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ADDENDUM
TO
FINAL REPORT
DEVELOPMENT OF A DRIVE SYSTEM
FOR A SEQUENTIAL SPACE CAMERA

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ADDENDUM

TO

FINAL REPORT

DEVELOPMENT OF A DRIVE SYSTEM
FOR A SEQUENTIAL SPACE CAMERA

BY

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1. GENERAL

At the time the final report was submitted, a short time period remained until the scheduled completion of the study. To make the best use of this time, Perkin-Elmer Aerospace Division (ASD) felt that only one of the two motor drive techniques should receive a concentrated test effort in the breadboard configuration. Based on a study of the test results to date, the since electronically commutated motor drive scheme had shown the most promise and was therefore selected for further testing. To provide further backup for this decision, a synopsis of the test effort to date on the dual motor approach is included in Paragraph 8 of this Addendum.

2. SINGLE MOTOR APPROACH

This technique utilizes a single electronically commutated motor to drive the claw and shutter without resorting to a solenoid actuated clutch for pulse operation. Shutter speed is established by a combination of the cinemode speed and the opening of the conventional DAC two piece shutter. Pulse mode operation is obtained by applying power at a fixed clock rate and removing power at an appropriate point in the mechanical cycle such that the motor comes to rest by system friction. The following paragraphs describe the additional tests that were made, and discuss the results.

3. TEST PARAMETERS

Performance parameters which will most likely be influenced by a commutated motor drive scheme were selected for measurement. These parameters are listed below:

- a. Shutter Speed - Frame to frame
- b. Shutter Speed - Across the frame (banding effect)
- c. Maximum Frame Rate - Pulse mode
- d. Start-up Time - (Number of frames required)
- e. Current - Start-up (peak)
Running (peak and average)

4. TEST CONFIGURATION

The test circuits for measuring the parameters listed in Paragraph 3 are shown in Figures 1 and 2. The physical relationship between the shutter, aperture and LED/Sensor assembly used to measure shutter speed and frame rate are shown in Figure 3.

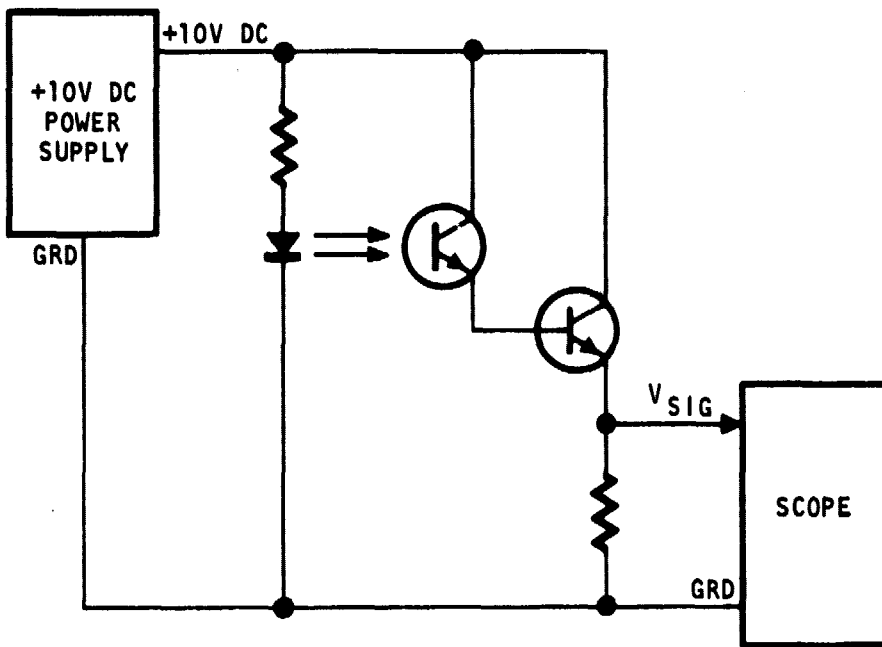


FIGURE 1. Led/Sensor Shutter Speed Test Circuit

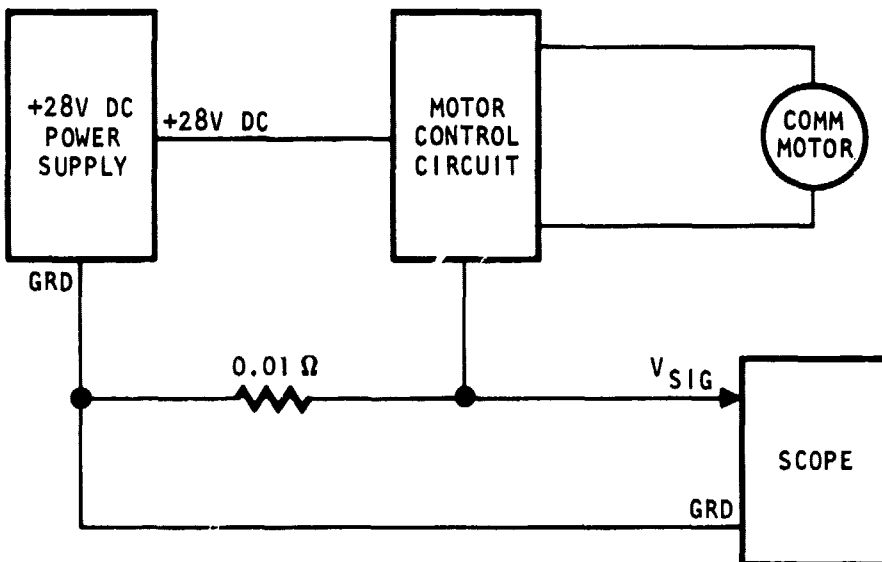


FIGURE 2. Input Current Test Circuit

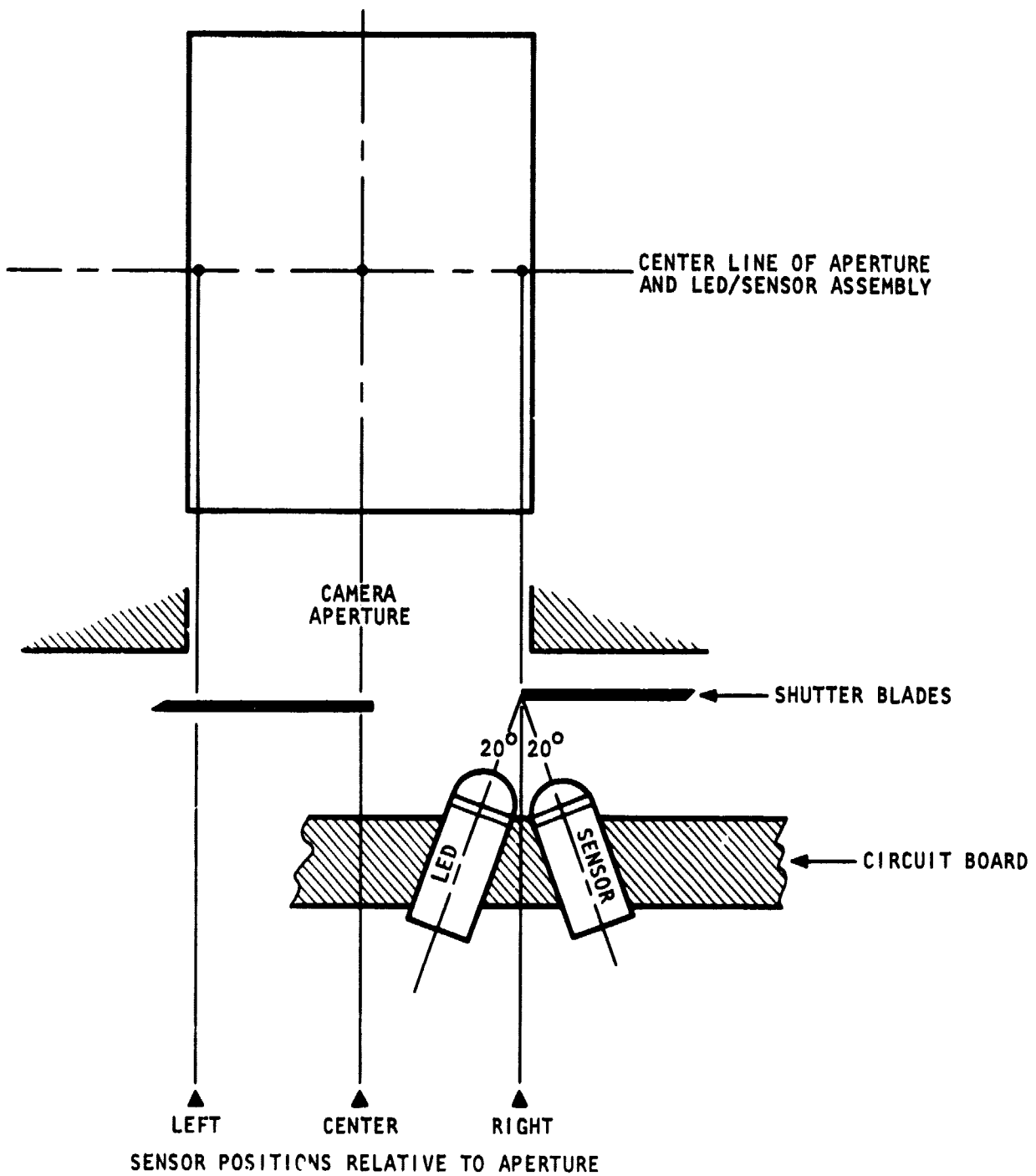


FIGURE 3. Optical Configuration for the Shutter Position Detector

5. TEST CONDITIONS

All testing was accomplished under room ambient temperature and humidity conditions. Input voltage was maintained at +28 V dc. Since the motor control circuitry contains a +14 V dc regulator, varying the +28 V dc does not affect the parameters being measured.

6. TEST PROCEDURE

6.1 SHUTTER SPEED - FRAME TO FRAME

The LED/Sensor configuration shown in Figure 3 was directed at a point just inside the right edge of the aperture. During the time the shutter covers this point, light is reflected to the sensor and a dc level of approximately +9 V dc appears at the output. When the shutter opening uncovers this point, the LED emits into a void and the light is not reflected back to the sensor. This causes the output signal to return to ground. The time duration of the ground level thus becomes a measurement of the shutter speed.

6.2 SHUTTER SPEED - ACROSS THE FRAME (BANDING EFFECT)

To ensure that a banding effect (uneven exposure across one frame) does not exist, the above described procedure was repeated with the LED/Sensor directed at the center and left edge of the aperture respectively.

6.3 MAXIMUM FRAME RATE - PULSE MODE

The maximum frame rate in pulse mode operation was determined by increasing the cinemode base speed above 6 fps and then increasing the clock rate at which power is applied above the 2 Hz rate until unreliable operation was observed.

6.4 START-UP TIME

The number of frames required to reach a constant shutter speed at frame rates of 2, 6, 12, and 24 fps was determined by photography, i.e., the camera was focused on a known light source of uniform density and actual photographs taken. The number of frames that were not exposed at the correct shutter speed were then counted. This method of testing also provided corroborating data relative to the possibility of banding effects, as well as a means of correlating exposure densities associated with the various frame rates.

6.5 CURRENT

Average current for each of the frame rates was obtained by reading the ammeter on the +28 V dc power supply. Peak currents (start-up and running) were determined by measuring the voltage drop across a precision 0.01 ohm resistor in series with the power supply.

7. TEST RESULTS

Test results for the breadboard configuration are presented in Table 1. Shutter speeds were measured at the shutter opening extremes of 8.6 and 138° respectively.

Less than one percent jitter in frame to frame shutter speed variation was noted at all frame rates with either shutter opening. Shutter speed correlation when compared at various cinemode frame rates was consistent, i.e., 16 ms at 24 fps, 32 ms at 12 fps and 64 ms at 6 fps, using the 138° opening. This same pattern repeated at 8.6°, i.e., 1.0 ms at 24 fps, 2 ms at 12 fps and 4 ms at 6 fps.

In comparing the 6 fps cinemode and the 2 fps pulse mode, note that the shutter speed is approximately 10 percent slower in the pulse mode. This indicates that the shutter has not quite reached speed during one revolution. By increasing the base cinemode speed to 6.6 fps, this difference was eliminated without any apparent shutter speed variation across the frame. In a production model camera this adjustment in base speed could be easily incorporated in the speed control electronics, and would be automatic, requiring no attention by the camera user.

The maximum frame rate achieved utilizing pulse mode operation was 6 fps. To obtain this speed, the base cinemode speed was increased to 8 fps. Even at this point, pulse mode operation was somewhat marginal as evidenced by shutter speed readings for the 8.6° opening. The two basic problems in attempting pulse modes at this frame rate, and at higher frame rates, is apparently the inability of the system friction to stop the transport mechanism consistently at the same point, and the inability of the drive system to reach and stabilize at the higher speed in less than one revolution. This is demonstrated by the 6 fps pulse mode data, which shows that the system is in an overshoot condition when the shutter opens and the shutter speed is faster than it should be for a base cinemode speed of 8 fps.

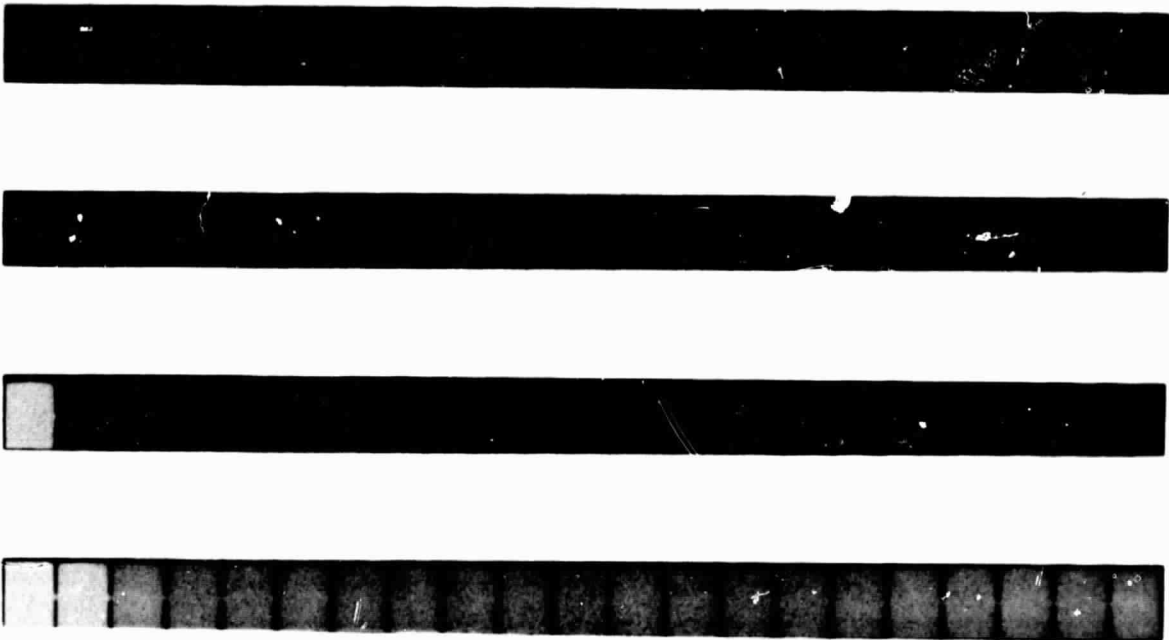
As indicated in paragraph 6, the number of frames lost during start-up was determined by photography. Reproductions of the results are shown in Figure 4. These photographs do not show a loss at 2 and 6 fps. One frame is lost at 12 fps and two frames are lost at 24 fps. The developed film also corroborates the readings obtained utilizing the LED/Sensor technique. Banding is not evident and verifies the right, left, and center measurements shown in Table 1.

The current measurement data indicates that the maximum average current is 400 mA at 24 fps. Also, note that this is based on a motor and control circuit designed for a 14 V dc input. If the motor were wound for a higher voltage, this current would be reduced. The peak start-up currents for the cinemode speeds are similar to the surge current characteristics of a conventional brush type motor and drop off as the motor reaches speed. In the pulse mode, the peak start-up and peak running currents are synonymous since the power is continuously applied and removed at the selected pulse rate.

TABLE 1. Electronically Commutated Motor Drive Test Results

| Frame Rate (fps) | Shutter Opening (Degrees) | *Exposure Time (Milliseconds) | | | Avg Current (Amperes) | Peak Current (Amperes) | | Remarks |
|------------------|---------------------------|-------------------------------|------------|------------|-----------------------|------------------------|-------|---------------------------------------|
| | | Left | Center | Right | | Start | Run | |
| 24 | 138 | 16 | 16 | 16 | 0.400 | 2.5 | 0.600 | Cinemode |
| 12 | 138 | 32 | 32 | 32 | 0.350 | 2.0 | 0.750 | Cinemode |
| 6 | 138 | 64 | 64 | 64 | 0.320 | 1.5 | 0.7 | Cinemode |
| 2 | 138 | (65) 70 | (65) 70 | (65) 70 | 0.160 | 1.5 | 1.5 | Pulse mode with base speed of 6 fps |
| 2 | 138 | 64 | 64 | 64 | 0.160 | 1.5 | 1.5 | Pulse mode with base speed of 6.6 fps |
| 6 | 138 | 40 | 39 | 38 | 0.350 | 1.75 | 1.75 | Pulse mode with base speed of 8 fps |
| 24 | 8.6 | 1.0 | 1.0 | 1.0 | | | | Cinemode |
| 12 | 8.6 | 2.0 | 2.0 | 2.0 | | | | Cinemode |
| 6 | 8.6 | 4.0 | 4.0 | 4.0 | | | | Cinemode |
| 2 | 8.6 | 4.3 | 4.3 | 4.3 | | | | Pulse mode with base speed of 6 fps |
| 2 | 8.6 | 4.0 | 4.0 | 4.0 | | | | Pulse mode with base speed of 6.6 fps |
| 6 | 8.6 | 2.3 | 2.5 | 2.4 | | | | Pulse mode with base speed of 8 fps |

*This measurement made with reflecting LED/Sensor combination looking at center, right, left of aperture. Stop command in pulse mode issued just as claw enters film sprocket hole.



REPRODUCTION OF THE
ORIGINAL FILM NEGATIVES

NOTE

To facilitate publication, this figure is a positive reproduction of the original film negatives.

FIGURE 4. Exposure Density Comparison Electronic Commutated Motor Drive
2, 6, 12 and 24 fps, Uniform Light Source of 1300 fL

8. DUAL MOTOR APPROACH

This technique, as previously described in the final report, utilized a stepper motor to drive the shutter and an electronically commutated dc motor to drive the claw and magazine functions. The two motors are synchronized electronically.

Exposure control over the 1/30 to 1/500 second range imposed two conflicting requirements on the stepper motor performance; first, fast step response; and second, positional accuracy with minimal overshoot at completion of the step. Preliminary calculations indicated that a 90° stepper motor driving a shutter of minimal inertia could cover the exposure range if two fixed openings were utilized. These calculations were also based on the availability of an off the shelf motor to meet the following specifications:

- a. Step 90° and come to rest in less than eight milliseconds with less than 10° overshoot.
- b. Step 180° (two consecutive 90° steps) and maintain constant speed during the time the shutter opening was passing the aperture.
- c. Maintain constant speed over two steps with lower voltage applied such that the shutter speed rate could be varied (slope change).

To provide a confidence level for the feasibility of this technique, initial tests were conducted utilizing a 90° stepper motor with an Alnico 5 permanent magnet rotor. Measurements were made for both the single step and two step advance utilizing the test circuit shown in Figure 5. The results of the single step test are shown in Figure 6 for three different voltage levels applied to the motor. The three photographs shown in Figure 6, Sheet 1 represent the position and rate response with no retrotorque applied. The three photographs shown in Figure 6, Sheet 2 represent a retrotorque applied at approximately the 45° position. The results of the two step response over 180° with the same three voltage levels applied are shown in Figure 7.

The significance of these results were:

- a. A 90° step could be achieved in less than eight milliseconds with minimal overshoot if a retrotorque was applied.
- b. The rate of change (slope) could be controlled by varying the motor voltage.
- c. A constant slope could be maintained over two steps if the second step was applied at the proper point in the rotation.

During the performance of the above tests, the permanent magnet rotor began to show demagnetization at the lower voltages. A discussion with the motor manufacturer indicated that this was due to the higher voltage application. The manufacturer also indicated that a motor utilizing a samarium cobalt magnet would not demonstrate this degradation. A second motor was therefore ordered for subsequent testing. This motor, however, was rejected almost immediately

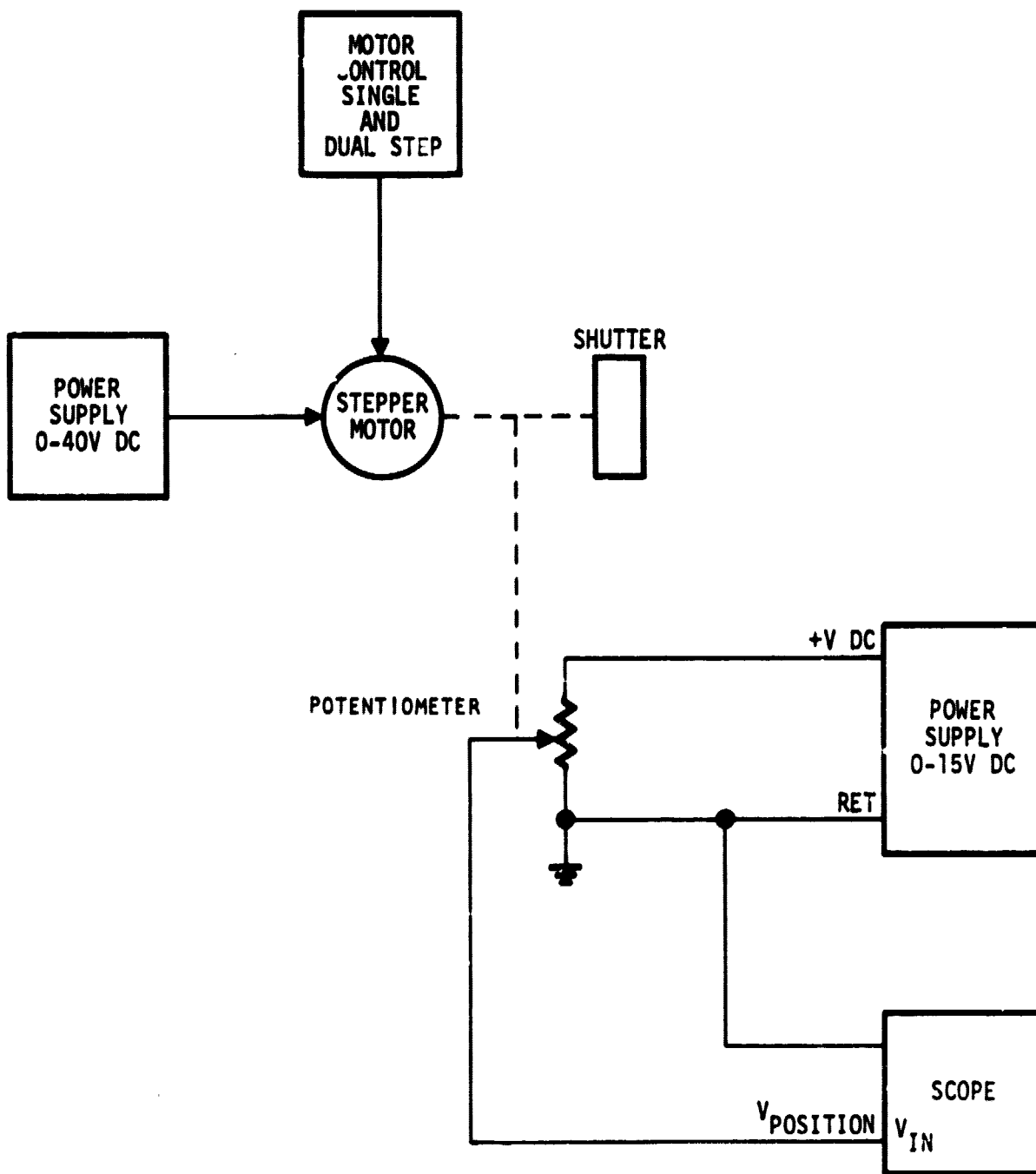
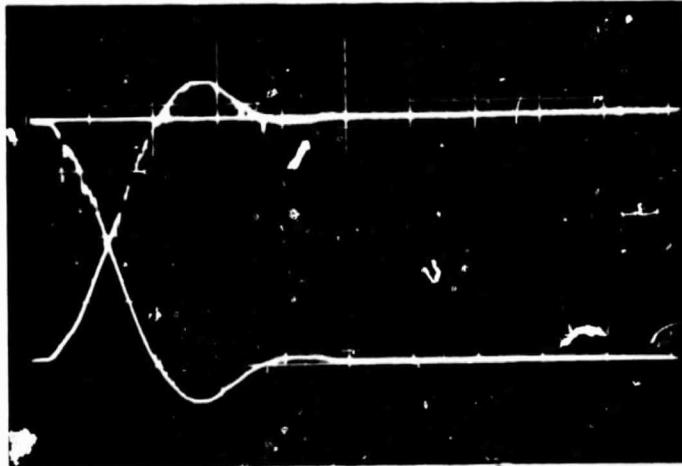


FIGURE 5. Stepper Motor Response Test Circuit

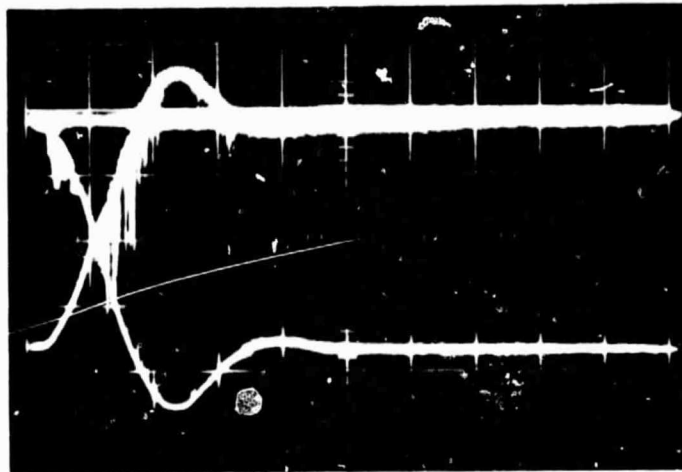
NO RETRO - TORQUE



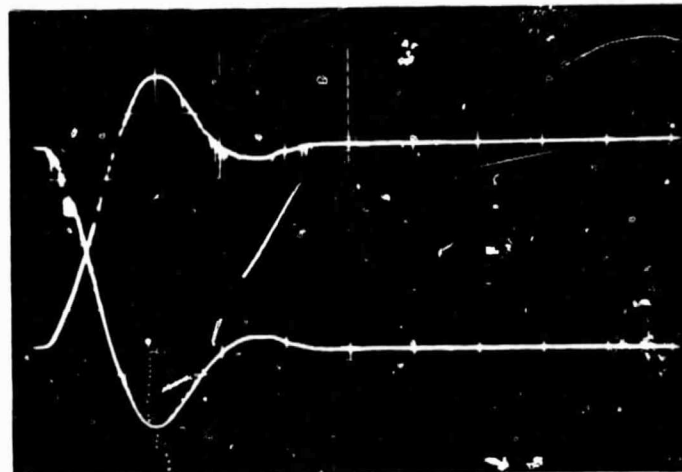
HORIZ 2 ms/cm VERT 30°/cm +20V DC

NOTE

NOISE SUPERIMPOSED
ON THE SIGNAL IS
DUE TO THE POTENTI-
OMETER.



HORIZ 2 ms/cm VERT 30°/cm +30V DC



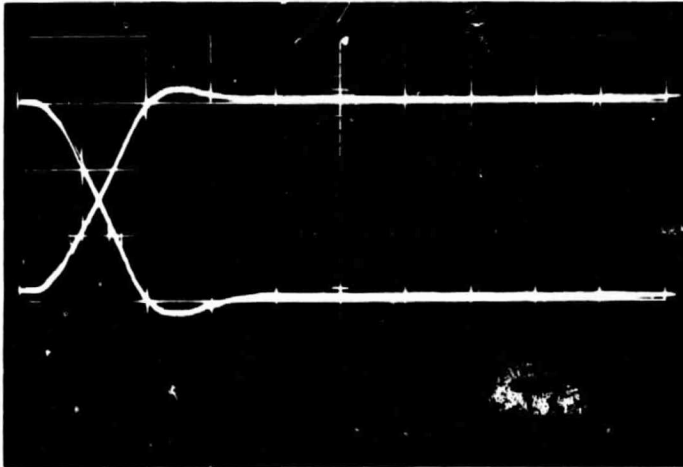
HORIZ 2 ms/cm VERT 30°/cm +40V DC

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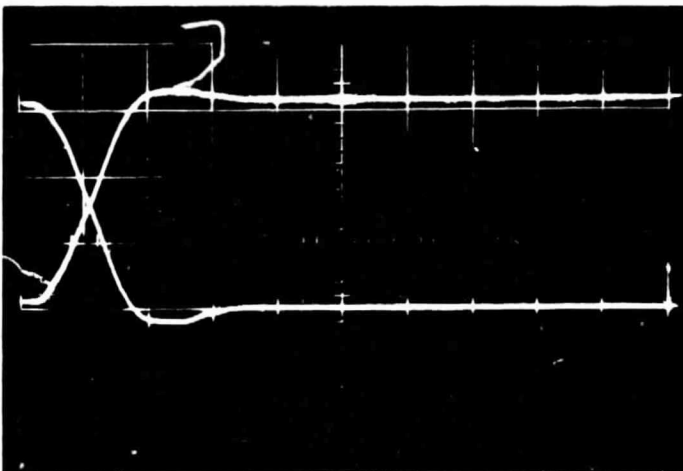
FIGURE 6. Single Step Test Results (Sheet 1 of 2)

RETRO - TORQUE



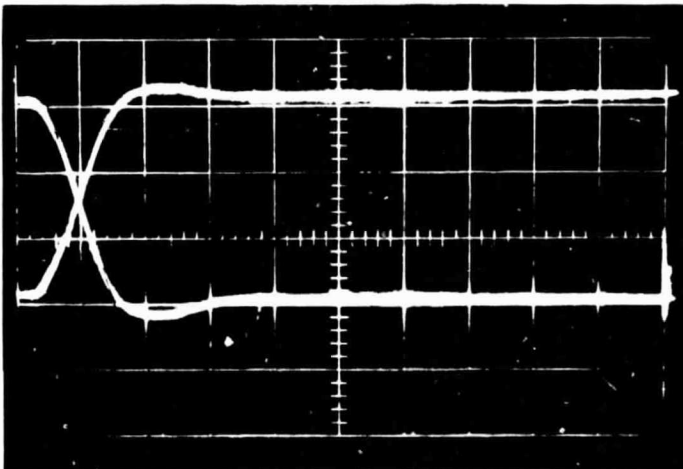
HORIZ 2 ms/cm

VERT 30°/cm +20V DC



HORIZ 2 ms/cm

VERT 30°/cm +30V DC



HORIZ 2 ms/cm

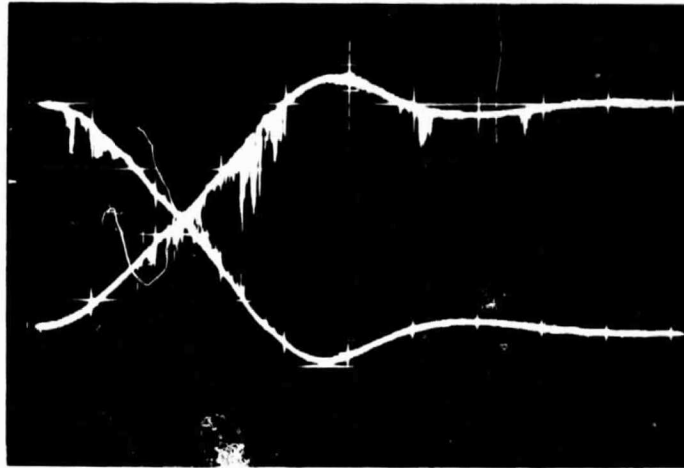
VERT 30°/cm +40V DC

FIGURE 6. Single Step Test Results (Sheet 2 of 2)

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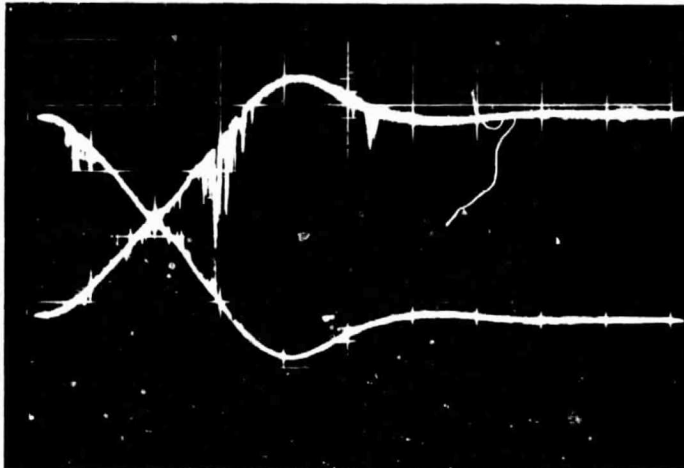
NOTE

NOISE SUPERIMPOSED
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DUE TO THE POTENTI-
OMETER.



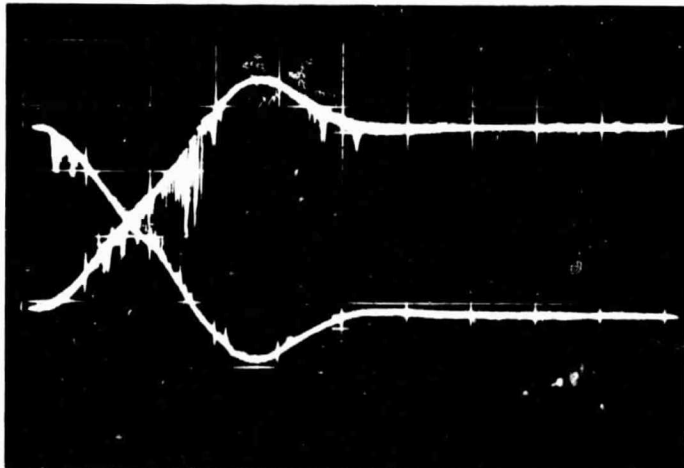
HORIZ 5 ms/cm

VERT 60°/cm +20V DC



HORIZ 5 ms/cm

VERT 60°/cm +30V DC



HORIZ 5 ms/cm

VERT 60°/cm +40V DC

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FIGURE 7. Two Step Test Results

due to an extremely wide dead band (30°) at the detent points; i.e., with full voltage applied the motor shaft could be rotated approximately 30° with no noticeable torque being produced by the motor. A third motor was then ordered utilizing Almico 8 for the permanent magnet. This motor was, according to the manufacturer, much less likely to demagnetize if voltage above the rated voltage of the motor was applied.

This series of events resulted in the present breadboard configuration. The third motor, along with an optical encoder which could produce the appropriate retrotorque and advance pulses, was installed in the system. Initial testing of this configuration achieved operation in time exposure and at the slower exposures ($1/30$, $1/60$ and $1/125$ seconds). These exposure times rely on the ability of the system to take a single 90° step, dwell (for selected exposure time) with no power applied, and step 90° to close the shutter. An extremely important requirement of this technique is the ability to remove power between steps. Otherwise, the average power consumption becomes prohibitive. The system as presently configured did not allow the removal of power between steps.

The two faster shutter speeds ($1/250$ and $1/500$ seconds) rely on the ability of the system to take two consecutive 90° steps while maintaining constant speed over the midrange of the positional change. Testing indicated that the motor was slewing correctly in one direction, but overshooting quite badly in the other. This resulted in an unstable and therefore inoperable system at these two speeds.

In attempting to analyze these results, it appears that the inability to remove power and the stabilization problems at the higher speeds are directly related. Specific characteristics of the system which, by themselves, or in combination could contribute to these problems are:

- a. Mismatched motor windings, resulting in a different response for each pair of windings being driven.
- b. Optical encoder misalignment, resulting in the retrotorque and advance pulses being applied at the wrong time in the rotation cycle.
- c. Fixed position application of the retrotorque and advance pulses at 45° and 90° respectively, i.e., this may not be the optimum point for application of these pulses.

As indicated in Paragraph 1, a decision on which way to proceed with the test was required at this juncture of the program. Since all of the above indicated problems must be resolved before the final results could be determined, and since this condition required additional time and cost, the direction was given to complete final testing on the single motor drive technique.