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# Design, construction, and verification of a photographic color paper sensitometer

Daniel Marc Denkin

# DESIGN, CONSTRUCTION, AND VERIFICATION OF A PHOTOGRAPHIC COLOR PAPER SENSITOMETER

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Science in the School of
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## ABSTRACT

The thesis problem is to produce a sensitometer to expose photographic color paper to be used as control strips in a photographic color paper process. This problem involves designing, constructing, and verifying the sensitometer.

Designing the sensitometer is done by looking at different methods of exposing each dye layer of a photographic color paper. These methods include: fiber optics or light guides, light integrating devices, and projection systems. The method which was chosen for this experiment is the projection system. After the method had been decided upon, a lamp model will be calculated using the spectral sensitivity curve of a photographic color paper. The rest of the components will then be designed as needed to complete the sensitometer.

# ACKNOWLEDGMENTS

I would like to thank the Central Intelligence Agency for funding received. I would also like to thank James A. Budney of the BD Company for ray velour material, Steve Pasquarella of Vincent Associates for the timer explination, and Cross Country Color Corporation for use of their facility and for photographic color paper and Kodak control strips. A special thanks goes to my thesis adviser, Professor John F. Carson for his guidance and support.

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# INTRODUCTION

Photographic sensitometry is the process used in measuring the response of light sensitive materials to radiant energy.[1] The basic steps in photographic sensitometry are: exposing a light sensitive material using a known exposure, developing the material, measuring the developed image, and evaluating the data.[2]

The instrument used in exposing a light sensitive material is called a sensitometer. The sensitometer consists of a light source of known luminous intensity and spectral composition, an exposure surface, a shutter, and an exposure modulator used to alter the exposure at the exposure area.[3] To operate the sensitometer, the exposure modulator must be set for the type of light sensitive material being exposed. Now the sensitometer is ready for operation; after the light sensitive material is placed at the exposure surface, the shutter opens and closes sending light through the exposure modulator to form a latent image at the exposure surface on the light sensitive material.

One of the many uses of a sensitometer is to produce control strips used in the analysis of a photographic process such as the processing of a photographic color paper.

A photographic finishing lab would find having a sensitometer for photographic color paper very helpful in keeping its process in control. A more true representation of what a lab's process is doing to the photographic color paper could be reached by using a sensitometer to produce control strips using the same emulsion paper and similar exposure times as the finished work being produced by the lab. Defects in the paper can be found easier using the same emulsion paper in making control strips and then comparing these strips to other strips known to have been made on good paper. The control strips and finished work will react to exposure conditions in similar manners because of the same storing conditions and warm up times of the paper. Similar exposure times will eliminate differences in latent image forming times.

All of the above details have led to designing, constructing, and analyzing a photographic color paper sensitometer to produce control strips for use in the photographic finishing industry.

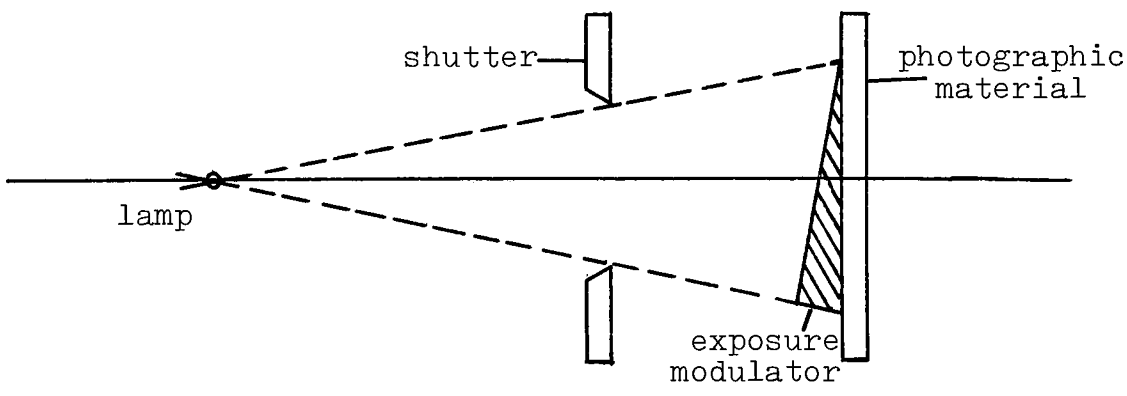
# OBJECTIVES

The objective of the experimental work was to design, construct, and test a photographic color paper sensitometer. This sensitometer will be used to produce control strips for a photographic color paper process. The objective was broken down into three goals. The first goal of the work done was to design a sensitometer for a photographic color paper. The second goal of the experiment was to construct a working model of the sensitometer design. Finally, the third goal was to test the sensitometer model by checking the exposure radiometrically and densitometrically with control strips made from the sensitometer.

## EXPERIMENTAL

In order to carry out the first goal of the experiment, a basic sensitometer design had to be reviewed. This design includes the placement of the shutter, exposure modulator, lamp, and exposure surface. Figure 1 illustrates a basic sensitometer design.[4]

Figure 1

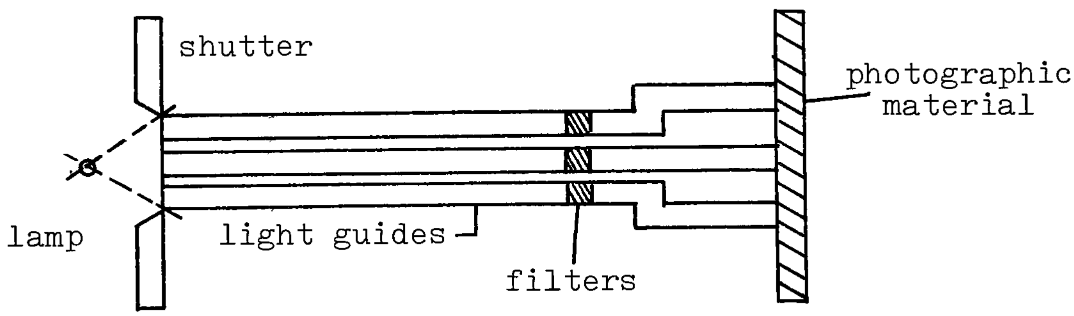



Basic Sensitometer Design

The major factor in deciding the placement of the sensitometer components is the spectral sensitivity of the photographic color paper for which the model sensitometer is being designed. The spectral sensitivity versus wavelength plot will show the best transmission wavelength for the exposure modulators for the cyan, magenta, and yellow dye layers and also the overlap wavelength transmissions. The specifications for the lamp can now be determined with the use of the spectral sensitivity curve and the known transmission wavelength of the selected filters. A tungsten halogen lamp which meets the correct specifications for light output is looked for because of its stability and long life. The shutter placement and diameter is chosen to illuminate the designated area on the exposure surface. The placemant of the exposure surface depends on the projection of the lamp through the filters and onto the designated exposure area. The projected area must be large enough to use a reflection densitometer for reading the density of the exposed areas. The reflection densitometer needs an area of approximately a quarter inch radius circle.

The first design idea for the lamp to exposure surface geometry of a sensitometer was with the use fiber optics or light guides such as plexiglass bars. Light from the lamp would travel only in the fiber optics or light guides to the filters and emerge as colored light of specific wavelengths depending on the filter encountered. The colored light would then travel through more fiber optics or light guides to the exposure surface. The exposure surface would be in contact with the fiber optics or light guides. The purpose of having a sensitometer of this design is because of the compactness of the lamp to exposure surface path. The sensitometer would be easy to store and relocate. The design was decided against because of the size of the exposures needed at the exposure surface. Fiber optics or light guides would have to be placed all around the lamp because of the cross-sectional area needed to expose the paper with an area of over a quarter inch radius circle. This would produce different illumination to each fiber optic or light guide. Figure 2 illustrates this sensitometer design.

Figure 2

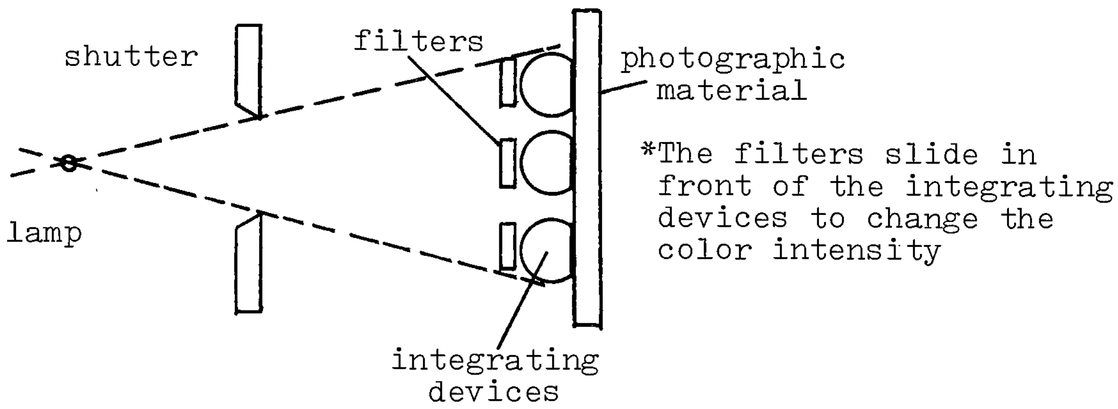



Fiber Optic/Light Guide Sensitometer Design

Another idea for the lamp to exposure surface geometry was with the use of a light integrating device. Light leaving the lamp would travel through a filter for either red, blue, or green exposing light and then into a light integrating device. Each filter would have its own integrator.

Colored light leaving the integrator would then strike the exposure surface. The advantage of a sensitometer having an integrating device is for changing the colored light saturation striking the paper surface. The disadvantage and reason for not using this idea is a yellowing of the integrator walls with time. Styrafoam or Kodak white high reflectance paint would be used for the walls and both do yellow with time. Thus the spectral output of the sensitometer would change with time. Figure 3 illustrates this design.

Figure 3

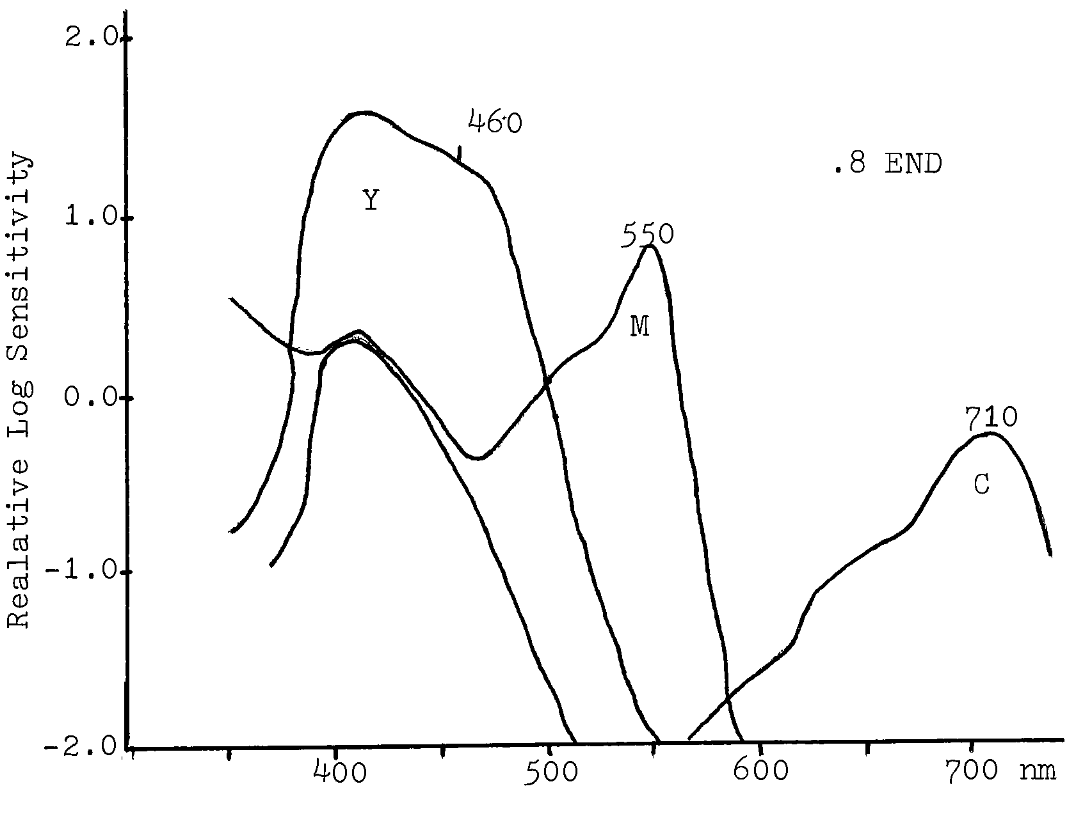



Integrating Device Sensitometer Design

The design which was finally decided upon is a simple projection system. The lamp output strikes the filter for either the cyan, magenta, or yellow sensitive layer and colored light emerges from each filter and strikes the paper surface. Baffles are used to separate the filters and their emerging light from one another and from stray unfiltered light. The exposure surface is curved with the lamp being at the center of curvature for even illumination. Each filter is placed parallel to its corresponding exposure surface along each optical axis which is from each exposure surface to the lamp. The shutter is placed inbetween the lamp and filters so that all the filters are illuminated.

Now that the basic design had been decided upon, the first step towards completing the design was the calculation of the correct filters.

Figure 4




Spectral Sensitivity Curve

The plot in Figure 4 is a representative of the spectral sensitivity curve for a photographic color paper. The peak sensitivity values picked for the filters were: 460 nm for the yellow layer, 550 nm for the magenta layer, and 710 nm for the cyan dye layer. The next step in designing the sensitometer was to model a lamp.

The first calculation in determining a model lamp is the relative exposure ($H_r(\lambda)$) for each wavelength using Planck's Equation for blackbody radiation.[5]

$$H_r(\lambda)=(10^{18}/\lambda^5)(1/(e^{c_2/\lambda T}-1))$$

where $c_2=1.4388\times10^7$ nm·K

$\lambda$ is in nm

T=3000K

This model was made simple by setting each filter transmission ($t\lambda$) at .5 and each filter bandwidth at 10 nm.

The second step in the lamp model calculation is using the Van Kreveld Addition Law to get an END of 0.8 .[6]

$$\sum S(\lambda)H(\lambda)t(\lambda)\Delta\lambda=1$$

where $S(\lambda)$ is the absolute sensitivity

$H(\lambda)$ is the absolute exposure

$$H(\lambda)=KH_r(\lambda)$$

where K is a constant

$\bar{K}$ is defined as the maximum K and is used to normalize the transmissions of the filters. Calculating for $\bar{K}$:

$$K_B=\frac{1}{H_r(460)S_B(460)t_B(460)\Delta\lambda}=\frac{1}{1.440x20x.5x10}=6.94x10^{-3}$$

$$K_G=8.82x10^{-3}$$

$$K_R=55.2x10^{-3}=\bar{K}$$

where B, G, R are Blue, Green, Red respectively.

Normalizing the Red transmission to 1, then:

Blue transmission$=\frac{6.94}{55.2}=.126$; $-\log(.126)=.9$ ND

Green transmission$=\frac{8.82}{55.2}=.160$; $-\log(.160)=.8$ ND

Table 1

| Wavelength (nm) | $KH_r(\lambda)$ | $E(\lambda)=KH_r(\lambda)/1$ sec. |
|---|---|---|
| 400 | .033 | .0033 |
| 450 | .070 | .0070 |
| 500 | .121 | .0121 |
| 550 | .179 | .0179 |
| 600 | .240 | .0240 |
| 650 | .297 | .0297 |
| 700 | .348 | .0348 |

Model Filter Exposures

In order to calculate the number of lux at the exposure surface with unfiltered light, this equation is used.[7]

$$E=680\sum E(\lambda)V(\lambda)\Delta\lambda$$

where $V(\lambda)$ is the photopic luminosity function

$\Delta\lambda=50$ nm.

$$E=13.75 \text{ lux}$$

To convert lux into lumens, the inverse square law is applied.[8]

$$E=I/d^2$$

where I is in lumens/sr or cd.

d is the lamp to exposure surface distance=.3048 m.

$$I=(.3048)^2(13.75)=1.28 \text{ lumens/sr or cd.}$$

At 3000K the lamp efficacy is about 2 cd/watt, therefore:[9]

$$(1.28 \text{ cd})/(2 \text{ cd/watt})=.64 \text{ watts}$$

The lamp with the closest specifications to the model lamp was a GE Quartz Line Miniature Halogen-cycle #1985 rated at 2900K, 16 watts, 6 volts, and 1000 hours of life. Even though this lamp has more power than calculated, it was chosen because of its long life, compact size, and it had the smallest watt rating of all the GE and other lamps examined.

A power supply was needed to run the lamp at the proper voltage. A Standard brand power supply was chosen for its reliable output. The Standard SPS 30-6 has an input of 120 volts and an output of 6 volts with .1% regulation. This power supply is also equiped with a voltage adjustment potentiometer, temperature compensated circuitry, and .1% ripple.

The last basic sensitometer component to be considered was the shutter assembly which included the shutter, timer, and timer and shutter power supplies. Before this component could be calculated, the sensitometer design had to be worked out in order to know a rough shutter diameter. The first dimension to pick was the lamp to exposure surface distance. Here, twelve inches was used as in the lamp model example. The angular spread of the lamp through the shutter must cover all the filters and an unfiltered area for a $D_{max}$ exposure. The baffles which separate the filters were set at ten degree intervals to allow enough space between two baffles for a three quarter inch filter and its holder. With three filters and an area for $D_{max}$, a forty degree illumination spread was needed.

The shutter must be placed away from the lamp so that the heat from the lamp does not effect the shutter's moving parts. A one inch diameter shutter was selected to give the forty degree spread with a maximum distance away from the lamp. The shutter used was a model 225 L Uniblitz electronic shutter manufactured by Vincent Associates. This shutter has a combined opening and closing time of 6.7 milliseconds or .67% for a one second exposure. This shutter was powered by a model 100-B driving unit also manufactured by Vincent Associates. The driving unit operates on an input voltage of 120 volts and outputs five volts to operate the shutter.

The electronic timer chosen to keep the shutter open was a 555 IC timer chip with the appropriate circut as shown in the Appendix.[10] The timer circuit was powered by the shutter driving unit. The output of the timer is connected directly to the shutter power. Both the shutter and timer were connected to the same ground.

After all the components had been ordered, a possible design was sketched out. The exposure surface was designed as two curved pieces of sheet metal placed twelve inches away from the lamp with a sixteenth of an inch separating the two pieces. The closest piece had holes drilled in it where the paper needed to be exposed. See diagram in the Appendix. This piece of sheet metal acted as a mask or template. The back piece of sheet metal was to hold the paper at the exposure surface flat against the template.

A wooden model of the sensitometer was constructed out of half inch plywood and one-eighth inch masonite. This model was used to arrange the placement of the power supplies and the timer circuit. The model was also used to experiment with different mounting methods for the shutter, lamp, filters, and exposure surface assembly; and to determine the overall dimensions of the sensitometer. The final design came from working with the model and is diagramed in the Appendix.

After the final design was altered with corrections from the model, construction of the second and improved model was started. This model has sheet metal baffles instead of masonite to allow the filters to be placed closer to the lamp for a larger projection onto the exposure surface. This model is also three inches longer than the first model and the exposure surface is fourteen and a half inches instead of twelve inches from the lamp. All the changes made between the first and second models resulted in the completion of the design goal of the experiment.

The final goal of the thesis objective, verification of the sensitometer, was done using an EG and G spectroradiometer for constant exposure verification, a Bausch and Lomb 505 Spectronic for measuring filter transmission versus wavelength, and actual control strips made from the sensitometer then measured on a densitometer for uniform density from strip to strip.

# RESULTS

The final and constructed color paper sensitometer design and component designs are diagrammed in the Appendix. The model sensitometer will be in the possession of the Photographic Science department of RIT.

Verification of the sensitometer was done by measuring exposure versus time, measuring exposure versus input voltage, and measuring density repetition of the control strips made from the sensitometer.

Table 2

| Seconds | Relative Exposure Output* | |
|---|---|---|
| | Trial 1 | Trial 2 |
| 20 | .167 | .166 |
| 40 | .165 | .165 |
| 60 | .164 | .165 |
| 80 | .164 | .164 |
| 100 | .163 | .163 |
| 120 | .164 | .164 |
| V | V | V |
| 600 | ** | ** |

* Output was measured on the EG and G Spectroradiometer.
**The remaining output varied between .163 and .164 .

Cold Start versus Exposure Output

Table 2 shows the relationship of the stabilization of the sensitometer when the sensitometer is first turned on. All measurments were taken in the green exposure area.

Table 3

| Volts (100-130) | | | | | | |
|---|---|---|---|---|---|---|
| 100 | 105 | 110 | 115 | 120 | 125 | 130 |
| .158 | .156 | .158 | .158 | .157 | .158 | .158 |
| .157 | .156 | .157 | .157 | .158 | .158 | .159 |
| .157 | .156 | .157 | .158 | .158 | .158 | .158 |
| .157 | .157 | .157 | .157 | .157 | .159 | .159 |
| .157 | .157 | .157 | .158 | .158 | .159 | .159 |

Relative Exposure of Input Voltage

The resulting sensitometer design has a high and low density exposure area for each dye layer. This was done to allow two different points for each dye layer on the paper D Log H curve be determined. Neutral density filters are placed over one exposure area for each dye layer, the low density exposure area to get the lower exposure with less light.

Table 4

| | Black | White | Yellow | | Magenta | | Cyan | |
|---|---|---|---|---|---|---|---|---|
| | | | High | Low | High | Low | High | Low |
| 1,1 | 2.33 | .12 | 1.71 | 1.08 | 1.66 | 1.07 | 1.65 | .98 |
| 1,2 | 2.33 | .12 | 1.70 | 1.09 | 1.67 | 1.07 | 1.66 | .99 |
| 1,3 | 2.32 | .12 | 1.67 | 1.08 | 1.65 | 1.06 | 1.64 | .98 |
| 1,4 | 2.32 | .13 | 1.69 | 1.08 | 1.67 | 1.07 | 1.66 | 1.00 |
| 1,5 | 2.34 | .12 | 1.70 | 1.09 | 1.67 | 1.08 | 1.65 | 1.00 |
| 2,1 | 2.36 | .13 | 1.70 | 1.08 | 1.74 | 1.12 | 1.74 | 1.03 |
| 2,2 | 2.38 | .13 | 1.72 | 1.11 | 1.73 | 1.12 | 1.72 | 1.02 |
| 2,3 | 2.37 | .14 | 1.69 | 1.09 | 1.75 | 1.12 | 1.72 | 1.02 |
| 2,4 | 2.39 | .14 | 1.69 | 1.08 | 1.75 | 1.13 | 1.73 | 1.03 |
| 2,5 | 2.38 | .14 | 1.70 | 1.11 | 1.76 | 1.12 | 1.70 | 1.01 |

Control Strip Density Values for Two Trials

The two trials were done at different times to determine if the sensitometer will reproduce the same results.

A 2.0 ND filter was placed inbetween the lamp and the shutter to bring the overall light level down so the high density exposures would be near 1.65 . The low density exposures also had .34 ND filters in their light paths which produced a density difference of approximately .65 as measured with the reflection densitometer. The exposure time for making the control strips was 5.2 seconds. The density levels as measured by the densitometer were set by trying to match a Kodak control strip for Ektacolor-74 photographic color paper.

# ANALYSIS

The sensitometer designs which were not constructed could be looked into for future projects, especially the light guide method of exposing. A wedged light guide with the smaller end near the lamp would allow more guides near the lamp in the same area for illumination which would be approximately even across the guides. The lamp model which was worked out was incorrect due to the transmissions of the filters used in the sensitometer. See transmission versus wavelength plot for the filters used in the Appendix.

The construction of the first sensitometer model helped the concept of sensitometer geometry become clear. Placement of components was finalized by using the first model for trials and errors. The second model was the result of these trials and errors and is believed to have the best usage of space and geometry.

Verification data is shown in Tables 2-4. In Table 2, the sensitometer output stabilized after the power had been on for one minute. The difference in output after stabilization had been reached was approximately .6% which could be attributed to the limit of accuracy of the spectroradiometer. In Table 3, the input voltage versus exposure output is shown to have approximately .6% difference in exposure output as changes to the input voltage were made. This again could be attributed to the accuracy limit of the spectroradiometer. Table 4 shows two distinct groups of processed strips. Trial 1 has lower density values in the black, magenta, and cyan exposure regions. This could have been caused by the 2.0 ND filter not being in the same place between the lamp and shutter for both exposure series. Kodak control strips were processed along with the control strips made from the model sensitometer for use as a standard or control of what the paper process was doing. The Kodak control strips also had an increase in density in the black, magenta, and cyan regions. This shows the photographic paper processor was causing the density change from Trial 1 to Trial 2 on the model sensitometer control strips. The standard deviation difference on the same measured areas between trials was calculated to be .005 or .015 within 99% of the time the process is run. This can be attributed to the reflection densitometer's limit of accuracy.

# CONCLUSION

A sensitometer for photographic color paper can be designed with the use of: a spectral sensitivity curve of a photographic color paper, a plot of filter transmissions versus wavelength, and knowledge of sensitometer geometry.

Construction of the sensitometer design can produce a model with which a better understanding of the design and this model can be used to make all changes in the design in order to construct a working model sensitometer.

Measuring: the input voltage versus relative exposure output, stabilization time, and density values from control strips made from the sensitometer; it can be concluded that the model sensitometer can repeat exposure output and therefore be used to make control strips used for a photographic color paper process.

# FOOTNOTES

1. J. Paul Weiss, in S.P.S.E. Handbook of Photographic Science and Engineering, W. Thomas, ed., Wiley and Sons, 1973, p. 767.
2. Ibid.
3. Ibid., p. 769.
4. Ibid.
5. Ibid., p. 6
6. Ibid., p. 445
7. Ibid., p. 803
8. Ibid., p. 149
9. Ibid., p. 45
10. Popular Electronics, November 1973. pp. 55-56

# APPENDIX

## List of Parts

(1) 75 cfm 120v Fan

(2) GE Quartz Line Miniature Halogen-cycle Lamp #1985

(3) Power On/Off Switch

(4) Electrical Hook-up Hubbell Twist-lock

(5) 1" Diameter Shutter from Vincent Associates

(6) Standard SPS 30-6 Power Supply

(7) Model 100-B Driver Board from Vincent Associates

(8) Filters and Filter Holders

(9) Ray Velour covering on sheet metal plates from BD

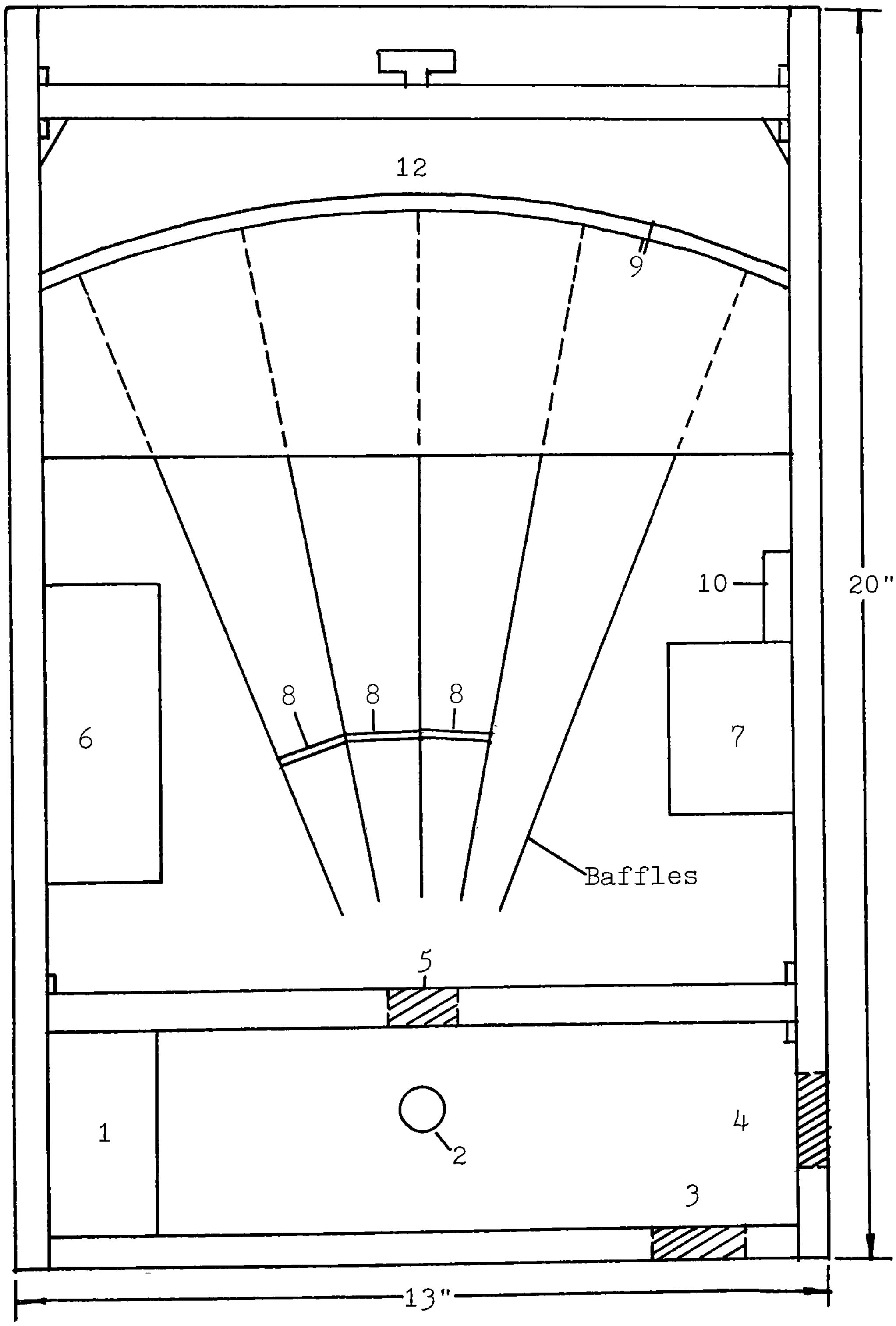
(10) 555 IC Timing Circuit

(11) Exposing Switch (SPST)

(12) Removable Back Plate Section for measuring light output

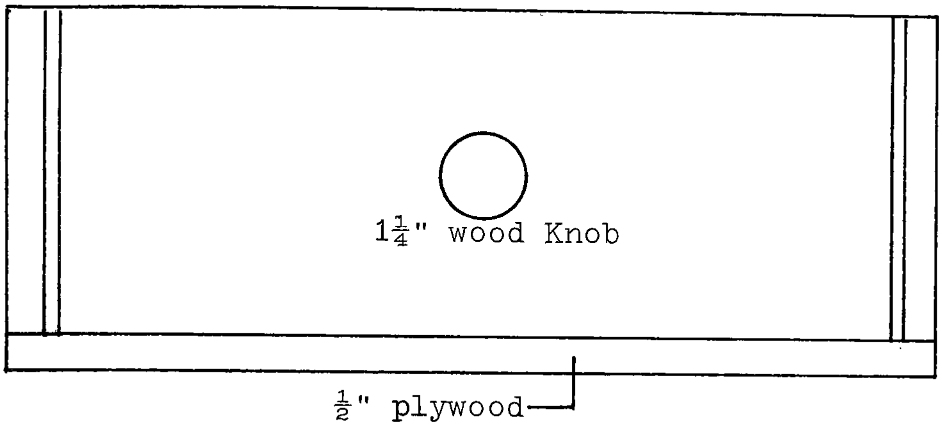
(13) Paper Template

Figure 5



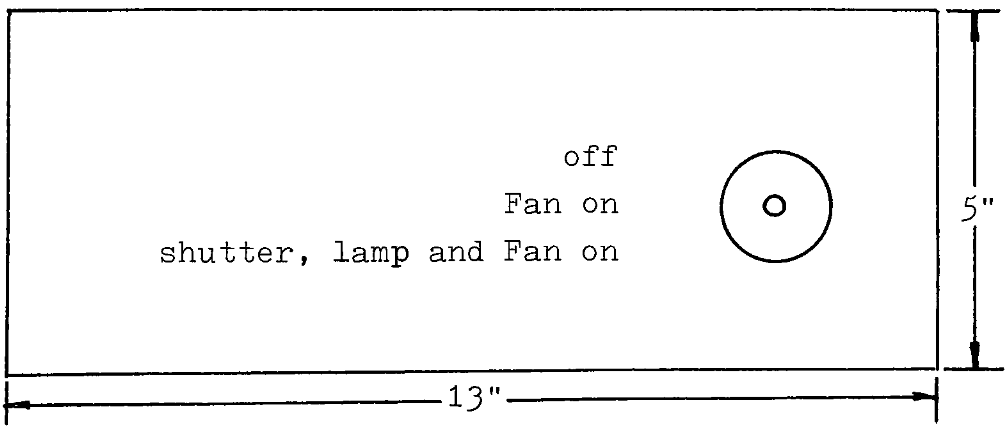

Sensitometer Top View

Figure 6



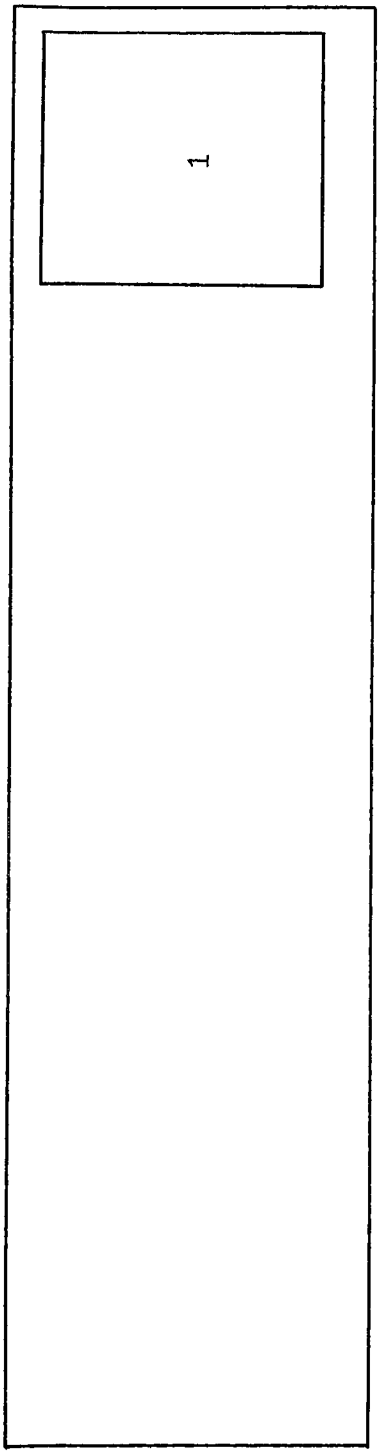

Front View

Figure 7



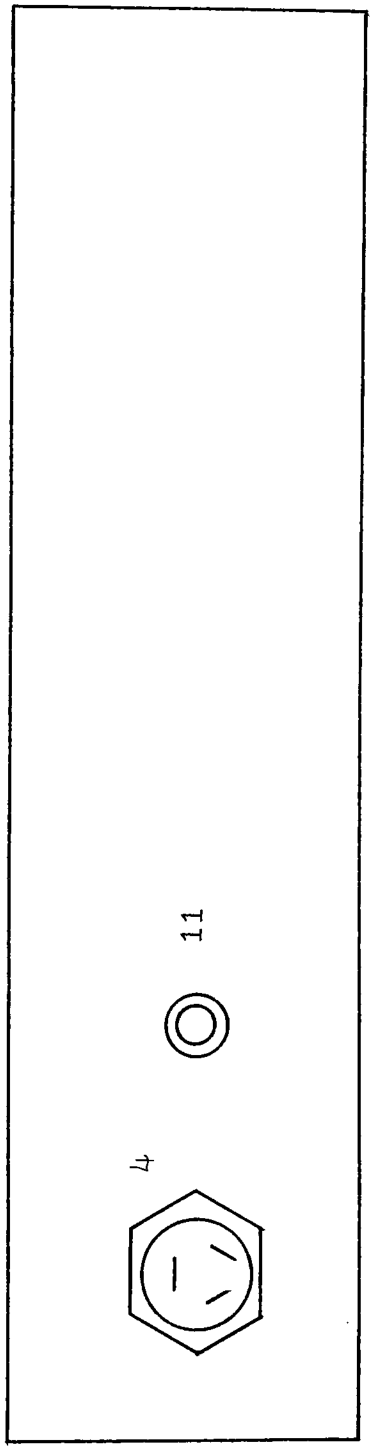

Rear View

Figure 8



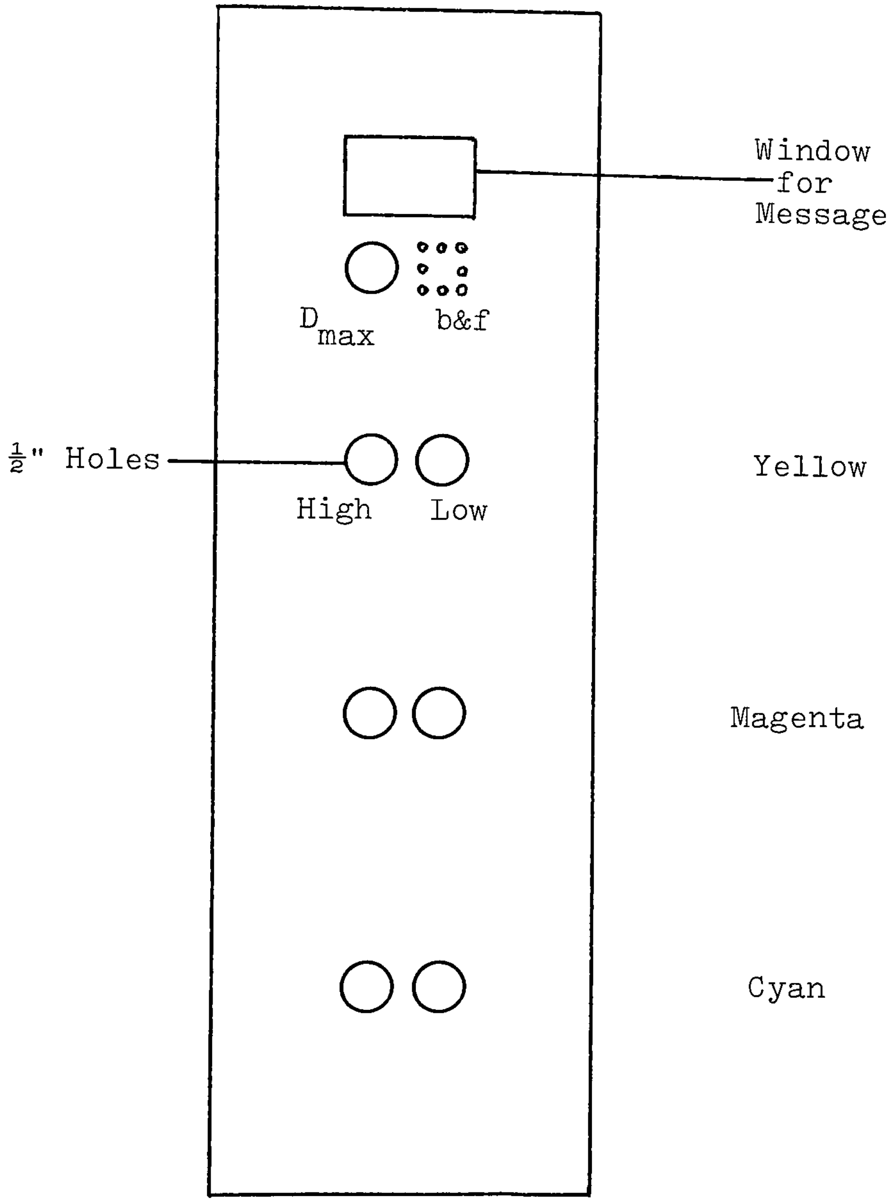

Left Side View

Figure 9



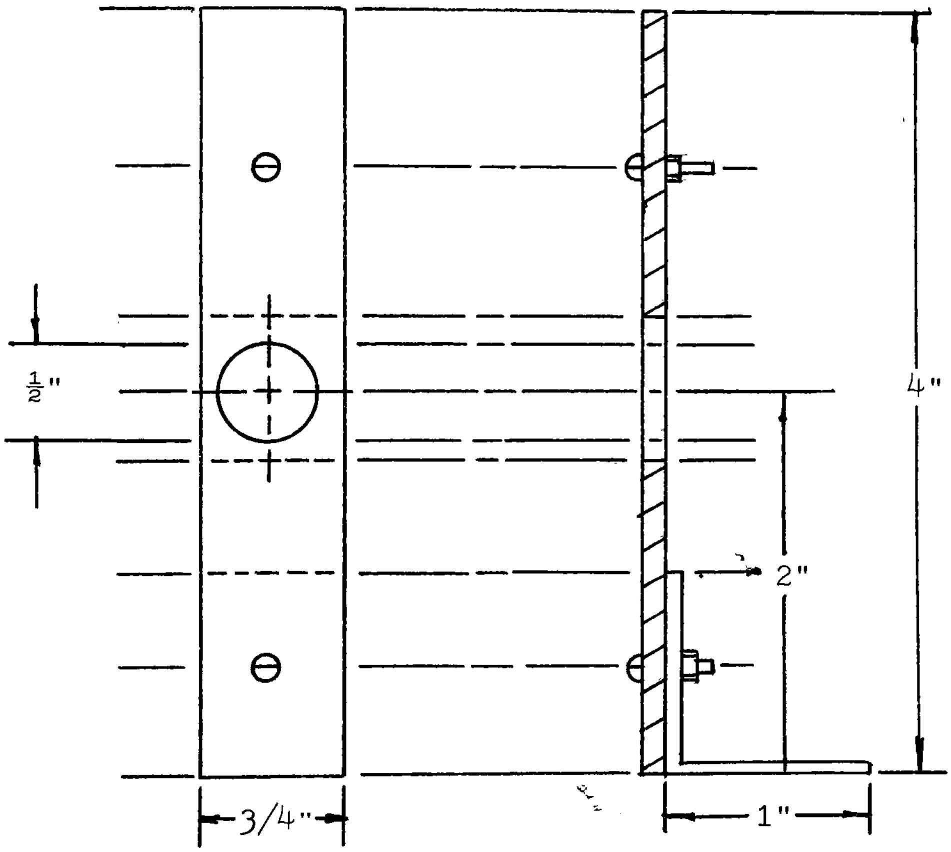

Right Side View

Figure 10




Paper Template
(Control Strip Layout)
Paper Template 4"x12$\frac{1}{2}$"
(Control Strip 5"x12")

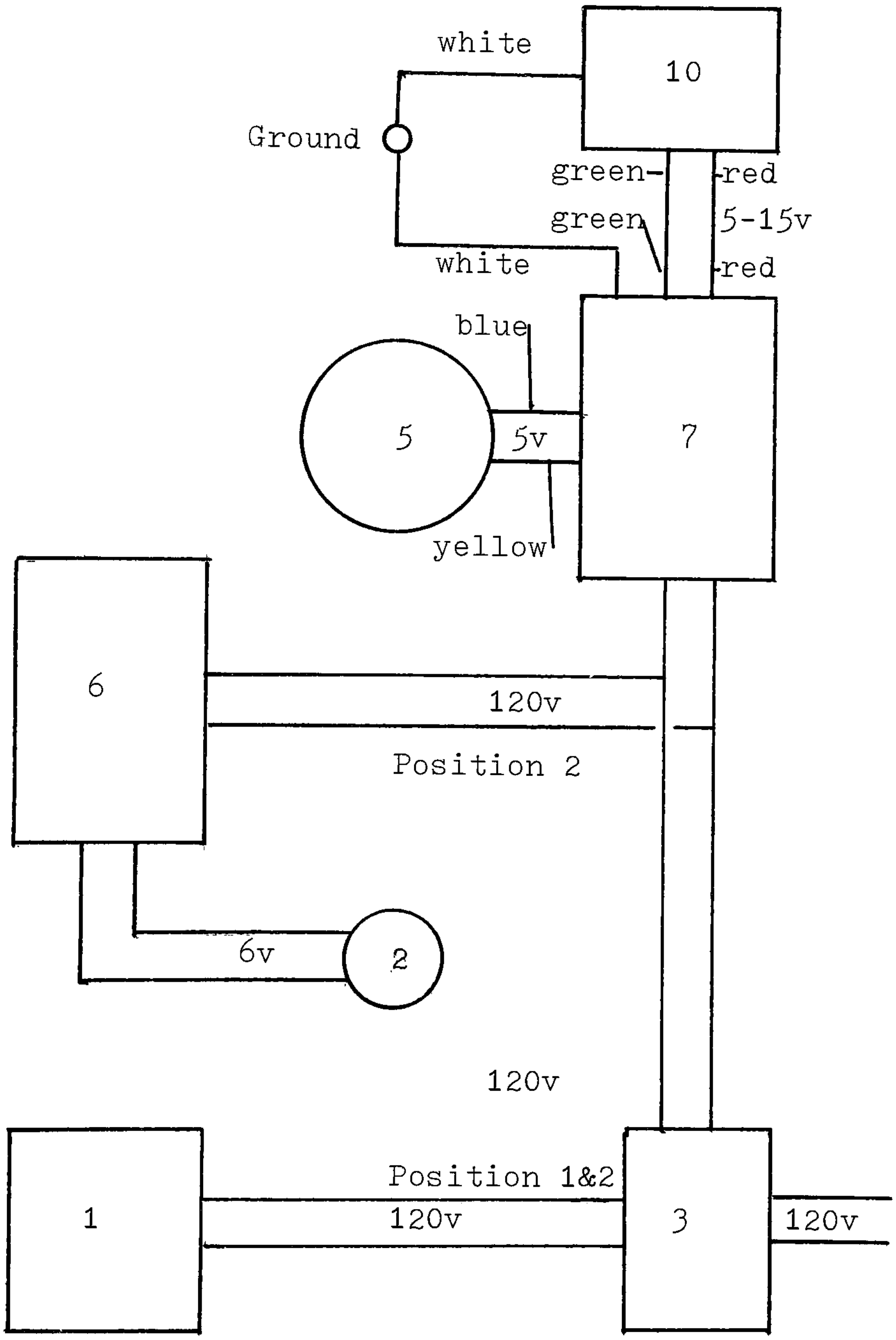
Figure 11




1/8" masonite covered with sheet metal

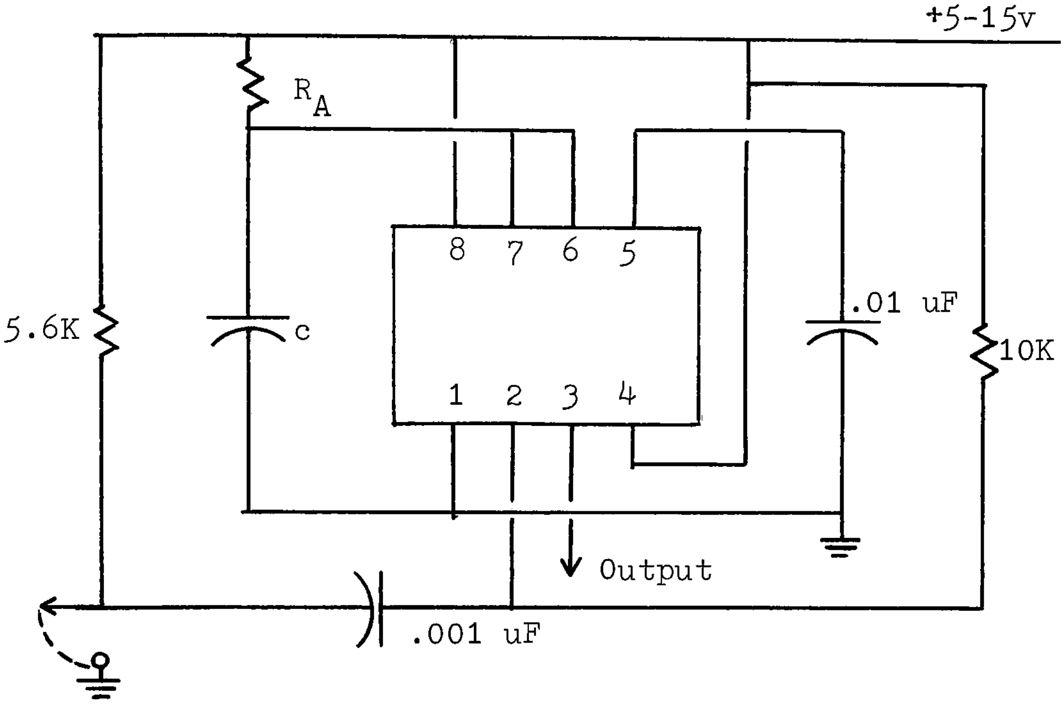
Filter Holder

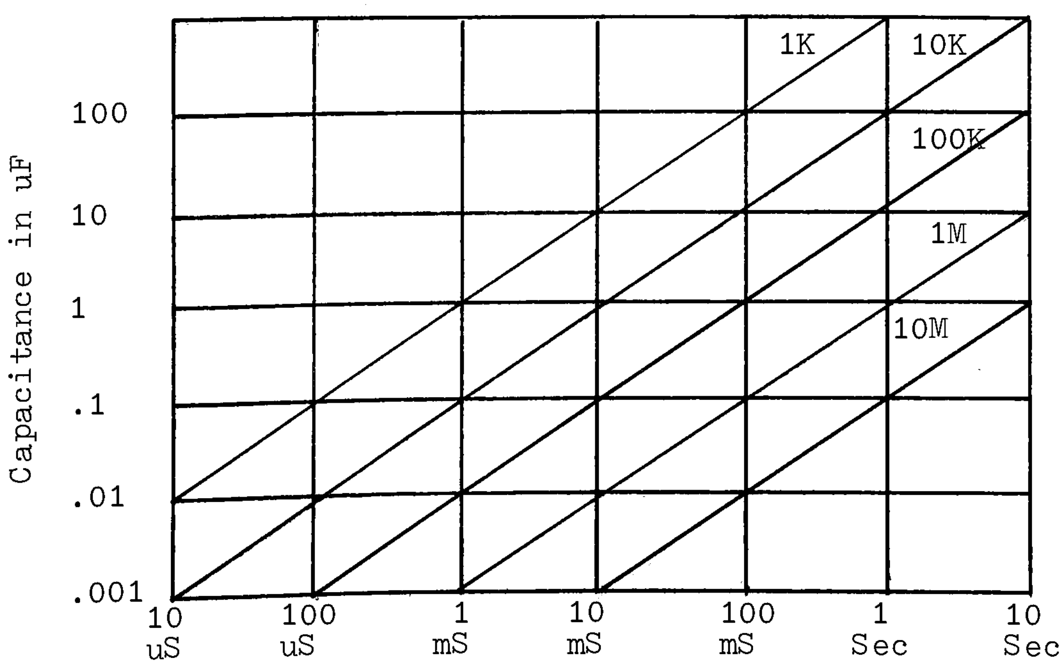
Figure 12




Wiring Layout

Figure 13

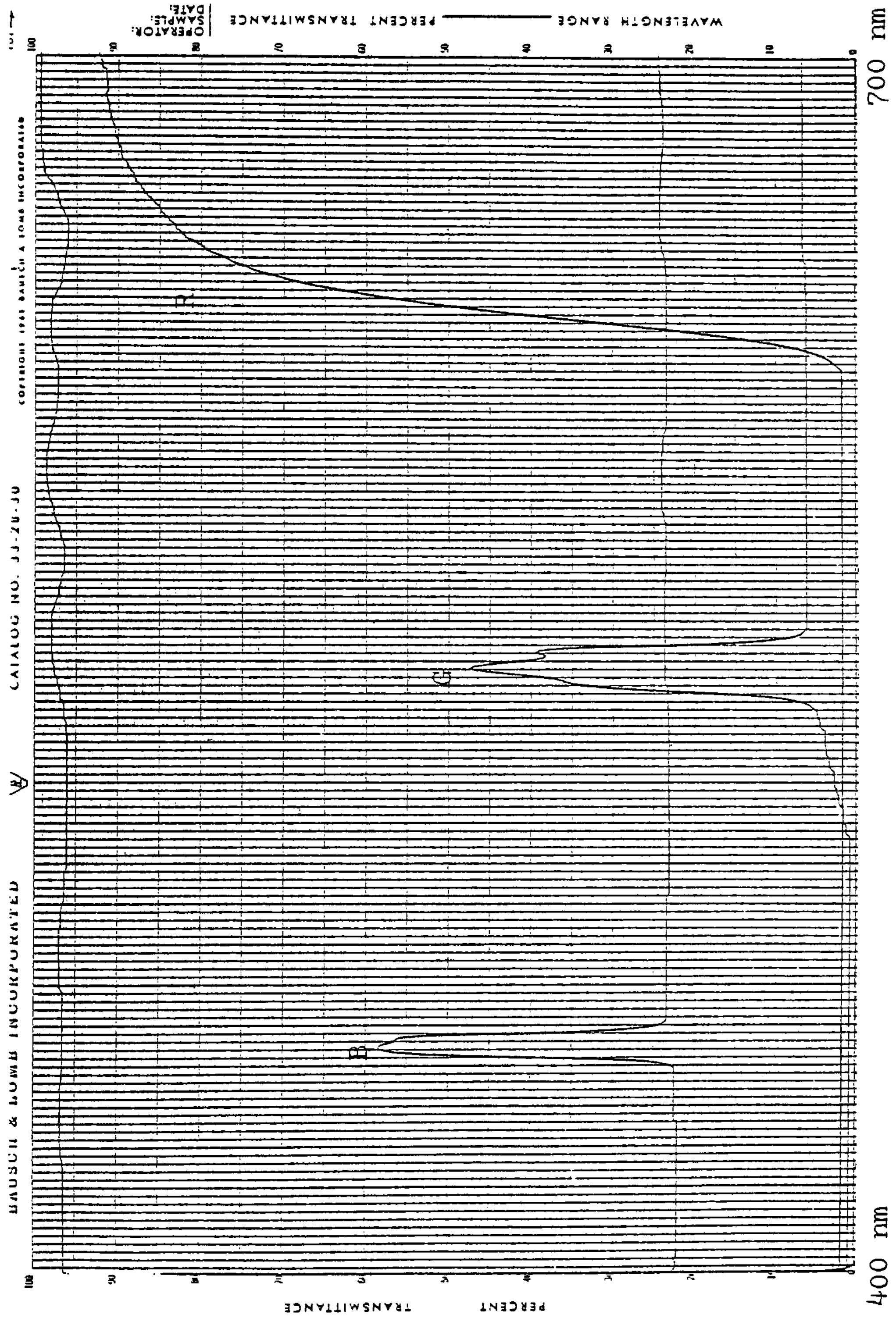



*$R_A$= 5M and c=.1 uF

555 IC Timer Circuit

Figure 14




Filter Transmission vs. Wavelength