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James A. Fitz

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THE DESIGN AND CONSTRUCTION OF AN EXPOSURE METER FOR USE WITH INFRARED SENSITIZED FILM

by

James A. Fitz

A thesis submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Science in the School of
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Signature of the Author..
Photographic Science
and Instrumentation

Certified by..
Thesis Adviser

Accepted by..
Supervisor, Undergraduate Research

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Submitted to the
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ABSTRACT

In this project, an exposure meter which is sensitive to, and calibrated for infrared radiation was designed and constructed. An EG&G SGD-100A silicon photodiode was chosen to use as the photodetector. This choice was based on cost, availibility, ruggedness, stability, and sensitivity.

A circuit using an operational amplifier to amplify the output of the photodetector was used. The circuit design allowed easy variation of the signal gain to give a detectable meter deflection under varying lighting conditions. Five different gains were used to allow use of the meter under conditions ranging from outside under direct sunlight, to inside with typical room lighting. The gains used were empirically established.

The film used was Kodak HIE 135-20. This is a black-and-white panchromatic emulsion with special sensitizing

agents added to extend the film's sensitivity into the near infrared to about 900 nanometers. The spectral response of the photodetector was to be filtered to match the spectral response of this infrared sensitized film. This proved not to be possible, due to the unavailibility of any regular, stock filter which cuts off wavelengths above 900 nanometers. Despite this problem, the meter is much more accurate for setting exposures for the infrared sensitized film used than a normal exposure meter. The designed meter typically indicates within one stop of the optimum exposure for this film. A normal exposure meter reading made using Kodak's exposure recommendations was incorrect by as much as three stops.

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INTRODUCTION

Photographic films which have been spectrally sensitized through the visible portion and into the near infrared portion of the spectrum are currently used for many different purposes. Document authentication, aerial surveys, forensic photography and botanical studies are just a few of the many uses for this special type of film.

The most readily available black-and-white infrared sensitized film is Kodak High Speed Infrared Film. This is a panchromatic silver halide emulsion to which special sensitizing dyes have been added to extend its spectral into the near infrared portion of the spectrum to approximately 900 nanometers. It is available in 35mm rolls as HIE 135-20.

There are two main difficulties in using infrared sensitized films. The first problem is that the focal plane of the infrared radiation is not at the same distance from the lens as the focal plane of the visible radiation(light) used to focus the camera. This problem can be overcome by a simple adjustment in the focus setting of the lens.

The second, and more serious problem is that of exposure. Infrared sensitized films, since they are sensitive to radiation beyond the visible portion of the spectrum, have no ASA speed rating, as this speed rating is based on a film's response to visible radiation only. Kodak addresses this problem by providing approximate exposure indexes to use with their infrared sensitive film. This does not solve the exposure problem totally, however. The typical photographic exposure meter cannot be reliably used with infrared sensitized film, because the exposure meter is only calibrated for visible radiation. Using this typical exposure meter would give no indication of the infrared radiation present, which is of major concern when using infrared sensitized film. Figure 1 shows the relative sensitivities of a typical exposure meter and of the photodetector used in this project. The usual procedure at the present time, when using infrared sensitized film with an ordinary exposure meter, is to take a visual light reading to determine the proper visual exposure setting, and then make several exposures, bracketing on both the over and under-exposed sides of the light reading. This is often unreliable, unpredictable, and expensive. It is the problem of exposure control which was addressed by this project.

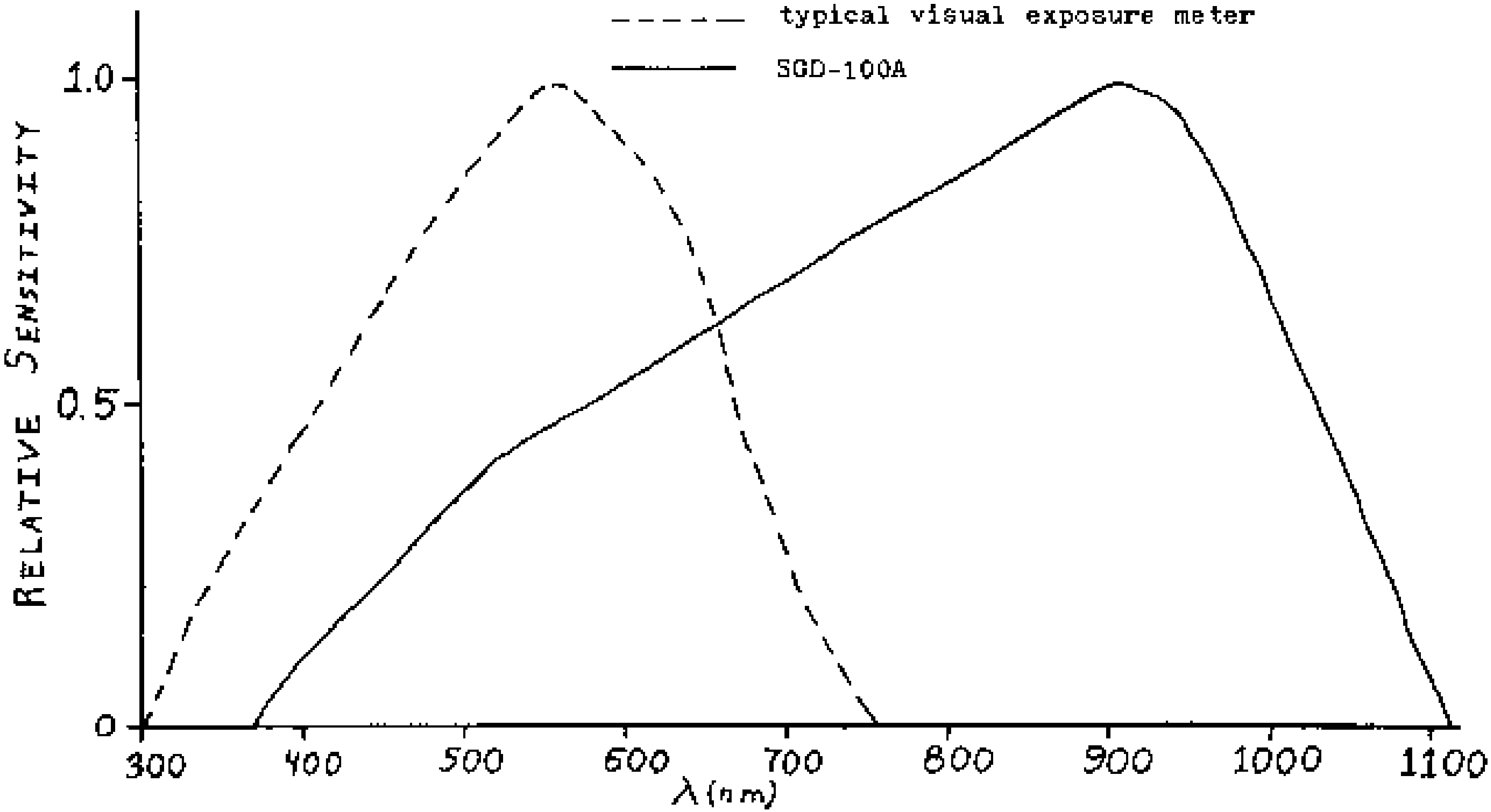

Figure 1 Relative sensitivities of a typical exposure meter and the SGD-100A

DISCUSSION

A. Photodetector

The first point addressed in this research was the selection of a suitable photodetector. Ideally, the spectral response of this detector should match the spectral response of the film to be used. The detector should also be rugged, stable, have a high sensitivity with a low dark current, be inexpensive and readily available. In actuality, no detector could be found which had a spectral response which matched the spectral response of the film to be used. This meant that a filter would have to be found which would alter the response of the detector to more closely match that of the film. The detector used was the EG&G SGD-100A, a silicon photodiode with a guard ring. This guard ring helps reduce the dark current of the photodiode. This detector is supposed to be rugged, have linearity of ±1% over seven decades, and be useful over a wide range of biasing voltages. It has a spectral sensitivity ranging from about 350 to 1100 nanometers. The region between 900 and 1100 nanometers would need to be cut off to make the detector's response more closely match that of the film. Unfortunately, no filter which is a regular, stock item from any company could be found which cuts off at 900 nanometers. Fortunately, the sensitivity of the detector drops off very rapidly past 900 nanometers, so that the contribution of this part of the spectrum to the meter reading is relatively small. The spectral sensitivity curve of the SGD-100A detector is shown in Figure 1, along with the spectral response of a typical exposure meter. With the filters typically used for infrared photography, the useful range of the film is no more than 500 to 900 nanometers. Between 500 and 900 nanometers, the spectral sensitivity curves of the film and the detector match fairly closely without filtration. Figure 2 shows the relative sensitivities of the film and the detector for the region between 500 and 900 nanometers. The data used for this graph was normalized at 700 nanometers. Figure 3 shows the transmittance, between 500 and 900 nanometers, of the filter which was calculated to be necessary to match the spectral response of the detector to the spectral response of the film.

B. Circuit Design

The circuit used to produce a voltage useful for a typical meter was based on basic circuit designs provided by EG&G. For schematics and parts lists of the circuits tested, see Appendix A.

The first circuit tested was very simple. A 9-volt battery was used to bias the photodetector. This circuit was only capable of producing an output voltage ranging from 0 to about 1 millivolt before the dark current became

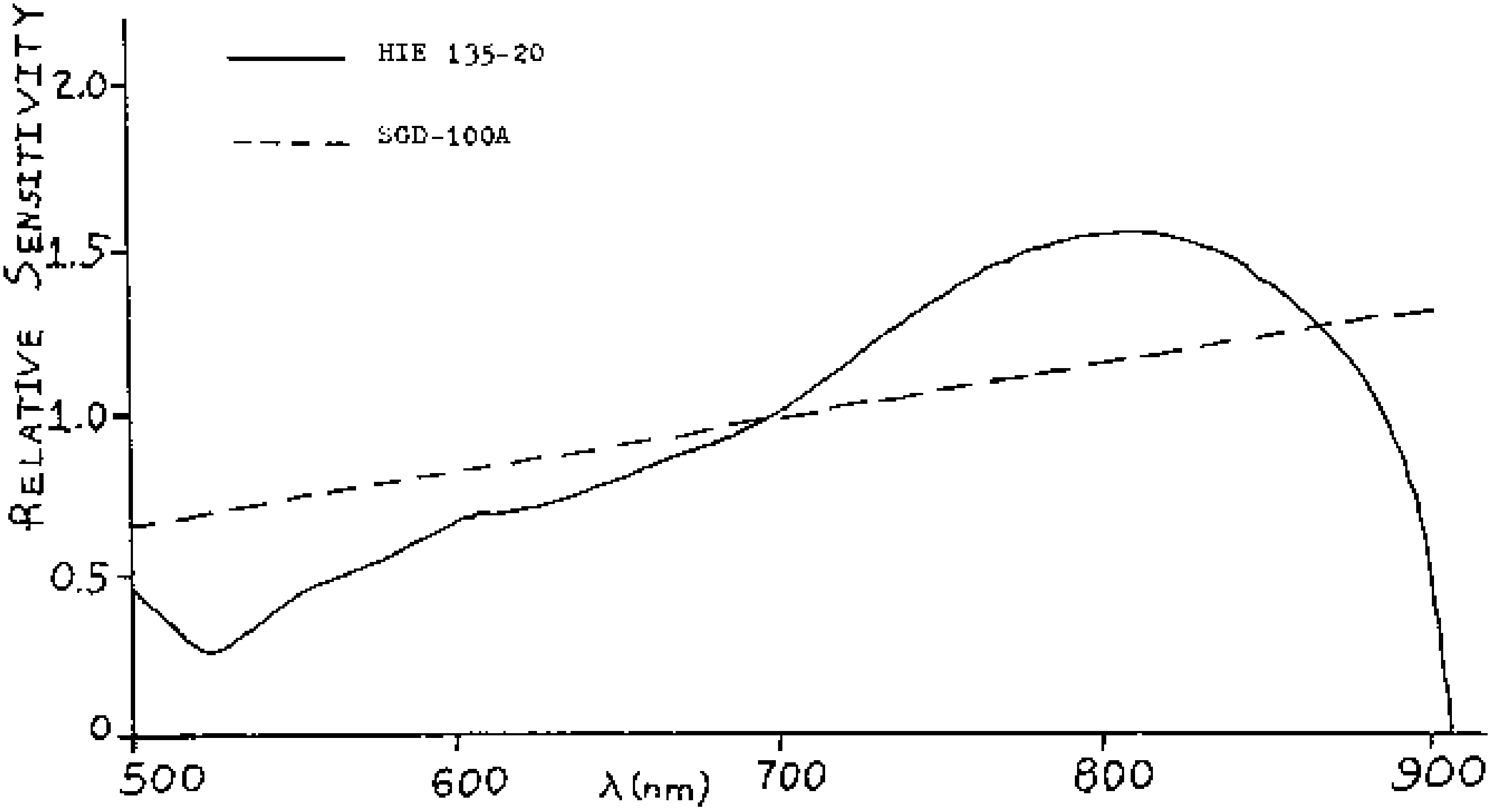

Figure 2 Relative sensitivities of film HIE 135-20 and photodetector SGD-100A

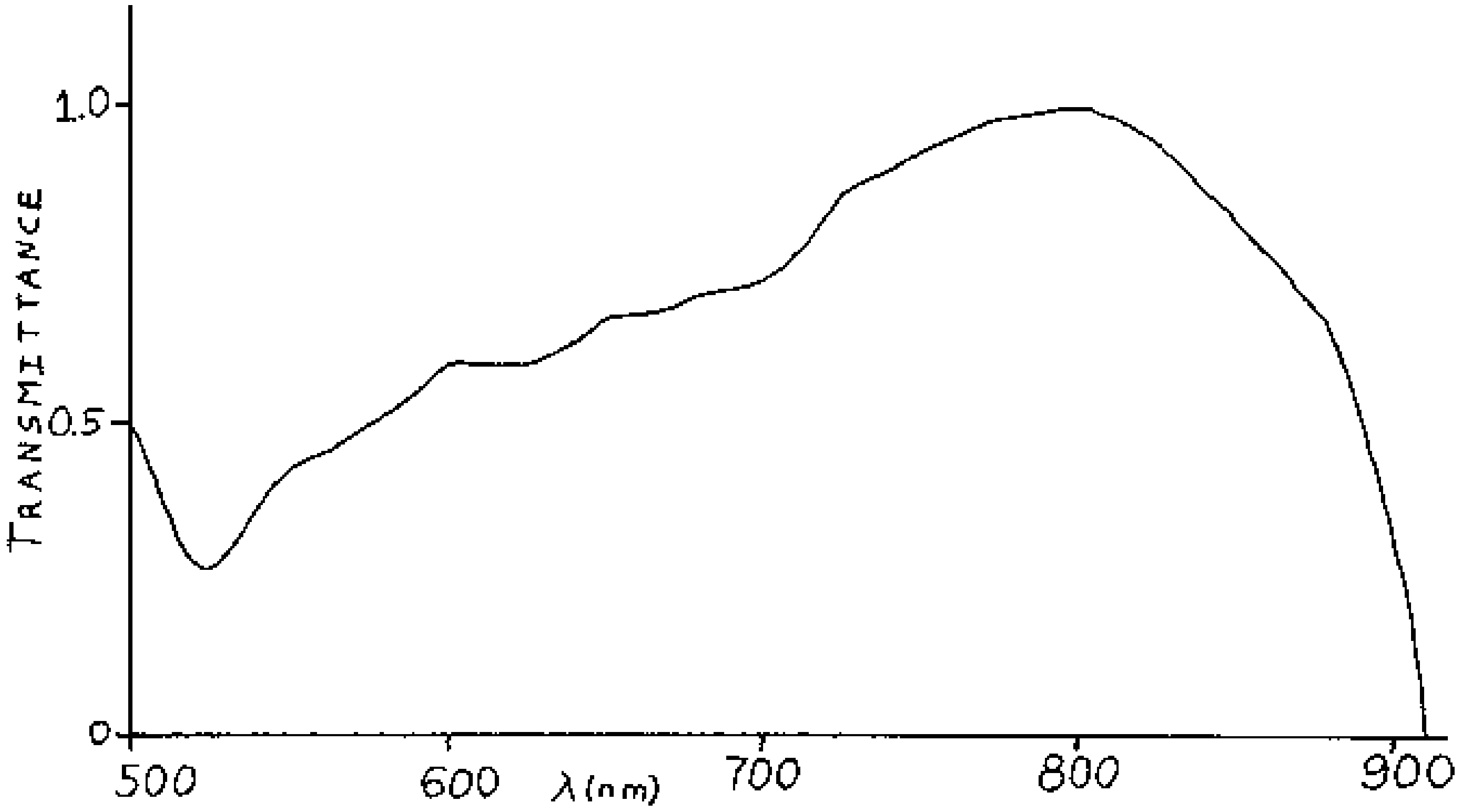

Figure 3 Filter necessary to make SGD-100A spectral response match HIE 135-20

unacceptably high.

The next circuit tested incorporated a Fairchild 1458 operational amplifier to give the gain needed for the photovoltage to be in a useful range. This circuit gave erratic results. It is thought that these erratic results may have been due to the use of a single 9-volt battery to bias the photodiode and power the op-amp, and the lack of a good ground for the circuit. Due to the power requirements of the op-amp, the third circuit design was then tested. This final circuit configuration uses two 9-volt batteries in series to give a higher voltage to power the op-amp and bias the photodiode, establishes a good ground, and gave much more consistent results than the previous circuit designs. This circuit uses five different signal gains to enable lighting conditions ranging from direct sunlight to a single incandescent bulb to give useful meter deflections. These gains were picked arbitrarily, using the lighting present in the laboratory as the low level, and direct sunlight outside as the upper limit. These gains are 1, 1.5, 15, 165, and 500. An ordinary rotary switch is used to select the desired resistor.

This final circuit design gives an output from the op-amp ranging from 0 to about 7.5 volts, for all sensitivity ranges. This output is passed through a 78K ohm resistor, which drops the output to a range from 0 to just less than 100 microamps. A 100 microamp meter was chosen to display the output signal to minimize the load on the circuit caused by the meter.

C. Calibration of Meter

Once the circuit design was finalized, the circuit was hard-wired and environmentally packaged. Figure 4 shows photographs of the packaged circuit. A series of photographs were then taken to begin calibration of the meter with the film. Meter readings, and exposures, were made through a Wratten 89B filter. This filter is one commonly used for infrared photography. It is visually opaque, cutting off radiation below 700 nanometers.

Pictures were taken of a large gray scale borrowed from the Professional Photography department. The majority of the exposures were made outside. This was done to attempt to obtain an exposure index for the film by using the rule- of-thumb that for direct sunlight, the proper exposure for a film is f/16 at a shutter speed of 1/ASA of the film. Using exposure index in place of ASA in this equation, an approximate exposure index of 100 was determined for this film and filter combination. This contrasts to a recommended daylight exposure index of 50 provided by Kodak for this film and filter combination.

The exposure indicated by the visual exposure meter was overexposed in all pictures taken. The exposures indicated by the visual exposure meter turned out to be as

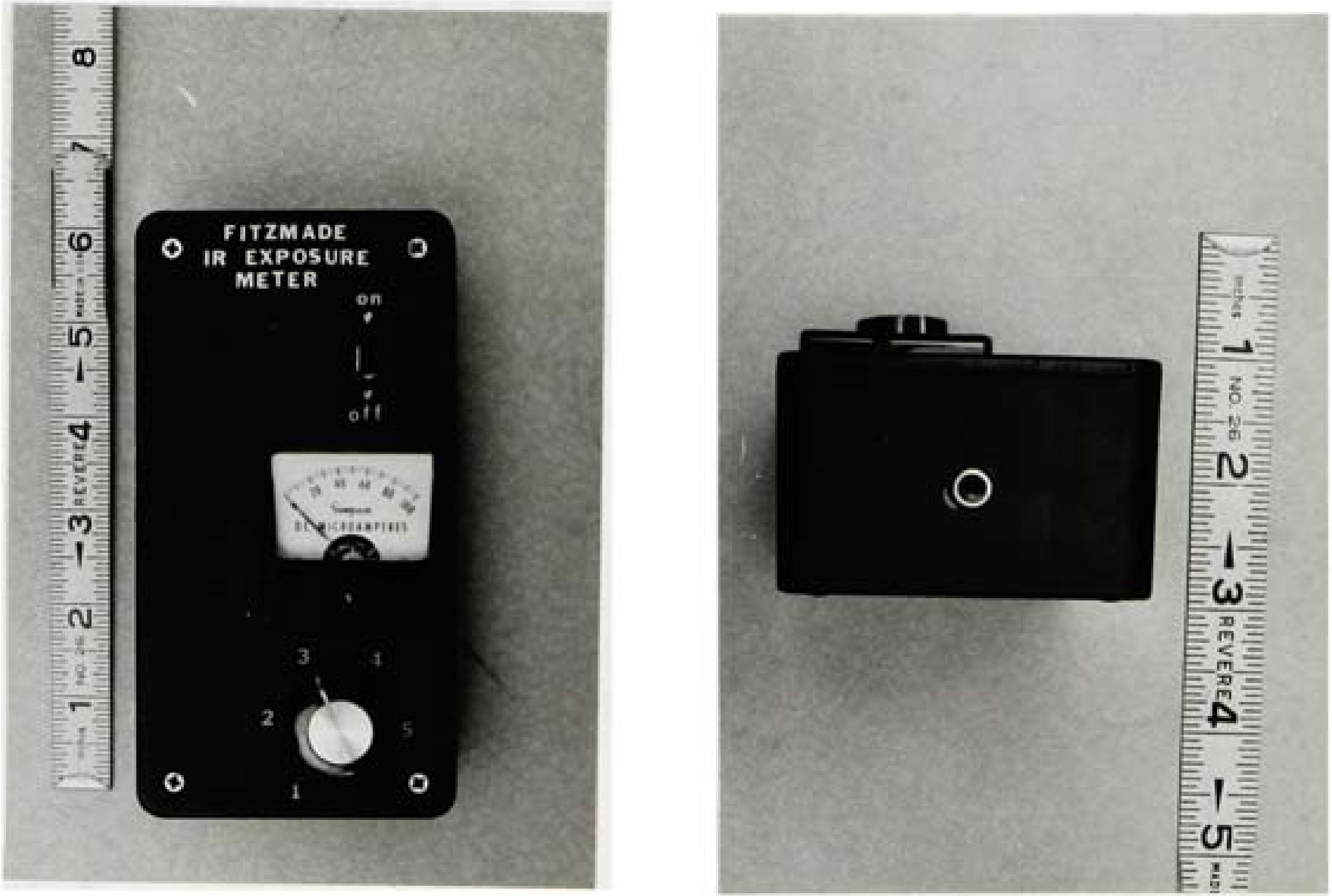

Figure 4 Top and front views of completed and packaged infrared exposure meter

much as three stops overexposed when the film was developed. The infrared meter gave much more consistent results, usually within one stop of the proper exposure. This variation of the infrared meter is probably caused by the response of the detector between 900 and 1100 nanometers which could not be filtered out.

The film was developed in D76, fixed for 8 minutes, and then the densities of the gray scale patches were read using the Macbeth TD-504 densitometer owned by the Photoscience department. The film seems to have a latitude of about two stops when processed in this manner.

Table 1 shows the meter readings for the infrared meter along with the exposure which turned out to be proper, and the exposure indicated by the visual meter.

Table 1 Visual exposure readings, infrared meter readings, and proper exposures

visual reading	Infrared meter range and reading					Proper exposure
	1	2	3	4	5	
f/16,1/15			12			f/16,1/30
f/16,1/30			19			f/16,1/60
f/16,1/30			25			f/16,1/60-1/125
f/16,1/60			32			f/16,1/125
f/16,1/60			40			f/16,1/250
f/1.8,1/30				38		f/5.6,1/30

D. Gray Scale Inconsistencies

The large gray scale used consisted of ten Kodak gray cards varying from a density of 0.01 to 1.84. The visual reflection densities of these cards were measured with a

Kosar reflection densitometer. The densities of the images on the film were measured using a Macbeth TD-504 visual transmission densitometer.The densities of the gray scale patches measured on the film do not seem to be as far apart as you would expect from the reflection densities of the gray cards. This could be explained if the infrared reflectance of these cards is not as neutral as the visual reflectance. This has not been a problem in this work but is an interesting finding. Table 2 gives the reflection densities of the gray scale, and some typical transmission densities resulting on the film.

Table 2 Reflection densities of gray scale and some typical densities resulting on the film

	Gray Patch Number									
	1	2	3	4	5	6	7	8	9	10
Original scale densities	.01	.09	.15	.29	.42	.66	.99	1.28	1.47	1.84
Typical densities on film	1.17 1.34	1.12 1.30	1.10 1.29	1.01 1.22	.94 1.16	.78 1.02	.62 .87	.49 .80	.49 .82	.49 .77

For all densities, see Appendix B

E. Other Circuit Designs

The gains used in the final circuit design were arbitrarily chosen. After testing, it was found that these gains were not optimum. The lowest gains of 1 and 1.5 need not have been so low. Better gains may have been 5, 15, 100, 200, and 500. Alternatively, a logarithmic amplifier circuit could be used. If properly designed, as much as a 20 stop range could be measured with such a meter without having to switch sensitivity ranges. Also, since photographic film responds to radiation in a logarithmic manner, a meter which responds in a logarithmic manner also would be very logical.

F. Better Filtration of Detector

As stated earlier, the spectral response of the detector used in this project did not match the film's spectral response, especially between 900 and 1100 nanometers. Detectors are available which are radiometrically filtered. This means the manufacturer incorporates a filter in the construction of the detector which causes the spectral response of the detector to be almost flat from about 450 to 950 nanometers. This would cause the detector's spectral response to match the film's spectral response even better than the current design does. One problem with using one of these radiometrically filtered detectors is the cost of these detectors. They typically cost over $200 each. This would greatly increase the total cost of this project, but it should reduce the error between the meter's readings and the film's response.

With more time to work on this project, it would also be desirable to determine a filter which would make this meter match the spectral response of Kodak's Ektachrome infrared sensitized film. The spectral response of this color transparency film differs considerably from the black-and-white film's spectral sensitivity.

CONCLUSIONS

The infrared meter built for this project gives much more consistent results than a visual exposure meter. Variations in the infrared content of daylight does cause the meter to indicate a change in exposure when a visual meter does not indicate a change is needed. Pictures taken using the infrared meter indications are usually within one stop of the correct exposure, where the visual exposure meter readings are wrong by as much as three stops. This variation in the infrared meter could be caused mostly by the response of the detector beyond 900 nanometers which could not be filtered out.

Recommendations for future work are as follows.

1. Use a radiometrically filtered detector. This should make the detector more accurate for the film used.
2. Change the processing of the film to determine to what extent the speed of the film is dependent on processing.
3. Calibrate the meter for use with infrared sensitized color film.
4. Change the gains of this circuit design. Use a circuit design incorporating a logarithmic amplifier.

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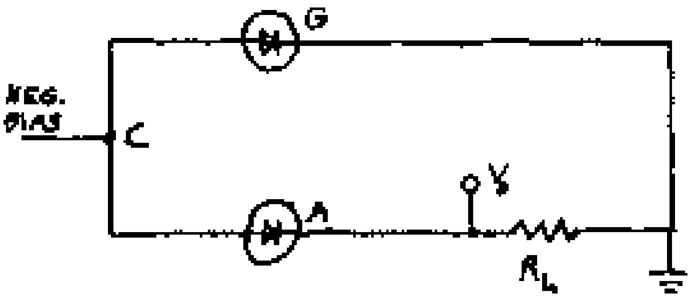
APPENDICES

APPENDIX A

APPENDIX A

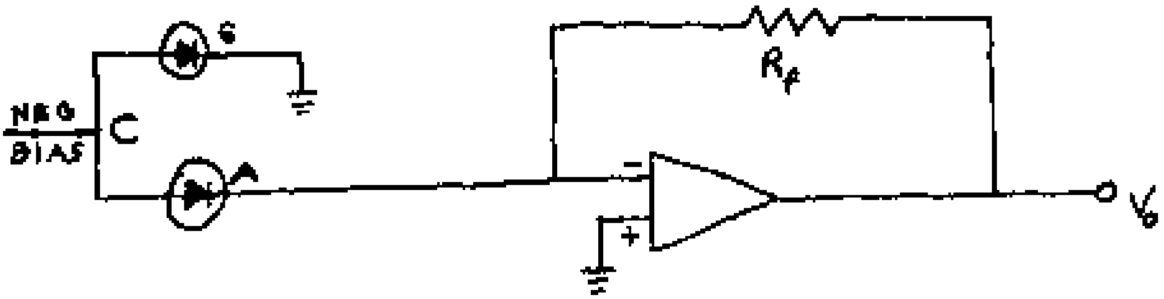
Circuit Designs

Photodiode for all schematics is the EG&G SGD-100A. Bias is provided by one 9-volt battery for Figures A1 and A2, and by two 9-volt batteries for Figure A3.



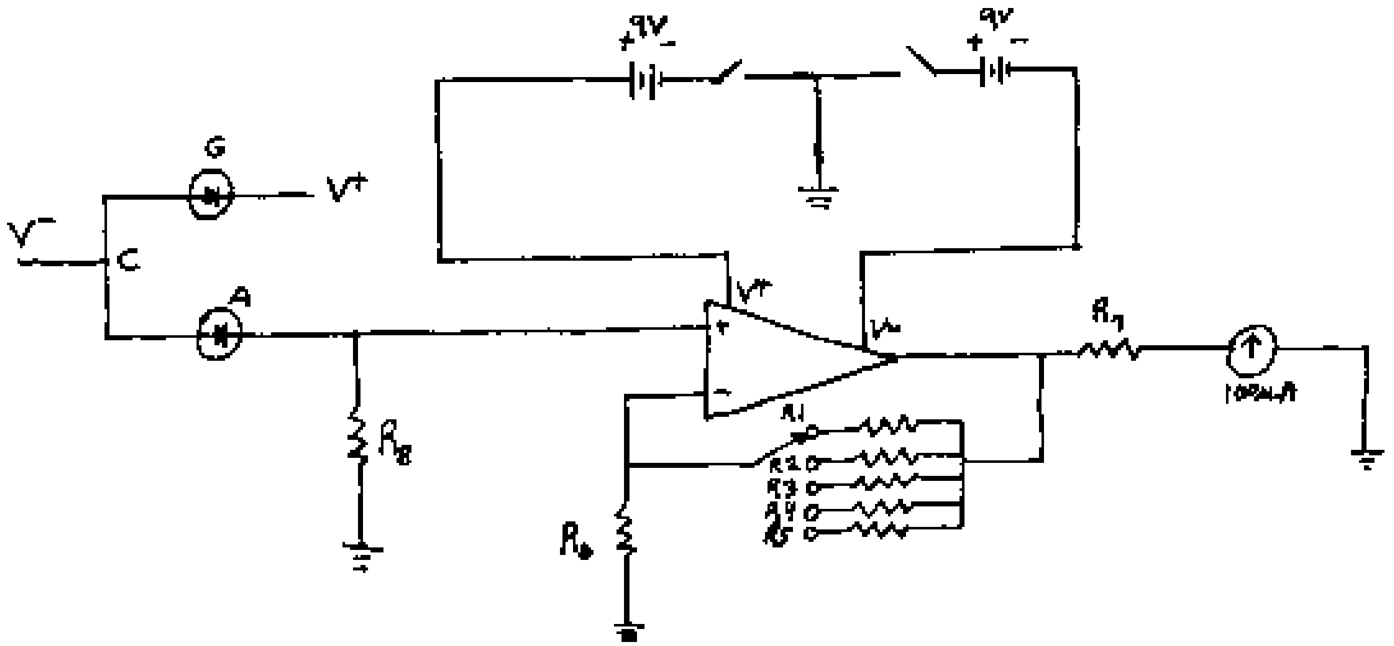
A= active area cathode G= guard ring cathode C= common anode
V_o= output volts R_L = load resistor =75K ohms

Figure A1 First circuit design



A= active area cathode G= guard ring cathode C= common anode
V_o = output volts R_f= feedback resistor= 1M ohms
Op-amp = Fairchild 1458

Figure A2 Second circuit design



R1= 20K ohms R2= 30K ohms R3= 300K ohms R4= 3.3M ohms
R5= 10M ohms R6= 20K ohms R7= 78K ohms R8= 2.7K ohms
A= active area cathode G= guard ring cathode C= common anode
Op-amp= Fairchild 1458

Figure A3 Third circuit design

APPENDIX B

APPENDIX B

Densities from gray scale pictures

f#.shutter	Gray Patch Number and Density									
speed	1	2	3	4	5	6	7	8	9	10
16,1/1000	.99	.68	.54	.38	.28	.18	.11	.10	.10	.10
16,1/1000	.55	.50	.48	.39	.32	.21	.13	.10	.10	.10
16.1/500	.74	.69	.67	.57	.49	.35	.21	.14	.14	.14
16,1/500	.77	.72	.70	.60	.51	.37	.23	.17	.17	.16
16.1/250	.94	.89	.86	.75	.66	.53	.38	.28	.28	.28
16,1/250	.94	.89	.86	.77	.69	.55	.39	.29	.28	.28
16,1/250	.96	.91	.90	.80	.70	.56	.40	.29	.29	.29
16,1/125	1.17	1.12	1.10	1.01	.94	.78	.62	.49	.49	.49
16,1/125	1.17	1.14	1.12	1.00	.92	.77	.62	.50	.50	.50
16,1/60	1.36	1.33	1.31	1.24	1.18	1.05	.87	.73	.73	.72
16,1/60	1.34	1.30	1.29	1.22	1.16	1.02	.87	.80	.82	.77
16.1/30	1.45	1.41	1.40	1.35	1.29	1.18	1.05	.93	.93	.92
16,1/30	1.43	1.41	1.38	1.32	1.26	1.16	1.04	.92	.92	.91
16.1/30	1.44	1.41	1.43	1.39	1.36	1.29	1.16	1.02	1.01	.97

3 other rolls shot at same exposures, results almost identical