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Small area densitometry utilizing fiber optics

Eric D. Bruening

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SMALL AREA DENSITOMETRY
UTILIZING FIBER OPTICS

by

Eric D. Bruening

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

May 12, 1981

Signature of the Author........Eric D. Bruening........
Photographic Science
and Instrumentation

Certified by........Frank J. Bogachi........
Thesis Advisor

Accepted by..
Supervisor, Undergraduate Research

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Eric D. Bruening

Submitted to the
Photographic Science and Instrumentation Division
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ABSTRACT

A transmission densitometer utilizing fiber optics for the efflux geometry was designed, constructed, and tested with several black and white films, and one color film. The system was semi-specularly illuminated and used semi-specular collection. The system demonstrates the feasibility of using fiber optic bundles in sensitometric equipment. Scattering properties of silver emulsions, color dye Infra-red radiation transmission, and assorted electronic factors which introduce error in densitometric values are observed and discussed.

To

Kevin, Pam, Rick, John, Deepak, Harold, Cathy, Lynn and Fred

I love you all

ACKNOWLEDGMENTS

Special thanks to Mr. Fred Behnke of the Eastman Kodak Co., who shared many long discussions with the author of this text, provided motivation when it was felt nothing would ever work, and supplied the majority of the equipment used to build and test the Fiber Optic Transmission Densitometer.

The author would also like to thank Mr. Frank Bogacki for advising this thesis at a great personal sacrifice of his own valuable time.

To Dr. Ed Granger, who supplied the Silicon photocell and the Radio Shack voltmeter.

The author would also like to extend his thanks to Professor Al Rickmers, whose wise words guided this project to its completion, and steered it away from the treacherous rocks of disillusionment and despair.

And last, but surely not least, my warmest thanks to Professor John F. Carson, whose enthusiasm, patience, experience and gentle disposition have made the whole Photographic Science program an enjoyable, challenging and rewarding one.

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INTRODUCTION

This thesis deals with the design and construction of a densitometer which uses fiber optic bundles as the transmission system. Idealy, the final model would contain no lenses or mirrors; in order to have sufficient energy throughout the system, it was necessary to use one lens in the influx geometry.

Fiber optic bundles operate as light pipes. The acceptance cone angle of off-axis rays is determined by the critical angle of the bundle. The critical angle is the maximum angle at which a ray can enter the core of a fiber, propagate to the surrounding cladding, and then be reflected back through the core; this is a function of the index of refraction for both the core and the cladding. Typical cone half-angles are approximately 30 degrees.

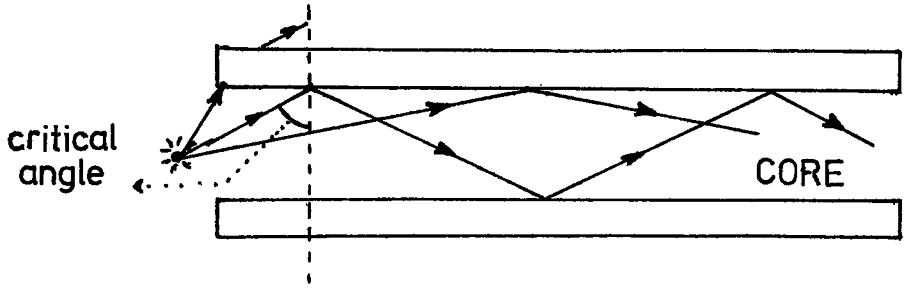


Figure 1

The major advantage of fiber optic optical systems is the ability to bend the optical path around corners, or separate the detector system from the output system without worrying about transmitting through the atmosphere. It was felt that some attempt should be made to utilize fiber bundles in sensitometric equipment; a long range goal would be the miniaturization of sensitometers and densitometers.

Building a transmission densitometer using fiber bundles would serve to show the feasibility of fiber bundle transmission systems as well as examine some of the characteristics associated with such a system. From this type of data, further work on sensitometry, reflection densitometry, and microdensitometry could be attempted.

APPARATUS

A schematic of the final Fiber Optic Transmission Densitometer (FOTD) is shown in Figure 2. From left to right, the system was composed of:

25 watt Bausch and Lomb microscope lamp
Ealing Bi-Convex, 5 cm. focal length lens
Corning 90-21 Cold Mirror
6 mm. thick piece of Infra-red absorbing glass
Empty slide mount
Fiber bundle (32 or 18 fibers in diameter)
Silicon photocell plus operational amplifier
Radio Shack digital voltmeter

The influx geometry had a half-angle of 35 degrees and the efflux geometry had a half-angle of 30 degrees.

Several detector and amplifier circuits were investigated prior to settling on the circuit shown in Figure 3. This arrangement yielded the best signal-to-noise-ratio and had the greatest useable sensitivity over the largest optical range. Among those combinations rejected were photodarlingtons and PIN photodiodes. The photodarlingtons were too sensitive and had a tendency to saturate or burn out. The PIN photo diodes were difficult to operate in the linear region.

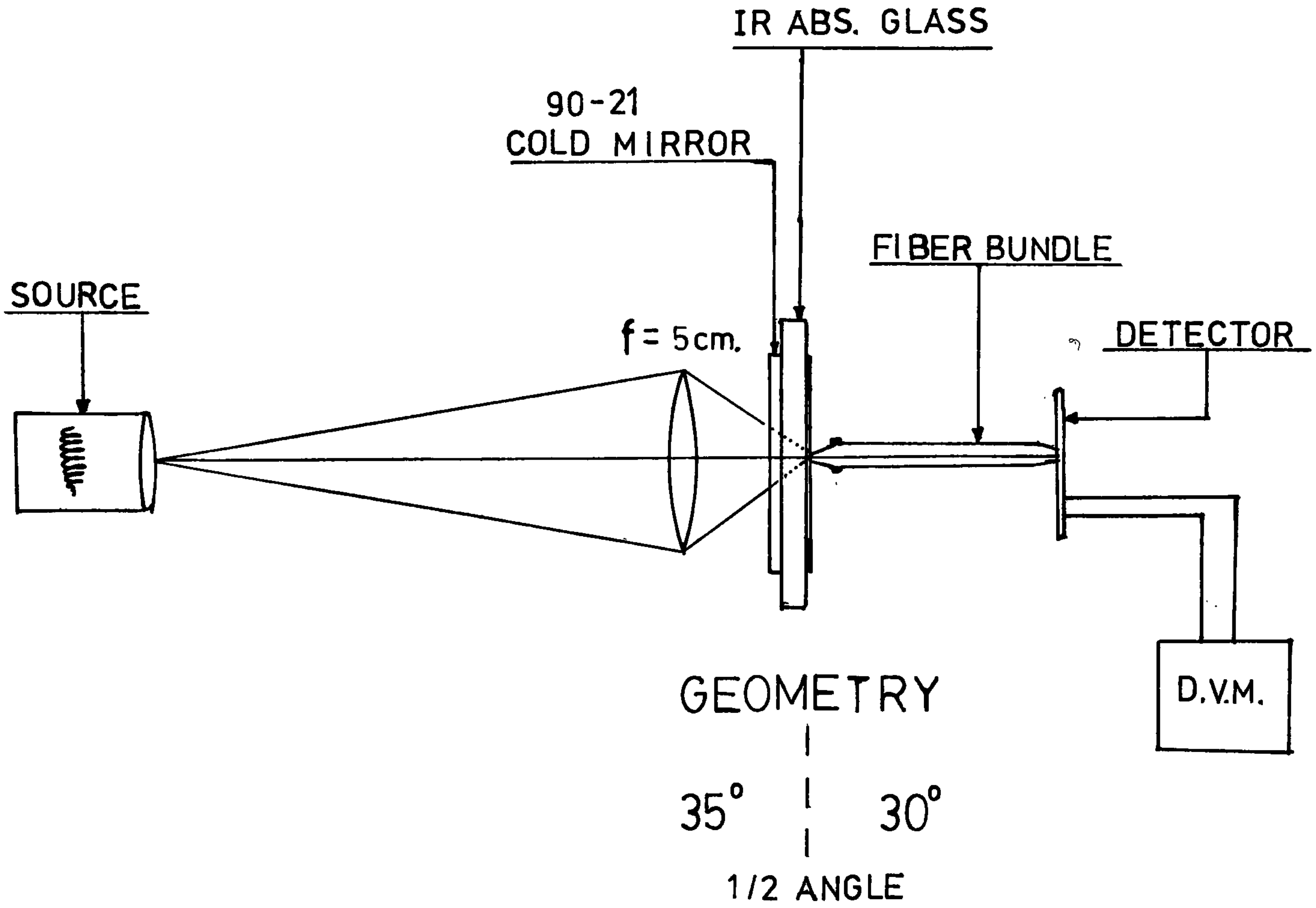

IR ABS. GLASS
90-21
COLD MIRROR
FIBER BUNDLE
SOURCE
f = 5cm.
DETECTOR
D.V.M.
GEOMETRY
35°
30°
1/2 ANGLE

Figure 2

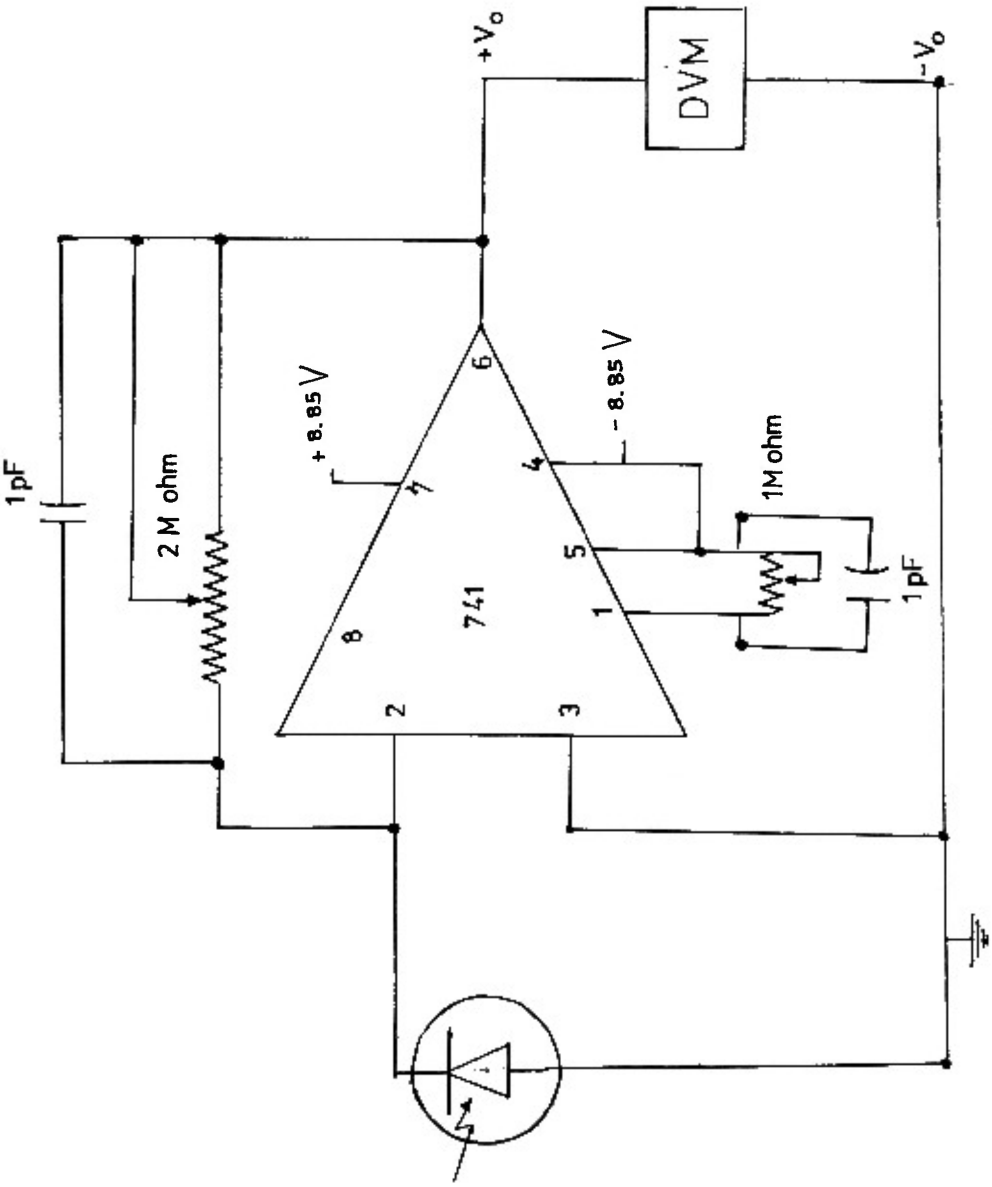


Figure 3

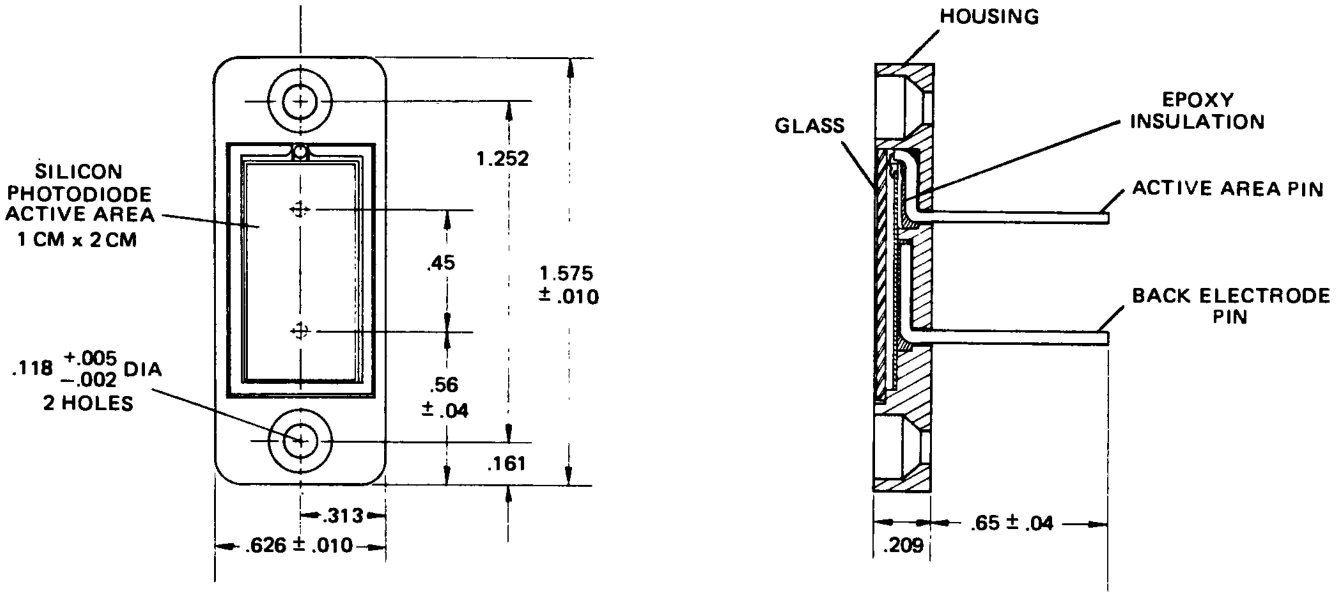
THE DETECTOR SYSTEM

The silicon photocell, used in the photovoltaic mode, was followed by a 741 operational amplifier, used in the inverting mode to increase the output. Noise in the system would lead to erroneous density measurements. An attempt was therefore, made to avoid overly large and numerous resistors. It was for this reason that only one op-amp was used, rather than a cascaded system.

The 741 was powered by two 9 V transistor batteries. These batteries are not stable voltage supplies, and should be avoided in any future work; they introduce noise in the sense that the offset DC voltage continually fluctuates, making measurements at the output of less than 0.01 volts questionable. Although the offset null was adjusted before every run, to a value of 0.000 = 0.003 volts, the average offset voltage at the completion of 36 experiments was .00189 volts with a standard deviation of .003205 volts. The capacitors across the 2 MΩ and 1 MΩ pots average out any signal fluctuations, making the response of the system slighlty more well-behaved.

The physical dimensions of the Silicon photocell are shown in Figure 4. The majority of the cell's surface area was not being used and was taped over to prevent stray light

MECHANICAL CHARACTERISTICS



ALL DIMENSIONS IN INCHES
NOTE: ALL DIMENSIONS GIVEN ARE FOR REFERENCE ONLY

1. FOR REVERSE BIAS APPLY NEG (−) VOLTAGE TO ACTIVE AREA AND APPLY POS (+) VOLTAGE TO BACK ELECTRODE.

Figure 4

from striking its surface. The fiber bundle hooked up to a connector 6 mm square which was secured to the cell insuring consistent readings on the same area of the detector. The detector's response peaks in the near Infra-red as seen in Figure 5. This was corrected somewhat by the filtration throughout the system.

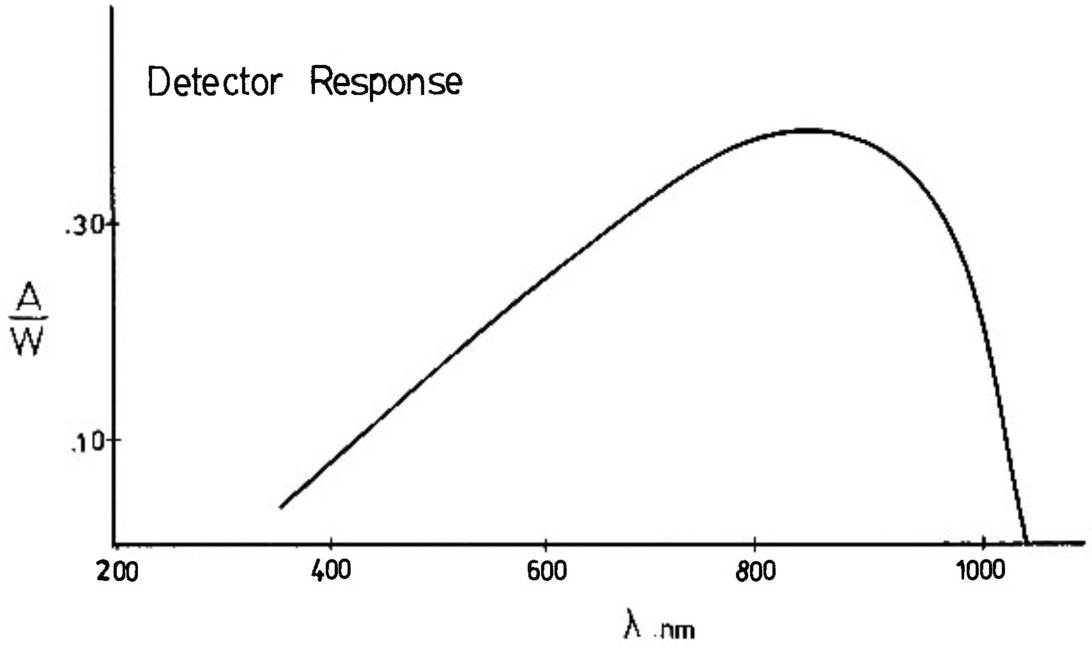


Figure 5

INFLUX CHARACTERISTICS

An EG+G 555 spectro radiometer was used to measure the spectral output of the lamp as filtered by the infra-red absorbing glass. A plot of the data is shown in Figure 6. The spectral throughput with the Corning 90-21 cold mirror in place was not determined due to problems experienced with the spectro-radiometer.

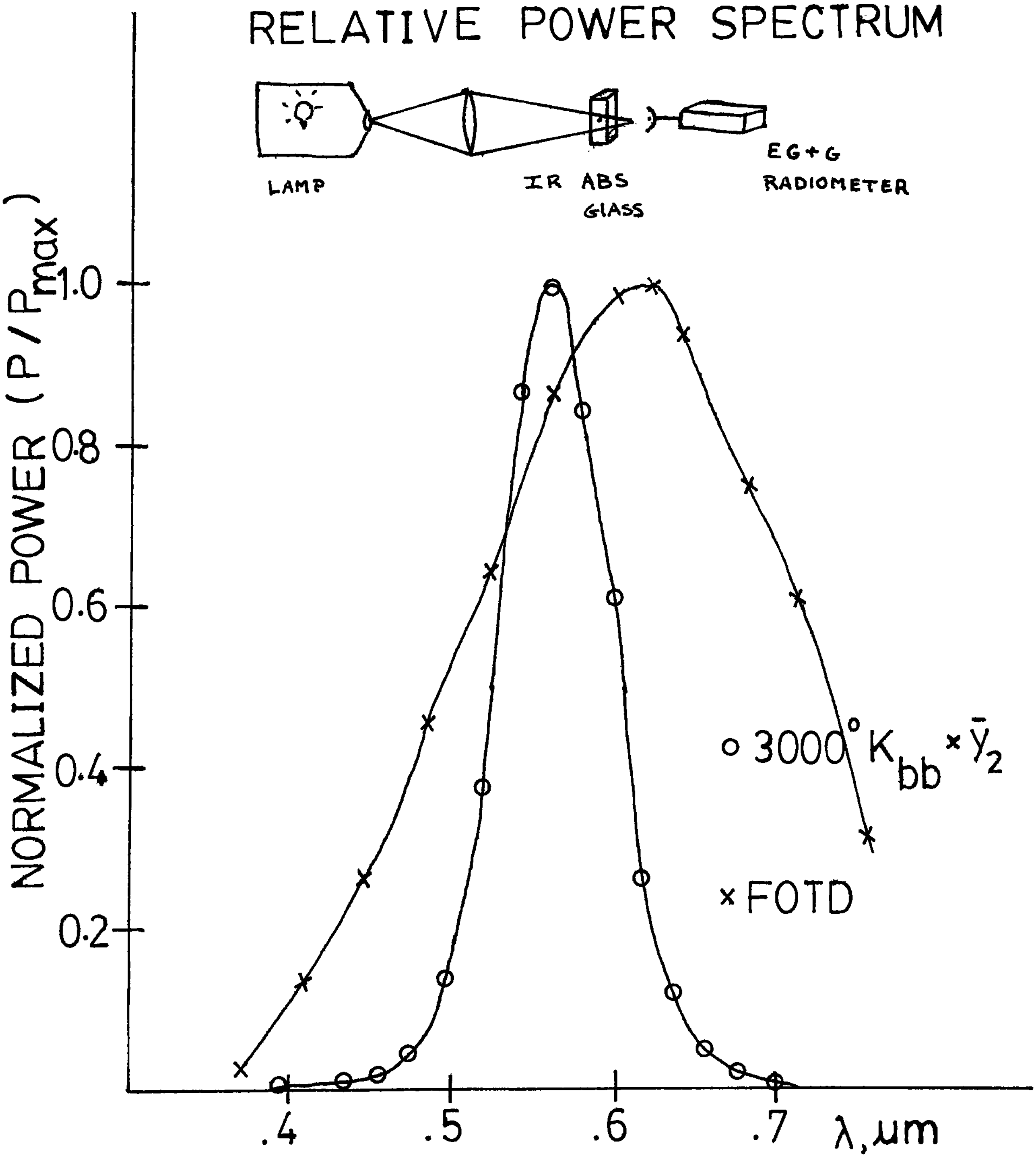

RELATIVE POWER SPECTRUM
LAMP
IR ABS GLASS
EG+G RADIOMETER
NORMALIZED POWER (P/P_{max})
1.0
0.8
0.6
0.4
0.2
○ 3000°K_{bb} × $\bar{y}_2$
× FOTD
.4
.5
.6
.7
λ, μm

Figure 6

EFFLUX CHARACTERISTICS

Figures 7 and 8 show the numerical aperture and transmission of the fiber bundles verses wavelength, respectively. Over the region of consideration, it is clear that the fibers do not spectrally filter the throughput, and the system's spectral response will be dominated by that of the detector, source and IR filter. The average numerical aperture of the fibers is 0.325.

The final system spectral response is shown in Figure 9. Again notice the definite shift toward the IR region as compared to the product of the spectral output of a 3000 K blackbody radiator and the CIE photopic luminosity function.* The amount of filtration needed to correct the response would have cut the power of the system too greatly.

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* ANSI Ph2.19-1976: American National Standard Conditions for Diffuse and Doubly Diffuse Transmission Measurements (Transmission Density).

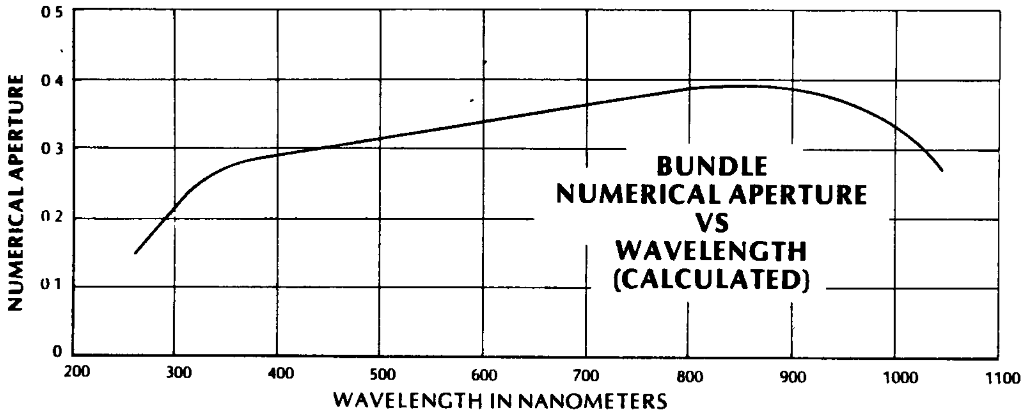
BUNDLE
NUMERICAL APERTURE
VS
WAVELENGTH
(CALCULATED)
NUMERICAL APERTURE
0 5
0 4
0 3
0 2
0 1
0
200
300
400
500
600
700
800
900
1000
1100
WAVELENGTH IN NANOMETERS

Figure 7

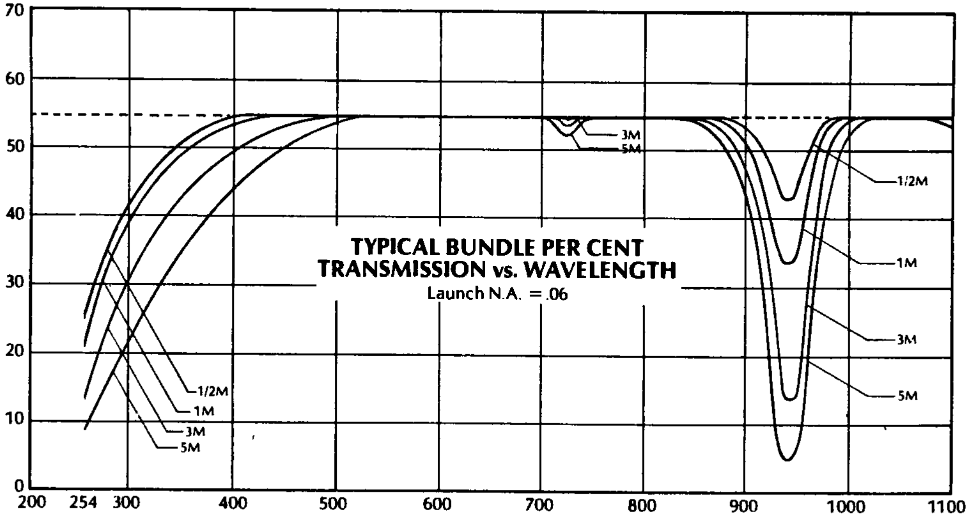
TYPICAL BUNDLE PER CENT
TRANSMISSION vs. WAVELENGTH
Launch N.A. = .06
70
60
50
40
30
20
10
0
200
254
300
400
500
600
700
800
900
1000
1100
1/2M
1M
3M
5M
3M
5M
1/2M
1M
3M
5M

Figure 8

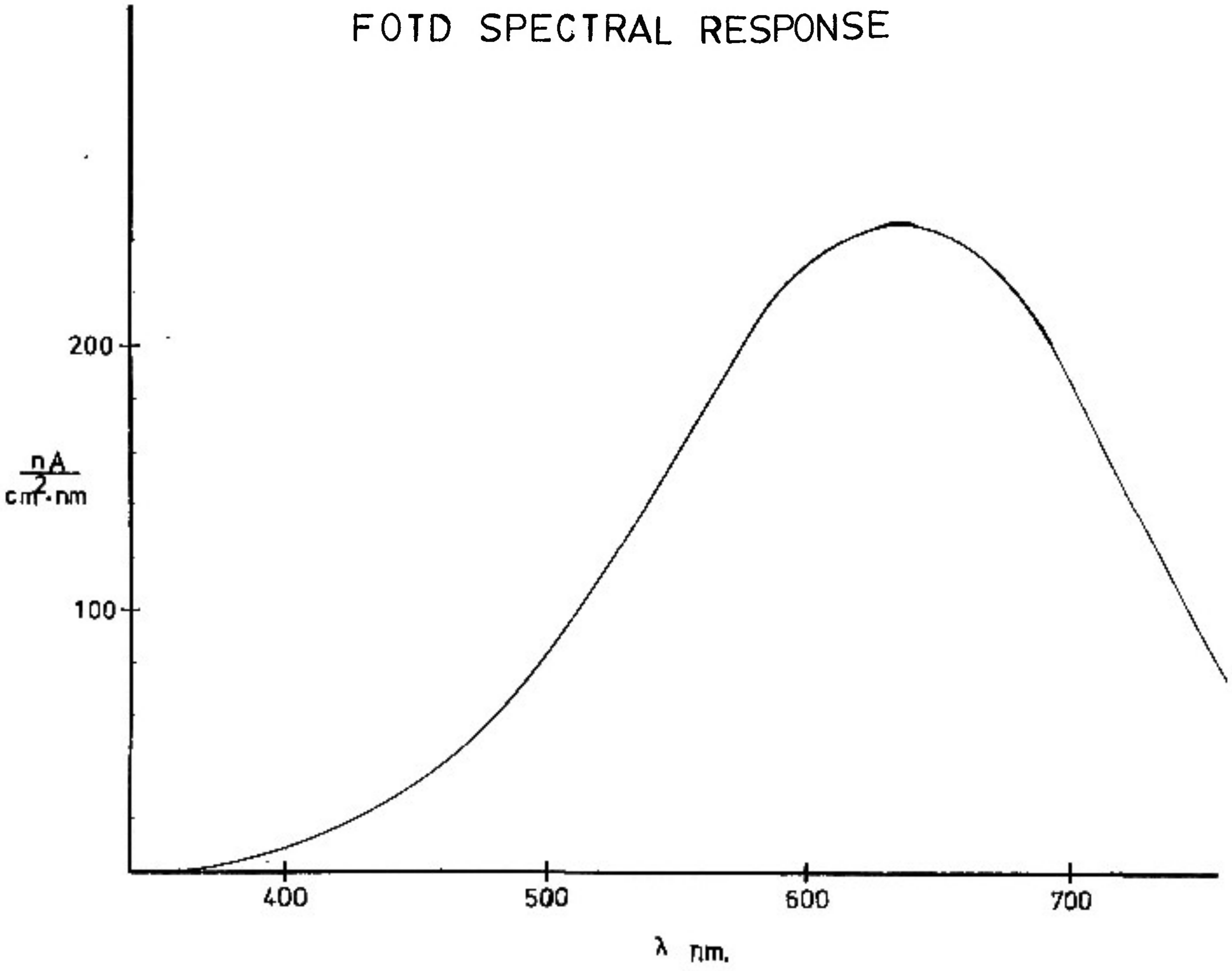

Figure 9

EXPERIMENTAL PROCEDURE

The FOTD was tested with a Kodak #2 step tablet, a sensistrip of Ilford FP-4 fine grain film, and Kodak 4125 professional copy film. After the first several sets of black and white film data were collected and the resulting densities compared to those of a MacBeth TD-504 Transmission densitometer, it was noticed that the densities were consistently higher on the FODT. The TD-504 uses specular illumination and diffuse collection with an opal diffuser and was used with the visual filter. The higher measured densities are thought to be due to the scattering property of silver and the non-diffuse collection scheme of the FOTD. An E-6 process control strip was tested; these values were much closer to those of the TD-504.

The standard operating procedure for the FOTD went as follows:

1. adjust offset null of 0.000 + -0.003 volts measured at output
2. adjust lens position to achieve maximum output voltage with open gate
3. adjust x and y position of fiber bundle
4. repeat 1 and 2 until no further increase
5. without disturbing fiber, place test strip into slide mount
6. move strip to desired measuring point, read voltage on digital volt meter
7. record offset value at beginning and end of each run as well as open gate values
8. Density = - Log (V sample/V open gate)

EXPERIMENTAL RESULTS

The FOTD worked exceedingly well on color films. Figure 10 shows a plot of TD-504 densities verses FOTD densities of an E-6 control strip, supplied by the RIT Graphic Arts Lab. The two curves represent typical results on color films for a system with and without proper IR rejection. For diffuse density values greater than 2.00, the FOTD grossly underestimates the value. This was noticed in the testing of black and white films as well, although these densities, as seen in Figure 11 are still higher than diffuse densities due to silver scattering.

When tested on black and white films, the FOTD responded as the curve in Figure 11 would indicate. The FOTD consistently reads densities greater than the corresponding TD-504 values. The ratio of FOTD density to TD-504 density was determined for all black and white film measurements. The ratios were between 1.10 and 1.4, which correlates well with the many studies done on silver and the Callier Q factor.

Figure 12 and 13 show the difference between the expected and observed FOTD densities measured for all the films tested. Figure 13 was plotted in order to show, at a glance,

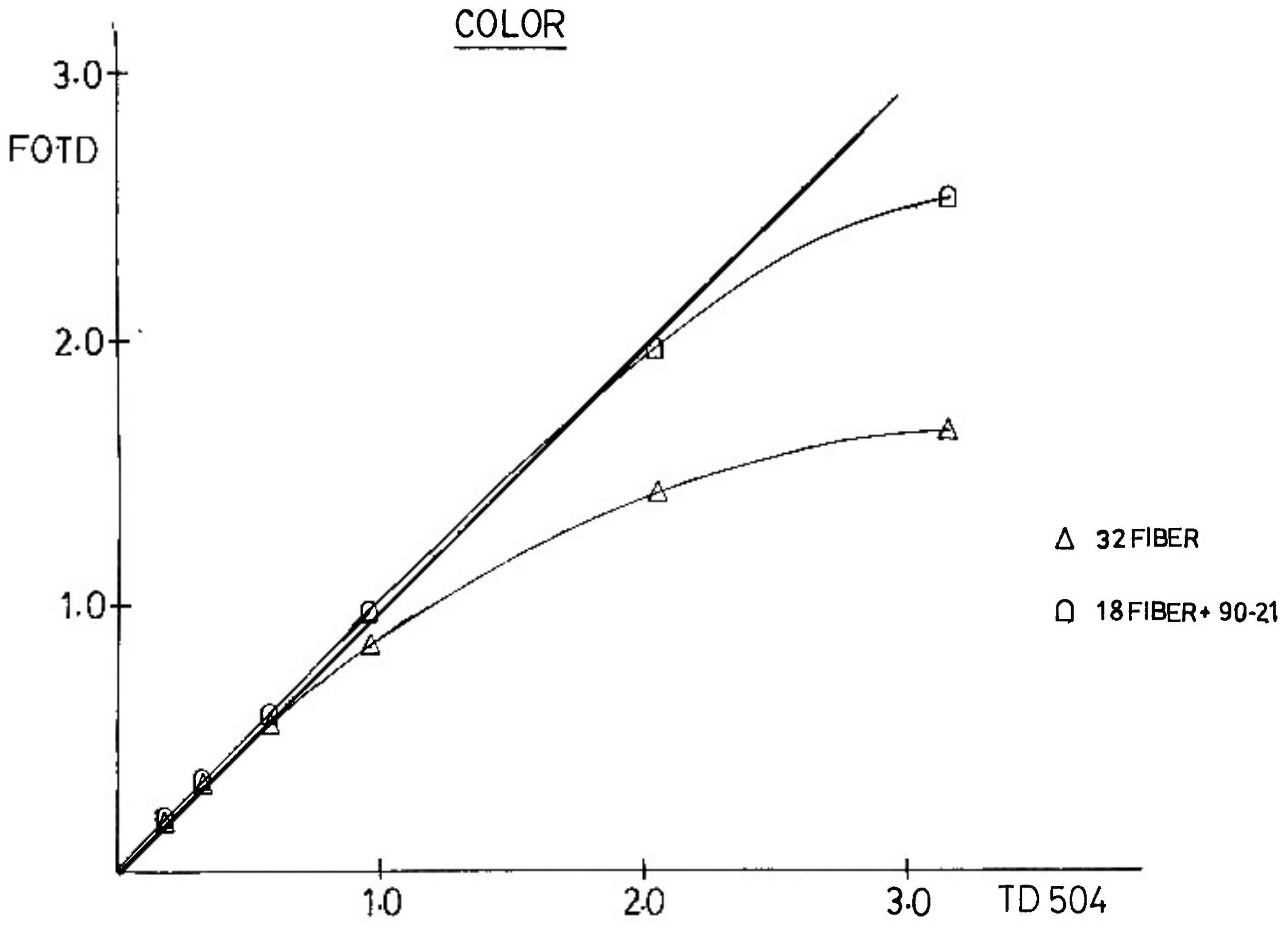

Figure 10

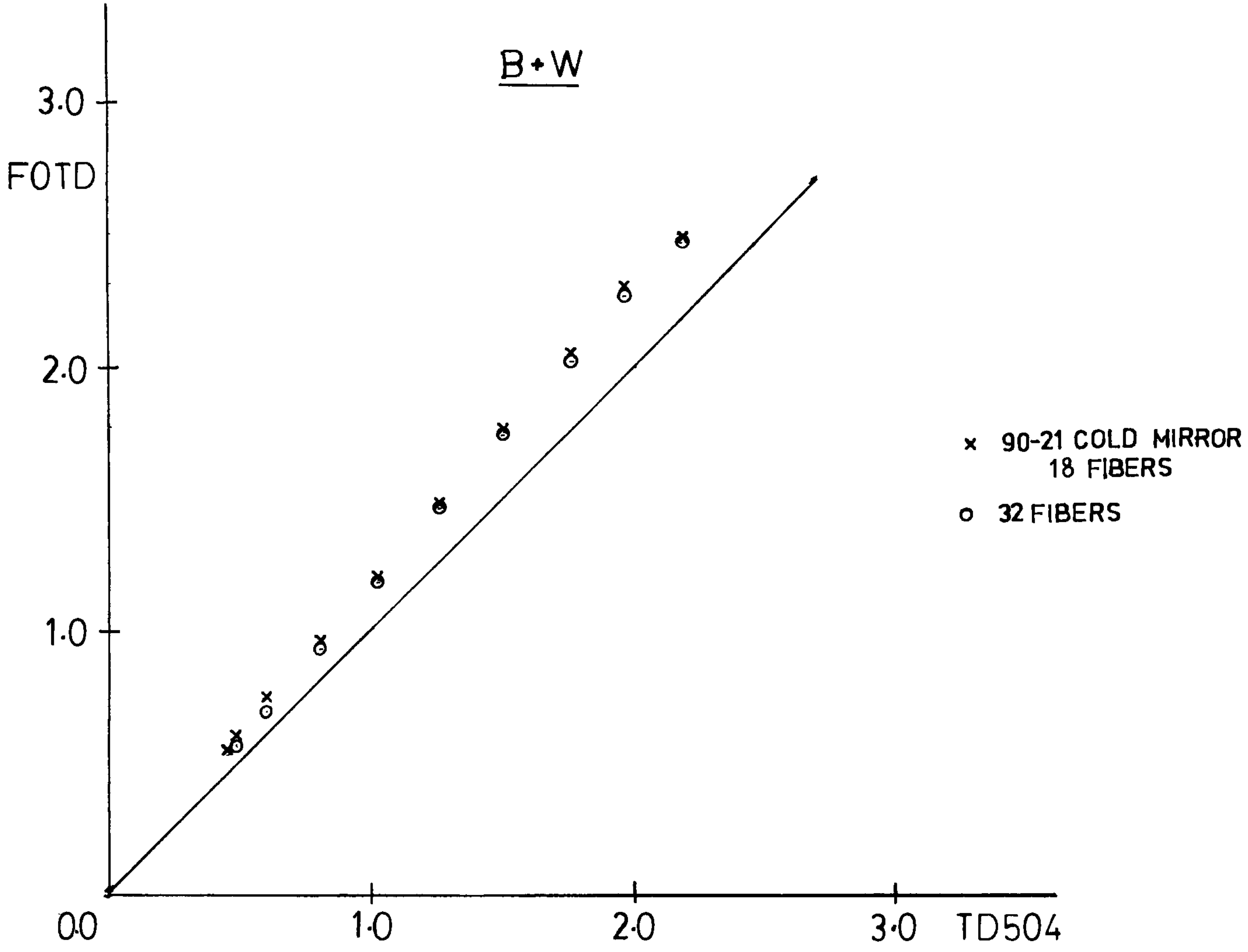
B+W
3.0
FOTD
2.0
1.0
0.0
1.0
2.0
3.0
TD504
× 90-21 COLD MIRROR
18 FIBERS
o 32 FIBERS

Figure 11

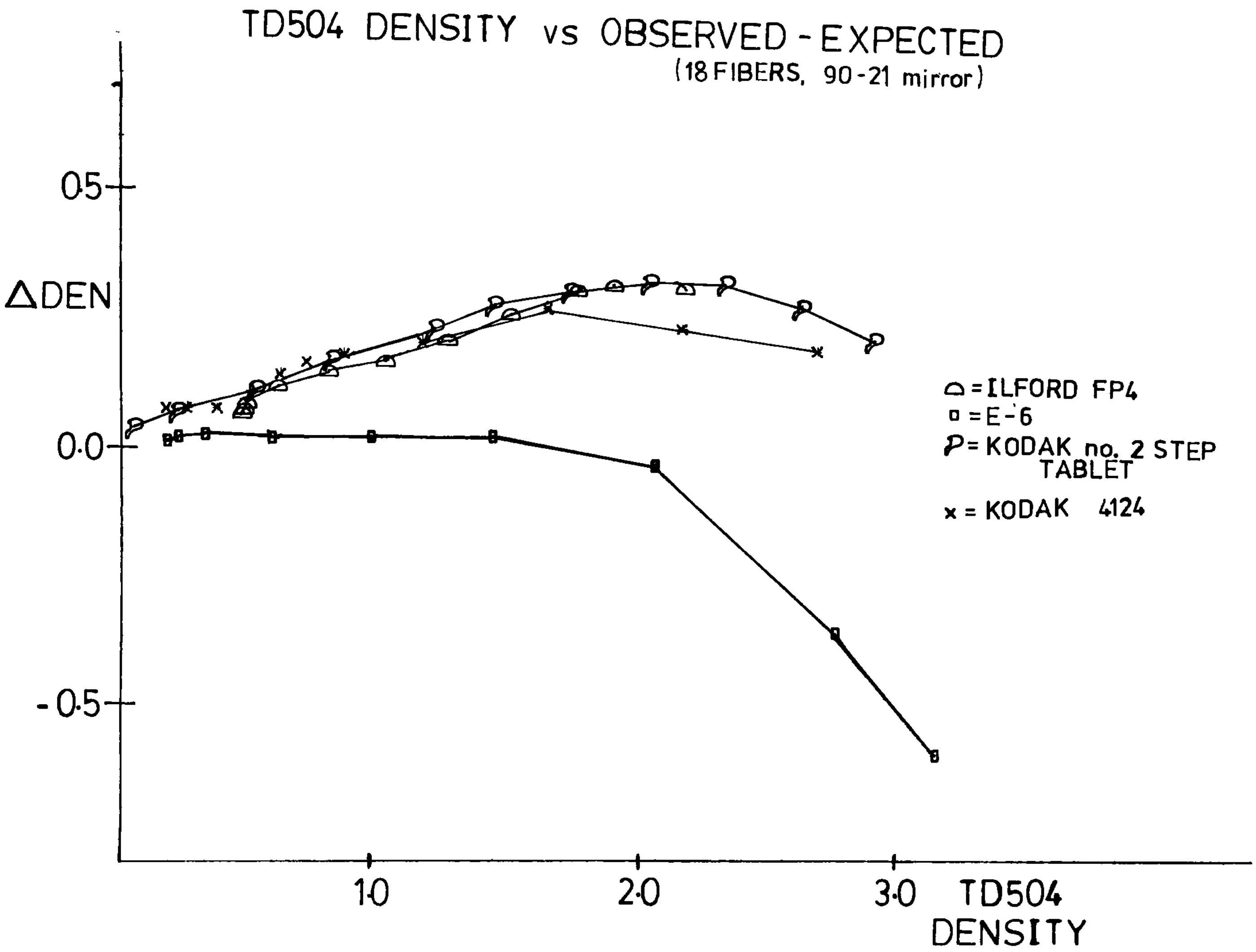
TD504 DENSITY vs OBSERVED - EXPECTED
(18 FIBERS, 90-21 mirror)
ΔDEN
0.5
0.0
-0.5
1.0
2.0
3.0
TD504 DENSITY
⌓ = ILFORD FP4
▫ = E-6
℘ = KODAK no. 2 STEP TABLET
x = KODAK 4124

Figure 12

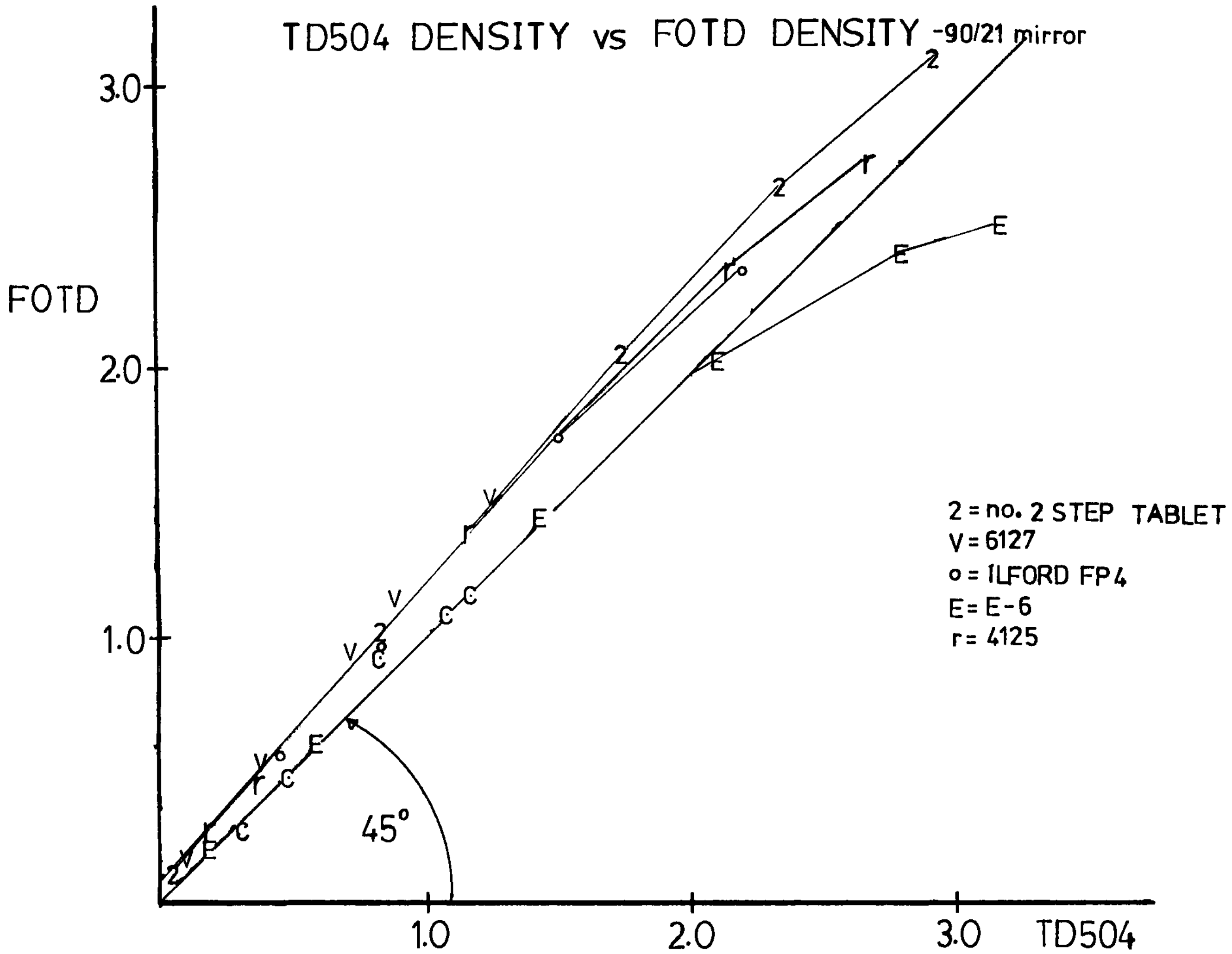
TD504 DENSITY vs FOTD DENSITY -90/21 mirror
FOTD
3.0
2.0
1.0
1.0
2.0
3.0
TD504
45°
2 = no. 2 STEP TABLET
V = 6127
o = ILFORD FP4
E = E-6
r = 4125

Figure 13

the similarities between most of the black and white films tested and the difference of accuracy between silver systems and color dye systems.

CONCLUSIONS

When using a Corning 90-21 cold mirror to correct for IR leakage, the FOTD system will, on the average, measure densities between 0.10 and 2.00 to within 0.02 density units above MacBeth TD-504 density values. For densities greater than 2.00, the FOTD measurements will be less than TD-504 densities; at a density of 3.15, the FOTD will read only 2.50. These low values can be explained by insufficient IR rejection. Without the 90-21 mirror, the system begins to under-estimate densities at 0.50. Color film dyes transmit in the near IR region, which happens to be near the peak spectral response of the system and the photocell.

Several interesting results occured when using the FOTD to measure Black and White films. The FOTD does not collect over 180 degrees as does the TD-504. Silver systems have a high degree of scatter associated with them. The Callier Q-factor, which is the ratio of specular to diffuse density, varies between 1.1 and 1.5, dependent upon the gamma of the black and white film. Except for the diffuse densities below 0.10 on the Kodak #2 step tablet, all the ratios of FOTD density/TD-504 density are between 1.0 and 1.4, these values agree with those found in "the Theory of the Photographic Process" page 425.

Once a particular film's transfer curve has been plotted, (TD-504 density vs. FOTD density) the FOTD can be used to measure any density within the limits of the transfer curve and expect to predict TD-504 densities to within 0.05 units.

To summarize, it has been shown that:

fiber optic bundles can be used as the efflux geometry of a densitometer,

color densities can be measured to within 0.02 units over a diffuse density range of 0.10 to 2.00,

black and white densities are read consistently high due to the scatter of silver and the nearly specular geometry of the FOTD.

FUTURE WORK

1. An experiment to increase the collection angle of FOTD using opal glass or an integrating sphere should be investigated.
2. Reversing the geometry and some further design considerations could lead to a miniaturized sensitometer.
3. Microdensitometry using one or two imaging fibers might be investigated.
4. The possibility of building an on-line condenser enlarger transmission and/or reflectance densitometer exists.
5. Improving the FOTD with a stable voltage supply, a more sensistive digital voltmeter, a more sophisticated electronic system, an improved detector - possible an EGG HAV - and an improved spectral response should be attempted.

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