications can be made to increase the output if future testing calls for this need. The breadboard is capable of stepping rates up to 280 cps at 500 bpi before there is crowding due to the start/stop transient time. Some work remains to be done in this area.

Since completion of the design, the incrementor has been operating in the incrementing mode without failure for 1000 hours.

In consideration of power consumption, further reduction can be achieved by utilizing a data storage buffer in association with this incrementor. Power is reduced in direct proportion to the storage capacity.

Ampex recommends that a study program for a complete Engineering Model of a flyable transport be considered as the next program phase. The model would enable environmental evaluations of the transporting mechanism including the reeling. Space for miniaturized electronics would be provided but miniaturization of all electronics could be done in the final phase. In this second phase, the major work would be involved in weight reduction of the motor, if considered necessary, and the design of an adequate reeling system.

REFERENCES

1. Chai, Steven, "Evaluation of Performance Characteristics of Magnetic Clutch-Brake System", Tech. Note # 436-2, Ampex Computor Products, June 24, 1963.

2. Kleist, R. A. "TM-7 Advance Development" Ampex TR63-003, April, 1963.

APPENDIX I

OPERATING INSTRUCTION

Equipment Necessary
Audio oscillator (Hewitt Packard 200 CD or Equivalent)
Oscilloscope

To Operate:

1. Power switch to "off" position.

2. Function switch to manual.

3. Record switches to reproduce.

4. Connect power cord to 117 VAC 60 cps.

5. Inspect top plate to insure that the tape is properly threaded; that there are no obstructions in tape path; and pinch rollers are properly engaged.

6. Turn power switch to "on" position.

7. To make tape move press manual forward buttons. Tape will move forward at approximately one inch per second. The isolating arm will be kept approximately in a neutral position by the loop servo.

8. To stop, press manual "stop" button.

Incremental Reproduce

1. Audio oscillator connected to start input. Frequency set to repetition rate desired.
2. Power switches "on".
3. Jumper wire from detector output to stop input.
4. Record-reproduce switches to reproduce position.
5. Function switches to "auto" position.

Azimuth and Tilt Adjustment

Azimuth and Tilt adjustment are provided in the head assembly. Additional adjustment should not be necessary, unless heads are changed.

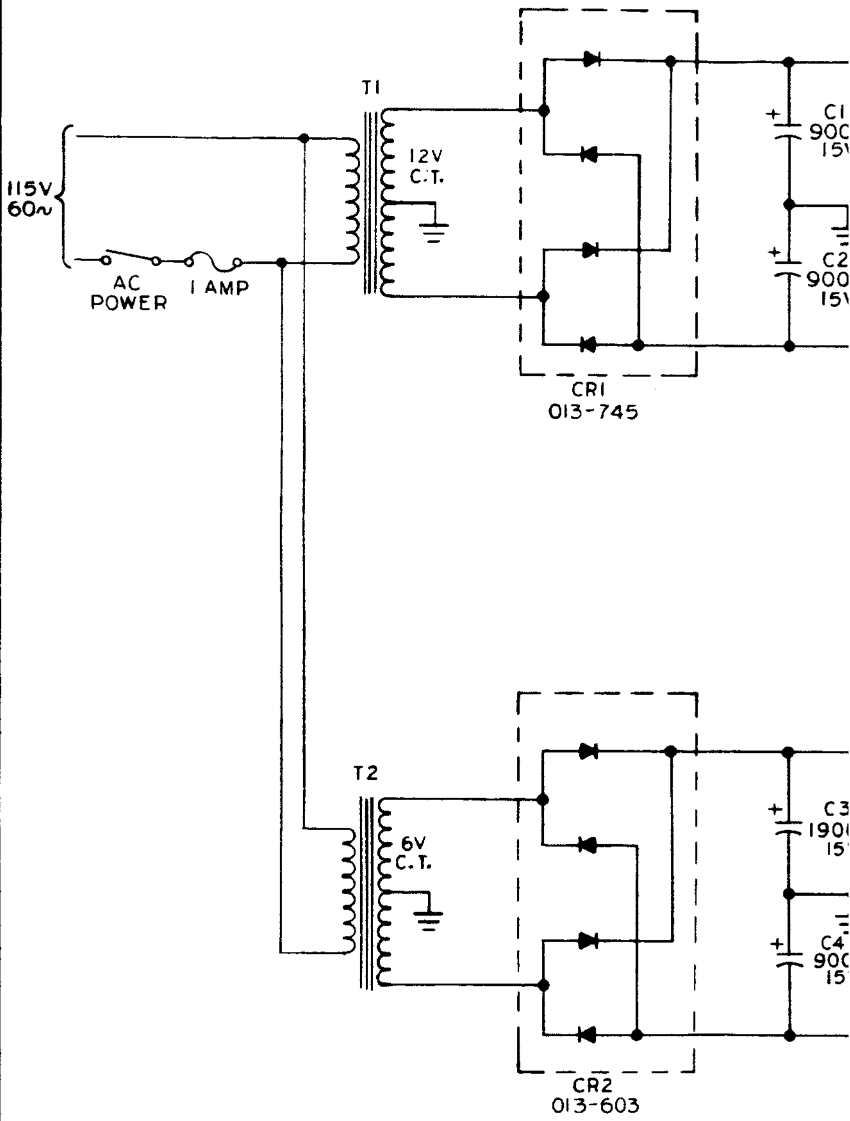
To Record:

1. Attach audio oscillator (20 volts RMS) to record input connector. 50 cps will give 100 bits per inch NRZ packing density.
2. Record-reproduce switches to record position.
3. Function switches to manual.
4. Press manual forward button.
5. About two minutes is required to record one complete pass. No erasure is necessary since saturation recording is used.
6. When recording is complete press manual stop button.

7. Turn amplitude of oscillator down and remove connections to record input.

8. Turn record-reproduce switches to reproduce position.

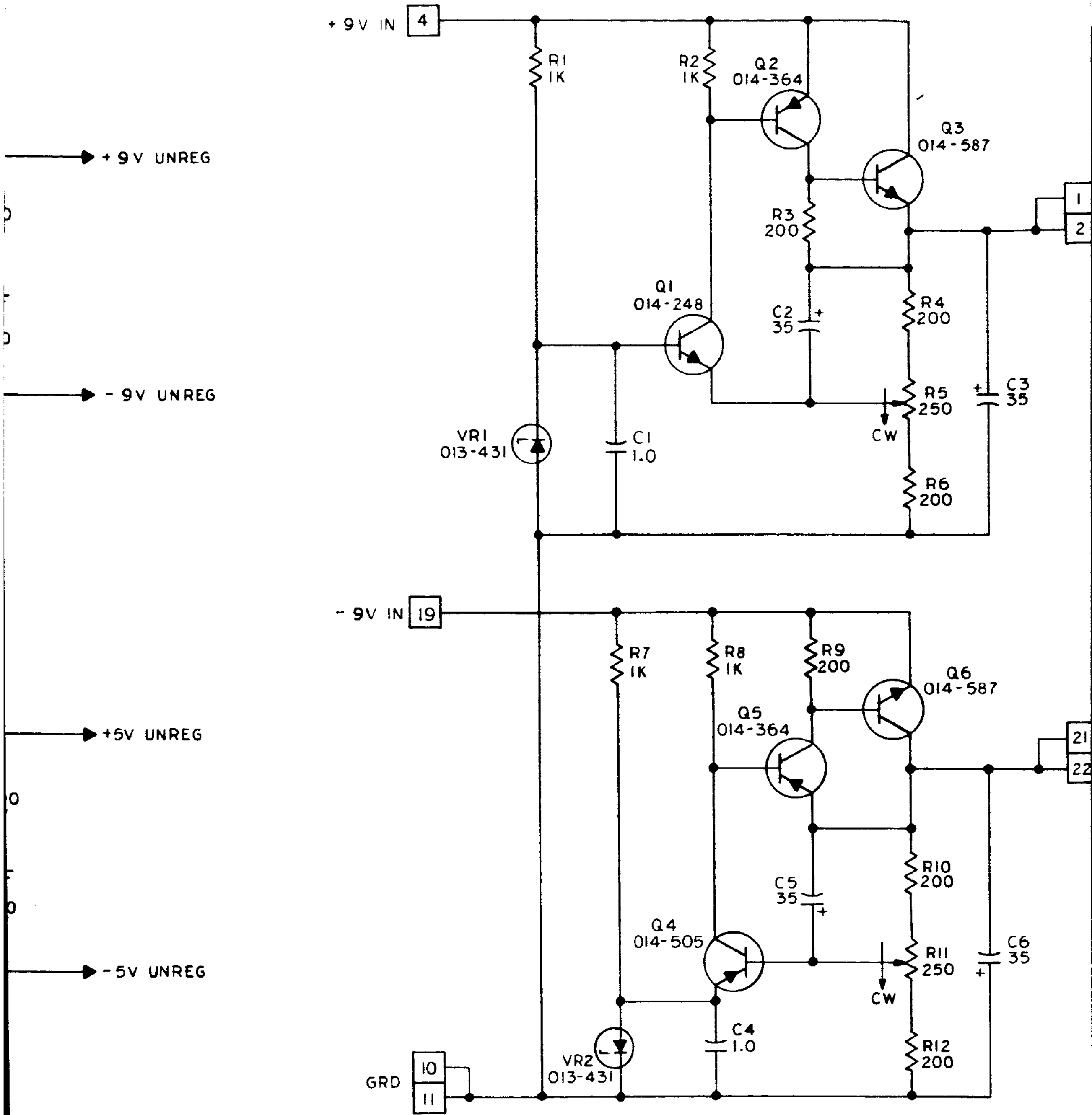
9. Connect oscilloscope to preamp output connectors. Press manual forward button to verify on the oscilloscope that the data was properly recorded.



NOTES: UNLESS OTHERWISE SPECIFIED

1. ALL RESISTOR VALUES ARE IN OHMS, 1/4W, 5%
2. ALL CAPACITOR VALUES ARE IN MICROFARADS

6 5 4



QTY RE
UNL
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2

3 | 2 | CODE: S | 1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

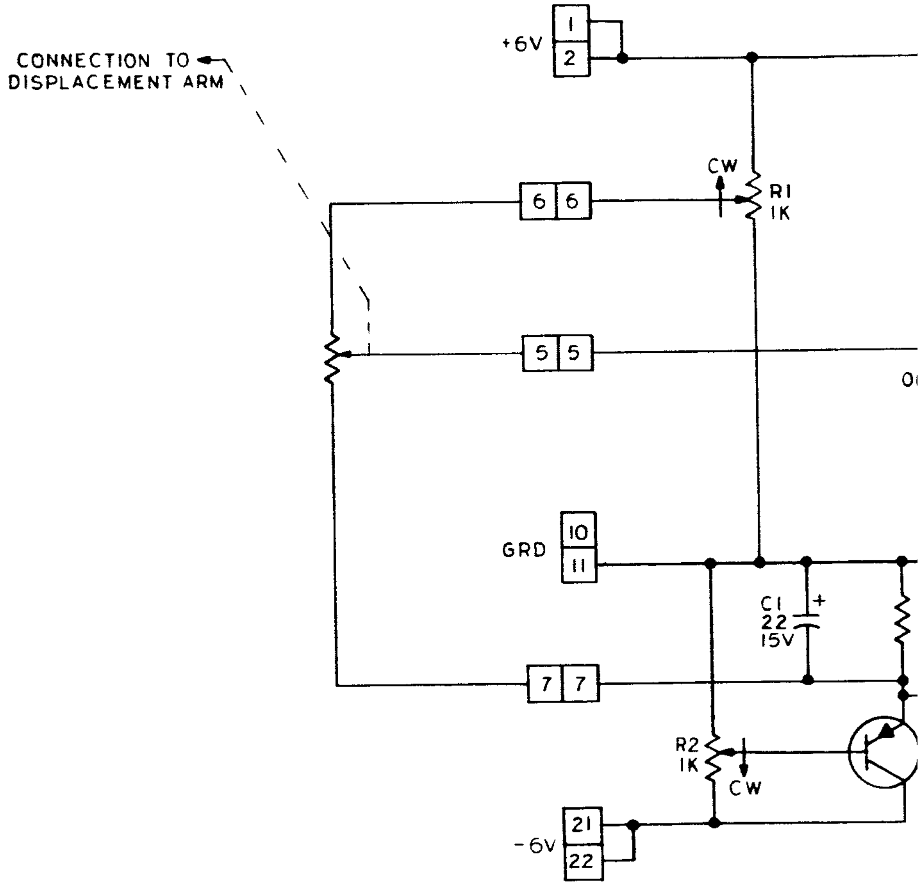
+6V

-6V

3

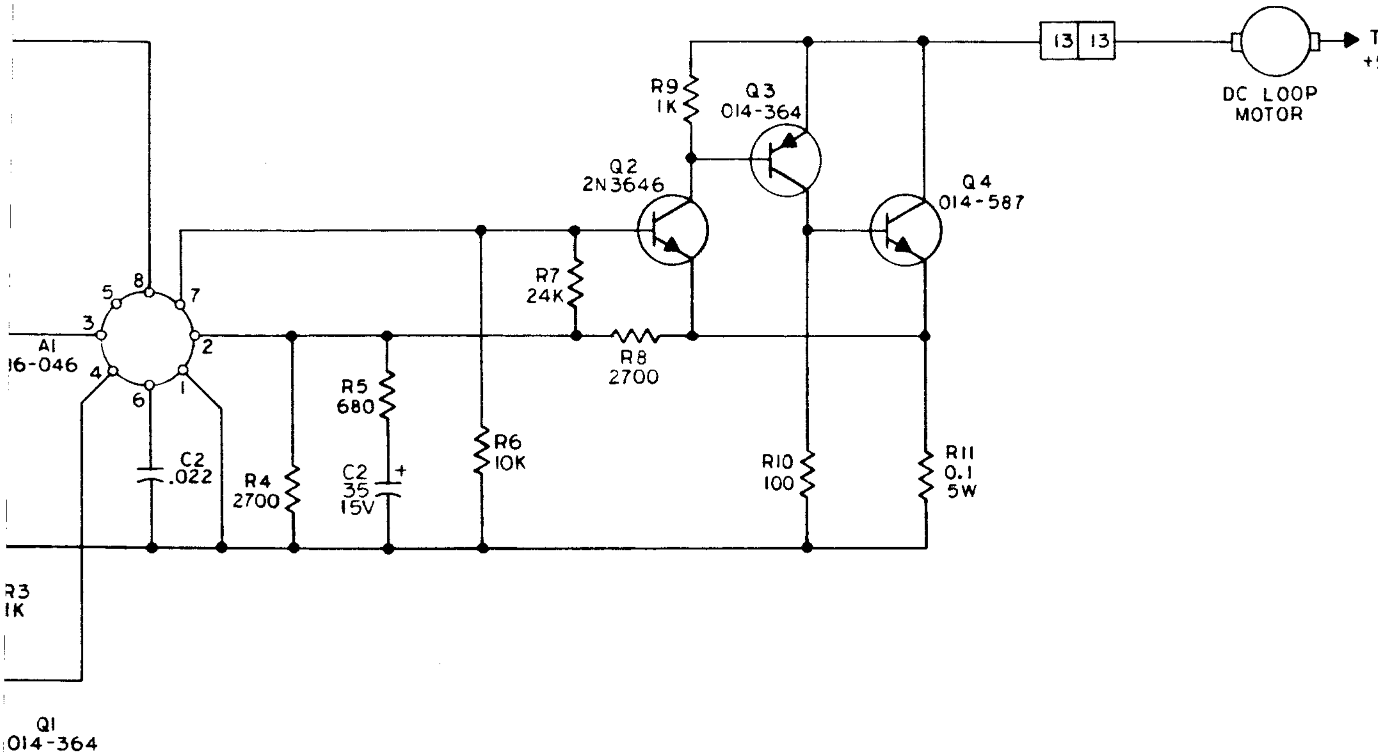
ITEM NO.	PART NUMBER	DESCRIPTION
QD PER DASH NUMBER	LIST OF MATERIALS	

...SS OTHERWISE SPECIFIED ...SIONS ARE IN INCHES AND ...DE CHEMICALLY APPLIED OR ...) FINISHES	SIGNATURE / DATE	AMPEX — VIDEO & INSTRUMENTATION DIV. REDWOOD CITY, CALIFORNIA U.S.A.
...ICES 2 PLC ± — 3 PLC ± — ANGLES ± —	DRAWN BY K. Lampson 3/9/66	SCHEMATIC DIAGRAM POWER SUPPLY JPL INCREMENTOR
...DS CLASS 2 PER ASA Y14.6	CHECKED BY	
...E BURRS AND SHARP EDGES	ENGR APPD	
...TOL. APPLY TO STOCK SIZES	APPD BY	
...CE FINISH √	DESIGN ACTIVITY APPROVAL —	SIZE D / CODE IDENT NO. 92739 / 7137-1035
...) NOT SCALE THIS PRINT	CUSTOMER APPROVAL —	SCALE — / WEIGHT — / SHEET 1 OF 1



NOTES: UNLESS OTHERWISE SPECIFIED

1. ALL RESISTOR VALUES ARE IN OHMS, 1/4W, 5%
2. ALL CAPACITOR VALUES ARE IN MICROFARADS



QTY REQD PER DASH NUMBER

UNLESS OTHERWISE SPECIFI

DIMENSIONS ARE IN INCHES
INCLUDE CHEMICALLY APPLIED
PLATED FINISHES

TOLERANCES 2 PLC 3 PLC AN

NEXT ASSEMBLY USED ON

APPLICATION

MATERIAL

FINISH

THREADS CLASS 2 PER ASA Y

REMOVE BURRS AND SHARP ED

COML TOL APPLY TO STOCK S

SURFACE FINISH

DO NOT SCALE THIS PRIN

2

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

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ITEM NO	PART NUMBER	DESCRIPTION

LIST OF MATERIALS

	SIGNATURE	DATE
DRAWN BY	Thompson	3/10/66
CHECKED BY		
ENGR APPD		
APPD BY		
DESIGN ACTIVITY APPROVAL		
CUSTOMER APPROVAL		

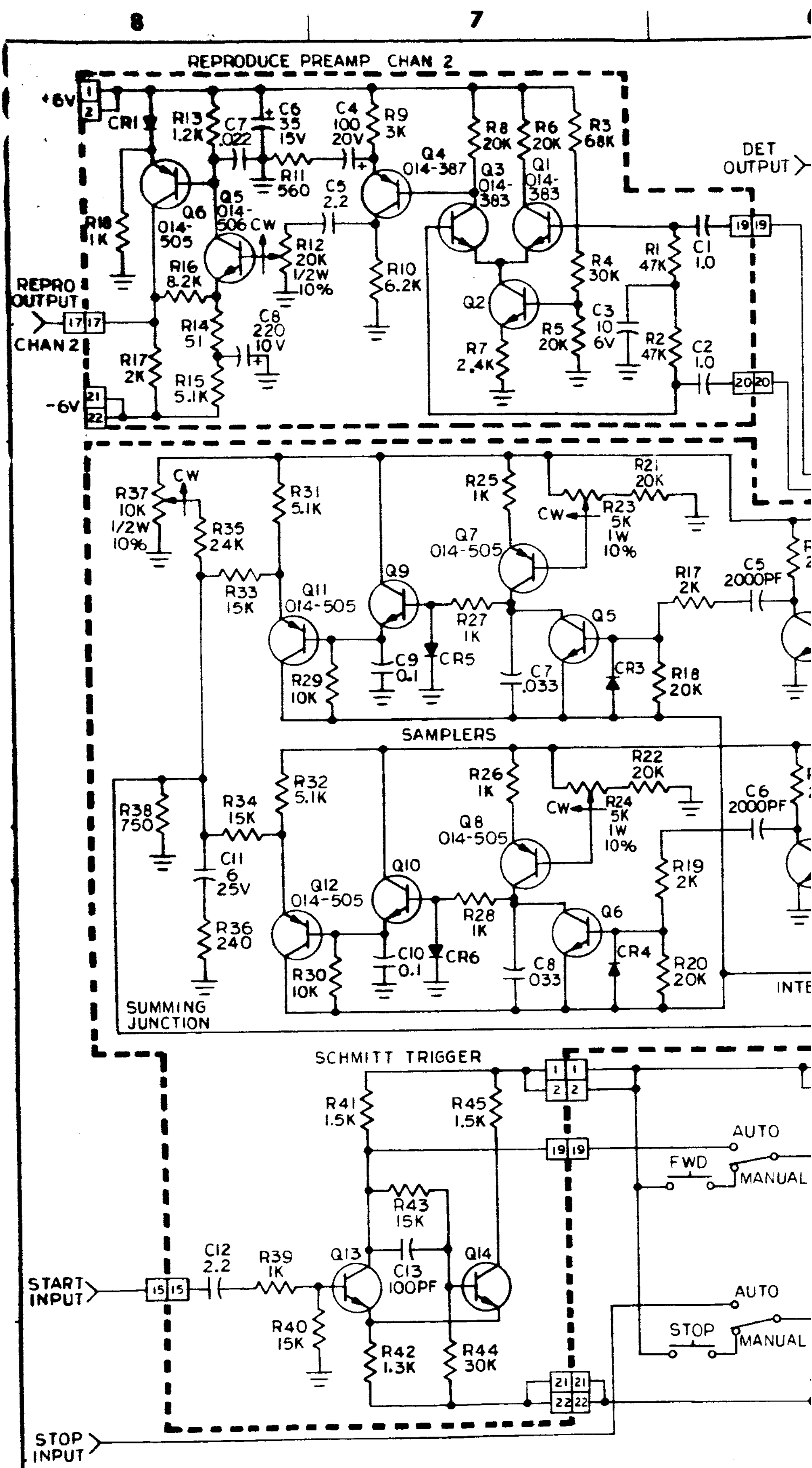
AMPEX VIDEO & INSTRUMENTATION DIV. REDWOOD CITY, CALIFORNIA U.S.A.

SCHEMATIC DIAGRAM
REELING SYSTEM
JPL INCREMENTOR

SIZE	CODE IDENT NO	
D	92739	7137-1036

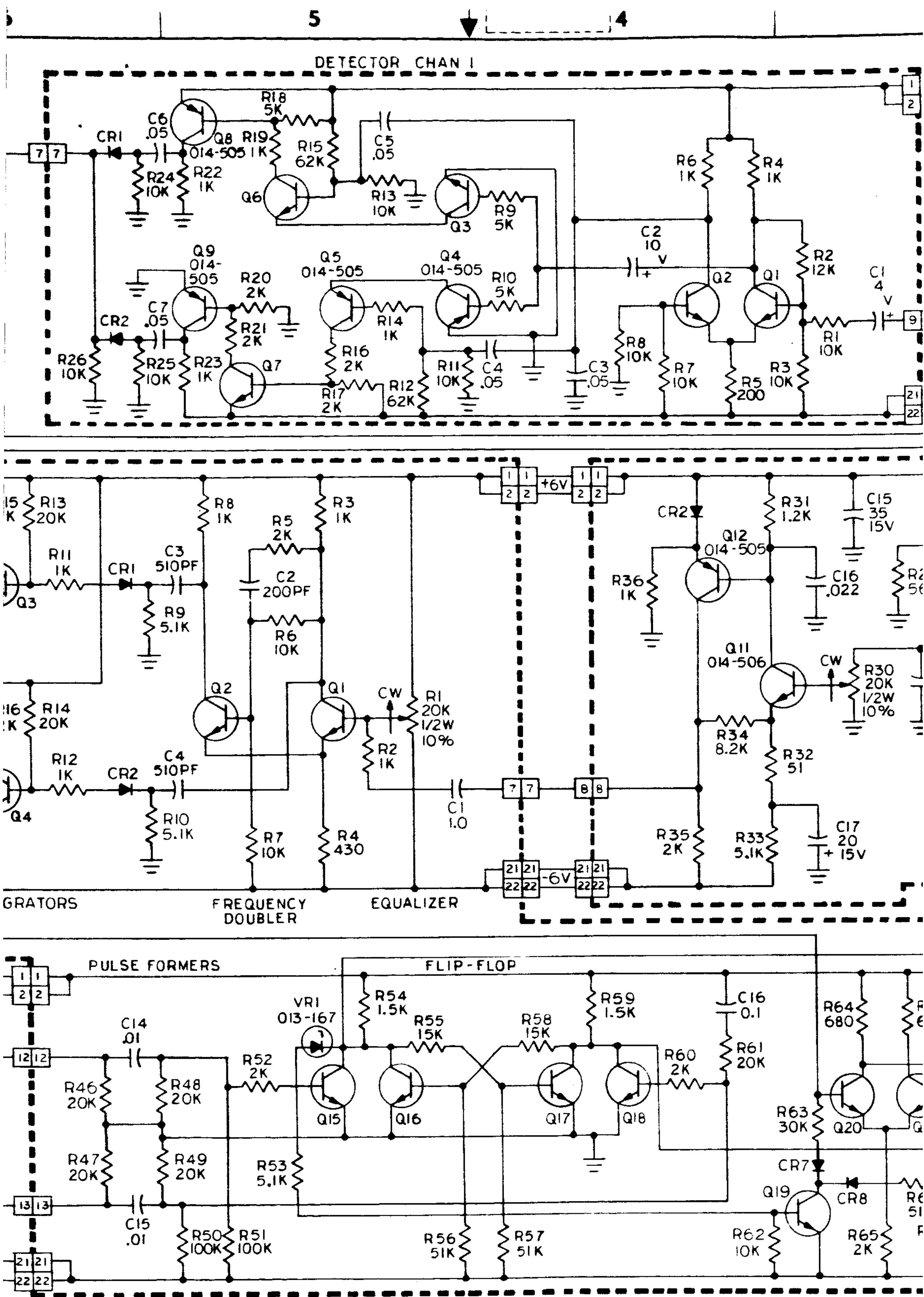
SCALE — WEIGHT — SHEET 1 OF 1

3



NOTES: UNLESS OTHERWISE SPECIFIED

1. ALL RESISTOR VALUES ARE IN OHMS, 1/4W, 5%
2. ALL CAPACITOR VALUES ARE IN MICROFARADS
3. ALL DIODES ARE TYPE 013-599
4. ALL TRANSISTORS ARE TYPE 014-248



NEXT ASSEMBLY | USED ON

APPLICATION

MATERIAL

FINISH

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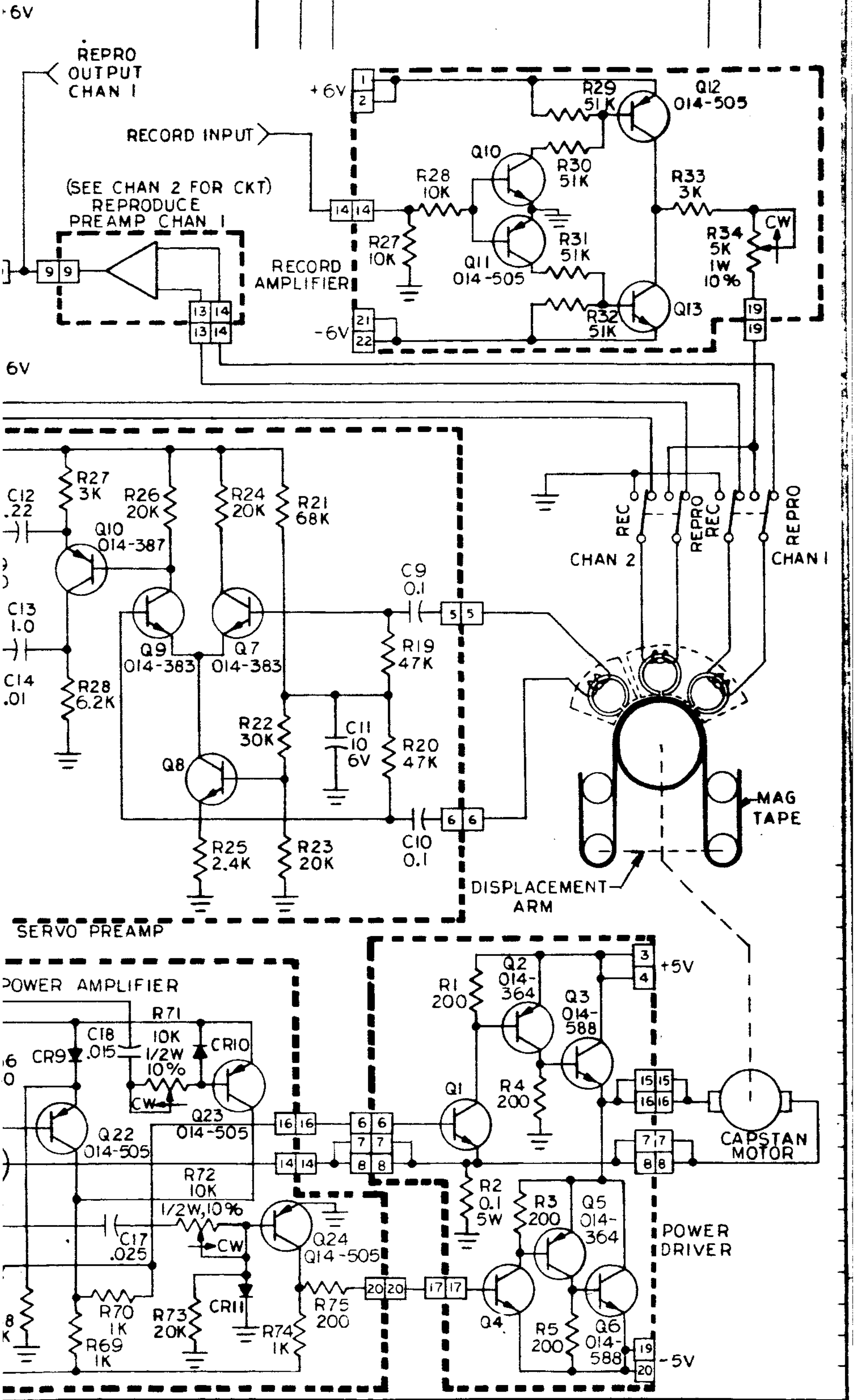
2

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



ITEM NO	PART NUMBER	DESCRIPTION
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	SIGNATURE	DATE	
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SIONS ARE IN INCHES AND DE CHEMICALLY APPLIED OR D FINISHES	DRAWN BY Klamp[illegible]	3/11/66	
CES 2 PLC ± 3 PLC ± ANGLES ±	CHECKED BY		SCHEMATIC DIAGRAM CAPSTAN SERVO JPL INCREMENTOR
	ENGR APPD		
DS CLASS 2 PER ASA Y14.6	APPD BY		
E BURRS AND SHARP EDGES	DESIGN ACTIVITY APPROVAL		SIZE D CODE IDENT NO 92739 7137-1037
TOL APPLY TO STOCK SIZES			
CE FINISH √	CUSTOMER APPROVAL		
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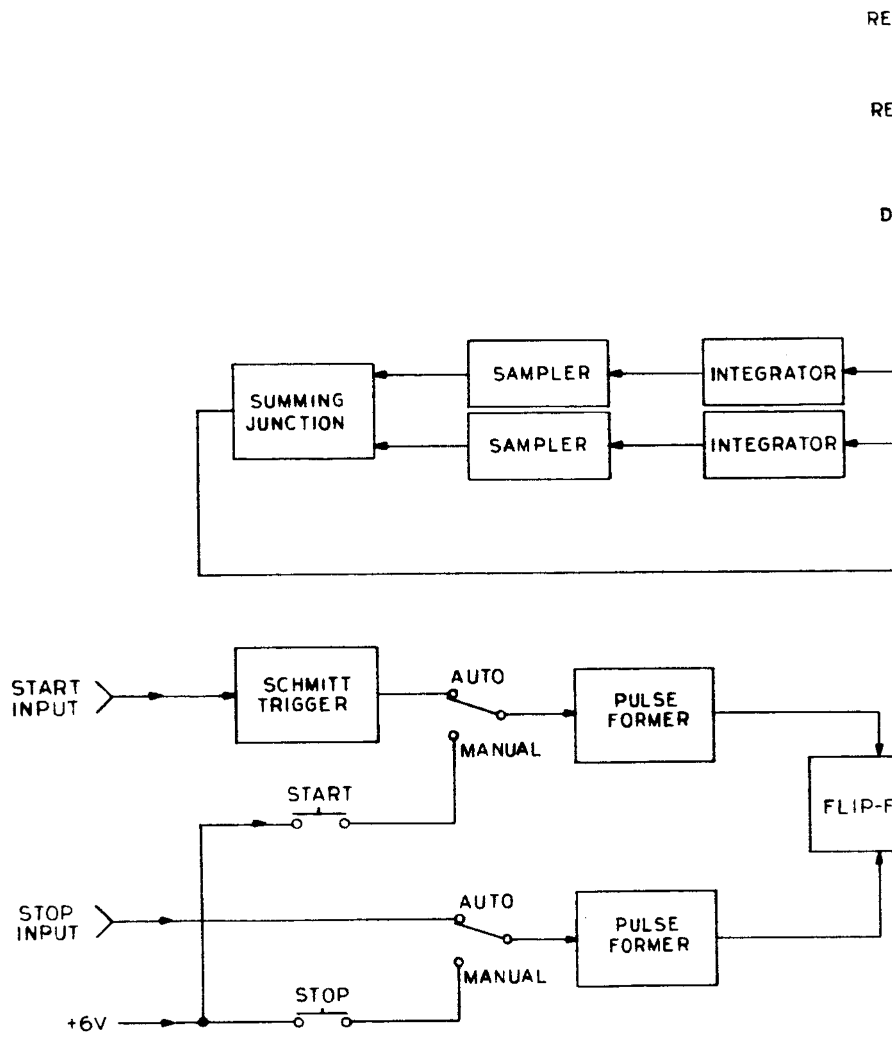

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AUTO
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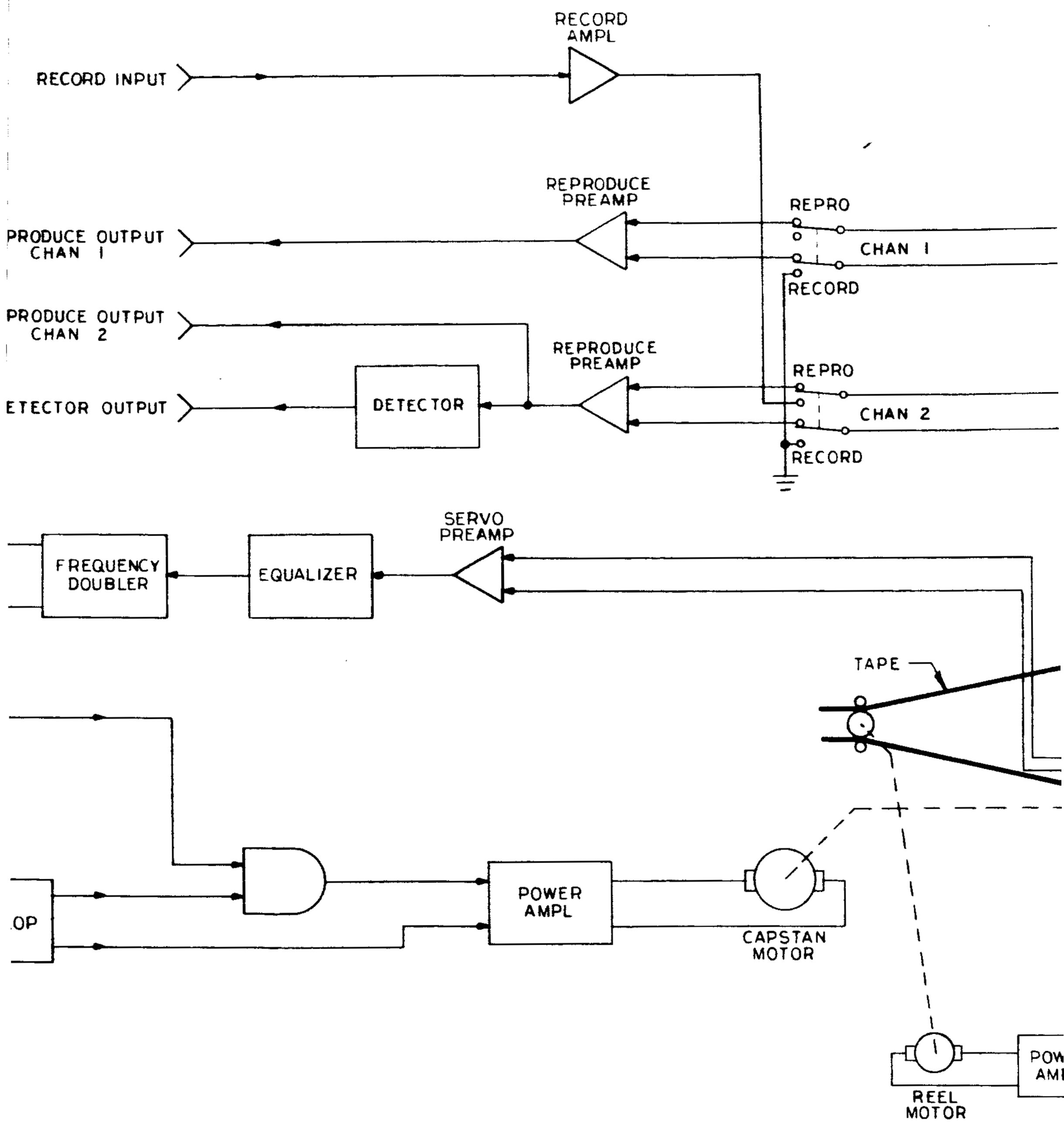

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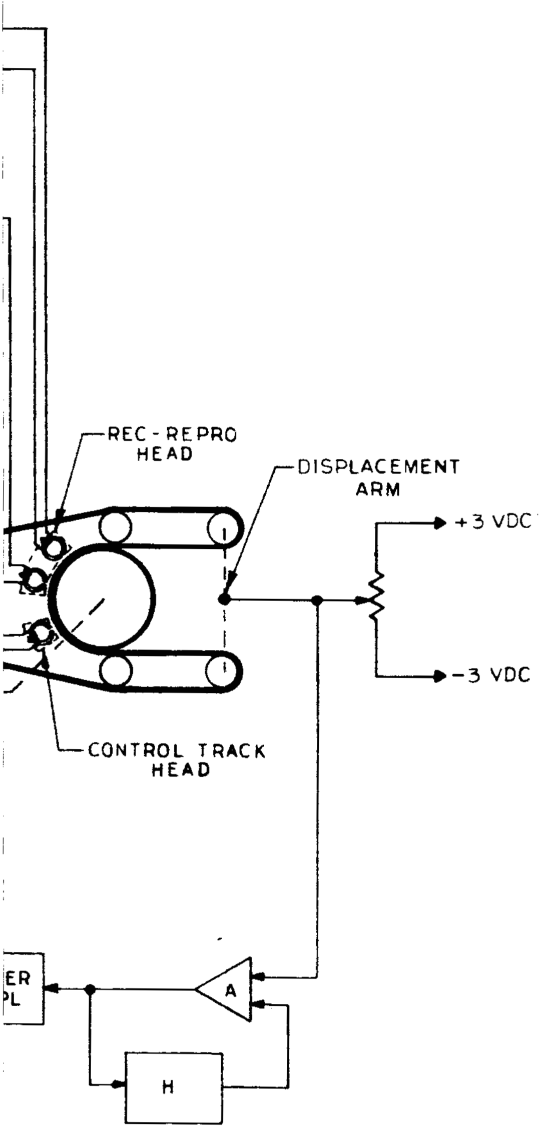
REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



	ITEM NO	PART NUMBER	DESCRIPTION	
) PER DASH NUMBER	LIST OF MATERIALS			

; OTHERWISE SPECIFIED	SIGNATURE	DATE	AMPEX — VIDEO & INSTRUMENTATION DIV. REDWOOD CITY, CALIFORNIA U.S.A.
)NS ARE IN INCHES AND , CHEMICALLY APPLIED OR FINISHES	DRAWN BY K. Simpson	3/21/66	BLOCK DIAGRAM JPL INCREMENTOR
2 PLC ± / 3 PLC ± / ANGLES ±	CHECKED BY		
	ENGR APPD		
CLASS 2 PER ASA Y14.6	APPD BY		
BURRS AND SHARP EDGES	DESIGN ACTIVITY APPROVAL		SIZE D — CODE IDENT NO 92739 — 7137-1038
L APPLY TO STOCK SIZES			
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IOT SCALE THIS PRINT			SCALE — WEIGHT — SHEET 1 OF 1

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