1.0 SUMMARY

An earth and moon scanning television system was carried aboard the payload on the Able-1 missile, flight 3. The system operated from launch, but no data were obtained since the major portion of the earth seen by the vehicle during its flight was in darkness.

2.0 INTRODUCTION

The lunar payload contained a television system for the purpose of obtaining a rudimentary image of that part of the lunar surface normally unseen by earth observers.

The TV system was designed to utilize vehicle motions to accomplish both line and frame scanning. A nominal output bandwidth of 1 cps was provided in order that the microlock telemetry link could be employed to transmit the image information to earth. The system had an optical resolution of 0.5 degree; a single scan line contained 126 resoluble elements.

Within this report is a description of system operation, a discussion of trajectory parameters as they affect system design, and a description, including schematics, of the various units comprising the TV.

3.0 SYSTEM OPERATION

Figure 1 is drawn to illustrate system operation. An optical unit, containing a concave spherical mirror which reflects light on a photosensor, is fixed within the vehicle. Light arriving within an acceptance cone, or "optical beam" of 0.5 degrees (total angle), causes the voltage of the sensor to increase.

As the payload rotates and moves forward along its trajectory, the optical beam scans a cylindrical helix in space. Over a small area of this helix, line scanning is produced by vehicle spin and frame scanning by vehicle motion along the trajectory.

At the rate of two elements per second, a 128 by 128 element image of the test pattern required about two hours for readout. A scope camera was employed to record the TV picture presented on the scope face. The camera was opened at the beginning of the 2-hour interval and left open while the test image was scanned. A picture resulting from such a test is shown in Figure 28.

8.0 FLIGHT DATA

No flight data were obtained from Pioneer II due to the brevity of the flight, and the fact that most of the earth scanned was in darkness.

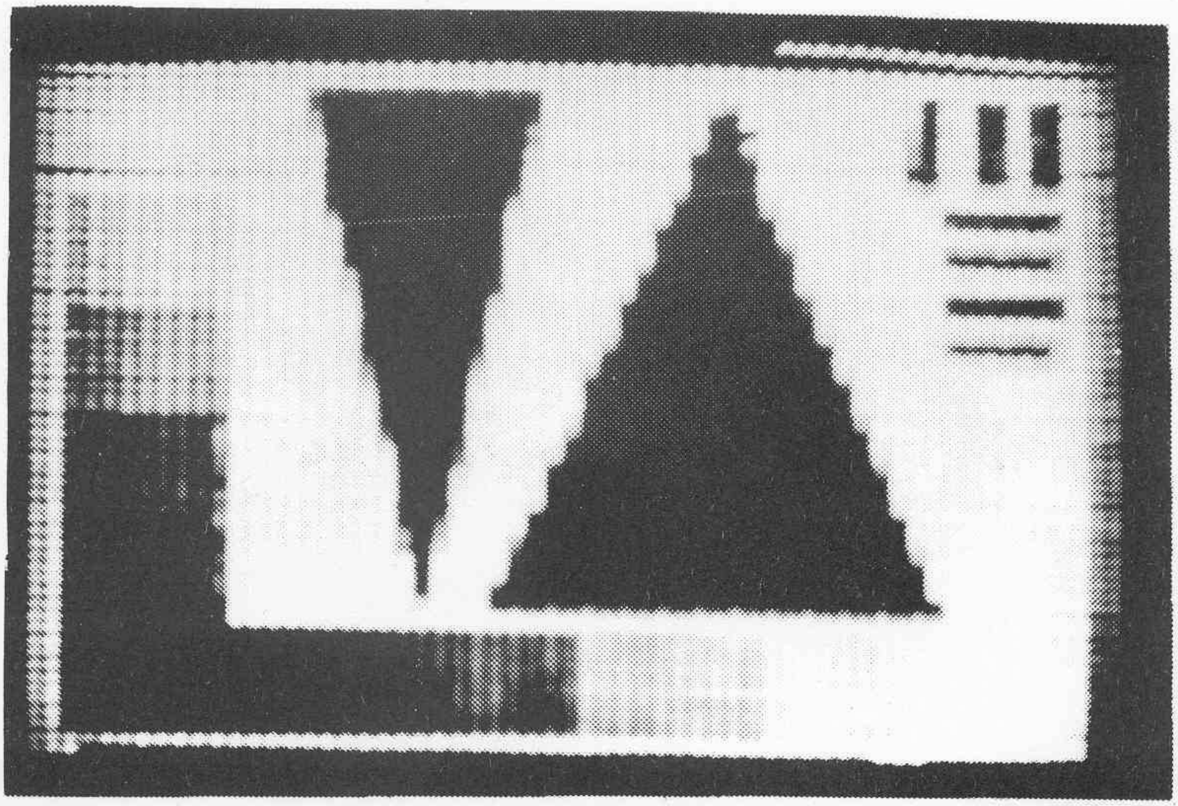


Figure 28. 64 x 64 Element TV Image of Test Pattern.

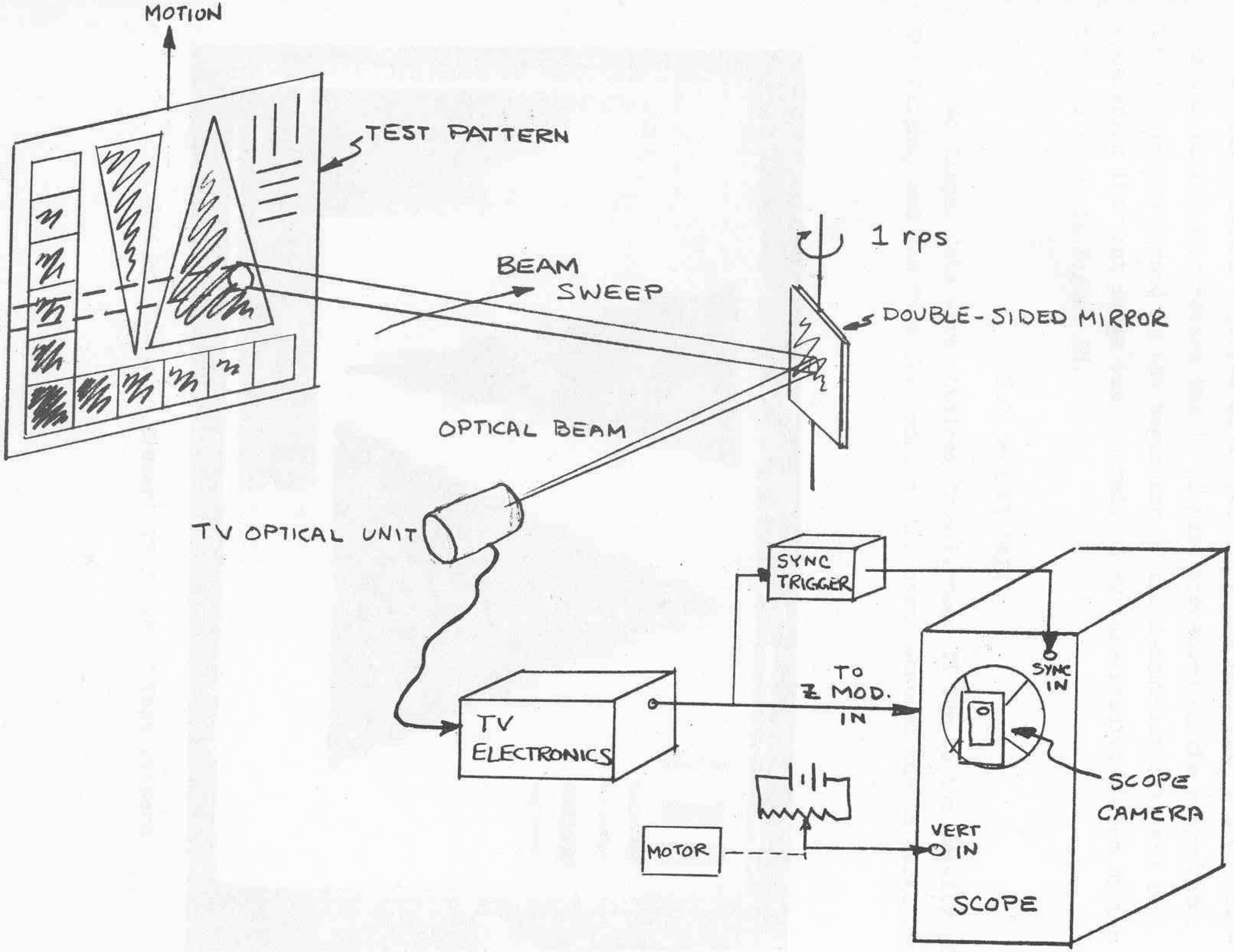


Figure 27. TV Test Setup.

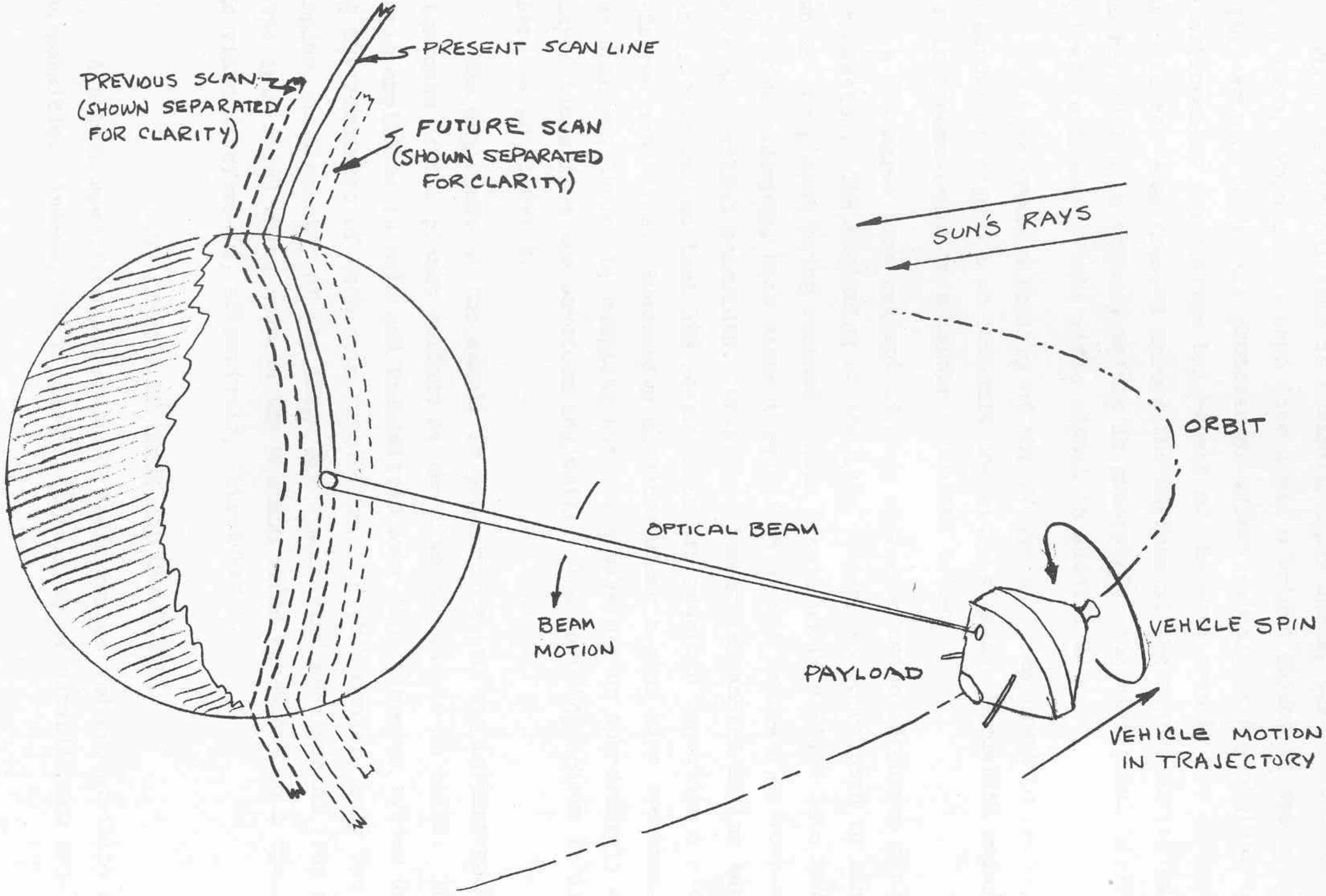


Figure 1. Illustration of TV System Operation.

When the optical beam is scanning empty space, the photosensor output is zero. When a beam scan intersects a bright object in space, such as the earth or moon, the photosensor output voltage at any instant is proportional to the average brightness of the area seen by the optical beam. As the beam travels across the surface of the planet during each spin revolution, a video waveform is generated. The electrical bandwidth required to transmit this video signal is about 1 Kc.

The electronic circuitry of the TV system is employed to reduce the bandwidth required to transmit the video signal. Bandwidth reduction is accomplished in a manner explained below.

A 64-degree line segment of each scan revolution is chosen for transmission. The beginning of the line is made to correspond to the limb of the planet being scanned. Each scan line is divided into 128 successive elements, each element about 0.5 by 0.5 degrees, corresponding to the optical beamwidth. Only one element is sampled during each spin revolution, so that 128 revolutions are required to obtain a single 64-degree scan line. Successive elements along a scan line are obtained each spin revolution by sampling the video waveform at successively more delayed times from the waveform beginning. The sampling scheme is illustrated in Figure 2.

The amplitude of the sample is proportional to the instantaneous brightness of the planet surface at the time the sample is taken. The sample amplitude is held and transmitted over the telemetry system during the remainder of each spin revolution. In this manner, only two samples, or elements, of the image are transmitted each second (for a 2-rps spin rate) which reduces the minimum video bandwidth to 1 cps. The video waveform is, effectively, "stretched."

4.0 EFFECTS OF ORBIT AND TRAJECTORY

A priori specification of lunar orbit radius and eccentricity was not possible. Indeed, the a priori probability of establishing any lunar

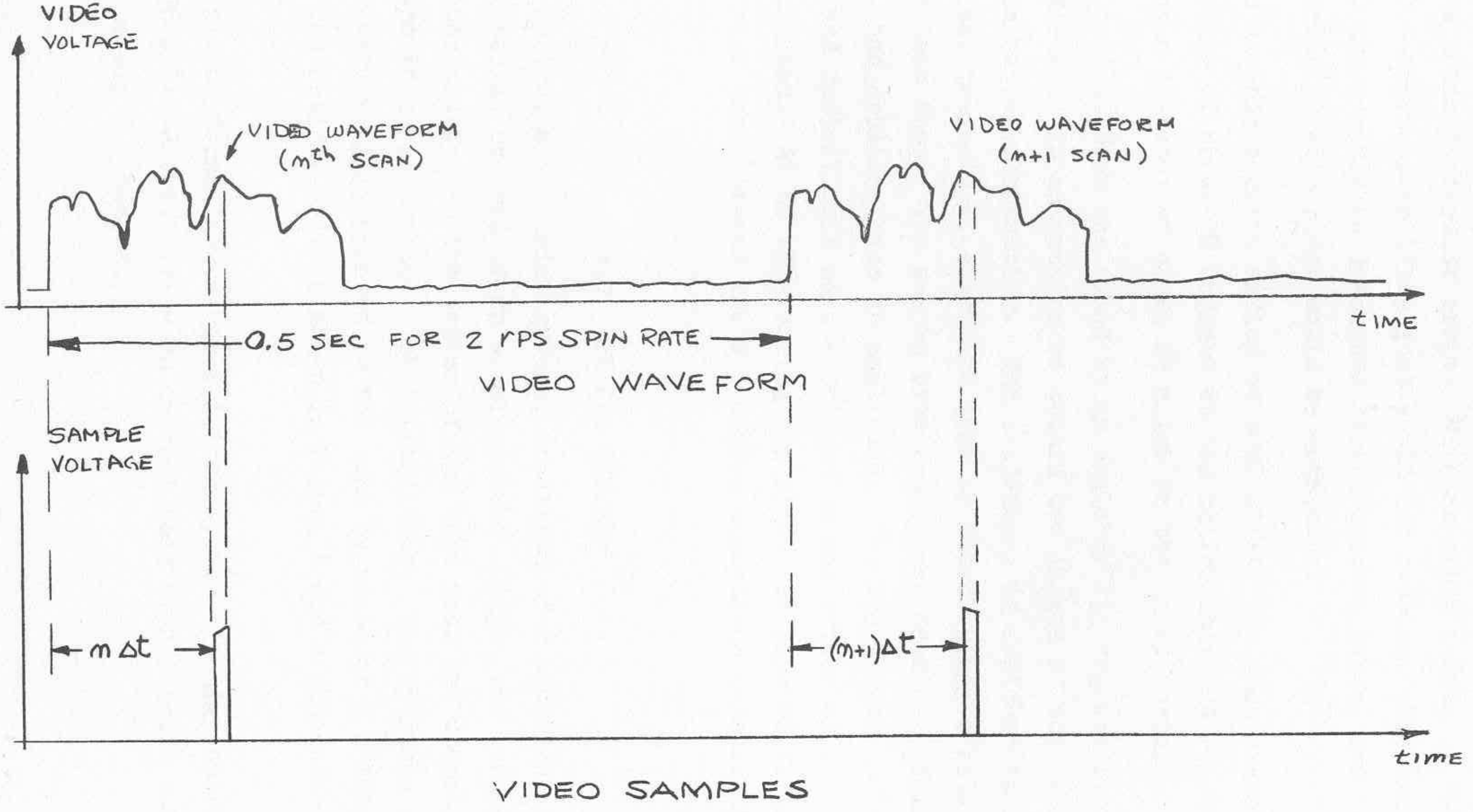


Figure 2. Sampling Scheme Shown for Two Spin Cycles.

orbit was not more than 50 percent. Hence, the TV design could be based only upon a nominal circular orbit. With an orbit radius of 4000 miles, adjacent 0.5-degree scan lines just would not overlap. For smaller orbit radii, there would be unscanned strips between lines; and for larger radii, overlap of scan lines would be obtained.

With a vehicle orbit radius of 4000 miles, the moon diameter subtends an angle of about 30 degrees at the optics unit. A resolvable element has a diameter of about 25 miles on the lunar surface.

The optical beam was aimed at an angle of 135 degrees from the spin axis (nozzle end) in an attempt to obtain two images of the moon's back side before battery exhaustion. The trajectory is sketched in Figure 3 for a nominal trajectory, about the time of retrofiring; a half-moon would have been seen. The second view would have been of a full moon, back side, had orbiting been accomplished. The 135-degree angle between spin axis and optical axis also permitted an early view of the earth, half illuminated. At no time during the first few days of flight would the sun's rays have entered the 0.5-degree acceptance cone of the optics unit.

5.0 OPTICAL SYSTEM

The optics, a Newtonian system, consisted of a spherical concave mirror located at one end of an aluminum tube. Light was focused on an aperture stop mounted in the center of the tube near the opening. Behind the aperture was located a phototransistor. The aperture and phototransistor were rigidly mounted to the tube by means of a spider. A sketch of the optical unit is shown in Figure 4 and a schematic in Figure 5.

The mirror focal length was 2.5 inches, the circular aperture diameter 0.576 millimeters, giving an optical beam with a total cone angle of approximately 0.5 degree.

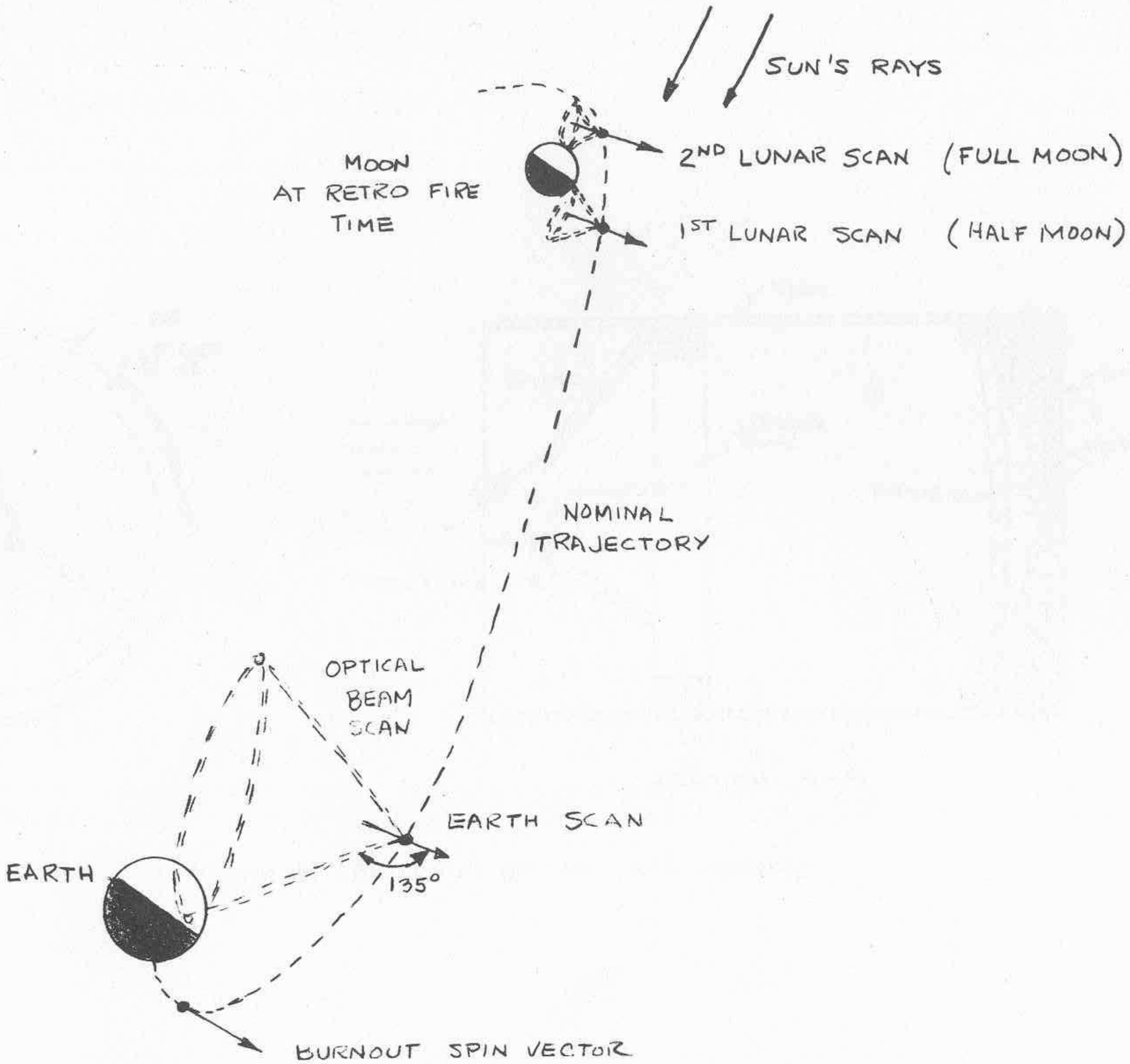


Figure 3. Sketch of Trajectory and Viewing Possibilities.

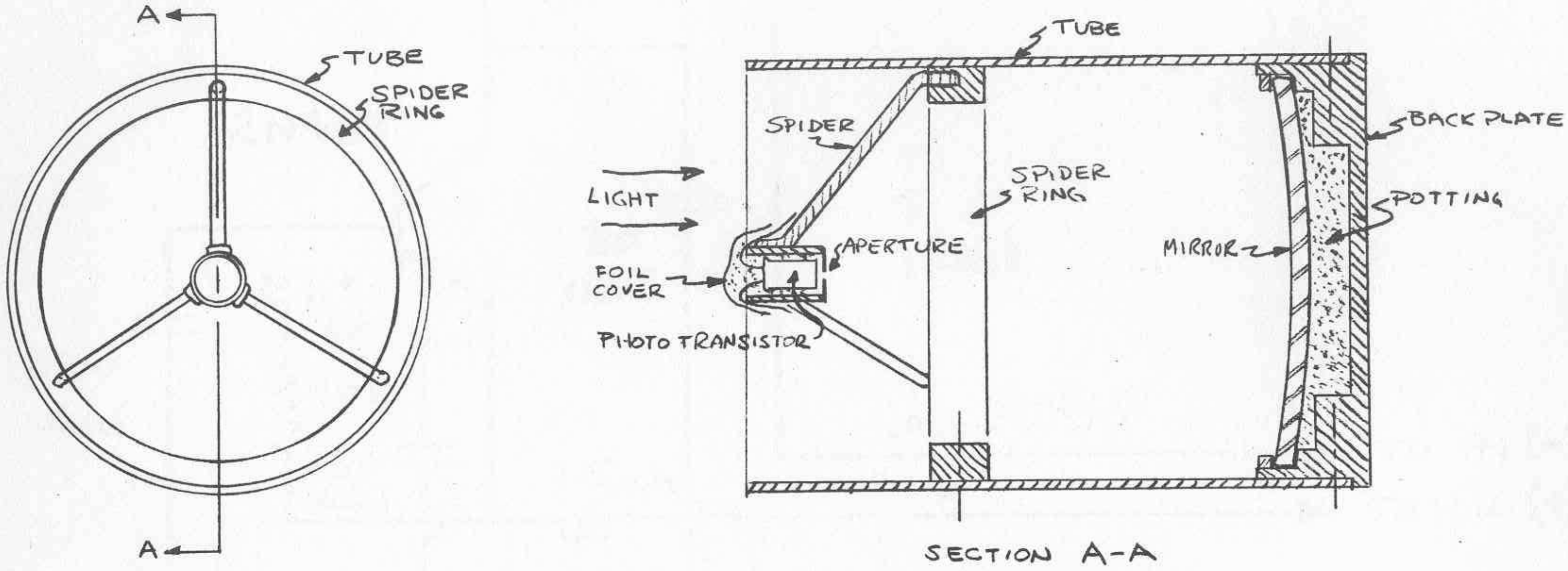


Figure 4. Sketch of Optical Unit Assembly.

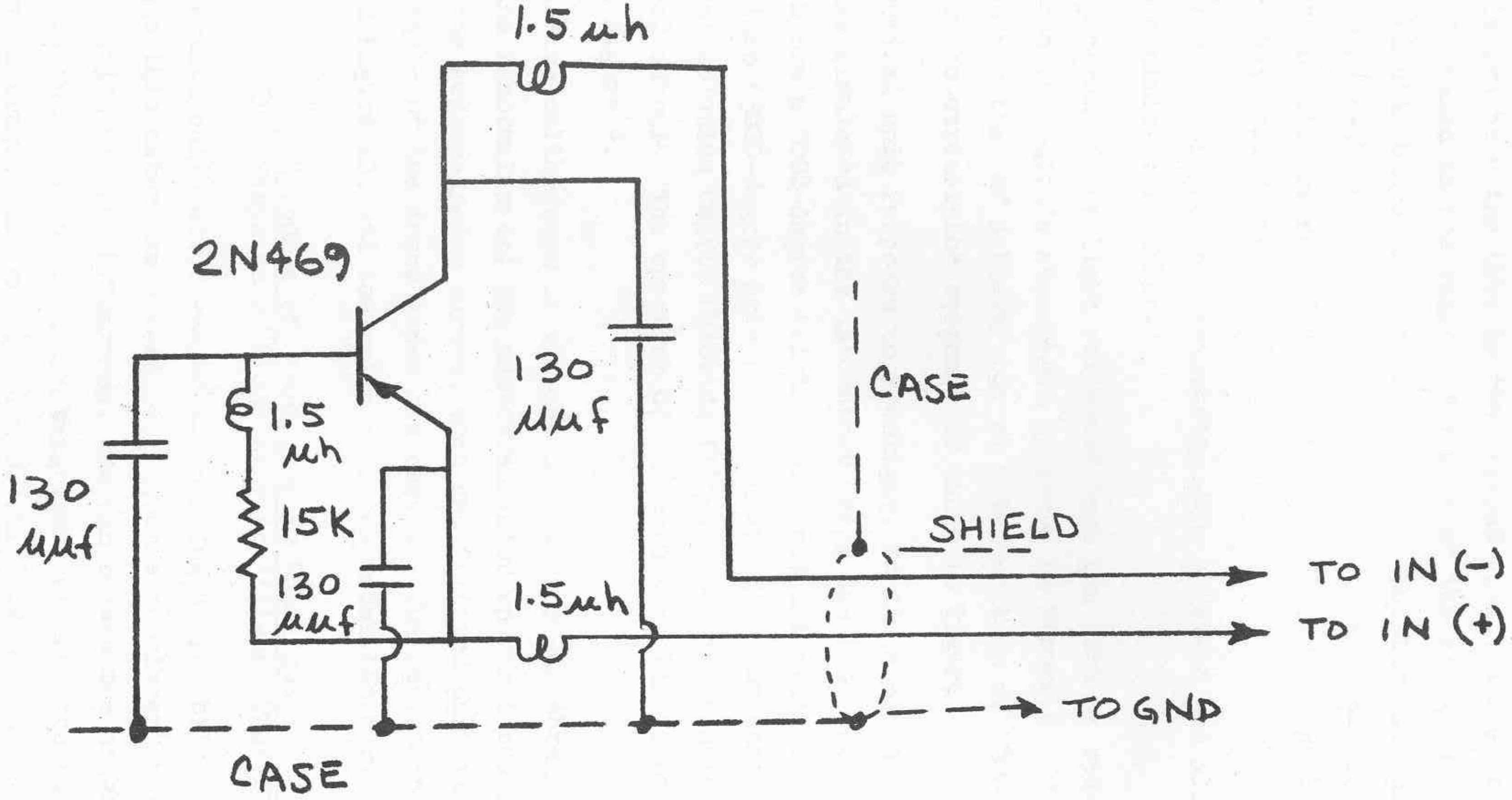


Figure 5. Schematic for the Optical Unit.

Two flanges held the tube to the payload shell, and a third mounting bracket fastened to the shelf. The side of the aluminum tube facing the hat was painted black to help maintain a temperature in the region of 70-degrees Fahrenheit. In addition, a piece of aluminum foil, cleaned before flight of all grease and dirt, was placed over the portion of the photosensor that looked into space.

All elements of the phototransistor were bypassed and all leads shielded to minimize r-f pickup.

The spectrum of the light reflected from the moon as seen by an observer above the earth's atmosphere is shown in Figure 6. This curve is approximately that of a black body at a temperature of 6000-degrees kelvin. The phototransistor response is shown in Figure 7.

The optical unit response to moonlight, in the absence of an atmosphere, was simulated in the laboratory using the test setup shown in Figure 8. Since a 6000-degree kelvin source was not available, a GE photoflood lamp (3000-degree kelvin) was employed in conjunction with a 2-1/2 percent solution Cupric Chloride filter 2-centimeters thick to reduce infrared output. The spectrum of the resulting laboratory source is shown in Figure 9.

A relative calibration of the phototransistor was obtained by multiplying (and renormalizing) the phototransistor spectral response curve by each of the source-system curves, moon and filtered photoflood, and taking the ratio of the areas under the curves. The resultant responses are shown in Figure 10, and the ratio of areas under the curves is

$$\rho_1 = \frac{\text{Response of Transistor to Moonlight}}{\text{Response of Transistor to Filtered Photoflood}} = \frac{2.32}{0.41}$$

An absolute calibration was obtained using a spot brightness (SB) meter. Since this meter has a spectral response consistent with the optical definition of spot brightness, one can relate the brightness of the laboratory source with the known brightness of the moon (about 1400 foot-lamberts average, full moon). The spectral responses of moonlight

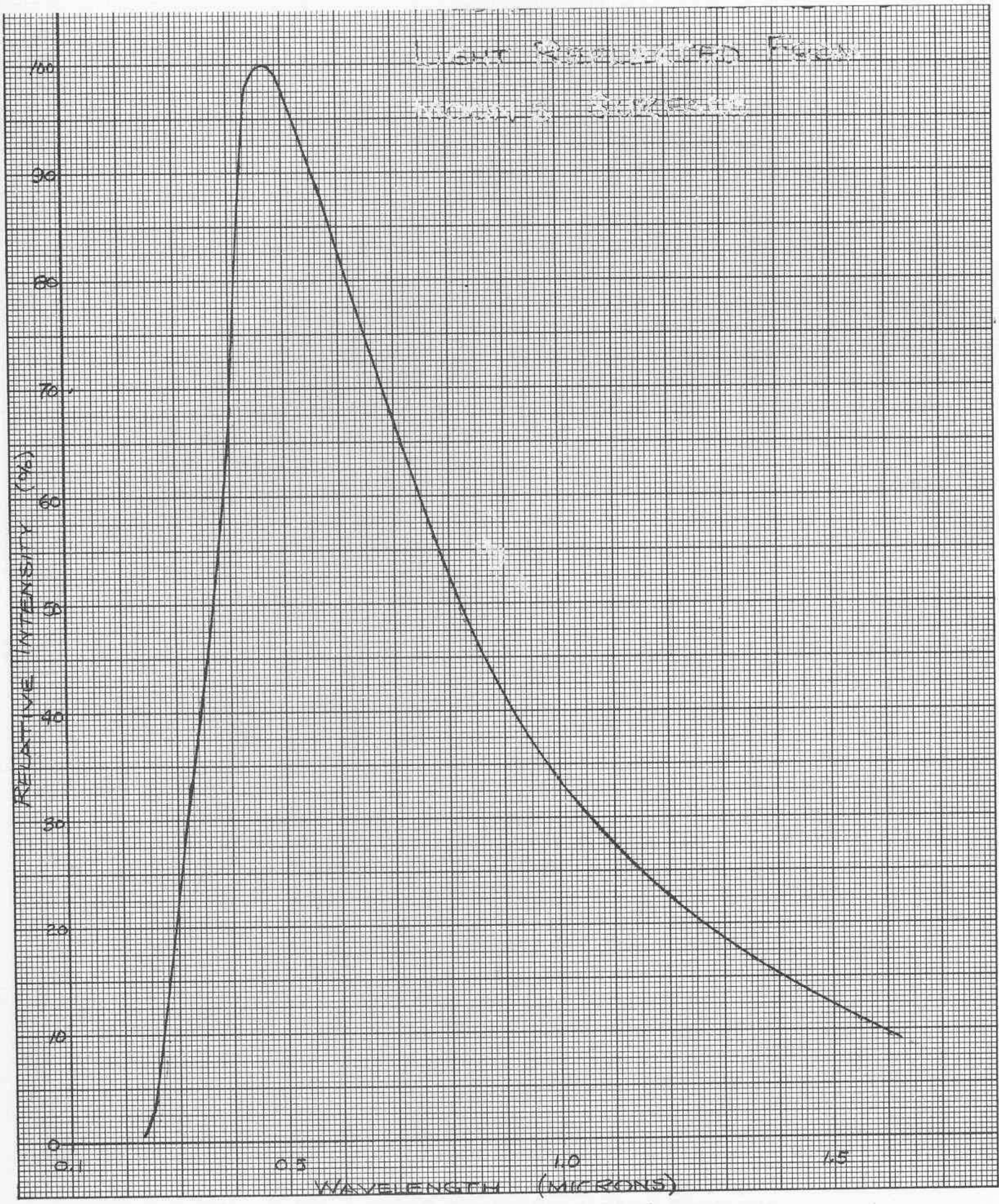


Figure 6. Spectrum of Light Reflected From Moon's Surface.

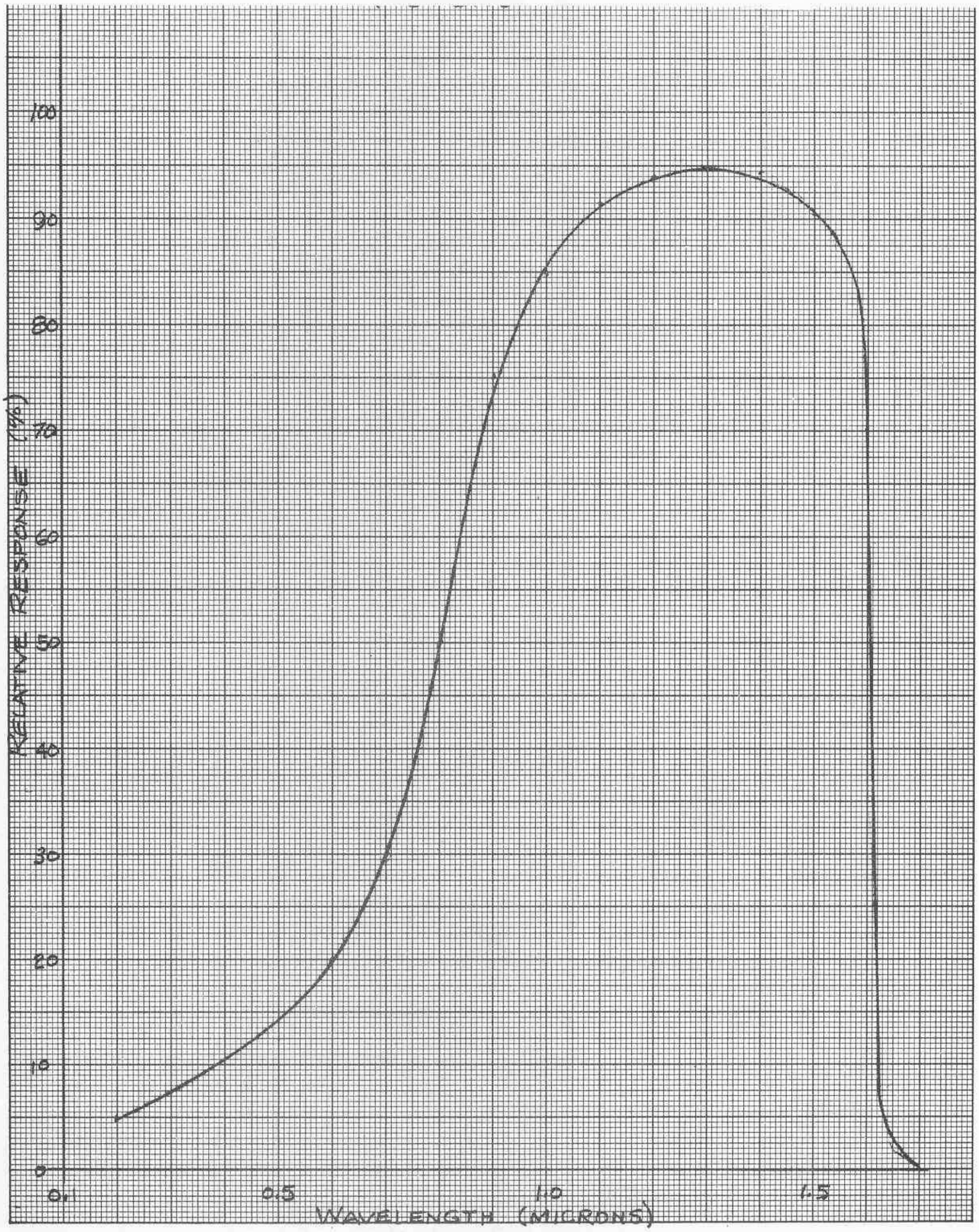


Figure 7. 2N469 Phototransistor Response.

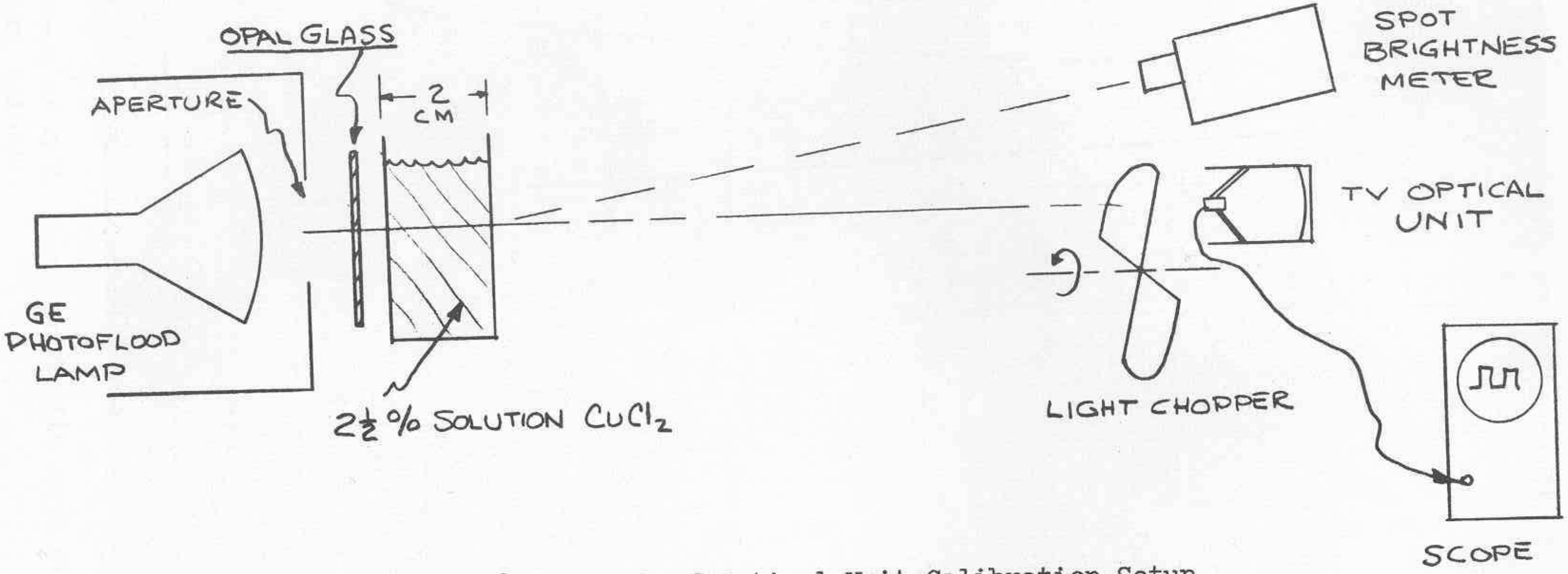


Figure 8. Sketch of Optical Unit Calibration Setup.

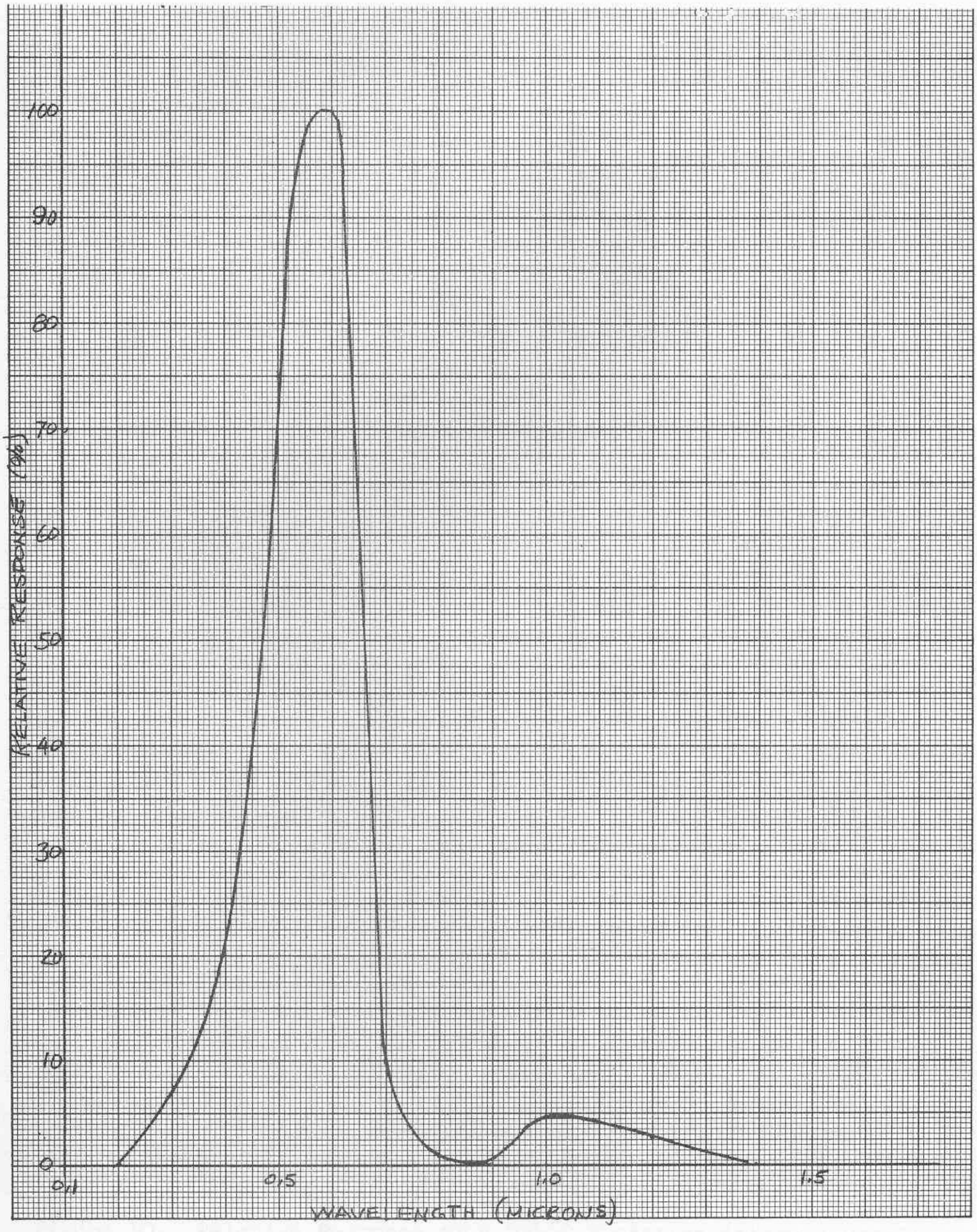


Figure 9. Spectrum of G.E. Photoflood with 2-cm Filter of $CuCl_2$, 2-1/2 Percent Soluble.

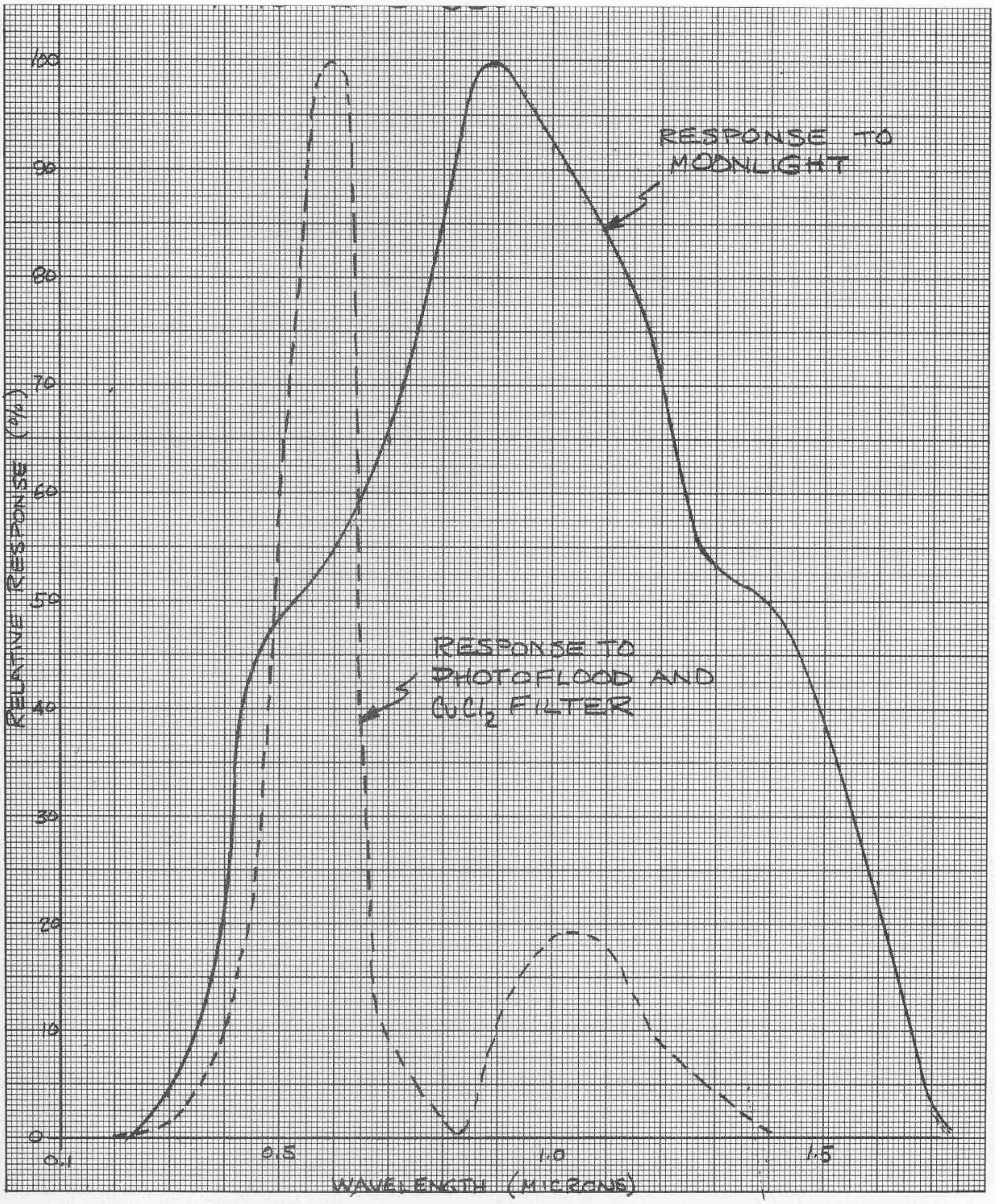


Figure 10. Relative Response of a 2N469 Phototransistor to Moonlight and Lab Source.

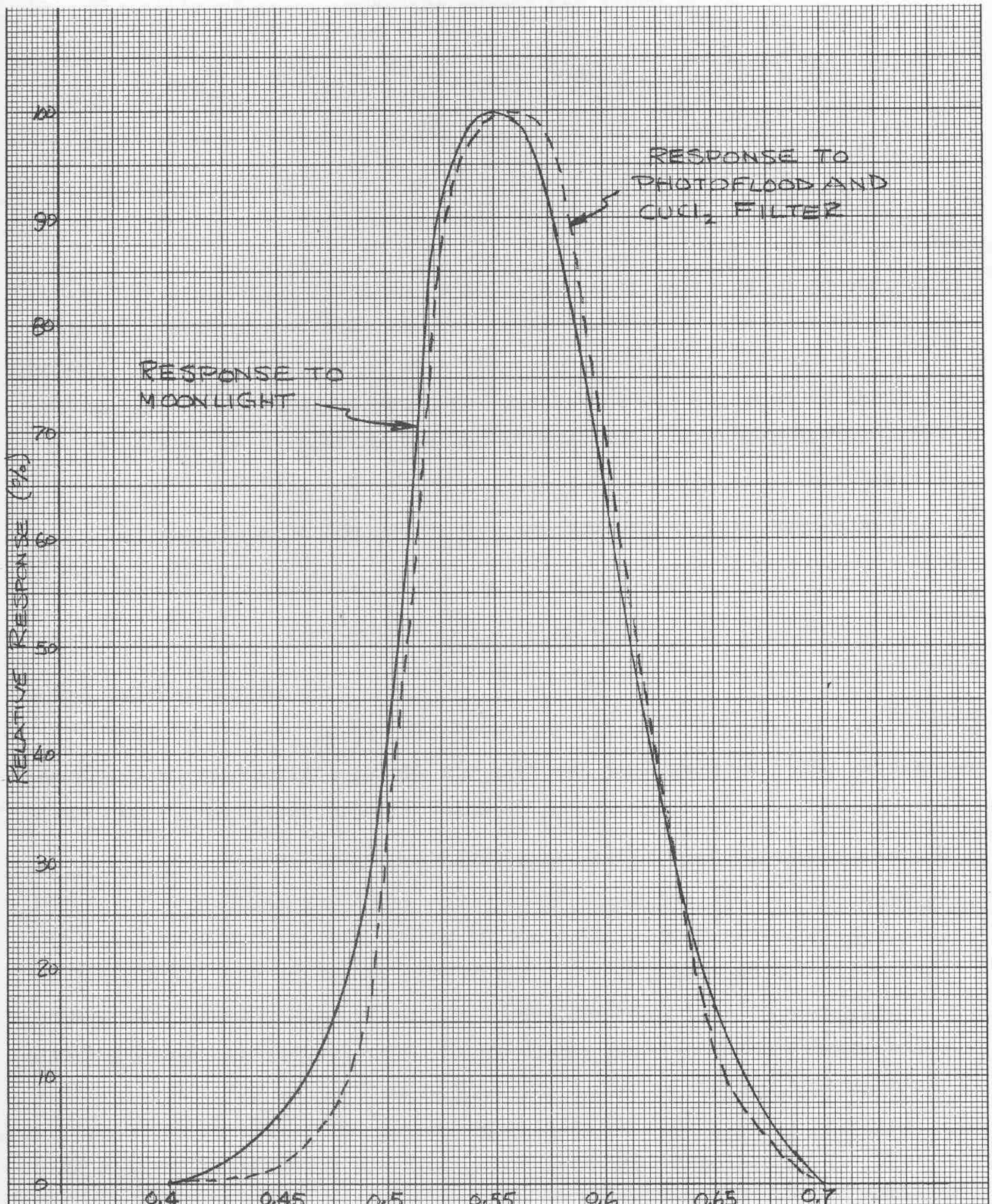


Figure 11. Response of Spot Brightness Meter to Moonlight and Lab Source.

and filtered photoflood as modified by the SB meter are shown in Figure 11. The ratio of areas under the curves was found to be

$$\rho_2 = \frac{\text{Response of SB Meter to Moonlight}}{\text{Response of SB Meter to Filtered Photoflood}} = \frac{0.90}{0.95}$$

The absolute calibration is found, then, by taking the ratio of ρ_1 and ρ_2

$$K = \frac{\rho_1}{\rho_2} = 6$$

Hence, the transistor response to moonlight is a factor of 6 greater than to the filtered photoflood lamp for equal readings on the spot brightness meter.To simulate moon brightness (in terms of phototransistor output voltage), the laboratory source spot brightness was adjusted to about 240 foot-lamberts by placing the photoflood lamp the proper distance behind the opal glass.

The variation of the moon's average brightness with moon phase is plotted in Figure 12.

6.0 ELECTRONICS

6.1 GENERAL DESCRIPTION

A block diagram of the electronics is given in Figure 13. Voltage waveforms at appropriate points are sketched in Figure 14. The electronic operation is described briefly below.

The video waveform generated by the optical unit was amplified and presented to a trigger circuit and a sampling gate. The initial rise of the video waveform, corresponding to the optical beam crossing the limb of the planet, was sensed by the trigger, which generated a rectangular pulse. The leading edge of the pulse was employed to turn on a free-running multivibrator (clock). Clock pulses were fed into a seven-bit scaler (scaler A), which counted down the clock pulses for the duration of the clock on-time. The count accumulated on scaler A was compared with a fixed count which previously had been read into scaler B. When

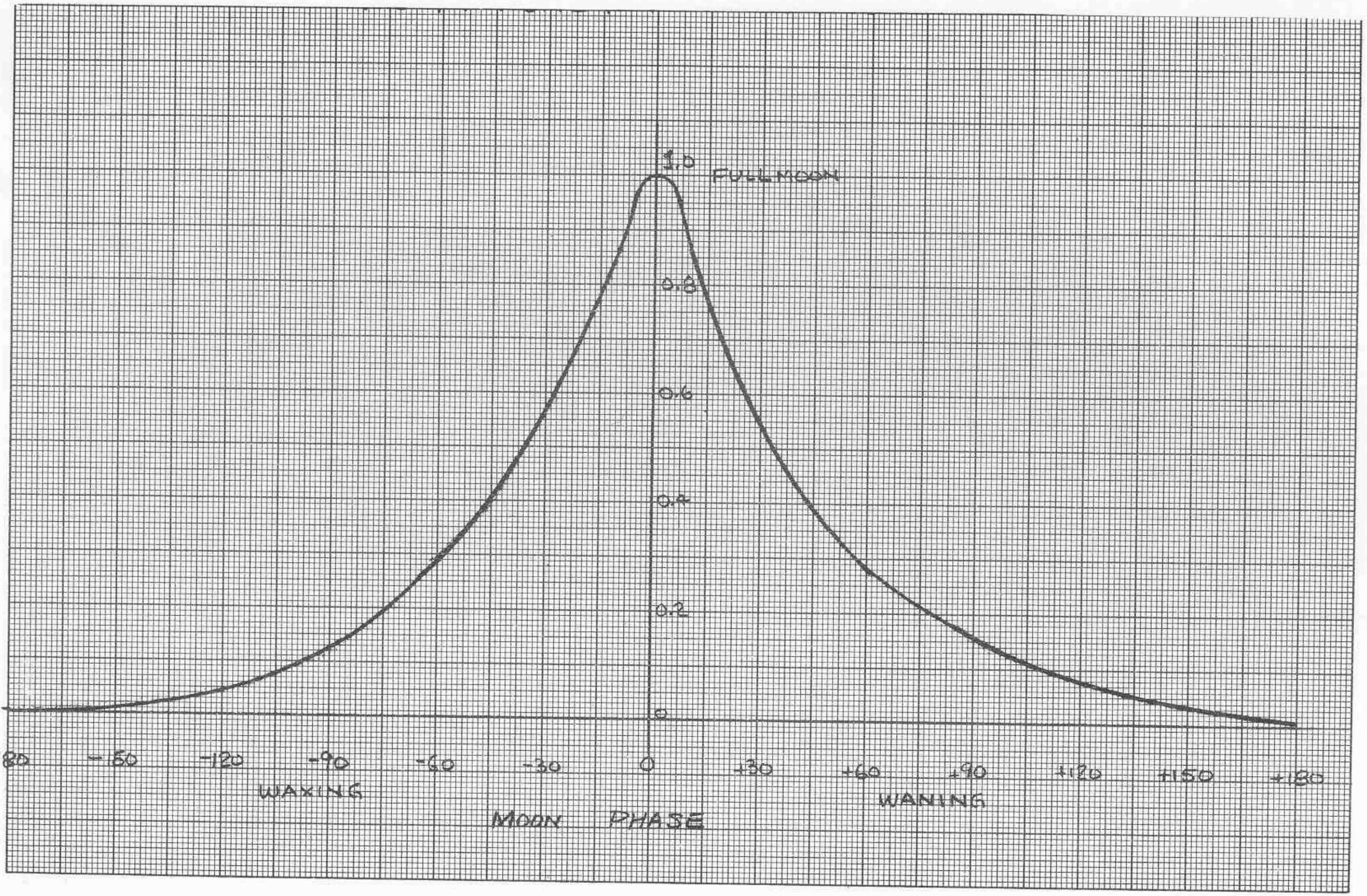


Figure 12. Relative Brightness of Lunar Surface as a Function of Lunar Phase.

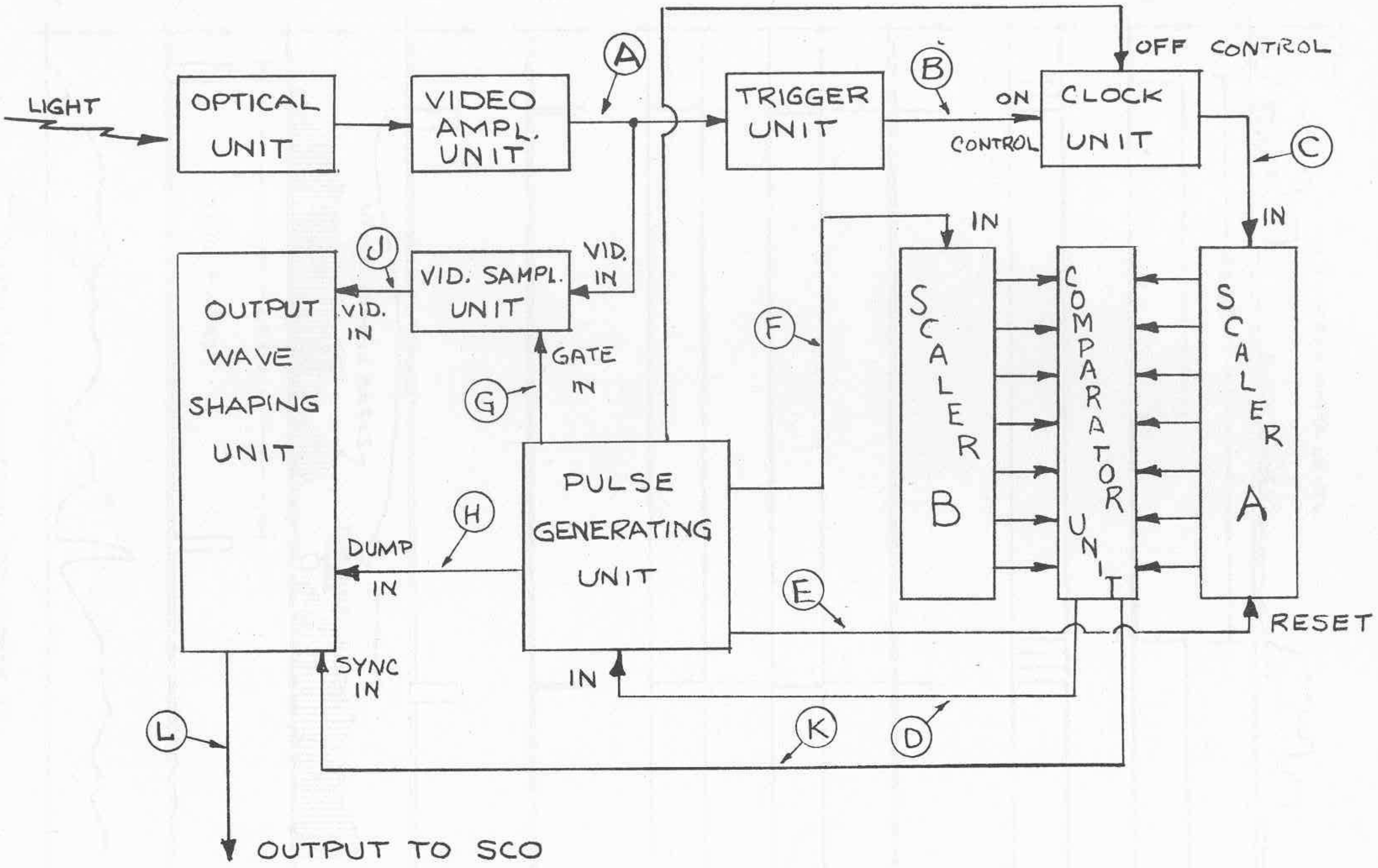


Figure 13. Block Diagram of TV System.

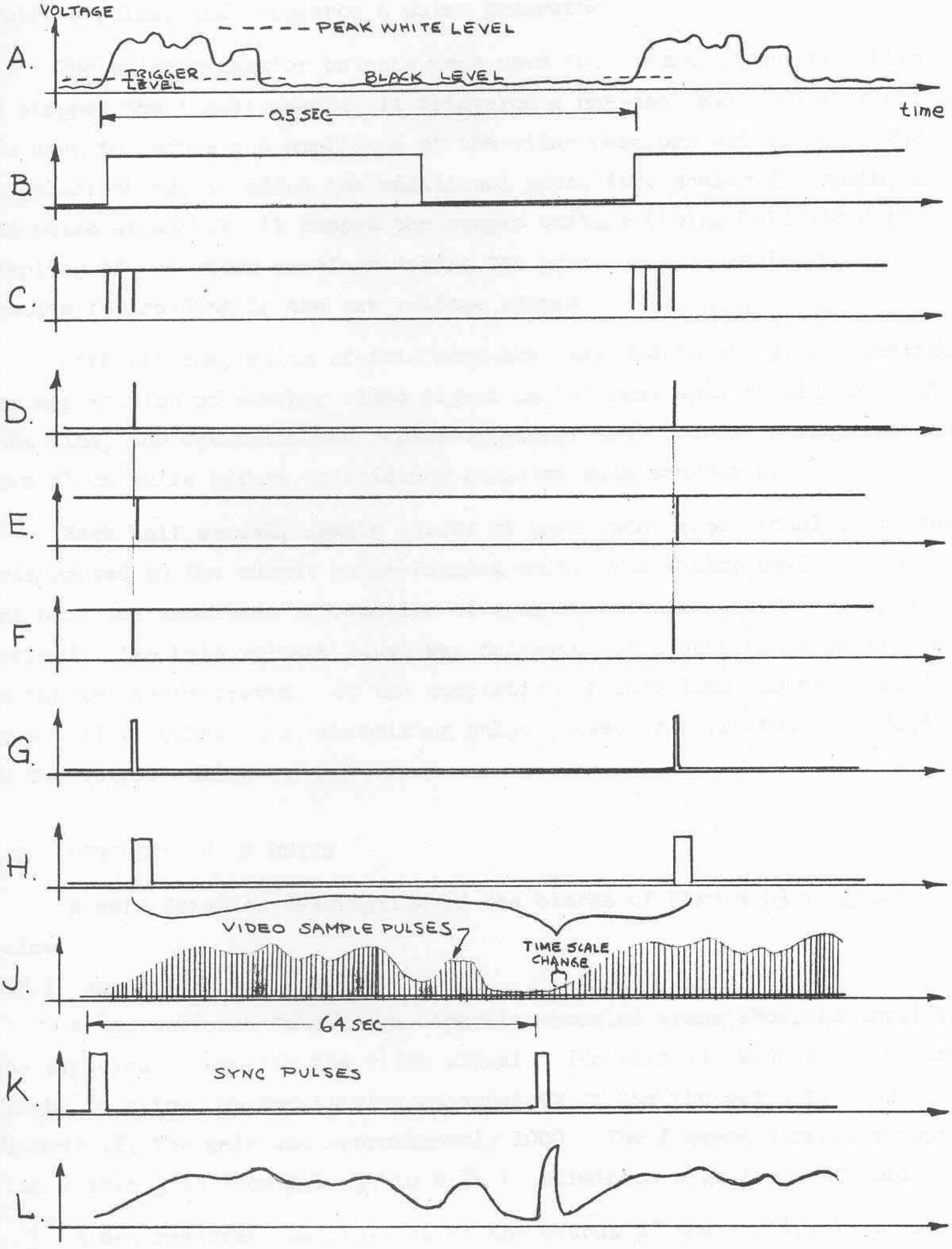


Figure 14. Waveforms for Figure 13.

the counts on both scalers exactly agreed, the coincidence circuit generated a pulse, and triggered a pulse generator.

The pulse generator outputs were used for several purposes. First, it stopped the clock; second, it triggered a one-shot multivibrator which was used to sample the amplitude of the video waveform and to reset the A scaler; third, it added one additional count into scaler B; fourth, in the pulse stretcher, it dumped the sample voltage (being held since the sampling of the video waveform during the previous spin cycle) in preparation for reading in the new voltage sample.

With the completion of this sequence, the electronic system awaited the application of another video signal on the next spin revolution. At that time, the operation was repeated, except that counter A required one more clock pulse before coincidence occurred with counter B.

Each half second, sample pulses of amplitude proportional to brightness routed to the output pulse-forming unit. The latter device read and held the amplitude information of each pulse until the next sample arrived. The held voltage level was delivered to a subcarrier oscillator in the telemetry system. At the completion of each line, as determined by a full B scaler, a synchronizing pulse (1-second duration) was added to the output voltage.

6.2 DESCRIPTION OF UNITS

A more detailed description of the blocks of Figure 13 is given below.

6.2.1 Amplifier

A conventional four-stage capacitor-coupled transistorized amplifier was employed to amplify the video signal. Its gain was adjustable before flight to allow for sensitivity uncertainty of the photosensor. For Pioneer II, the gain was approximately 1000. The frequency response was flat within 3 db from 0.1 cps to 2 kc to eliminate high-frequency noise.

A d-c restorer was provided at the output of the amplifier to maintain a reference black level independent of video waveshape.

The schematic for the amplifier and d-c restorer is shown in Figure 15.

6.2.2 Trigger

A Schmidt trigger and one-shot multivibrator were employed to initiate the clock. A schematic for this block is given in Figure 16. The purpose of the one-shot (1/4-second duration) was to prevent clock initiation twice in one spin revolution.

6.2.3 Clock Unit

The clock and clock control circuitry is given in Figure 17. The clock was a standard multivibrator using stable "West-Cap" capacitors in the feedback branches. One base resistor was returned to B plus when clock operation was desired and returned to ground when the clock was to be stopped. The clock frequency was 1440 cps.

The clock control was a standard flip-flop circuit with individual base controls.

6.2.4 Scalers A and B

Both scalers were identical, each consisting of seven bistable multivibrators (counters) shown in Figure 18. In each scaler, the counter units were wired in series, the output 1 of one counter feeding the input of the next.

The input to the first counter of scaler A was from the clock, and the input to the first counter of the scaler B from the pulse generator.

6.2.5 Comparator Unit

The comparator unit, shown in Figure 19, accepted the individual outputs of the counters from both scalers and compared the counts on scalers A and B. When these counts agreed, an output pulse was generated. In addition, a second coincidence pulse on a separate output line was generated during the last two (127th and 128th) counts read into scaler B. This 1-second sync pulse, marking the completion of a scan line, was fed to the output circuitry where it was mixed with the video signal.

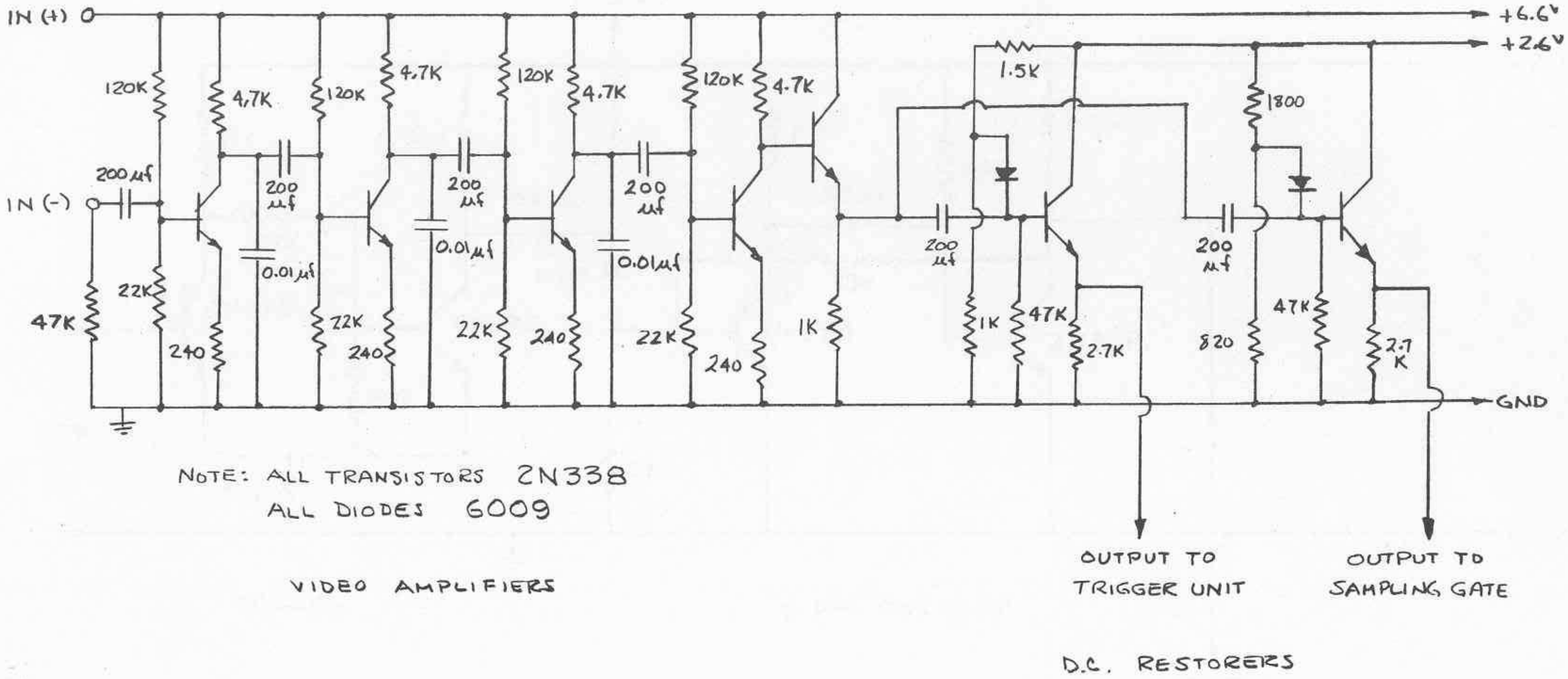


Figure 15. Video Amplifier and D-c Restorer Schematic.

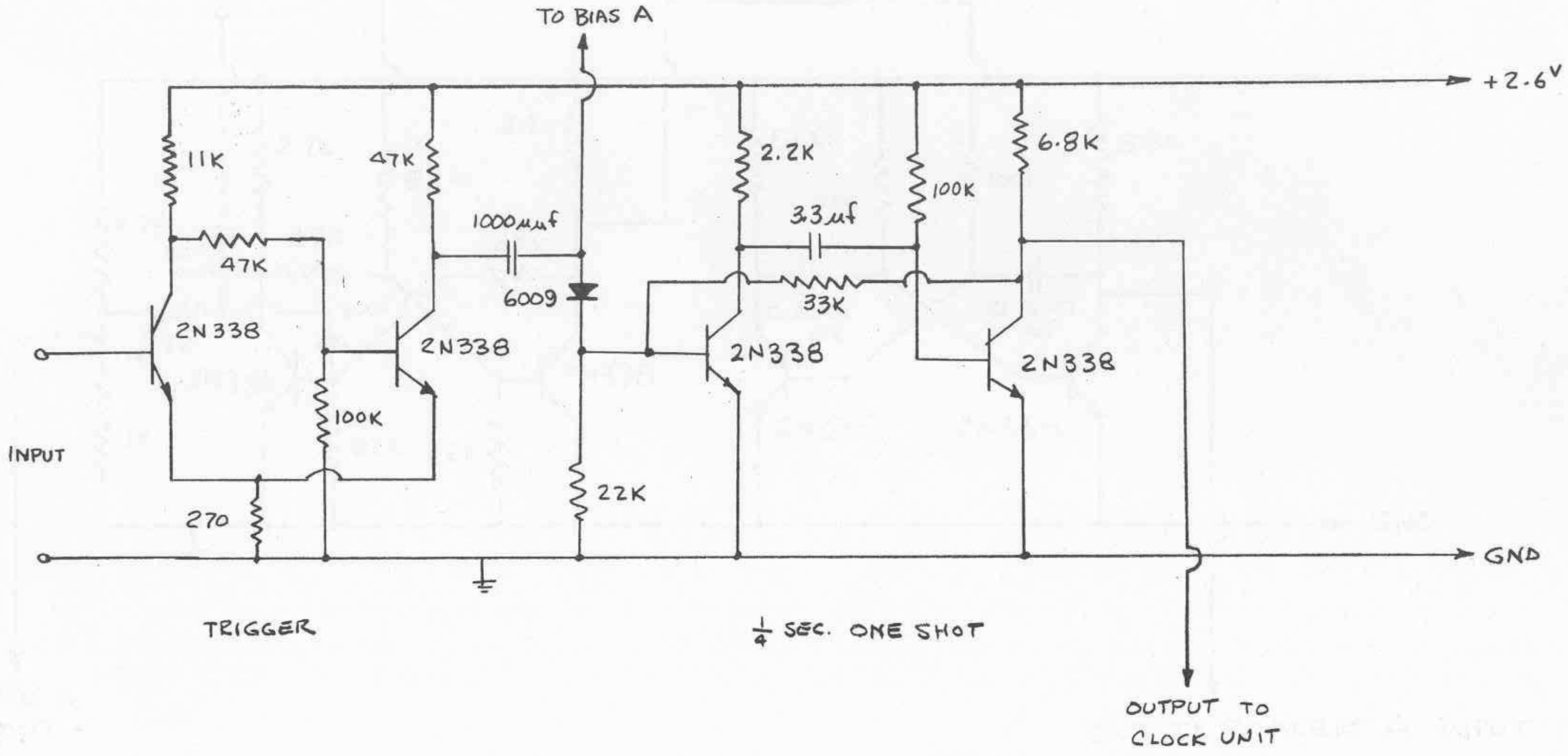


Figure 16. Trigger Unit Schematic.

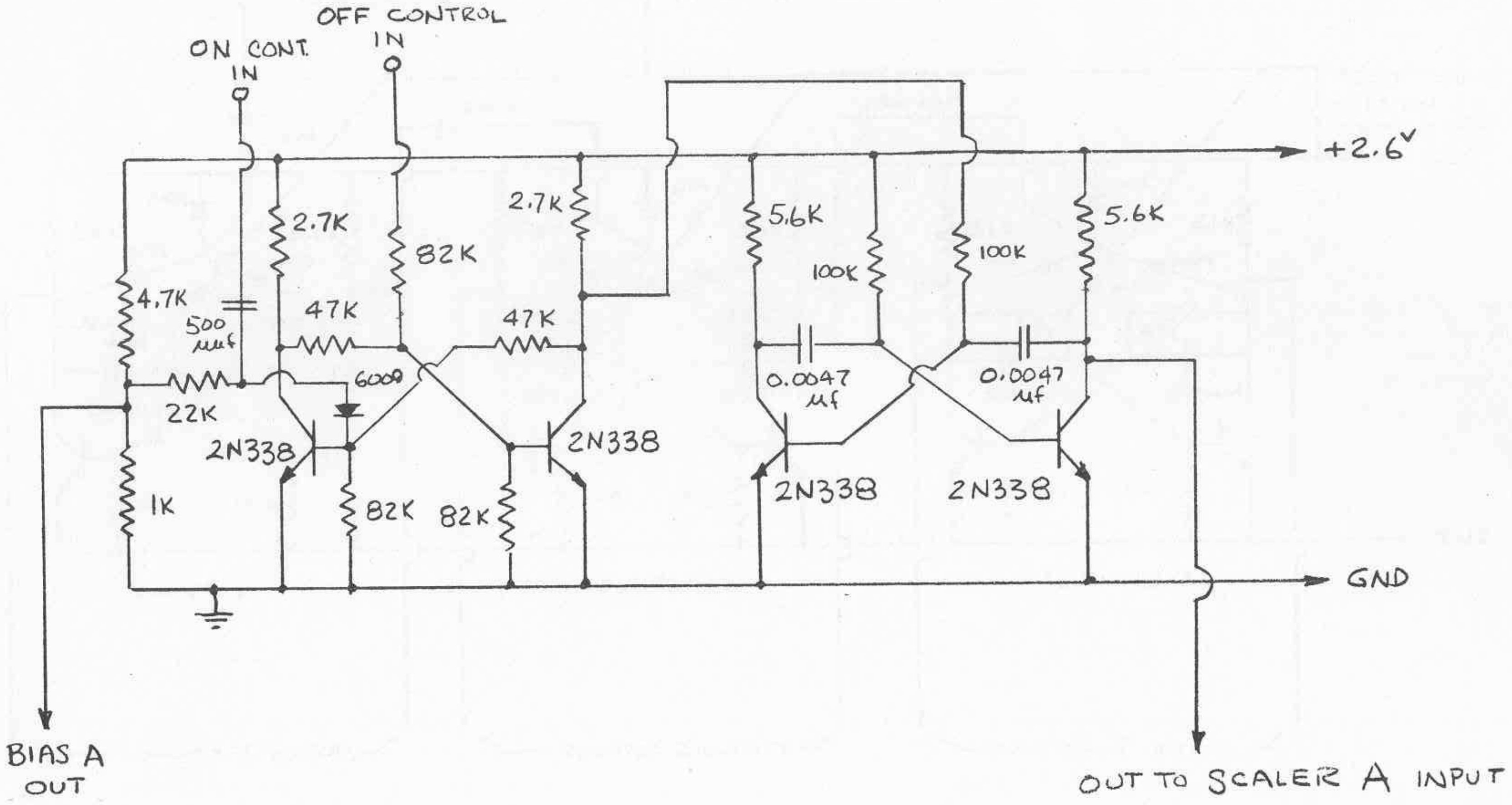
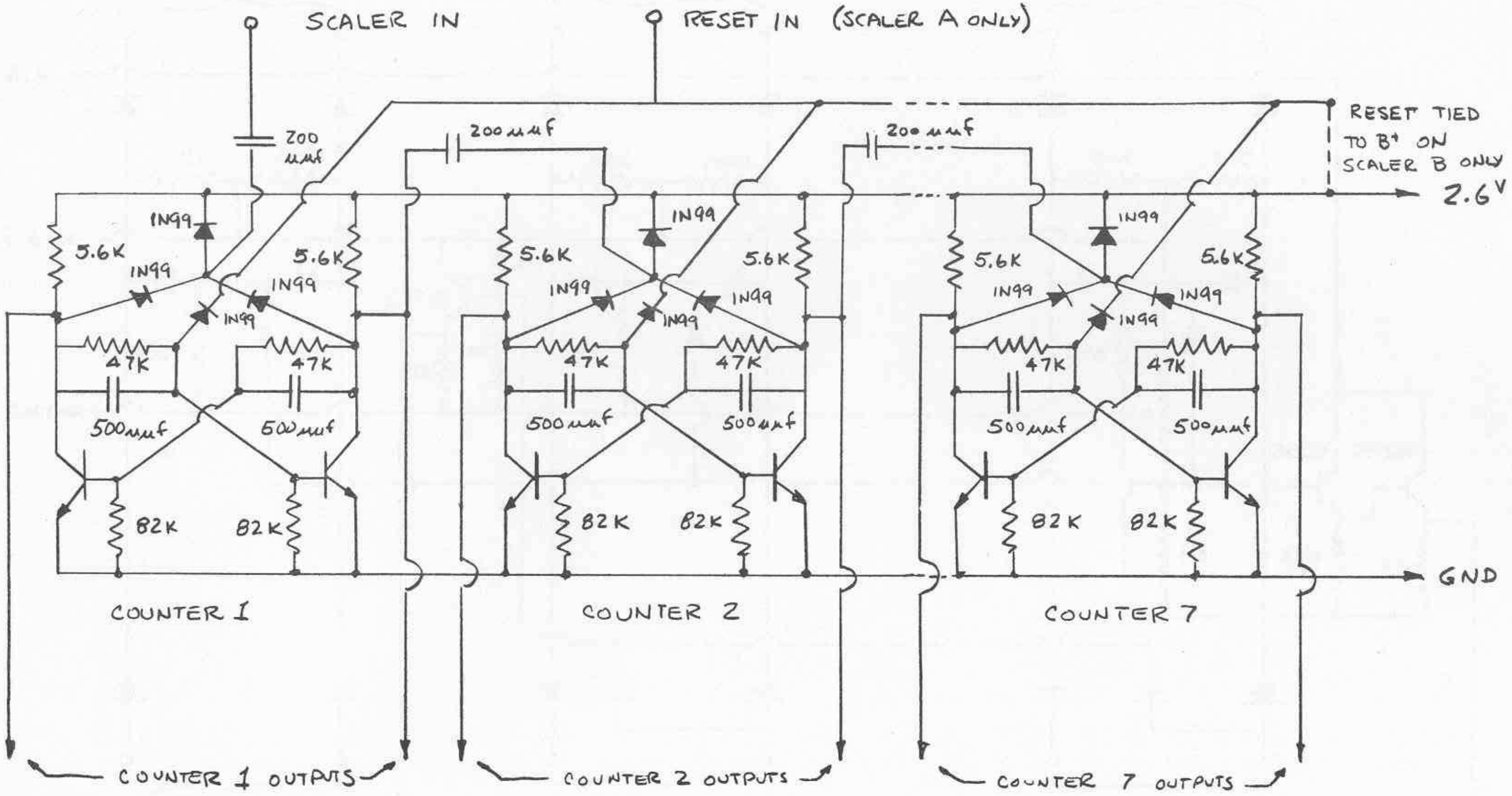


Figure 17. Clock Unit Schematic.



NOTE: ALL TRANSISTORS 2N338

Figure 18. Scaler Schematic.

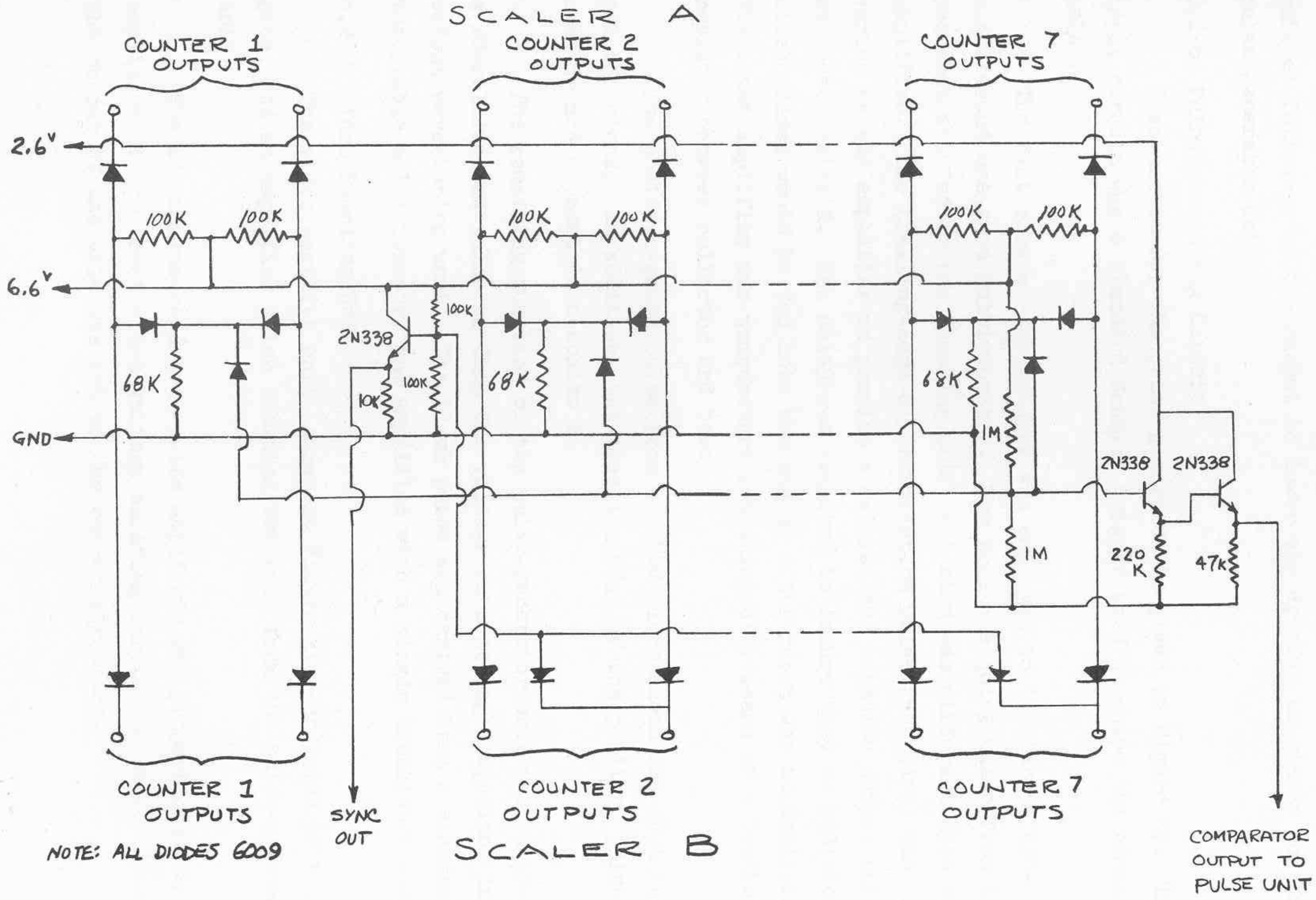


Figure 19. Comparator Unit Schematic.

Standard diode coincidence circuits make up the comparator, with emitter followers at the output to lower the driving impedance to the pulse generator unit.

6.2.6 Pulse-generating Circuit

A schematic for the pulse generator is given in Figure 20. The input circuit was a standard Schmidt trigger used to shape the comparator pulse.

The fast rise of the trigger was employed to initiate a 200-microsecond one-shot multivibrator. The negative-going pulse from the one-shot was fed to the sampling unit, and also was differentiated and amplified. The trailing-edge differentiation pulse (positive) was inverted by the amplifier to provide a delayed and negative output pulse to reset scaler A. The delay was required to insure that no additional clock pulses would be fed into the scaler after reset was accomplished. The reset amplifier was temperature compensated by means of a feedback resistor between collector and base.

The positive-going pulse from the 200-microsecond one-shot turned off the clock. In addition, the trailing edge of the positive pulse was used to add a count into scaler B.

The remaining function of the pulse-generator unit was to provide a 10-millisecond pulse to dump the voltage on a storage capacitor in the output waveshaping unit. The 10-ms pulse was derived from a standard monostable multivibrator, and amplified with a single transistor stage.

6.2.7 Video Sampling Unit

The video sampling unit, shown in Figure 21, consisted of a diode gate, and an amplifier which isolated the gate from the pulse-generating unit.

The 200-microsecond gate-pulse amplitude was proportional to the amplitude of the input video voltage existing for the pulse duration. The output of the gate was fed to the output circuitry.

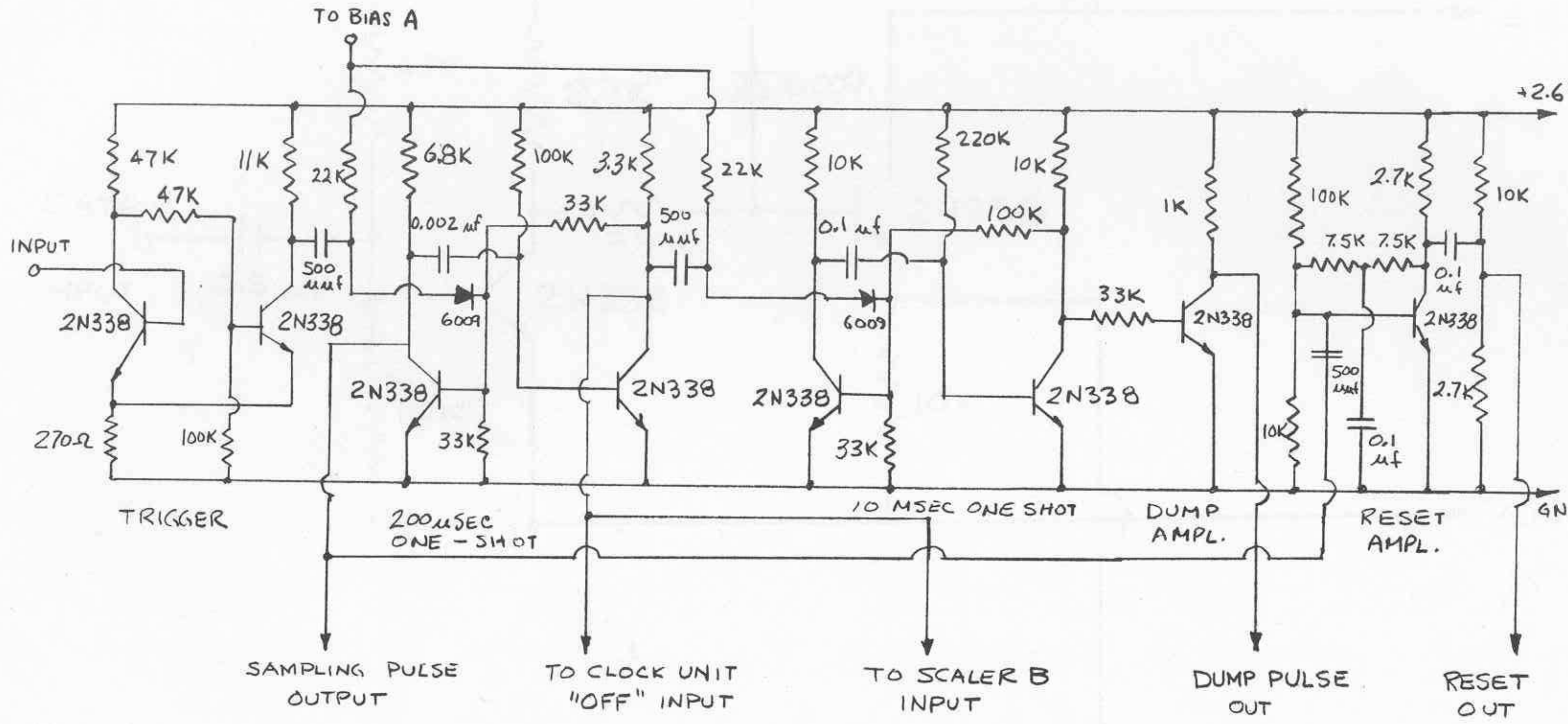


Figure 20. Pulse Generating Unit Schematic.

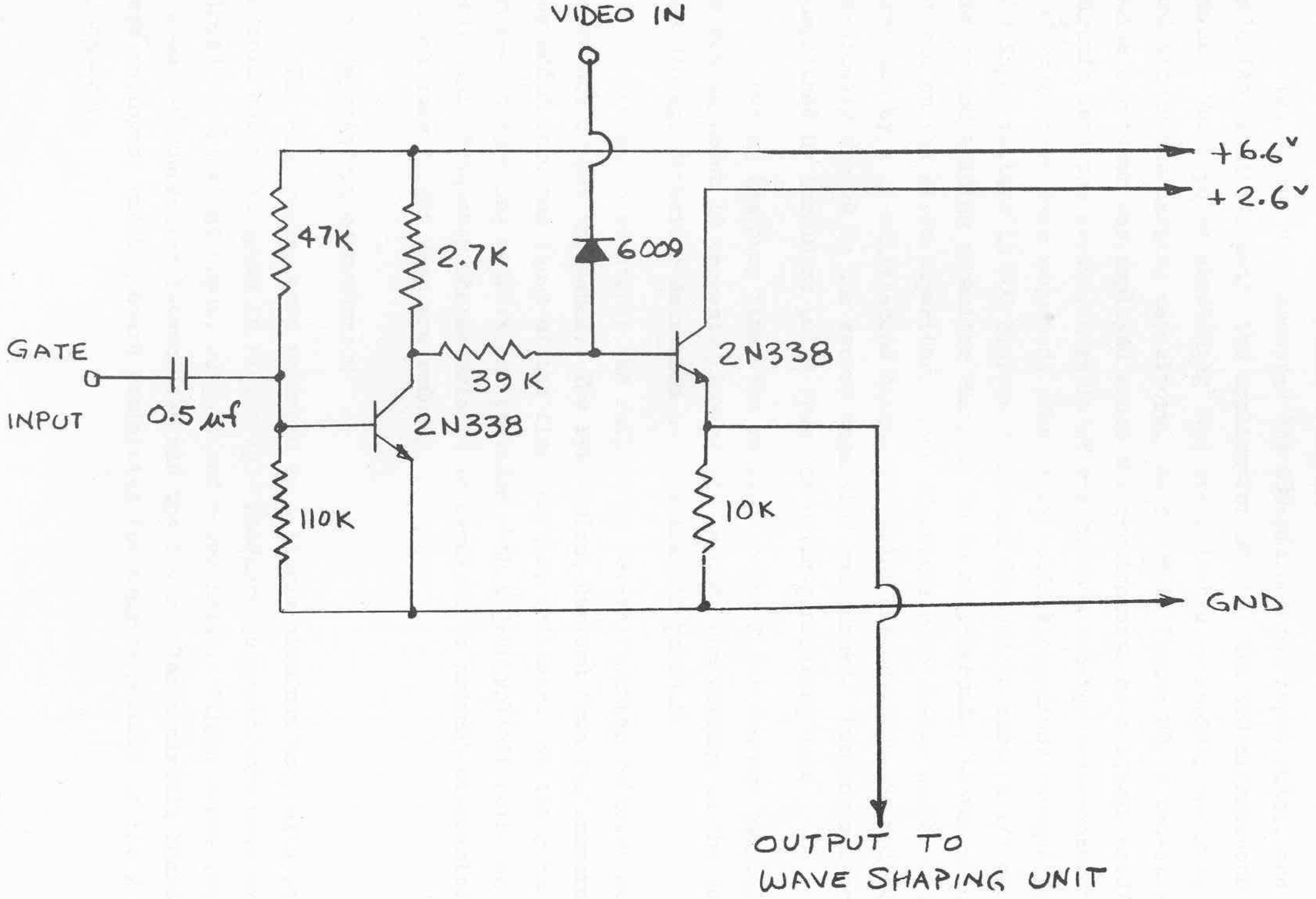


Figure 21. Video Sampling Unit Schematic.

6.2.8 Output Waveshaping Unit

The output unit accepted the 200-microsecond input pulse, and held its amplitude until the application of the next 200-microsecond pulse. This "pulse stretching" was accomplished by rapidly charging and slowly discharging capacitors. As shown in Figure 22, a two-stage pulse stretcher was employed since the requirements on a single holding circuit were too severe; a ratio of charge-to-discharge resistance of 10^5 would have been required. The first holding capacitor charged to the input voltage in 200 microseconds, and decayed to zero in 1/2 second. The second holding capacitor charged, in 10 milliseconds, to the value stored on the first capacitor. This 10-microsecond charge period was preceded by a 10-millisecond discharge period during which the voltage previously stored on the second capacitor was dumped. Dumping was accomplished by the 10-ms pulse from the pulse-generating unit.

During the dump time, the voltage on the first storage capacitor decreased about 10 percent. During 1/2 second, the voltage on the second storage capacitor decreased no more than 10 percent.

The pulse stretcher was follwed by several emitter-follower stages to reduce output impedance. The sync pulse, derived from the comparator, was added into the input of the final emitter follower. At the output, an r-c integrating network was provided with a 3-db rolloff point at 1 cps. This frequency characteristic is required to prevent discriminator unlock when flight data are reduced.

6.3 MECHANICAL CONSTRUCTION

The electronics were packaged in a single aluminum can, with removable cover, as shown in Figure 23. Feedthrough capacitors were employed to bring out input, output, and power leads. Finger stock insured a good r-f connection between can and the cover. Three circuit boards were employed, the top board containing the counter modules of the A and B scalers.

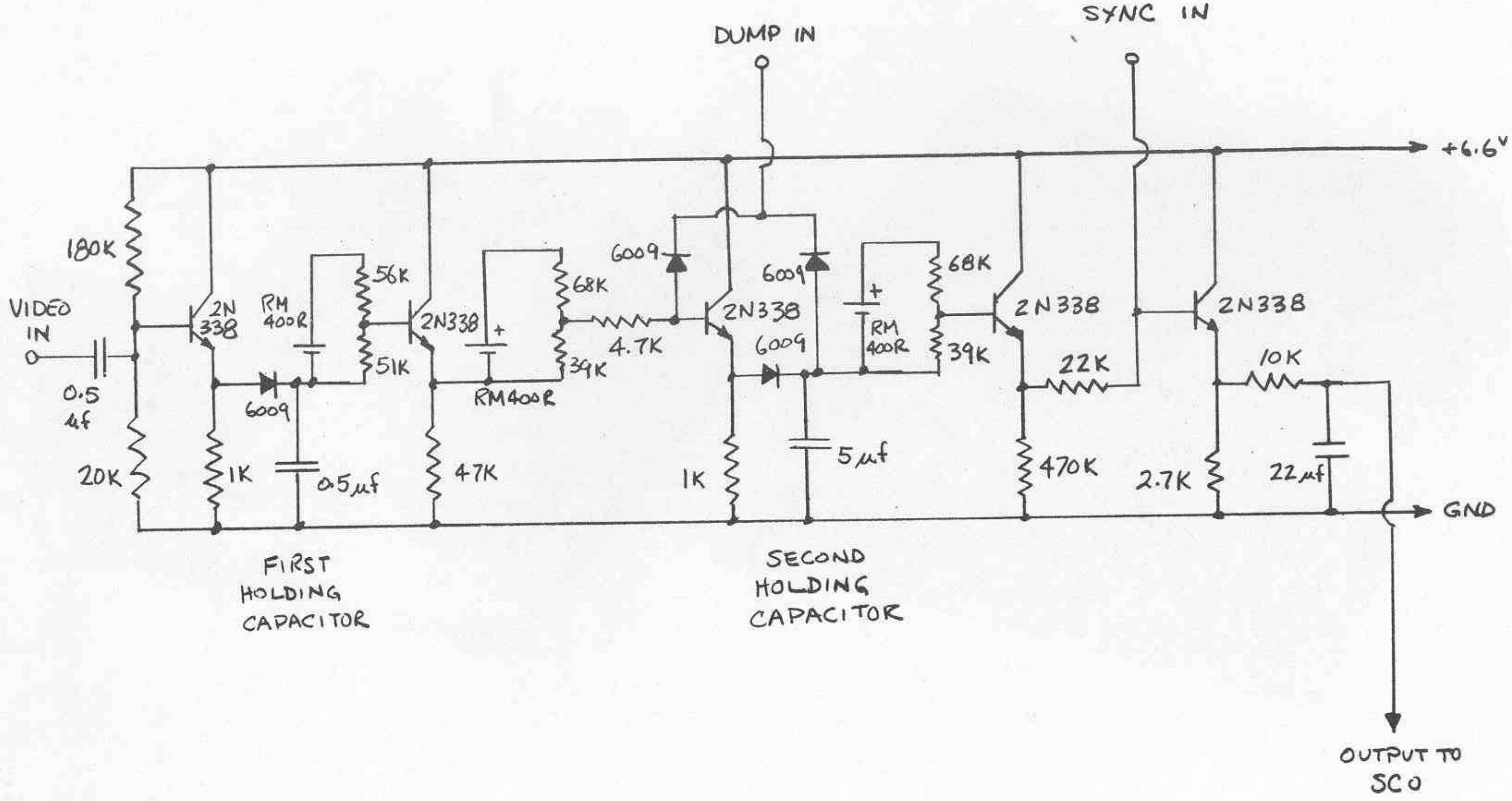


Figure 22. Output Wave Shaping Unit Schematic.

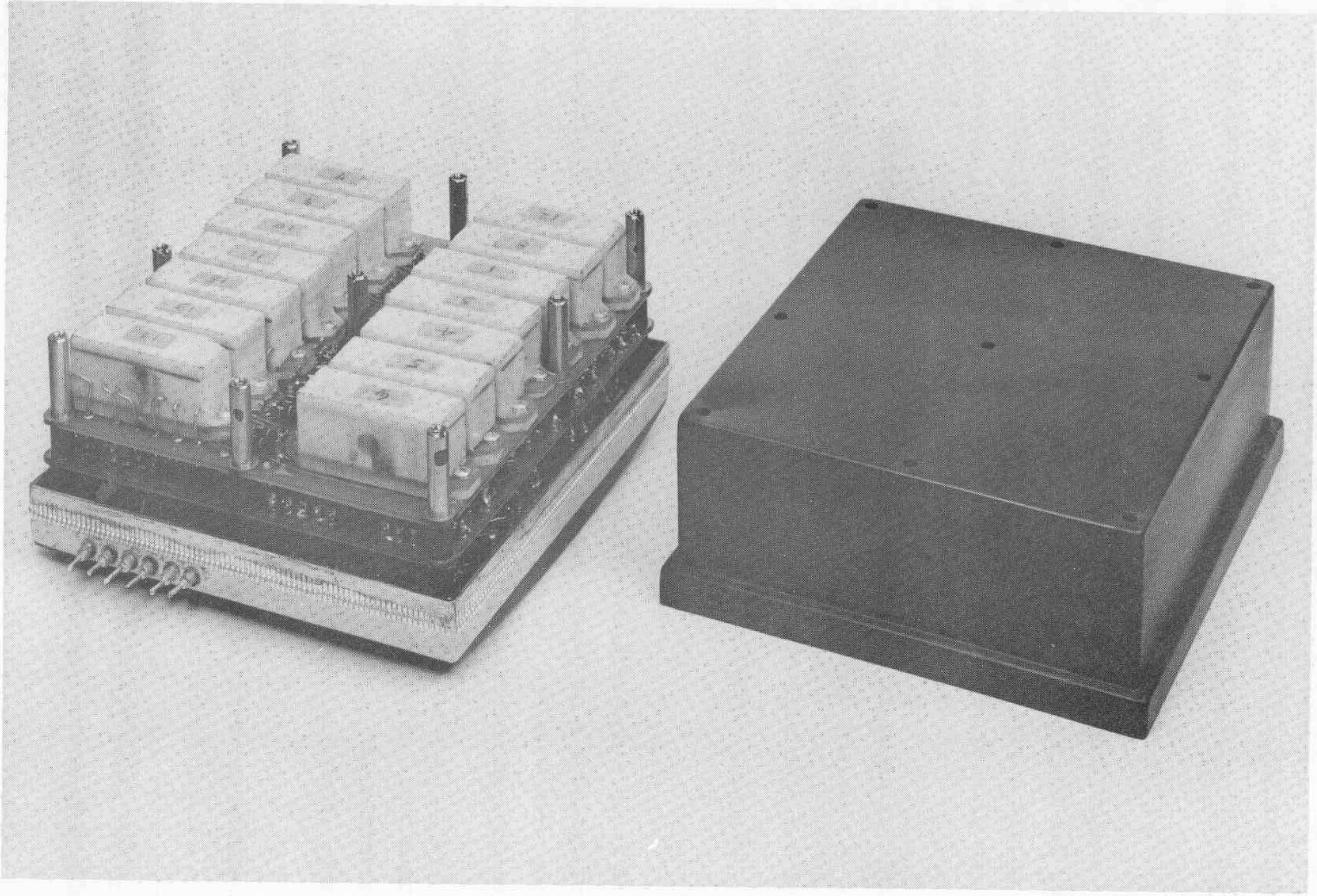


Figure 23. TV Electronics Package.

All circuit boards were designed with printed wiring, and coated with epoxy as a precaution against the effects of moisture. The boards were fastened to the can, at nine points, by bolts and black anodized aluminum spacers.

6.4 FLIGHT BATTERY PACK

The flight battery pack employed seven RM 12R mercury cells. Two voltages were provided; 2.6 volts by two cells in series, and 6.6 volts by five cells in series. The current drains for each series string were approximately 15 milliamperes. Total life of the battery packs was about 240 hours.

The batteries were mounted on an epoxy board, as shown in Figure 24, which attached to the bolts holding the circuit boards.

R-f chokes were placed in each B-plus line to eliminate r-f interference.

7.0 SYSTEM CHECKOUT

A test pattern, sketched in Figure 25, was drawn on a heavy cardboard sheet, 39 inches by 39 inches. It was placed in a vertical frame illustrated in Figure 26. A motor, shaft, pulley, and wire arrangement allowed a slow, continuous motion of the test pattern in the vertical direction, simulating vehicle motion along its trajectory.

The optics unit was placed before a rotating double-sided mirror, providing optical beam scanning across the test image. The mirror revolution rate was 1 rps, in simulation of the 2-rps vehicle spin. A sketch of the test setup is shown in Figure 27.

The output of the TV electronics was used to intensity modulate the beam of an oscilloscope. The scope sweep was adjusted so that it completed a sweep just prior to the TV line completion. Each scope sweep was initiated by the TV sync pulse. The scope vertical sweep was provided by a slowly varying d-c voltage from a helipot driven by a 1/16-rpm motor.

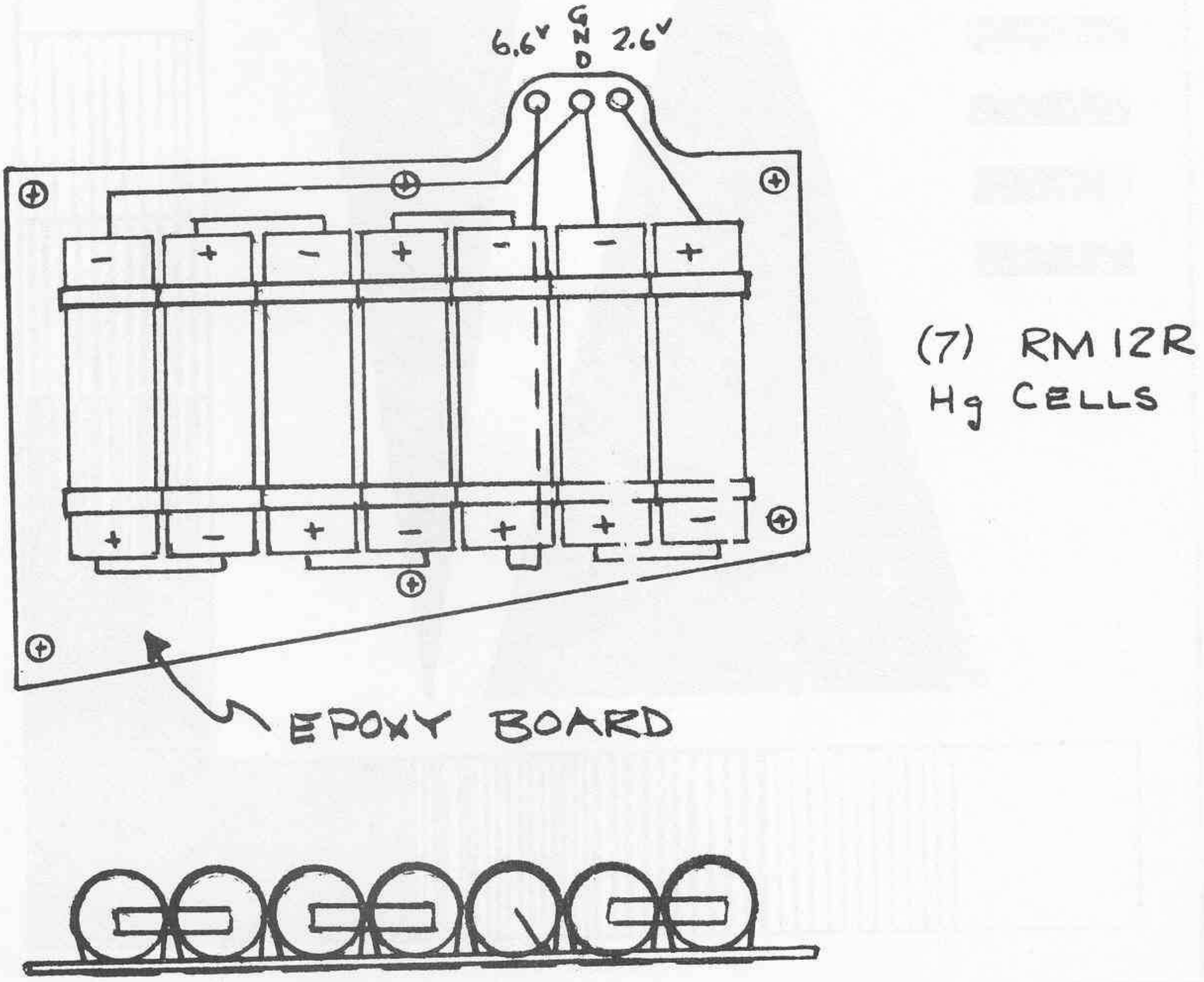


Figure 24. Sketch of Battery Pack.

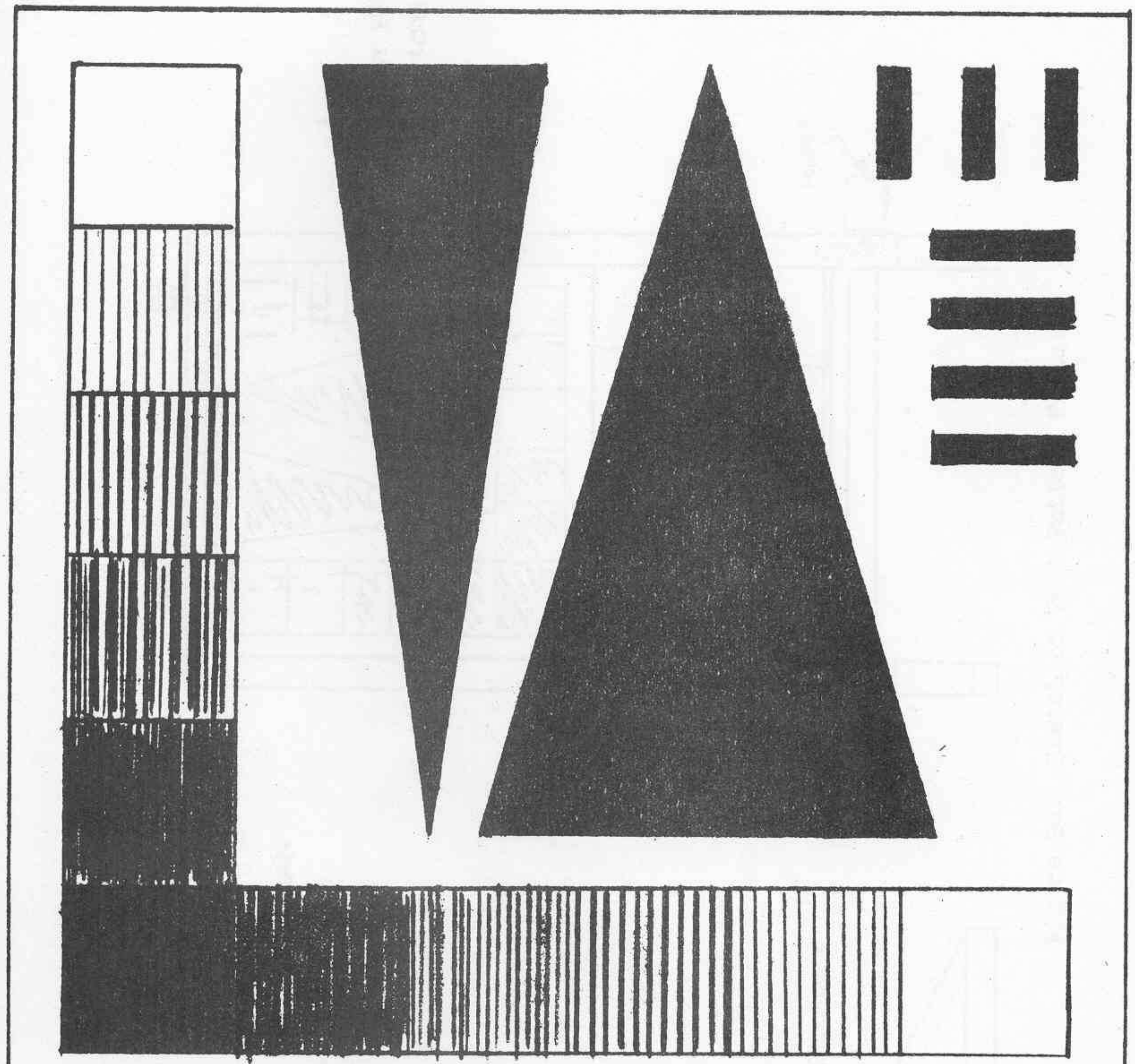


Figure 25. Sketch of Test Pattern.

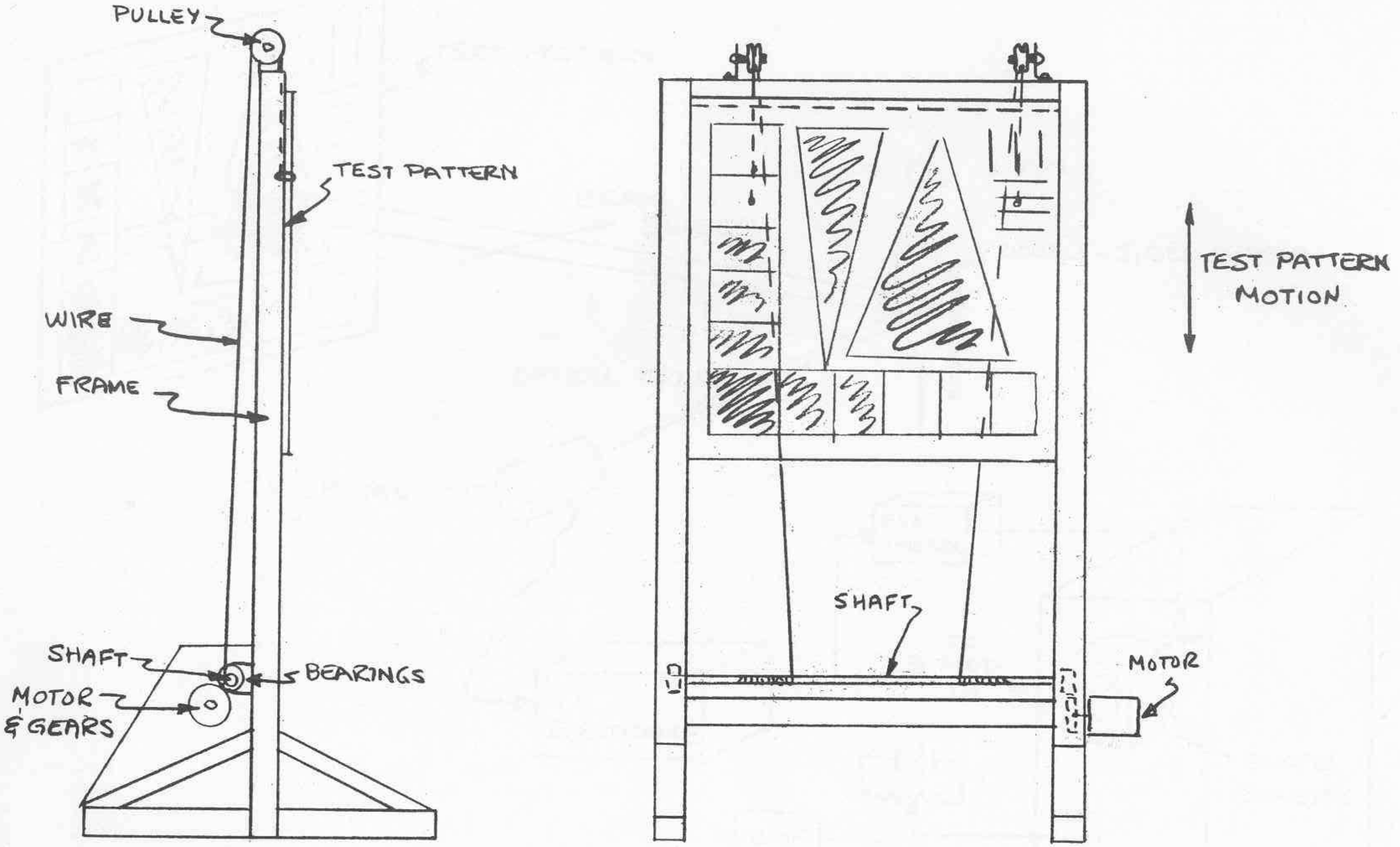


Figure 26. Sketch of Test Pattern Frame.