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May 13, 1965

PROGRESS REPORT ON THE FEASIBILITY OF AN AUTOMATIC FOCUSING SYSTEM

I. Summary of Work Performed.

A. A re-evaluation of the theoretical principles underlying the autofocus sensor showed that a modification of the original scheme was required. This, however, does not adversely affect the overall program.

B. Solid state focus sensor panels were prepared and tested. They were found suitable for proving the operating principles.

C. An optical unit was designed, fabricated, aligned and tested. It proved satisfactory for the project except for its light gathering power.

II. Analysis of Work Performed.

A. Theoretical.

A re-evaluation of part of the theoretical principles of a solid state autofocusing sensor is presented to show that a modification of the original auto correlation sensor is necessary to produce a suitable autofocusing sensor. However, the modification of the sensor does not significantly change the total autofocusing system.

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 25X1

It has been established that the total current I flowing across the solid state correlator is given by

$$I = K \int \frac{L(x,y)\,L(x+\tau,y+S)}{L(x,y)+L(x+\tau,y+S)}\,dx\,dy \qquad (1)$$

where L is the intensity distribution on the surface of the correlator and τ and S represent the displacement of the image on the opposite face of the correlator. The valve of the integral is determined largely by the product appearing in the numerator of the integral. Thus, it may be appreciated that the total current is approximately proportional to the correlation function of the two displaced images given by

$$R_f(\tau,S) = \int_{-\infty}^{+\infty} L(x,y)\,L(x+\tau,y+S)\,dx\,dy \qquad (2)$$

The following theorem was proved in the appendix of the proposal: "The peak value of the autocorrelation function for a defocused image is less than the autocorrelation for the corresponding sharp image." With the help of this theorem it is now possible to derive an optimum focus condition. The theorem states that

$$R_F(0) \geq R_g(0) \qquad (3)$$

where $R_g(0)$ is the autocorrelation of the defocused image and $R_f(0)$ that of the sharp image. Another way of stating this is that in order to optimize the focus we need to make $R_g(0)$ as large as possible.

$$R_g(0) = \int [L(x,y)]^2 \, dx \, dy \qquad (4)$$

where $L(x,y)$ is the illuminance function given by $f(x,y) * h(\sigma_1, \sigma_2)$. $f(x,y)$ is the illuminance function of the sharp image and $* \, h(\sigma_1, \sigma_2)$ is the convolution with the spread function due to defocusing. $L(x,y)$ will be positive definite and it may be readily shown that a condition for best focus can be made more general; namely that the integral

$$\int L^m(x,y) \, dx \, dy \qquad (5)$$

be a maximum for $m > 1$ or a minimum for $m < 1$.

Under the conditions for correlation given by equation 2, the current given by equation 1 will be a maximum when the two images are in register. However, under the conditions of autofocusing given by equation 4, equation 1 reduces to

$$I = K \int \frac{L(x,y)}{2} \, dx \, dy \qquad (6)$$

which is independent of the correlation function and just equal to half the current through either side of the (ssc) alone.

If the current density $j(x,y)$ is given by

$$j(x,y) = K L^{m}(x,y) \qquad (7)$$

then the equation 6 can be written

$$I = \frac{K}{2} \int L^{m}(x,y)\, dx\, dy \qquad (8)$$

which means that I satisfies the conditions of equation 5 for $m \neq 1$. Thus, any non-linear photodetector can be utilized to implement the criterion for autofocusing. It need not be a two layer device since for a single image only the 1/2 in equation 8 is lost.

B. Solid State Focus Sensor Panels.

After experimenting with a number of matrixes, we have produced a photoconductor system with a large light to dark current ratio having an η as defined by equation 7, of less than 0.5. The system consists of a commercial powder Cd(S,Se) Sylvania PC-102 homogenized in a RV-615 silastic binder and drawn on a glass plate having a conductive NESA coating. The mixture is drawn with a doctor knife device to give a plastic film 4 mils thick having a dense uniform distribution of photoconductor grains. The plastic film is sprayed with a silver

 25X1

loaded conducting paint and cured at 150°C for 30 minutes. Figure 1 shows the current through this system as a function of displacement from focus of the image of a medium contrast 35 mm slide. The output of two such sensors can be combined by a differential amplifier to operate an appropriate servo focusing device. Sublinear photoconductors such as the one above offer good sensitivity, but a sharper minimum than is possible with m = .5 would be desirable. Materials exist with m as large as 3. m greater than 1 gives a maximum, and when m is greater than 2, the system has an effective gain greater than unity which would give sharper focus. There is good indication that sintered layers of CdS with high copper content will exhibit superlinear photoconductivity between 2 and 3.

C. Optical System.

To evaluate solid state sensors for both autocorrelation and autofocusing applications, we have designed and built an optical test rig. This optical system is shown in Figures 2 and 3. The system takes a single beam of light and produces two images. These images, both real, are mirror images of each other. Micrometer adjustments are provided both with respect to focus and register.

III. Summary of Work to be Performed in Next Interval.

A. Preparation of more sensor panels with higher nonlinearities.

B. Evaluation of Autofocus performance with these sensors.

C. Projection of system capability with improved panels.

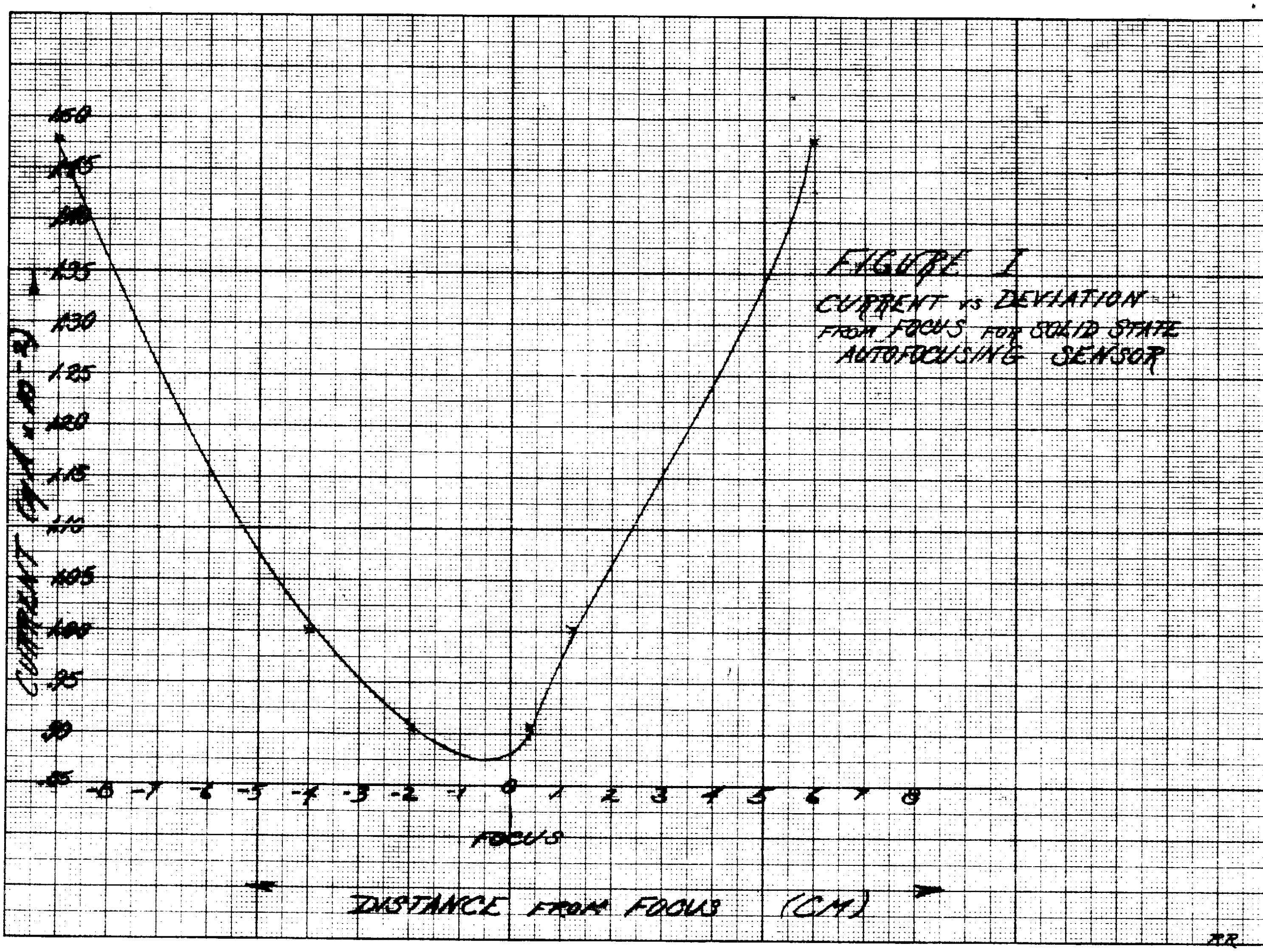
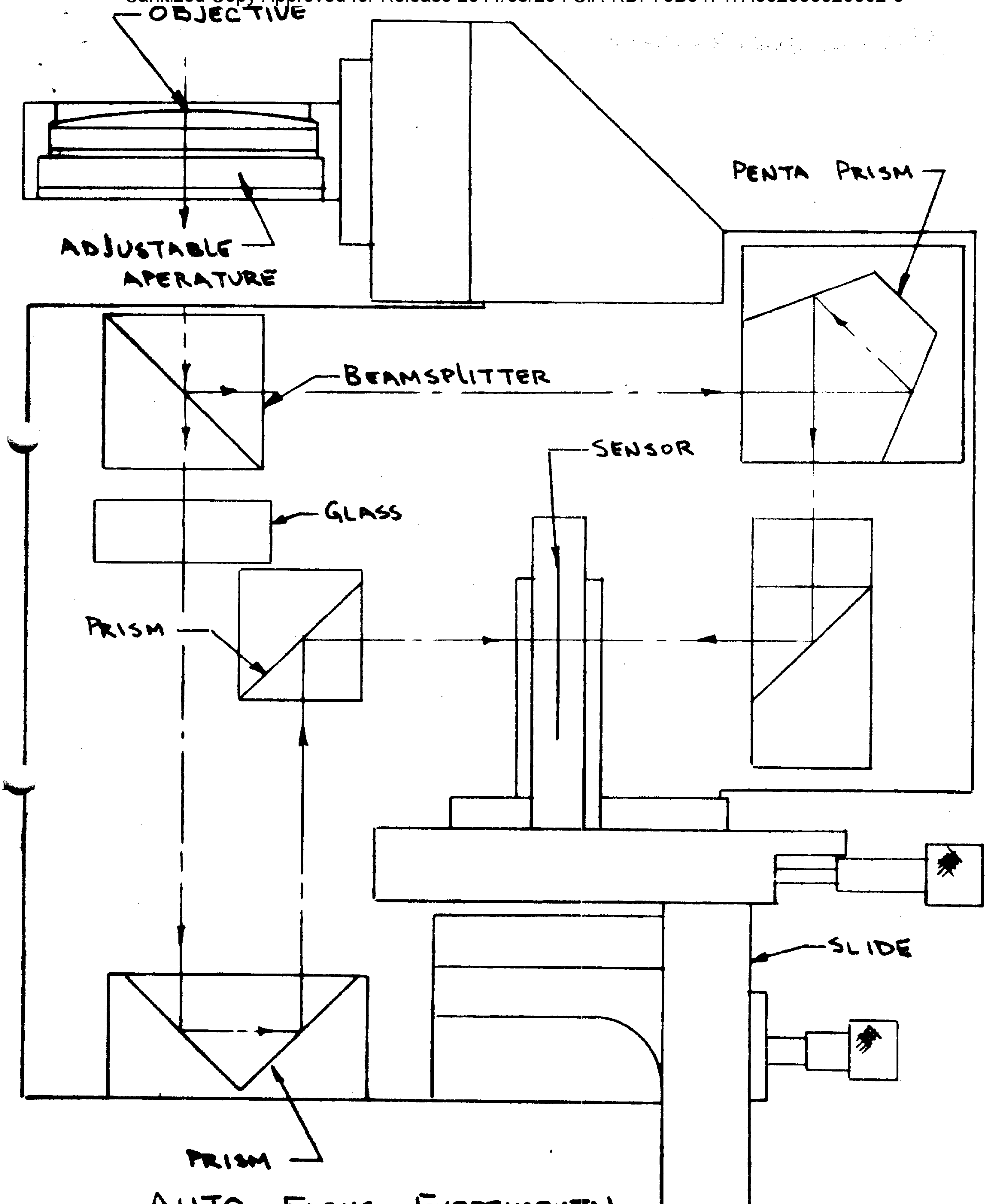


FIGURE I
CURRENT vs DEVIATION FROM FOCUS FOR SOLID STATE AUTOFOCUSING SENSOR
CURRENT (A x 10^-?)
150
145
140
135
130
125
120
115
110
105
100
95
90
85
-8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
FOCUS
DISTANCE FROM FOCUS (CM)
RR



AUTO FOCUS EXPERIMENTAL OPTICAL ASSEMBLY FIGURE 2

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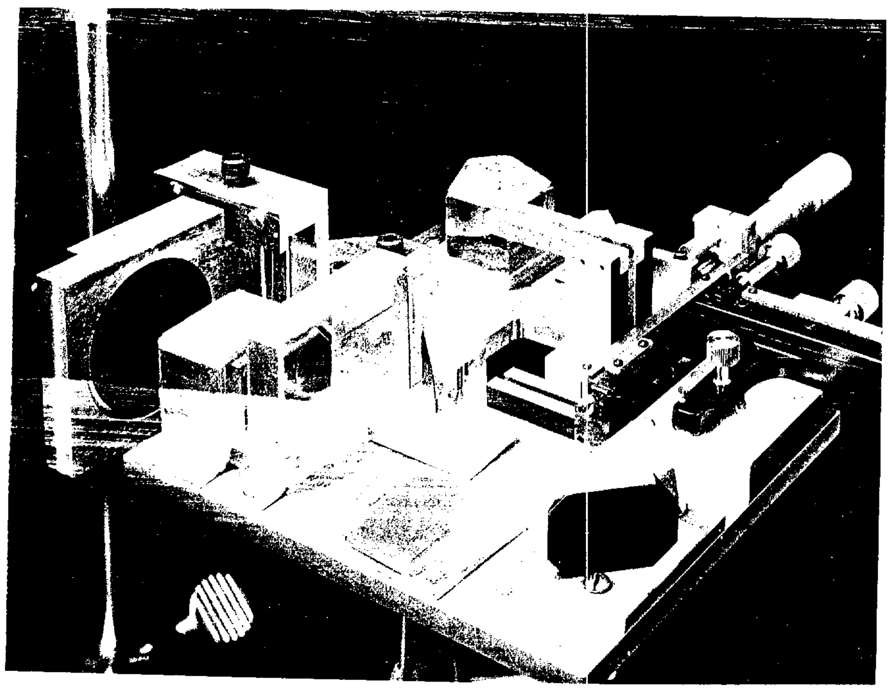

FIGURE 3 - OPTICAL TEST RIG