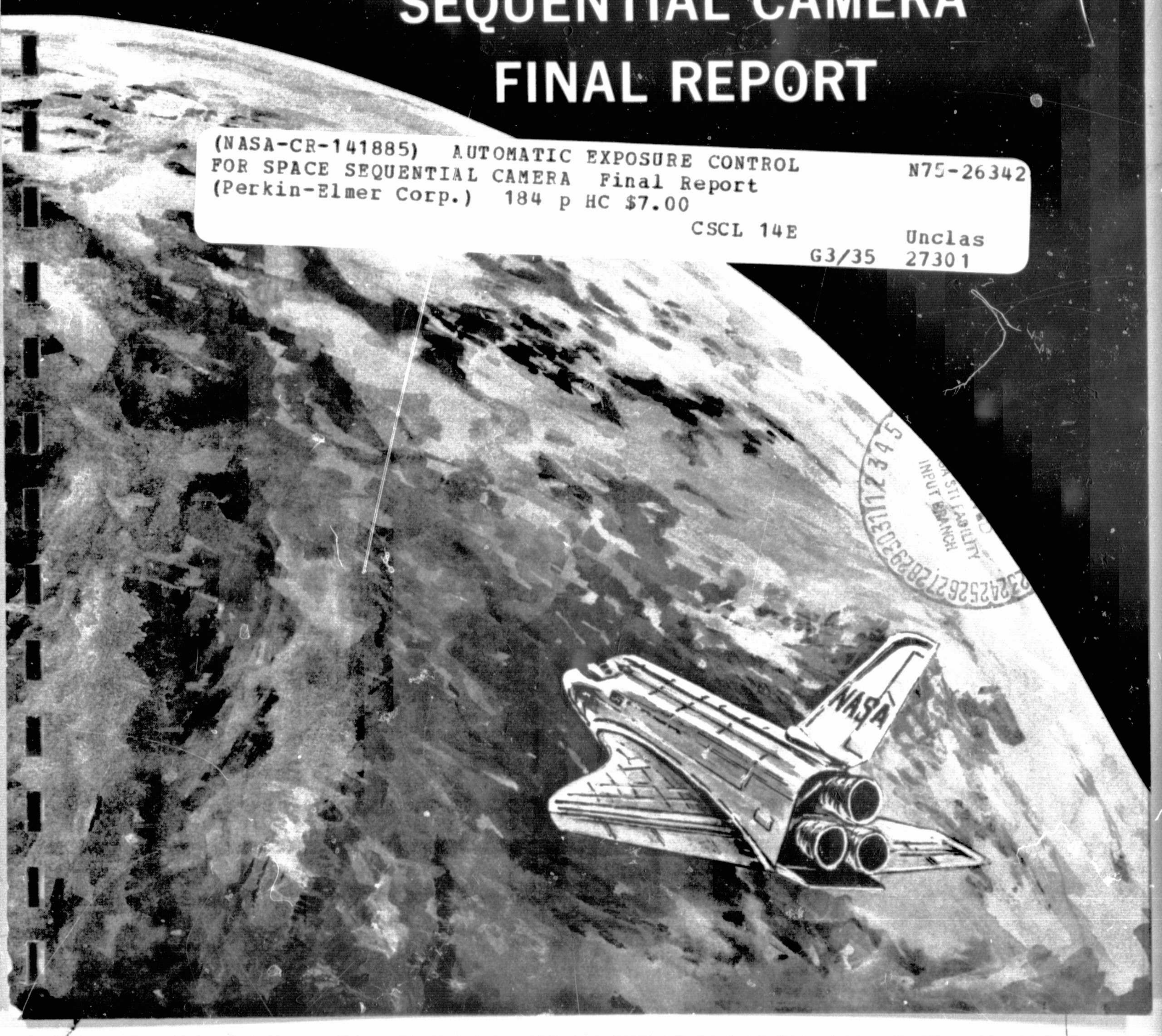
PERKIN-ELMER
AEROSPACE DIVISION

NASA CR-
141885

SPACE SHUTTLE
AUTOMATIC EXPOSURE CONTROL FOR SPACE SEQUENTIAL CAMERA
FINAL REPORT

(NASA-CR-141885) AUTOMATIC EXPOSURE CONTROL FOR SPACE SEQUENTIAL CAMERA Final Report (Perkin-Elmer Corp.) 184 p HC $7.00 CSCL 14E
N75-26342
Unclas
G3/35 27301



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AUTOMATIC EXPOSURE CONTROL FOR SPACE SEQUENTIAL CAMERA FINAL REPORT

by

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April 1975

Perkin-Elmer SPO 30284
NASA Contract Number NAS9-12790

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Johnson Space Center
Houston, Texas 77058

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1.0 INTRODUCTION

This document is the final report for the automatic exposure control study for space sequential cameras, under NASA contract number NAS9-12790, conducted by the Perkin-Elmer Corporation, Aerospace Division, Pomona, California for the Johnson Space Center. The material is presented in the same sequence that the work was done under the contract.

The purpose of the automatic exposure control (AEC) is to automatically control the lens iris as well as the camera shutter such that the subject is properly exposed on the film. It is the goal of the AEC that the full brightness range of the subject be recorded within the high slope region of the film sensitometric curve.

Task 1 of the contract was the study of design approaches. Analysis of the light range of the spectrum covered indicated that the practical range would be from approximately 20 to 6,000 foot-lamberts, or about nine f-stops. Observation of film available from space flights showed that optimum scene illumination is apparently not present in vehicle interior photography as well as in vehicle-to-vehicle situations. Section 2.0 of this report presents the study of approaches to the solution of this problem.

Task 2 of the study was the design of a demonstration breadboard based on the conclusions of the study of approaches. This design incorporates the following features:

a. Automatic compensation for film sensitivity.

b. Capability in the electronics to provide coded photometric data which can be presented to a camera data block.

c. Control of shutter and iris adjustments with separate stepping motors and controls.

d. Remote operation capability without degradation in accuracy or reliability.

e. Manual or automatic operation.

Section 3.0 of this report describes the breadboard design.

Section 4.0 includes the evaluation test procedure for the breadboard, and the results, which verified the validity of the AEC approach which was selected, and provided information for the design of a brassboard.

Section 5.0 is the proposed end item specification for the automatic exposure control system for the 16mm data camera for manned space flight.

Certain critical electronic and electromechanical parts were evaluated by environmental testing for suitability for use in the automatic exposure control camera. A description of the tests and results are covered in Section 6.0. The results of these tests clearly indicated that certain components, such as the stepping motors, are totally acceptable for this application, while others, notibly the potentiometers, would not be satisfactory. This led to the selection of a totally new approach for the position feed back transducers, specifically digital encoders.

Section 7.0 summarizes electronic and mechanical design changes which were made to the breadboard during its development, to provide improvements indicated from the development of the hardware. These design changes provided substantial improvement in the operation of the automatic exposure control.

From the results of the study, and experience from the breadboard testing, a brassboard of the automatic exposure control system camera was designed to test the system concepts and mechanical components in a package size and weight which would typify the space hardware. This brassboard incorporated all the improvements determined during the prior phases of the program, but with the electronic circuits packaged in a separate control box without regard to minimum size and weight. This design, designated Task 6 of the study, is described in Section 8.0.

Section 9.0 reports the results of evaluation tests of the brassboard.

Section 10.0 covers Perkin-Elmer's conclusions drawn from the results of this study.

2.0 DESIGN APPROACHES

System Considerations

Light Study.- The basic features of the space photographic problem in the earth-moon region are discussed in the following paragraphs. The emphasis, of course, is on features which are important to Automatic Exposure Control. First, the principal sources of illumination are identified and a systematic method of estimating their importance is outlined. The principal sources include the sun, moon, earth and the photographic platform. Artificial illumination is also important inside a spacecraft cabin.

The illumination of the subject by these sources is calculated for representative space photographic conditions. For the illuminance calculations, the subject brightness (luminance), subject contrast and the background contrast can be determined.

Several subject and background geometry categories are noted and examples from past space photography are presented. Geometric factors are sometimes a cause of serious exposure error when a photodetector is used to measure the subject brightness (or luminance). The problem is especially serious when the scene contrast is high, a situation which often occurs in space photography.

Illumination Sources.- Space photography and conventional daylight photography share the single most important source of illumination in the solar system, the sun. However, unlike conventional daylight photography, space photography usually does not have the benefit of atmospheric scatter, or skylight, to fill in and soften the shadows. This is the cause of the harsh, severe contrast which frequently occurs in space photography.

Contrast, of course, is very important in AEC. When the brightness range of the subject exceeds that which can be recorded on the film, correct exposure is not possible. If the exposure is set to record the highlights, the shadows are lost; if the exposure is set for the shadows, the highlights are washed out. In general, exposure becomes more critical and more difficult as the subject contrast increases.

Fortunately, there are many photographic situations in the earth/moon region of space where significant amounts of reflected light are available to fill in and soften the shadows. The earth, moon and the photographic platform can act as important sources. Figure 1 shows the geometric parameters which are needed to determine which sources are in a position to contribute.

The photographic platform is always in a perfect position to reflect light into the shadows. The earth and the moon are more subtle. Generally, these bodies are more effective fill light reflectors when they are in the opposite hemisphere (centered at the subject) from the sun. This condition is met when the scalar product between their unit vector and the sun unit vector is negative.

Another important consideration is whether the reflective body contributes front, side or back lighting to the subject. (Back lighting is not very useful in filling shadows.) The front and side lighting conditions can be expressed in terms of scalar products between the source unit vector and the camera unit vector.

The optimum shadow fill condition for the moon or earth occurs when the body is on the same side of the subject as the camera and on the opposite side as the sun. This condition and the above conditions for front and side lighting, expressed in scalar product form, are summarized in Table 1.

TABLE 1.- Source Lighting Criteria

Illumination Source	Front Lighting Criteria	Side Lighting Criteria	Optimum Shadow Fill Criteria
Sun	$\vec{U}_s \cdot \vec{U}_c \geq 0.5$	$\lvert \vec{U}_s \cdot \vec{U}_c \rvert < 0.5$	
Moon	$\vec{U}_m \cdot \vec{U}_c \geq 0.5$	$\lvert \vec{U}_m \cdot \vec{U}_c \rvert < 0.5$	$\vec{U}_m \cdot \vec{U}_c > 0$ and $\vec{U}_s \cdot \vec{U}_m < 0$
Earth	$\vec{U}_e \cdot \vec{U}_c \geq 0.5$	$\lvert \vec{U}_e \cdot \vec{U}_c \rvert < 0.5$	$\vec{U}_e \cdot \vec{U}_c > 0$ and $\vec{U}_s \cdot \vec{U}_e < 0$

The photographic platform can be the astronaut while holding the camera, or the spacecraft on which the camera is mounted. While the platform is always in the best direction for reflecting sunlight into the subject shadows, it can provide a significant amount of illumination only when it is close to the subject. The earth and the moon, because they are much larger, can provide significant shadow illumination at much greater distances.

The illuminance of a space subject by the sun, the moon, and the earth is estimated in the following discussion. The calculations assume that the subject presents a flat surface with its normal pointing directly at the source.

<u>Subject Illuminance by the Sun</u>.- The illuminance from the sun in the earth/moon region is well represented by the solar constant, 1.57×10^5 lux.

Subject Illumination by the Moon.- A precise estimate of the subject illuminance when the subject is very close to the moon is complex. However, by assuming that the moon's integrated phase curve is satisfied at large distances and that the moon is approximately lambertion at moderate altitudes (5000 kilometers) the following expression is useful:

$$E_M = K_M f_M (\alpha_m)(1 + h_M/r_M)^{-2} \tag{1}$$

where:

E_M is the target illuminance in lux

K_M is the constant, to be determined

f_M is the moon's integrated phase curve, normalized

α_M is the moon's phase angle as observed from the subject

h_M is the altitude of the subject, above the moon's surface

r_M is the moon's radius

Equation (1) can be used at altitudes below 5000 kilometers provided a reasonable error can be tolerated

The moon's integrated phase curve is tabulated in Table 2.

The value of K_M was determined two different ways with two different results, differing by a factor of approximately 2. Since a sure way of selecting the most accurate value was not available, both are presented.

Method 1: The lunar constant is defined as the illuminance of a flat surface at the earth's surface, oriented perpendicular to the moon's direction. The constant is corrected for atmospheric attenuation and assumes a full moon at apogee with the earth at its mean distance from the sun.

Kuiper[1] gives a value of 0.342 lux as the lunar constant. At the earth's surface, the following values are appropriate:

$E_M = 0.342$ lux

$f_M(0°) = 1.0$

TABLE 2.- INTEGRATED PHASE CURVE OF THE MOON[2]

Phase Angle (°)	Integrated Phase, f (°)
0°	1.00
10°	0.725
20°	0.578
30°	0.437
40°	0.339
50°	0.263
60°	0.208
70°	0.166
80°	0.115
90°	0.080
100°	0.056
110°	0.039
120°	0.025
130°	0.016
140°	0.009
150°	0.004
160°	0.00002

[1] PLANETS AND SATELLITES, "The Solar System", Volume III, Gerald P. Kuiper and Barbara M. Middlehurst, The University of Chicago Press, 1961, Page 214.

[2] PLANETS AND SATELLITES, Gerald P. Kuiper and Barbara M. Middlehurst, University of Chicago Press, 1961, Page 214.

$$h_M = 3.844 \times 10^5 \text{ km}$$

$$r_M = 1.738 \times 10^3 \text{ km.}$$

Solving Equation (1) for K_M and substituting the above values:

$$K_M = (0.342 \text{ lux}) \left(1 + \frac{3.844}{1.738} \times 10^2\right)^2$$

$$K_M = 1.69 \times 10^4 \text{ lux.} \tag{2}$$

Substituting this value for K_M and the value for r_M into Equation (1) obtains:

$$E_M = (1.69 \times 10^4 \text{ lux})\, f_M\, (\alpha_M) \times$$

$$[1 + (5.75 \times 10^{-4}\, K_M^{-1}) h_M]^{-2} \tag{3}$$

Method 2: The second method is based upon a value for the moon's luminous emittance as tabulated in the AMERICAN INSTITUTE OF PHYSICS HANDBOOK.[3] The reported value is 0.8 lamberts which has a corresponding luminance (brightness) of 2.54×10^3 cd/m^2. The value is obtained through the earth's atmosphere.

The illuminance at the earth by a full moon can be calculated from the equation

$$E_M = \Pi\, B_M \left[\frac{r_M}{h_M}\right]^2 \tag{4}$$

where:

B_M is the moon's luminance.

Substituting the above values for B_M, r_M and h_M into Equation (4):

$$E_M = (3.14)(2.54 \times 10^3 \frac{\text{lumens}}{\text{m}^2}) \left[\frac{1.738 \times 10^3 \text{km}}{3.844 \times 10^5 \text{km}}\right]^2 \tag{5}$$

[3]AMERICAN INSTITUTE OF PHYSICS HANDBOOK, McGraw-Hill Book Company, Inc., 1957, Pages 6-78.

$$E_M = 1.63 \times 10^{-1} \frac{\text{lumens}}{m^2}.$$

Using the procedure of Method 1, but substituting the earth illuminance value, E_M, of Equation (5), the following is obtained:

$$E_M = (8.05 \times 10^3 \text{ lux})\, f_M\, (\alpha_M) \times \left[1 + (5.75 \times 10^{-4}/\text{km}) h_M\right]^{-2} \tag{6}$$

In considering the results of the two methods, the author has greater confidence in Method 1. The conditions under which the value of the moon's brightness was determined was not clearly defined in the AMERICAN INSTITUTE OF PHYSICS HANDBOOK and may not even be for a full moon. Equation (3) is probably more correct and will be used for the remainder of this program.

Subject Illumination by the Earth.- Subject illumination by the earth is exactly analogous to that of the moon. However, the data available for the calculation is not as complete. In particular, the earth equivalent of the moon's integrated phase curve has not been measured. The earth's integrated phase curve could be expected with cloud cover and might very well show some cyclical seasonal patterns.

The subject illumination, E_E, by the earth is then given by:

$$E_E = K_E\, f_E\, (\alpha_E) \left(1 + \frac{h_E}{r_E}\right)^{-2} \tag{7}$$

where:

K_E is a constant to be determined

$f_E\, (\alpha_E)$ is the earth's integrated phase curve

α_E is the earth's phase angle, from the subject

h_E is the altitude of the subject above the earth's surface

r_E is the earth's radius.

An approximate K_E value can be obtained by considering the relative albedos of the earth and the moon. Using this approach the following is obtained:

$$K_E \cong \left(\frac{\text{Earth Albedo}}{\text{Lunar Albedo}}\right) K_M. \tag{8}$$

The earth albedo is 0.39 and the lunar albedo is 0.07. Substituting these values and the value of K_M (from Equation (2)) into Equation (8):

$$K_E = \frac{0.39}{0.07} \ (1.69 \times 10^4 \text{ lux}) \tag{9}$$

$$K_E = 9.4 \times 10^4 \text{ lux}$$

Substituting the value for K_E and the value of the earth's radius, 6370 km, into Equation (7):

$$E_E = (9.4 \times 10^4 \text{ lux}) \ f_E \ (\alpha_E) \ \times$$

$$[1 + (1.57 \times 10^{-4} \text{ km}^{-1}) h_E]^{-2} \tag{10}$$

The K_E value obtained above is probably reasonably accurate. However, it may be somewhat high since the value of K_M reflects the highly retroreflective nature of the moon's surface.

The earth's integrated phase curve may be estimated by assuming that the earth is a lambertion reflector. However, such an assumption would have resulted in a significant error had it been applied to the moon.

Selected Subject/Background Geometrics and Lighting.- Table 3 presents a partial list of cases and examples which are of special interest in space photography. From an AEC point of view, the worst case is when Cases 1 and 2 occur simultaneously. When the subject brightness is very different from its background, a conventional AEC System is probably misleading. This possibility is even more likely when the subject represents a small, but unknown fraction of the field of view, however, in both cases the subject image will appear in maximum contrast to its background.

TABLE 3.- SUBJECT/BACKGROUND/LIGHTING EXAMPLES

Case	Subject/Background/Lighting	Examples
1	Small bright subject/black background	Rendezvous and docking, satellite inspection, Earth from Moon orbit
2	Extreme subject contrast	Subject remote from Earth, Moon or photographic platform
3	Rapidly changing exposure	Lunar surface pan by astronaut, Lunar surface from lunar orbit, especially approaching limb
4	Low light level	Subject shadowed from Sun, limited Earth/Moon light
5	Bright Foreground/black background	Lunar surface photography
6	Artificial lighting, moderate contrast	Cabin photography
7	Thin distributed radiator	Reentry fireball

Film Study.- The film sensitivity indicated in the NASA/MSC prime specification ranged from ASA 20 to 6000, or approximately nine f-stops. In general, the analysis of the film indicates that the sensitivity ranges from ASA 40 to 640 will accommodate the light range expected as a result of the Light Study subtask. The practice of increasing the apparent sensitivity by forcing the processing degrades image resolution and color quality. The advantage is with normal processing for all aspects of photographic evaluation. Should other than normal processing be necessary it should be limited to not more than two f-stops of correction.

Relation of Photographic Film Response to Detector Output

The relative spectra responses of two common detectors and two typical films, listed in the base specification, are shown in Figure 2. To show their characteristics throughout the required light range, having high detector response is desirable at wavelengths where film response is high. By comparison, EK 3400 film could be used with the cadmium sulfide detector since both exhibit high response in the visible range, although their response drops off in the near infrared region. The silicon Schottky Barrier detector could be used with either film type shown since it has high response throughout the visible and near infrared region.

Sensor Study. - The sensor study may be an extensive project in itself. The problems involved with sensing low light levels, where the level striking the sensor is near the sensors Dark Noise output, becomes a very significant factor. The choice of sensors will basically be in two categories.

Silicon Sensors.- The characteristics of the silicon detectors are:

(1) Wide dynamic range, on the order of 30 stops

(2) Relative change over temperature range is minimal

(3) Signal to noise ratio is on the order of 200:1

(4) Linearity within 1% over active range

(5) Low light levels sensitivity, useable outputs from 10^{-11} W/cm^2, signal/noise 10:1

(6) Available in several sizes and configurations, as small as 0.080 inch diameter, both photodiode and phototransistor.

Cadmium Sensors.- The characteristics of the cadmium detectors are:

(1) Dynamic range of approximately 7 stops

(2) Relative change at low temperature, -55°C causes linearity to vary approximately 0.01% per degree below 0°C.

(3) Output is logarithmic, that is, an equal change in resistance per change of 1 f stop.

(4) Linearity within 3% over active range, provided heating is supplied to maintain temperature at 0°C minimum.

(5) Low light level sensitivity, 10 mW/cm^2 for useable output, signal/noise 10:1.

(6) Available in sizes down to 0.200 inch diameter, photodiode only.

The advantages of locating the sensor to view through the lens, behind the iris, are so great that even at this early stage considering any other locations is unnecessary. The only argument against through the lens viewing is the complication of the physical mounting of the sensor to receive the lens light bundle without interfering with the film image.

The arrangement of the sensor or sensors as well as the methods for directing the light levels to the sensors are discussed in Subtask 9 - Light Monitoring.

Sensed Luminance.- In this approach a light sensor with appropriate optics is used to sense the luminance of the scene.

The fundamental assumption in a sensed luminance AEC approach is that the luminance which is sensed is representative of the subject of interest. When the subject and background are of approximately the same brightness, this assumption is well justified. As the subject to background contrast increases, the validity of this assumption becomes less assured. When the subject also represents a small, unknown fraction of the field of view, the assumption is precarious at best. Exposure errors which result are commonly referred to as Subject Failure.

In consideration of the variety of the scenes anticipated, several approaches to the sensor view are considered, so as to minimize subject failure.

The approaches analyzed are:

(1) Spot Sensing. In this method, the luminance is sensed by a spot sensor which should be smaller than the smallest subject anticipated. Although the advantage of spot sensing is that the exposure can be optimized for the specific subject photographed, the disadvantage is that either the location of the subject in the scene must be known or the spot sensor must be precisely positioned by the operator. This, of course, indicates that there must be provisions for precise viewing by the operator (see Figure 3A).

(2) Area Weighted Sensing. This method emphasizes the brightness of a particular portion of the format. As is the case of the spot sensing method, the area weighted sensing is only fully accurate if the scene brightness over the format is known. A good example of this would be the lunar surface photography in which the foreground is representative of the subject. However, the weighted area sensor need not be as accurately aimed as the spot sensor (see Figure 3B).

(3) Average Area Sensing. In this method, the sensing is accomplished by arrangement of the sensor so that it views the entire format area. This method does not require any specific aiming of the sensor other than being pointed at the same scene as the lens. The disadvantage of the area sensor is that if the object of interest is a small percentage of the picture format it will not greatly affect the resultant exposure. However, the object image will appear in maximum contrast to whatever background it is against (see Figure 3C).

(4) Scanning Spot Sensing. This method developes a low resolution luminance image of the scene. The Scanned Spot Meter approach has been discussed for many years, but has not, to Perkin-Elmer's knowledge been used in any production cameras. If the statistical properties of the scene are known and provide a useful way of discriminating between the subject and background, the scanned spot meter approach has real merit. However, where the scene luminance statistics can vary or are not known, the approach is of limited value. Generally, the increase in complexity would have to be accompanied by a significant improvement in exposure accuracy to justify serious consideration of scanned spot sensing.

Considerations for Sensor Selection

The factors which affect the selection of a detector (or light transducer) for use in AEC are briefly reviewed in this section. On the basis of available data, two types of detectors, silicon and cadium sulfide, are recommended for further consideration in this program. Finally, relationships are developed between the Noise Equivalent Power of a detector and the ASA film speed, exposure time, scene luminance, and lens f/number (see Figures 4 and 5).

Selection Factors. - The following factors are important in selecting a detector for use in automatic exposure control.

Spectral response: Ideally, the sensor would have a uniform response over the spectral range of common photographic materials. A uniform response permits the use of spectral filters to match the spectral response of the detector to that of the film. If infrared films are included, the sensor response should range from 3500 to 8500 Å.

Responsitivity: This term describes the change in signal or output from the sensor for a given change in light.

Noise equivalent power: The noise equivalent power (NEP) of a detector is the amount of radiant power (or radiant flux) which will produce a signal equal to the detector internal noise. This factor specifies the detector's low light level limit.

Linearity: Linearity expresses the extent to which a detector's signal is proportional to the light falling upon it. When a wide range of brightness levels is anticipated, a detector which is linear over the same range can offer some significant advantages.

A special from of linearity is logarithmic linear in which the detector output is proportional to the logarithm of the light falling on the detector. A logarithmic form of dynamic range compression also offers some advantages. As a matter of fact, the Exposure Value method of exposure specification is actually logarithmic.

Sensitive area and uniformity: The sensitive area of a detector determines the amount of light which it intercepts. The uniformity of that area determines whether all of the light is given equal weight. For example, if a scene were focused on the surface of a nonuniform sensor, more weight is given to the brightness of the image at points where the sensor is more responsive.

Frequency response: The frequency response specifies the electrical bandwidth over which the detector can be effectively used. Often the actual frequency response is determined by the circuit on which it is used.

Dynamic range: The dynamic range is the range of light values over which the sensor provides a useful signal. In a more restrictive sense, the dynamic range may be expressed as the range of light values over which the detector satisfies certain linearity requirements.

Hysteresis: Some detectors exhibit a sort of a memory after having been subjected to high or low light levels. This should be considered when the light levels are likely to change over large ranges in a short period of time.

Temperature characteristics: The variation with temperature of the sensor responsivity, dark current, noise, etc.

Damage susceptibility: The ability of the sensor to sustain radiation, temperature, vibration, current and voltage overloads without altering its normal operating performance.

In addition to the above factors such considerations as circuit compatibility, current state of technology and space qualification can be important. The availability of the detector in custom shapes, sizes and arrays may also be of interest.

<u>Detector Classes</u>.- The quantum photodetectors of interest generally fall into one of the following categories:

(1) Photoemissive (including PMT)

(2) Photoconductive (Bulk Effect)

(3) Phototransistor

(4) Photovoltaic (Junction)

(5) Photoconductive (Schottky Barrier)

(6) Photoconductive (Diffused Junction)

The relative performance of these six detector categories is summarized in Table 4. This summary is from the United Detector Technology, Inc. Silicon Photodetector Design Manual. A numerical rating of 1 indicates that the particular category of detector is the best type for the particular characteristic. Two types having the same rating denote equal performance in that characteristic.

Several observations are in order regarding Table 4. First, the high responsivity and low light level sensitivity ratings of the photoemissive detector apply only to the photomultiplier configuration, not the vacuum photodiode. The photomultiplier, in turn, requires extremely stable high voltage power. This requirement is not very appealing in space applications.

The phototransistor is characterized by a very small photosensitive surface, a feature not considered in Table 4. In designing an AEC, a large detector of arbitrary dimensions is a desirable characteristic. A small area generally implies a narrow field of view and a limited amount of light, depending partly upon the optics with which it is used.

The three forms of photoconductive and the photovoltaic detectors are all good candidates for an AEC sensor. The cadmium sulfide cells, which are commonly used in exposure meters, are an example of bulk type photoconductor. The uniformity of response of these sensors is not as good as the junction devices. Also, they exhibit significant hysteresis, or light memory, under certain conditions. Nevertheless, they are inexpensive, have been widely and successfully used in the past and will be considered further in this program.

The Schottky and diffuse barrier junction silicon photoconductors are attractive for a variety of reasons. Their principal disadvantage is that they operate best when the light is chopped at above 300 Hertz. However, they have a number of redeeming characteristics such as linearity, uniformity, overload recovery, spectral response (350 to 1000 nm) and small signal detection. They, too, deserve further consideration.

Finally, the silicon photovoltaic cell is a unique device, which does not have dark current (i.e., dc) and does not require external power. While not as sensitive as the silicon photoconductors, the cell is worthy of consideration when the lowest light levels are not required.

TABLE 4.- DETECTOR TYPE COMPARISON

	PHOTO-EMISSIVE	PHOTO-CONDUCTIVE (BULK EFFECT)	PHOTO-TRANSISTOR	PHOTO-VOLTAIC (JUNCTION)	PHOTO-CONDUCTIVE SCHOTTKY BARRIER (JUNCTION)	PHOTO-CONDUCTIVE/ DIFFUSED (JUNCTION)	
Sensitivity at Low Light Level	1	3	5	3	2	2	Derived as NEP (Noise Equivalent Power) and/or D* characteristics the minimum amount of power that can be detected by the detector. Units: $D^* = \frac{Cm\sqrt{Hz}}{W}$ NEP = W
Responsivity	1	3	2	5	4	4	Output per unit input at various wave lengths of the detector, which related directly to quantum efficiency. Units: R = A/W, or μA/μW or QE in %.
Speed	2	6	4	5	1	3	Time for detector to respond to a step function input of radiation from 10 to 90% points. Units: ns, μs, ms.
Near IR Response	2	4	3	3	2	1	Response from 8000Å thru 1.06 micron. R = μA/μW or Quantum Efficiency in %.
Visual Response	2	1	4	4	1	3	Response thru visual range from 450 thru 650 nm.
UV Response	1	5	4	4	2	4	Response from 2000Å thru 4000Å.
Overload Recovery	3	5	2	2	1	1	Ability to respond to normal inputs after overloads.
Lifetime Stability	6	4	4	3	2	1	Stability of responsivity over a period of months or years after initial calibration.
Power Consumption	5	3	4	1	2	2	Amount of supply power required for operation.
Multi-element Flexibility	5	4	3	2	1	1	Ability to make close spaced arrays with high degree of cross-talk isolation and interelement uniformity.
Ruggedness	4	2	2	1	1	1	Ability to withstand thermal and mechanical shock and vibration.
Linearity	3	4	4	2	1	1	Linearity of output per unit input usually measured in number of decades to remain within 1% nonlinearity.

Low Light Level Automatic Exposure Control.- The ability of an AEC System to control exposure at low light levels is ultimately limited by the ability of the detector to sense those levels. This section examines this limitation and its photographic implications. The derivation will assume a through the lens exposure control system which has an efficient reflex mirror.

First, the illuminance, I, on the film and the detector is given by:

$$I = \frac{\pi \tau B}{4f^2} \tag{11}$$

where:

τ is the lens transmittance

B is the scene brightness in nits (cd/m^2)

f is the lens f/number

I is in meter candela

From USA Standard PH 2.15-1964,[4] the film illuminance is related to the exposure time and film speed as follows:

$$I = \frac{qK}{TS} \tag{12}$$

where:

q is a constant, 0.69

K is a constant, 11.4

T is the exposure time in seconds

S is the ASA film speed.

Given the spectral distribution of the illumination, the film irradiance, H, is related to the film illuminance by:

$$H = C_H I \tag{13}$$

where:

H is the irradiance in W/m

C_H is a constant (W/lm).

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[4]USA Standard PH 2.15 - 1964, Equation 3.

The total radiation, P, falling on the detector is given by:

$$P = A_D H \tag{14}$$

where:

P is the radiant flux on the detector

A_D is the detector area.

Substituting Equation (13) into Equation (14) produces:

$$P = A_D C_H I. \tag{15}$$

On the other hand, a sensors ability to detect small light signals is limited by its own internal Noise Equivalent Power (NEP). When Shot noise is the limiting mechanism, the actual NEP is given by:

$$NEP = NEP\ (1\ Hz) \times \sqrt{BW} \tag{16}$$

where:

BW is the electronic bandwidth in Hz

NEP (1 Hz) is the noise equivalent power at 1 Hz bandwidth.

When the detectivity (D) of a sensor is known, the noise equivalent power can be computed from:

$$NEP = \frac{\sqrt{A_D \times BW}}{D^*} \tag{17}$$

where:

D* is the detectivity.

Therefore, the signal to noise ratio must exceed 1.0, or the signal power must exceed the detector noise equivalent power. In other words:

$$P > NEP. \tag{18}$$

Substituting from Equation (15) into Equation (18) the following is obtained:

$$I > \frac{NEP}{A_D C_I}. \tag{19}$$

At this point the detector NEP can be related to the scene brightness and camera f/number. Substituting Equation (11) into Equation (19) and solving for B,

$$B > \frac{4(NEP)}{\pi\tau\ A_D\ C_E}\ f^2. \tag{20}$$

Another useful relationship between exposure time and film speed is obtained by substituting Equation (12) into Equation (19) and solving for the product TS:

$$TS < \frac{qK\ A_D C_E}{NEP}\ . \tag{21}$$

Equations (20) and (21) summarize the photographic restrictions upon AEC imposed by the detectors ability to sense and quantify low light levels.

<u>A Low Light Level Example</u>.- For a typical example assume that the parameters are for a PIN 10 Schottky Barrier diode, manufactured by United Detector Technology, Inc. Then:

$$NEP\ (1\ Hz) = 10^{-12}\ W$$

$$A_D = 1.25 \times 10^{-4}\ m^2$$

$$NEP\ (5\ Hz) = 2.2 \times 10^{-12}\ W.$$

The following additional values are assumed as representative:

$$\tau = 0.9$$

$$C_E = 10^{-2}\ W/1m$$

$$q = 0.69$$

$$K = 11.4.$$

Assuming a five Hertz electronic bandwidth and substituting into Equation (20):

$$B > (2.5 \times 10^{-7}\ nit)\ f^2. \tag{22}$$

Substituting the same parameters into Equation (21):

$$TS < 4.5 \times 10^6/\text{meter candela} \tag{23}$$

The exclusions implied by Equations (22) and (23) are presented in Figure 4 (sheets 1 and 2.)

Equation (22) indicates that the PIN 10 detector is capable of determining the proper exposure under some extremely low light levels. However, the NEP which is supplied by the manufacturer assumes that the illumination falling on the detector is chopped at 1000 Hertz and also assumes that the preamplifier is capable of sensing the 3×10^{-13} amperes which would result from this low radiation level.

In a practical AEC System, neither of these assumptions are necessarily valid and the ultimate low light level capability of the detector will not be realized. However, note that the detector is inherently capable of providing the signal required for low light level AEC.

Control Methods.- Methods of control were established by interpretation of the basic requirements of the specification and other methods found desirable after the discussions held between NASA and Perkin-Elmer personnel.

Three basic modes of operation are considered under this task.

Automatic Control.- This mode uses the output of a light sensor and associated electronics to control the correct exposure settings for iris opening and shutter angle.

Remote Control.- The remote mode interrupts the output of the camera sensor from the control mechanism. In the remote position, the camera adjustments can be set from other sources such as:

(1) Remote located computer

(2) Control panel switching

(3) Master sensing unit.

Manual Control.- In this mode, the AEC functions are decoupled and the operator can manually adjust iris opening and shutter angle for correct exposure.

During all modes of operation, the magazine/camera electrical interface will include:

(1) AEC compensation for the ASA sensitivity of the film in the magazine.

(2) Data output from the camera to the data block. This information is composed of a binary signal containing the lens iris setting, camera shutter angle and perhaps the camera sensor measured light.

Power Requirements.- The design approaches discussed in this report were conceived using the design goal of 150 mA at 24 V dc. The detailed discussion in Electronic Sub-System Approaches, outlines the findings as a result of the preliminary design analysis.

EMI Considerations.- EMI considerations for the AEC are essentially concerned with interference generated by the AEC both conducted and radiated. Susceptibility of the AEC will not be of particular concern because of the nature of the AEC, i.e., inherently nonsusceptible because of electrical and mechanical configurations.

Specific Requirements.- The AEC will be designed with the end result of meeting the requirements of MIL-STD-461A, Class 1C.

Because of the nature of the AEC, the following tests are not regarded as significant and/or applicable.

(1)	CE02	(7)	CS05
(2)	CE04	(8)	CS07
(3)	CE05	(9)	CS08
(4)	CE06	(10)	RE01
(5)	CS03	(11)	RE04
(6)	CS04	(12)	RS01

Design considerations to meet the remaining requirements will include possible case shielding to prevent radiated interference. Perkin-Elmer assumes, however, that all EMI filtering will be accomplished by the camera filter, without requiring additional filtering in the AEC electronics of the camera.

Light Monitoring.- An AEC System must provide a means of measuring scene brightness and establish an exposure based upon this information. Utilizing through the lens sensing, methods of capturing a portion of light for sampling will be discussed with a summarization provided in Table 4.

In considering the allowable envelope for the various light monitoring devices, a standard C mount lens with a clear aperture of 0.500 and a flange to focal plane distance of 0.690 inch was assumed.

Since some of the approaches discussed may need more space than available with a standard lens, consideration may be given to lenses with an extended back focal distance.

The following approaches will be discussed in detail:

(1) Shutter mounted sensor

(2) Shutter mounted reflectors

  (a) Reflecting wedge

  (b) Mirrored conical shutter

  (c) Staggered multiple wedges

  (d) Mirrored Fresnel

(3) Shutter mounted light fibers

  (a) Staggered light pipes

  (b) Light pipe

  (c) Thin film light guide

(4) Fixed sensors/reflectors

  (a) Cantilever light pipe

  (b) Beam splitter/pellicle

  (c) Light guide deposition

  (d) Aperture perimeter sensing

  (e) Direct sensing phototransistor chip

Shutter Mounted Sensor.- Scene brightness monitoring, employing through the lens sensing, would first suggest a sensor mounted directly on the shutter (Figure 6) which rotates directly across the photographic aperature, thereby sampling the entire format. This provides simplicity in mounting as well as a thin profile. However, transferring this signal from a rotating member presents a problem since sliprings are normally

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TABLE 5. SENSOR MOUNTING CONFIGURATION

Light Sensing Methods	Fixed	Rotating Shutter Mounted)	Through Lens Sensing	Extended Back Focus Req'd	Sensor Matrix Array: Area	Sensor Matrix Array: Spot	Sensor Matrix Array: Weighted	Sensing Phase: During Exposure	Sensing Phase: Before Exposure	Advantages	Disadvantages
Shutter Mounted Sensor		X	X	No	X	X	X		X	Senses before exposure ∴ no obstruction of photographic light path.	Requires sliprings or a more complex means of obtaining signal.
Shutter Mounted Reflecting Wedges		X	X	Yes	X	X	X		X	Senses before film exposure. ∴ no obstruction to photographic light path.	Requires extended back focus lens. Requires dynamically balanced shutter.
Mirrored Conical Shutter		X	X	Yes	X		X		X	Senses before film exposure. ∴ no obstruction to photographic light path.	Requires lens system with extended back focus.
Mirrored Fresnel		X	X	No	X		X		X	Senses before exposure ∴ no obstruction to photographic light path.	Results in light scatter to sensor. May require back focus lens. Dynamically balance shutter. Offers finer profile than wedge or conical shutter.
Staggered Multiple Wedges		X	X	No	X		X		X	Offers very low profile.	Results in light scatter to sensor.
Shutter Mounted Radio Light Fibers		X	X	No	X	X	X		X	Offers very low profile. Concentration of fibers reduces light scatter considerably. Permits close proximity sensor.	
Light Fiber Array		X	X	No	X	X	X		X	Sampling light is piped clear of lens area and projected to close proximity sensor.	

TABLE 5. SENSOR MOUNTING CONFIGURATION (Cont)

Light Sensing Methods	Fixed	Rotating (Shutter Mounted)	Through Lens Sensing	Extended Back Focus Req'd	Sensor Matrix Array			Sensing Phase		Advantages	Disadvantages
					Area	Spot	Weighted	During Exposure	Before Exposure		
Thin Film Light Slide		X	X	No	X	X	X		X	Extremely low profile. Permits close proximity sensor location to fibers. Superior sensing technique. No shutter balancing required.	State of the Art limited process availability
Cantilever	X		X	Yes	X (only one)	X		X		Light pipe attached directly to sensor ∴ eliminating light scatter.	Sampling area very limited. Shadowing of film at f/22.
Beam Splitter or Pellicle	X		X	Yes	X	X	X	X		Provides aperture sensing combination. Full aperture pickup. Pellicle offers best possibility. Continuous sampling.	Through lens sensing. Requires extended back focus lens.
Thin Film Light Guide	X		X	No	X	X	X	X		No light obstruction during sampling. No extended back focus lens required Any sensing array configuration is permitted. Fixed plate permits sensor to interface directly at the film output. Continuous sampling.	State of the Art limited process availability. Fixed plate permits sensor to interface directly at the film output.
Aperture Parameter Sensing	X		X	No	X			X		No light obstruction during sampling. No extended back focus lens required. Direct sensor pickup. Continuous sampling.	Sampling occurs outside clear aperture of lens. No sensing array selection.
Direct Photo Transistor Chip	X		X	No	X			X		Direct sensor pick-up. No extended back focus required. Minimum light obstruction during sampling.	Area sensing only.

not acceptable for space applications. Other methods to consider may be the use of a hermetically sealed bearing containing an electrically conducting fluid or the use of a rotating coil for current generation. Neither of these methods indicate great promise for further consideration.

Shutter Mounted Reflectors.- In the following discussion, four methods of light reflection from the shutter are presented.

Reflecting wedge: This method employs a polished or mirrored wedge mounted to the rotating shutter (Figure 7). The wedge will provide a surface to transfer the light to a sensor mounted at a predetermined angle to the wedge. In this approach one sensor will cover the total light cone directed from the wedge, and the size of the wedge will in all probability dictate the use of a lens with an extended back focal distance.

Mirrored conical shutter: For this method, a formed conical shutter is used (Figure 8) whereby the surface facing the lens is either highly polished or coated to transfer the light to the light sensor. As was the case for the reflecting wedge approach, a lens with an extended back focal distance must be used. The advantage of this approach is that both shutters can be formed in the same shape, whereby the light sampling can be averaged over a longer period of time.

Staggered multiple wedges: While this method in principle is the same as the reflecting wedge approach discussed in the mirrored conical shutter paragraph above, a multiple of wedges is used (Figure 9). Two major advantages of this approach are that first, the profile light is sharply reduced so lenses with a standard back focal distance can probably be employed and second, if area sampling is applied, the light cones reflecting from the wedges can be directed to separate light sensors. A disadvantage may be that light scatter could occur, thereby reducing the sensor output.

Mirrored Fresnel: For staggered multiple wedges, the mirrored Fresnel (Figure 10) can be used in the same manner. In this design, the Fresnel lens is either machined as part of the shutter or as a separate item mounted to the shutter, the light may be directed to separate light sensors. This design possibly allows the lowest profile of all, but heavy light scattering may create a problem too difficult to eliminate.

Shutter Mounted Light Fibers.- The following is a description of three possible methods for the use of light fibers.

Staggered light pipes: Although this method is principally the same as for the staggered wedge technique, it differs in that light is transmitted to the sensor rather than reflected (Figure 11). Through this method, the possible light scatter may be reduced, but light losses will occur through fiber transmission loss. The fiber end configuration could be bevel cut and mirrored or bent to receive incoming light.

Placement of fibers and associated light sensors will allow area sensing design applications.

Light pipe: A slight variation of the previous light pipe concept (Figure 12) would be to route the transmitted image to an area clear of the lens and reflect it to a sensor array mounted just above the shutter. By isolating portions of the sensor into a matrix and selectively positioning the light fibers, obtaining a weighted area or spot sensing capability would be possible.

Thin film light guide: This method is offered as an improvement over the light pipe routing configuration. New developments in light pipe technology (Figure 13) permit thin hair like glass or crystal strips to be deposited as a film on flat plates. The film strips can be shaped into relatively sharp bends and interconnected to combine the light input.

The light monitoring methods discussed in the preceding paragraphs were all associated with light transmission through the use of a rotating shutter. The sampling methods considered in the following paragraphs are all associated with the design whereby the light transfer unit is fixed between the shutter and the lens. Since some of these methods probably require the maximum light envelope, it is expected that in some cases only lenses with an extended back focal distance can be used.

Fixed Sensors.- Five methods for the use of fixed sensors are discussed in the following paragraphs.

Cantliever light pipe: This approach considers the application of a cantilevered light pipe (Figure 14). The fixed cantilever light pipe is rigidly supported and extended into the center of the clear aperture to allow sensing when the iris is set at f22. Placement of the bundle above the film plane will be optimized by considerations of imaging on the focal plane versus shadowing of the aperture.

Beam splitter/pellicle: A superior method to the cantilever light pipe approach would be to mount a fixed prism (Figure 15) or a glass pellicle (Figure 16) in the light path between the lens and shutter. If space is available, Perkin-Elmer feels that this method will provide the most direct method of light transmission to the sensor, with the least amount of light loss to the focal plane. A main prerequisite of this method is that the optical design of the lens will incorporate the glass used in the prism or pellicle to minimize loss of resolution.

Thin film light guide: The light guide discussed in the staggered light pipes paragraph above could also be used as a fixed sensor pickup. By depositing the crystal film on a glass plate (Figure 17) in a staggered radial configuration, area or spot sampling of the photographic aperture would be possible by connecting selected light strips and directing them to the appropriate sensor array. Very little light is obstructed from the film plane since the width of the light guide is about 1/10 the diameter of a human hair. Since fibers are so thin, they could be placed closer to the film plane without imaging and using a lens with a standard back focal distance may be possible.

Aperture perimeter sensing: Application of this method employs a fixed ring sensor (Figure 18) mounted just outside the picture area of the aperture lens. This permits a direct sensor pickup without obstruction of the light path. Providing weighted sensing may be possible by dividing the sensor array, but this pickup method would probably be best suited for area sensing. Since the sensor is located outside the picture area, the spacing between the filmplane and lens may be adjusted to the back focal distance of the lens.

Direct Sensing Phototransistor Chip.- Direct sensing may be accomplished by mounting a detector chip directly in the light path behind the lens. The chip could be fixed to the rear element of the lens or it could be suspended on cross hairs far enough above the film plane to prevent imaging (see Figure 19). Another mounting approach would be to fix one or more chips to a glass plate and suspend it in the light path. This permits more flexibility in sensor arrangement, but requires a tradeoff in light transmission to the film plane since the glass plate represents another lens element in the light path.

Calculated Illuminance Automatic Exposure Control.- An alternate approach which may be used in conjunction with the AEC is to calculate the subject illuminance by the principle sources of light, i.e., the sun, moon, earth, and the photoggraphic platform. This method requires that the position, relative to the subject, of these light sources is known which in many space photographic situations is the case.

This approach takes into account the locations of the sun, earth, moon, and the photographic platform to compute the illuminance of the subject. This method would first determine which of the reflected light sources are in a position to contribute shadow fill illumination. Table 1 illustrates a simple mechanism for making this determination. Next, the subject shadow illuminance (as viewed from the photographic platform) is computed for the reflected light sources which are in a good position to contribute. This calculation for the earth and moon is shown in Equations (3) and (10), pages 6 and 8, and a similar calculation applies to the photographic platform, once its shape and reflective properties are known.

The Calculated Illuminance method of AEC assumes that the subject reflectance (usually the diffuse reflectance) falls within some reasonable range, say ten to eighty percent. The camera shutter and apertures would then be set to expose a thirty percent exposure in the center of the film dynamic range. For a high contrast film of limited dynamic range (for example, a reconnaissance color film) a subject reflectance below ten percent would be seriously underexposed.

The calculated illuminance AEC can determine the subject contrast, or at least the contribution of illuminance to subject contrast, and adjust the exposure to accommodate both shadows and highlights. This is particularly true on manmade space objects where the external reflectance is controlled to within a limited range for thermodynamic stability.

The principle disadvantage of the Calculated Illuminance AEC is that it would require an interface with the spacecraft flight computer. The axis of the camera must also be known to the computer in making the calculations. For these reasons, the Calculated Illuminance AEC approach would not be suitable for hand held photography.

Calculated Illuminance AEC and sensed luminance can be incorporated in a single camera. The Calculated Illuminance method simply requires that a remote control override be incorporated in the camera.

Electronic Sub-System Approaches

General Requirements.- Developing technical approaches to the design of a given system dictates that basic system parameters be established. Those parameters which are considered of prime importance in the development of an electronic Automatic Exposure Control (AEC) System are listed below:

(1) Power consumption

(2) Light range that will be covered

(3) Exposure compensation technique, i.e., iris, shutter, etc.

(4) Light sensor that will be utilized

(5) Location of sensor

(6) ASA compensation

(7) Remote control

(8) Input voltage

(9) Automatic/manual switching

(10) Outputs required, i.e., shutter position, iris position

(11) Response time.

In the following discussion, three general approaches to the design of an electronic AEC System are provided. A summary section is included at the end of the discussion to relate the various approaches.

Approach No. 1 - Single Motor/Cadmium Sulfide Sensor.- A conceptual schematic of the type of system is shown in Figure 20. The approach makes several basic assumptions:

(1) Exposure compensation will be accomplished by driving a combination of iris and shutter utilizing a single stepping motor.

(2) Home position for the iris and shutter would be f/8 and 45° respectively, with an input of 1280 footlamberts and ASA 80 film selected.

(3) Shutter compensation would take place only with the iris at f/8, i.e., the shutter would have to be at one extreme or the other before exposure compensation would be in the form of iris movement. (See Table 6.)

(4) A cadium sulfide light sensor would be utilized which is linear over seven stops.

(5) The digital output representing iris and shutter position would be six binary bits weighted as indicated in Table 6.

Operation of the system would be in the following manner. Assume initially that the iris is at f/8, the shutter is at 45°, ASA 80 film has been selected and 1280 footlamberts of illumination is the light intensity external to the camera. Referring to Figure 20, the AEC System is energized by placing the AUTO/MANUAL switch in the AUTO position.

The above switch action applies primary power to the voltage regulator/constant current generator and the center-tap of each motor winding. By applying the primary voltage directly to the motor windings, this greatly reduces the requirements placed on the voltage regulator, since it only has to provide regulated voltages for the low current devices in the system, i.e., the logic elements, comparators, etc. This means that the motor current would be drawn directly from the input power line rather than through the regulator. As long as the motor can provide the maximum torque required over the input voltage range, this technique would suffice.

With an iris setting of f/8 and an external light level of 1280 footlamberts, the light level incident upon the sensor, which is located behind the iris, would be 128 footlamberts. This causes the sensor to demonstrate a specific resistance value corresponding to the light input. For this discussion, the sensor is assigned a value of 800 ohms for a light input of 128 footlamberts and will vary inversely in 100 ohm increments each time the incident light is doubled or halved over a range of 8 to 1024 footlamberts (seven stops).

With the remote control signal at a false level, constant current I_2 passes through the cadmium sulfide sensor to develop a reference voltage at the input to the dual comparator which controls the motor drive logic. At the same time, constant current I_1, which is equal to I_2, is passed through a 600 ohm fixed resistance and a 400 ohm potentiometer connected in series. The 600 ohm resistance represents an ASA 80 film speed and the potentiometer wiper is set at the midpoint, or 200 ohms

TABLE 6.- BINARY REPRESENTATIONS FOR IRIS AND SHUTTER POSITIONS

ASA 80 1280 (fL)

	22	16	11	8				8	5.6	4	2.8
	IRIS				SHUTTER				IRIS		
				11.25°	22.5°	45°	90°	180°			
LSB	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	0	1	0	1	0	1	0	1	0	1	0
	0	0	1	1	0	0	1	1	0	0	1
	0	0	0	0	1	1	1	1	0	0	0
MSB	0	0	0	0	0	0	0	0	1	1	1

which corresponds to a shutter position of 45°. Since I_1 is equal to I_2 and the two resistance values equal 800 ohms, the feedback voltage present at the dual comparator is equal to the voltage generated by the sensor network. This condition causes the output of both comparators to be false, which inhibits the motor drive logic and, thus, a null condition is achieved.

A position potentiometer is mounted on the single motor shaft and its wiper midpoint corresponds to the shutter potentiometer midpoint. With the motor shaft at a shutter position of 45°, the voltage picked off of the position potentiometer is therefore V/2. This voltage is applied to the dual comparator in the data block circuitry. Utilizing a voltage of V_R as the fullscale reference voltage for a six bit D/A, the output of the D/A is compared with the position potentiometer voltage. If the voltages do not compare, a six bit binary up/down counter is driven either up or down, depending on whether the position voltage is higher or lower than the D/A voltage, until a null point is reached. At this point the binary counter contains the digital representation of the shutter/iris position of 45° and f/8 as indicated in Table 6. This six bit configuration assumes $V = 40/64\ V_R$.

From this point, assume that the external light level increases in intensity by 1/4 f-stop. To maintain the same film exposure, the exposure time must be reduced by closing down the shutter 1/4 stop or by reducing the amount of light reaching the film by closing the iris 1/4 stop. Since the mechanical design is such that the iris moves only after the shutter has reached an extreme (11.25° or 180°) the shutter will move first, resulting in exposure time compensation.

The increase in the external light level intensity of 1/4 stop corresponds to a decrease in sensor resistance of 25 ohms. This produces an incremental voltage change at the input to the dual comparators which control the motor drive logic. By biasing the comparators such that they trip when this voltage difference is reached, the comparator output (close) will go true. This causes the code in the four bit right/left shift register to shift. When this occurs, the stepping motor steps one increment. By gearing the shutter position potentiometer such that an incremental change of the stepping motor represents a change of 25 ohms on the potentiometer, a null condition is achieved. Utilizing a logarithmic cam to drive the actual shutter mechanism, with the application of four equal steps, either can be halved if the light intensity doubles (1 stop) or doubled if the light intensity halves (1 stop).

At the same time that the shutter closes 1/4 stop, the position potentiometer moves incrementally by an amount equal to the potentiometer resistance divided by 40. This reduces the count in the binary counter by one, resulting in a binary configuration of 010011. This would be provided at the output to represent an iris setting of f/8 and a shutter position of 1/4 stop below 45°.

Once the external light level is either increased or decreased by two stops, the shutter angle has reached an extreme (either 11.25° or 180°). At this point, exposure time compensation ceases and exposure intensity compensation begins in the form of iris adjustment. By connecting a logrithmic iris (or a linear iris driven by a log cam) to the same motor shaft, any increase in the light level above 5120 footlamberts will cause the motor to drive the iris from f/8 toward f/22 or conversely any decrease below 320 footlamberts will cause the iris to move from f/8 toward f/2.8. Locating the sensor behind the iris requires that the shutter potentiometer does not change in value which in effect serves as a constant light level reference and the iris opens or closes to maintain this constant light level on the sensor and, thus, the film. If the shutter were at 11.25°, this sensor level would be 512 footlamberts and if the shutter were at 180°, the sensor level would be 32 footlamberts. Utilizing this technique, note (refer to Table 7) that 10 stops of external light level change can be compensated with only four stops of change at the sensor if ASA 80 film is used.

As mentioned above, this technique requires that the shutter potentiometer resistance remain constant once a shutter position extreme has been reached. Since the motor shaft continues to rotate to drive the iris, the potentiometer must have a shorted section on each end to accomplish this action.

The position potentiometer continues to drive in the same manner for the iris as for the shutter. The extreme conditions would therefore be represented by 101000 (180° and f/2.8) and 000000 (11.25° and f/22). These codes would also be decoded as discrete levels to indicate a Too Dark and a Too Light condition respectively.

ASA compensation is accomplished simply by reducing or increasing the resistance in series with the shutter potentiometer. For example, if a slower film, such as ASA 20 were selected, the exposure must be increased by two stops above that of a corresponding light input to ASA 80 film. By reducing the series resistance to 400 ohms, the shutter is forced to move to 180° for an external light level of 1280 footlamberts. Conversely, if higher speed film were selected, the series resistance would be increased and, thus, the exposure would be decreased by decreasing the shutter angle and/or iris opening.

TABLE 7.- ASA COMPENSATION AS RELATED TO IRIS/SHUTTER POSITION AND SENSOR ILLUMINATION

INPUT ILLUM (FL)	ASA 80			ASA 20			ASA 5120		
	IRIS	SHUTTER	SENSOR ILLUM	IRIS	SHUTTER	SENSOR ILLUM	IRIS	SHUTTER	SENSOR ILLUM
163840.0				22.0	8.6	2048			
81920.0				16.0	8.6	2048			
40960.0	22.0	8.6	512	11.0	8.6	2048			
20480.0	16.0	8.6	512	8.0	8.6	2048			
10240.0	11.0	8.6	512	8.0	17.2	1024			
5120.0	8.0	8.6	512	8.0	34.5	512			
2560.0	8.0	17.2	256	8.0	69.1	256			
1280.0	8.0	34.5	128	8.0	138.2	128			
640.0	8.0	69.1	64	5.6	138.2	128	22.0	8.6	8.0
320.0	8.0	138.2	32	4.0	138.2	128	16.0	8.6	8.0
160.0	5.6	138.2	32	2.8	138.2	128	11.0	8.6	8.0
80.0	4.0	138.2	32				8.0	8.6	8.0
40.0	2.8	138.2	32				8.0	17.2	4.0
20.0							8.0	34.5	2.0
10.0							8.0	69.1	1.0
5.0							8.0	138.2	0.5
2.5							5.6	138.2	0.5
1.25							4.0	138.2	0.5
0.625							2.8	138.2	0.5

The result of the ASA compensation as related to iris/shutter position and sensor illumination for a given light range is shown in Table 7. Note that the ASA compensation simply offsets the 10 stop AEC compensation to a different external light level range, i.e., ASA 20 for 160 to 163,840 footlamberts, ASA 80 for 40 to 40,960 footlamberts and ASA 5120 for 0.625 to 640 footlamberts. It was previously assumed that the cadmium sulfide sensor would be linear over seven stops from 8 to 1024 footlamberts. Table 7 shows that if ASA 80 film is used, linearity problems would not result from this sensor. However, if ASA 20 film were selected, attempting to compensate for an external light level beyond 10,240 footlamberts would result in nonlinear operation on the sensor, even though there are four stops of adjustment remaining on the iris. This results in compensation over 6 stops of external light level change rather than 10. If ASA 5120 film is selected, linear operation on the sensor is confined to three stops (80 to 640 footlamberts) of external light level change. By utilizing level detectors as shown in Figure 19, these conditions could be detected and a discrete level outputted indicating operation above or below the sensor capability. These signals could also be utilized to inhibit the normal mode of operation and drive the iris/shutter to one extreme or the other. Whether this is desirable, rather than simply letting the compensation continue even though it might be nonlinear, is questionable at this time.

To provide remote compensation rather than local sensor compensation, the remote control signal would be raised to a true level. This would disable the return path for the cadmium sulfide sensor and enable a return path for a remotely located variable resistance to simulate the sensor. The AEC could then be controlled from various sources such as a programmed resistance by a computer, a manual adjustment on a control panel or possibly a remotely located sensor.

Approach No. 2 - Single Motor/Silicon Sensor.- A conceptual schematic of this system is shown in Figure 21. The only difference between this system and the one discussed in Approach No. 1, above is the sensor and its associated circuitry. This discussion will, therefore, be confined to this area only since the remainder of the operation has already been covered in detail.

The cadmium sulfide sensor previously discussed demonstrates the characteristics of a logarithmic amplifier with an inverted output, i.e., as the light is doubled or halved, the resistance is reduced or increased in the same fixed increment. This, of course, allows a direct comparison with a linear potentiometer geared to a stepping motor which steps in fixed angular increments. The only requirement here is that the iris/shutter mechanisms be logarithmic such that, for a fixed angular rotation representing a one stop external light level change, the shutter/iris opening either doubles or halves depending on the direction of motor rotation.

The silicon sensor, however, operates in a direct linear fashion in that its current either decreases or increases directly with the external light level input. To interface this sensor with the single motor drive system, replacing the sensor resistor network with an inverting logarithmic amplifier is therefore necessary. Assuming that the plus terminal of the amplifier is biased at $V_{cc}/2$, the output voltage would then vary inversely about this point in an incremental fashion as the sensor input is increased or decreased, i.e., if the external light level doubles, the output voltage would reduce by a fixed increment as a function of the amplifier gain. When the external light level halves, the output voltage would increase by this same fixed increment. From this point the voltage can simply be compared with the voltage developed in the shutter potentiometer/resistor network in the same manner as the cadmium sulfide sensor. The resulting shutter/iris operation would then be identical to that discussed in Approach No. 1 above.

Remote control could be accomplished in one of two ways. By switching the input to the motor drive logic comparator from the log amplifier output to a remote source, the AEC could be controlled using an externally programmed voltage source. If resistance programming is still desirable, a constant current source could be passed through a fixed resistor and the externally programmed resistance as discussed in Approach No. 1.

The basic advantage of the silicon sensor over the cadmium sulfide sensor would be in terms of an expanded linearity range. If the linearity range was twelve stops and assuming a dynamic range of four decades on the log amplifier, this system could then compensate over a range of 18 stops in terms of external light level change with proper film (ASA 20 to ASA 5120) selection. Refer to Table 7.

Approach No. 3 - Dual Motor/Utilizing Either Sensor.- In the discussion of technical Approach No. 1, a single motor drive, connected to both the iris and the shutter, was described. This technique has two possible disadvantages.

(1) It does not allow for independent adjustment of the iris and shutter positions when in a manual mode of operation, i.e., the shutter must be sitting at an extreme (11.25° or 180°) before the iris setting can be changed.

(2) In either the automatic or manual mode of operation the time exposure compensation (shutter adjustment) always takes place about f/8. It may be desirable to have a system where the shutter adjustment (11.25° to 180°) can take place about any iris setting, depending on the operator requirements.

Item (1) above could probably be accomplished mechanically, such that when the AEC is switched to manual, the shutter and iris are disengaged from their normal motor drive shaft. This would mean, however, that the iris and shutter mechanisms would have to be returned to their original positions with respect to the motor shaft prior to switching the AEC to automatic.

To provide for an adjustable iris home position about which the shutter would adjust, however, requires a completely different approach than discussed in the two previous design concepts.

Figure 22 provides a conceptual schematic of a possible solution to both items discussed above. This system would utilize the same sensor/comparison circuitry and voltage regulator/constant current generator as described in the previous approaches. They are, therefore, not included as part of this discussion.

The major differences between this system and the single motor drive are as follows:

(1) Two independent stepping motors, one to drive the shutter and one to drive the iris.

(2) Reset comparator circuitry necessary to not only determine the initial positions of iris and shutter, but to allow for a comparison between an initial iris setting (home position) and the actual iris position.

(3) Utilization of the shutter potentiometer to provide shutter position signal as well as feedback to the sensor/comparator circuitry.

(4) Two independent five bit digital representations of the respective iris and shutter positions rather than a combined six bit configuration as described in Approach No. 1.

Operation of this system will be as follows. When switched to automatic, a power on reset would be generated which would reset the iris flip flop and set the CONV (conversion) flip flop. Setting the CONV flip flop would disable the sensor comparator inputs to the right/left shift register, thus keeping the shutter or iris from changing position. Resetting the iris flip flop makes the iris signal true which allows the S POS signal from the shutter potentiometer to be applied to the dual comparator which enables the 5 bit up/down counter.

The counter is driven until the output of the five bit D/A agrees with the S POS signal. At this point the counter contents (digital representation of the shutter position) are transferred to a five bit storage register and the reset gating generates a signal to set the iris flip flop.

Setting the iris flip flop allows the I POS signal from the iris position potentiometer to be applied to the same dual comparator and the A/D conversion as described above again takes place. This time, however, the contents of the counter are transferred to a separate five bit storage register which outputs the iris position in digital format. This technique allows time sharing of the comparators, counter and D/A, thus minimizing the circuitry required.

Upon completion of the iris position conversion to a digital format, this binary number is also transferred to a five bit (iris home register). The initial manual adjustment of the iris to a specific position thus establishes the iris home position about which the shutter will vary for AEC compensation.

The five bit digital representation of the shutter and iris positions are routed from their respective buffer registers to the five bit digital comparator and reset gating circuitry. The shutter position is decoded to determine if it is an extreme (00000 = 11.25° and 10000 = 180°). At the completion of the conversion process the CONV flip flop is reset which allows the sensor comparator outputs to be applied to the right-left shift register. If the output light level is such that an adjustment is required and the shutter is at an extreme, the iris flip flop remains set and the iris begins to drive. Referring to the schematic, note that the iris flip flop true and false signals are utilized to enable + V through a transistor switch to the iris motor and disable + V through a separate transistor switch to the shutter motor. This allows time sharing of the right/left shift register and motor power drivers, again reducing the circuitry required.

As long as the light level continues to change in the direction being compensated for by the iris, the shutter remains disabled. If the light level change reverses direction, the iris motor will reverse and drive toward home. By utilizing a five bit comparison of the iris position, as indicated by the position potentiometer with the initially established home position contained in the iris home register, transferring compensation control to the shutter is possible, when this point is reached, by resetting the iris flip flop. Once the shutter has reached the other extreme, this position will be decoded and the iris flip flop again set, thus transferring compensation control back to the iris. The digital representation for the iris extremes would be 00000 = f/22 and 11000 = f/2.8.

For all these approaches, the required response time of the system will determine the clock frequency and, thus, the stepping rate of the shutter/iris drive motor. Assume that the required response time for a ten stop change is a duration equal to five film frames being driven at a rate of 24 frames per second (approximately 200 ms). Forty steps are required to drive the iris/shutter in 1/4 stop increments over a 10 stop range which results in a stepping rate requirement equal to 200 steps/second (40/0.2).

SUMMARY

Table 8 summarizes the principal parameters of the previously described systems.

TABLE 8.- PRINCIPAL SYSTEM PARAMETERS

Parameter	No. 1 Single Motor/CdS Sensor	No. 2 Single Motor/Silicon Sensor	No. 3 Dual Motor/Silicon Sensor
[1]Estimated Power — Steady State / Peak	45 mA 115 mA	50 mA 120 mA	75 mA 145 mA
Input Light Range Compensation	10 stops-ASA 80 Limited-Other ASA	18 Stops Assumes Sensor Linearity of 12 Stops	18 Stops Assumes Sensor Linearity of 12 Stops
Exposure Compensation Control Technique	Iris/Shutter Single Motor	Iris/Shutter Single Motor	Iris/Shutter Dual Motor
Light Sensor	Cadmium Sulfide	Silicon	Silicon
ASA Compensation	ASA 20 - ASA 5120 Limited	ASA 20 - ASA 5120	ASA 20 - ASA 5120
Location of Sensor	Behind Iris	Behind Iris	Behind Iris
Remote Control	Yes Resistance or Voltage	Yes Resistance or Voltage	Yes Resistance or Voltage
Input Voltage	24 to 32 V dc	24 to 32 V dc	24 to 32 V dc
Auto/Manual Switching	Yes	Yes	Yes
Digital Output Representing Shutter and Iris Position	6 Bit Combined Configuration	6 Bit Combined Configuration	Two Independent 5 bit Configuration
Response Time Extreme to Extreme	200 ms	200 ms	200 ms
Adjustable Iris Home Position	No	No	Yes

[1]Estimated power assumes a torque requirement of less than 0.5 inch ounce at a speed of 200 steps per second on the motor with a minimum step angle of 7°30'. It also assumes the use of low power logic elements such as COS/MOS.

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Mechanical Sub-System Approaches

The two methods best suited for mechanically driving a shutter and iris for AEC are discussed in this section. The first method uses a single helical gear/cam phasing for both shutter and iris control, while the second method uses a differential angular phasing for the shutter control and a separate iris control drive.

Approach 1 - Helical Gear/CAM Phasing.- This approach is shown in Figure 23 and as indicated provides angular phasing provisions to the dual blade shutter for four f-stops from 11-1/4° to 180° as well as iris for six f-stops from f/2.8 to f/22.

In principal, the helical gearset provides shutter phasing when one gear slides axially along an adjacent gear with a reverse wrapped helix. There are two shafts supporting the helical gear, one of which is designated the drive shaft and supports a keyed helical gear and the coaxially mounted shutter blades. Adjacent to the drive shaft is the phasing shaft which drives the helical gear that is mounted to the phasing shutter. As this shaft is displaced axially by a logarithm cam, the helical gear climbs on the drive helix inducing rotation to the phasing shutter. The necessitated length of travel is shortened when two helicals are used since the second helix contributes to the rotation of the phasing shutter. Axial displacement of the phasing shaft is provided by a bearing mounted cylindrical cam whose follower rides on the inside surface, while iris adjustment is provided by a follower whose track is cut on the outside surface of the cam.

This concept of inner and outer cam profiles lends itself well to dual followers since the iris is off axis from the shutter. The indexing drive from the cam to iris could then be provided by a rack and pinion compounded to a worm gear intersecting the iris ring sector. The input from the cam could be either linear indexing or analog to match a linear or log iris.

Since both the shutter and iris adjustments are initiated from their respective midpoint settings, the entire shutter adjustment will be made before initiating iris adjustment. This requires that the iris follower dwell during shutter adjustment. Likewise, a dwell period must be provided at both ends of shutter follower travel to permit uninterrupted iris adjustment.

As shown in Figure 23, this method permits shutter and iris adjustment through the use of one drive motor.

Approach 2 - Differential Angular Phasing.- This method is shown in Figure 24 and provides the differential used for angular changes to the shutter while the iris is operated by a separate motor, thus using two separate motors for shutter and iris control.

The dual motor approach, like the previous helical drive method shows that power is transmitted directly to the positive drive shutter and the phasing shutter is powered by the differential gearset. With input power supplied to end gear A, end gear B must rotate in the opposite direction at a one to one ratio.

Since the differential phasing shaft is free to rotate independent of the end gears, the spider shaft is permitted to float without tumbling. The phasing shaft may then be rotated to advance or retard the relative positions of the shutters while they are rotating. An idler gear is incorporated into the train to correct the rotation of the phasing shutter. A stepper motor provides the best indexing of the phasing shaft since the detent capability of the motor permits the shaft to be held in place with a shaft mounted potentiometer, which is used to indicate position.

Application of a second stepper motor may then be used to provide iris adjustment. Indexing may be accomplished by using a spur and iris ring gear. The dual motor approach allows the shutter and its associated hardware to be mounted in the camera while the iris and its hardware can be mounted in a separate module associated with the lens. This design will require only optical alignment of the AEC with the camera.

The helical gear/cam phasing (Approach 1) for driving the shutter and iris employes a cam to displace the shutter. The cam profile will probably be a log function since electronics will be simplified if the driving pulse to the motor is linear.

Therefore, assuming a linear input, the differential gear set would also require a log input to the phasing shaft. This necessitates some form of function generator to change the input from a linear to a nonlinear form.

One cam was proposed in Approach 1, since both shutter and iris were driven from the same source. However, for the second method, only the differential requires a nonlinear driving function. For this reason, a four-bar linkage design would simplify the mechanical interface between the driving motor and the differential phasing shaft (see Figure 25).

In principal, the four-bar linkage may be designed so that the angular displacement of the driving and driven cranks will be related according to the following table:

DISPLACEMENT FROM STARTING POSITION IN DEGREES

Position Number	Drive Crank (A)	Follower Crank (C)	Δ Change
0	0	0	0
1	20°	11-1/4°	11-1/4°
2	40°	33-3/4°	22-1/2°
3	60°	78-3/4°	45°
4	80°	168-3/4°	90°

The drive crank may be designed as a sector gear, with indexing provided by the stepper motor pinion. The coupler arm would be a pinned arm linkage that connects to the follower crank which could be designed as a sector ring gear, a spur gear or a follower crank arm that would be fixed to the end of the differential phasing shaft. The remaining link is the theoretical fixed linkage between the pivot points of the drive and follower crank. Applying the motion to the dual motor approach permits an iris adjustment independent of the shutter.

Manual control may be accomplished by extending the shaft from the end of the cam or from the end of the differential phasing shaft and iris ring gear, as applicable, to the dual drive concept.

3.0 BREADBOARD DESIGN

Summary of Features

The purpose of the breadboard is to demonstrate the operation of an Automatic Exposure Control (AEC) for use with space sequence cameras.

The design presented in this section incorporates the following features:

(1) Compensation for Film Sensitivity.

(2) Photometric Data is made available from the AEC logic in coded form.

(3) Dual Motor Control for Shutter and Iris Adjustment. A stepping motor, through a differential gear train, is connected to the shutter blades which allows a phase change while the shutter blades are rotating. Another stepping motor drives the adjustment ring of a linear lens iris through a separate gear train. Both stepping motors incorporate a multiturn potentiometer which furnishes position information to the AEC logic.

(4) Remote Operation Capability Without Degradation in Accuracy or Reliability. This design provides for complete remote operation without recalibration. The remote station can be separated from the system from as much as fifty feet of cable.

(5) Manual or Automatic Operation. This feature provides for the specific modes of system operation.

This section is divided into three major subsections, Photometric, Design, Electronic Design and Mechanical Design.

Photometric Design

Sensor Selection.- The UDT-500 detector/amplifier combination is used in the breadboard of the AEC sensor. This device combines, in a single package, the advantages of a silicon detector (linearity, sensitivity, uniformity, large area and low noise) with the higher output of a low noise transresistance operational amplifier. The detector is operated in an unbiased, or photovoltaic mode. The package size can be reduced in a special order configuration.

A principal reason for selecting the UDT-500 is the detector sensitive area. The 16 mm format (7.5 mm x 10 mm) sets the minimum size for a detector located at the focal plane. Ideally, the diameter of the detector sensitive area would equal the format diagonal, 12.5 mm. The 11 mm diameter of the UDT-500 very closely matches this requirement. A summary of specifications for the UDT-500 is presented in Table 9.

The UDT-500 is a commercial device which **is not qualified for use** in spaceborne applications. However, with a MIL SPEC operational amplifier and a different package, a comparable space qualified device can be fabricated. United Detector Technology, Inc., the manufacturer, has produced a variety of space qualified detector configurations.

Area Weighting Considerations.- Area weighting is a method of placing different emphasis on the brightness of different areas of the camera field of view. For example, if the center of the format is likely to contain the subject, the brightness of the center can be emphasized in determining the proper exposure. A common example is the spot meter which measures only the brightness of a small center spot.

Area weighting is accomplished by multiplying the light received from each point in the scene by the weighting function associated with the point. The contribution from all points is then summed to determine the area weighted scene brightness. When the scene brightness is uniform, all area weighting functions should result in the same exposure setting.

An optical approach which can provide an area weighted measure of scene brightness is presented in Figure 26. In this approach, 10 percent of the light is diverted by a pellicle beam splitter to the mask and detector. The mask transmission varies as a function of format position. The detector response can, in principle, also vary as a function of format position. However, we will choose a detector whose response is uniform. The mask transmission function provides the area weighting. The format for 16 mm is presented in Figure 26B.

Assuming the optical approach of Figure 26, signal from a linear detector/amplifier can be expressed as:

$$V_S = \frac{KGR_D}{f^2} \int_{-3.75}^{3.75} \int_{-5}^{5} \tau_M (x,y)\, B_S (x,y)\, d x\, dy \qquad (1)$$

TABLE 9.- UDT-500 SPECIFICATIONS

Parameter	Symbol	Min	Typ	Max	Units
Detector					
Responsivity (8500 Å)	R	0.25	0.3		amp/watt
Dark Current (10 V)	i_d		10^{-7}	5×10^{-7}	amps
Capacitance (50 V)	C_d		50	70	pF
Active Area	A		1.0		cm^2
Active Diameter	D		0.444		inch
Zero Bias Impedance	R_s	5×10^5	5×10^6	10^7	ohms
Operational Amplifier					
Offset Voltage*			5	15	mV
Offset Current*			0.5		pA
Bias Current			5		pA
Output Resistance			100		ohms
Slew Rate		0.5	1		volts/μs
Unit Gain Bandwidth			0.20		mHz
Supply Voltage		± 12	± 15	± 18	volts
Supply Current			3	6	mA
Offset Voltage Drift With Temperature			± 5	± 50	μV/°C
Combination					
Light Range	L	10^{-3} to 10^{-12}			$\left(\frac{watts}{cm^2}\right)$
Feedback Resistor Range	Rf	10^3 to 10^8			ohms
Frequency Response Range	f	dc to 10^5			Hz
Spectral Range	λ	3000 - 11,000			Å
N.E.P. (1000 Hz, 1 Hz, 8500 Å)		10^{-12}			watts
N.E.P. (dc, 1 s, 8500 Å)		5×10^{-11}			watts
Broadband Noise Voltage (rms) (10 meg Rf)(5 Hz to 10 kHz)		0.2			millivolt

*Output voltage in the dark adjustable to zero.

where:

V_S is the signal

K is the constant

G is the electronic gain

R_D is the detector responsivity

f is the lens aperture number

τ_M (x,y) is the mask transmission at format point (x,y)

B_S (x,y) is the scene brightness at format point (x,y)

For a given film speed and aperture setting, the signal (V_S) determines the proper shutter time. The weighting is determined completely from the mask transmission function.

When the scene brightness is uniform (i.e., B_S (x,y) - a constant) the exposure must be independent of the choice of weighting function. This condition can be imposed upon Equation 1 by setting the following parameters equal to constants: V_S, R_D, f^2, and B_S (x,y). Equation 1 then reduces to:

$$K' = G \int_{-3.75}^{3.75} \int_{-5}^{5} \tau_M (x,y) \, d x \, d y \qquad (2)$$

where:

$$K' = \frac{V_S f^2}{K R_D B_S} \text{, a constant}$$

Equation 2 can be further simplified by noting that the double integral is the mask area times the average mask transmission. Then

$$K' = GA \langle\tau_M\rangle \qquad (3)$$

where:

$\langle\tau_M\rangle$ is the average mask transmission

A is the mask area

If the automatic exposure control is designed to function on a logarithmic basis, taking the logarithm of each side of Equation 3 yields:

$$\log (K'/A) = \log G + \log \langle\tau_M\rangle \tag{4}$$

Equations 3 and 4 summarize the conditions which must be met if the area weighting function is to be an interchangeable feature. Either the average mask transmission must be held constant or the electronic gain must be changed to compensate. When the AEC operation is logarithmic this correction is applied as a fixed offset.

Controlling the average mask transmission has two disadvantages. First, it would increase the cost of the mask by adding another control parameter. More important, the average transmission would be restricted to that when the smallest spot mask is used, perhaps one percent or less. This would reduce the signal-to-noise ratio at low light levels when exposure is based upon a larger portion of the format.

The simplest solution is to correct the electronic gain. This could be done in the same way as a filter factor is applied. If the masks are interchangeable, the correction could be keyed to the mask slide via a fixed resistor contained in the slide or a digital code.

The principal arguments favoring interchangeable weighting functions include:

(1) A particular area weighting function will not be optimum for all presently recognized camera applications. For example, hand held photography on the lunar surface would be benefited most from a weighting function which emphasizes the foreground. Accurate exposure of a small object in space would be best achieved by a small center weighted spot.

(2) The camera will undoubtedly be used for applications which have not been anticipated. These new applications can easily be accommodated.

(3) Improved weighting functions can easily be tried to correct for errors observed in existing photography.

The principal disadvantage of incorporating interchangeable weighting functions (i.e., transmission masks) is the increase in complexity and associated cost.

Figure 27 illustrates three area weighting mask configurations which might be considered in shuttle applications. These examples are by no means exhaustive. An infinite number of weighting functions are possible. The gain and log gain corrections associated with each configuration are indicated. These corrections compensate for light thrown away in order to achieve the desired weighting functions.

Example A, Figure 27, illustrates a center spot weighted mask. The center spot is a 1 mm diameter clear circle. The remainder of the format has a transmission of 10^{-2}. This configuration gives the center spot an importance equal to that of the remainder of the format.

The center spot weighted mask differs from a spot meter having a 1 mm diameter. A spot meter would not consider the brightness of the scene outside the spot in determining exposure. This would be achieved by making $\tau_B < 10^{-4}$. In other words, the spot meter requires a different weighting (or transmission) function than the center spot weighted mask of Example A.

The center spot weighted mask would be useful in rendezvous and docking and in other inter-vehicular photography. It is appropriate when the subject of interest is likely to be small and located in the center of the camera format.

Example B, Figure 27, illustrates a foreground weighted mask. This choice of weighting function gives the 2 mm x 5 mm rectangular area an importance equal to the remainder of the format, even though its area is much smaller. In the camera, the foreground may be located at the top of the format rather than as presented in Example B, Figure 27.

The foreground weighted mask would be appropriate in hand held lunar surface photography. It assumes that the foreground brightness is likely to be representative of the subject.

Example C, Figure 27, weights all portions of the scene equally. The mask transmission is unity throughout the format. Since all the light reaches the detector, a better signal to noise ratio is obtained at low light levels.

The uniform weighted mask is most appropriate when the entire scene (including the subject) encompasses a limited brightness range. It will tend to discount small specular reflections or other hot spots which are not representative. When no apriori information is available about the subject and background, it is a good choice. However, a spot meter under the control of a trained operator is superior.

The uniform weighted mask would be suitable for orbital photography of either the earth or the moon. It would probably be a good choice for any close up photography and especially appropriate for photographing astronaut activity within the vehicle cabin. Within the cabin, the enhanced low light level performance would be helpful.

Electronic Design

Requirements.- The requirements for the AEC are summarized as follows:

(1) Response time shall be 2 ±0.5 seconds. The response time is defined as the time for the iris and shutter to move from one extreme to the other (10 stops).

(2) Remote control from 50 feet away via wiring.

(a) Remote AEC Automatic. If remote operator selects AEC Automatic, the system selects the required shutter speed/f stop combination as determined by the sensor at the camera.

(b) Remote AEC Manual. If remote operator selects AEC Manual, he then has the capability of selecting any combination of shutter speed/f stop in full stop increments.

(c) Remote Trigger. This allows remote operator to start or stop camera; and also enables or inhibits the AEC in either the manual or automatic mode.

(3) Local control at camera identical to remote control operation as described above except that selection is made at camera.

(4) Operator control is independent of station, i.e., operator who takes command can exercise complete control over system irrespective of switch settings at other station.

(5) Film sensitivities, ASA values, shall be as follows: ASA 40, 64, 80, 100, 125, 160, 200, 320, 400, 500, 640, 800, 1000, 1250 and 1600.

(6) Prior to selection of AEC automatic mode, the operator will select an iris home position either from the remote or local station. This position will define the point about which the shutter will adjust two stops in either direction. AEC operation outside of this range will then cause the iris to adjust from its home position.

To meet the above requirements, a detailed electronic design has been completed and is described in the following sections.

Electronics General Design Description.- A system block diagram of the AEC electronics is shown in Figure 28. To provide further detail of the various sub-blocks, a complete schematic is provided in Figures 29, 30, and 31.

The system basically accomplishes automatic exposure control by providing ten stops of mechanical adjustment; four stops are provided by adjustment of the shutter and six stops by adjustment of the iris. By including ASA compensation and selection of corresponding film, the effective light range over which the system can compensate is sixteen stops as illustrated in Table 10. In this illustration, ASA compensation has been extended to the next full stop, i.e., ASA 2560.

Actual adjustment of the shutter and/or iris is accomplished by two independent stepping motors. In the manual mode of operation, these motors drive the iris/shutter to full stop positions as commanded by either the remote or local station. In the automatic mode of operation, the motors drive the shutter/iris to 1/4 stop positions dictated by the output of the camera sensor.

The actual positions of the iris and shutter, provided at the camera data block interface, are a five bit digital format to 1/4 stop resolution as shown in Table 11.

AEC Electronics Detail Design.- To describe the various subblocks within the electronics, a typical sequence of operation will be discussed.

System reset: Upon application of primary power, the system enters an automatic reset sequence. This is shown in the timing diagram of Figure 32. During this time both the shutter and iris motors are automatically aligned to their nearest full stop position respectively and their positions converted to a digital code which is made available at the camera data block interface. By aligning the motors mechanically during assembly such that their full stop positions have the same binary drive, discontinuities are avoided when switching either manually or automatically from one motor to the other.

TABLE 10.– ASA COMPENSATION AS RELATED TO IRIS/SHUTTER POSITION AND SENSOR ILLUMINATION

Input Illum (fL)	ASA 80			ASA 40			ASA 2560		
	Iris	Shutter	Sensor Illum	Iris	Shutter	Sensor Illum	Iris	Shutter	Sensor Illum
81920.0				22.0	8.6	1024			
40960.0	22.0	8.6	512	16.0	8.6	1024			
20480.0	16.0	8.6	512	11.0	8.6	1024			
10240.0	11.0	8.6	512	8.0	8.6	1024			
5120.0	8.0	8.6	512	8.0	17.2	512			
2560.0	8.0	17.2	256	8.0	34.5	256			
1280.0	8.0	34.5	128	8.0	69.1	128	22.0	8.6	16.0
640.0	8.0	69.1	64	8.0	138.2	64	16.0	8.6	16.0
320.0	8.0	138.2	32	5.6	138.2	64	11.0	8.6	16.0
160.0	5.6	138.2	32	4.0	138.2	64	8.0	8.6	16.0
80.0	4.0	138.2	32	2.8	138.2	64	8.0	17.2	8.0
40.0	2.8	138.2	32				8.0	34.5	4.0
20.0							8.0	69.1	2.0
10.0							8.0	138.2	1.0
5.0							5.6	138.2	1.0
2.5							4.0	138.2	1.0
1.25							2.8	138.2	1.0

TABLE 11.– SHUTTER/IRIS BINARY POSITIONS

ASA 80 1280 (fL)

IRIS | HOME

	IRIS					SHUTTER			IRIS		
Iris f-stop	22	16	11	8				8	5.6	4	2.8
Shutter angle				8.6°	17.2°	34.5°	69.1°	138.2°			

IRIS POSITION

LSB	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	1	0	1	0	0	0	0	0	1	0	1
	0	1	1	0	0	0	0	0	0	1	1
MSB	0	0	0	1	1	1	1	1	1	1	1

SHUTTER POSITION

LSB	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1	0	1	0	1	1	1	1
	0	0	0	0	1	1	0	0	0	0	0
MSB	0	0	0	0	0	0	1	1	1	1	1

As indicated in the timing diagram of Figure 32, the initial event which takes place is an analog-to-digital conversion of the shutter position. A logic comparison is then made to determine if the shutter is at a full stop. If it is not, a drive pulse is applied to the shutter motor and the logic comparison again made. If the shutter is initially at a full stop, the system automatically switches to the iris motor and performs an identical conversion, comparison, and pulse drive technique.

Upon completion of the system reset, the system is now ready to be operated in either a manual or automatic mode.

Manual mode: The manual mode is entered by either a remote or local operator pressing his respective manual AEC select pushbutton. The operator then selects the desired iris and shutter positions via seven and five position rotary switches respectively. To drive the shutter to the selected position he sets the iris/shutter select switch to Shutter and presses the Trigger switch. The shutter motor will then drive the shutter to the selected position. This operation is then repeated for the iris by setting Iris/Shutter select switch to Iris and again pressing the Trigger switch.

Utilization of the Iris/Shutter select switch greatly reduces the interface wiring and associated circuitry since either motor position can be selected from the same circuit source and the position code transmitted over the same lines.

The actual input control signals to the AEC circuitry are digital levels; since COS/MOS circuitry is being utilized throughout the design, a digital one level will equal +12 V and a digital zero level will be ground. This provides two advantages; the logic can be operated directly from the +12 V output of the ±12 V DC/DC converter, and greater immunity from noise is achieved by utilization of the higher one level voltage. If it is decided to utilize the same control circuitry in the remote control station as is used in the camera, then the +12 V and ground levels would be routed to the remote station from the AEC electronics to ensure logic level compatibility.

Utilizing a digital control technique, the manual selection is made simply by a momentary switch action to ground. A single input line determines iris or shutter selection; iris zero and shutter one. These lines are utilized to input the required position code as shown in Tables 12 and 13.

TABLE 12.- MANUAL POSITION INPUT CODES
FOR SHUTTER POSITIONS

SHUTTER POSITION	MSB 32	16	LSB 8
8.6	0	0	1
17.2	0	1	0
34.5	0	1	1
69.1	1	0	0
138.2	1	0	1

TABLE 13.- MANUAL POSITION INPUT CODES
FOR IRIS POSITIONS

IRIS POSITION	MSB 32	16	LSB 8
22	0	0	1
16	0	1	0
11	0	1	1
8	1	0	0
5.6	1	0	1
4	1	1	0
2.8	1	1	1

With application of the trigger the system reacts to the given set of inputs. If the manual selection has been made at the remote station, the remote inputs are recognized. If the manual selection has been made at the camera, the camera switch settings are recognized.

The actual positioning of either motor is accomplished by a digital comparison between the input code and the digital position feedback which has been acquired by converting a voltage generated by a position potentiometer mounted on the respective motor shaft. The initial comparison determines the direction which the motor has to move. If the input code is greater than the feedback code, the motor selected is stepped in a clockwise direction to open either the shutter or the iris, when the trigger is applied. This is illustrated by the timing diagram, Figure 33. If the input code is less, the selected motor is driven in a counterclockwise direction. When the two equalize, no further stepping takes place even though the trigger remains applied.

When a noncompare condition exists, the selected motor is stepped at a rate of 20 Hz by application of a four bit binary code to the motor drive windings. The 20 Hz clock is derived from a 20,480 Hz oscillator and divide by 1024 ripple counter. The binary code is available through a time shared ring counter which is stepped by the 20 Hz. Positive 28 V dc is applied through a switched transistor to one side of each of the winding pairs. By switching +28 V dc from one motor to the other, all of the necessary digital drive circuitry can then be time shared.

Each time a motor is stepped, the required binary code is applied for 25 ms and then removed. This means that power is drawn by the motor only during the stepping process, and is removed at all other times. Each step represents a 90° rotation of the selected stepping motor and a 1/4 stop charge in mechanical position of the iris or shutter. Therefore 16 steps cover the 4 stops of shutter change and 24 steps cover the 6 steps of iris charge. Since the stepping motor is moving in a linear manner and a stop change requires the shutter or iris opening be doubled or halved, a logarithmic interface is necessary between the motor and iris/shutter.

The A/D converter used in converting the shutter or iris position consists of the following; a five bit binary up-counter, a six bit digital to analog converter, two analog comparators, and gating circuitry to sample the comparator output associated with the motor which has been selected. During the application of the 25 ms pulse to the motor windings, the counter is reset. When the pulse is removed, the conversion processes begin by the counter counting at a 10,240 Hz rate. When the counter output drives the D/A converter to a voltage equal to 1/2 the least significant bit past the input voltage present at the comparator from the position potentiometer, the comparator output switches, which in turn disables the clock, and terminates the conversion. At this point, the digital position information is strobed into one of two 5 bit output registers, depending on whether it is a shutter or an iris conversion. This position information is made available at the camera data block interface and also fed back to the digital comparator for comparison against the input code. If iris and/or shutter has not reached a null, the step drive, conversion and comparison continues until a null is achieved.

The D/A converter output and position potentiometer comparison are accomplished in the following manner. The full scale output voltage is initially adjusted such that the least significant step represents approximately 150 millivolts. The D/A converter is operated in a bi-polar, complimentary mode such that 111111 is -5 V; 000001 is ground, and 000000 is +5 V. The output of the binary counter is inverted and applied to the D/A digital inputs. As an example, consider a shutter position of 8.6°. This is represented by a binary equivalent of 00100 which, when inverted, becomes 11011 to the input of the D/A converter. The most significant bit is permanently set at a one level since only five bits are being converted. This input causes the output of the D/A converter to step to -4.4 V dc. By initially selecting a 10,000 ohm, 10-turn potentiometer and applying a constant current source which provides a 150 millivolt change each time the potentiometer is moved 90°, a 1/8 stop, 75 millivolts of hysteresis can be achieved without any external circuitry added to the comparators. This is accomplished during mechanical assembly by adjusting the potentiometer such that with the constant current flowing through it, the output is -4.475. The potentiometer is then fixed to the shutter motor shaft at 8.6°. At this point, the potentiometer output is 75 millivolts more negative than the D/A converter output. When the motor is initially stepped clockwise, the potentiometer output goes to -4.325 which causes the D/A output to then step to -4.250, thus achieving 75 millivolts of hysteresis.

A similar procedure is utilized on the initial adjustment and assembly of the iris potentiometer to the iris motor shaft.

Automatic mode: The Automatic Mode of operation differs from the Manual Mode primarily in two areas. The position of the iris and shutter are determined by the output of a silicon light sensor which is located behind the camera iris. Typical levels which the sensor can expect to see are indicated in Table 10.

The iris/shutter operation is as follows. An iris home position is initially established by the remote or local operator while in the manual mode. This may be any of the seven iris full stop positions. From this point, and upon entering the automatic mode, the shutter always adjusts two steps in either direction. If the shutter reaches an extreme, the iris will then adjust. If the light level reverses, the iris returns to its home position before the shutter again adjusts. A typical example of this is indicated in Table 11, with the iris home position having been selected as f-8.

A timing diagram of a typical automatic sequence is shown in Figure 34. The operator enters the automatic mode by momentarily pressing the Automatic Mode select switch either locally or remotely. When the operator presses the Trigger, a dual comparison is immediately made between the output of a logarithmic amplifier, and two voltages from the shutter potentiometer network. If the log amplifier output and the feedback voltages are at a null condition no adjustment is made. However, if a null condition is not present, the shutter begins to adjust in the proper direction in a manner identical to that of the manual mode; i.e., step motor, convert position and compare. The comparison now, however, is between the sensor output and the feedback potentiometer. The digital conversion of the shutter position is utilized to determine if the shutter is at either extreme. Once a shutter extreme is reached, the system automatically switches to the iris if further adjustment is necessary.

Upon entering the iris adjustment a two-fold comparison is made. One between the sensor output and the shutter potentiometer, the other between the iris digital output and the iris input code set in the iris position switch. At this point the shutter potentiometer is no longer adjusting but acting as a reference for the iris adjustment. That is each time the sensor signal increases above the reference or decreases below this reference, if the shutter were at the other extreme, the iris closes or opens to bring the sensor signal back to the reference established by the shutter potentiometer. This is accomplished by locating the sensor behind the iris and reduces the range over which the sensor has to operate to ten stops as shown in Table 10. The digital comparison is necessary to keep track of the iris home position. Once the light level reverses, the iris continues to drive in the opposite direction until its home position is detected by the digital comparison, at which time the system automatically switches back to shutter.

The digital comparison technique makes use of the same circuitry utilized in the manual mode by simply disabling the normal manual operation and comparing the iris output register signals to the input digital code from the iris position select switch on a continuous basis. A considerable amount of circuitry is thus able to be time shared.

The dual analog comparison between the log amplifier output and the shutter potentiometer network is best explained by assuming an initial set of conditions; ASA 80 film, shutter at 34.5° and iris at f-8.

The total number of incremental steps on the 10,000 ohm, ten-turn potentiometer is equal to (10) (360°)/90° = 40 steps. The ΔR change per step is then 10000/40 or 250 ohms. A one stop change is then equal to 4 x 250 or 1000 ohm resistance change. We have already established in the manual mode discussion, a least significant digital to analog step change of 150 millivolts. Therefore, the constant current necessary to provide correct comparison is equal to 150 millivolts/250 ohms = 600 μA.

The correct potentiometer setting for the shutter at 34.5° and a constant current of 600 μA will establish the output of the potentiometer at -3.275 V dc which is 75 millivolts more negative than the output of the D/A converter corresponding to a digital position of 01100. Referring to the schematic, Figure 31, the ASA compensation resistor is set at 5,000 ohms. This compensation causes the potentiometer network inputs to the dual comparators to be -6.725 V dc and -7.025 V dc respectively. The gain of log amplifier is initially set such that a one stop increase causes the output to change in a negative direction by 0.6 V dc and a one stop decrease causes an output change of 0.6 V dc in the positive direction. With the initial setting of the iris at f-8, the log amplifier is biased such that its output is -6.875 V dc when the input to the sensor is 128 foot lamberts, refer to Table 10. The output of both the CWA and the CCWA comparators is therefore low and a null condition is achieved.

If an increasing light level condition is detected, the output of the log amplifier goes more negative until it reaches -7.025 V dc, a 1/4 stop change. The CCWA comparator output then switches to a high state and the shutter motor is stepped in a counterclockwise direction which closes the shutter down by 1/4 stop. The potentiometer network outputs then become -6.875 V dc and -7.175 V dc respectively. If the light level now decreases, the output of the log amplifier goes positive until it reaches -6.875 V dc. The CWA comparator output then goes high which drives the shutter motor in a clockwise direction, thus again opening the shutter. This technique therefore not only provides 1/4 stop recognition but also 1/4 stop hysteresis; that is, a change does not take place in either direction unless a 1/4 stop light level is detected by the sensor. This should eliminate hunting which is commonly associated with dc motor control systems. As previously discussed in the Manual Mode operation, the A/D conversion of the shutter and iris positions still maintain a 75 millivolt hysteresis dead band.

By utilizing the 750 ohm and 500 ohm fixed resistances in the feedback loop as indicated in the schematic, Figure 31, ASA compensation in full stops can be accomplished by simply changing the 5,000 ohm resistance in 1,000 ohm increments. ASA 40 would be compensated for by increasing the resistance to 6,000 ohms. This would cause the CWA comparator to turn on, and the shutter to adjust to 69.1°; a slower film would thus produce a larger opening for the same set of light conditions. For an ASA of 2560, the ASA compensation would be a short and the shutter would drive to 8.6° and the iris to f-22 for the same set of input conditions. Refer to Table 10. The faster film therefore closes the system down and effectively shifts the operation to a lower level light range.

The digital codes representing the shutter and iris position, as noted before, are shown in Table 11. In addition to this, two discrete levels are available which indicate a too dark or too light condition. If both the shutter and iris are at an extreme open position, the too dark signal is true. If they are both at the extreme closed position, the too light signal is true. If either of these conditions is true, the motor drive circuitry is also disabled such that no additional drive pulses can be applied, regardless of the input to the sensor.

Summary.- The basic criteria established during the AEC electronic design are listed below.

(1) Control Modes. Remote Manual, Remote Automatic, Local Manual, Local Automatic.

(2) AEC Activation. Activated only when trigger is applied.

(3) Manual Control. Any combination of five shutter stops and seven iris stops.

(4) ASA Compensation. ASA 40 to ASA 2560, utilizing resistor located in magazine.

(5) Automatic Exposure Compensation Range. Ten stops for specific film; with proper film selection, 16 stops, refer to Table 10.

(6) Remote Input Commands. Digital format.

(7) Outputs.

  (a) 5 bit digital shutter position

  (b) 5 bit digital iris position

  (c) Too dark status level

  (d) Too light status level.

(8) Response Time. 2.0 $\pm$0.5 seconds (from one extreme to other).

(9) Resolution. 1/4 stop.

(10) Input Power. 24 to 32 V dc.

(11) Approximate Input Current

(a) Standby. Less than 40 mA.

(b) Activated. 160 mA peak.

(12) Estimated Package Count

(a) 54 integrated circuits

(b) 80 discrete components.

Mechanical Design

Approach.- The mechanical part of the Automatic Exposure Control System consists of the enclosure, the packaging and the drive trains inclusive of the drive motors. The mechanical drive system is shown schematically in Figure 35. The study is primarily concerned with a breadboard model of the AEC. Thus, primary emphasis is placed on a discussion of the shutter and iris mechanical drive trains. A cursory discussion of the enclosure and packaging of the mechanical portion of the design is presented in this section.

In Mechanical Sub-System Approaches, two methods are discussed for mechanically driving a shutter and an iris disk. The first method uses a single helical gear/cam combination for both shutter and iris control. The second method uses differential angular phasing for the shutter control with a separate iris control drive.

Consideration of the design problems associated with the helical gear/cam approach shows that this approach is, by the very nature of transforming rotary motion to linear motion, the more complex of the two. Further, the rectilinear bearing is not compatible with minimum backlash in the shutter mechanism, or with a maximum efficiency transmission system. Also, the design contraints, both electrical and mechanical, imposed by using one motor to control both shutter differential angle and iris opening are considered to be excessive compared to the doubtful advantage of using one rather than two motors. For these reasons, a separate differential shutter and iris control system are selected for the breadboard design. The shutter system is considered first.

Shutter Drive and Control.- As shown in Figure 36, a top view showing the schematic arrangement of the differential shutter drive, the shutter is driven by the main drive dc motor. The motor pinion, 1, drives the end gear, 2, of a differential, the spider shaft of which is clamped by the differential stepper motor through a gear train. With the end gear driven and the spider shaft clamped, the opposite end gear, 4, will rotate in a sense opposite to the driven gear, 2. If, now, the driven end gear, 2, drives a gear, 3, on one shutter shaft and the opposite end gear, 4, is belted to a gear, 5, on the other shutter shaft, a phase inversion occurs between gears 2 and 3 and no phase inversion takes place across the belted gears 4 and 5. Thus, the inversion occurring across the differential is rectified, and the coaxial shutter wheels rotate in the same direction. This establishes the primary rotation of the shutter blades.

Differential angular position of the shutter blades relative to each other is controlled by the differential stepper motor. The differential stepper motor pinion, 6, drives gear 7 which rotates a jackshaft. The jackshaft mounts a noncircular gear, 8, which drives another noncircular gear, 9, mounted on the differential spider shaft. Rotation of the spider shaft causes gear 2 and gear 4 to rotate in a manner to drive the shutter wheels differentially.

The differential spider shaft, the jackshaft on which gears 7 and 8 are mounted, and the main drive motor and differential stepper motor are all mounted on parallel aluminum plates spaced by blocks. The structure is screwed and taper pinned together. Bearing bores for the jackshaft and spider shaft are jig bored with the structure assembled. The front plate is machined with a boss to provide a housing for the jackshaft bearings. Servo clamps are used to secure the motor to the structure to facilitate adjustment.

Flanged ABEC Class 5 angular contact ball bearings are used in the spider shaft and jackshaft assemblies. The bearings are preloaded with wave washers and bearing shims to minimize radial free play. The bearings are shielded and lubricated with Windsor L-245X oil per MIL-L-6085. The same type of bearings and lubricant are used for the shutter mechanism. A 0.25 inch shaft is used for the inner shutter assembly.

The differential selected for use in the breadboard is the Sterling Instrument Model T719. This differential has a hollow shaft that allows wide latitude of mounting shaft length. A 0.25 inch shaft diameter was selected in anticipation of heavier loads and greater bearing separations occurring in the breadboard than might occur in a camera application.

One output gear from the differential is mated with a spur gear on one shutter shaft. The other output is a PIC Design Corporation no slip geared pulley belted to a pulley mounted on the other shutter shaft. A PIC coreless no slip drive belt is used to connect the two geared pulleys. The ratio between the differential output pulley and the shutter shaft pulley are the same as the ratio between the differential output gear and the shutter shaft gear, so the shutter blades are synchronized. The combination belting and gearing arrangement diminishes the alignment problem between the differential assembly and the shutter assembly, because the belt is more tolerant of alignment than would be another gear. Also, because of the phase inversion across the differential, an idler gear would be required to rectify the phase if a gear drive is used on both ends of the differential. Differential specifications are presented in Table 14.

TABLE 14.- COMPONENT MANUFACTURER SPECIFICATIONS

Component	Characteristics
Sterling T719 Differential	Shaft Diameter - 1/4 in; max load rating 35 in-oz; max operating speed, 1000 rpm; breakaway torque, 0.2 in-oz; weight 1.9 oz.
Tormax 008-845 Stepper Motor	Permanent Magnet; step angle, 90°; input voltage, 28 V dc; max response 105 steps/second; running torque, 0.21 in-oz; detent torque, 0.05 in-oz; stall torque, 0.50 in-oz; resistance per phase, 450 ohms; rotor moment of inertia 0.65 $gm\text{-}cm^2$

The requirement for doubling the shutter angle for equal increments of stepper motor shaft rotation dictates nonlinear coupling between the differential stepper motor and the differential spider shaft. Of the several possibilities available for generating the required motion, noncircular gearing was selected for the AEC breadboard. Linkages are more complex than gearing and are perhaps less tolerant of wear and misalignment. Also, recent increases in the commercial availability of noncircular gears makes their use economically feasible in a mechanism of this type.

The geometrical relationships that exist in the shutter differential angle drive are: (1) 90° motor step angle; (2) 10:1 motor to jackshaft gear ratio; (3) 4 steps double or halve the shutter angle; (4) differential end gear relative rotation is twice the spider shaft rotation angle.

These geometrical relationships along with the shutter angle variation range from 8.6° to 138° are summarized in Table 15. The shutter angle cardinal points of 8.6°, 17.3°, 34.5°, 69° and 138° were derived from the NASA basic specification where the relative shutter speeds were listed as 1/62 second to 1/1000 of a second at a rate of 24 frames per second. The formula used in the calculation is:

$$\text{Relative Shutter Speed} = \frac{\text{Frame Rate x 360}}{\text{Shutter Angle}} \qquad (5)$$

The jackshaft cumulative angle to differential spider shaft angle may be expressed in closed form by the relationship:

$$\Theta_o = 4.32 \left(e^{0.0192\Theta_J} - 1 \right) \qquad (6)$$

where

Θ_o = spider shaft angle (degrees)

e = natural logarithm base

Θ_J = jackshaft angle (degrees)

This logarithmic function is available in a noncircular gear set on special order from sterling Instrument and Cunningham Industries. For the data in Table 15, the ratio extremes of the noncircular gear set are 8.34:1 and 2.22:1, which results in a ratio variation of 3.75:1.

The stepper motor selected is a Tormax Model 008-845 permanent magnet type with a 90° step. A permanent magnet motor was selected because it provides detent torque capability in the power OFF condition to minimize system power consumption. Motor running torque is 0.21 in-oz, and detent torque is 0.05 in-oz. The overall gear ratio to the differential spider shaft varies from 83:1 to 22:1. Torque at the differential shaft thus varies from 4.1 in-oz to 1.1 in-oz in the energized or detent motor condition. Assuming a transmission efficiency of 50%, the remaining torque is 2.0 in-oz maximum to 0.5 in-oz minimum.

Assuming that the shutter wheel is accelerated to speed in 2 seconds, that the inertia moment of the shutter blades is approximated by a steel disk 2.25 inches in diameter by 0.010 inch thick, that the other rotating elements contribute an equal moment of inertia, and finally, that the rate of angular acceleration is constant, then the torque required to accelerate one shutter blade is:

TABLE 15.- AUTOMATIC EXPOSURE CONTROL STUDY
SHUTTER ANGLE AND TRANSMISSION GEOMETRY SUMMARY

Step Number	Stepper Cumulative Angle (°)	Jackshaft Cumulative Angle (°)	Differential Input Shaft Cumulative Angle (°) (Spider Shaft Angle)	Shutter Angle	Remarks
0	0	0	0	8.6	Minimum shutter opening
1	90	9			
2					
3					
4	360	36	4.32	17.28	
5					
6					
7					
8	720	72	12.96	34.56	
9					
10					
11					
12	1080	108	30.24	69.12	
13					
14					
15					
16	1440	144	64.8	138.24	Maximum shutter opening

$$\tau = I\ddot{\Theta} \tag{7}$$

$$= 0.368 \times 10^{-4} \quad sec^2 \times 75 \text{ rad/sec}^2$$

$$= 0.0441 \text{ in-oz}$$

where

τ = Constant torque required to accelerate 1 shutter blade to 24 grams/s in 2 seconds

I = Estimated inertia moment of one shutter blade mechanism

$\ddot{\Theta}$ = Average angular acceleration required to bring one shutter blade from 0 to 24 frames per second in 2 seconds

The spider gear operates at a 2:1 mechanical disadvantage to the differential end gear; hence, the spider shaft clamping torque required to prevent differential shutter motion will be 2 x 0.0441 in-oz or 0.088 in-oz. This is well within the lower detent torque range of the motor through the gearing. This means that the shutter position will be unchanged if the AEC system is turned OFF and ON, assuming of course, the control logic does not reset to some nominal position in that process.

ADC motor controlled by a tachometer loop drives the shutter through gearing compatible with 24 frames per second shutter rate.

Iris Control.- The iris mechanical drive is shown in Figure 37. The Rolyn Optics Iris Model 54-19-PG, with a range of six f-stops is used in the breadboard. This range is covered in 77° of iris wheel rotation. A design requirement is four motor steps per f-stop change, or a total of 24 steps from one iris extreme to the other, which, for a 77° total iris angle, results in a 3.21° rotation of the iris ring per motor step.

The stepper motor for the iris drive is the same as used for the shutter differential drive, for compatibility with the driving electronics which are time shared between the shutter and iris drive systems. For a 90° step, the gear ratio from motor to iris is:

$$\frac{90°/\text{Step}}{3.21°/\text{Step}} = 28:1 \tag{8}$$

This 28:1 ratio is accomplished with a two stage reduction. The motor pinion drives a jackshaft which drives the iris wheel. The motor to jackshaft drive is a gear drive; the jackshaft to iris drive is a toothed pulley-cogged belt drive of the PIC variety. As in the shutter drive train, the final belt drive link is used to minimize alignment problems.

Motor running torque at the iris is 28 x 0.21 = 5.86 in-oz and detent torque is 1.47 in-oz. The estimated torque required to move the iris ring is 0.1 in-oz, leaving better than an order of magnitude motor torque margin.

Bearings for the iris system are of the same type as for the shutter dirve.

Summary. - Packaging of the mechanical breadboard provides accessibility for observation, instrumentation, and possible modification.

The following components fulfill the system requirements of the mechanical breadboard:

A. Shutter Drive and Control:

(1) Stepper Motor - Permanent magnet, 90° step angle, Tormax 008-845

(2) Drive - Spur gears and PIC "no slip" pulleys and belt

(3) Logarithmic Function Generator - Noncircular gear pair, Cunningham Industries

(4) Differential - Sterling T719

(5) Shutter - Rotating pie sector, variable angle.

4.0 BREADBOARD EVALUATION TEST AND DEMONSTRATION

Test Date and Personnel.- The breadboard demonstration was held on 23 January 1974. Attendees for:

NASA-JSC:

R. Gerlach	Technical Monitor
V. Meyers	Technical Consultant

Perkin-Elmer ASD:

L. Stoap	Department Manager, Photo-Mechanical Programs
G. McAtee	Project Manager, Photo-Mechanical Programs
C. Solheim	Senior Engineer, Electronic Development
S. Fall	Test Technician

The breadboard demonstration was conducted in accordance with the procedure specified by Perkin-Elmer ASD Document TP 84-0208, Rev. A, titled, "Evaluation Test for NASA Automatic Exposure Control". A copy of the test procedure, data record and check-off list and the unit response prediction are presented for reference purposes in Appendix B.

5.0 END ITEM SPECIFICATION (CD42-S-770)

Scope.- This specification defines the design and performance requirements and environmental test parameters that will be used in the design, development and fabrication of an Automatic Exposure Control System which will be incorporated in a 16mm data camera for manner space flight.

Applicable Documents.- The following documents, to the latest revision, shall form a part of this specification, through reference herein, to the extent specified. In all other cases, these documents are listed only as a source of supplying information to aid in the design effort.

a.	MIL-A-8625	Anodic Coatings for Aluminum and Aluminum Alloys
b.	MIL-A-21180	Aluminum-Alloy Castings, High Strength
c.	MIL-E-5400	Electronic Equipment, Airborne, General Specification for
d.	MIL-STD-150	Photographic Lenses
e.	MIL-STD-461/ NASA Supplement	Electromagnetic Interference Requirements for Equipment

f.	TBD	Test Plan for the Type Qualification Testing of the 16mm Cameras for use on Spacecraft
g.	Metals Handbook, Vol 1 American Society for Metals Metals Park, Ohio	Properties and Selection of Metals

Definitions.- The following are the definitions of terms used in this specification.

a.	AEC	Automatic Exposure Control System
b.	ASA Rating	The exposure index of sensitivity adopted by the American Standards Association (also referred to as the ASA speed)
c.	Stop	The term "stop", for the purposes of this specification, is an index of relative light energy level. It is a logarithmic relation, so that each successively larger stop means a doubling of energy over the previous number. Thus, two stop changes indicate a range 4 to 1; three stop changes is a range of 8 to 1; and 10 stop changes is 1024 to 1.
d.	f-stop	The term "stop" applied to the iris setting
e.	PDR	Preliminary Design Review
f.	TBD	To Be Determined

Requirements

Performance Criteria.- The Automatic Exposure Control System (AEC) shall be optically, electrically and mechanically integrated into the camera system.

The AEC shall automatically control the lens iris as well as the shutter opening such that the subject is properly exposed on the film.

The AEC shall be activated by the camera trigger.

The AEC shall provide the capability of preselecting the iris "home position". This setting shall define the iris f-stop about which the shutter will adjust. AEC operation beyond this range will cause the iris to adjust from the home position. The iris home position shall be adjustable in one f-stop increments and will be a premission adjustment. Readjustment capability during a mission is not a requirement.

The AEC shall be activated in the automatic mode when the camera trigger is actuated. The AEC shall set the iris to home position first, then adjust the shutter opening and, if further adjustment is required to achieve the desired light level, adjust the iris.

The AEC shall compensate for film sensitivity. Each film compensation value shall be a constant set by the film magazine for the particular film being used. The AEC shall use this value in performing its function. Film compensation values shall correspond to the ASA film ratings presented in Table 16 below.

TABLE 16.- ASA FILM RATINGS

1.	40	7.	200	12.	800
2.	64	8.	320	13.	1000
3.	80	9.	400	14.	1250
4.	100	10.	500	15.	1600
5.	125	11.	640	16.	2560
6.	160				

The AEC shall provide coded f-stop and shutter speed position data to the camera data block. This data shall be available from the AEC logic in binary coded form and shall have 1/2 stop resolution.

The AEC shall provide the manual and automatic operation options, from local and remote stations.

The AEC shall be commanded from the camera, or remotely from a station. The remote station shall be connected to the camera by a maximum 50 foot cable. Accuracy or reliability shall not be degraded by the remote capability. Switching from local to remote or reverse operation shall not require recalibration.

The AEC shall not degrade camera performance.

The AEC shall function as specified herein, regardless of orientation, when subjected to either zero gravity or the specified operating environments.

To conserve power, the AEC shall function only when the camera is operating.

Manual control shall be in one stop increments and shall provide any combination of the five shutter speeds and the seven iris f-stops.

The AEC automatic mode shall adjust the camera to within 1/4 $\pm$ 1/16 stop with respect to the input light level. This shall be accomplished by adjusting the shutter and/or iris.

The AEC shall provide exposure control over a 10 stop mechanical adjustment range. By including ASA compensation and corresponding film selection (see Table 16), the effective system light level compensation range shall be 1.25 to 81,920 footlamberts (16 stops).

System response time shall be TBD. Response time is defined as the time required for the iris and shutter to move from one extreme to the other (10 stops) in either direction.

The AEC, either local or remote (via wiring), shall provide the following functions.:

a. AEC Automatic. If the operator selects AEC automatic, the system selects the required shutter speed/f-stop combination as determined from the output of the detector.

b. AEC Manual. If AEC manual is selected, the operator shall have the capability of selecting any shutter speed and f-stop combination in full stop increments.

c. F-Stop. Operator selects lens iris position.

d. Shutter Speed. Operator selects shutter speed.

Operator control shall be independent of station, i.e., the operator taking command, by actuating the camera on/off button, can completely control the system, irrespective of settings at another station.

In addition to the coded data for the shutter and iris positions, the AEC shall provide signals to the data block to indicate too dark or too light status.

The AEC shall meet all environmental requirements imposed on the camera and magazine, as specified in TBD.

The AEC shall not be damaged or permanently degraded by TBD hours exposure to direct sunlight. Performance shall recover within TBD time after exposure to direct sunlight.

The AEC shall perform as specified herein when used with any of the following camera lenses.

List TBD

Mechanical

The AEC size and weight shall be minimum. The physical configuration shall provide optimum integration within the camera.

The AEC system structural parts shall conform to the same standards as the camera.

Aluminum structural parts, except ball bearing support surfaces, shall be Type II light gray anodized per MIL-A-8625. Ball bearing support surfaces shall be allodined.

Any metallic gears used in the AEC shall be 400C stainless steel, manufactured to the same standards imposed on the camera drive gears, or aluminum alloy, 24ST or equivalent, if the resulting reduction in weight and mass moment of inertia justifies the lighter alloy. Aluminum gears shall be protected by the same surface treatment as the structural parts, except for tooth surfaces, which shall be treated by the TBD process. Other internal mechanism metallic components shall be 300 series or 17-4PH stainless steel to take advantage of the supeior corrosion resistance of these materials, unless weight and mass moment considerations require application of a lower density material, in which case the parts shall receive appropriate surface treatment to render them suitable to meet the life and environmental requirements.

In general, all rotating elements shall be mounted on ball bearings meeting the same standards imposed on the camera. Using plain bearings shall be subject to approval by the Technical Manager.

All springs shall be beryllium copper to take advantage of the superior fatigue characteristics of this material.

AEC to lens attachment details shall be subject to approval by the Technical Manager at the PDR.

The AEC shall be designed to produce a minimum of acoustical noise and mechanical vibration during operation.

In order to facilitate maintenance, mechanical connections by gears or other mechanisms between the AEC, camera and lens shall be clearly marked to insure proper orientation between the AEC mechanism and the camera shutter and iris. Marks shall be provided, as required, so that complete AEC disassembly and reassembly can be accomplished without resorting to measurements, adjustments or trial and error methods to obtain proper orientation with the mechanisms.

AEC manufacturing tolerances for the various parts shall be maintained such that all parts are interchangeable without modifications or alterations.

In general, tapped holes in aluminum for screws shall require helicoil thread inserts.

Using Locktite or other adhesives to secure screws shall, in general, be limited to cases where vibration loosening of screws cannot otherwise be overcome. If Locktite is used, use Grade C only. Locktite shall be used only with the approval of the Technical Manager. Locktite or sealants shall not be used in proximity to lubricants.

The AEC shall be considered a major camera subassembly and shall be permanently and conspicuously serialized with approved marking techniques.

Workmanship shall be controlled to the requirements of MIL-E-5400, except where a conflict exists, this specification shall take precedence.

Antivibration techniques shall be employed where overcomplication will not result and performance will be improved.

The camera shutter controlled by the AEC shall be the rotating disc type.

In order to provide satisfactory operation in outer space, all sliding and rolling contacts in the AEC mechanism, including bearings, shall be dry lubricated, lubricated by a proven space lubricant with nonmigration characteristics, or shall be run dry. The later choice shall be used only after analysis and testing has justified the design, including materials, surface treatments, speeds, and loads for the specific parts and their applications in the AEC, and the environmental and service life requirements of the AEC.

Electrical

AEC input power requirements shall not exceed 150 mA when activated. Power will be provided by the camera, using spacecraft or battery power.

The AEC shall function per all requirements of this specification when the camera is subjected to the 24 to 32 V dc input voltage range of MIL-STD-704, Category C requirements.

DC system transients, as defined in MIL-STD-704, shall not cause damage or permanent degradation to the camera system.

Electromagnetic interference shall conform to MIL-STD-461A, as amended by NASA supplement dated June 1973.

All electrical wiring shall be of the TBD insulation type.

If electronic modules are used, they shall be interchangeable without component selection.

The use of motors employing brushes and components with sliding contacts shall be minimized.

Any motors used in the AEC shall provide a minimum 1000 hours operating life when installed in the camera and operated in earth atmosphere under normal loading conditions. Motors shall not require maintenance more than once every 400 hours of operation. Under a vacuum condition of 1×10^{-6} mmHg, any motors, or components with sliding contacts shall provide a minimum 20 hours of operation when installed in the camera and operated under normal loading conditions and without interim maintenance.

The electrical power connection between the camera and AEC shall be as follows: filtered line voltage and return; chassis ground; and ± 15 V dc regulated.

The AEC chassis shall be isolated from the signal and operation circuits by a minimum of 1.0 MΩ dc resistance when measured at 35 V dc per specification TBD.

No circuit component shall operate in excess of 80% of its rated value under any combination of the environments imposed on the camera.

Reverse polarity of the camera input power shall not damage the AEC. Operation on reverse polarity power is not a requirement.

Shorting of any signal output lead to ground shall not cause circuit or component failure, but operation of that circuit is not required during the shorting.

AEC test points shall be provided as follows:

List TBD

One of the design goals of the AEC logic circuits shall be to provide a minimum of control leads from the remote control station to the camera.

Electrical connections between the AEC and camera shall be soldered connections to terminals on the AEC, or the AEC shall be integral to the camera electronics. Terminals shall be clearly identified.

Adjustable potentiometers and select components shall be held to a minimum and require approval by the Technical Manager at the design reviews.

Mechanical relays or reed switches shall not be used.

Photometrics

AEC light measurements shall be made through the camera lenses.

A detector shall be used for AEC light sensing. The detector shall sense the light over the entire film format.

Provisions shall be provided for area weighting to place emphasis on the brightness of different areas within the camera field of view. The area weighting device shall be an interchangeable mask. If corresponding electronic circuitry adjustments are required for the mask change, the adjustments shall be made as simply as possible for the camera technician.

The pellical in the light path shall not reduce light transmission to the film to less than TBD percent of the light traveling through the lens. The pellical shall reflect TBD percent of the light to the detector.

The AEC optics shall not cause internal reflections.

The AEC optics shall not cause any vignetting or loss of edge brightness greater than the percentage specified above.

The detector selected shall provide linearity, sensitivity, uniformity, active area, and low signal noise as required for AEC performance. The spectral range of the detector combined with its amplifying electronics, shall be from TBD to TBD angstroms.

Optical surfaces shall conform to MIL-STD-150.

NOTES

1. This end item specification for an automatic exposure control for a space camera was prepared by Perkin-Elmer Aerospace Division, Pomona, California under NASA Contract NAS9-12790.

6.0 ENVIRONMENTAL TESTS

This section discusses the environmental test program for the automatic exposure control components. All testing was conducted at Perkin-Elmer, Aerospace Division, Pomona, California. Raw data from the tests is on file at ASD.

Test Articles

(1) Potentiometer

a. Type: Single turn, wire wound
b. Manufacturer: Spectrol Electronics Corporation
c. Model: 142-3-0-103
d. Total Resistance: 10K ohms
e. Rotation: $350° + 0° - 4°$
f. Linearity: $\pm 1.0\%$

(2) Detector/Operational Amplifier

a. Type: Silicon schottky barrier
b. Manufacturer: United Detector Technology, Inc.
c. Model: UDT-500
d. Active Area: 1 cm^2

(3) Detector

a. Type: Silicon schottky barrier
b. Manufacturer: United Detector Technology, Inc.
c. Model: PIN-5
d. Active Area: 0.04 cm^2

(4) Stepper Motor

a. Type: Permanent magnet
b. Manufacturer: IMC Magnetics Corporation
c. Model: 008-845
d. Size: 8
e. Step Angle: 90°

(5) Pellicle

a. Type: Glass membrane
b. Mount: Adhesive bonded to aluminum frame
c. Size: 0.750" clear aperture diameter

Test Dates and Personnel

The component evaluation test was accomlished on 14 to 16 January 1974. This test series was conducted by Perkin-Elmer personnel:

L. Stoap	Department Manager, Photo-Mechanical Programs
G. McAtee	Project Manager, Photo-Mechanical Programs
C. Solheim	Senior Engineer, Electronic Development
J. Sharpsteen	Senior Engineer. Mechanical Development
C. Littletone	Test Technician
R. Richardson	Supervisor, Test Services

This test series was witnessed by V. Meyers, NASA Technical Consultant.

Test Tolerances, Test Conditions and Testing Procedure

The evaluation tests were conducted in accordance with the requirements of Perkin-Elmer ASD Document TL 74-0035, titled "General Plan for Testing of Automatic Exposure Control Components for NASA/JSC". A copy of this test plan is presented below:

Scope.- This document describes the general plan for environmental testing of the automatic exposure control components as required by NASA. All testing will be conducted at Perkin-Elmer, ASD, Pomona, California.

Applicable Documents.- Report No. CF32-A-300, MIL-STD-810B.

Test Program.-

a. Random Vibration

b. Sine Vibration

c. Thermal Vacuum

Test Tolerances.- The following tolerances will be maintained with respect to all environmental test equipment.

a.	Random Vibration	±3 dB over the frequency band of 10 to 2000 Hz
b.	Sine Vibration	Acceleration ±10%
		Frequency ±10%
		Time ±10%
c.	Thermal Vacuum	Temperature ±3°C
		Vacuum ±10% in feet
d.	Standard Test Equipment	All standard test equipment will be calibrated in accordance with the established procedures and will be within manufacturer's specified accuracy.

Test Conditions.- Unless otherwise specified, testing will be conducted under the following conditions.

a.	Temperature	25 $\pm$10°C
b.	Relative Humidity	90% RH max
c.	Barometric Pressure	28 - 32 inHg

Testing Procedure.- Testing will be conducted as follows.

The AEC components shall be subjected to an operational test, to verify proper operation, prior to and following each environmental test.

The sequence of testing shall be in the order most advantageous in conducting the test program in a minimum length of time without jeopardizing the test results.

The sensor shall not be affected by direct sun for TBD time. This shall be checked by TBD.

a. Random Vibration - The AEC components will be attached to the vibration head. The system, while operating, will then be subjected to random vibration of 8 g's rms for 10 minutes duration in each of the three mutually perpendicular axes. Refer to Figure 38. for PSD and frequency. Prior to actually performing the test the vibration head will be equalized for the proper level.

b. Sine Vibration - Following the verification of proper operation the AEC system will be subjected to sinusoidal vibration in each of the three axes. The level will be 5 g's pk, the frequency range will be 5 to 2000 to 5 Hz and will be traversed over a 10 minute period at a logarithmic sweep rate. The vibration level below 14 Hz will be limited to 0.5 inch diameter.

During the vibration exposure the AEC system will be checked for proper operation.

c. Thermal Vacuum - The AEC system will be installed in a thermal vacuum chamber utilizing the same mounting configuration as used during vibration. The appropriate wiring will be connected to special feedthrough ports in order to operate the system components while being subjected to the thermal vacuum environment. Prior to sealing the chamber the system will be checked for proper operation.

During the test, chamber pressure will be maintained at 10^{-5} torr or less. If test time becomes critical, the chamber pressure may be returned to ambient between temperature transitions.

Temperatures will be monitored and recorded by the thermocouples attached to the AEC system and/or mounting plate. Refer to Figure 39 for the actual temperature and system operating cycle.

Test Results

(1) Random Vibration

(2) Sine vibration

a. Potentiometer.- The test circuit is shown in Figure 40. In order to make the results meaningful for the intended application, the data was reduced to show deviations from a linear (ideal) potentiometer with end points identical to the device under test (as measured prior to the start of the X-axis vibration tests). These results are plotted in Figure 41 for static tests prior to and after the X-axis vibrations, and Figure 42 for results during X-axis random and sine vibrations. Thus, Figure 41 shows the random errors when there is no vibration, superimposed on the basic nonlinearity of the device, while Figure 42 shows random errors during vibration superimposed on top of the nonlinearity of the device. In all cases, the deviations from linearity are well within the system allowable error band, which is on the order of ±200 millivolts in this set-up, and the component specification (±1%).

Since all results were well within allowable limits, the remainder of the data is reported in terms of maximum deviation for each axis and vibration condition, shown in Table 17. Note that the maximum deviations always occurred at Position 5, 6, or 7, sometimes during increasing positions on the potentiometer, and sometimes during decreasing positions.

b. Light Sensors.- Results are summarized in Tables 18, 19, and 20 for X, Y, and Z axis, respectively. Two types of sensors were tested; a UDT-500, which has a relatively large sensing area, and a PIN-5 which is smaller. The UDT-500 has its signal conditioning amplifier packaged with the sensor, while the PIN-5 used an external amplifier during the test, which was not subjected to the test environments. The results in Tables 18, 19, and 20 are reported in the order that the tests were conducted. Another variable for each vibration condition was filtering of the light input to the sensors. Each test was made with none, one, and two 47.5% transmission filters. The light input voltage refers to the input to the light source used in these tests. These results indicate that the environmental vibrations imposed do not show a significant impact on the performance of the sensors.

c. Stepper Motor.- The stepper motor, through suitable gearing, was used to position the potentiometer during all of its environmental tests, with the intention of environmentally testing the motor as well as the potentiometer. The motor performance was completely satisfactory in that intermittent or erroneous stepping did not occur throughout all of the vibration tests.

d. Pellicle.- A standard pellicle was attached to the common mounting plate with the other test articles, and subjected to the same environments. No damage or deterioration was observed.

TABLE 17.- VIBRATION TESTS - POTENTIOMETER

Maximum Deviations from Linearity
(In Millivolts)

	Axis					
	X		Y		Z	
Condition	Pos	MV	Pos	MV	Pos	MV
Static	6 ↑	58	6 ↕	56	6 ↓	57
Random	5 ↑	65.5	6 ↑	52	6 ↓	59
Sine	6 ↓	54	7 ↓	70.5	6 ↓	67

↑ = Increasing Positions   ↓ = Decreasing Positions

TABLE 18.- VIBRATION TEST - LIGHT SENSORS, X-AXIS

Test No. 3 (Random)
Test No. 4 (Sine)

Sensor	UDT-500 (Large)			PIN-5 (Small)			Light Input Voltage
Filters*	0	1	2	0	1	2	
Condition	Amplifier Output			Amplifier Output			
Static	.100	.065	.040	.076	.045	.025	25.3
Random	.098	.064	.040	.076	.045	.026	
Random	.098	.063	.040	.076	.044	.026	
Random	.098	.064	.040	.076	.045	.027	
Random	.098	.065	.039	.076	.046	.026	
Random	.098	.064	.040	.076	.046	.027	
Random	.098	.065	.040	.076	.046	.028	
Static	.098	.065	.040	.076	.047	.027	25.15
Static	.097	.061	.038	.076	.045	.026	25.13
Sine	.096	.062	.039	.076	.045	.026	
Sine	.096	.063	.037	.076	.046	.025	
Sine	.095	.063	.040	.076	.046	.026	
Sine	.095	.063	.039	.076	.045	.026	
Static	.097	.063	.040	.077	.046	.027	25.3

*Each Filter = 47.5% Transmission

TABLE 19.- VIBRATION TEST - LIGHT SENSORS, Y-AXIS

Test No. 1 (Random)
Test No. 2 (Sine)

Sensor	UDT-500 (Large)			PIN-5 (Small)			Light Input Voltage
Filters*	0	1	2	0	1	2	
Condition	Amplifier Output			Amplifier Output			
Static	.103	.068	.042	.078	.050	.032	
Random	.104	.068	.040	.078	.056	.026	
Random	.104	.069	.042	.078	.050	.033	
Random	.104	.069	.042	.078	.057	.026	
Random	.104	.068	.041	.078	.047	.027	
Random	.104	.069	.045	.078	.048	.030	
Random	.104	.069	.046	.078	.047	.029	
Static	.103	.068	.040	.078	.048	.028	
Static	.103	.068	.040	.078	.048	.028	28.02
Sine	.103	.067	.042	.078	.047	.028	
Sine	.103	.067	.041	.078	.048	.028	
Sine	.103	.067	.041	.078	.048	.026	
Sine	.102	.067	.042	.077	.049	.028	

* Each Filter = 47.5% Transmission

TABLE 20.- VIBRATION TEST - LIGHT SENSORS, Z-AXIS

Test No. 5 (Random)
Test No. 6 (Sine)

Sensor	UDT-500 (Large)			PIN-5 (Small)			Light Input Voltage
Filters*	0	1	2	0	1	2	
Condition	Amplifier Output			Amplifier Output			
Static	.092	.059	.034	.081	.048	.026	16.62
Random	.092	.061	.037	.080	.050	.030	
Random	.092	.061	.037	.080	.049	.027	
Random	.092	.061	.037	.080	.050	.028	
Random	.092	.061	.038	.080	.048	.027	
Random	.092	.061	.037	.080	.049	.029	
Random	.092	.061	.036	.080	.048	.032	
Static	.092	.061	.037	.080	.048	.028	16.59
Static	.092	.061	.036	.080	.049	.030	16.59
Sine	.091	.059	.038	.078	.046	.030	
Sine	.097	.064	.039	.084	.052	.028	
Sine	.097	.065	.039	.084	.052	.030	
Sine	.095	.062	.039	.081	.049	.029	16.60

*Each Filter = 47.5% Transmission

(3) Thermal Vacuum

a. Potentiometer.- As with the vibration tests, data was reduced to show deviations from an ideal linear potentiometer at each of the 17 positions that would be used in a camera automatic exposure control system. These results are summarized in Tables 21 and 22. Table 21 reports results from test in the thermal vacuum chamber, where Steps A, B, C, and D refer to the test procedure in TL 74-0035, except that during increasing temperature in Step D, the chamber failed at 25° F short of the test plan. All deviations from linearity were small, on the same order as those during vibration tests. However, the maximum deviation always occurred at Position 8.

Following the thermal vacuum test, the potentiometer was subjected to a straight thermal environment in a temperature chamber. Maximum deviations from linearity are shown in Table 22. All deviations were reasonable except for three test runs, one at 150° F, and two at 160° F. The exact reason for these high deviations is unknown, but they do indicate a potential unreliability for this type of device under adverse environments.

b. Light Sensors.-Table 23 summarizes results from the thermal vacuum test, where for the last two conditions supplementing the heating with heat lamps was necessary. Even so, the final temperature fell 10° F short of the test plan.

A large variation in amplifier output was noted for the UDT-500 sensor, where the amplifier is built-in and therefore subjected to the same temperature environment. The PIN-5 sensor, however, which used an external amplifier outside of the environment, showed much smaller variations, about 5% maximum from the initial ambient level.

Table 24 summarizes the results in the temperature environment only. Again, variations with the PIN-5 sensor only are reasonably small, whereas with the UDT-500 sensor and amplifier, the variations are very large over the temperature range.

TABLE 21.- THERMAL VACUUM TEST - POTENTIOMETER

Maximum Deviations from Linearity (in Millivolts)

Test Step*	Temp.	Pot. Position	MV
A	0°F	8 ↓	65
B	-50°F	8 ↓	57
C	0°F	8 ↑	67
D	135°F**	8 ↓	62

↑ = Increasing Positions

↓ = Decreasing Positions

* Refer to TL 74-0035, Fig. 2

** Highest Temp. Reached (25°F short of Test Plan)

TABLE 22.- POTENTIOMETER TEST

Maximum Deviations from Linearity (in Millivolts)

Temp. (°F)	Position	MV
94°	6 ↑	58
100°	6 ↓	59
110°	6 ↕	61
120°	6 ↑	59
130°	5 ↑	61.5
140°	5 ↑	94.5
150°	13 ↓	149.5
160°	13 ↓	202.5
160°	6 ↓	184
160°	5 ↑	88.5
110°	6 ↑	58

Temp. (°F)	Position	MV
10°	8 ↓	62
0°	8 ↓	60
-20°/-30°	8 ↓	63
-40°	6 ↑	63
-50°	8 ↓	67
-50°	6 ↓	62
-50°	6 ↑	60
-30°	6 ↑	60
20°/30°	6 ↑	61
50°	6 ↓	62
Door Open	6 ↓	60

↑ = Increasing Positions

↓ = Decreasing Positions

TABLE 23.- THERMAL VACUUM TEST - LIGHT SENSORS

Sensors		UDT-500 (Large)			PIN-5 (Small)			Light Input Voltage
Filters (47.5% Trans. Ea.)		0	1	2	0	1	2	
Base Temp. (°F)	Sensor Temp. (°F)	Amplifier Output			Amplifier Output			
70 (1 Atm.)	70 (1 Atm.)	.091	.058	.036	.081	.047	.029	33.79
0 (Vacuum)	70 (Vacuum)	.062	.040	.027	.081	.047	.029	
0	75	.063	.041	.027	.081	.046	.027	
0	76	.064	.041	.026	.081	.047	.028	
0	77	.064	.041	.026	.081	.048	.028	
0	79	.065	.041	.026	.082	.047	.027	
-50	50	.070	.047	.031	.078	.046	.027	33.78
-50	52	.073	.048	.033	.078	.045	.027	
-50	46	.074	.049	.034	.077	.044	.027	
-50	36	.076	.050	.034	.077	.044	.027	
-50	40	.077	.051	.034	.077	.044	.027	
0	50	.066	.043	.029	.079	.045	.029	33.75
0	54	.066	.044	.029	.080	.046	.029	33.79
0	57	.066	.043	.028	.080	.046	.029	
132	108	.009	.003	.000	.084	.048	.031	33.81
132	126	.002	.000	.000	.086	.049	.031	
132	146*	-.005	-.006	-.007	.087	.050	.031	
132	150*	-.007	-.008	-.008	.087	.0 0	.032	

* With heating lamps

TABLE 24.- SENSOR TEST - TEMPERATURE ONLY

Sensor		UDT-500 (Large)			PIN-5 (Small)			Light Input Voltage
Filters (47.5% Trans. Ea.)		0	1	2	0	1	2	
Chamber Temp.(°F)	Sensor Temp.(°F)	Amplifier Output			Amplifier Output			
75°	90°	.019	.010	.007	.082	.043	.030	59.50
	100°	.014	.006	.002	.083	.038	.025	
	110°	.010	.003	.001	.084	.038	.026	
	120°	.005	.000	.000	.085	.040	.033	
Increasing	130°	.000	.000	.000	.086	.038	.026	
	140°	.000	.000	-.002	.086	.038	.025	
	150°	-.001	-.004	-.005	.086	.039	.025	
	160°	-.004	-.006	-.007	.087	.042	.026	
	160°	-.003	-.006	-.006	.086	.041	.026	
160°	160°	-.003	-.004	-.006	.086	.054	.034	
160°	110°	.004	.000	.000	.086	.053	.040	59.50
	65°	.023	.014	.010	.085	.052	.035	
	30°	.058	.037	.023	.084	.041	.025	
	10°	.087	.052	.035	.083	.046	.036	
	0°	.103	.066	.042	.082	.042	.025	
Decreasing	-10°	.114	.073	.043	.081	.043	.023	
	-20°	.131	.086	.051	.081	.043	.023	
	-30°	.135	.089	.056	.080	.042	.023	
	-40°	.143	.091	.052	.080	.041	.022	
	-50°	.149	.091	.052	.080	.041	.022	
	-50°	.155	.093	.051	.079	.039	.021	
-50°	-50°	.157	.095	.055	.079	.041	.023	
-50°	-30°	.153	.092	.056	.079	.043	.023	59.51
	0°	.148	.089	.053	.080	.041	.023	
Increasing	20°	.140	.084	.046	.080	.038	.022	
	40°	.131	.083	.047	.080	.039	.022	
	50°	.125	.070	.042	.081	.040	.021	
80°	60°	.119	.068	.041	.082	.041	.021	

c. Stepper Motor.- The stepper motor performed satisfactorily throughout the thermal vacuum and thermal environments. No physical deterioration was noted after the tests.

d. Pellicle.- No physical deterioration of any kind was noted after completion of the thermal vacuum and thermal tests.

Discussion

The stepping motor tested showed very promising results in that intermittent or erroneous stepping did not occur during vibration or thermal vacuum testing. The potentiometer appeared to exhibit some wiping action problems over temperature. This type of action would definitely be detrimental to the overall system accuracy and is one of the reasons why a digital encoder is recommended instead. The use of the digital encoder will also provide additional benefits beyond improved reliability and accuracy. Since the position is digitally encoded directly, a portion of the A/D converter presently used would be eliminated; i.e., the counter and the comparators. The D/A converter would be retained simply to provide the reference for the sensor relative to the shutter position. Elimination of ASA resistors (replaced by a digital code) also reduces the systems susceptibility to noise and inaccuracies from resistor selection.

The two sensors tested, one a UDT-500 (silicon schottky barrier sensor with an operational amplifier) and the other, a PIN-5 (silicon schottky barrier sensor with no amplifier) pointed out the need for a detailed analysis and design approach to the log amplifier/sensor combination relative to temperature compensation. Manufacturer's specifications indicate that neither of these devices is intended for operation above 125°F. For operation over wider ranges (-67 to +275° F) they recommend a planar diffused rather than a schottky barrier sensor. Responsivity variation is also improved with the planar diffused type going from a maximum of 0.3%/°F to a maximum of 0.1%/°F. The offset variation in the UDT-500 amplifier over temperature completely masked any meaingful results relative to linear responsivity of the sensor itself. Test results of the PIN-5 were encouraging, however, in that over the temperature range tested, responsivity did not vary more than about 5% from the initial ambient level. The impact on the electronics is that the log amplifier must be carefully selected or designed relative to the operating temperature. There are presently integrated circuits on the market which are compensated for a temperature range of 0° to

70° C. Sufficient investigation has not been made at this time to determine whether a wider temperature range device is available. Perkin-Elmer has designed log amplifiers for their mass spectrometer market which cover the range of 10^{-3} to 10^{-10} amperes over the full temperature range within 1%. However, this type of design involves more components than would be desirable considering packaging constraints. Perkin-Elmer believes that by reducing the range (the AEC requires only four decades) and relaxing the accuracy requirement to possibly 5%, a less complicated discrete design can be utilized or possibly an integrated circuit made available.

Conclusions

Potentiometer.- The potentiometer, which is a standard industrial design, performed satisfactorily throughout the random and sine vibrations. Its performance was also satisfactory throughout most of the thermal vacuum and thermal testing, but limited data at the higher temperatures indicates unreliability in this environment. Redesign for space application would probably overcome this shortcoming. However, an optical encoder, reading out directly in binary code, would be a more logical approach to position sensing in the AEC system.

Sensors.- Both the detector/amplifier and the detector performed satisfactorily throughout the sine and random vibration environments. In the thermal environments, however, only the detector with amplifier external to the environment performed satisfactorily with a variation over the temperature range of 5%. Therefore, a temperature compensated amplifier/detector combination will be required in the system design.

Stepper Motor.- The stepper motor, which was also used to position the potentiometer, performed perfectly throughout all of the environments. Therefore, this type motor is an acceptable choice for the AEC system.

Pellicle.- The pellicle, which was subjected to all of the environments, showed no damage or deterioration from the tests. Therefore, a standard pellicle and mounting technique will be suitable for the intended application in the AEC system.

7.0 BREADBOARD MODIFICATIONS

During the construction and testing of the breadboard, various modifications to the existing design were considered. Those modifications which might prove beneficial to the Automatic Exposure Control (AEC) performance, relative to the overall camera design, were then incorporated. The implementation of these changes is discussed below.

The electronic design modifications have provided substantial improvement in the Automatic Exposure Control. These changes have resulted in the near elimination of standby current; recommendations for reduction of peak current and possible elimination of motor winding holding current; elimination of status indicators and a more simplified reset design has resulted in fewer IC and less interface connections between the local and remote box.

The mechanical features of the breadboard as constructed are in essential agreement with the mechanical design concepts discussed in Section 3. One major difference is the noncircular gears. The Cunningham gears were replaced by a new device developed by Perkin-Elmer, which offers more flexibility in design and manufacture.

Electronic Design

Immediately following each discussion is a brief summary of the impact on the AEC design relative to performance, parts, etc. A basic understanding of the AEC electronics has been assumed in these discussions. If a more detailed understanding of the total system is needed, refer to the section on Breadboard Design.

<u>AEC System Current</u>.- Current should be drawn from the +28 V dc power lines only when the Remote or Local trigger is applied; this requires that the AEC system start from a total power off condition. To implement this, an R-S type flip-flop was mechanized from two 4-input NAND gates. A momentary 2 position switch with center off was added at both the local and remote control boxes. When the primary +28 V dc is applied to the system, the R-S flip-flop is reset to an OFF condition by use of an R-C combination on one input to the reset gate. By momentarily placing the remote or local trigger to ON, the flip-flop is set and power is applied through a power switching transistor to the AEC electronics. The base drive for the power transistor is provided by a Darlington pair such that very little standby current (less than 1.5 mA) is drawn by the circuitry which is connected directly to the primary +28 V dc line.

As indicated above, this method of triggering the AEC system results in a standby current of less than 1.5 mA. There are various other methods which might be utilized to accomplish the trigger function. However, Perkin-Elmer believes that this function must be accomplished as part of the overall camera design, since many other functions must be taken into account relative to total switching current. This circuit was merely added to prove the capability of the AEC to arrive at a stable position from a total power off condition.

Iris/Shutter Motor Drive Current.- Eliminating any requirement for holding current on either of these motors, when no change is being commanded, would be desirable. To implement this change in the logic is relatively easy and does not require additional devices. The ability of the motors to hold can actually be observed without implementing this change, since only one motor is being driven at any one time, i.e., when one motor is being commanded, the other motor has power totally removed.

During AEC checkout, both motors appeared to hold position effectively without holding power applied. However, the shutter motor exhibited some difficulty in holding position when the main drive motor was energized and for this reason, total removal of holding current was not implemented. The decision as to whether holding current will be necessary on either motor should be based on a mechanical design which comes close to approximating the actual package rather than on the present breadboard configuration. Vibration requirements will also weigh heavily on this decision. In the event holding current does become necessary, various methods might be considered which would reduce the total current requirement; i.e., utilizing a holding voltage much lower than the normal +28 V dc step voltage might be possible.

System Reset to Automatic.- In the initial AEC breadboard design, energizing the AEC electronics resulted in the iris and shutter motors simply resetting to the nearest f-stop and the system resetting to a Manual mode. To enter the Automatic mode, the operator would press the associated pushbutton switch and set the trigger switch to ON. The present configuration has been reimplemented such that the system automatically resets to the automatic mode when the momentary trigger on is applied. Prior to this, power is not drawn by the electronics. This reset method is accomplished by first driving the iris to its home position utilizing a digital comparison of the home code and an A/D conversion of the iris potentiometer feedback. The shutter is then allowed to respond to the sensor input and the system drives to a null relative to the Light input.

Allowing the AEC to reset to automatic resulted in a more simplified reset sequence and, thus, the elimination of two integrated circuits. In addition, utilizing a single 2-position switch with center off to select Auto or Manual eliminated two momentary switches, one at the local box and one at the remote box. Status lamps indicating Local, Remote, Auto and Manual along with their associated lamp driver circuitry were also eliminated.

Manual Operation.- To assume Manual control of the AEC electronics in the earlier breadboard design, the operator had to: (1) press the Manual pushbutton; (2) select shutter or iris through use of a 2-position select switch; (3) select the desired position; and (4) place the trigger switch to ON. This method of selection proved rather cumbersome and an alternate method has been implemented. As indicated in the System Reset to Automatic discussion above, the AEC is presently energized by momentarily placing the Local or Remote trigger to ON and the system resets to an Automatic mode. To enter the Manual mode, the operator at the local or remote station momentarily places the Auto/Manual switch to Manual. The iris and shutter are then driven to the positions which are set in the respective position select switches. If the switch action has taken place remotely, the remote settings are assumed. A new shutter or iris position is achieved simply by rotating the respective switch, either from local or remote. To implement the logic such that each motor would follow its respective switch without an additional select switch and without increasing the number of interface connections from the remote box, a switched ground technique was devised. By using a quad bilateral switch, a ground is alternately applied to the pole of either the iris or shutter select switch on a continuously cycling basis. Depending on the position within this cycle, the logic is looking for a change on the three lines which provide the binary reference position relative to either motor. If a change is detected, the system locks on to the proper motor drive and the motor is driven to the new position. Once a null is achieved, alternate ground cycling is then resumed.

The above implementation was accomplished with no net increase in IC count. Two select switches have been eliminated, one on the local box and one on the remote box. One additional interface wire has been added to accomplish the remote binary position encoding automatically. The overall changes to the Manual operation have made it much more straightforward in terms of operator intervention.

Time Exposure.- A time exposure mode has been added. This mode may be selected by a momentary pushbutton action from either the local or remote station. When this mode is selected, the Auto or Manual mode is overridden and the iris and shutter are driven to their full open positions respectively; i.e., f2.8 for the iris and 138° for the shutter. To return to Auto or Manual, the operator simply selects the mode desired and the system returns to the corresponding settings relative to the mode selected. Implementation of this requirement involved what might be considered a "secondary" manual mode. By forcing the system to recognize a fixed binary code representing a wide open iris and shutter, the normal binary inputs in the manual mode or the sensor inputs in the automatic mode are overridden and the system nulls to the fixed code reference. Actual mechanization required the addition of two momentary pushbutton switches and two integrated circuits.

Electronic Design Summary.- All of the changes enumerated above have been implemented and tested. The results of these changes have provided a substantial improvement in the AEC design from many aspects.

(1) Standby current has been nearly eliminated (less than 1.5 mA) since the system draws current only when the trigger is actuated.

(2) Peak current drawn by the present system is approximately 170 mA. Peak current is a combination of the electronics (50 mA), the DC/DC converter (60 mA), and an energized winding of one motor (60 mA). A more efficient converter design or elimination of the converter by using zener regulation may reduce the current required by this section to 30 mA. The motor winding current will be completely eliminated, except when a change is taking place if the detent torque of the motors proves sufficient to hold position in the final mechanical configuration. Combining these results would provide an AEC system which would draw less than 1.5 mA standby current, 140 mA peak current, and 80 mA when exposure changes are not taking place.

(3) System reset to automatic, a more simplified manual operation, the addition of a time exposure mode, and a remote trigger control have resulted in fewer ICs and less interface connections between the local and remote box. This is partially due to the elimination of status indicators and partially to a more simplified reset design. The net reduction in ICs were three from the local box and two from the remote box. The number of interface connections was reduced from 15 to 12.

Mechanical Design

The mechanical features of the breadboard are with one exception, in essential agreement with the mechanical design concepts discussed in Section 3. The one major difference is the noncircular gears. In the original design, the 90° stepping angle motor is followed by ten to one circular gearing which drives the logarithmic gear set, which in turn drives the differential spider shaft. The shaft angle relationships are shown in Table 15 in the section on Breadboard Design.

During the final design of the breadboard, Perkin-Elmer found that by changing to two, 4.8 to 1 gear sets with the logarithmic gears in between, that a standard logarithmic set with a 1.75 inch center-to-center spacing (available from Cunningham Industries) would provide the necessary geometric relationships. The two versions are shown schematically in Figure 43. The revised version of the Shutter Control Table, which agrees with the breadboard as actually constructed, is included in this section as Table 25. The corresponding equation for Table 25 is:

$$\theta_o = 21.4\left(e^{0.00915\theta_i} - 1\right)$$

Whereas the gear train design in the breadboard was perfectly satisfactory from the geometrical standpoint, it does not represent an optimum design for the AEC. By placing all of the circular gear reduction in front of the logarithmic gears, the space requirement for the logarithmic set is minimized, even with the same center-to-center spacing. This is shown in Figure 44.

Problems occurred in breadboard testing due to friction and hysterisis in the belts, and to high inertia, unbalance and backlash in the large relatively heavy brass Cunningham gears.

The belts were eliminated by replacing them with idler gears between the pulleys. Because the sprocket teeth on the PIC "no-slip" pulleys are standard 32 pitch, ordinary spur gears could be used for the idlers.

The Cunningham logarithmic gears were replaced with a new device developed by Perkin-Elmer, which offers considerably more flexibility in design and manufacture. As mentioned earlier, a particular Cunningham gear set was selected because it was off-the-shelf. The new approach can be easily manufactured on standard machine tools, and therefore allows greater flexibility in physical size and mathematical function. A disclosure, with descriptive title "Mechanical Nonlinear Function Generator", was submitted to NASA under the new technology clause of the contract, on 28 November 1973.

The device is similar in operation to a pair of noncircular gears where the teeth have been eliminated and the two gears (cams) are in contact, or close to contact, at their pitch lines. The two cams are kept in positive angular relationship to each other through small wires or bands which are fastened at the end points of the cams and run in shallow grooves as shown in Figure 45. One wire or band constrains the cams in one rotational direction and the other band or wire in the opposite direction. As the cams rotate, each wire rolls off one cam and onto the other. Ideally, the two cams are always in contact at one point but, in actuality, a moderate gap is possible without hurting the accuracy or smoothness of operation. This is one of the main advantages over gears in that high accuracy is not important. The device can be designed to generate almost any mathematical function that does not reverse its slope or have discontinuities or excessive ratios.

Inertia and unbalance in the logarithmic cams was minimized by boring lightening holes at appropriate places. Since complete

TABLE 25.- AUTOMATIC EXPOSURE CONTROL SHUTTER ANGLE AND TRANSMISSION GEOMETRY USED IN THE BREADBOARD

Step Number	Stepper Cumulative Angle(°)	Jackshaft Cumulative Angle (°)	Logarithmic Gears Output Angle (°)	Differential Input Shaft Cumulative Angle (°)	Shutter Angle
0	0	0	0	0	8.32 (Min)
1	90	18.8			
2					
3					
4	360	75	21	4.32	17.28
5					
6					
7					
8	720	150	63	12.96	34.56
9					
10					
11					
12	1080	225	146	30.24	69.12
13					
14					
15					
16	1440	300	312	64.8	138.24 (Max)

balancing in this manner was impossible, balance mass was added on the cam shafts. When incorporated in the breadboard, the function generator met all of its design requirements (no backlash, minimum friction, correct input/output relation).

Adding balance weights to the shutters was also necessary. This was accomplished by adding lead weights of appropriate shapes, and trimming up to final balance by drilling holes in the weights after assembling the breadboard.

After the above modifications were made, the breadboard met all of its mechanical requirements. The balancing requirements were accentuated greatly by the large size of parts, and their materials. Unbalanced forces will be minimal in the much smaller camera parts, and will be easily balanced out if necessary.

8.0 BRASSBOARD DESIGN

Electronic Design

General.- The major portion of this study phase (Task 6) was devoted to design of a mechanical system which would typify space hardware. Certain changes, however, were incorporated in the electronics to further improve the total system performance. These included: (1) Operation from positive voltage only (elimination of the ± 15 V dc-dc converter). (2) Replacement of the logarithmic amplifier design with a monolithic circuit. (3) Use of optically encoded digital feedback, along with digital ASA selection, rather than potentiometer feedback, for determining shutter and iris position. The following sections discuss the impact of each of these respective changes. Schematics depicting the configuration at the completion of Task 6 are shown in Drawing SK-348939.

Operation from Positive Supply.- This modification was made primarily to eliminate the inefficiencies of the ± 15 V dc-dc converter and also to verify performance of the D/A, log amp, and comparators when run off a positive supply only. Stable +10 V dc and +20 V dc references were obtained by addition of the circuitry shown in SK-348939, sheet 4. The net effect was to reduce the system peak current (including one stepping motor energized) from 170 mA to 130 mA with no degradation in amplifier performance.

Monolithic Logarithmic Amplifier.- The previous breadboard utilized two separate integrated circuit amplifiers and a matched transistor pair to generate the logarithmic function. To provide information on the performance capabilities of monolithic structures presently on the market, an Intersil 8048 was selected to replace the previous design. This amplifier is capable of handling six decades of current input and is temperature compensated over the range of 0° to 70°C. No problems were encountered in substituting this device, and performance was satisfactory. However, the survey of various available devices did indicate that nothing is presently available in monolithic construction for wider temperature range operation. The major problem at higher temperatures is the requirement for an extremely good, low leakage front end amplifier. At the lower temperatures, the temperature compensating element (a thin film resistor deposited on the monolithic chip) becomes non-linear. These two disadvantages force the designer to employ a design approach using more discrete components if operation outside the 0°-70°C range is required.

Optically Encoded Digital Feedback and Digital ASA Selection.- The major modification to the electronics during this phase occurred as the result of changing the shutter and iris position feedbacks from analog signals (potentiometers) to optically encoded digital values. The encoders are described in detail in section Shutter and Iris Position Encoders. This discussion will therefore be confined to the impact on the electronics.

Referring to SK-348939, sheet 4, two 5-bit digital codes are received from the shutter and iris position encoders respectively. The iris code varies from a binary 00100 (f/22) to 11100 (f/2.8) and the shutter code varies from 00100 (8.6°) to 10100 (138°) in 1/4 stop increments. The iris code is routed directly to the data block circuitry and also to the manual control circuitry for comparison during manual positioning of the iris. The shutter position code is also routed to the data block and manual control circuitry but, in addition, is routed to a four bit binary adder. By summing this code with a digital input from the ASA selector, a digital reference is established. This reference is in turn converted to an analog voltage through the use of a six bit D/A converter. The output of the D/A is summed with the output of the logarithmic amplifier such that the system will achieve a null if these outputs are equal and of opposite polarity. If change in light level is detected, the output of the summing amplifier will no longer be balanced, which triggers the proper comparator and drives the shutter motor until a null is again achieved. Once the shutter has reached an end point, the shutter digital position along with the particular ASA selection provides a reference for the iris. The iris opens or closes in response to light stimuli, to return the output of the summing amplifier to zero. The ASA selection code ranges from 0010 (ASA 40) to 1000 (ASA 2560) with the least significant bit representing a one stop change.

The above technique has several key advantages over the previous design. (1) The shutter and iris position information is instantly available upon power turn on. No A/D conversion or complex reset routine is required. (2) Elimination of the potentiometers and their associated circuitry (series resistors, constant current source, etc,) simplifies the initial alignment of iris and shutter, as well as eliminating many components which would be likely contributors to noise and error. (3) Digital encoding of ASA selection eliminates the requirement for selecting SAT resistors for each independent ASA required. (4) By digitally summing the ASA and shutter position before converting with the D/A, only one analog reference is required. Once the logarithmic amplifier and the D/A have been zero adjusted, the only gain adjustment required is adjusting the log amplifier so that a 1/4 stop light change equals the least significant bit change of the D/A.

Mechanical Design

General.- A brassboard camera was designed and constructed (Task 6) to demonstrate the suitability of the new approaches developed in Tasks 1 through 5 of the study, within size and weight constraints compatible with the final camera requirements. Whenever possible parts from an existing data acquisition camera were used. These included the magazine, which required only minor modifications, the drive motor, clutch, and associated electronics, and the magazine drive system. A new camera body and separate front end housing were constructed. These were made slightly larger than the final desired camera envelope, to accommodate the new shutter and iris control systems, but Perkin-Elmer is confident that these can be sufficiently reduced in size in the final camera design to meet the desired goal.

The following sections describe each of the mechanical subsystems which differ significantly from the standard DAC.

Shutter Sub-System.- The spur gear differential scheme used in the DAC for changing the shutter opening is also used in the brassboard. However, new gears and bearings were required. The system is shown schematically in Figure 46.

The shutter adjustment mechanism is driven by a 90 degree stepping motor, (the same model used in the breadboard) which receives its commands from the electronic system. The standard 13-tooth pinion on the shaft of the motor engages a 130-tooth, 120-pitch gear, which rotates 9 degrees for each motor step.

A pair of logarithmic cams, similar to the design described in Section 7.0 converts the equal 9 degree inputs to steps which increase exponentially as the shutter angle increases, each step of the motor changing the shutter opening by 1/4 f-stop. In other words, 4 steps of the motor double or halve the shutter angle, depending on the direction of rotation. Since the shutter opening can be doubled four times, from smallest to largest opening, in 1/4 stop increments, 16 motor steps (17 positions) are required.

Figure 47 compares test measurements made on the assembly with the desired logarithmic relationship between the input cam (measured on the encoder wheel) and the output cam. The deviations from the ideal straight line are due as much to measurement error as to cam error. All points fall well within the allowable $\pm 1/8$ stop band. A screw and slot adjustment between the encoder wheel and the input cam shifts the horizontal axis right or left, up to $\pm 1/4$ stop.

Optical encoder patterns are attached to the opposite sides of the 130-tooth gear. The construction and operation of the encoder is described in the section Shutter and Iris Position Encoders. The input cam of the logarithmic cam pair is also mounted to one face of the 130-tooth gear. A slotted hole, mentioned above, allows for adjustment of plus and minus one-quarter f-stop. This adjustment facilitates alignment between the logarithmic cams and the linear encoder pattern when the brassboard camera is assembled, but it should not be a requirement in the final design of an operational camera.

To eliminate light leaks around the shutter, the rotating blades were increased to 1-1/2 inch diameter, and moved as close as possible to the film plane. In other respects, their design is very similar to the DAC. The larger diameters require a change in the claw design. This is described in section Film Pull-down Mechanism.

Iris Control Sub-System.- The iris control mechanical sub-system is shown schematically on Figure 48. The 90 degee stepper motor is the same model as used in the shutter control. Since the lens has a linear relationship between angle of rotation of the iris ring and iris f-stops, a simple gear drive is used, as shown in the figure. A 130-tooth gear with encoder patterns on both faces is also engaged to the stepper motor pinion, to provide position feedback to the electronics. This is further described in the section Shutter and Iris Position Encoders.

Each 90 degree step of the motor provides a one-quarter f-stop iris change. Since the iris has 7 f-stops (f2.8 to f22), 24 motor steps (25 positions) are required to go from one extreme to the other.

Shutter and Iris Position Encoders.- Digital encoders provide position feedback in binary format to the electronics for both the iris control sub-system and the shutter control sub-system, replacing the potentiometers and analog-to-digital converter used in the breadboard. These encoders, illustrated in Figure 49, are identical in design, using IR energy from LEDs, which is reflected back from the encoder pattern onto photo darlington detectors. Figure 50 shows the relationships of the code to the iris and shutter openings.

Five (5) tracks on each wheel (3 on one side, 2 on the other) encode all of the necessary information in binary format. An infrared light emitting diode for each track provides the IR energy. Photo darlingtons detect the reflected energy, and produce high and low signal levels in accordance with the code.

The code patterns were prepared photochemically using photosensitive nameplate material and master artwork similar to that used for making printed circuit boards. The resulting contrast between lustrous aluminum and black provides differences in reflectivity of infrared energy sufficient to establish 1 and 0 logic levels. Pressure sensitive adhesive on the nameplate material attaches the code patterns to the gears.

The LEDs and photo darlingtons are packaged in DO-31 cases for mounting in circuit boards. In this design, the holes for the devices are drilled at 20 degree angles with the normal, so that energy from each LED is reflected back to the appropriate photo darlington. Using reflected rather than transmitted energy for the operating principle offers several advantages. These include twice the area available for the code (both sides of the wheel versus one side), and the ability to easily adjust or change codes. The circuit boards can also be adjusted closer to or further from the encoder wheels to obtain the optimum energy transfer between the LEDs and sensors.

Replacing the potentiometers with the optical encoders made it possible to considerably simplify the electronics in the system, and also eliminated problems discovered during the environmental testing reported in section 6.0.

Film Pull-down Mechanism.- The film pull-down mechanism in the brassboard uses the same principle used in the DAC. However, due to the larger diameter shutters in the brassboard, it was necessary to re-design the claw mechanism to engage the film sprocket holes one pitch further from the aperature than in the DAC. This change, shown in Figure 51, required modification in the claw mechanism geometry and a slightly different crank design. The light leak problem was completely eliminated by this change. Considerable effort was made in the design to minimize sawing action of the claw in the film holes during pull-down, and to insure that it leaves the film without touching the edges of the holes, as it retracts to begin another pull-down cycle.

Light Sensor System. Many schemes, enumerated in Section 2.0 Light Monitoring were considered and tested in order to find the optimum approach for sensing light level for the automatic exposure control. It was determined early in the study that light for level sensing should be collected through the camera lens system. In the final configuration selected for the brassboard design, a pellicle, similar to the one used in the breadboard, diverts approximately 9% of the light coming through the lens, at a 90 degree angle with the lens axis. A tapered fiberoptic image guide reduces this light bundle from 0.5 inch to 0.2 inch diameter, to match the sensing element in a UTD PIN-6DP silicon schottky barrier photodiode light sensor. The physical arrangement of the system is shown schematically in Figure 52.

Area Weighting Considerations discusses the advantages gained from area weighting (masking certain portions of the sensor to compensate for different brightness areas in the scene). For this reason, the image guide is placed with input at the focal plane of the light which has been diverted by the pellicle, so that the scene is imaged on the sensor. If it is decided at a later date to try area weighting in the AEC, there is sufficient space between the output of the image guide and the detector to insert various mask designs.

Camera Gears.- The proposed specification for the camera (Section 5.0 of this report) only allows use of dry lubricants, space proven nonmigrating lubricants, or no lubrication, if this can be justified by analysis and testing. In order to avoid the very costly dry lubing processes that are approved for space applications, Perkin-Elmer chose to use a special metallic plating on aluminum gears, known as Electrolizing, without lubrication. Electrolizing is a patented process of the Electrolizing Corporation, which provides low coefficient of friction, smooth sliding properties, excellent antiseizure characteristics, and good corrosion resistance. The maximum build-up of plating on the tooth surfaces was specified at 0.0002 inch. These gears show no evidence of wear, or any other adverse characteristics, from unlubricated use in the brassboard.

9.0 BRASSBOARD EVALUATION TEST AND DEMONSTRATION

Test Date and Personnel

The brassboard demonstration was held in February 1975. Attendees for:

NASA-JSC:

R. Gerlach	Technical Monitor
V. Meyers	Technical Consultant

Perkin-Elmer ASD:

L. Stoap	Department Manager, Photo-Mechanical Programs
G. McAtee	Project Manager, Photo-Mechanical Programs
C. Solehim	Senior Engineer, Electronic Dvelopment
S. Fall	Test Technician

The brassboard demonstration was conducted in accordance with the procedure specified by Perkin-Elmer ASD Document TP 84-0240, titled, "Evaluation and Demonstration Test Procedure for NASA Automatic Exposure Control Brassboard". A copy of the test procedure, data record and check-off list and the unit response prediction are presented for reference purposes in Appendix C.

10. SUMMARY AND CONCLUSIONS

This final report covers the development at Perkin-Elmer, Aerospace Division of an automatic exposure control system for a NASA 16mm data acquisition camera. The effort began with a study of approaches, followed by selection of the optimum approach, and design and development of a breadboard. Development and testing of the breadboard revealed areas where improvements could be made. These were incorporated in the design of a brassboard, representing a camera with automatic exposure control approaching final form suitable for space flight. The brassboard was tested and its performance established.

All of the objectives of the study contract have been met. The results of the study definitely establish that the approach that was selected for the automatic exposure control, and developed into the preliminary design, can be successfully incorporated into a 16mm data acquisition camera.

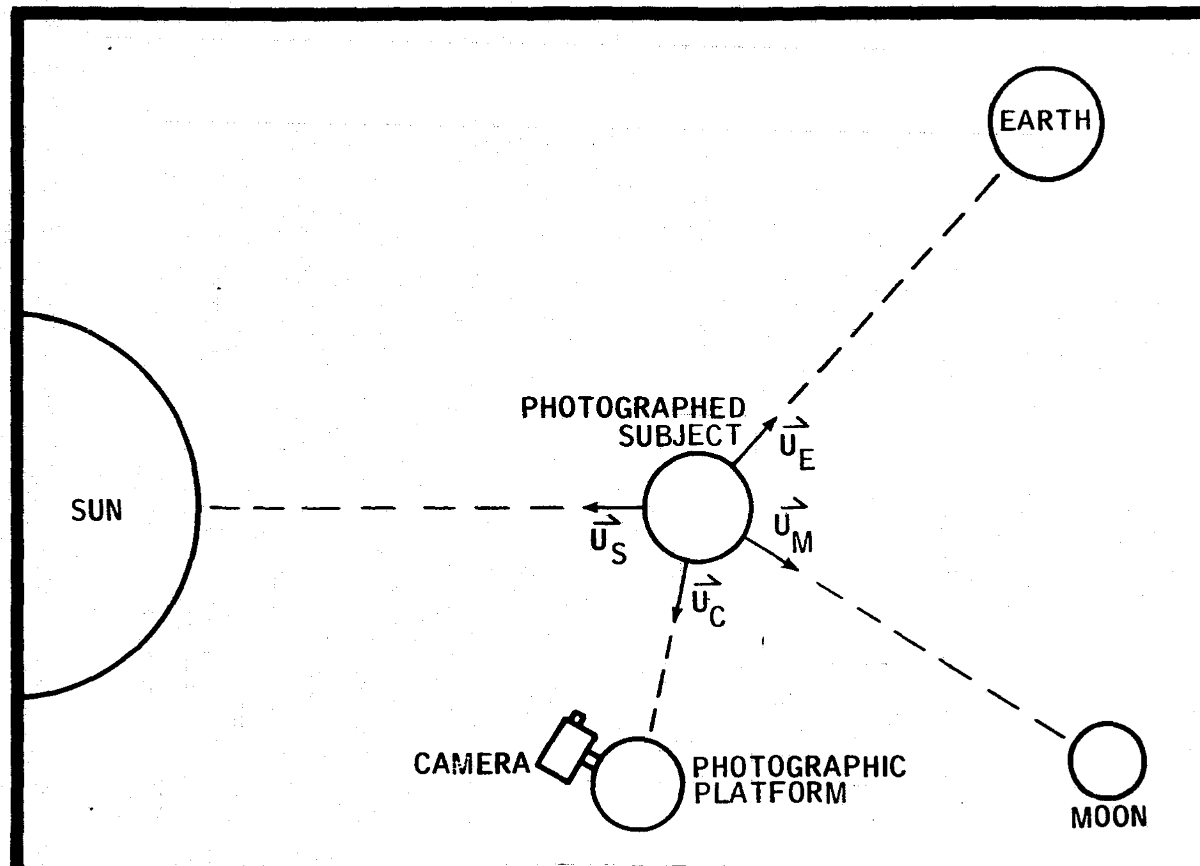
Although all of the design details have been established in this study, there are areas which can be refined to improve ease of construction and maintenance, reliability, and more effective use of the camera. One noteable area for development is the feedback encoders. Efforts should include further study of the preparation of the reflective and non-reflective surfaces, and improved methods for adjusting the positions of the light emitting diodes and sensors for optimum performance.

Circuits developed for use in the breadboard and brassboard established that the electronic performance requirements have been met, but a major effort remains in re-packaging these circuits to fit into the final camera configuration.

In summary, all of the objectives of the A.E.C. study have been met, and the design and development have been carried to the point where final design for flight hardware can begin.

APPENDIX A

ILLUSTRATIONS



NOTE: $\vec{U}_S$, $\vec{U}_C$, $\vec{U}_M$, AND $\vec{U}_E$ ARE UNIT VECTORS EXPRESSING THE DIRECTIONS (FROM THE SUBJECT) OF THE SUN, THE CAMERA, THE MOON AND THE EARTH RESPECTIVELY.

FIGURE 1. Illumination Sources

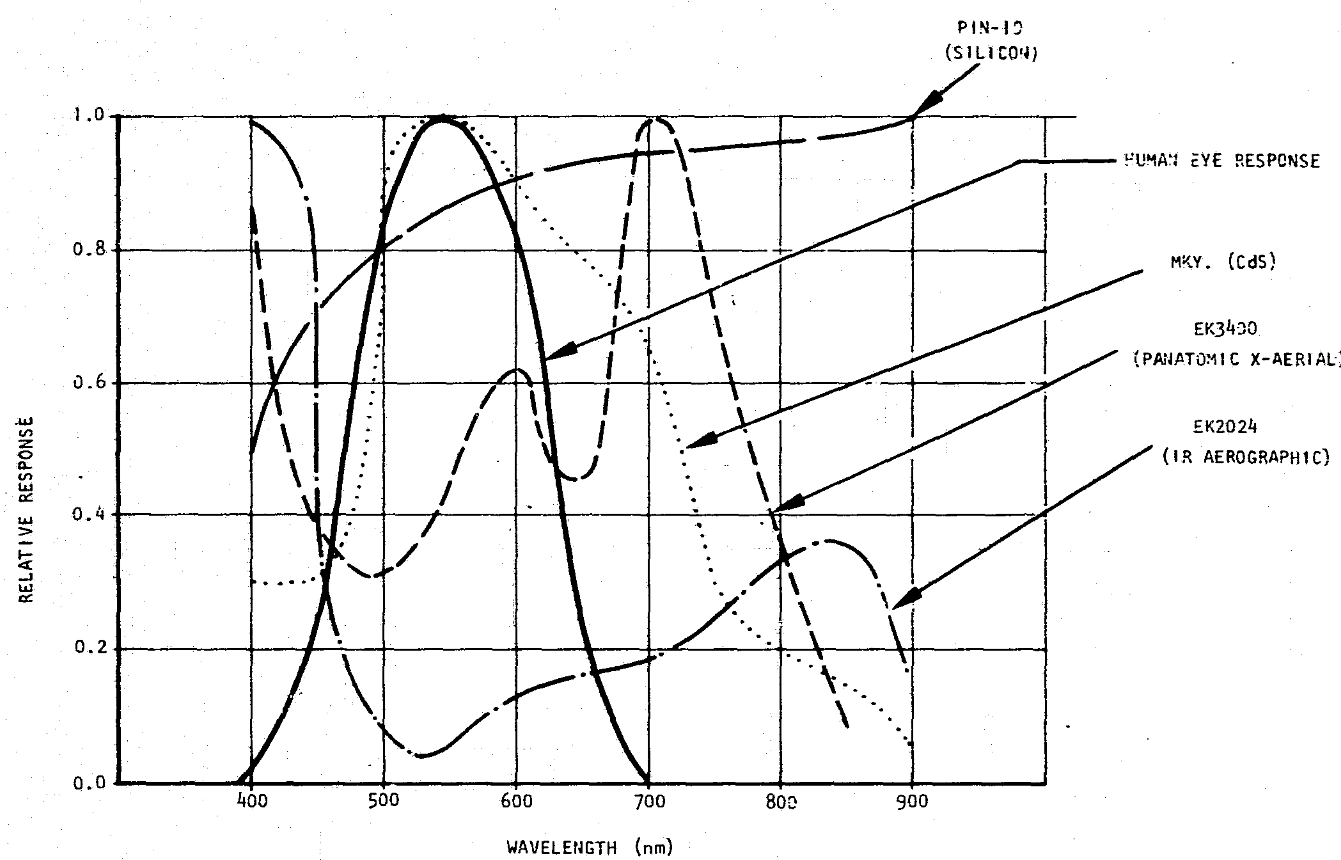


FIGURE 2. Film vs Detector Spectral Response

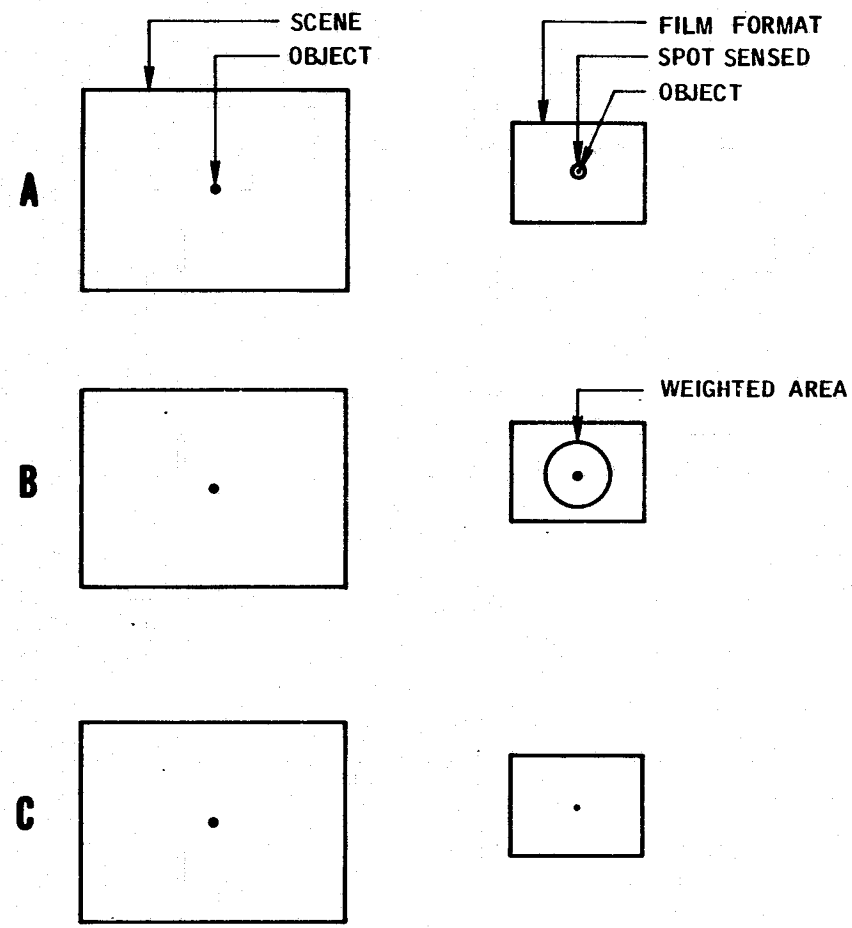


FIGURE 3. Sensor View Comparison

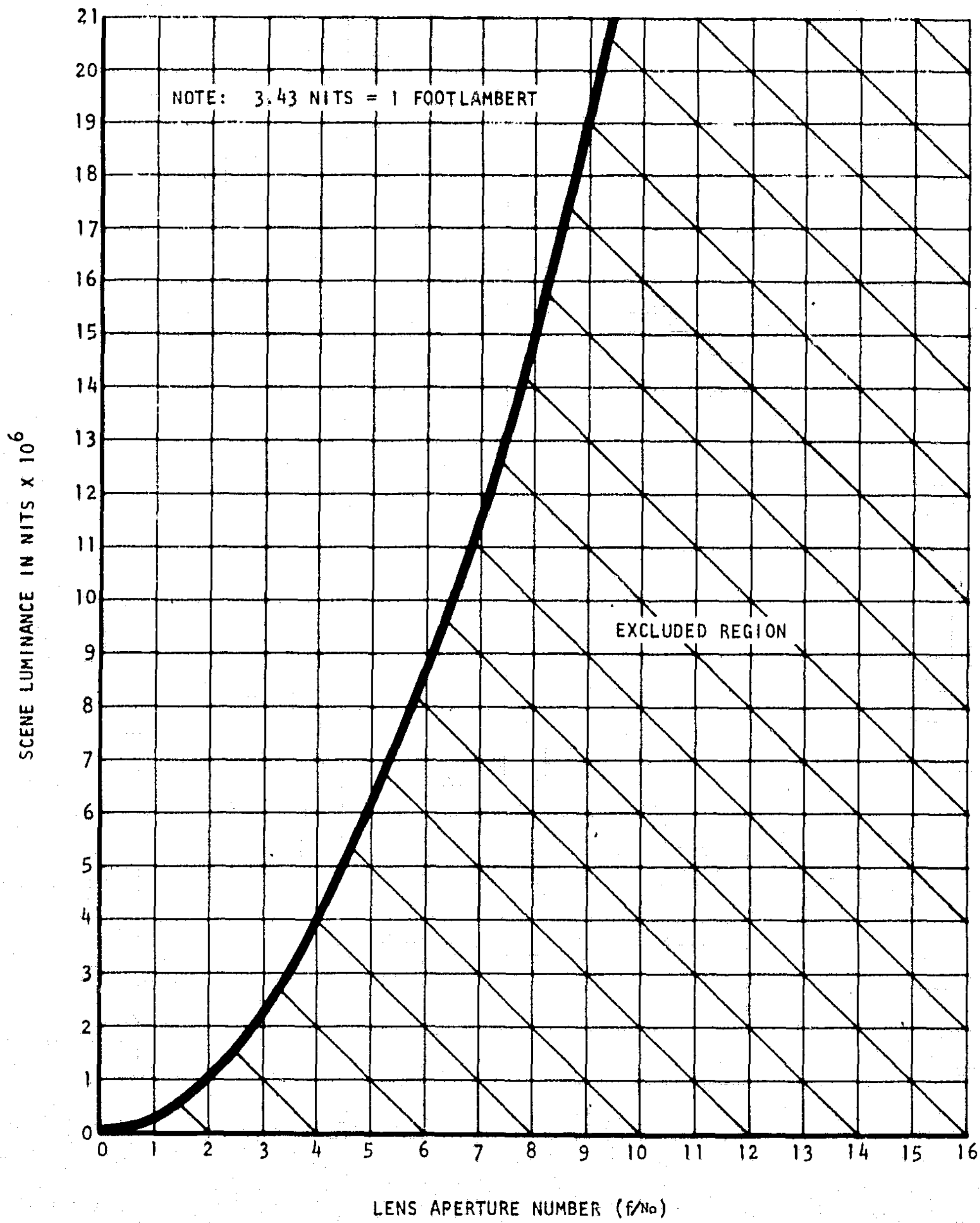


FIGURE 4. Scene Illuminance vs Aperture Exclusion

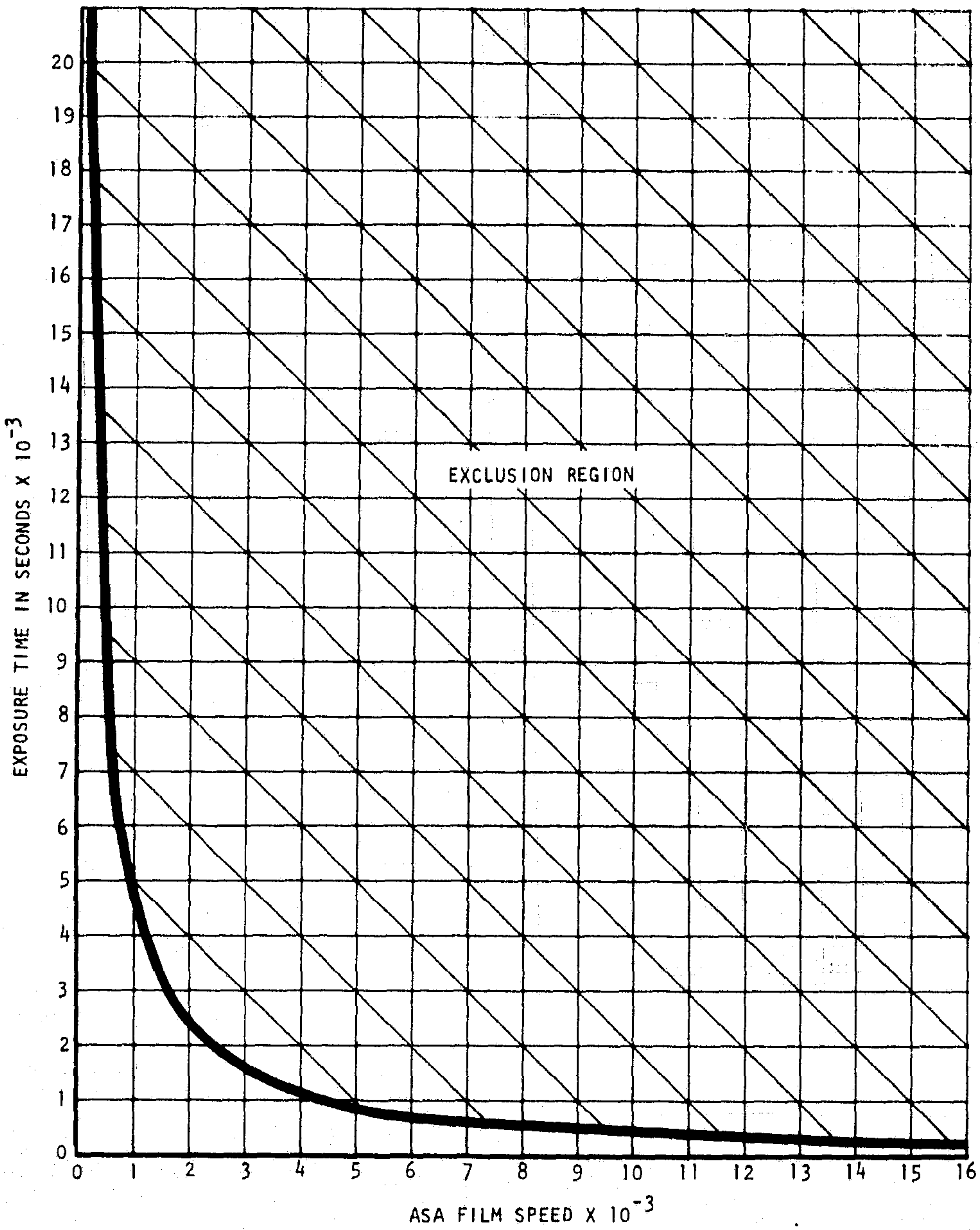


FIGURE 5. Exposure Time vs Film Speed Exclusion

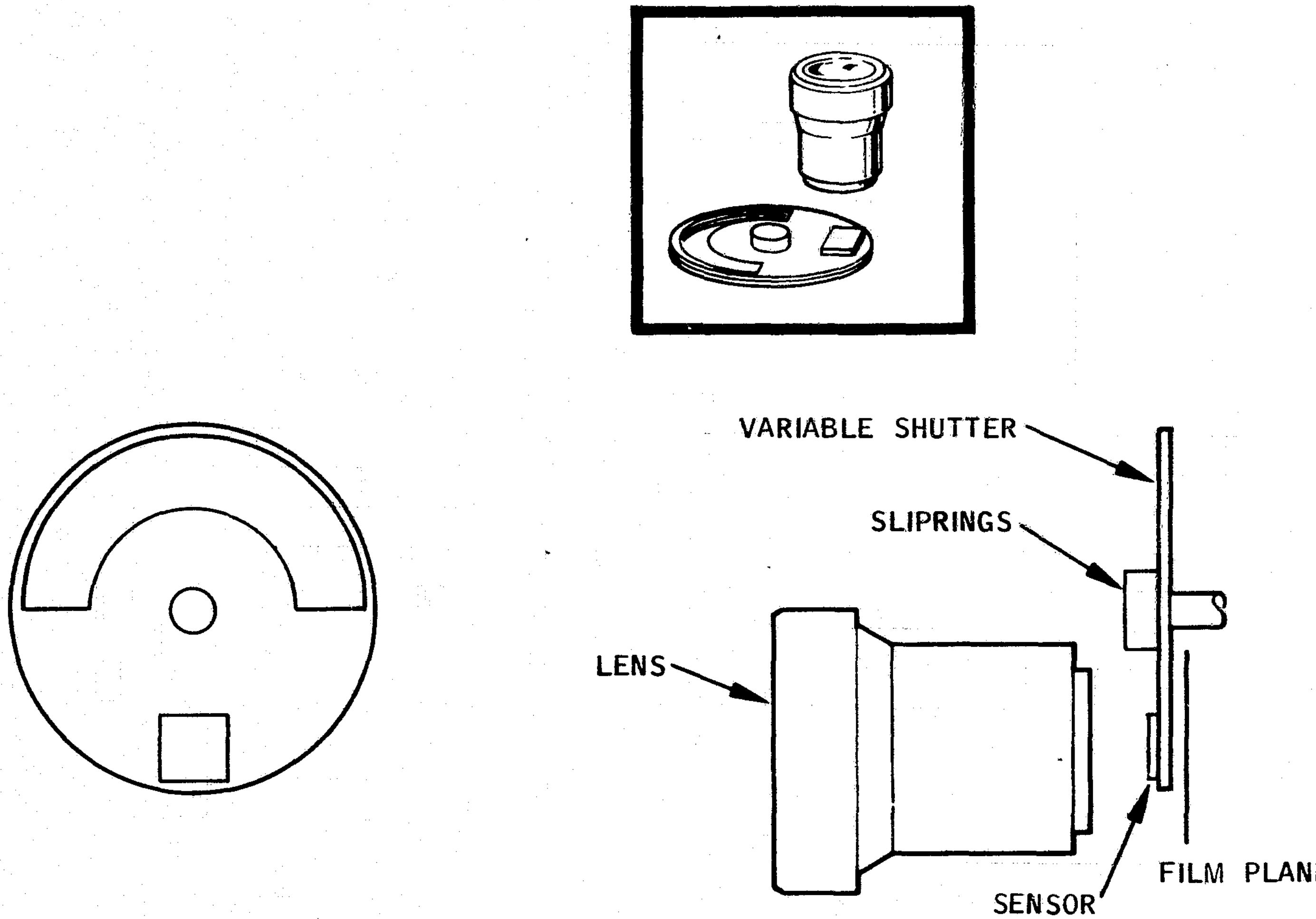


FIGURE 6. Shutter Mounted Sensor

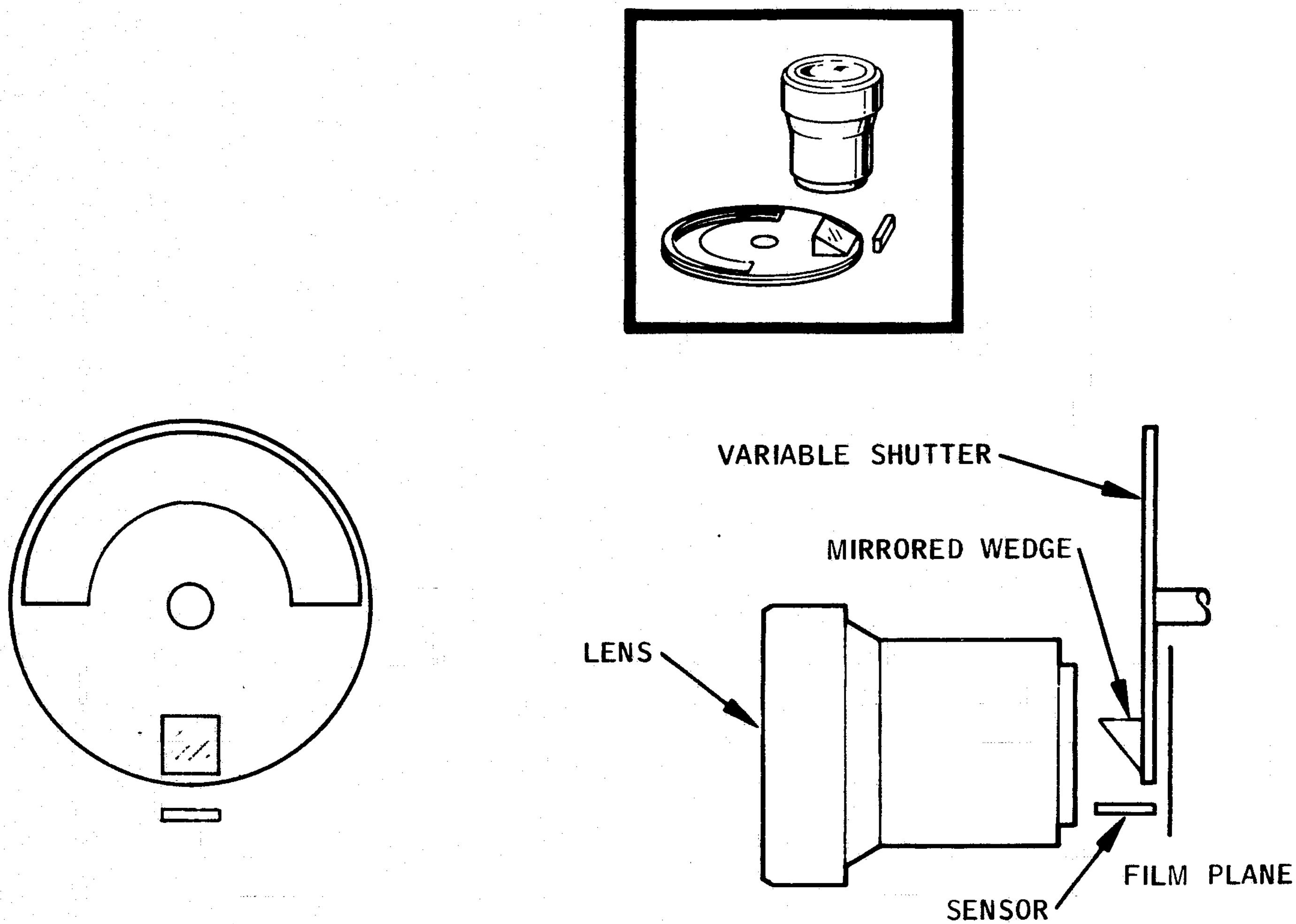
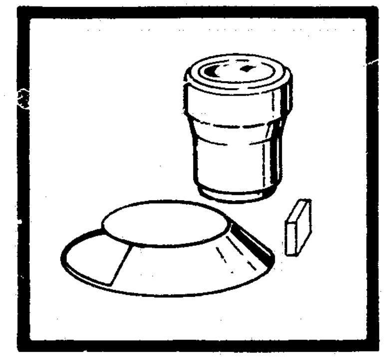
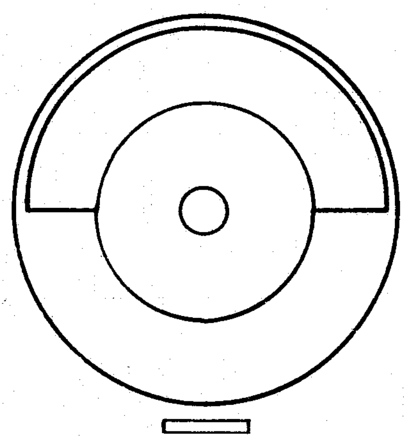


FIGURE 6. Shutter Mounted Reflector - Reflective Wedge





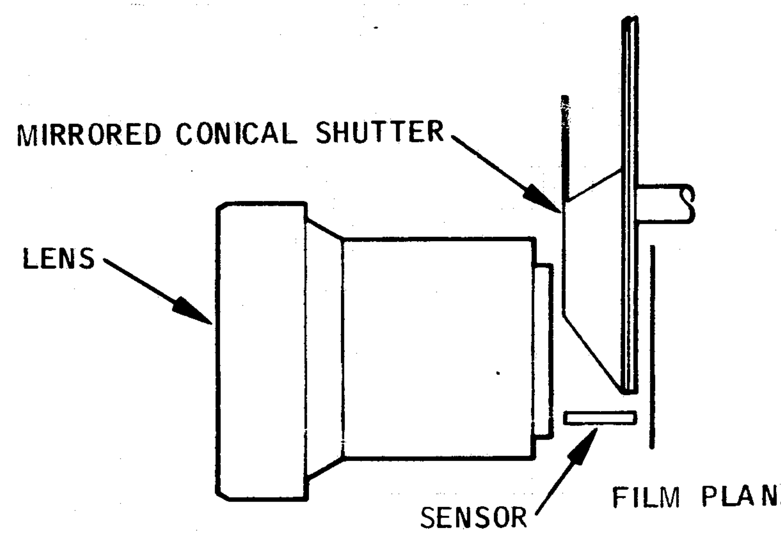


FIGURE 8. Shutter Mounted Reflectors - Mirrored Conical Shutter

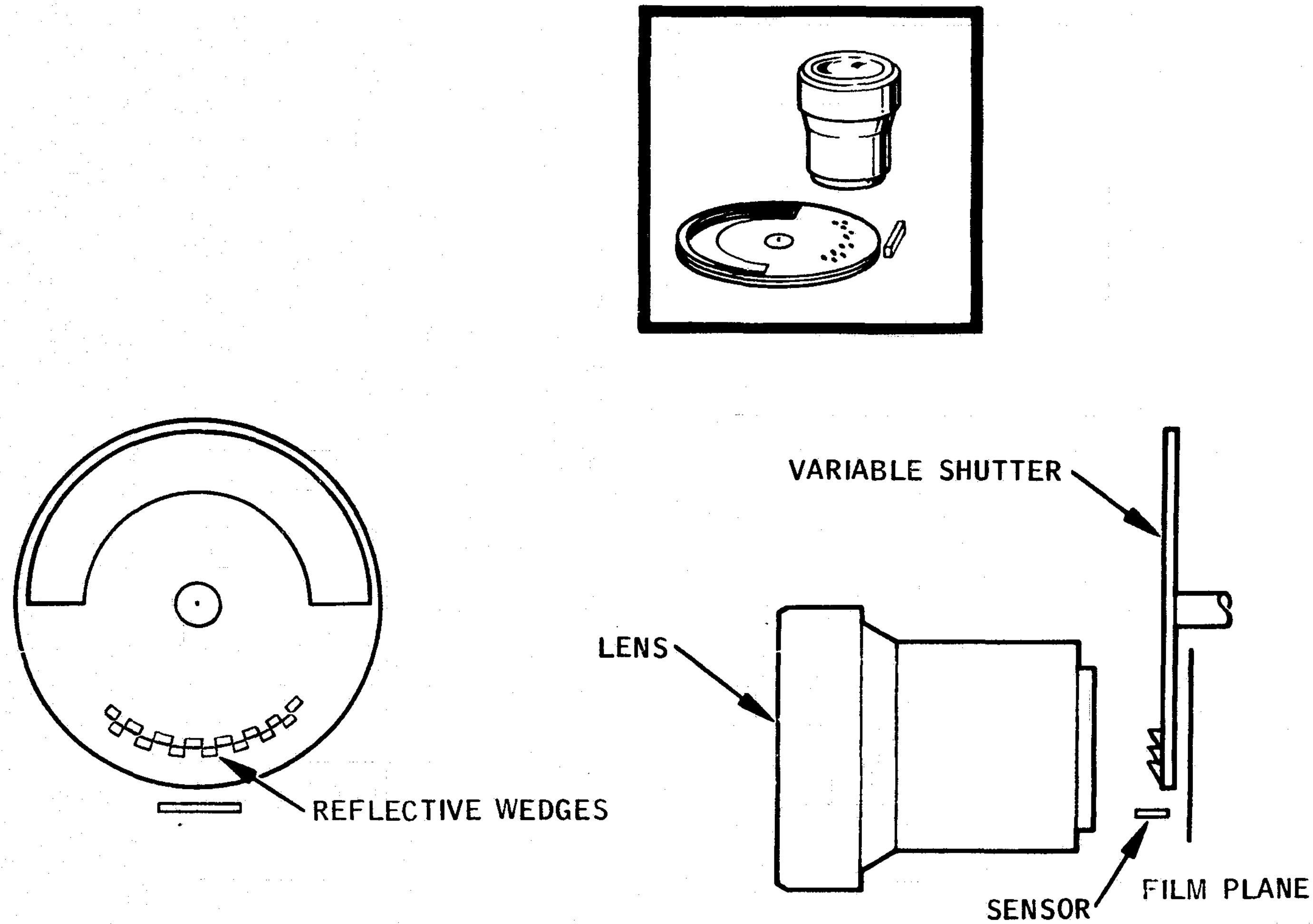


FIGURE 9. Shutter Mounted Reflector - Multiple Wedges

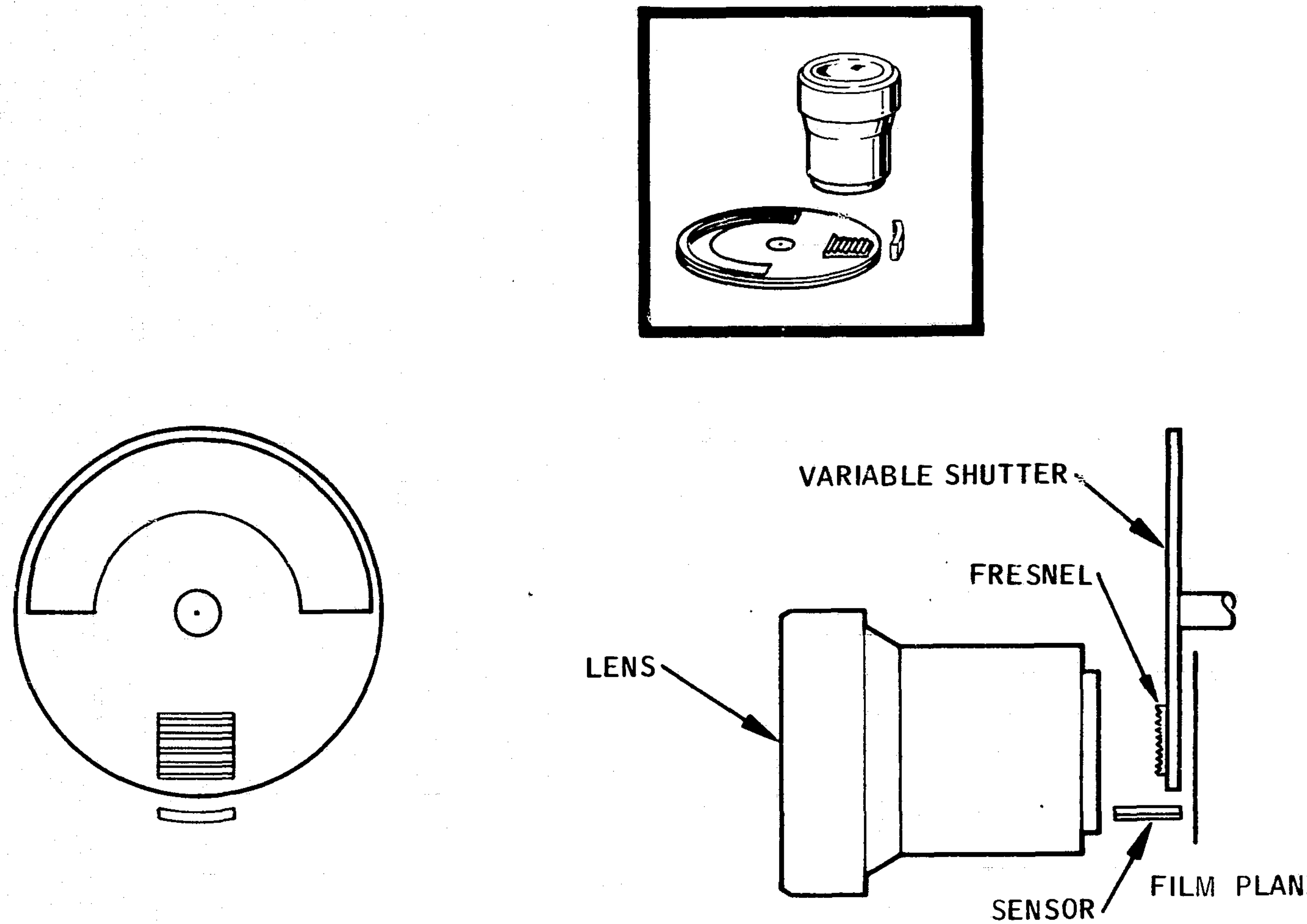


FIGURE 10. Shutter Mounted Reflector - Mirrored Fresnel

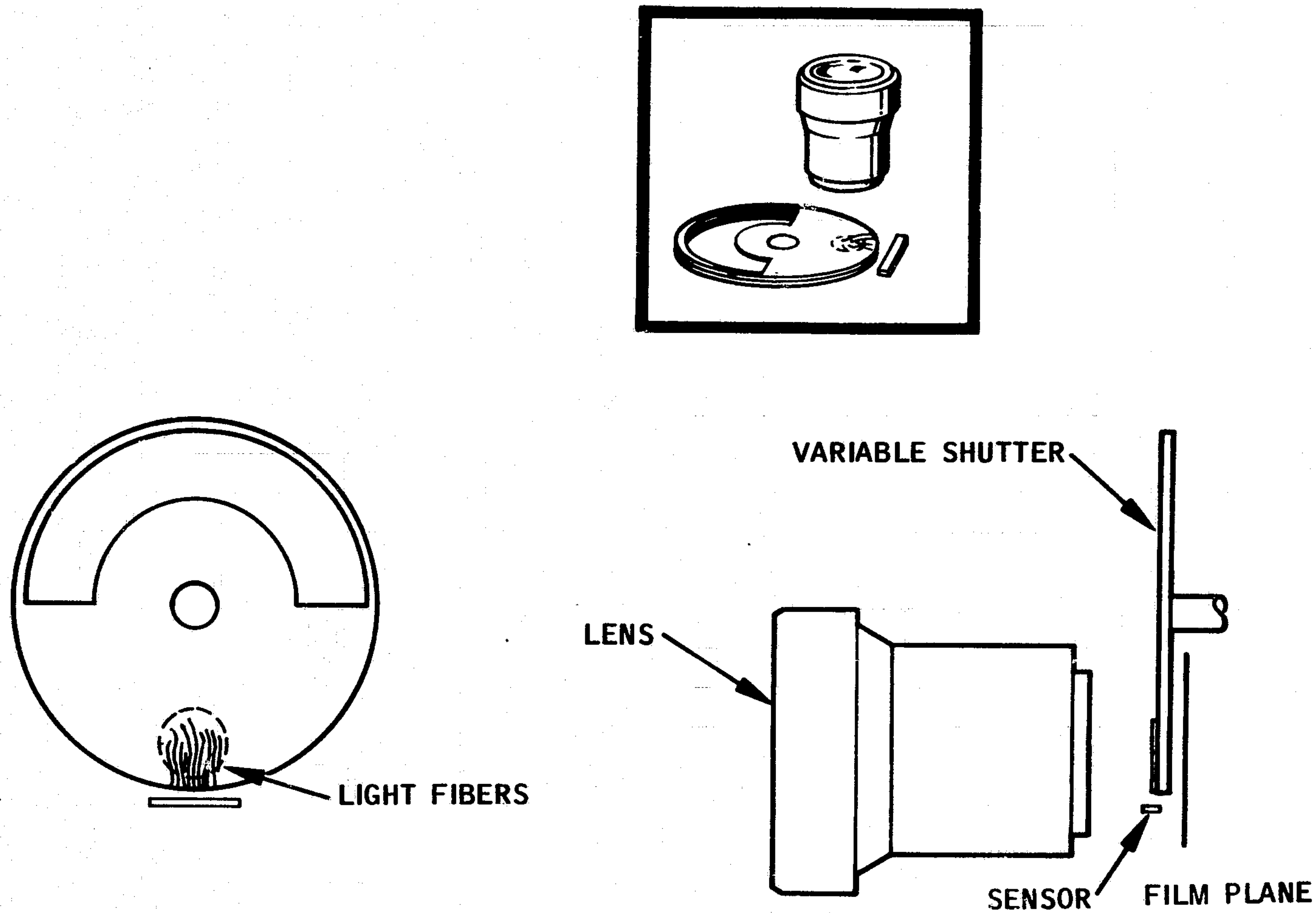


FIGURE 11. Shutter Mounted Light Fibers Radial Light Pipe

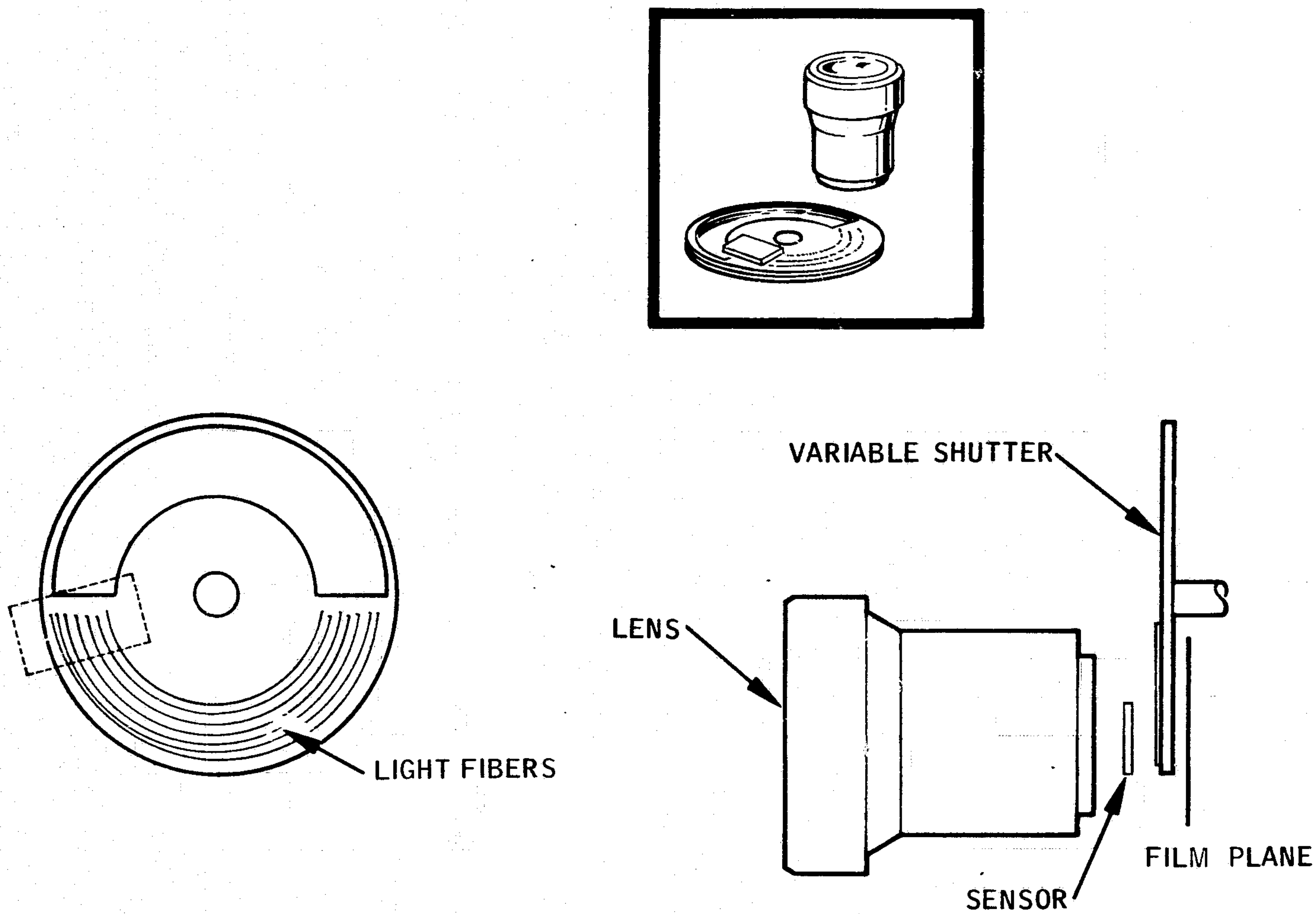


FIGURE 12. Shutter Mounted Light Fibers - Light Pipe

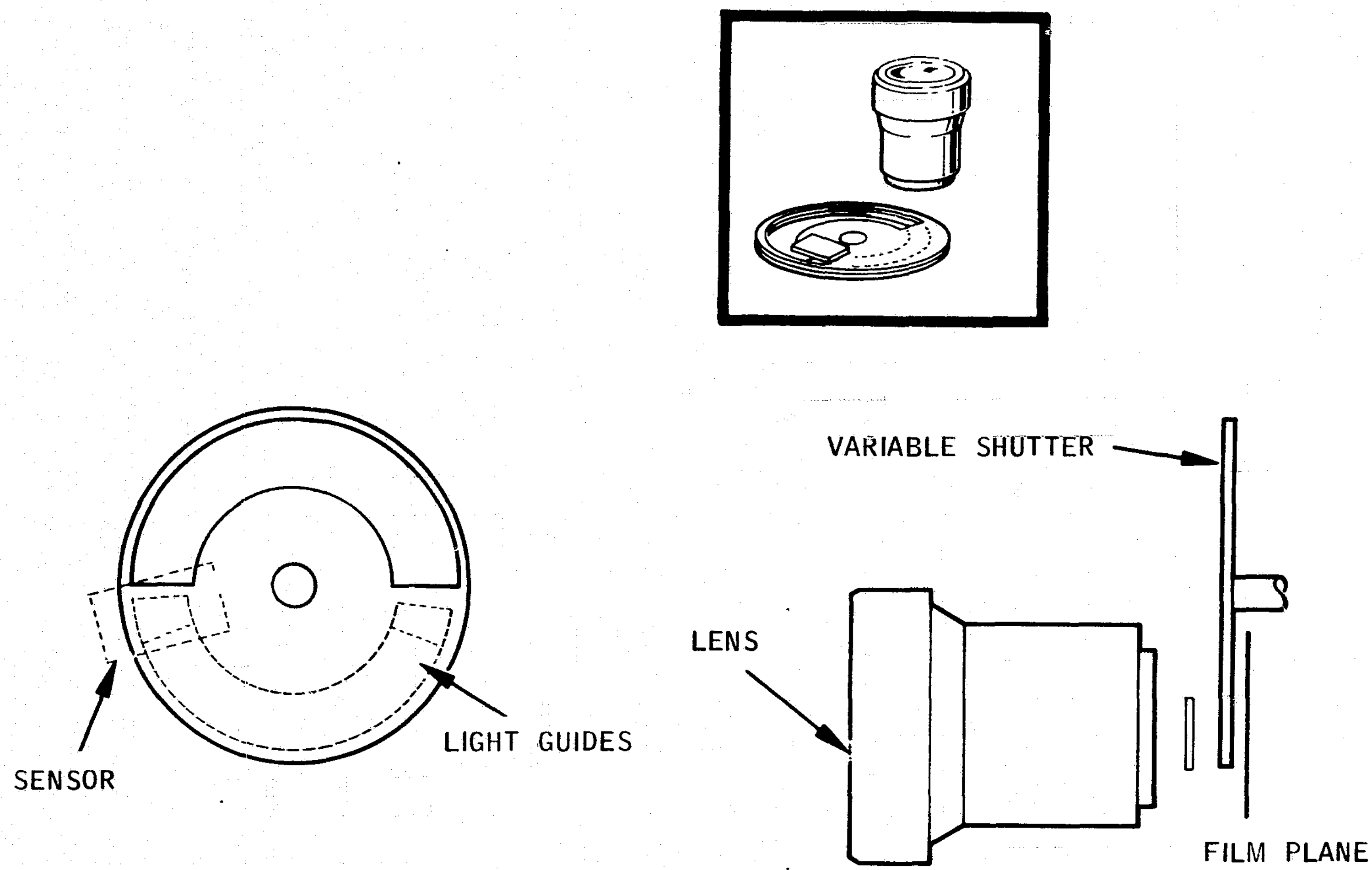


FIGURE 13. Shutter Mounted Light Fibers - Thin Film Light Guides

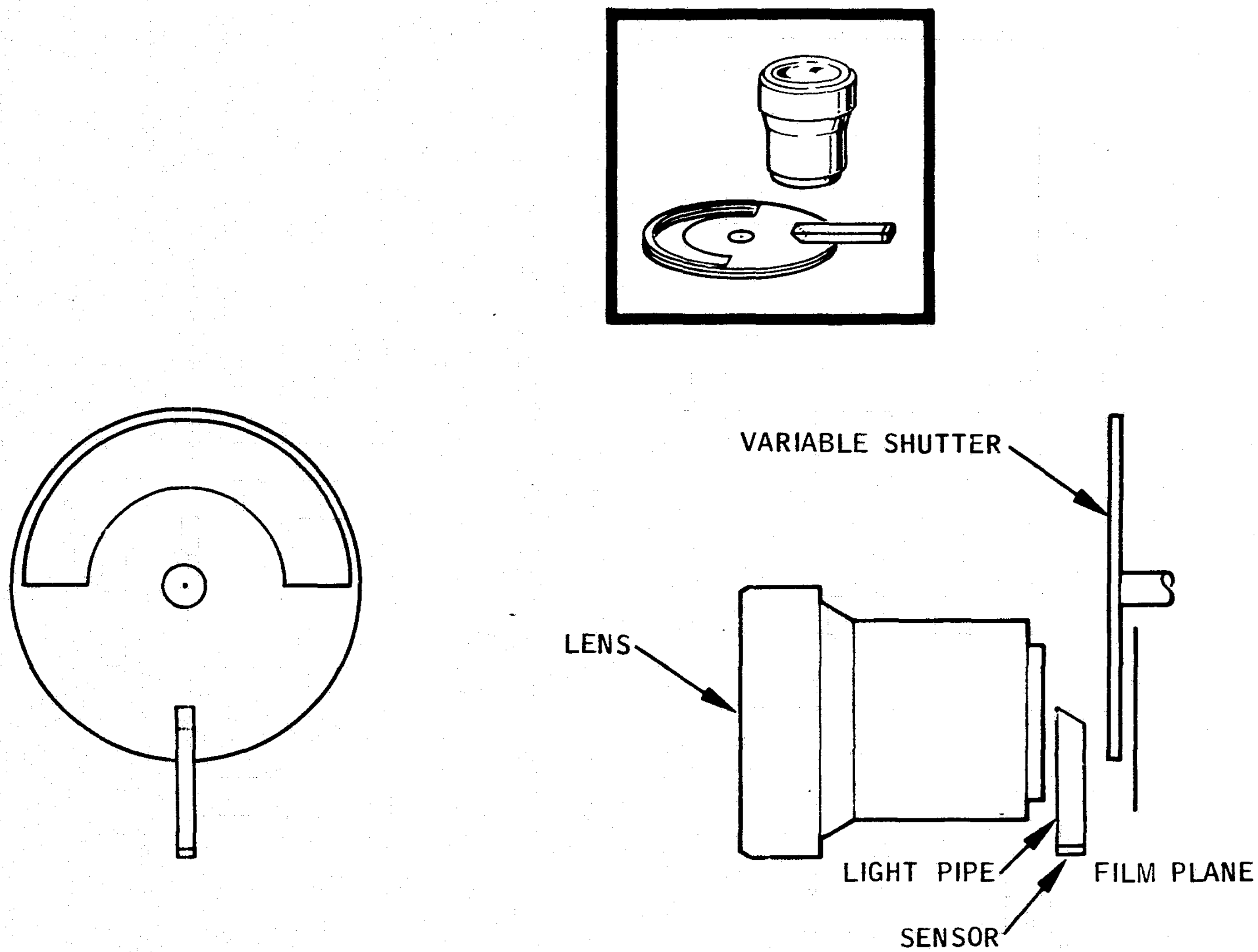


FIGURE 14. Fixed Reflector - Cantilever Light Pipe

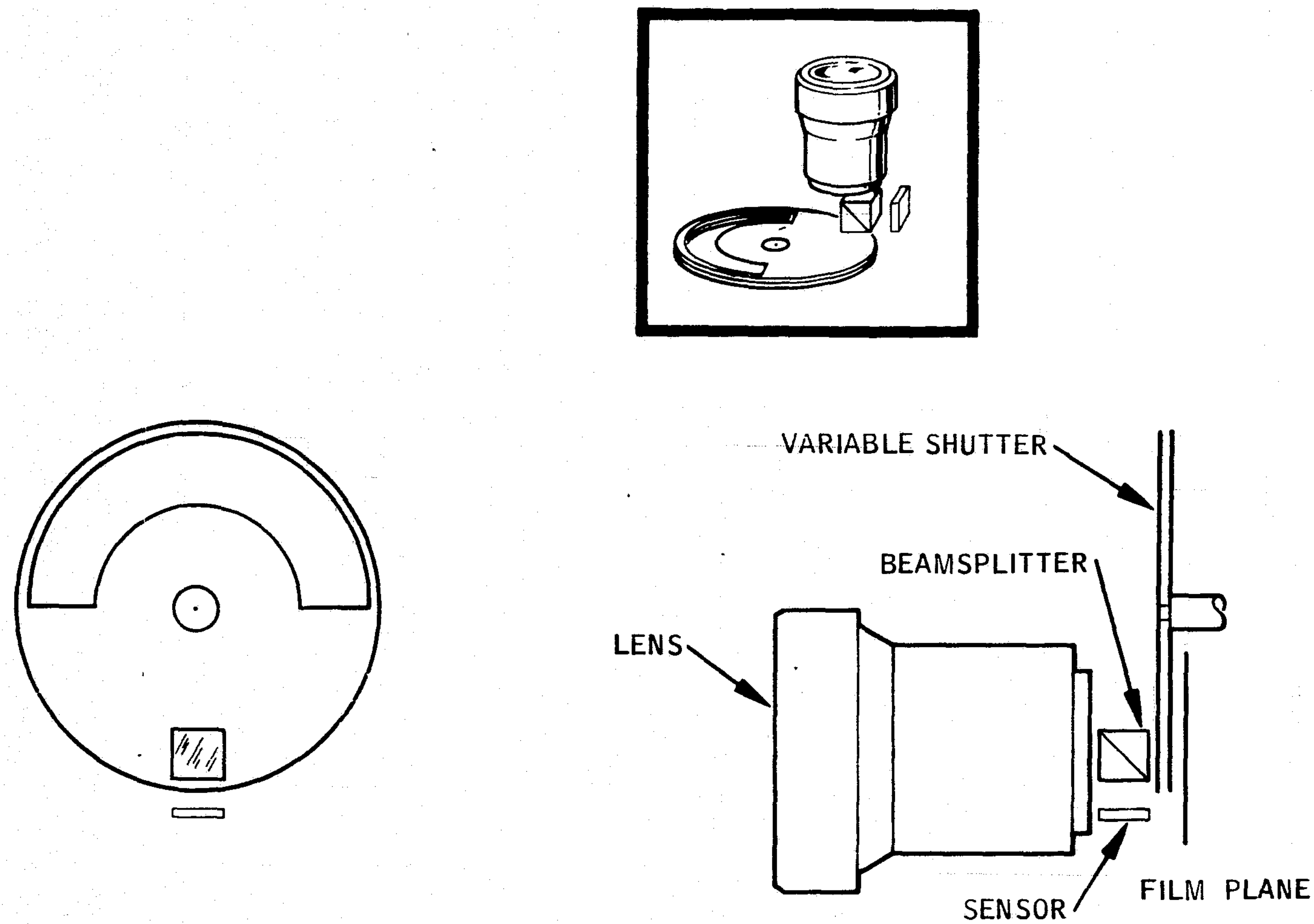


FIGURE 15. Fixed Reflector - Beam Splitter

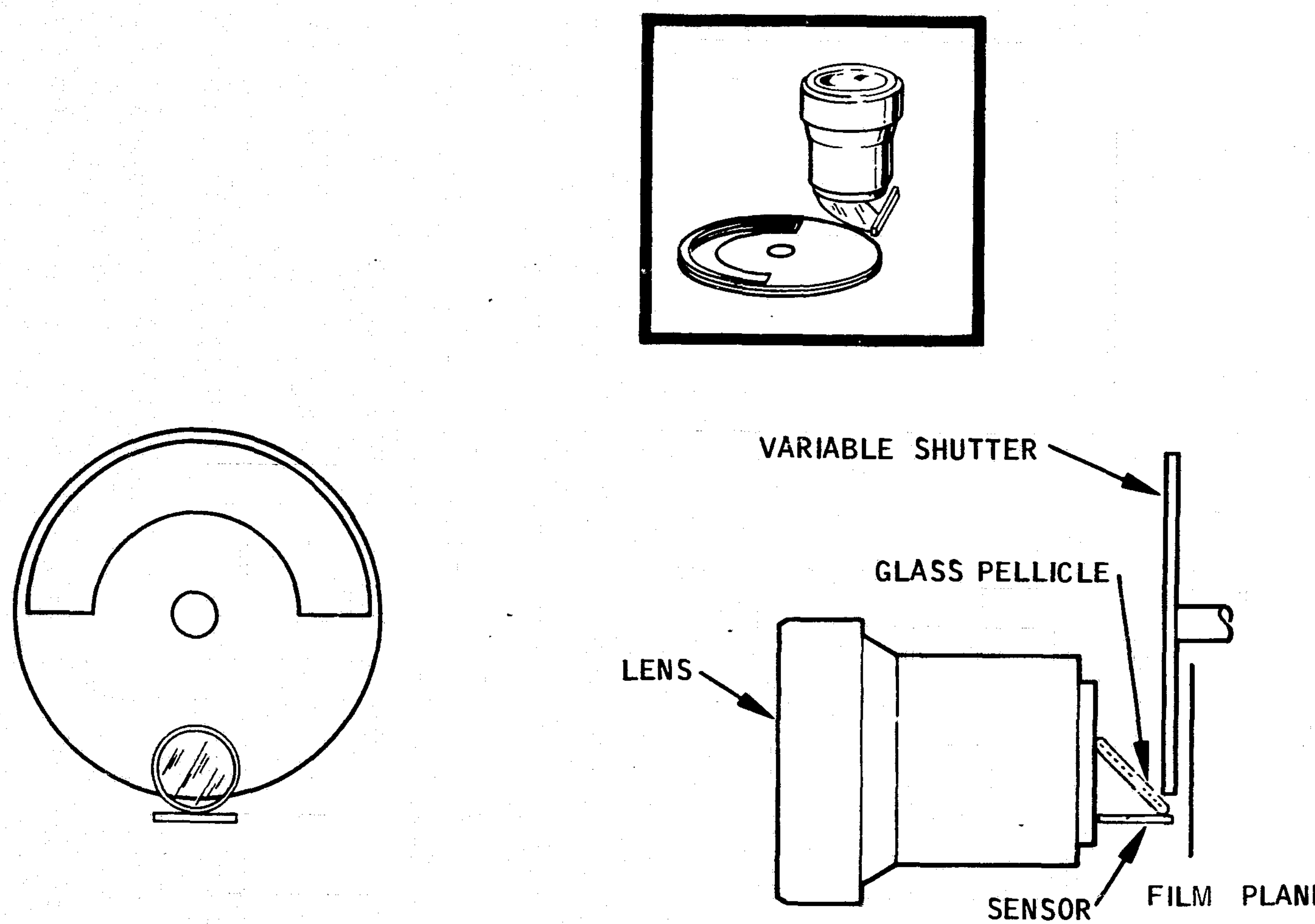


FIGURE 16. Fixed Reflector

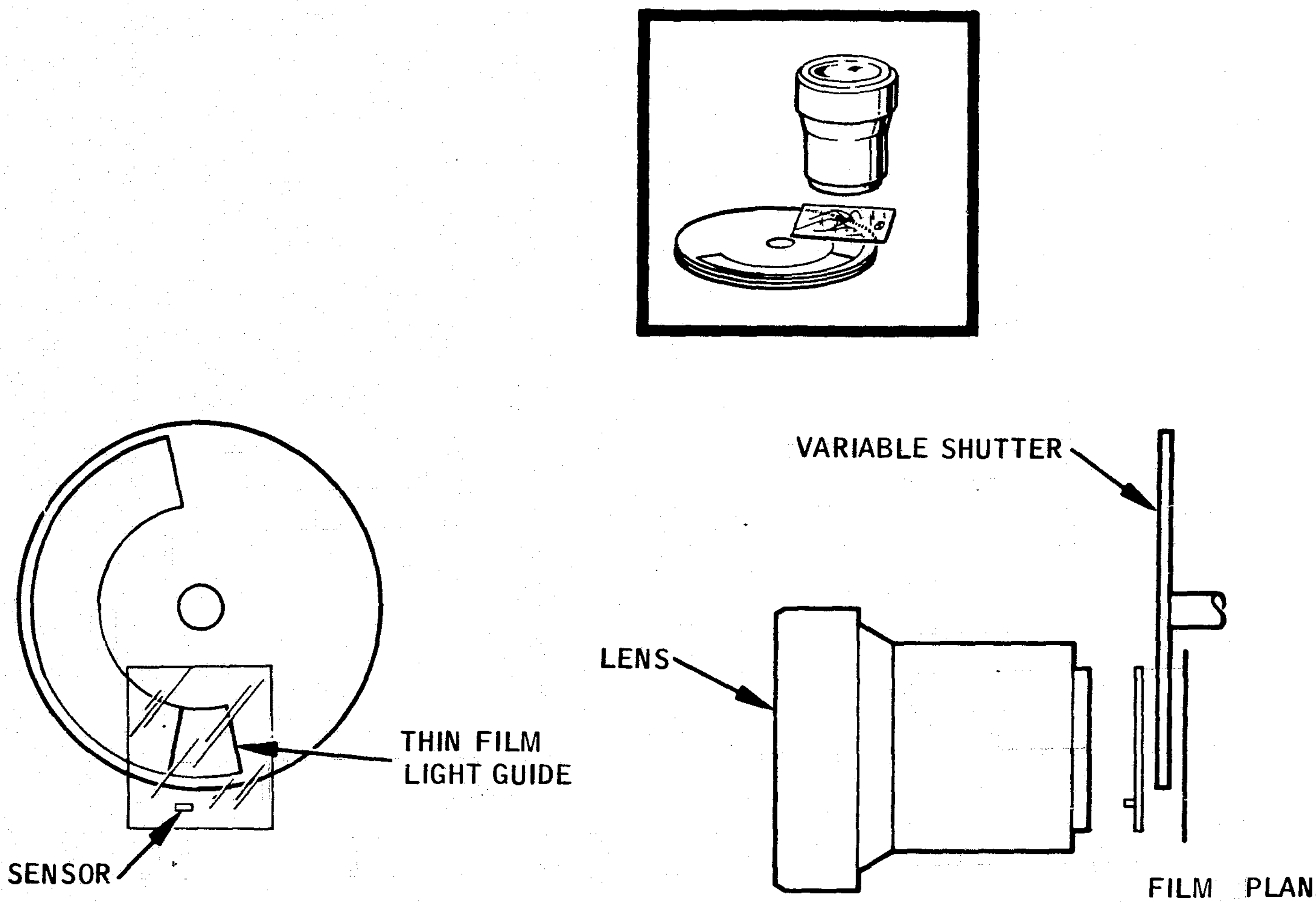


FIGURE 17. Fixed Reflector - Light Guide Deposition

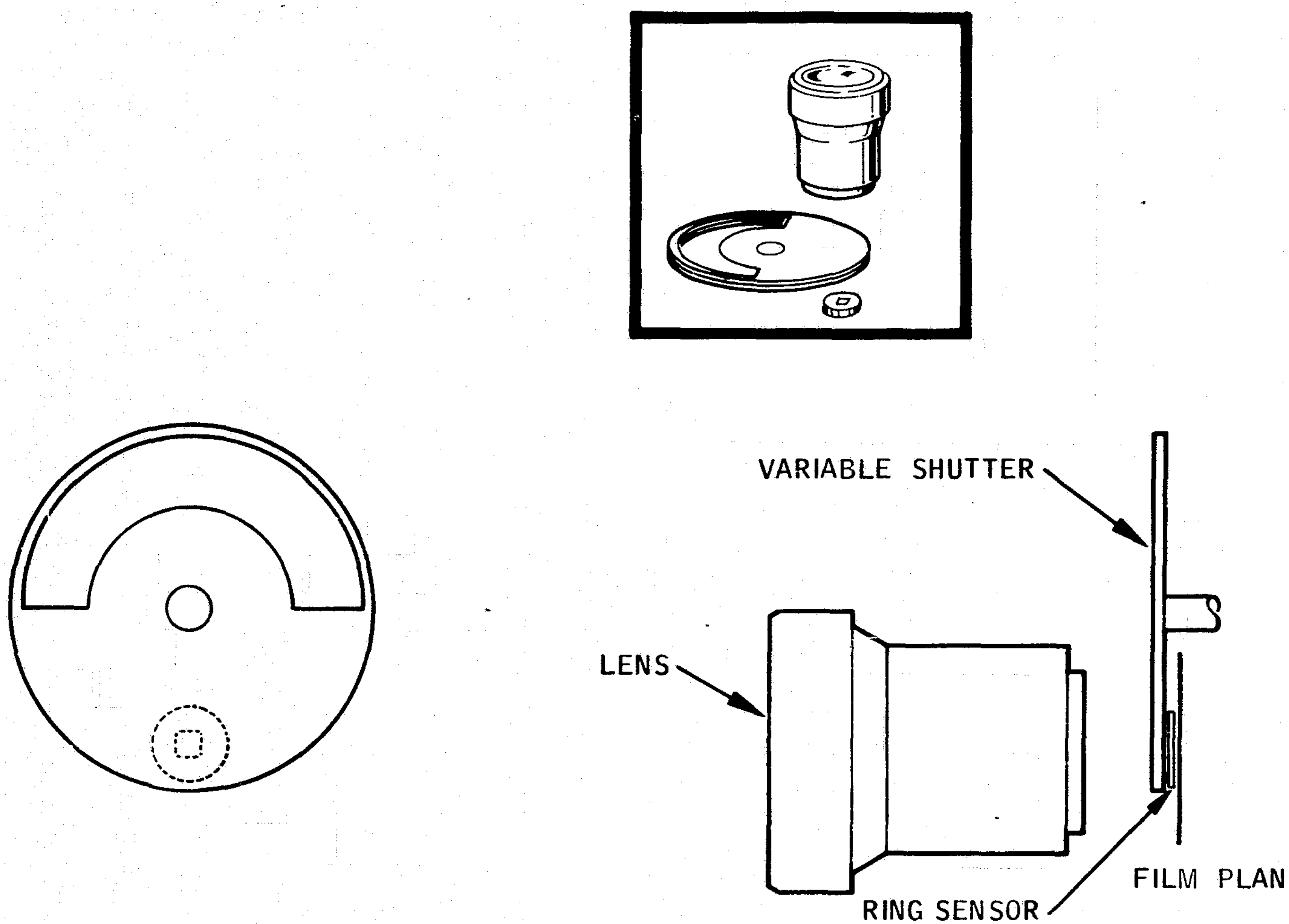


FIGURE 18. Fixed Sensor - Aperture Perimeter Sensor

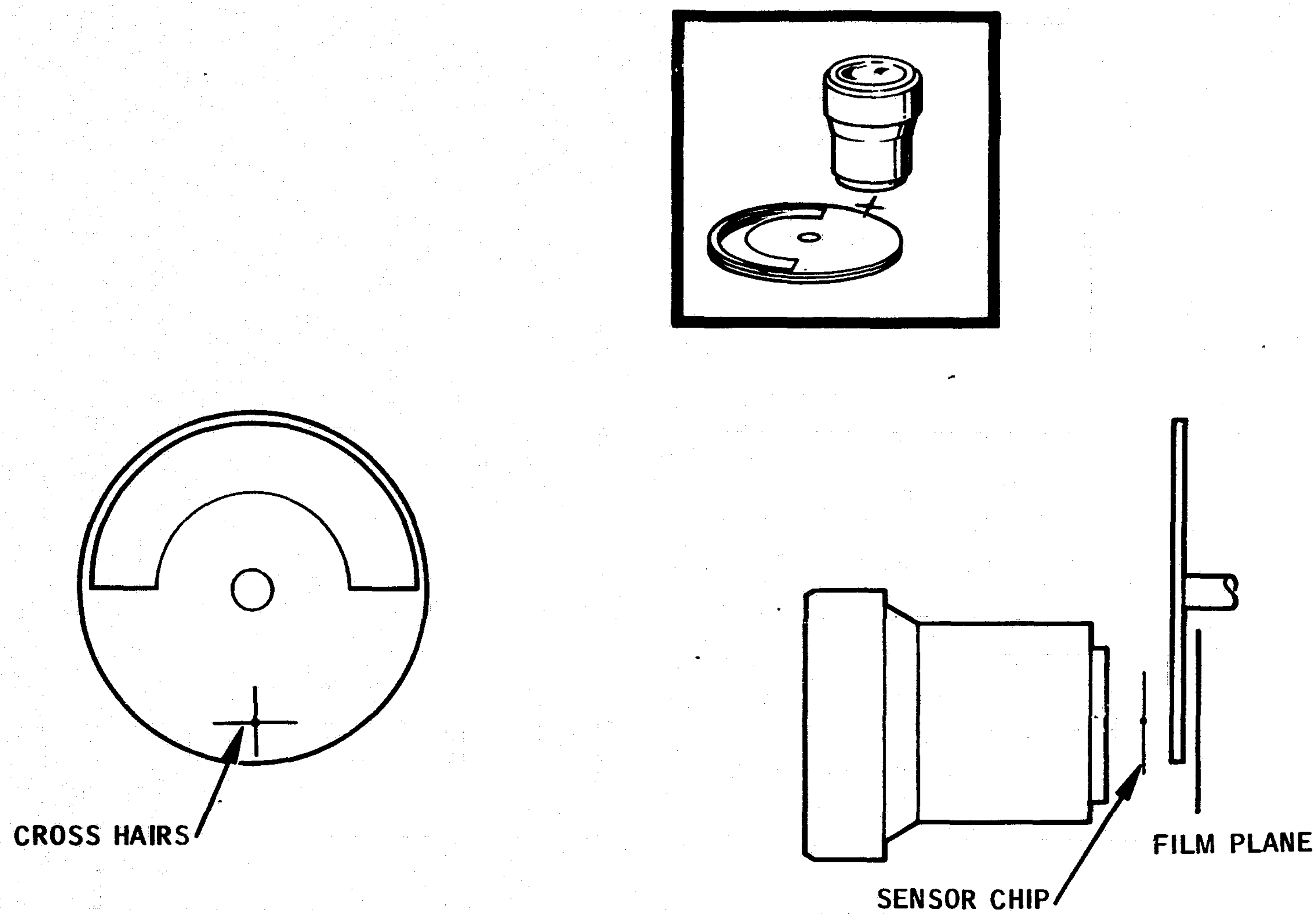


FIGURE 19. Fixed Sensor - Sensor Chip

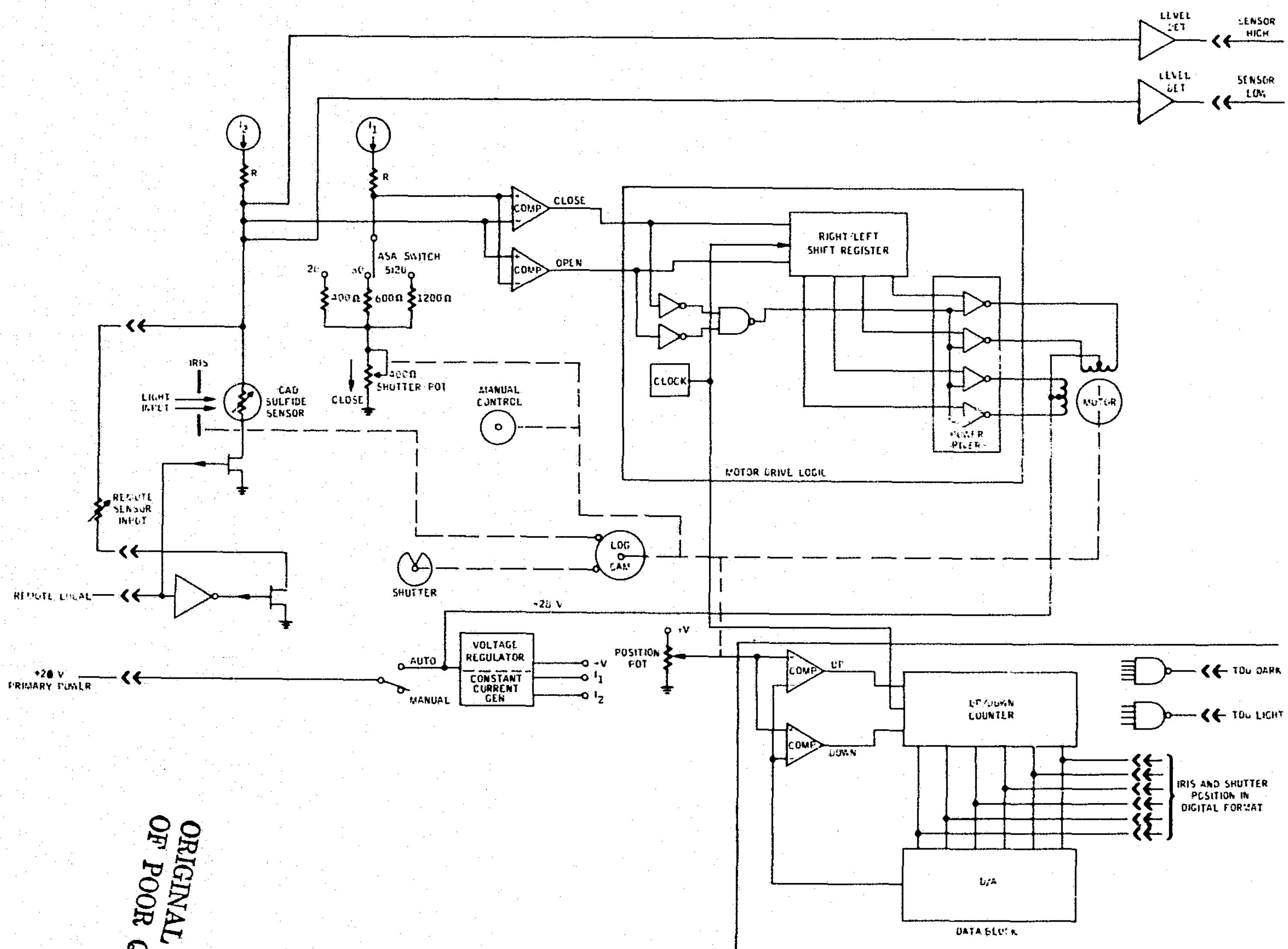


FIGURE 20. Schematic - Single Motor - Cadmium Sensor

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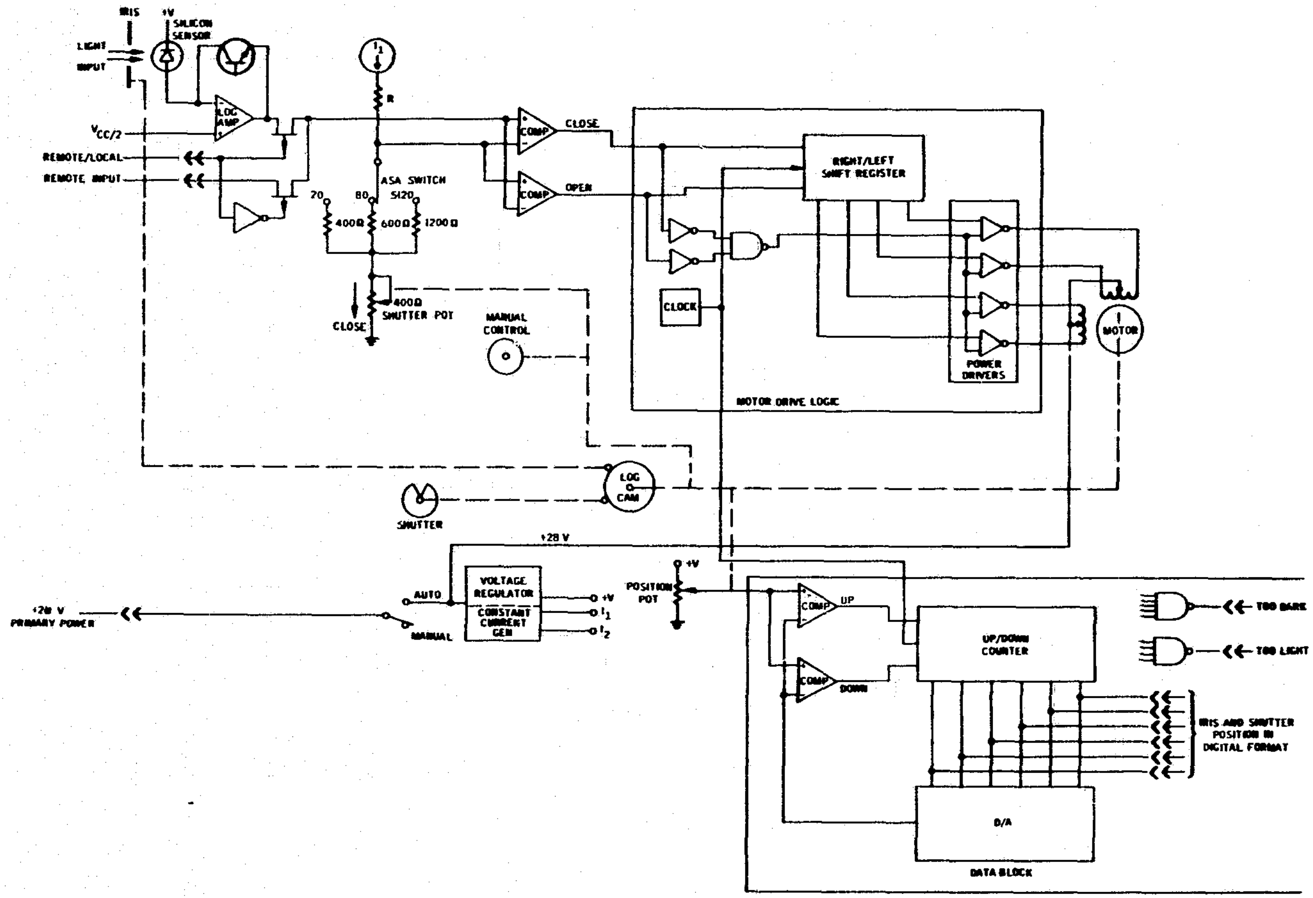


FIGURE 21. Schematic - Single Motor - Silicon Sensor

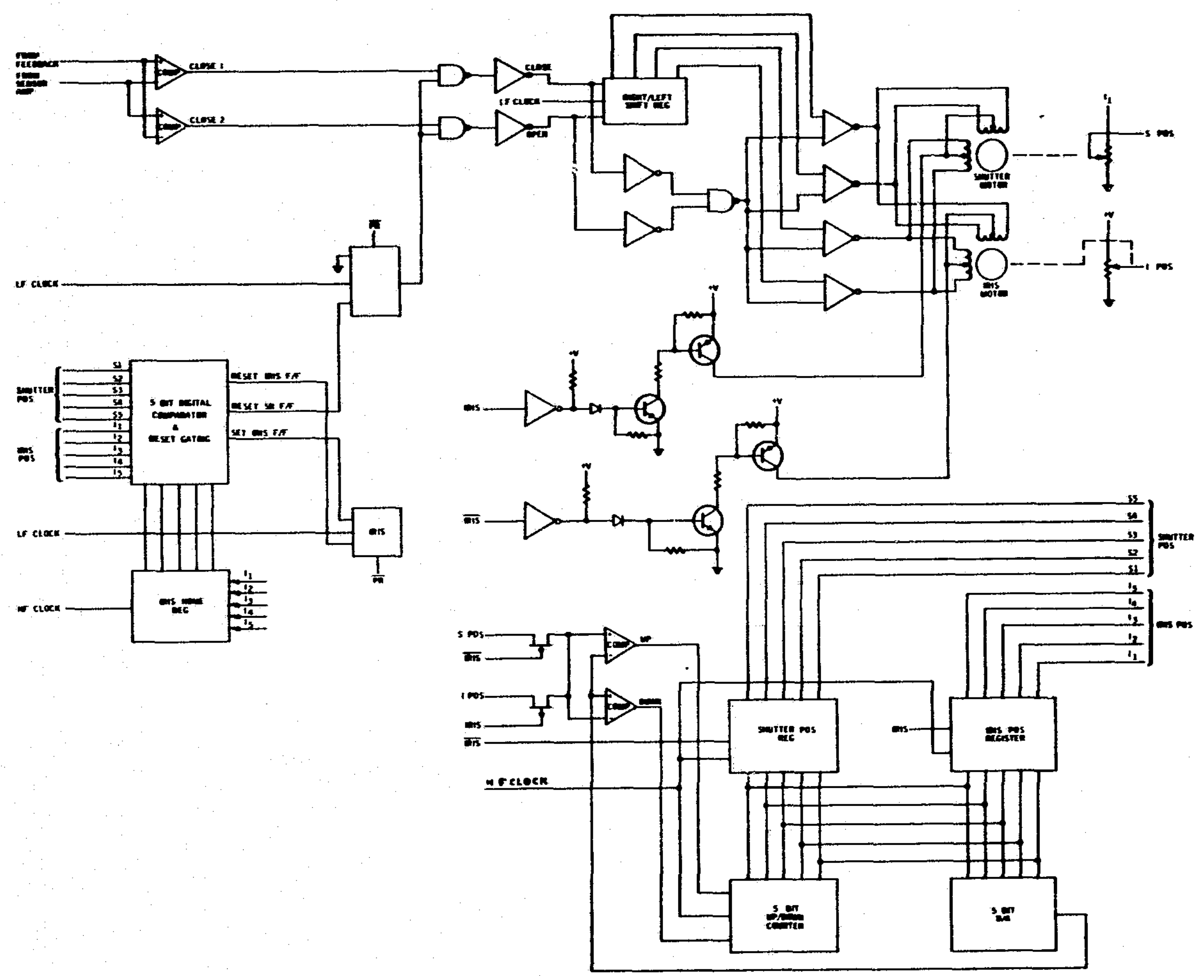


FIGURE 22. Schematic - Dual Motor Control

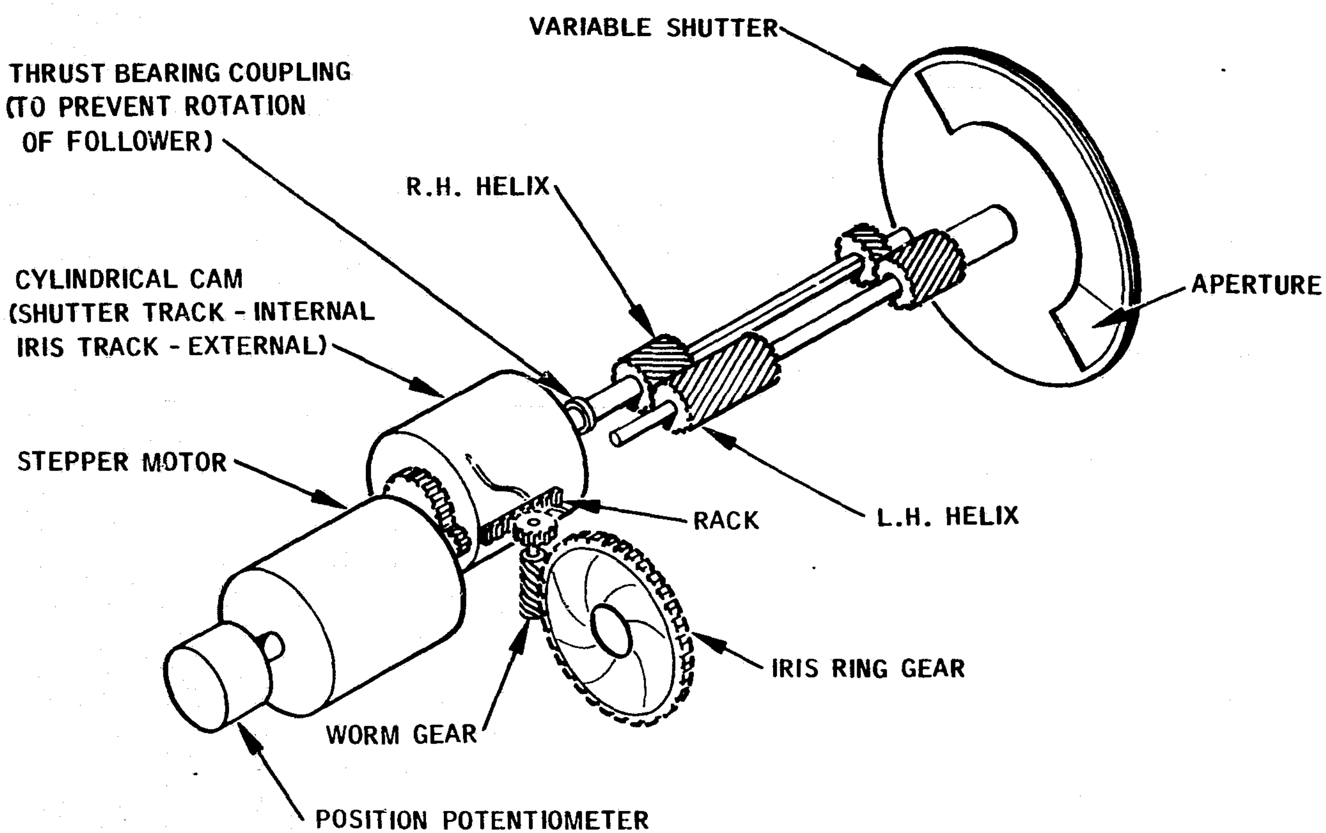


FIGURE 23. Variable Shutter and Iris Control Helical Gearset

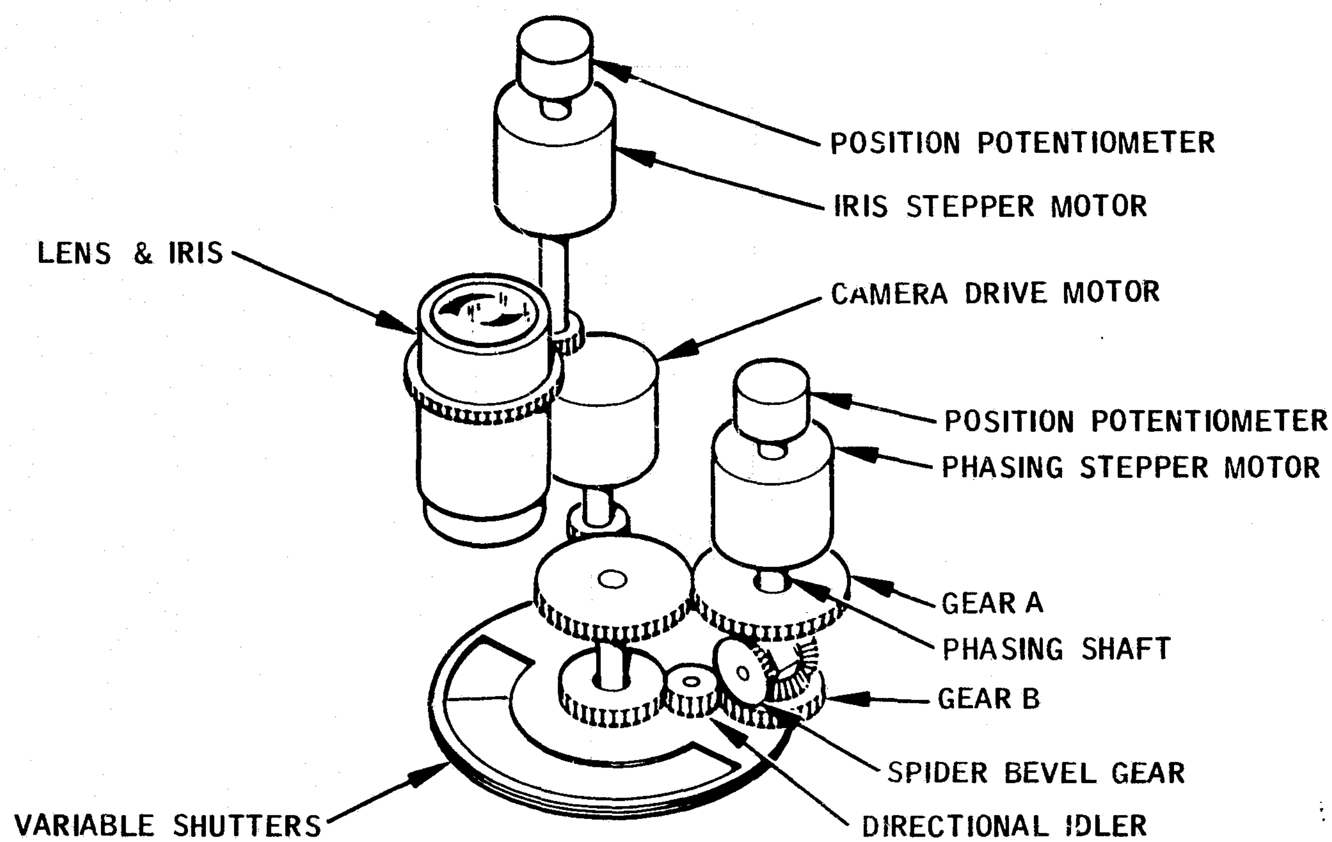
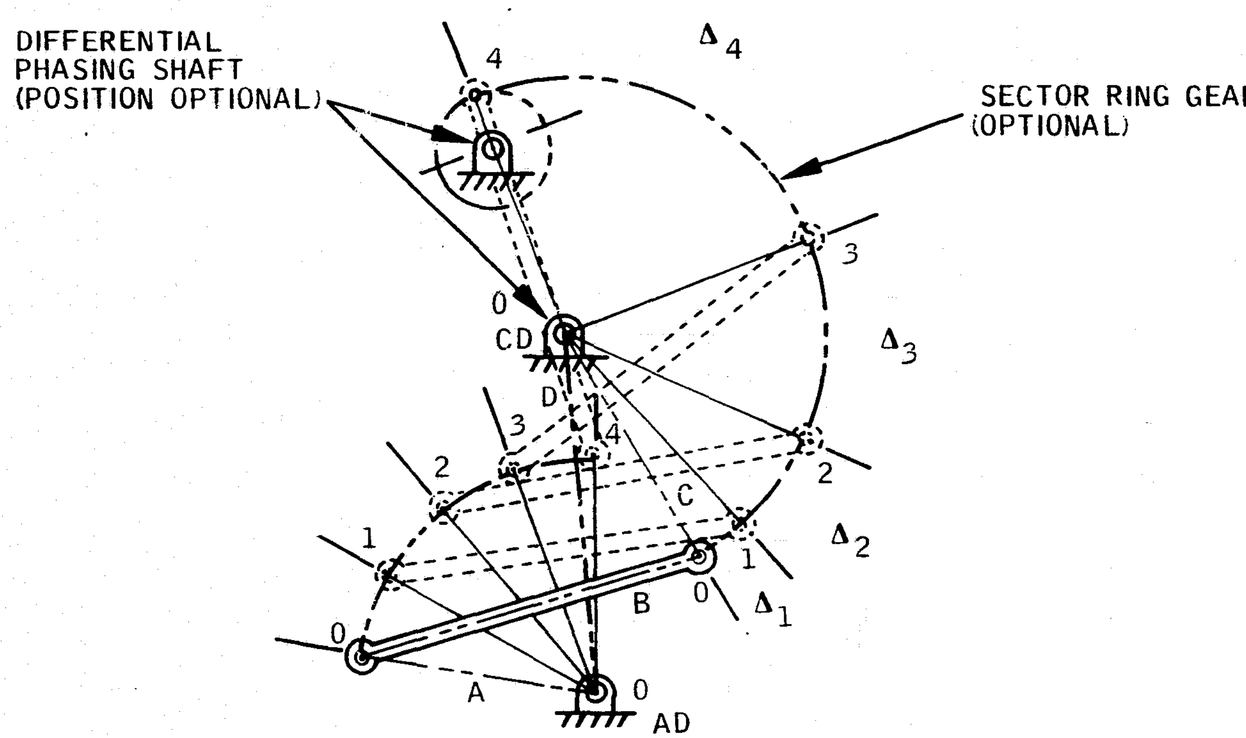
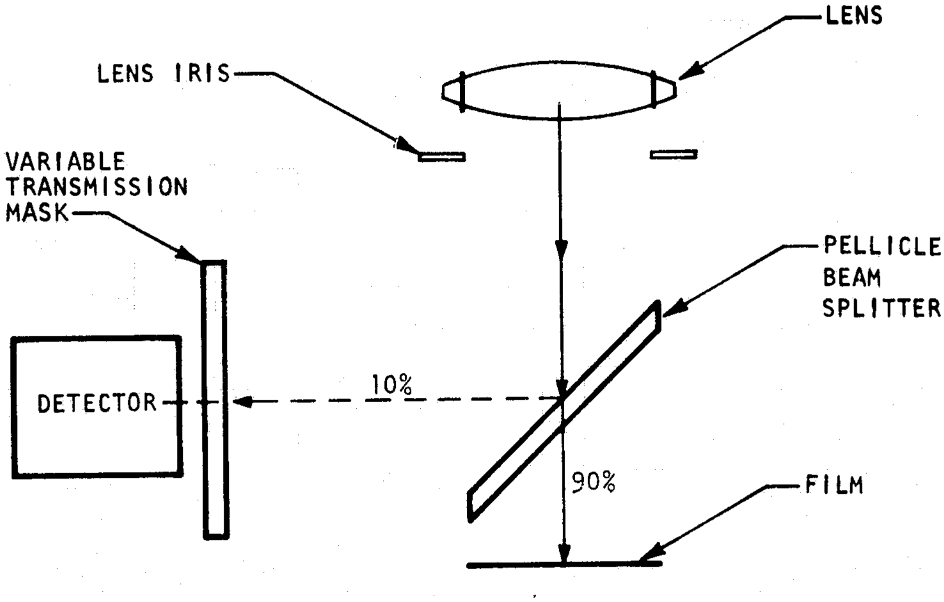


FIGURE 24. Differential Angular Phasing

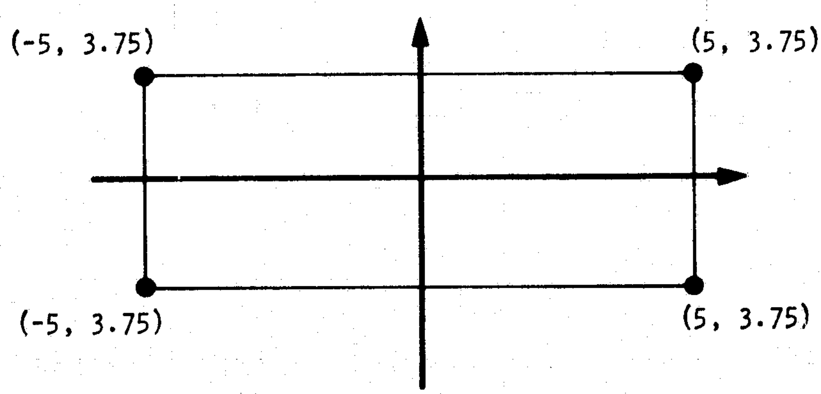


LINKAGE A: DRIVE CRANK
LINKAGE B: COUPLER ARM
LINKAGE C: FOLLOWER CRANK
LINKAGE D: THEORITICAL FIXED LINK

FIGURE 25. Four Bar Linkage

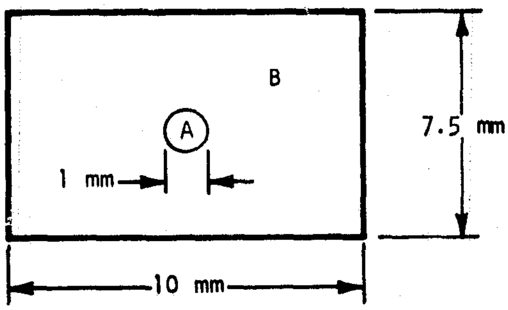


A. OPTICAL SCHEMATIC



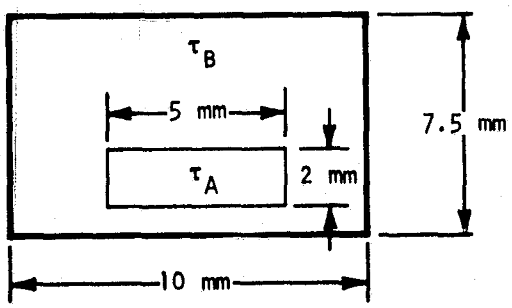
B. FORMAT (DIMENSIONS IN MILLIMETERS)

FIGURE 26. Optical Schematic and Format



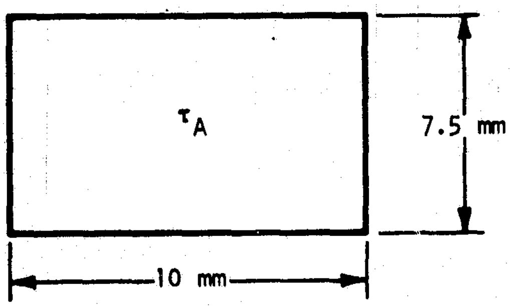
$\tau_A = 1.0$
$\tau_B = 10^{-2}$
$\langle\tau\rangle = 2 \times 10^{-2}$
$\mathrm{LOG}_{10}G = 1.7$

A. A CENTER SPOT WEIGHTED MASK



$\tau_A = 1.0$
$\tau_B = 0.154$
$\langle\tau\rangle = 0.267$
$G = 3.75$
$\mathrm{LOG}_{10}G = 0.574$

B. A FOREGROUND WEIGHTED MASK



$\tau_A = 1.0$
$\langle\tau\rangle = 1.0$
$G = 1.0$
$\mathrm{LOG}_{10}G = 0$

C. FULL FORMAT UNIFORM WEIGHTED MASK

FIGURE 27. Representative Mask Configurations

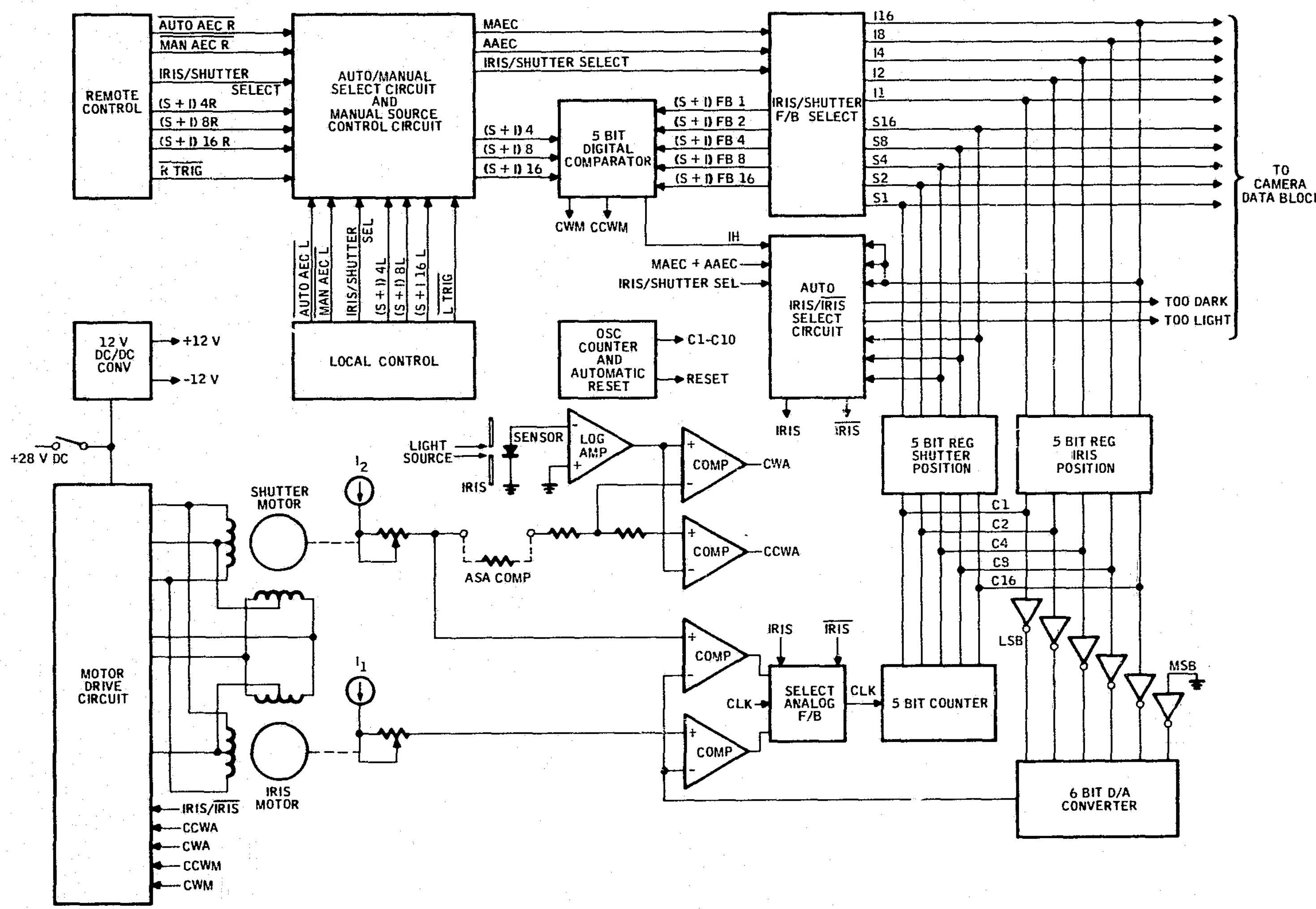


FIGURE 28. AEC Electronic System Block Diagram

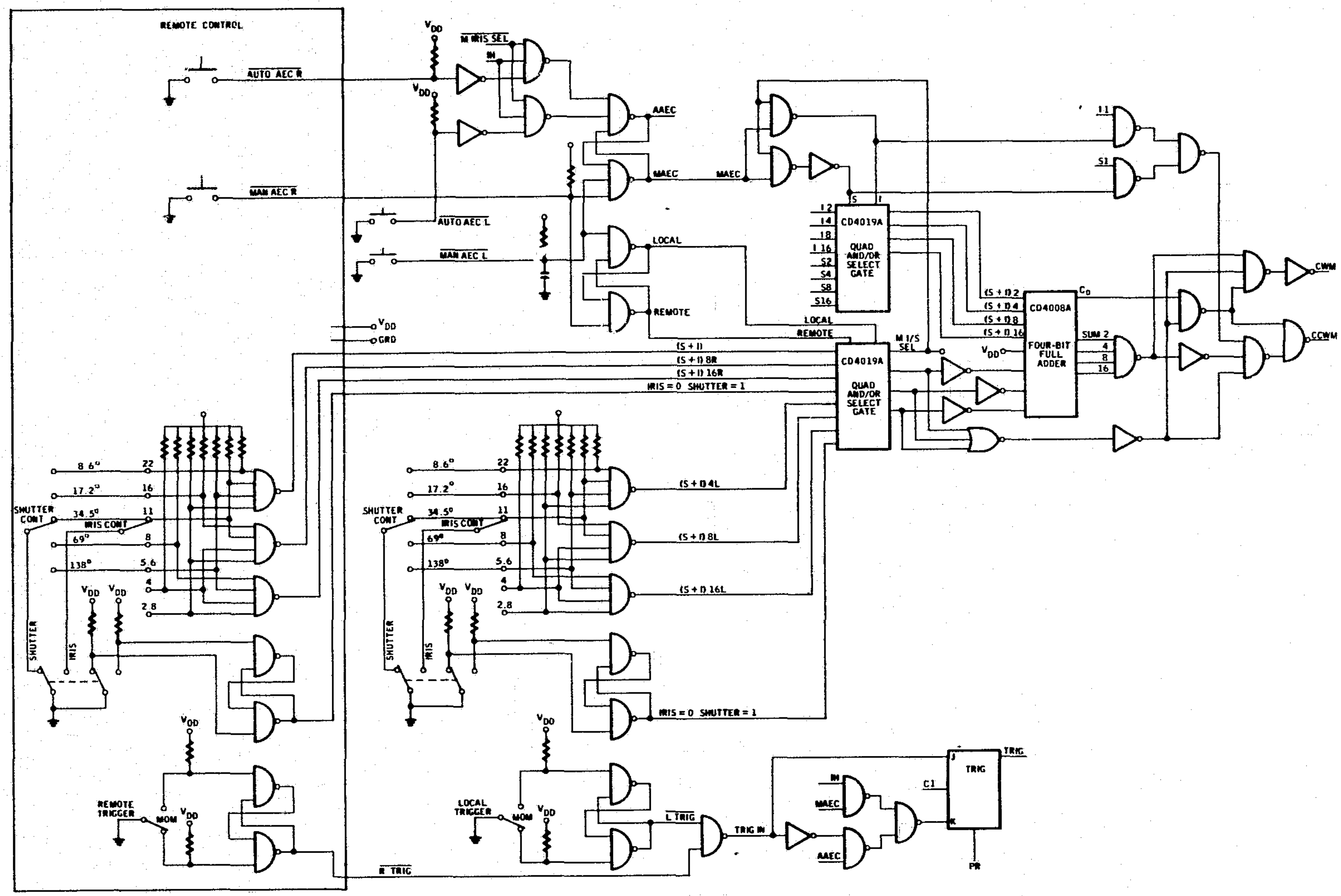


FIGURE 29. AEC Electronics Manual Interface Schematic Diagram

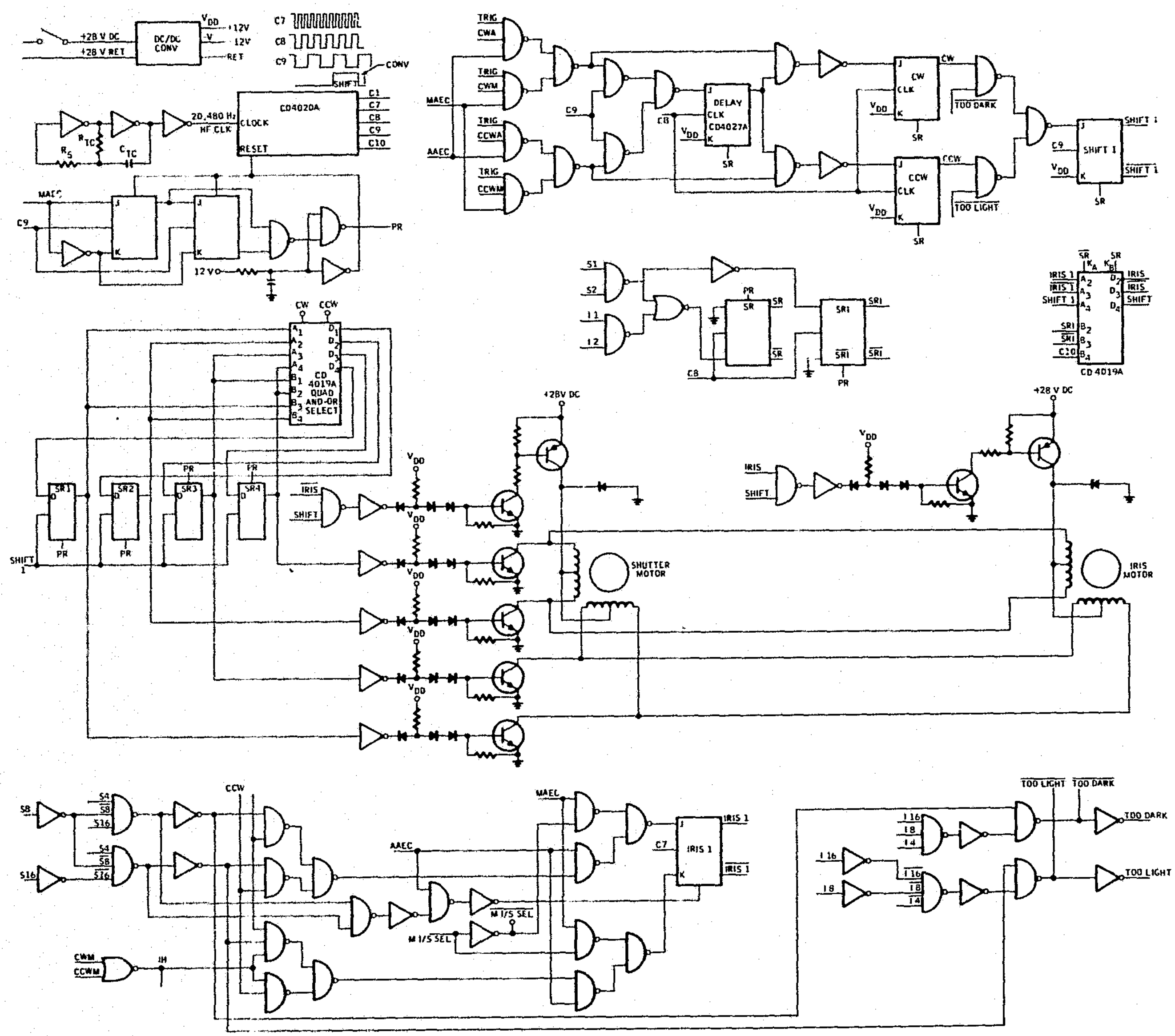


FIGURE 30. AEC Electronics Motor Control Schematic Diagram

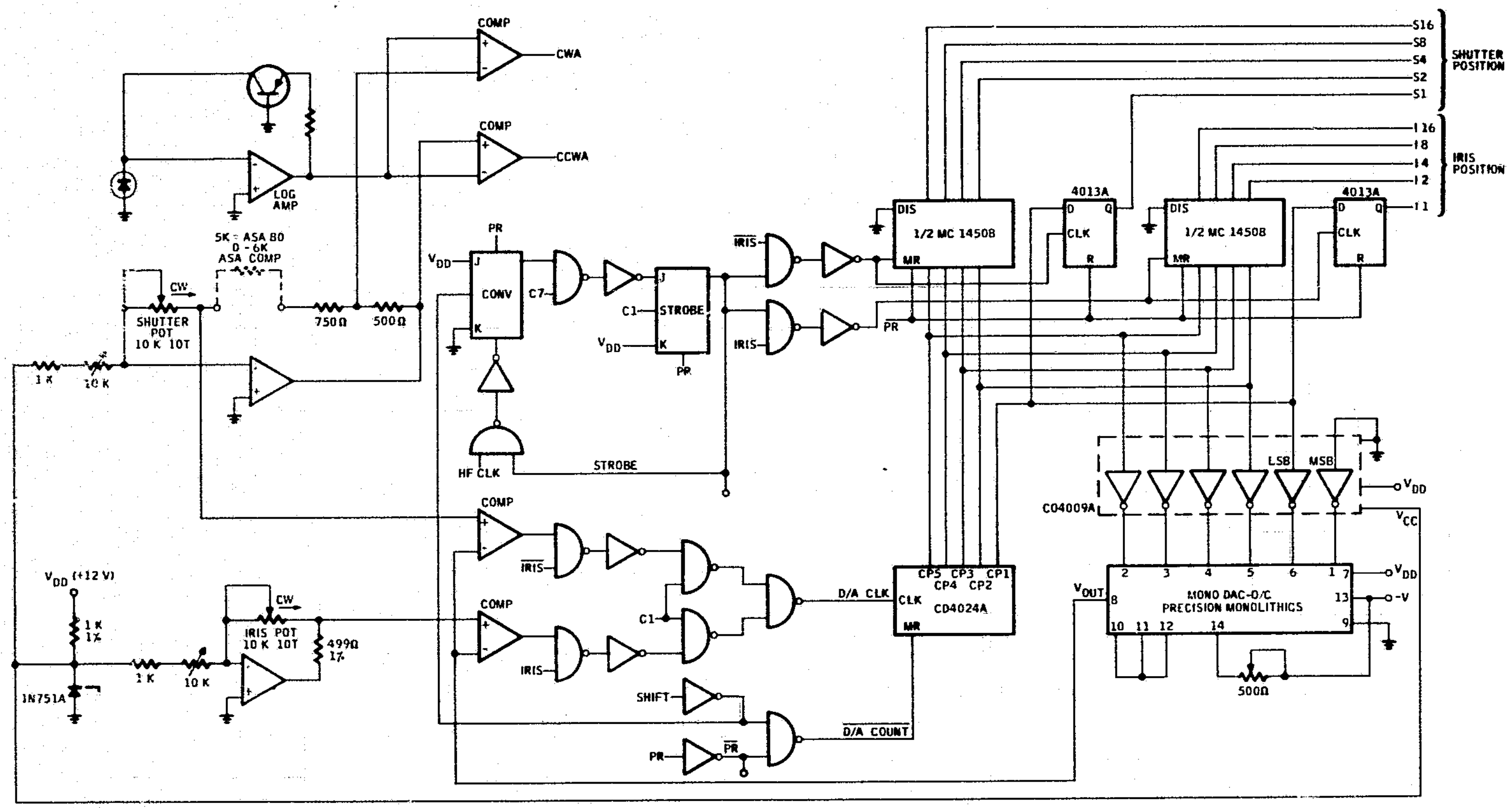
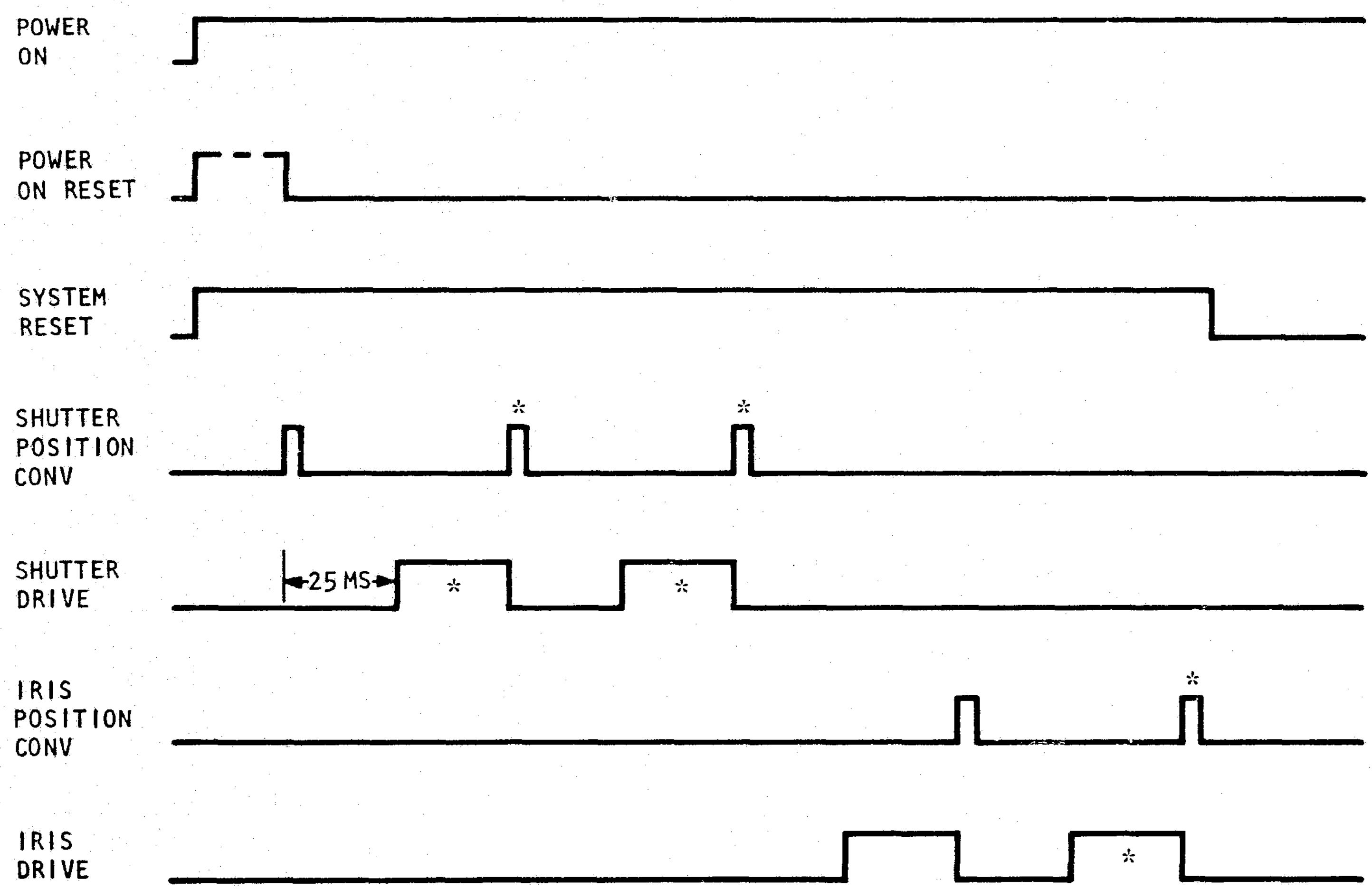


FIGURE 31. AEC Electronics Camera Data Block Interface Schematic Diagram



*MAY OR MAY NOT OCCUR, DEPENDING ON INITIAL POSITION OF MOTOR

FIGURE 32. Timing Diagram Reset Sequence

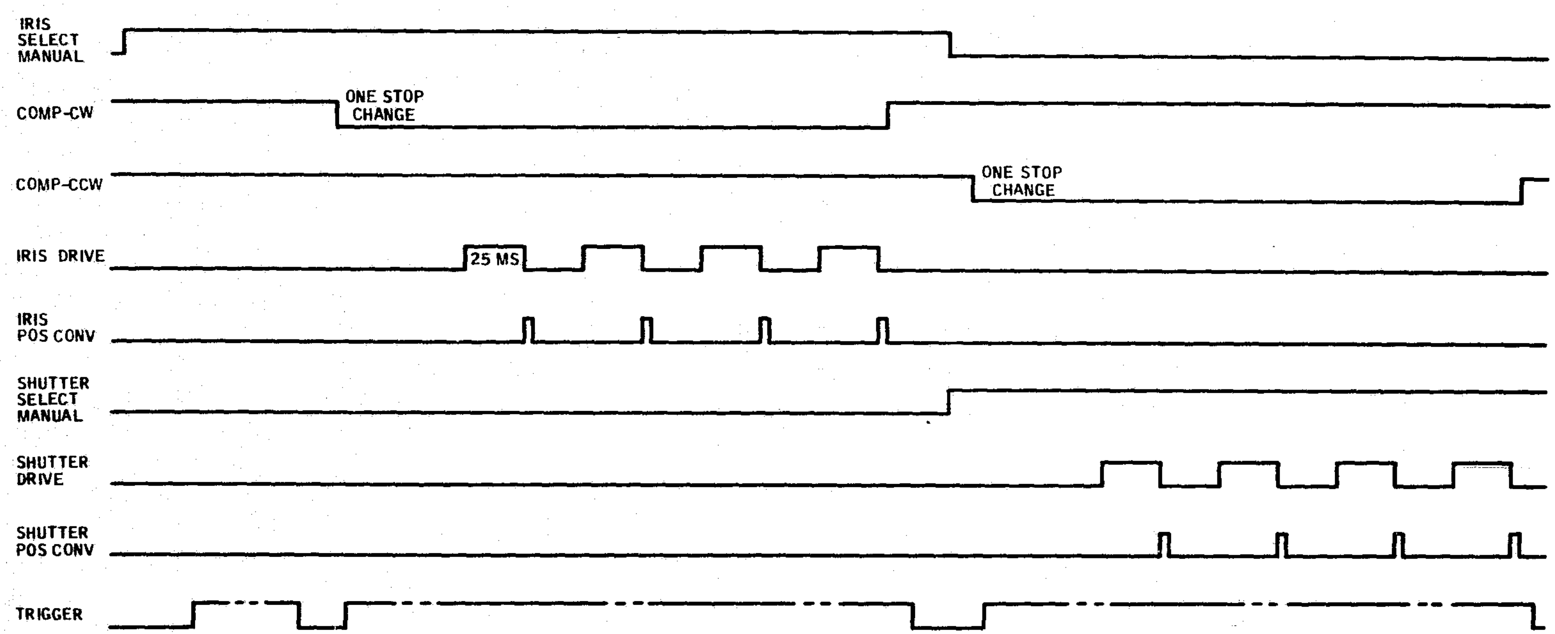


FIGURE 33. Timing Diagram Manual Operation

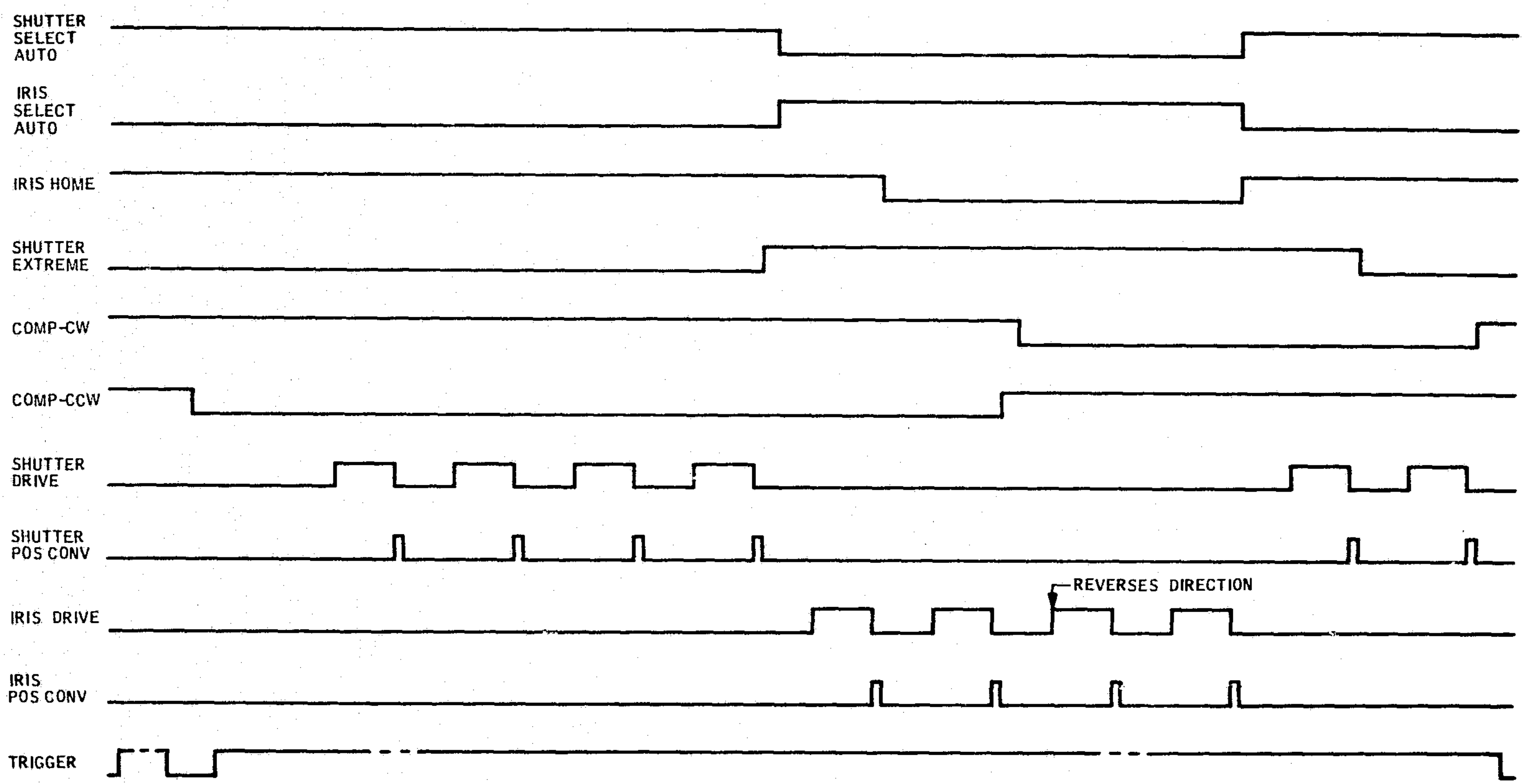


FIGURE 34. Timing Diagram Automatic Operation

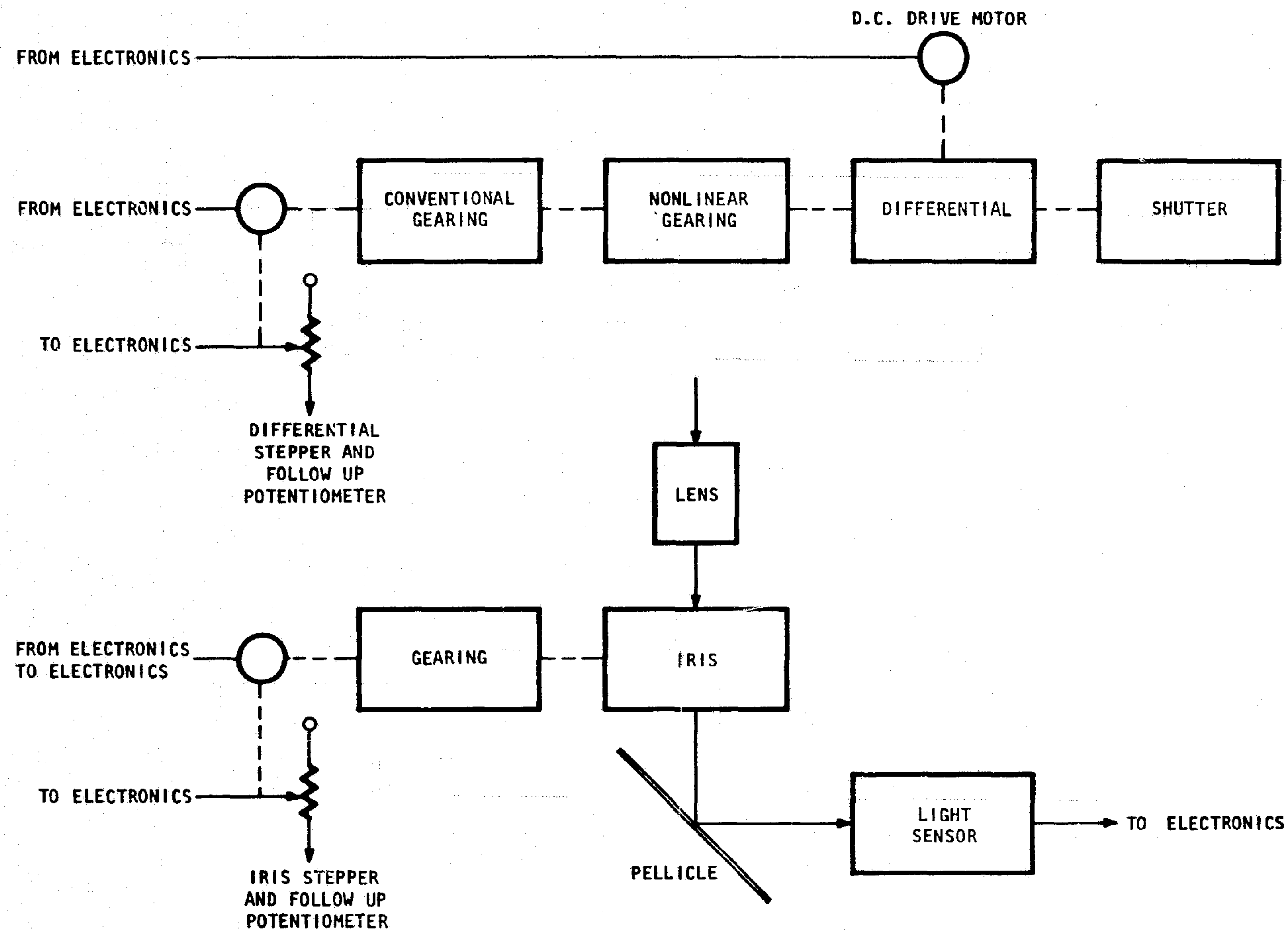


FIGURE 35. Automatic Exposure Control Drive Train Schematic

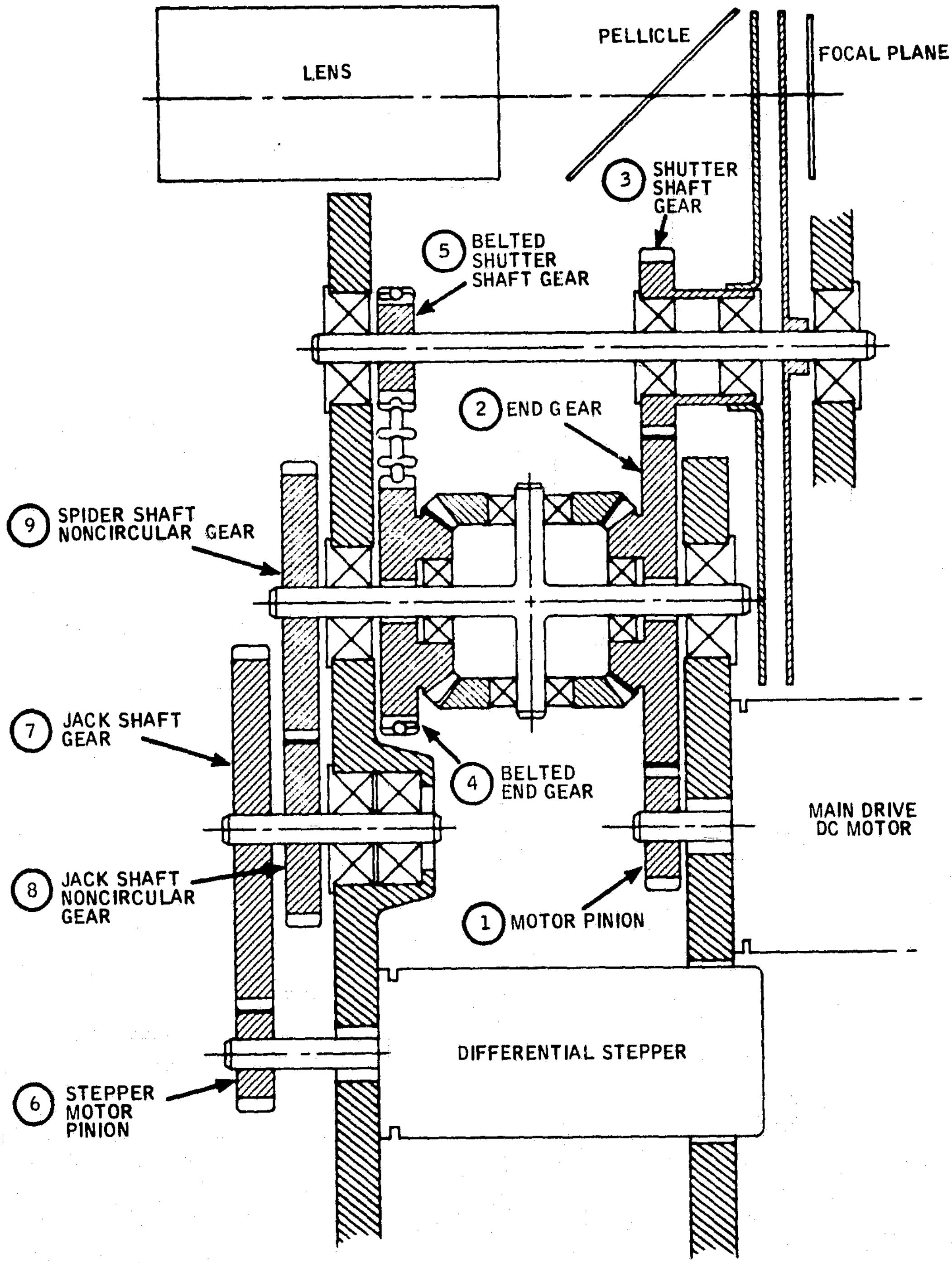


FIGURE 36. Shutter Differential Drive System

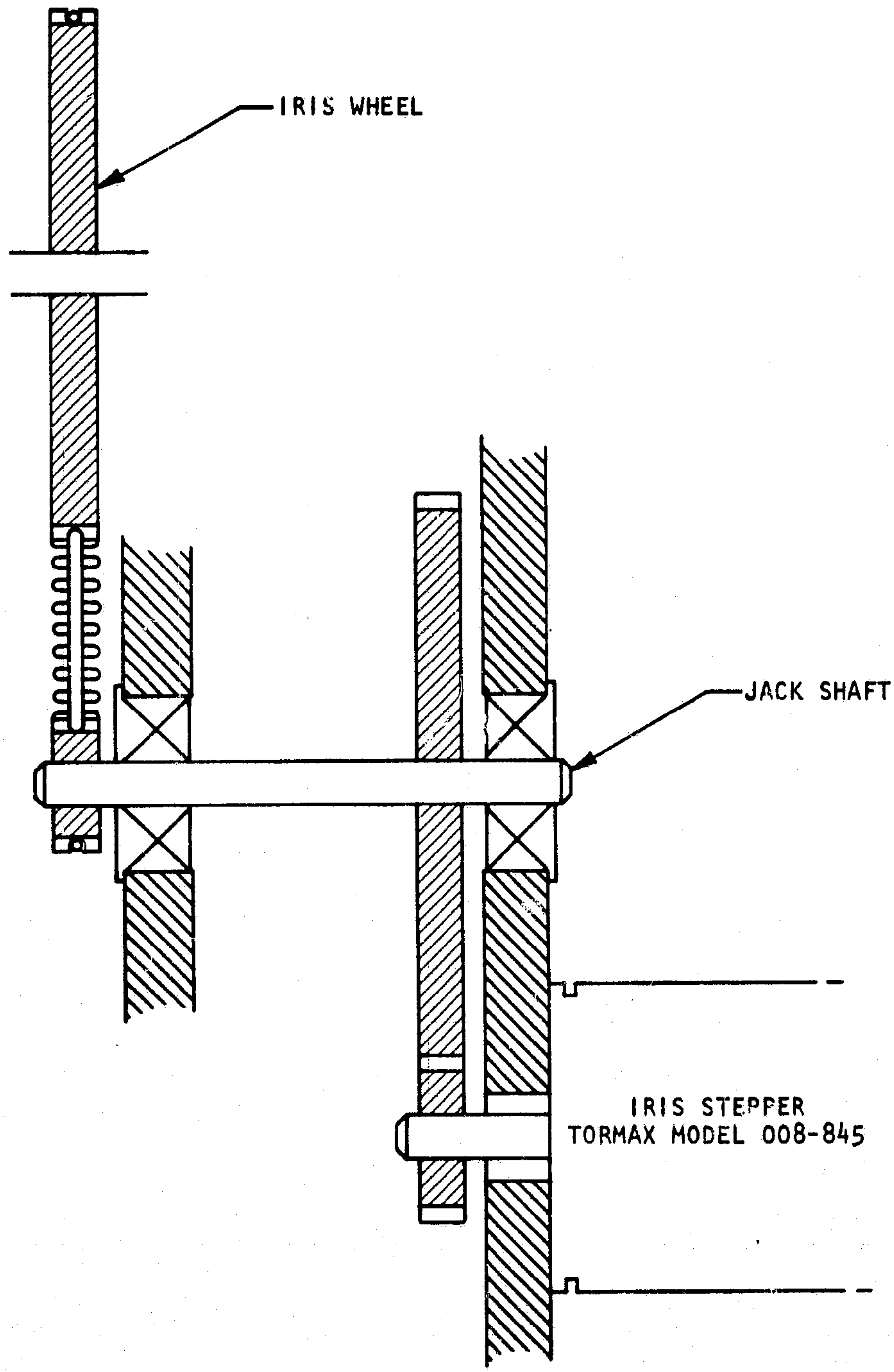


FIGURE 37. Iris Drive System

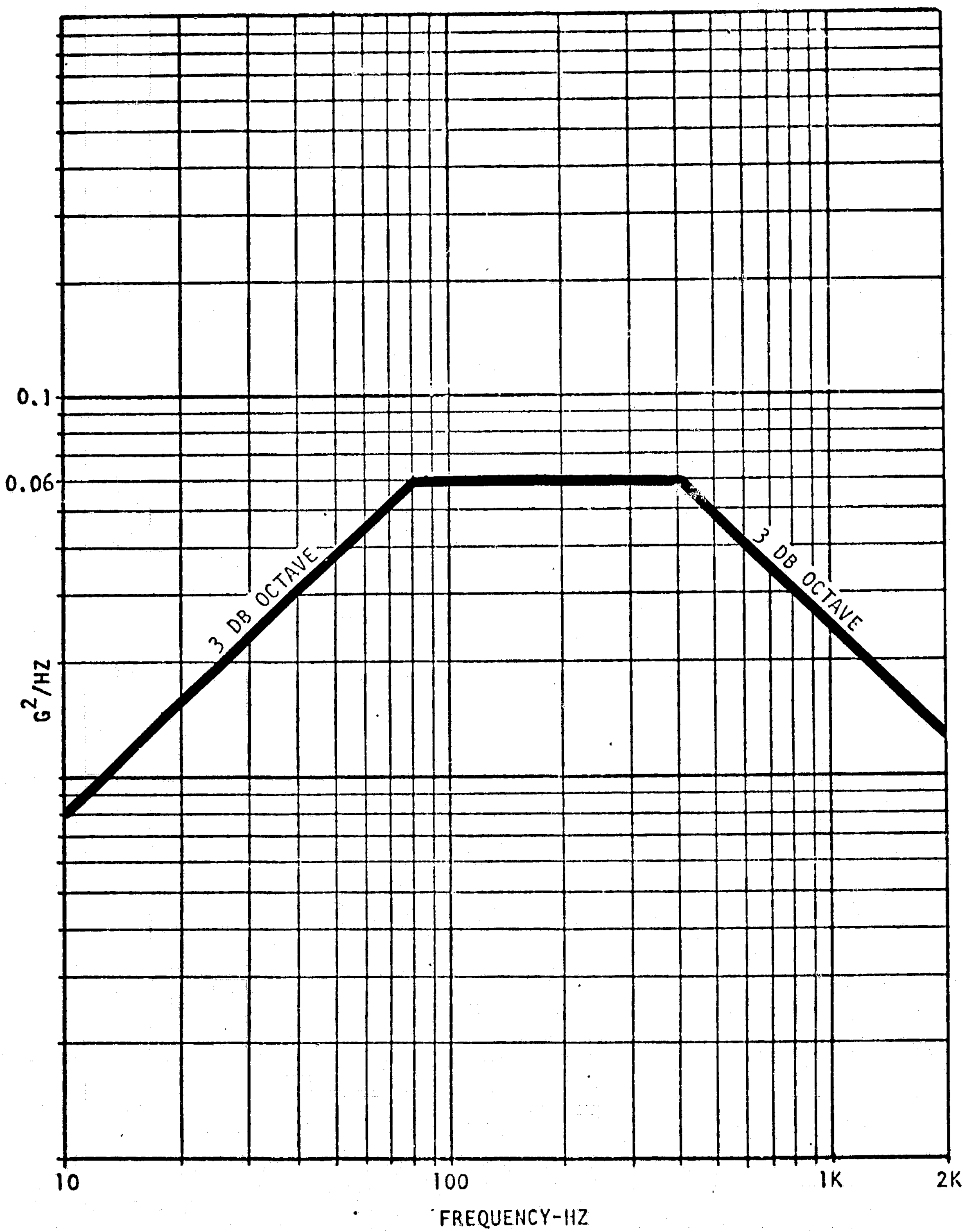


FIGURE 38. Random Vibration

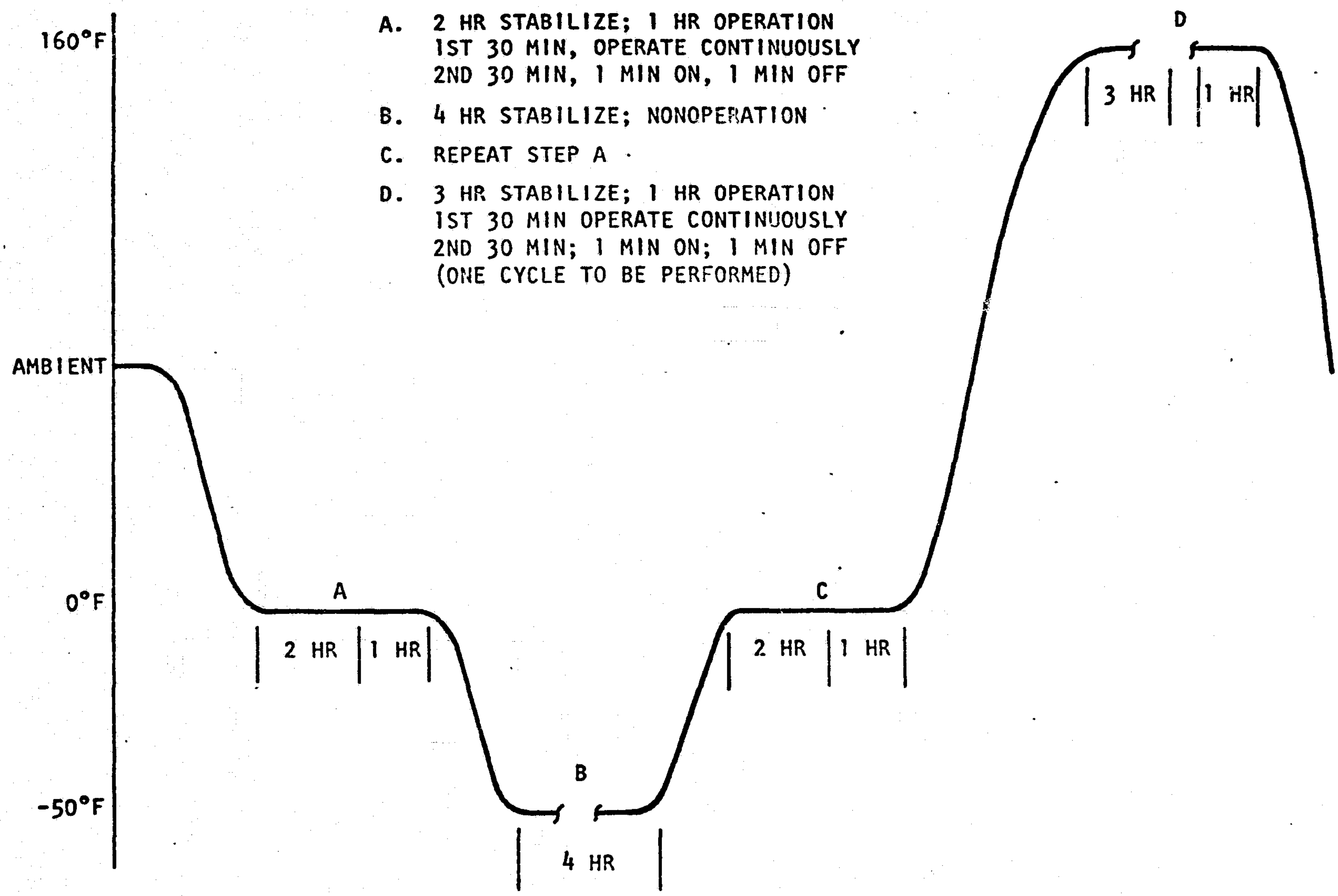


FIGURE 39. Temperature and System Operating Cycle

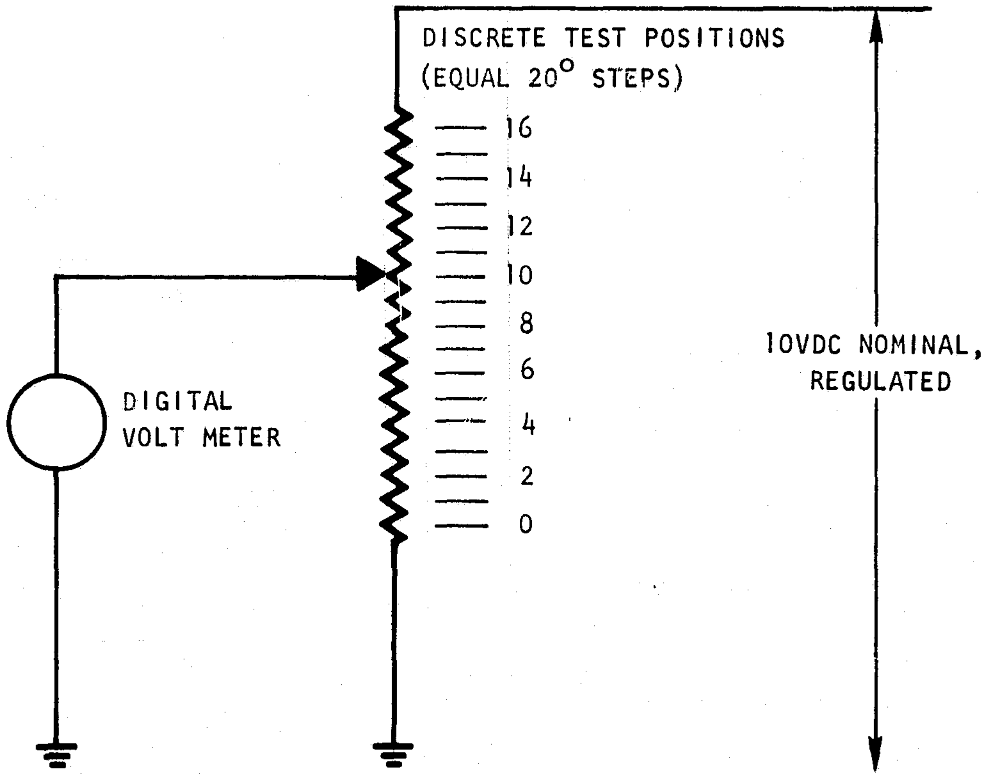


FIGURE 40. Potentiometer Test Circuit

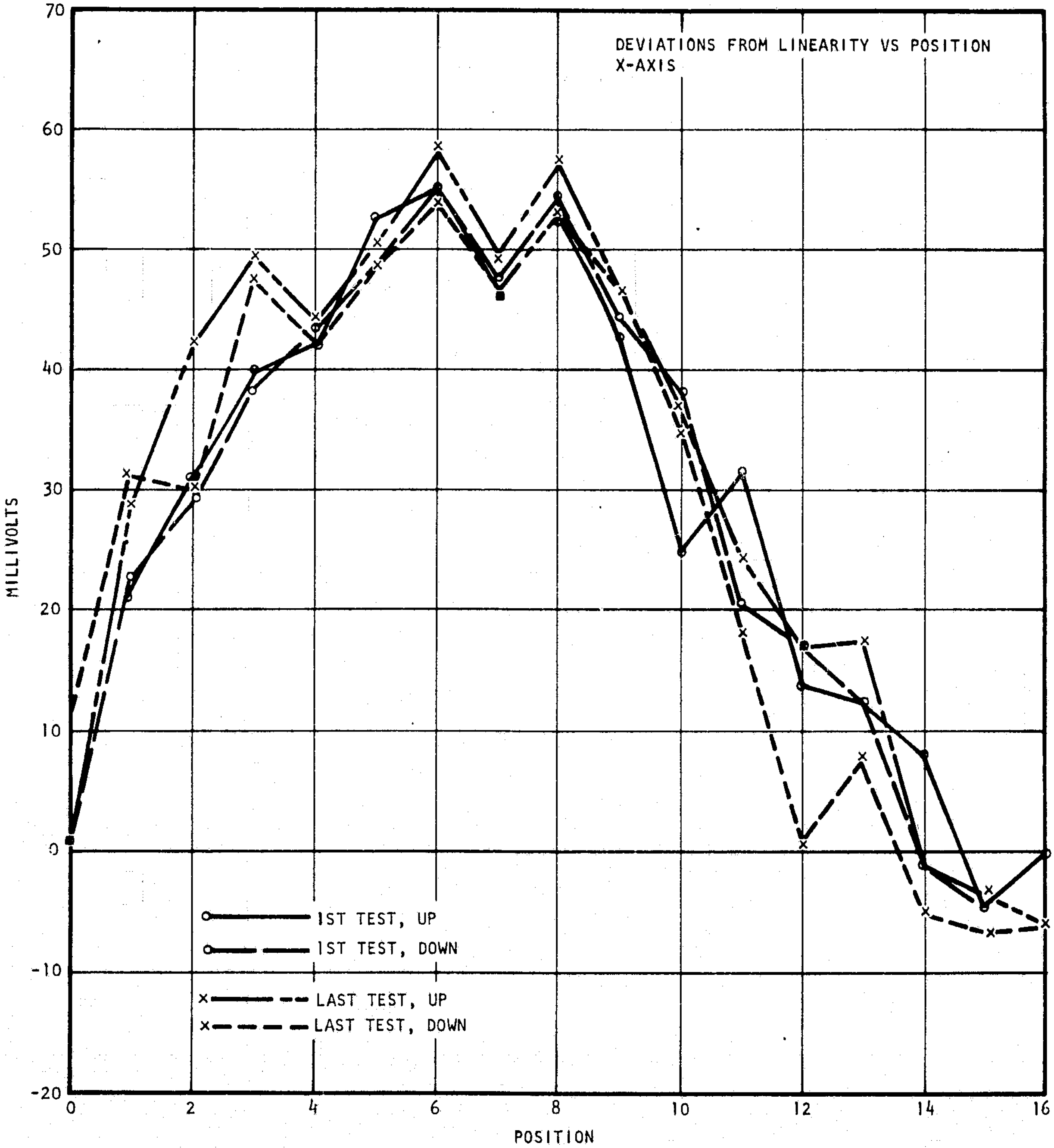


FIGURE 41. Potentiometer (at Static Condition)

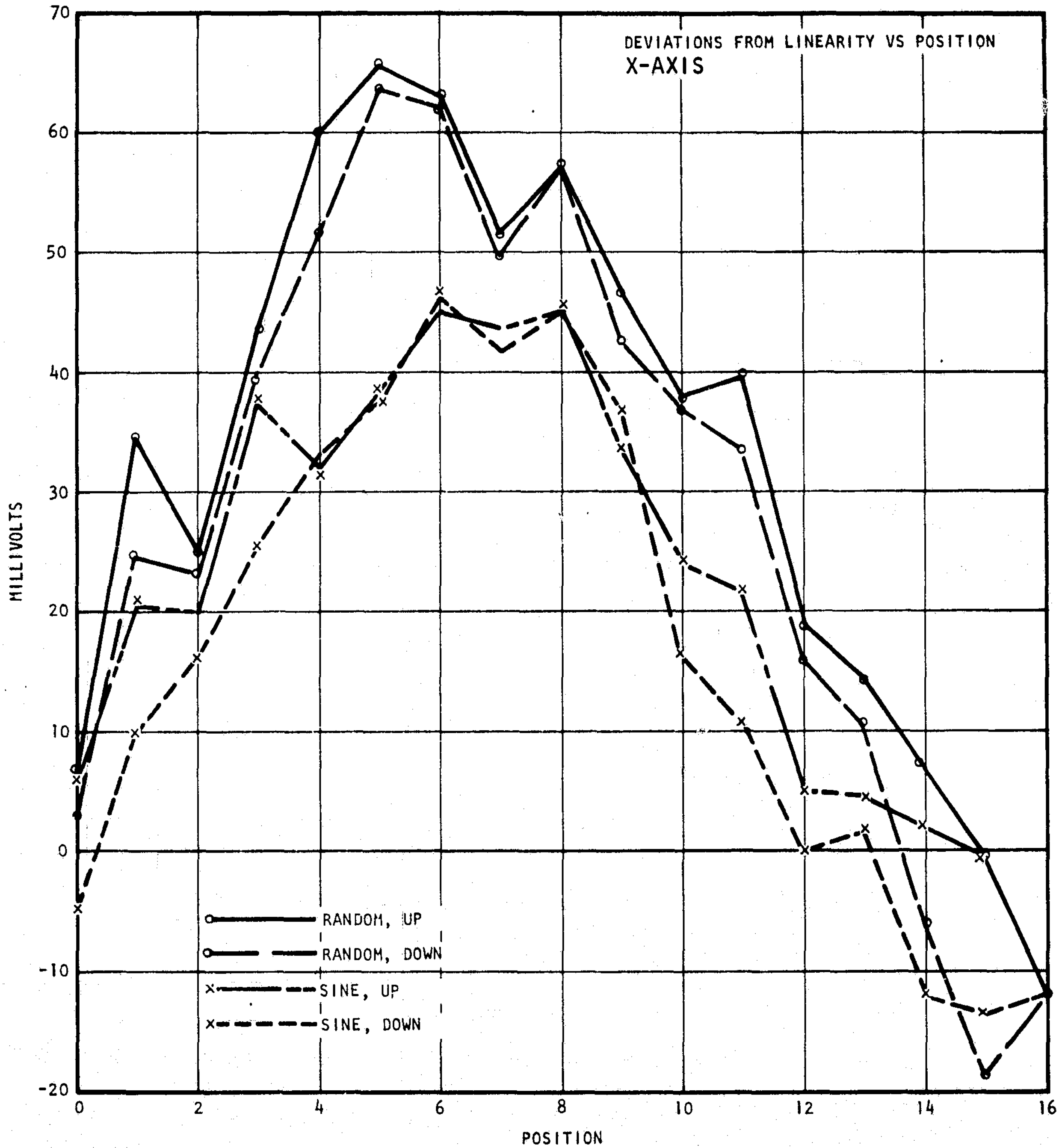


FIGURE 42. Potentiometer Vibration Tests

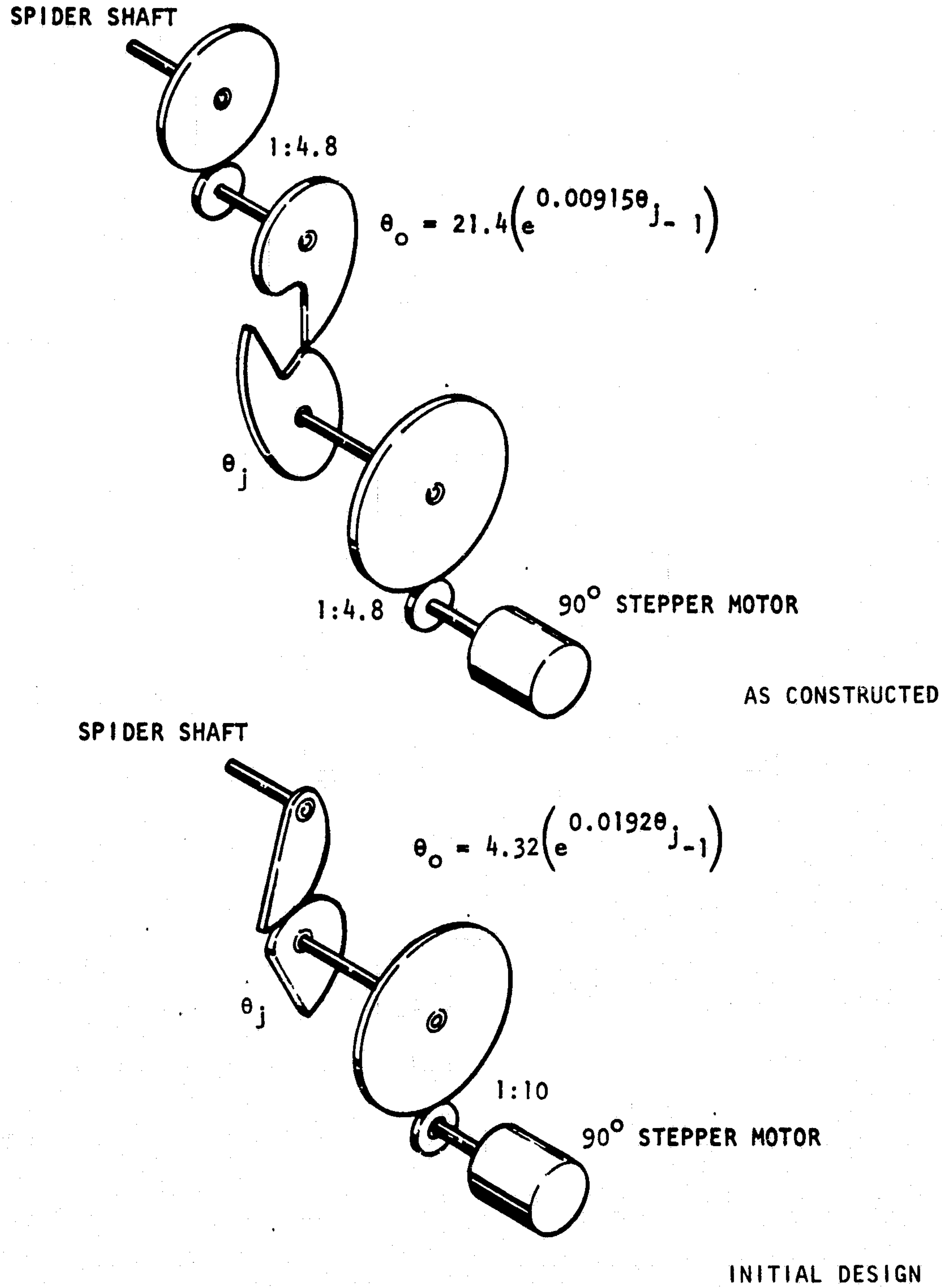


FIGURE 43. Gearing Schematics for Breadboard Shutter Control

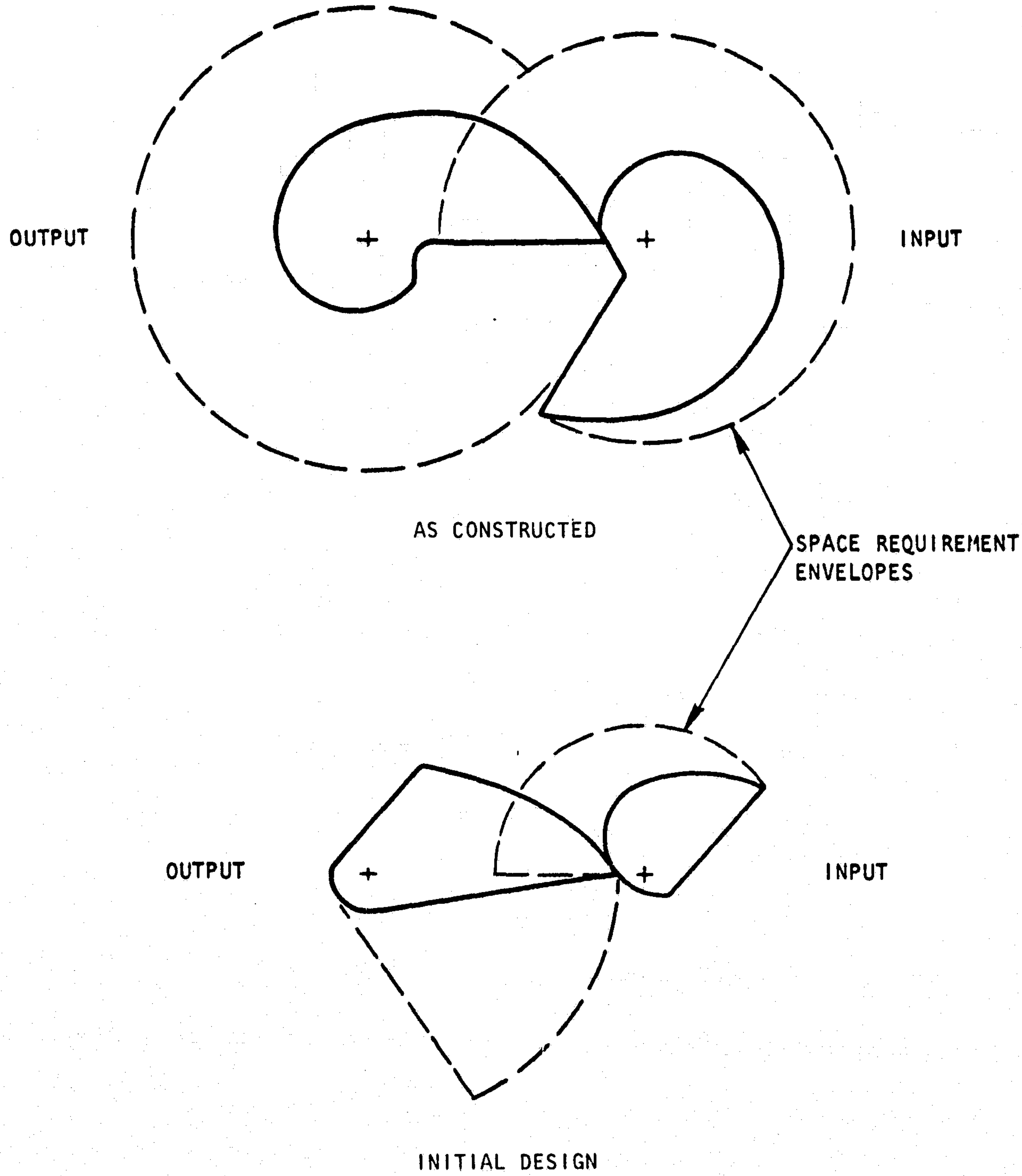
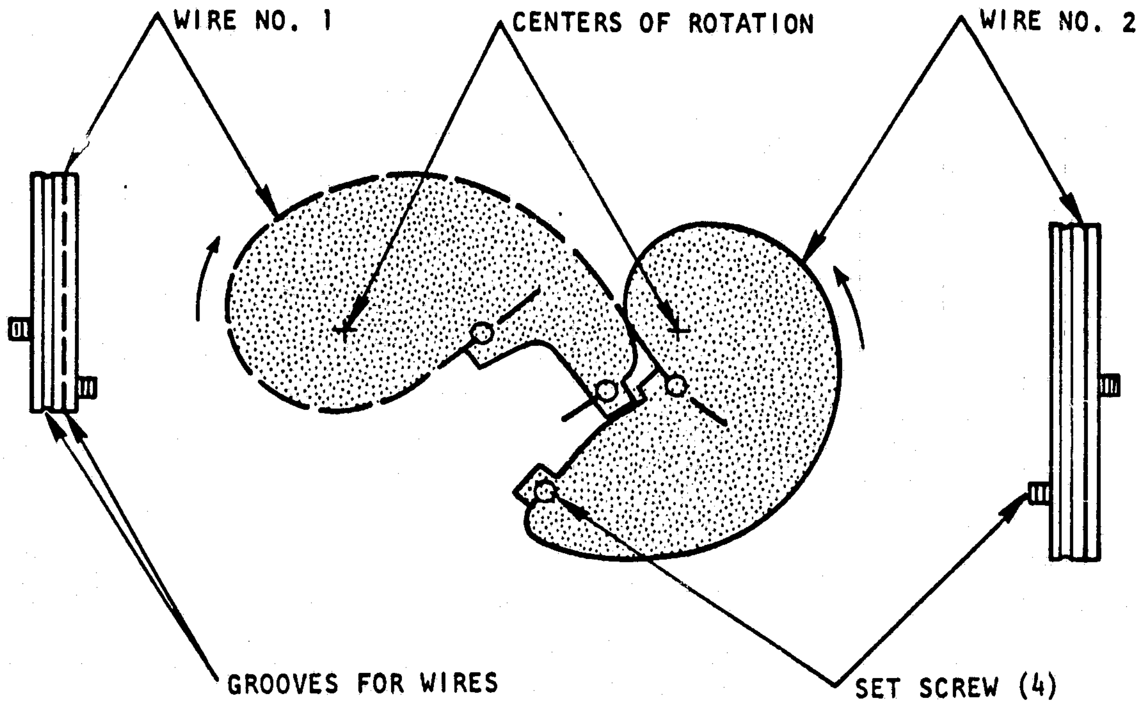


FIGURE 44. Logarithmic Gear Pairs for Breadboard, Comparison of Space Requirements



θ_1 & θ_2 ARE INPUT AND OUTPUT, OR VICE-VERSA

SEE C-SK-347656 AND C-SK-347657 FOR FURTHER DETAILS

FIGURE 45. Mechanical Nonlinear Function Generator

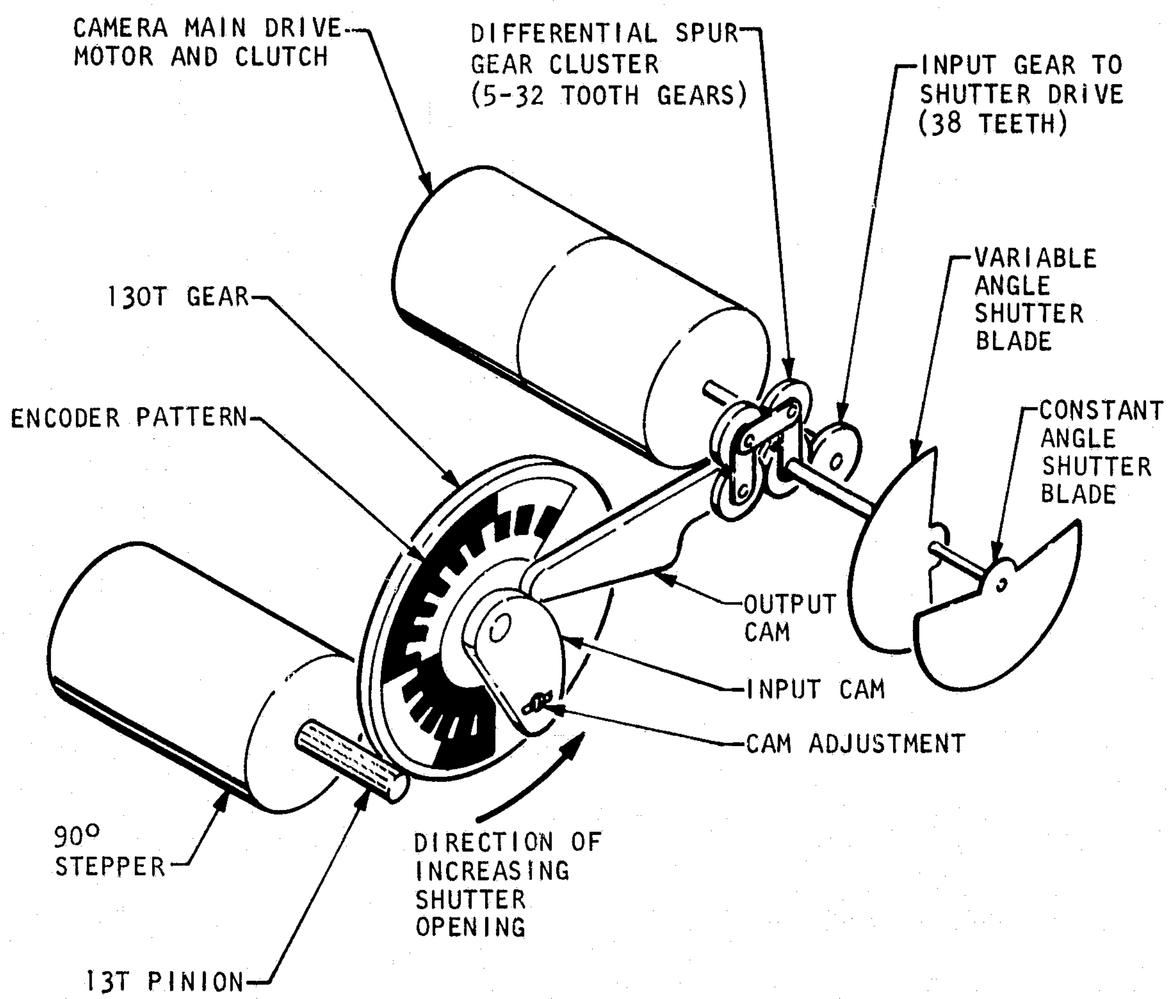


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FIGURE 46. Shutter Control Mechanical Sub-System

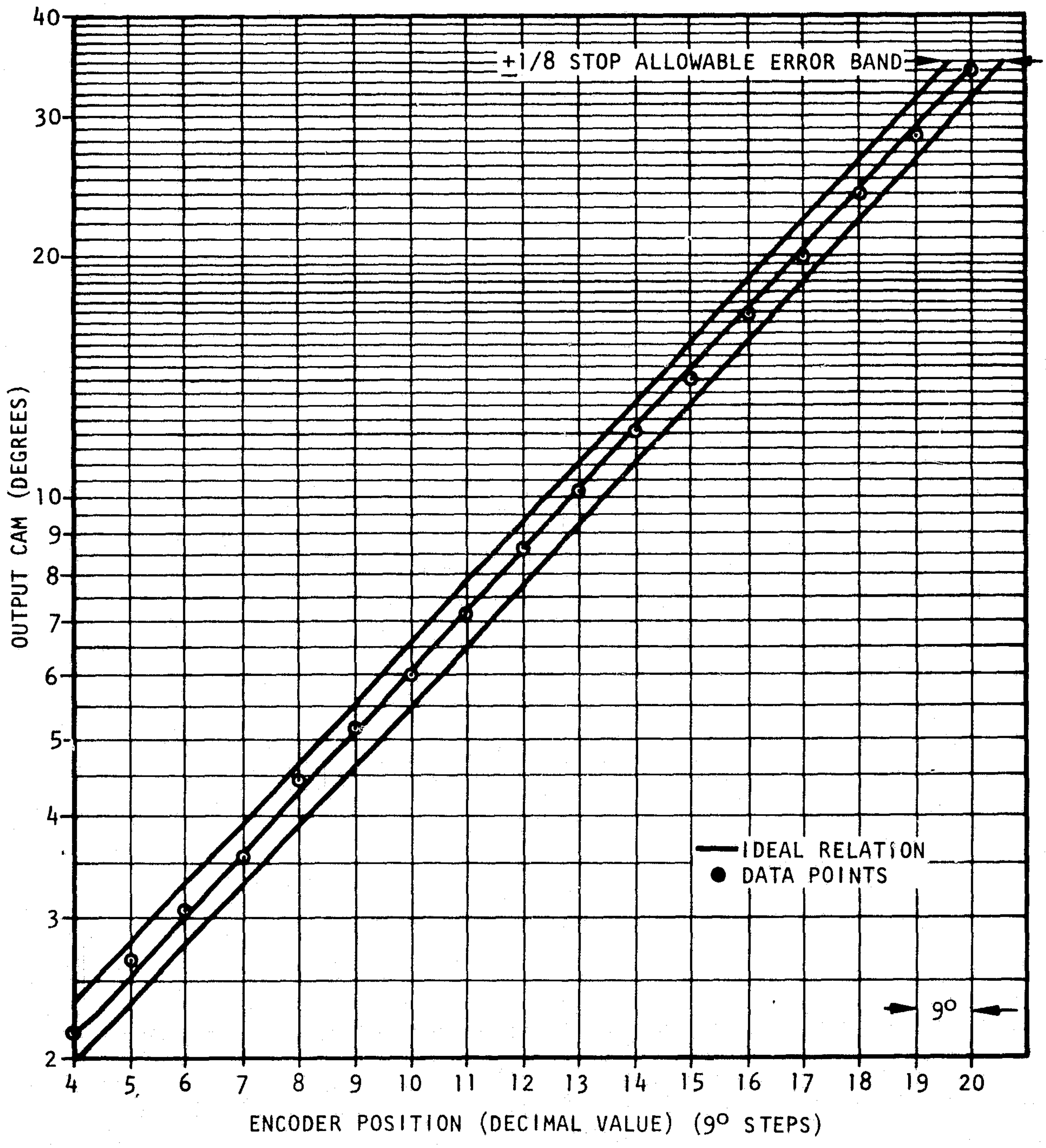

FIGURE 47. Logarithmic Relation Between Shutter Encoder Position and Output Cam

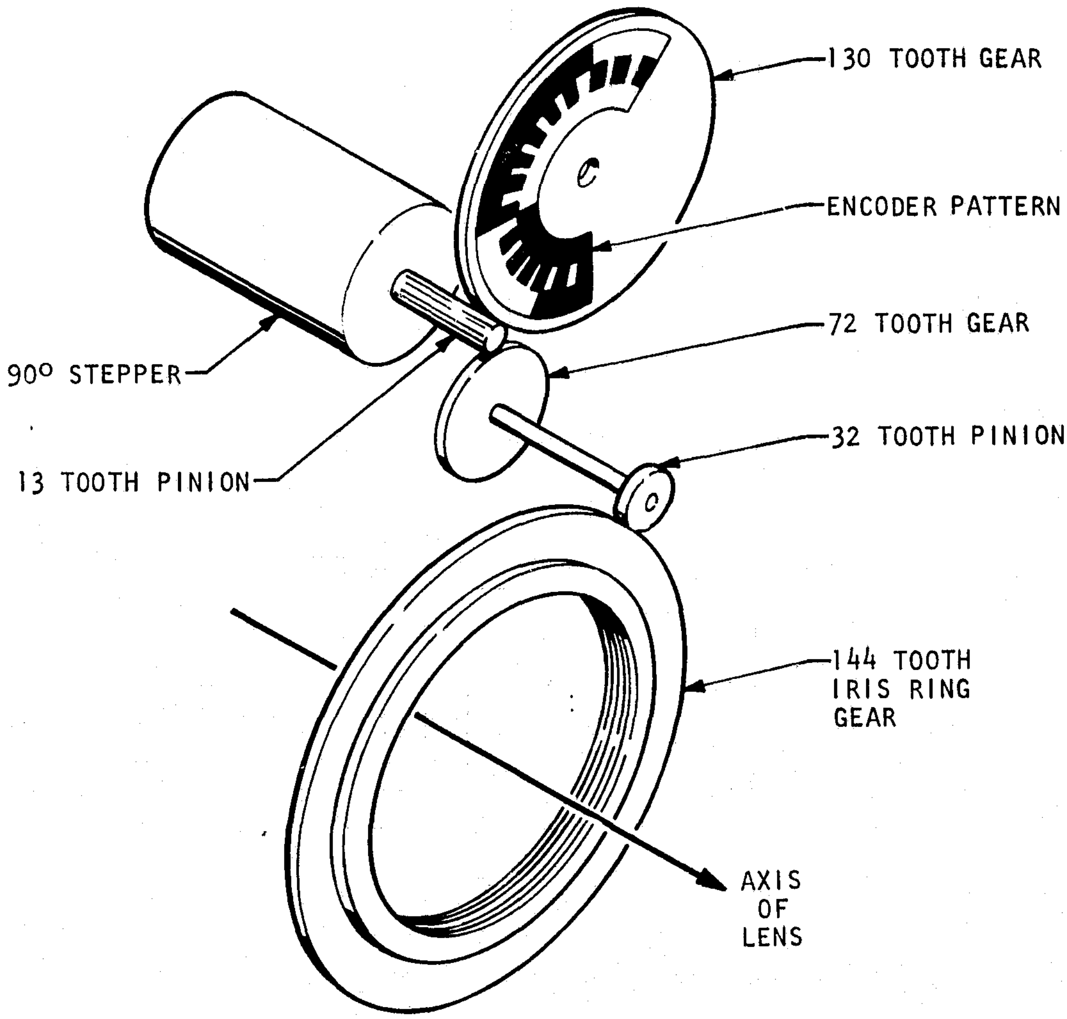

FIGURE 48. Iris Control Mechanical Sub-System

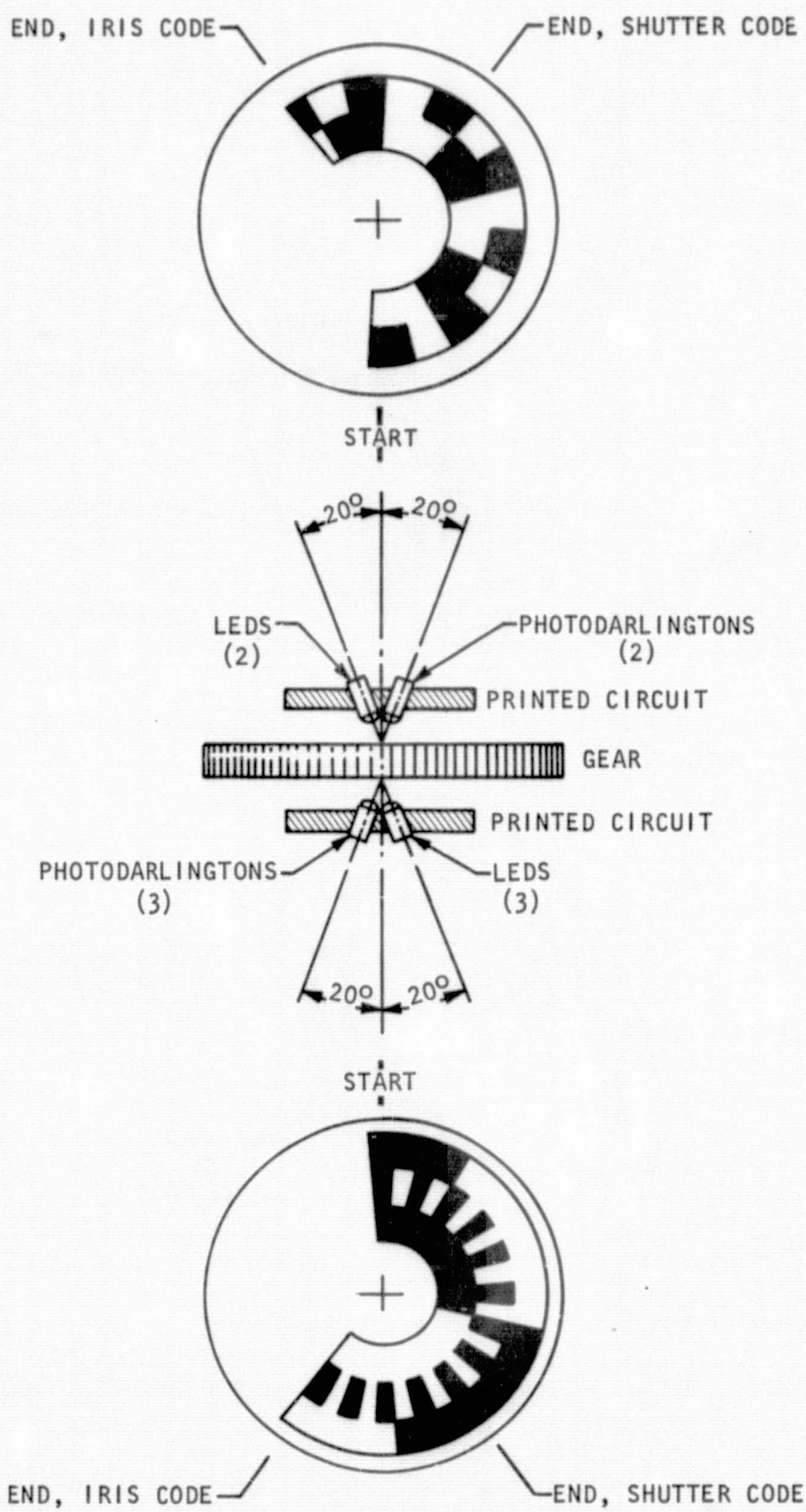

FIGURE 49. Shutter and Iris Position Encoders

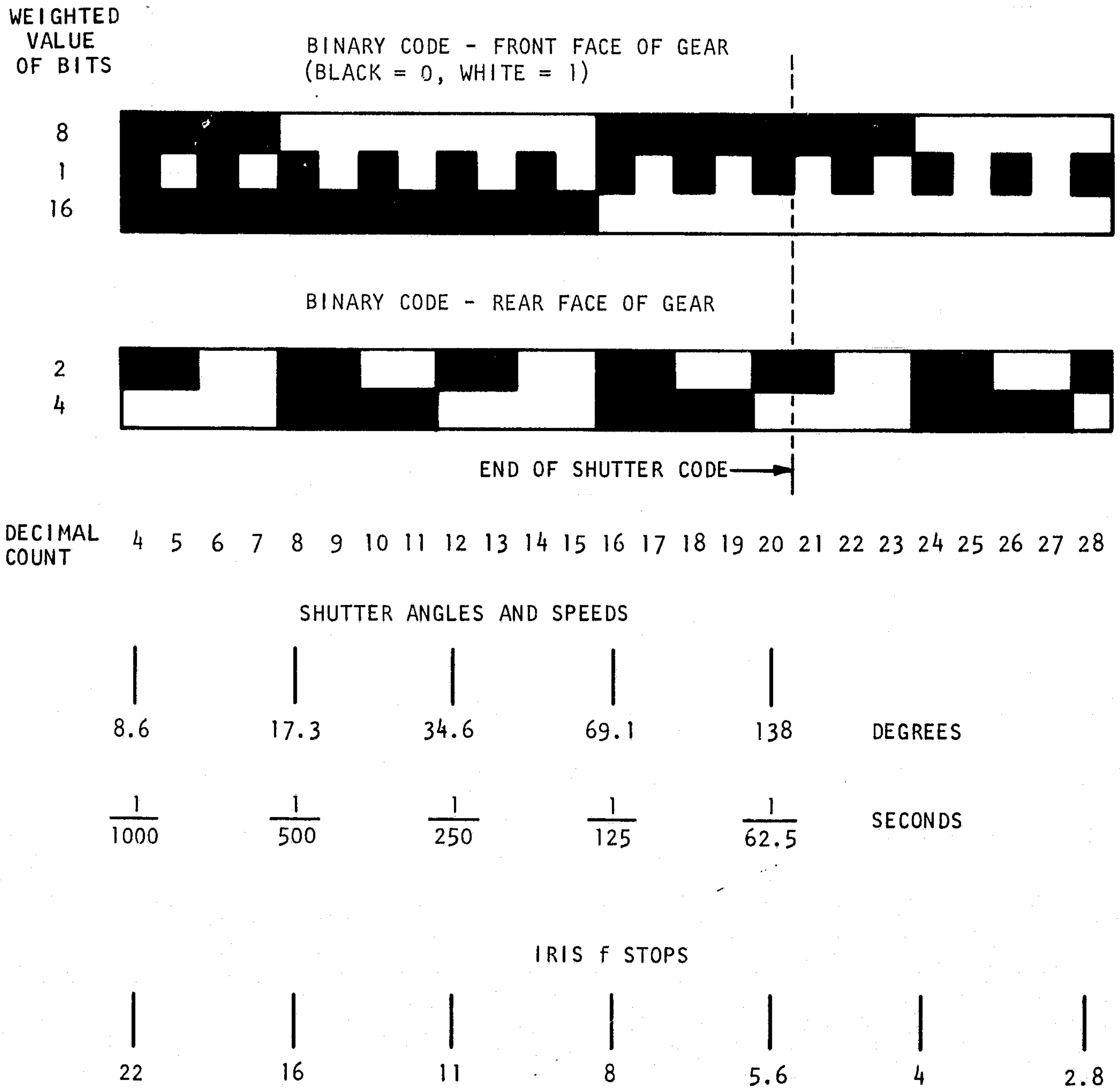

FIGURE 50. Code Versus Position Relationships

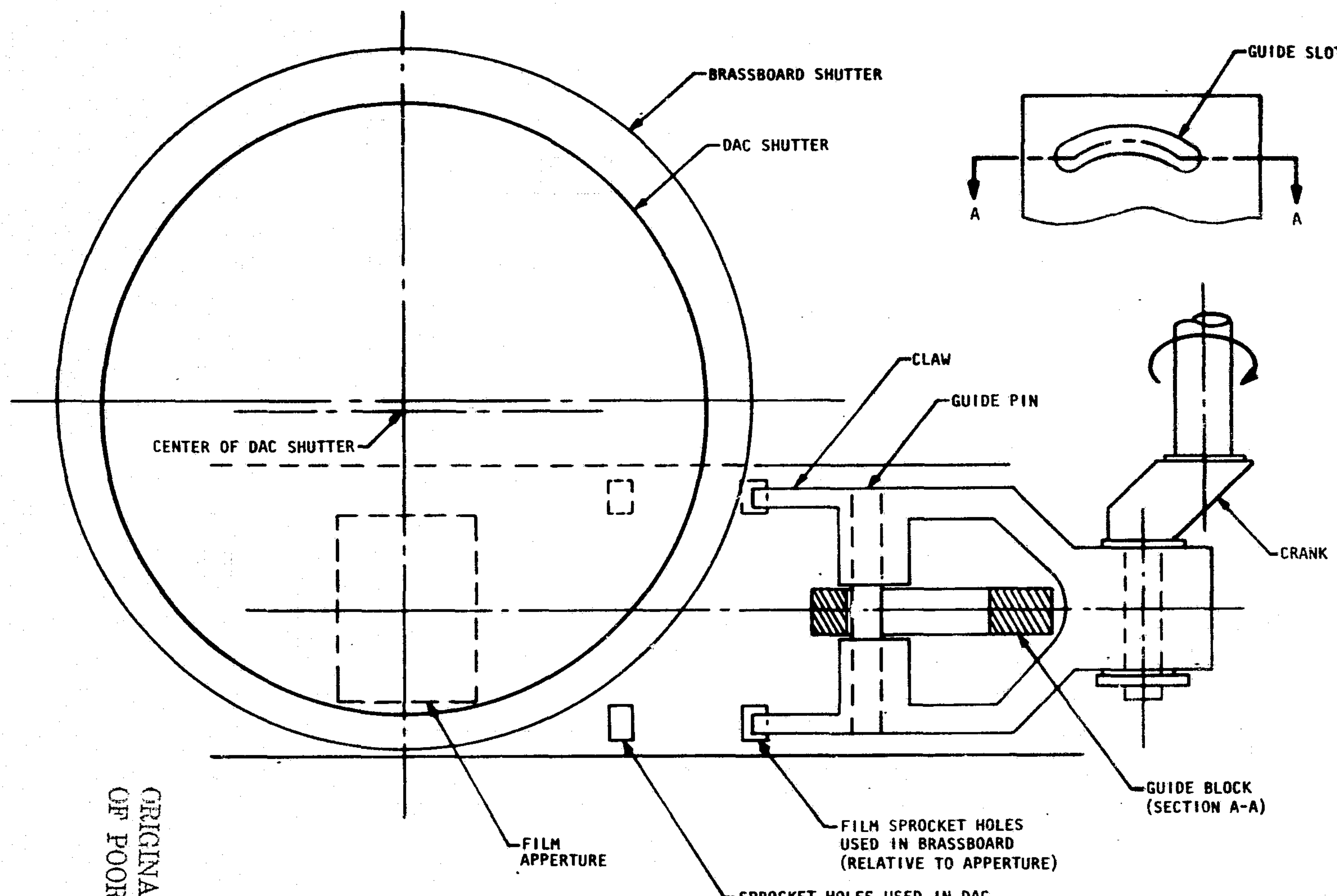

FIGURE 51. Shutter and Film Pull-Down Mechanism,
Showing Differences Between the DAC and the Brassboard Camera

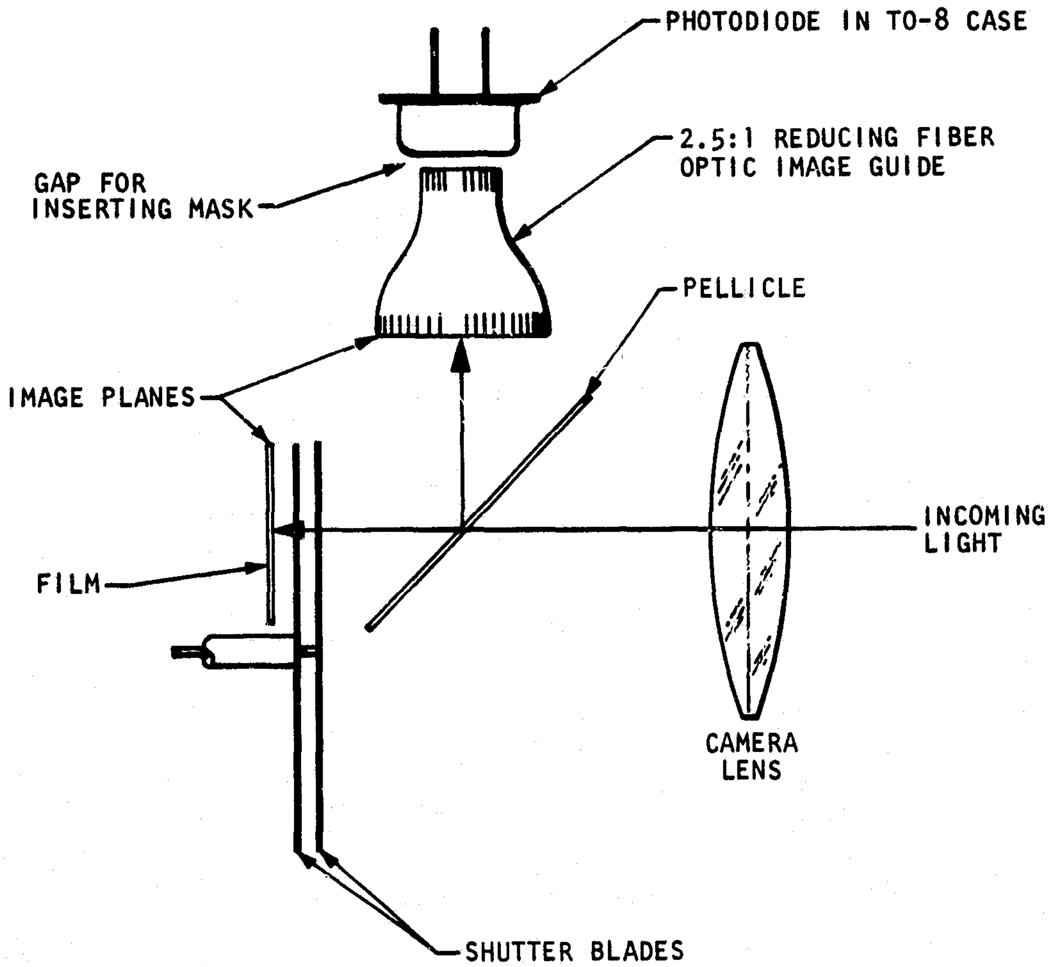

FIGURE 52. Optical Schematic for the Light Sensing System

APPENDIX B

EVALUATION TEST FOR NASA AUTOMATIC EXPOSURE CONTROL

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED
		A	ECO 32664 Corrections Pages 1 thru 5, added Page 6	10 Jan 74	G. M.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANG ±0°30' DEC .XX ± .XXX ±	CONTRACT NO. DWG NO.		PERKIN-ELMER AEROSPACE DIVISION
	DRAWN		
MATERIAL:	CHKD E. McGee	9 Nov 73	EVALUATION TEST FOR NASA AUTOMATIC EXPOSURE CONTROL
	DESIGN	9 Nov 73	
		9 Nov 73	SIZE A · CODE IDENT NO. 26581 · TP 84-0208
	WFN	9 Nov 73	SCALE · Rev A · SHEET 1 of 8

1. PURPOSE

1.1 The purpose of this test is to prove the operational characteristics of the NASA Automatic Exposure Control (AEC) breadboard.

NOTE

All unit responses are subject to an accuracy tolerance of ±1/4 f stop.

2. REQUIREMENTS

2.1 The AEC breadboard must demonstrate the following capabilities:

a. Automatically compensate for a change in scene brightness of 5000 to 39 footlamberts.

b. Compensate for a total film sensitivity range of ASA 40 to 2560.

c. Respond to commands which override the automatic unit functions.

d. Automatically drive the iris aperture to f/2.8 and the shutter angle to 138° when TIME EXPOSURE mode is selected.

e. Operate from a remote command station.

f. Automatically reset the logic when system is turned on.

g. Provide an input to a data block indicating iris position, shutter angle and TOO LIGHT/TOO DARK status.

3. METHOD OF DEMONSTRATION

3.1 SCENE BRIGHTNESS COMPENSATION

3.1.1 Compensation for scene brightness (Ref paragraph 2.1a) will be demonstrated by exposing the lens to a light source whose output is calibrated at fixed settings. The demonstration will be accomplished as follows:

a. Turn unit on, then select ASA 80 film sensitivity.

b. Activate light source, set output level to 5000 footlamberts (fL). Insure that unit lens is aligned with light source output port. The unit will respond to this input by setting the iris to f/8 and the shutter angle to 8.6°.

c. Reduce the light source output level to 2500 fL. The unit will respond by changing the shutter angle to 17.3°.

d. Continue reducing the light source output level, 1 f stop at a time, i.e., 1250, 625 and 312 fL. The unit will respond by changing the shutter angle 1 f stop per light level change until the angle reaches 138° at 312 fL.

e. Reduce the light source output level one stop at a time to 156, 78, and 39 fL. The unit will respond by changing the iris aperture 1 f stop per light level change until the iris aperture reaches f/2.8 at 39 fL. Turn unit and light source off.

3.2 COMPENSATION FOR CHANGE IN FILM SENSITIVITY

3.2.1 Compensation for a change in film sensitivity (Ref paragraph 2.1b) will be demonstrated as follows:

a. Turn unit on, then select ASA 80 film sensitivity.

b. Activate light source, set output level to 156 fL. The unit will respond to this light level by setting the shutter angle to 138° and the iris aperture to f/5.6.

c. Reset unit film sensitivity switch to ASA 2560. The unit will respond to this film change by adjusting the iris aperture to f/8 and the shutter angle to 8.6°.

d. Reset light source output level to 312 fL. The unit will respond to this light level change by adjusting the iris aperture to f/11.

e. Reset unit film sensitivity switch to ASA 40. The unit will respond to this film change by adjusting the shutter angle to 138° and the iris aperture to f/5.6. Turn unit and light source off.

3.3 RESPONSE TO OVERRIDE COMMANDS

3.3.1 Response to override commands (Ref paragraph 2.1c) will be demonstrated as follows:

a. Select ASA 80 film sensitivity.

b. Activate light source, set output level to 1250 fL and turn unit on. The unit will be in AUTOMATIC mode. The unit settings will be iris aperture f/8 and shutter angle 34.5°.

c. Select any shutter and iris manual control setting combinations. The unit will not respond.

d. Select any manual control setting combinations other than f/8, 34.5°, and set unit MODE switch to MANUAL. The unit will adjust to the manual control settings selected and will follow any changes in the manual control settings.

e. Change the light source output to any level and the film sensitivity to any setting. The unit will not respond.

f. Return the light source to 1250 fL and set MODE switch to AUTOMATIC. The unit will adjust to an iris setting of f/8 and a shutter angle of 34.5°, with a film sensitivity selection of ASA 80. Turn unit and light source off.

3.4 TIME EXPOSURE

3.4.1 Time Exposure (Ref paragraph 2.1d) setting is demonstrated by:

a. Turn unit on and activate TIME EXPOSURE switch. The unit will respond by setting the iris aperture to f/2.8 and the shutter angle to 138°. This action is independent and will not be changed by film sensitivity, manual selections or input light level. Turn the unit off.

3.5 REMOTE COMMAND STATION OPERATION

3.5.1 Remote or alternate command station operation (Ref paragraph 2.1e) is demonstrated by repeating the paragraph 3.3 sequence using the remote station simulator. The unit will respond to a TIME EXPOSURE selection at any time, from any station, if the system is on.

3.6 AUTOMATIC RESET

3.6.1 Automatic reset of the unit (Ref paragraph 2.1f) is demonstrated by:

a. Turn the unit on, then select film sensitivity of ASA 80.

b. Activate light source and set output level to 156 fL. The unit will adjust to f/5.6 and 138°.

c. Turn unit off, then on, the unit will reset automatically by first adjusting the iris aperture to f/8 and then return the iris aperture to 5.6.

3.7 DATA BLOCK INPUT

3.7.1 A light display simulating a data block (Ref paragraph 2.1g) is provided on the master control panel. This display indicates the units shutter angle and iris aperture in binary code. Each code count divisible by 4 indicates a full f stop position of the units exposure controls. Each count other than a full f stop indication signifies a control position in one-quarter f stop increments.

BINARY COUNT EQUIVALENCE TO UNIT CONTROL SETTINGS

Count	Control Setting Shutter Angle
4	8.6°
8	17.3°
12	34.5°
16	69.0°
20	138.0°
	Iris Aperture
4	f/22
8	16
12	11
16	8
20	5.6
24	4
28	2.8

The TOO LIGHT and TOO DARK indicators are operated when the unit automatic range limit has been exceeded. The TOO DARK indicator will light when the iris indicator count is 28 and the shutter indicator count is 20 and the input light level is equal to, or less than 20 fL, with a film sensitivity of ASA 40 selected.

The TOO LIGHT indicator will light when the iris indicator count is 4, the shutter indicator count is 4 and the light level input is equal to, or greater than 2500 fL, with a film sensitivity of ASA 2560 selected.

The input to the display/data block is active whenever the unit is on, regardless of operational mode, including TIME EXPOSURE or control location.

4. CHECK-OFF, LIST ACCEPTANCE TEST FOR NASA AUTOMATIC EXPOSURE CONTROL, DATA RECORDING

The technician will indicate the demonstration result at the conclusion of each test.

Reference Paragraph		Correct	Incorrect
3.1	Scene brightness compensation	Yes	
3.2	Compensation for change in film sensitivity	Yes	
3.3	Response to override commands	Yes	
3.4	Time exposure setting	Yes	
3.5	Remote command station operation	Yes	
3.6	Automatic reset demonstration	Yes	
3.7	Data block input demonstration	Yes	

Witnessed by [illegible signature] 23 Jan 74
Perkin-Elmer/Date

NASA/Date

SIZE	CODE IDENT NO.	
A	26581	TP 84-0208
SCALE	Rev A	SHEET 6 of 8

Data Record for Evaluation Test of NASA Automatic Exposure Control.
Reference TP 84-0208

Record Unit Response

Ref Para

3.1 Compensation for Scene Brightness

	Light Input	Iris Setting	Shutter Angle
b.	5000 fL	f8	8.6
c.	2500 fL	f8	17.3
d.	1250 fL	f8	34.5
	625 fL	f8	138
	312 fL	f8	138
e.	156 fL	f5.6	138
	78 fL	f4.0	138
	39 fL	f2.8	138

3.2 Compensation for Change in Film Sensitivity

	ASA	Light Input	Iris Setting	Shutter Angle
b.	80	156 fL	f5.6	138
c.	2560	156 fL	f8	8.6
d.	2560	312 fL	f11	8.6
e.	40	312 fL	f5.6	138

3.3 Response to Override Commands

	ASA	Light Input	Iris Setting	Shutter Angle
b.	80	1250 fL	f8/f8	34.5/34.5
c.	80	1250 fL	f8/f8	34.5/34.5

d. Iris manual command f5.6/f16 Iris response f5.6/f16

Shutter manual command 69/138 Shutter response 69/138

e. Light source changes from 156/156fL to 5000/5000fL

Iris/Shutter response None/None

f.

Light Input	ASA	Iris Setting	Shutter Angle
1250 fL	80	f8/f8	34.5/34.5

3.4 Time Exposure

a. Iris setting f2.8 Shutter Angle 138

Response to automatic None

Response to manual command None

3.5 Remote Command Station

Repeat Paragraph 3.3 from remote station and record data in second segment of line.

3.6 Automatic Reset

	ASA	Light Input	Iris Setting	Shutter Angle
b.	80	156	f5.6	138

c. Iris reset to f/8 f8 and adjusted to f/5.6 f5.6

3.7 Data Block

Data block indication agrees Yes/disagrees___ with command settings.

Too light indicator ON Yes/OFF___ with light input greater than 2500 fL at ASA 2560.

Too dark indicator ON Yes/OFF___ with light input less than 20 fL at ASA 40.

APPENDIX C

EVALUATION AND DEMONSTRATION TEST PROCEDURE
FOR
NASA AUTOMATIC EXPOSURE CONTROL BRASSBOARD

PROJECT DOCUMENT COVER SHEET

EVALUATION AND DEMONSTRATION TEST PROCEDURE FOR NASA AUTOMATIC EXPOSURE CONTROL BRASSBOARD

REPORT NUMBER	DATE
ETP 84-0240	8-21-74

PREPARED BY:	Geo. E. McCleech
APPROVED:	(BRANCH AND/OR SUPPORT OFFICE) Ronald H. [illegible] 9/21/74
APPROVED:	
APPROVED:	

NO. OF PAGES 17

REVISIONS					CHG. LETTER
DATE	PREPARED BY	APPROVALS			
		BRANCH	DIVISION	PROGRAM OFFICE	

REPORT NUMBER

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANG ±0°30′ DEC .XX ± .XXX ±	CONTRACT NO. DWG NO.		PERKIN-ELMER AEROSPACE DIVISION
MATERIAL:	DRAWN Geo E. McAtee	8/21-74	EVALUATION AND DEMONSTRATION TEST PROCEDURE FOR NASA AUTOMATIC EXPOSURE CONTROL BRASSBOARD
	CHKD	8/22-74	
	DESIGN		
			SIZE A · CODE IDENT NO. 26581 · ETP 84-0240
			SCALE · SHEET 1 of 16

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1. PURPOSE

1.1 The purpose of this procedure is to test and demonstrate the capabilities of the NASA Automatic Exposure Control (AEC) brassboard.

NOTE

All unit responses are subject to an accuracy tolerance of $\pm 1/4$ f stop.

2. REQUIREMENTS

2.1 The AEC brassboard must demonstrate the following capabilities:

a. Automatically compensate for a change in scene brightness of 5000 to 39 footlamberts.

b. Compensate for a total film sensitivity range of ASA 40 to 2560.

c. Respond to commands which override the automatic unit functions.

d. Automatically drive the iris aperture to f/2.8 and the shutter angle to 138° when TIME EXPOSURE mode is selected.

e. Operate from a remote command station.

f. Automatically reset the logic when system is turned on.

g. Provide an input to a data block indicating iris position, shutter angle and TOO LIGHT/TOO DARK status.

h. Maintain a constant, $\pm 1/4$ f stop, density/energy level at the film plane over an input range of 39 to 5000 footlamberts (fL).

i. Maintain a constant, $\pm 1/4$ f stop, density/energy level at the film plane over an ASA compensation range of 40 to 2560.

j. Photographically record a gray scale over a light range of 5000 to 39 fL at an accuracy of $\pm 1/4$ f stop.

k. Photographically record typical scenes for visual evaluation.

3. METHOD OF DEMONSTRATION

3.1 SCENE BRIGHTNESS COMPENSATION

3.1.1 Compensation for scene brightness (Ref Paragraph 2.1a) will be demonstrated by exposing the lens to a light source whose output is calibrated at fixed settings. The demonstration will be accomplished as follows:

a. Turn unit on, then select ASA 80 film sensitivity.

b. Activate light source, set output level to 5000 footlamberts (fL). Insure that unit lens is aligned with light source output port. The unit will respond to this input by setting the iris to f/8 and the shutter angle to 8.6°.

c. Reduce the light source output level to 2500 fL. The unit will respond by changing the shutter angle to 17.3°.

d. Continue reducing the light source output level, 1 f stop at a time, i.e., 1250, 625 and 312 fL. The unit will respond by changing the shutter angle 1 f stop per light level change until the angle reaches 138° at 312 fL.

e. Reduce the light source output level one stop at a time to 156, 78, and 39 fL. The unit will respond by changing the iris aperture 1 f stop per light level change until the iris aperture reaches f/2.8 at 39 fL. Turn unit and light source off.

3.2 COMPENSATION FOR CHANGE IN FILM SENSITIVITY

3.2.1 Compensation for a change in film sensitivity (Ref Paragraph 2.1b.) will be demonstrated as follows:

a. Turn unit on, then select ASA 80 film sensitivity.

b. Activate light source, set output level to 156 fL. The unit will respond to this light level by setting the shutter angle to 138° and the iris aperture to f/5.6.

c. Reset unit film sensitivity switch to ASA 2560. The unit will respond to this film change by adjusting the iris aperture to f/8 and the shutter angle to 8.6°.

d. Reset light source output level to 312 fL. The unit will respond to this light level change by adjusting the iris aperture to f/11.

e. Reset unit film sensitivity switch to ASA 40. The unit will respond to this film change by adjusting the shutter angle to 138° and the iris aperture to f/5.6. Turn unit and light source off.

3.3 RESPONSE TO OVERRIDE COMMANDS

3.3.1 Response to override commands (Ref Paragraph 2.1c.) will be demonstrated as follows:

a. Select ASA 80 film sensitivity.

b. Activate light source, set output level to 1250 fL and turn unit on. The unit will be in AUTOMATIC mode. The unit settings will be iris aperture f/8 and shutter angle 34.5°.

c. Select any shutter and iris manual control setting combinations. The unit will not respond.

d. Select any manual control setting combinations other than f/8, 34.5°, and set unit MODE switch to MANUAL. The unit will adjust to the manual control settings selected and will follow any changes in the manual control settings.

e. Change the light source output to any level and the film sensitivity to any setting. The unit will not respond.

f. Return the light source to 1250 fL and set MODE switch to AUTOMATIC. The unit will adjust to an iris setting of f/8 and a shutter angle of 34.5°, with a film sensitivity selection of ASA 80. Turn unit and light source off.

3.4 TIME EXPOSURE

3.4.1 Time Exposure (Ref Paragraph 2.1d.) setting is demonstrated by: Turn unit on and activate TIME EXPOSURE switch. The unit will respond by setting the iris aperture to f/2.8 and the shutter angle to 138°. This action is independent and will not be changed by film sensitivity, manual selections or input light level. Turn the unit off.

3.5 REMOTE COMMAND STATION OPERATION

3.5.1 Remote or alternate command station operation (Ref Paragraph 2.1e.) is demonstrated by repeating the override commands as indicated in Paragraph 3.3b. thru f. using the remote station simulator. The unit will also respond to a Time Exposure selection in accordance with Paragraph 3.4 at any time from this station if the system is in the on position.

3.6 AUTOMATIC RESET

3.6.1 Automatic reset of the unit (Ref Paragraph 2.1f.) is demonstrated by:

a. Turn the unit on, then select film sensitivity of ASA 80.

b. Activate the light source and set output level to 156 fL. The unit will adjust to f/5.6 and 138°.

c. Turn unit off, then on, the unit will reset automatically by first adjusting the iris aperture to f/8 and then return the iris aperture to 5.6.

3.7 DATA BLOCK INPUT

3.7.1 A light display simulating a data block (Ref Paragraph 2.1g.) is provided on the master control panel. This display indicates the units shutter and iris aperture in binary code. Each code count divisible by 4 indicates a full f stop position of the units exposure controls. Each count other than a full f stop indication signifies a control position in one-quarter f stop increments.

BINARY COUNT EQUIVALENCE TO UNIT CONTROL SETTINGS

COUNT	CONTROL SETTING
	SHUTTER ANGLE
4	8.6°
8	17.3°
12	34.5°
16	69.0°
20	138.0°
	IRIS APERTURE
4	f/22
8	16
12	11
16	8
20	5.6
24	4
28	2.8

The TOO LIGHT and TOO DARK indicators are operated when the unit automatic range limit has been exceeded. The TOO DARK indicator will light when the iris indicator count is 28 and the shutter indicator count is 20 and the input light level is equal to, or less than 39 fL, with a film sensitivity of ASA 40 selected.

The TOO LIGHT indicator will light when the iris indicator count is 4, the shutter indicator count is 4 and the light level input is equal to, or greater than 2400 fL, with a film sensitivity of ASA 2560 selected.

The input to the display/data block is active whenever the unit is on, regardless of operational mode, including TIME EXPOSURE or control location.

3.8 ENERGY LEVEL MAINTENANCE

3.8.1 The energy level maintenance (Ref Paragraph 2.1h. and i.) will be tested by directing the brassboard camera at a light source whose output is calibrated at fixed settings. The energy level shall be measured by a sensor positioned at the film plane of the camera. The camera shutter shall be positioned so that the film aperture is open during this sequence.

NOTE

The light level settings in the following test will be the calibrated position of the source plus the threshold required by the system deadband. The shutter angles will be determined by reading the data block.

This test will be conducted as follows:

a. Mount the camera so that the lens field of view will be filled by the light source output port.

b. Position the test sensor at the camera aperture.

c. Disconnect the power to the camera film drive motor, set the ASA compensation to ASA 80 and turn the system on.

d. Set the light source output to 5000 fL. The system will adjust to a lens iris setting of f/8, data block count of 16 and a shutter angle of 8.6°, data block count of 4. The sensor output will be -34.6 millivolts.

e. Reduce the source output ot 2500 fL. The system will keep the iris at f/8 and adjust the shutter angle to 17.3°, data block count of 8. The sensor output will be -17.3 millivolts.

f. Reduce the source output to 1250 fL. The system will keep the iris at f/8 and adjust the shutter angle to 34.5°, data block count of 12. The sensor output will be 0 millivolts.

g. Reduce the source output to 625 fL. The system will keep the iris at f/8, and adjust the shutter angle to 69°, data block count of 16. The sensor output will be +17.3 millivolts.

h. Reduce the source output to 312 fL. The system will keep the iris at f/8 and adjust the shutter angle to 138°, data block count of 20. The sensor output will be +34.6 millivolts.

i. Reduce the source output to 156 fL. The system will adjust the iris to f/5.6, data block count of 20 and the shutter angle will remain at 138°. The sensor output will remain at +34.6 millivolts.

j. Reduce the source output to 78 fL. The system will adjust the iris to f/4, data block count of 24 and the shutter angle will remain at 138°. The sensor output will remain at +34.6 millivolts.

k. Reduce the source output to 39 fL. The system will adjust the iris to f/2.8, data block count of 28, and the shutter angle will remain at 138°. The sensor output will remain at +34.6 millivolts.

3.9 PHOTOGRAPHIC TEST, GRAY SCALE RESPONSE

3.9.1 The gray scale response (Ref Paragraph 2.1j.) will be tested using type 3400 film in the camera film magazine. The operating procedure for this test is as follows:

NOTE

Limit the operation of the camera to produce approximately 1 foot, 40 frames of exposed film for each condition specified.

Separate each condition record by covering the camera lens while operating the camera for approximately 10 frames.

a. Mount the camera so that the lens field of view will be filled by the light source output port. Reconnect the camera main drive motor power.

b. Attach the film magazine to the camera.

c. Set the camera frame rate control to 24 fps (cine) and the ASA compensation to 80.

d. Turn the light source on and set the output level to 5000, 2500, 1250, 625, 312, 156, 78 and 39 fL. Photograph each output level, turning the camera off wille setting the source.

e. Reset the camera frame rate control to 2 fps (pulse) and turn the camera on and repeat Paragraph 3.9.1d.

3.9.2 At the conclusion of this test process the film as follows:

a. Process the film in total darkness.

b. Use Kodak type D19 developer at 68 to 70° for 8 minutes.

c. Rinse and fix the emulsion, thoroughly dry the film before proceeding with the evaluation.

3.9.3 EVALUATION CRITERIA

The film density is to be measured by back lighting the film and measuring the resultant density with a photo densitometer as follows:

a. Position the film on an evenly lit, diffused surface light source.

b. Position the sensor of the densitometer so that 1 frame of the first test sequence is viewed in the center of the frame.

c. Read each test seuqence, frame by frame, at least 5 frames per test and record the resultant density. The density variation should not exceed 10% frame to frame within a test sequence or 25% from one sequence to another.

3.10 PHOTOGRAPHIC TEST, TYPICAL SCENE

3.10.1 The typical scene photographic test is intended to produce footage which is representative of the actual material using natural lighting and subjects rather than laboratory props. This footage is to be visually examined for correct exposure and balance. The test will be accomplished as follows:

a. This test will be run once using black and white positive film type 3400 for "quick look" purposes and once with color positive film type Ektachrome - MS, both to be commercially processed.

b. Set the camera frame rate to 24 fps cine mode and the ASA compensation to 80 for the black and white sequence. The camera system should be in "automatic" mode.

c. Photograph scenery and subjects available which represent high and low contrast, direct light and shadow in as many combinations as are available.

d. Set the camera frame rate to 2 fps pulse.

e. Photograph scenery and subjects available which represent high and low contrast, direct light and shadow in as many combinations as are available.

f. Set the AEC to MANUAL mode.

g. Measure the light levels of the scenes photographed in Paragraph 3.10.1c. with a standard light meter.

h. Set the lens iris and shutter angle in accordance with the measurements taken in Paragraph 4.10.1g.

i. Photograph the same scenery taken in Paragraph 4.10.1c.

j. Down load the film magazine and reload with color film type Ektachrome - MS. Forward the black and white film for commercial processing to a positive print.

k. Set the camera to 24 fps, cine mode and the ASA compensation to 80. The camera system should be in AUTOMATIC mode.

ℓ. Photograph scenery and subjects available which represent high and low contrast, direct light and shadow in as many combinations as are available.

m. Set the camera frame rate to 2 fps.

n. Photograph scenery and subjects available which represent high and low contrast, direct light and shadow in as many combinations as are available.

o. Set the AEC to MANUAL mode.

p. Measure the light levels of the scenes photographed in Paragraph 4.10.1ℓ. with a standard light meter.

q. Set the lens iris and shutter angle in accordance with the measurements taken in Paragraph 4.10.1p.

r. Photograph the same scenery taken in Paragraph 4.10.1ℓ.

s. Down load the film magazine and forward the film to NASA JSC for processing.

SPECTRA LUMINANCE STANDARD

CODE #2397 #1957

Calibrated on March 11, 1974

fL	MICROMETER SETTINGS			
	5500 K W/OB8 W/ND1.0 103.3 Volts	5500 K W/OB8 101.2 Volts	2870 K No Filter 90.6 Volts	3130 K No Filter 114.1 Volts
39.0	0.975			
46.4	0.994			
55.2	1.018			
65.6	1.049			
78.	1.086	0.857		
92.8	1.137	0.867		
110.4	1.208	0.877		
131	1.315	0.887		
156	1.507	0.899		
185.6		0.910		
220.8		0.922		
262		0.935		
312	0.950	0.856		
371.2		0.966	0.866	
441.6		0.985	0.877	
524		1.007	0.888	
625		1.035	0.899	0.858
742.4		1.069	0.911	0.868
883		1.114	0.924	0.878
1048		1.175	0.936	0.888
1250		1.269	0.952	0.900
1485		1.415	0.968	0.911
1767		1.772	0.988	0.924
2096			1.011	0.936
2500			1.040	0.952
2970			1.076	0.967
3534			1.123	0.986
4192			1.188	1.008
5000			1.284	1.037
5940			1.442	1.074
7068			1.886	1.120
8394				1.182
10000				1.279

Data Record for Evaluation Test of NASA Automatic Exposure Control, Brass Board.

Record Unit Response

Ref Para

3.1 Compensation for Scene Brightness

	Light Input	Iris Setting	Shutter Angle
b.	5000 fL	16 (f8)	4 (8.6°)
c.	2500 fL	16 (f8)	8 (17.3°)
d.	1250 fL	16 (f8)	12 (34.5°)
	625 fL	16 (f8)	16 (69°)
	312 fL	16 (f8)	20 (138°)
e.	156 fL	20 (f5.6)	20 (138°)
	78 fL	25 (f4 + 1/4)	20 (138°)
	39 fL	28 (f2.8)	20 (138°)

3.2 Compensation for Change in Film Sensitivity

	ASA	Light Input	Iris Setting	Shutter Angle
b.	80	156 fL	20 (f5.6)	20 (138°)
c.	2560	156 fL	16 (f8)	4 (8.6°)
d.	2560	312 fL	12 (f11)	4 (8.6°)
e.	40	312 fL	20 (f5.6)	20 (138°)

3.3 Response to Override Commands

	ASA	Light Input	Iris Setting	Shutter Angle
b.	80	1250 fL	8/ 8	34.5°/34.5°
c.	80	1250 fL	8/ 8	34.5°/34.5°

d. Iris manual command f11 Iris response f11

Shutter manual command 69° Shutter response 69°

e. Light source changes from 1250 fL to 312 fL

Iris/Shutter response No / No

f.

ASA	Light Input	Iris Setting	Shutter Angle
80	1250 fL	f8 / f8	34.5° /34.5°

3.4 Time Exposure

a. Iris setting f2.8 Shutter Angle 138°

Response to ASA Command No

Response to manual command No

3.5 Remote Command Station

Repeat Paragraph 3.3 from remote station and record data in second segment of line.

3.6 Automatic Reset

	ASA	Light Input	Iris Setting	Shutter Angle
b.	80	156	f5.6	138°

c. Iris reset to f/8 Yes and adjusted to f/5.6 f5.6

3.7 Data Block

Data block indication agrees Yes /disagrees ________ with command settings.

Too light indicator ON Yes /OFF ________ with light input greater than 2500 fL at ASA 2560.

Too dark indicator ON Yes /OFF ________ with light input less than 39 fL at ASA 40.

3.8 Energy Level Maintenance

d. 5000 fL

Verify iris is at f/8 Yes data block count of 16 Yes .

Verify shutter angle is 8.6° by data block count of 4 Yes .

Verify sensor reading of -34.6 mV is ________ mV.
Actual reading = -32.0 mV

e. 2500 fL

Verify iris is at f/8 Yes data block count of 16 Yes .

Verify shutter angle is 7.3° by data block count of 8 Yes .

Verify sensor reading of -17.3 mV is ________ mV.
Actual reading = -17.3 mV

f. 1250 fL

Verify iris is at f/8 Yes data block count of 16 Yes .

Verify shutter angle is 34.5° by data block count of 12 Yes .

Verify sensor reading of 0 is ________.
Actual reading = -0.0002

g. 625 fL

Verify iris is at f/8 Yes data block count of 16 Yes .

Verify shutter angle is 69° by data block count of 16 Yes .

Verify sensor reading of +17.3 mV is ________ mV.
Actual reading = +18.3 mV

h. 312 fL

Verify iris is at f/8 Yes data block count of 16 Yes .

Verify shutter angle is 138° by data block count of 20 Yes .

Verify sensor reading of +34.6 mV is ________ mV.
Actual reading = +41.4 mV

i. 156 fL

Verify iris is at f/5.6 Yes data block count of 20 Yes .

Verify shutter angle is 138° by data block count of 20 Yes .

Verify sensor reading of +34.6 mV is ________ mV.
Actual reading = +40.1 mV

j. 78 fL

(actually f/4 + 1/4)
Verify iris is at f/4 ________ data block count of 24 actually 25

Verify shutter angle is 138° by data block co-nt of 20 Yes .

Verify sensor reading of +34.6 mV is ________ mV.
Actual reading = +38.6 mV

k. 39 fL

Verify iris is at f/2.8 Yes data block count of 28 Yes.

Verify shutter angle is 138° by data block count of 20 Yes.

Verify sensor reading of +34.6 mV is ______ mV.
Actual reading = +50.5 mV

3.9 Photographic Test

3.9.3 Evaluation Criteria

c.

	Frame No.				
24 fps at:	1	2	3	4	5
5000 fL density	2	2	2.2	2.5	2.5
2500 fL density	2	2.1	2.1	2.1	2
1250 fL density	2	2	2	2	2
625 fL density	2.2	2.2	2.2	2.1	2.3
312 fL density	2.2	2.2	2.3	2.3	2.3
156 fL density	2.4	2.4	2.4	2.4	2.4
78 fL density	2	2	2	2	2
39 fL density	1.3	1.3	1.2	1.2	1.3
2 fps at:					
5000 fL density	1.9	1.8	1.9	1.8	1.8
2500 fL density	2.1	2	2.1	1.9	2
1250 fL density	2.1	2.2	2.2	2.2	2.2
625 fL density	2.2	2.2	2.2	2.2	2.3
312 fL density	2.6	2.5	2.6	2.5	2.6
156 fL density	2.6	2.6	2.6	2.6	2.6
78 fL density	2.3	2.3	2.3	2.3	2.3
39 fL density	1.4	1.4	1.4	1.3	1.4

Density should not exceed 10% frame to frame within a sequence or 25% from one sequence to another.

3.10 Photographic Test, Typical Scene

Visual examination

Compare and evaluate the footage produced by Paragraph 3.10.1c., d., i., ℓ., m and r for correct exposure and balance. Record comments.

Name	Title/Organization	Comment
Geo. E. McCtee Jr.	Program Mgr., P-E	Good film density (exposure) under all scene conditions.

Data Taken By [illegible signature] Date 14 March 85

Witnessed By Geo. E. McCtee Jr. Date 14 Mar. 1985

Additional Comments:

Initially measured 0.005 inch variation in frame line (frame to frame). Also noted tendency for film motion during exposure (appeared as an apparent double exposure). Corrective actions included check of shutter/claw timing, altered pressure plate pressure, adjusting film advance mechanism, and improved magazine clamp. Frame line variation reduced to 0.002 inch and "double exposure" effect eliminated.