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MODIFICATION OF AN AUTOMATIC PHOTOGRAPHIC EXPOSURE SYSTEM, TO CORRECT FOR LIGHT SOURCE COLOR-TEMPERATURE VARIATION

by

Jay Agular

A thesis submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Science in the School of
Photographic Arts and Sciences in the
College of Graphic Arts and Photography
of the Rochester Institute of Technology

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MODIFICATION OF AN AUTOMATIC PHOTOGRAPHIC EXPOSURE SYSTEM, TO CORRECT FOR LIGHT SOURCE COLOR-TEMPERATURE VARIATION

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Jay Agular

Submitted to the
Photographic Science and Instrumentation Division
in partial fulfillment of the requirements
for the Bachelor of Science degree
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ABSTRACT

An attempt was made to correct the spectral sensitivity of a silicon photodiode, by using optical filters, to match the spectral sensitivity of Kodalith ortho film, type 3, 2556, and Kodalith pan film, 2568, respectively. The correction would allow the diode to be used with a light-integrator and light source of varying spectral power distribution, when these films are used. A Corning 9782 blue/green filter was used for the ortho film and an O.C.L.I. detector trimmer, was used for the pan film.

Through experimentation and statistical analysis, it was found that there was 100% correction of the photodiode spectral response, with the Corning filter, from 3200K to

2600K, for the ortho film. There was, however, only partial correction by the O.C.L.I. detector trimmer, of the pan film, from 3200K to 2900K.

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My sincere appreciation and gratitude to

Seymour Schreck
John F. Carson
Brent Archer
Marge Dougherty
Carol Ann Crawford
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INTRODUCTION

In the graphic arts industry, reproduction photography is commonly used to produce high contrast, high quality negative copies of drawings or photographs that are to be reproduced in print. These negatives are used to make the printing plates that will print the image. These negatives, when screened, are called, "halftones"; lith films produce high contrast halftones.

A device that controls the total exposure of the film, is known as a "light integrator". The light-integrator is actually a light-time-integrator. It consists basically of a photovoltaic cell (light-sensor), an amplifier and a capacitor. The light-sensor receives influx energy and converts the influx energy to electrical energy. The electrical energy is amplified and stored in a capacitor. When the stored charge reaches a predetermined level, the current to the light source is disrupted.

The light sources used to illuminate the material being copied are, generally, tungsten lamps, although xenon lamps are also used. These tungsten lamps are usually operated at a color-temperature of 3200K or 3400K. The spectral energy output of these sources extends into the infrared region and is much greater in this region than in the ultraviolet and blue regions. As color-temperature decreases, the red-to-blue ratio increases.

The type of film used for halftone production is high contrast lith film, orthochromatic or panchromatic in sensitivity. Orthochromatic film has little, if any, sensitivity in the red region of the spectrum and no sensitivity to infrared radiation. Panchromatic film has extended sensitivity into the red region, but not the infrared. Therefore, the energy released from the light source in the form of infrared radiation is not used by the film but may be used by the sensor.

Silicon sensors are by nature very sensitive to infrared radiation; therefore, the sensor will efficiently convert the infrared influx energy into electrical energy to be amplified and stored in the capacitor in the light-integrator. The sensor is also sensitive to visible radiation. No problems arise if the color-temperature of the source is kept constant once the system is calibrated with film, but if it is changed or if it fluctuates significantly, the light-integrator will not give proper exposure to the film.

OBJECTIVES

The objectives of this research are:

1) To determine the best set of presently marketed filters that most closely match the sensitivity of each film,

2) To determine if using these filters to match the

spectral sensitivity of the sensor to the spectral sensitivity of each film, respectively, prevents incorrect exposure of the film if color-temperature decreases or fluctuates,

3) To examine the range of color-temperature over which the filters correct exposure to compensate for source color-temperature variation, if they do.

This work has been suggested by Seymour Schreck, Product Manager for Berkey Technical Co., New York, New York. This company manufactures and markets the light-integrator used in this investigation, and presently does not market any filters to be used with the sensor of that integrator.

THEORY

When exposure time necessary to produce a proper halftone is determined (for a given reproduction photography set-up with a specific color-temperature source), the light-integrator is calibrated, such that a certain amount of charge must be stored in the capacitor to produce that exposure time. This amount of charge, produced from visible as-well-as infrared radiation, corresponds to a correct amount of energy usable by the film to achieve proper exposure; however, if the color-temperature of the source is lowered significantly, the total energy output of the source is decreased. This decrease of the total energy output of the source corresponds to a greater percentage decrease in blue radiation output than in red radiation output. The light-integrator responds to the decrease in color-temperature and influx energy by increasing the exposure time. This increased exposure time occurs automatically, since the exposure time is controlled by the amount of charge in the capacitor; it now takes longer for the predetermined amount of charge to be stored because the sensor is receiving less influx energy. However, much more of the influx energy now is infrared than blue, and the film does not utilize infrared radiation. The decrease in blue and visible radiation is more significant to the film than to the sensor and when the capacitor reaches its predetermined level of charge now, the film has not received its necessary amount of energy. The sensor is unable to detect the change in the ratio of red-to-blue light and is unaware of the film's need for blue, not red, light.

HYPOTHESIS

It is suggested that a filter, or set of filters, be placed in front of the sensor to absorb influx radiation from the source that is not used by the film; only wavelengths of radiation that the film is sensitive to would be transmitted to the sensor. In other words, the filter-sensor combination would produce a sensor with an effective spectral sensitivity approximating the spectral sensitivity of the film.

If this filter-pack is placed over the sensor and then the light-integrator is calibrated to produce the proper exposure time necessary to produce the proper exposure, the film would receive the correct amount of exposure even if the color-temperature subsequently changes. The theory supporting this hypothesis is that if the sensor is storing a charge in the capacitor, produced from film-usable radiation only, then independent of the infrared output of the source and change in color-temperature, the sensor will always be detecting the same radiation that the film detects; therefore, the predetermined charge necessary stored in the capacitor, is directly correlated to the amount of usable radiation reaching the film. On this basis, the film will always receive the proper energy input because the sensor must receive a proportional energy input, independent of the time it takes to reach the predetermined level of charge. In other words, if the film is receiving a certain amount of usable radiation, the sensor receives a proportional amount of usable radiation, and when the predetermined amount of charge necessary to be stored in the capacitor for proper exposure is reached, the film also has received proper exposure.

In mathematical terms, we want

$$K_s T(\lambda) S_s(\lambda) = K_f S_f(\lambda) \tag{1}$$

for a given range of wavelengths, a to b; K_s and K_f are constants that normalize each side of the equation for that given range of wavelengths. $T(\lambda)S_s(\lambda)$ represents the response of the filter-sensor combination as a function of wavelength, and $S_f(\lambda)$ represents the sensitivity of the film as a function of wavelength.

$P(\lambda)$, the power output of the source as a function of wavelength, need not be included in the equation because only one source is being used for both the film and the sensor. $P(\lambda)$ would act as a multiplier on each side of the equation, and since $P(\lambda)$ on one side would be equal to $P(\lambda)$ on the other side, it can be divided out of both sides.

With some manipulation of equation 1, it is found that

$$(T(\lambda)S_s(\lambda))/S_f(\lambda) = p \qquad (2)$$

where p is a constant of proportionality. Restating the hypothesis, it is expected that if the deviation of the experimental value obtained for p at each wavelength of a given range of wavelengths is minimized, the effective spectral response of the sensor would approximate the spectral sensitivity of the film used, and exposure would be maintained independent of variation in the source spectral power distribution. Appendin A shows the mathematical progression from equation 1 to equation 2.

CONTINUED DISCUSSION

An important factor affecting the maintaining of proper exposure of the film if source color-temperature changes, is reciprocity law failure[1]. Reciprocity law failure refers to the inability of photographic films to maintain the same level of efficiency of latent image formation for extended/extremely short exposure times and for very high/low influx energy levels. For Kodalith ortho film[2] and Kodalith pan film[3](orthochromatic and panchromatic lith films), 98% of peak efficiency occurs at less than 20 seconds of exposure and more than 77 seconds of exposure; peak efficiency occurs between 33 and 45 seconds of exposure.

It should also be noted that when the filter-pack is placed over the sensor and the light-integrator is calibrated, if the light source is the same color-temperature as it was when the light-integrator was calibrated without the filter-pack over the sensor, and the intensity is the same, the exposure time should be the same. The reason for this is that only the sensor is receiving less input when the filter-pack is placed over it; when the light-integrator is recalibrated with the filter-pack over the sensor, exposure time doesn't change, only the amount of charge to be stored in the capacitor is decreased. If no recalibration takes place when the filter-pack is placed over the sensor, it takes longer for the capacitor to receive the necessary amount of charge than when there was no filter-pack over the sensor. Since there is no attenuation of the light reaching the film and exposure time has been increased, the film is overexposed.

EXPERIMENTAL

The experimental method used to test the hypothesis was rather simple. A sensitometer-like arrangement was set up, where exposure time was controlled by the light-integrator, and color-temperature was altered by a variable power supply to the lamp. After exposure time at the film plane necessary to produce a threshold exposure at a given step of the step-tablet was determined, the light-integrator was calibrated such that the sensor would receive influx energy from the lamp for that predetermined exposure time before interrupting the current to the lamp. This calibration procedure was performed at a lamp color-temperature of approximately 3200K. Once this was accomplished, a series of four separate exposures was made; each exposure was made with a different lamp color-temperature, the first being at 3200K. The length of time of each exposure was recorded to help determine whether or not reciprocity law failure might influence the results. The negatives were then developed and set aside. This series of four exposures was repeated five times. Then the light-integrator was recalibrated (at 3200K lamp color-temperature) with the chosen filter over the sensor, to give the exposure time determined previously for threshold exposure at the given step of the step-tablet. Once again, five series of four different exposures were made. This entire procedure was performed for two different films and their respective chosen filters. When all this work was completed, density measurements of several steps were taken from each negative (steps 4,6,8,10, and 12 on all of the Kodalith ortho negatives, and steps 8,9,10,11 and 12 on the Kodalith pan negatives), and the measurements were recorded for analysis.

Figure 1 shows a simple schematic of the exposing setup. A 24 volt tungsten-halogen lamp was used with a variable d.c. power supply. Table 1 lists the voltage levels at which the supply was set and the approximate color-temperatures of the lamp corresponding to those voltages. The power supply can be set by increments of two volts from

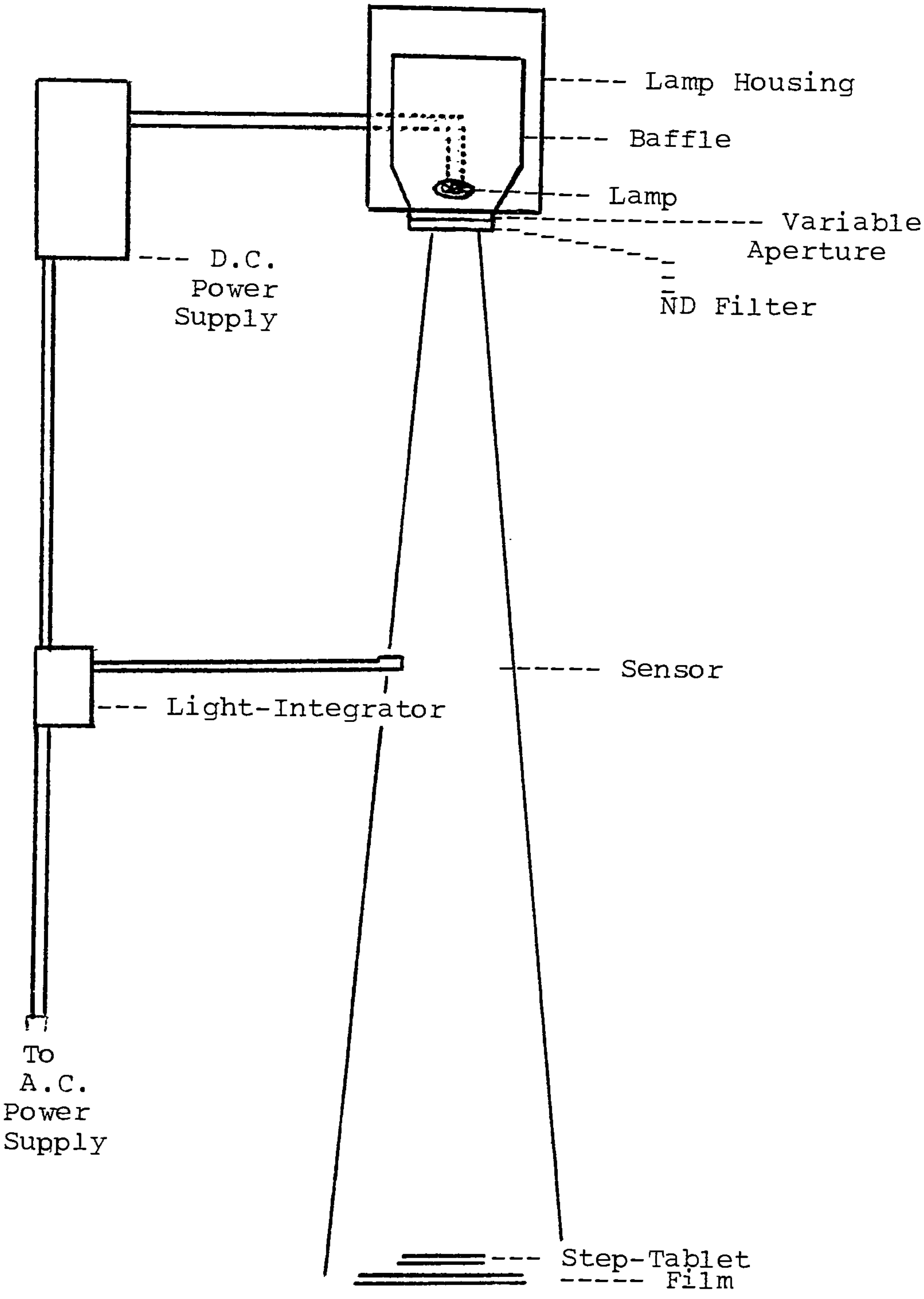

Figure 1. Exposing Set-Up.

Table 1. Lamp Color-Temperature corresponding to Supply Output.

supply voltage (volts)	approximate lamp color-temperature (k)
12¼	2600
16	2800
20	3000
22½	3200

0 to 28 volts, with a vernier control for any voltage between the even integers. In this experimentation, the voltage levels were set between 2 and 2½ volts lower than the desired voltage output, and were raised to the desired level with the vernier (e.g., to output 16 volts, the supply was set at 14 volts and raised with the vernier to 16 volts). The reason for setting the voltage levels in this manner, was to insure better precision of voltage output of the power supply and to avoid the influence of hysteresis on the output.

In order to attenuate the amount of influx energy to the film to provide the proper light level for a given exposure time, it was necessary to use a 1.99 neutral density Inconel filter, at the aperture, for the panchromatic film, and a 0.81 neutral density Inconel filter for the orthochromatic film. These filters are relatively constant in spectral transmittance and therefore do not change the spectral output characteristics of the lamp. Appendix B, figure 1, shows the spectral transmittance characteristics of both filters.

As shown in the schematic of the exposing set-up, the light-integrator sensor was between the light source and the film plane. In practice, the sensor is usually mounted as close to the light source as possible; however, due to the lack of area available within the lamp housing unit, it was necessary to locate the sensor in the light path to the film plane. It should be noted that a Kodak #2 step-tablet was used to make the stepped exposures.

The sensor is a UV/blue PIN5D/B silicon photodiode, made by United Detector Technology, Inc. Figure 2 or 3, shows the normalized spectral response curve of the sensor. As can be seen from either figure, the peak response of the sensor occurs at 830 nanometers wavelength, the near infrared region.

As mentioned earlier, the film types used were Kodalith ortho film, type 3, 2556, and Kodalith pan film, 2568. The spectral sensitivity curves for these films can be found in figures 2 and 3, respectively. These films have no sensitivity to infrared radiation. The filter chosen for the orthochromatic film, was a Corning 9782 blue-green filter; the filter chosen for the panchromatic film was a detector trimmer from Optical Coating Laboratories, Inc. in California. Figure 2 and figure 3 illustrate the normalized sensor spectral sensitivity curves in comparison with the normalized filter-sensor-combination spectral sensitivity

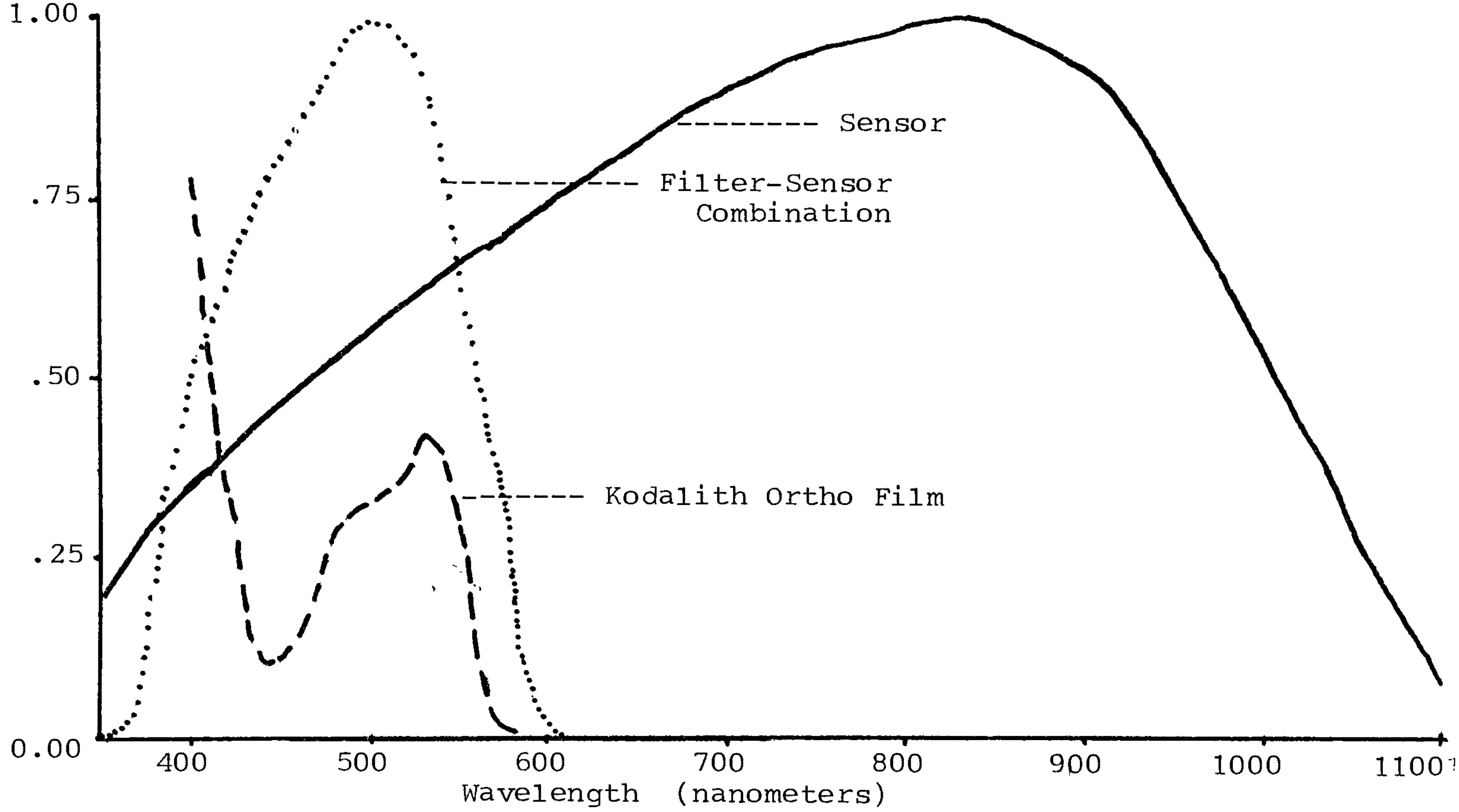

Figure 2. Normalized Spectral Response Curves.

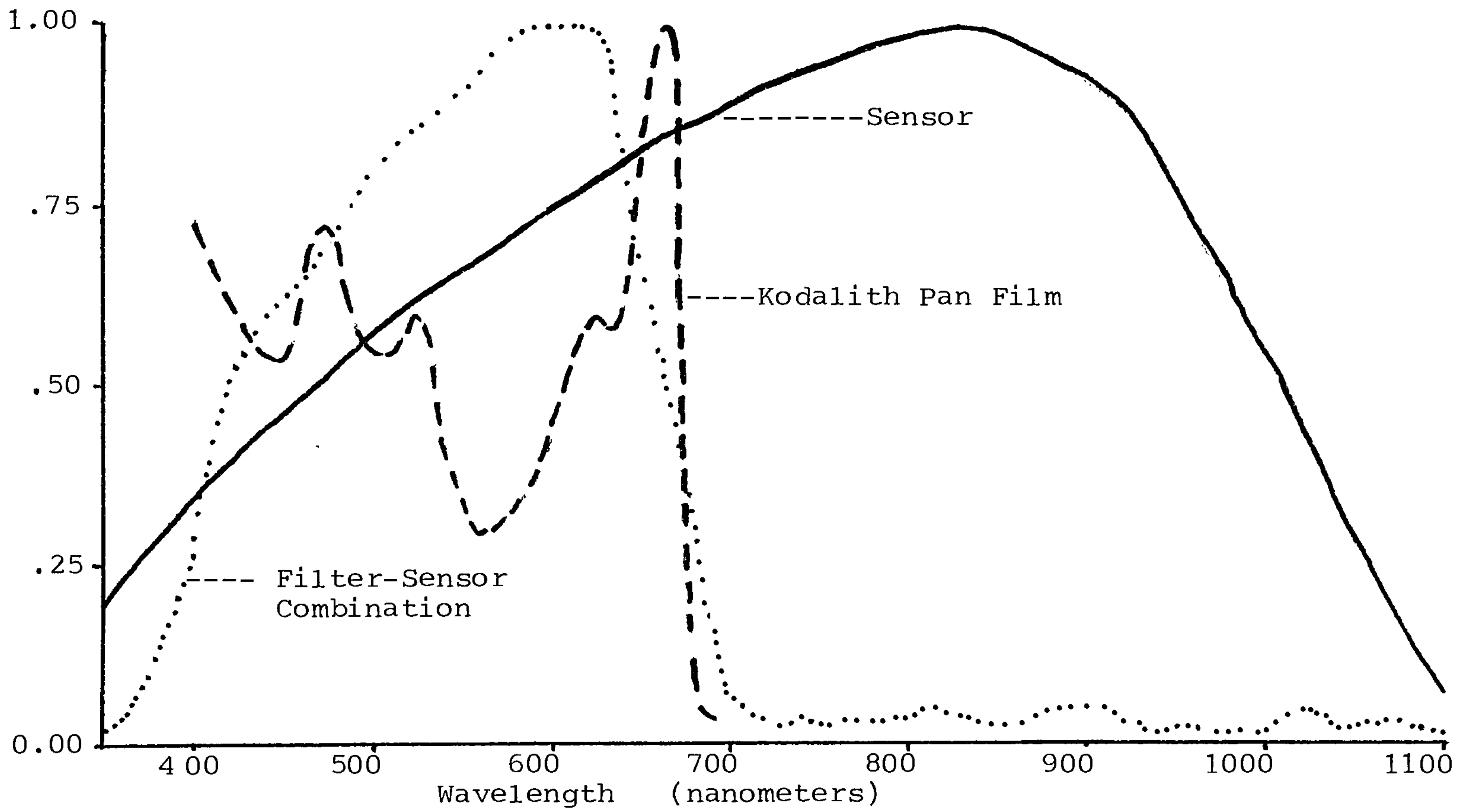

Figure 3. Normalized Spectral Response Curves.

curves, in comparison with the normalized film spectral sensitivity curves, respectively.

Since chemical development of the exposed film is directly related to the achieved film contrast and densities, it was necessary to keep the developing procedure constant. By doing this, discrepancies between negatives, in the density achieved at any particular step, was not attributed to variation in developing procedures.

To help insure equal chemical solution strength for each negative, negatives were developed four at one time and replenishment of developer took place between each set. Appendix C, table 1, lists the chemicals used and their respective corresponding times, and agitation time and procedure. The R.I.T. Tray Rock Method of Agitation was used.

ANALYSIS OF RESULTS

During the actual experimentation, the following factors were noted as possible causes of error in the results:

1) The power supply used was not as stable in output as was necessary to insure no fluctuation in lamp color-temperature.

2) The lamp intensity fluctuated over time, partially due to the instability of the power supply, and possibly partially due to the fact that the lamp is rated at 24 volts and was being operated at 22½ volts and less. The fluctuation was more notable at the lower voltages.

3) Since the negatives were taped to the bottom of the tray they were developed in, removal of the negatives was sometimes hampered; however, no negative was in the developer for more than 15 seconds beyond the prescribed time.

4) The negatives did not always remain affixed to the bottom and floated. This might have affected the results since agitation was not as effective on such negatives. The negatives should remain stationary in the tray.

5) The light-integrator decreases in precision and accuracy as less usable radiation reaches it. When filters were added to the sensor, and therefore less energy was reaching it, repeatability of exposure time at a given lamp color-temperature was decreased. It was necessary to move the sensor closer to the lamp and recalibrate the light-integrator, after the first series of exposures of the panchromatic film with the filter over the sensor, was made.

6) The surface upon which the film was placed was not perfectly flat, and the step-tablet did not lie flush against the film for the first two series of exposures made; therefore, some light did leak under the edge of the step-tablet, to give a greater exposure to the film than was expected. A method of keeping the step-tablet in contact with the film was devised after the second series of exposures was made and developed. This problem

caused some discrepancies in density measurements within steps.

7) The high densities achieved on the negatives, were greater than 5.0. It is most probable that measurements above this point were inaccurate since the densitometer is probably not as accurate at such high densities as it is at lower values.

8) Since the divisions on the voltmeter of the power supply were whole units (the meter is a needle-and-scale type, not digital display), it was difficult to obtain fractional voltages with very high accuracy; therefore, for example, the color-temperature of 2800K was not obtained with high precision whenever the voltmeter was set to 16 volts.

Not all of these causes for error were individually sufficient cause for discrepancies in the results, but together they might have been.

Appendix D, table 1, lists the approximate exposure times of each negative; table 2 lists the lamp-to-sensor distances and their calibration settings, respectively (calibration was at 3200K or 22½ volts). Appendix E, table 1, lists the measured densities of each negative at chosen steps, and orders the measurements by film type, filter-sensor arrangement, replication series number, step, and color-temperature.

Table 2, shows the average densities measured for each

Table 2. Average Densities for each exposure.

Film	Filter	Step	Color-Temperatures (K)			
			3200	3000	2800	2600
ortho	none	4	.03	.03	.02	.02
		6	.58	.40	.17	.03
		8	2.82	2.29	2.26	2.23
		10	4.42	4.36	3.77	2.76
		12	5.41	5.29	4.87	4.10
	9782	4	.04	.04	.10	.04
		6	1.65	1.41	1.98	1.73
		8	3.48	3.32	3.60	3.37
		10	4.75	4.63	4.80	4.62
		12	5.59	5.58	5.56	5.52
pan	none	8	.10	.09	.08	.07
		9	.72	.69	.40	.09
		10	2.24	2.10	1.81	.55
		11	3.40	3.38	2.69	1.61
		12	4.40	4.16	3.49	2.57
	OCLI	8	.32	.29	.18	.19
		9	1.30	1.32	1.15	.70
		10	2.78	2.47	2.21	1.89
		11	3.64	3.33	3.03	2.65
		12	4.28	4.12	3.66	3.39

film-type, sensor-filter combination, step and color-temperature. This is the set of data analyzed. It should be noted that for the panchromatic film, with the filtered sensor, the density measurements in the averaged values, do not include the first series of that combination; the values were obtained from the average of series 2,3,4 and 5 of that combination. This is due to the imprecision and inaccuracy of the sensor and light-integrator at low light levels. As mentioned earlier, it was necessary to move the sensor closer to the lamp and recalibrate the light-integrator after the first series of the combination.

By observation alone, it can be seen from table 2, that for the ortho film with no filter over the sensor, as color-temperature decreased, the developed densities for each step decreased. This shows that as color-temperature decreases, exposure is not maintained by the light-integrator when there is no filter over the sensor (for the ortho film). However, the densities achieved at each step, for this film, when the sensor is filtered, are approximately equal for each source color-temperature. The data shows clearly that for the orthochromatic film, the filtered sensor maintains exposure over a range of 3200K to 2600K, whereas the unfiltered sensor does not.

The effect of the filtered sensor for the panchromatic film is not as obvious; therefore, it is necessary to use a statistical approach to draw conclusions from this data.

The Kolmogorov-Smirnov "goodness-of-fit" test[4] was used to analyze this data; table 3, shows the probability that the exposure at any of the given color-temperatures, is the same as the exposure at 3200K for either the filtered or unfiltered sensor, and for both films.

Table 3. Probability of equivalent exposure.

Film	Filtered?	Source Color-Temperature Shift (K)		
		3200-3000	3200-2800	3200-2600
ortho	no	.960	.650	0.000
	yes	1.000	1.000	1.000
pan	no	.999	.278	0.000
	yes	.999	.760	.170

As can be seen from table 3, the light-integrator maintains exposure of the pan film without a filter over the sensor, from 3200K to 3000K but not at a color-temperature less than 3000K. Clearly, the filtered sensor maintains exposure of the pan film over a wider range of color-temperatures than does the unfiltered sensor; however, this filter still does not give a good enough match of the spectral response of the filter-sensor combination to the spectral sensitivity of the pan film. It is most probable that too much infrared radiation still reaches the sensor, and an additional filter or increased thickness of the filter (the detector trimmer from OCLI) might reduce sufficiently the amount of infrared radiation reaching the sensor. This would increase the range of color-temperatures over which exposure is maintained.

It is also possible that exposure was not maintained well because exposure time increased to a critical point where reciprocity law failure had a sizeable amount of influence; exposures were about two minutes long at 2600K. However, exposures for the ortho film recorded three minutes when the filter was used, and exposure was maintained even at 2600K; therefore, it does not seem that likely that reciprocity law failure was a cause for the discrepancy until the pan film tests.

SUMMARY AND CONCLUSION

In order to make clear the sum total of what has been done, the following material briefly summarizes the experiment, the results and the conclusions. The answers to the objectives and hypothesis are contained in this material.

Sensitometric exposures were made on Kodalith ortho film, type 3, and Kodalith pan film, where the source color-temperature was decreased successively from 3200K to 2600K in steps of 200K. Instead of using a sector-wheel as a shutter, a B.T.C. light-integrator was used to interrupt the current to the lamp power supply.

The light-integrator has a photodiode connected to it to receive energy from the lamp, such that when the light-integrator is calibrated properly, it will turn off the lamp when the film has been properly exposed. The light-integrator is supposed to keep the lamp on for as long as is necessary to properly expose the film, even if the output of the lamp changes; however, when the output of the lamp is decreased, the color-temperature of the lamp decreases, and the photodiode, not sensing the change in color-temperature, does not increase the exposure time enough to maintain the same exposure.

Two filters were found, that would when placed in front of the photodiode help match the spectral response of the photodiode to the spectral sensitivity of either film. Again, sensitometric exposures were made on each film, at the four color-temperatures mentioned; but this time the light-integrator was calibrated and used with a filter over the sensor. The ortho film was exposed with a Corning filter over the sensor, and the pan film was exposed with an O.C.L.I. "detector trimmer" filter over the sensor.

The experiment was repeated five times to decrease the influence of error in the results; four sets of averaged characteristic data were obtained. The data represents the exposures on both films to the four different color-temperatures, when the photodiode was and wasn't filtered to match the spectral sensitivity of the films.

It was found that the Corning filter very closely approximated the photodiode spectral response to the ortho film spectral sensitivity; it maintained exposure from 3200K down to 2600K. The O.C.L.I. "detector trimmer" did not approximate the spectral response of the photodiode to the pan film spectral sensitivity like the other film-filter set; however, it did partially maintain exposure from 3200K to between 2800K and 3000K.

In conclusion, the hypothesis was proven correct. Without a reasonable doubt, it must be concluded that matching the spectral response of the light-integrator sensor to the spectral sensitivity of the film being used, does indeed correct exposure for light source color-temperature variation.

FOOTNOTES

1. Kodak Professional Black-and-White Films; Kodak publication, F-5, Eastman Kodak Co., 1976.
2. Personal communication with Brent Archer, Graphic Arts Research Center, Rochester Institute of Technology, Rochester, New York.
3. Personal communication with Seymour Schreck, Berkey Technical Co., New York, New York.
4. Kolmogorov-Smirnov Type Test; by David Jasinski, paper for course PPHS 413, Rochester Institute of Technology, Rochester, New York, 1979.

APPENDICES

APPENDIX A

Progression from equation 1 to equation 2.

$$K_sT(\lambda)S_s(\lambda) = K_fS_f(\lambda) \quad , \qquad (1)$$

$$\frac{K_sT(\lambda)S_s(\lambda)}{K\ S\ (\lambda)} = 1 \quad ,$$

$$\frac{T(\lambda)S_s(\lambda)}{S_f(\lambda)} = \frac{K_f}{K_s} = p$$

$$\frac{T(\lambda)S_s(\lambda)}{S_f(\lambda)} = p \qquad (2)$$

APPENDIX B

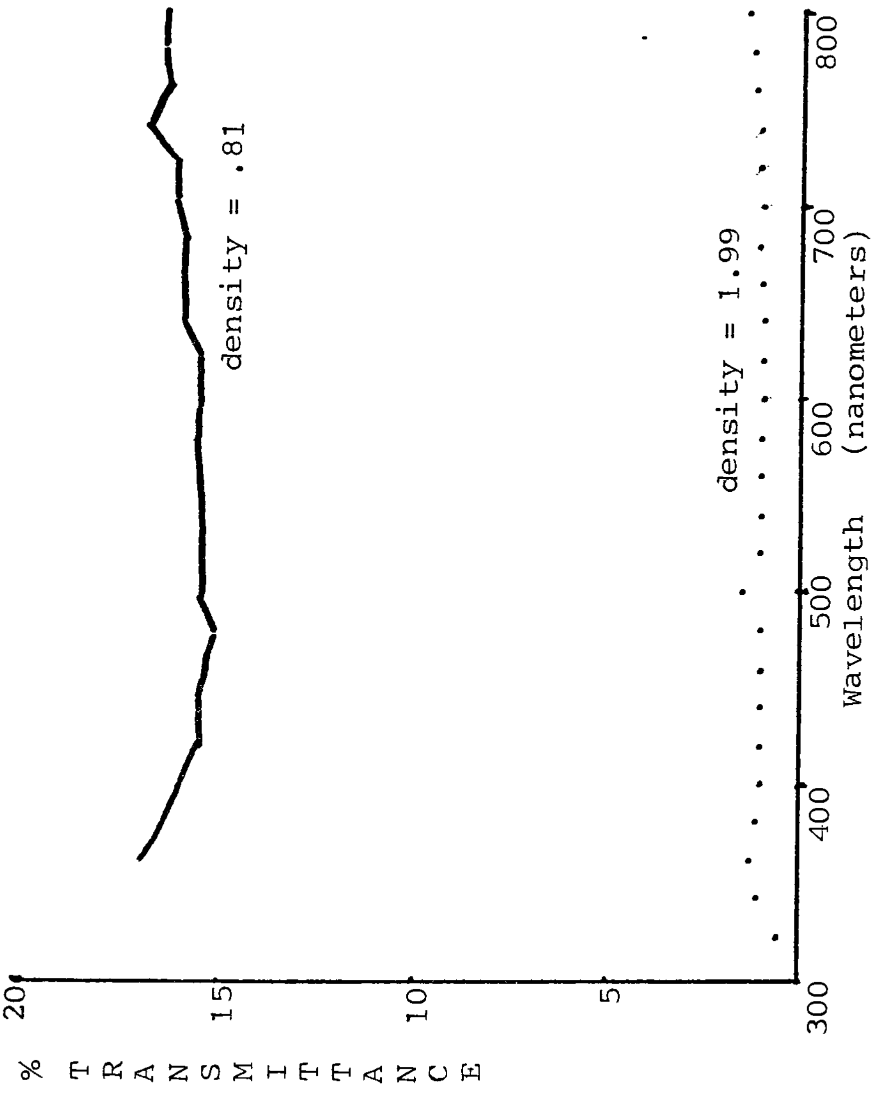

Figure 1. Transmittance of Inconel ND Filters.

APPENDIX C

Table 1. Chemical Dilutions and Development Times.

	ortho film	pan film
Kodalith A and Kodalith B (1:1)	2.75 min.	2.50 min.
Agitation	continuous	continuous
28% Acetic Acid	30 sec.	30 sec.
F6 Fixer (working strength)	5 min.	5 min.
Water Rinse	15 min.	15 min.

APPENDIX D

Table 1. Approximate exposure time of each negative. (sec.)

Film	filtered?	Color-Temp. (K)	Replication				
			1	2	3	4	5
ortho	no	3200	20	20	20	21	18½
		3000	24	25	25	23½	24
		2800	39½	39½	38	39½	35½
		2600	72	65	62	67	71
	yes	3200	20½	19	21½	20	22
		3000	27½	27½	30	27½	31
		2800	68½	70	68	68½	63
		2600	171	199	172	172	170
pan	no	3200	20	21	19½	22½	20
		3000	25	26	26½	26	27
		2800	39½	39½	39½	39½	40½
		2600	75	80	85	84½	79
	yes	3200	24	22	20½	20½	21
		3000	31	26½	34	26½	28
		2800	50	53	53	50½	49½
		2600	124	128	137	147	120

Table 2. Lamp-to-sensor distances and calibration settings.

Condition	Lamp-to-Sensor	Settings
ortho film, no sensor filtering	63". 0.81 ND filter	020, 0.8 on sensor
sensor filtering	44". 0.81 ND filter	013, 2.0 on sensor

Table 2 continued.

Condition	Lamp-to-Sensor	Settings
pan film, no sensor filtering	44". 1.99 ND filter	020, 1.6 on sensor
sensor filtering, set 1.	33½". 1.99 ND filter	007, 2.0 on sensor
sensor filtering, reps 2-5	24½". 1.99 ND filter	012, 2.0 on sensor

APPENDIX E

Table 1. Actual densities measured.

		ortho film unfiltered sensor			
reps.	step	3200	3000	2800	2600
1	4	.03	.03	.02	.03
	6	.13	.08	.05	.03
	8	2.65	2.23	2.46	.69
	10	4.51	4.28	3.83	3.00
	12	5.48	5.30	4.87	4.29
2	4	.04	.02	.02	.02
	6	.08	.05	.06	.03
	8	2.76	1.43	2.21	.38
	10	4.30	3.89	3.86	2.70
	12	5.28	5.34	4.96	4.11
3	4	.03	.03	.02	.02
	6	.43	.33	.16	.03
	8	2.56	2.69	2.13	1.06
	10	4.44	4.23	3.68	2.71
	12	5.45	5.31	4.83	4.01
4	4	.03	.02	.03	.02
	6	1.14	.57	.54	.02
	8	3.09	2.66	2.37	.92
	10	4.47	4.06	3.82	2 69
	12	5.41	5.16	4.88	4.04
5	4	.03	.03	.02	.02
	6	1.10	.95	.16	.03
	8	3.05	2.96	2.14	1.13
	10	4.36	4.33	3.64	2.72
	12	5.45	5.34	4.79	4.04

Table 1 continued.

		ortho film sensored filter			
reps.	step	3200	3000	2800	2600
1	4	.05	.02	.13	.04
	6	1.84	.52	1.97	1.51
	8	3.60	2.95	3.56	3.15
	10	4.98	4.34	4.86	4.49
	12	5.61	5.56	5.63	5.32
2	4	.03	.04	.08	.05
	6	.56	1.61	2.13	2.02
	8	3.25	3.46	3.72	3.66
	10	4.57	4.80	4.88	4.88
	12	5.56	5.67	5.61	5.63
3	4	.04	.06	.12	.03
	6	1.91	1.49	1.91	1.88
	8	3.46	3.38	3.59	3.39
	10	4.71	4.66	4.76	4.64
	12	5.57	5.56	5.46	5.32
4	4	.05	.02	.10	.03
	6	1.80	1.32	1.93	1.61
	8	3.46	3.22	3.45	3.22
	10	4.67	4.54	4.72	4.53
	12	5.54	5.50	5.48	5.74
5	4	.05	.06	.05	.04
	6	2.14	2.11	1.95	1.65
	8	3.63	3.60	3.57	3.44
	10	4.84	4.83	4.78	4.56
	12	5.68	5.62	5.63	5.59

Table 1 continued.

		pan film unfiltered sensor			
reps.	step	3200	3000	2800	2600
1	8	.10	.09	.09	.07
	9	.59	.23	.11	.08
	10	2.08	1.40	1.29	.10
	11	3.28	2.94	2.43	.83
	12	4.14	3.77	3.22	2.07
2	8	.12	.11	.09	.08
	9	.60	.85	.18	.09
	10	2.00	2.29	1.77	.14
	11	3.44	3.27	2.46	1.62
	12	4.32	4.02	3.26	2.58
3	8	.08	.93	.08	.06
	9	.12	2.16	.59	.07
	10	1.19	2.96	2.01	.12
	11	2.86	3.64	2.90	1.63
	12	4.15	4.36	3.74	2.71
4	8	.43	.08	.06	.07
	9	2.03	.45	.40	.09
	10	2.99	1.98	2.05	1.14
	11	3.88	3.31	2.93	2.01
	12	4.68	4.19	3.75	2.77
5	8	.10	.12	.09	.08
	9	.25	1.22	.71	.10
	10	1.93	2.74	1.92	1.24
	11	3.56	3.73	2.73	1.96
	12	4.72	4.44	3.50	2 72

Table 1 continued.

		pan film filtered sensor			
reps.	step	3200	3000	2800	2600
1	8	.81	.07	.06	.06
	9	1.98	.13	.18	.10
	10	2.94	1.10	1.51	1.27
	11	3.70	2.71	2.61	2.21
	12	4.35	3.78	3.36	2.96
2	8	.10	.09	.08	.07
	9	.86	1.23	1.02	.51
	10	2.87	2.29	2.15	1.73
	11	3.72	3.17	3.00	2.51
	12	4.50	3.93	3.73	3.26
3	8	.09	.08	.08	.07
	9	.75	1.22	.57	.31
	10	2.57	2.59	2.14	1.89
	11	3.54	3.53	3.01	2.76
	12	4.31	4.31	3.75	3.47
4	8	.35	.87	.31	.53
	9	1.59	1.69	1.58	1.42
	10	2.72	2.48	2.37	2.11
	11	3.54	3.29	3.12	2.87
	12	4.33	4.09	3.83	3.59
5	8	.74	.10	.23	.08
	9	1.98	1.15	1.44	.54
	10	2.90	2.50	2.17	1.73
	11	3.76	3.35	2.97	2.41
	12	4.50	4.13	3.70	3.25