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Redesign of the RMS Granularity Meter

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REDESIGN OF THE RMS GRANULARITY METER

BY

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and
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Also, we express our deepest gratitude to Miss Mary Ellen Jacobs and Miss Nancy Wright for their unrelenting help in the preparation of the manuscript and to the C.I.A. for their resources to make this project possible.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

A device for measuring RMS granularity of uniformly exposed and uniformly processed photographic material was built.

This paper deals with the construction of the major components of the system.. The components constructed were the lamp mount, lamp housing, current regulated ripple free power supply for the lamp, the replacement of the motor drive system for the sample stage with a synchronous motor, and the construction of the photo detection system. All these components were mounted on a triangular optical bench around an existing symetrical design microdensitometer with rotating sample stage.

CHAPTER 1

INTRODUCTION

In the photographic technical literature, the term graininess is often used to mean both graininess and granularity.[1] Both of these physical properties of the developed photographic image are important, but they are not synonymous; therefore, the two terms should not be used interchangeably.

Most photographic images appear to be homogeneous when viewed normally, however when magnified, there seems to be a inhomogeneous structure to them. This irregular structure is caused by clumping of silver grains in the gelatin. Because the photographic image is composed of microscopic silver grains, it is to be expected that under sufficient magnification, it would appear to be inhomogeneous. The impression of inhomogeneity or nonuniformity in the image produced on the consciousness of the observer when such an image is viewed is termed graininess.[2] Using this idea, then graininess is a subjective evaluation of nonuniformity of the photographic image. What this paper is concerned with is the objective evaluation of the nonuniformity of the photographic image that is termed granularity.

Granularity can be considered noise in the photographic image without granularity a higher single to noise ratio would occur. As a result the photographic material would be more sensitive with the imprint of the image. To know the granularity of a film tells us how much noise to expect in the film relative to the overall density where the information we are concerned with may lie. The combination of granularity and the image information gives us the single to noise ratio of the film.

Given the unit for determining RMS granularity designed and built by Melvin E. Pollard for his M.S. Thesis requirements in 1971, this paper deals with the modifications in the design of the instrument so that it could be made to produce a workable and stable instrument for the use of the Rochester Institute of Technology Photographic Science and Instrumentation Department, which will enable any student with a background in photographic sciences to easily make accurate granularity measurements of film samples.

The RMS granularity meter is a specialized form of a microdensitometer using a stage which traces a circular scan path on the film sample. Since the sole purpose of the instrument is to measure fluctuations in transmission caused by film grain structure and distribution, a linear scan path is not necessary.

The instrument is mounted on a triangular rail optical bench, with all optical components on movable, locking stages which can be shifted along the optical axis. The motor which drives the sample stage is mounted outboard. The basic arrangement of the components is similar to that of a conventional microdensitometer unit having symmetrical influx and efflux microscope optics. The major components of the unit are the lamp and condenser, the pre-aperture, the influx microscope, the sample stage and motor, the efflux microscope, the post-aperture, the neutral density continuous wedge, the ground glass and photomultiplier tube, and the instrumentation to read the output from the phtomultiplier tube.

The lamp housing has been modified to accept a 6v. 5a. Olympus microscope lamp. The filament is imaged on the ocular of the influx microscope so that the entrance pupil is filled. A Kodak 4 inch anastigmat (f = 102mm) is used as the condenser lens. Attached to the same mount as the condenser lens is the pre-aperture at a distance from the ocular such that the image is at 100x reduction on the sample plane, when using a 10x ocular and 10x objective. The pupose of the pre-aperture is to limit the illuminated field in the sample plane and thus cut down on flare. The sample stage is a six inch diameter rotating brass cylinder, mounted on a bearing and driven by a belt and motor. The sample is held in place by a spring loaded clamping mechanism The efflux microscope is the mirror image of the influx micrscope, having a 10x ocular and a 10x objective. There are four (4) scanning apertures with 48um, 24um, 10um, and 5um effective diameters, which are focused on the rotating sample plane. The neutral density wedge is placed between the scanning aperture and the PMT housing to adjust flux level. A ground glass is placed immediately in front of the PMT housing, to make alignment of the phototube.less critical and to minimize variations due to nonuniformity across the surface of the phototube. The voltage across the anode to dynode resister in the PMT is measured with a Fluke 931 RMS AC Differential Voltmeter. This voltage is then proportional to the RMS granularity of the film sample. See Figure I for the thin lens schematic and Figure II for the physical layout.

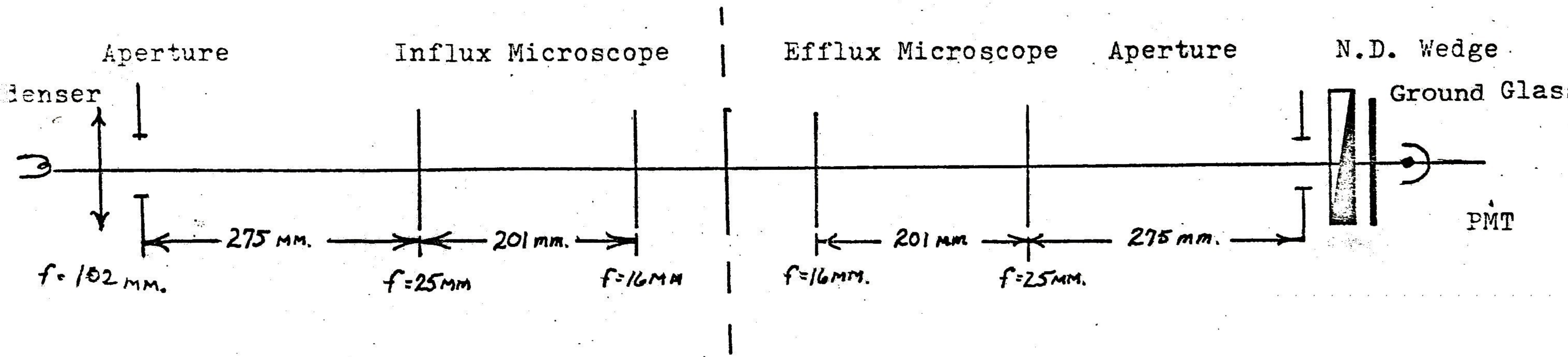


Figure I : Optical Schematic of Granularity Meter

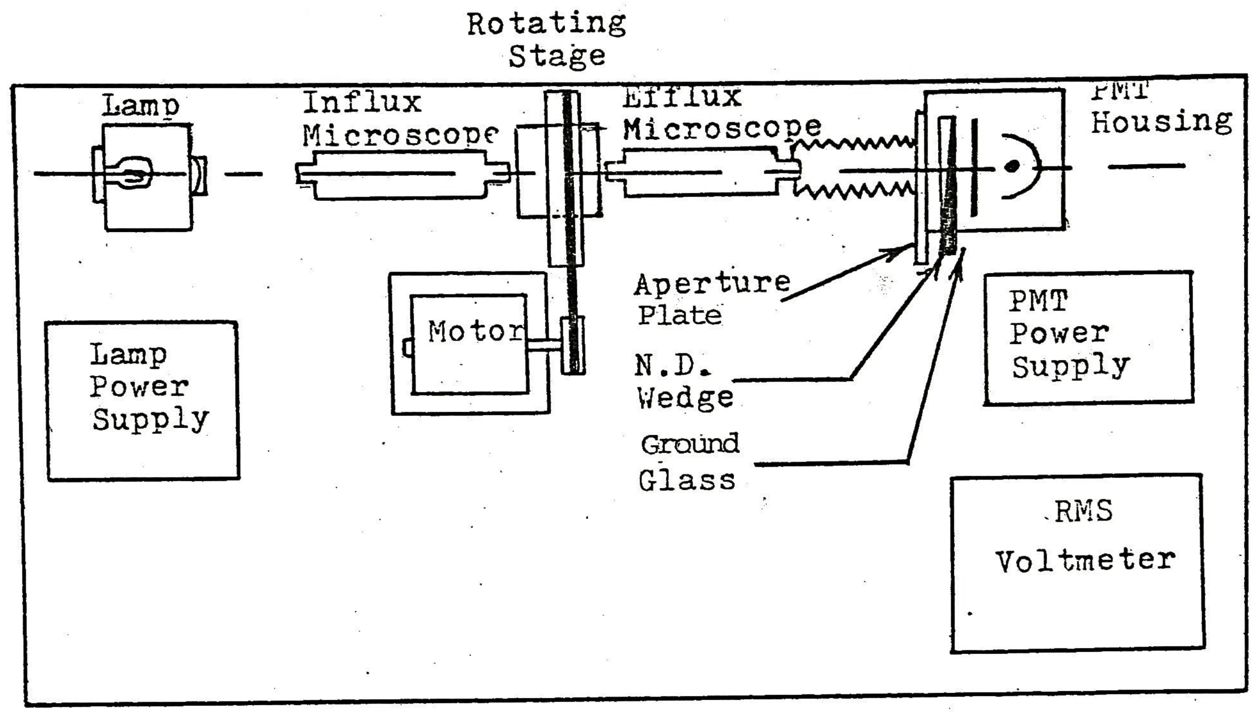


Figure II: Physical Layout

FOOTNOTES FOR CHAPTER 1

[1]Thomas H. James, Ph.D. and George C. Higgins, Ph.D. Fundamentals of Photographic Theory, (New York, 1968) p. 269

[2]C. E. Kenneth Mees and T. H. James, The Theory of the Photographic Process, (New York, 1966) p. 523.

CHAPTER 2

THEORY OF MEASUREMENT OF σ_D

The data output from the RMS Granularity Meter is not read directly as RMS granularity (σ_D). The output is read as voltage across the load resister (R_L) of the RCA 931A Photomultiplier tube. From this resistor, we obtain $\bar{V}$, the average D.C. level across R_L, and σ_V, the RMS voltage across R_L. Since the voltage across R_L is directly proportional to the transmittance of the sample, we can obtain from equation (1)

$$(1) \qquad K_1 \cdot \frac{\sigma_V}{\bar{V}} = \frac{\sigma_T}{\bar{T}}$$

where T is the transmittance and σ_T is RMS transmittance, and K_1 is a constant.

The relationship between σ_D and σ_T is : [1]

$$(2) \qquad \sigma_D = \frac{1}{2.30} \frac{\sigma_T}{\bar{T}} \left[1 + \frac{1}{12} \left(\frac{\sigma_T}{\bar{T}}\right)^2 + \frac{1}{80} \left(\frac{\sigma_T}{\bar{T}}\right)^4 + \ldots\ldots \right]$$

and for the case where $\sigma_T/\bar{T}$ is small, we can neglect the higher order term which will diminish rapidly. The relation is then:

$$(3) \qquad \sigma_D \approx \frac{1}{2.30} \left(\frac{\sigma_T}{\bar{T}}\right)$$

The error (E) in this approximation is:[2]

$$E = 1\% \quad \text{for} \quad \frac{\sigma_T}{\bar{T}} = 0.1 \qquad (\sigma_D = .04)$$

$$E = 10\% \quad \text{for} \quad \frac{\sigma_T}{\bar{T}} = 1.0 \qquad (\sigma_D = .4) \,.$$

For $\sigma_T/\bar{T}$ 1.0, the error E increases rapidly, reaching for $\sigma_T/\bar{T} = 2.0$.

If we now combine Equation (1) and Equation (3), we can calculate σ_D.[3]

$$\sigma_D \approx \frac{K_1}{2.30} \cdot \frac{\sigma_V}{\bar{V}} = K_2 \cdot \frac{\sigma_V}{\bar{V}} \,.$$

The values of σ_V and V may be measured across R_L on the photomultiplier tube. The value for K_2 may be determined for any given aperture, by scanning samples of known granularity at the same aperture with the RMS granularity meter.

Therefore, with K_2 known and with σ_V and $\bar{V}$ read from the RMS granularity meter, the granularity σ_D may be quickly and easily determined for any given sample

FOOTNOTES FOR CHAPTER 2

[1]M. Abouelata, "Notes from Image Evaluation Course" taught by Prof. M. Abouelata, 5/12/76, 5/13/76.

[2]Tino Celio, "A Device for Measuring the Granularity of Photographic Emulsions", Photographic Science and Engineering, V.5,N.1, Jan-Feb 1961 pp. 12-16.

[3]Melvin E. Pollard, M.S. Thesis, "An Instrument for Rapid Determination of Granularity in Photographic Film Samples", 11/15/71, p. 11.

CHAPTER 3

CONSTRUCTION OF APPARATUS

Lamp Housing and Condenser System:

The lamp housing as given used a side-on ribbon filament lamp (GE 9A/t8 $\frac{1}{2}$ 1P), which was cooled by an exhaust fan connected to the lamp housing with a length of flexible tubing. Since the lamp is no longer manufactured in that base configuration, it was necessary to choose another lamp as a replacement and to modify the lamphouse to suit it.

The chosen lamp was a 6 volt 5 ampere Olympus microscope lamp with a 4mm square filament array. The lamp was chosen both for its head-on, close spaced grid configuration of the filament and for its ready availability. The Olympus lamp gives off much less heat than the GE ribbon filament lamp, so we were able to remove the exhaust fan and sections of the lamp housing dealing with the exhaust system. The remaining housing provides adequate convection cooling for the Olympus lamp.

Since the existing design provided for a side-on lamp mounting, it was necessary to modify the lamp housing to accommodate the head-on filament of the Olympus lamp. A design for the mount was worked out with Mr. Richard Norman which allowed the lamp to be moved over a wide range in the x,y, and z dimensions. The mount was fabricated and attached to the lamp housing, as shown in Figure III.

The given condenser system was attached to the lamp housing and was found to be of too short focal length to provide a small enough image at the entrance pupil to the influx microscope, therefore a different condenser lens was used.

A Kodak 4" anastigmat enlarger lens was adapted. The distance from the influx aperture is fixed at 275mm, because of symmetry. The scanning aperture is fixed at 275mm. So therefore, with a focal length of 4 inches f = 101.6mm and s' = 275mm. Using the thin lens formula for the proper magnification:

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \qquad \frac{1}{s} = \frac{1}{f} - \frac{1}{s'}$$

$$\frac{1}{s} = \frac{1}{102\text{mm}} - \frac{1}{275\text{mm}}$$

$$\frac{1}{s} = .0062\text{mm}$$

$$s = 162\text{mm}$$

$$\text{Mag} = \frac{s'}{s} = \frac{275\text{mm}}{162\text{mm}} = 1.7\text{x}$$

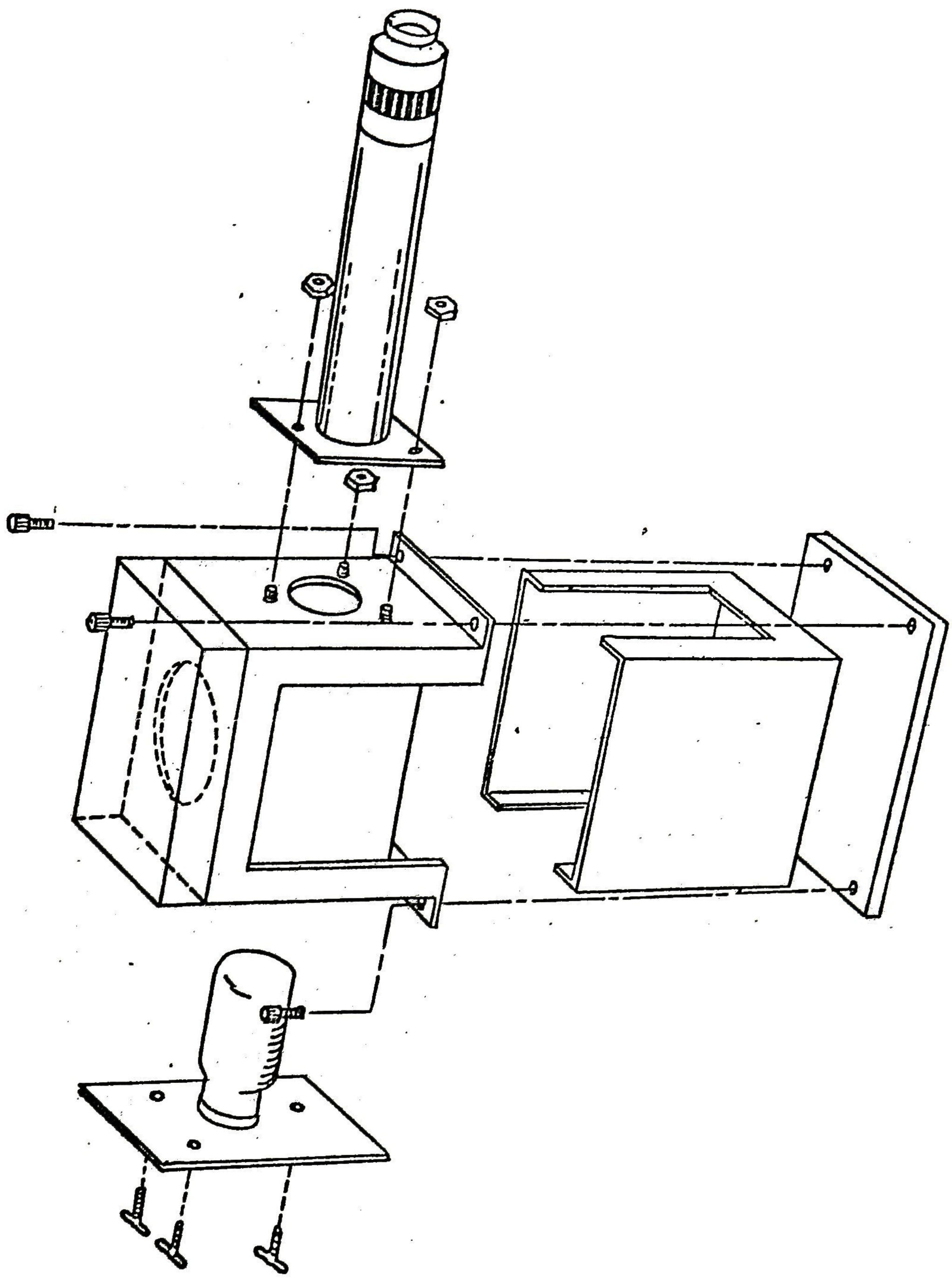


Figure III: Lamp Housing

A lens extension tube was made so that the magnification equaled 1.7x. So therefore, with a magnification of 1.7x the image of the 4mm square filament array equals 6.8mm square. Now the image of the square filament array fills the aperture of the ocular of the influx microscope. (See Figure IV)

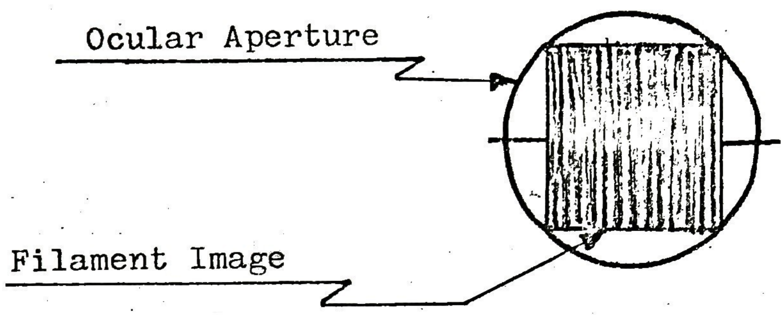


Figure IV: Image of Lamp Filament on Influx Ocular Aperture

The lamp is distant enough away from the condenser lens that there is no danger of damage to the condenser lens caused by heat dissipation from the source. The extension tube was baffled so to eliminate stray light. Also, the inside and outside of the tube have been painted a flat black.

Lamp Power Supply:

The power supply given was designed to supply 12 volts at up to 20 amps, with excellent ripple filtering but little or no regulation. Minor modification would be required to supply 6 volts at 5 amperes to the chosen lamp, but it would still be unregulated. The given power supply is shown in Figure V.

On the basis of discussion with our advisor and on the information of Tungsten lamps on page MTR-20 of Dr. Schumann's radiometry notes, it was decided to design and construct a current regulated power supply for the lamp. The power supply delivers a constant 5 amperes to the lamp. The design is shown in Figure VI. IC_1 maintains a constant 5 volts across CR_1, R_1, and the base-emitter junction of Q_1. The voltage drop across CR_1 and the base-emitter junction of Q_1 are constant and independent of current changes, while the voltage across R_1 is directly proportional to the current through it. IC_1 will sense any voltage change across CR_1, the base-emitter junction of Q_1, and R_1, and can vary the base current, I_B, of Q_1 to keep the current through R_1 constant. The lamp current will therefore be held constant, since the current through R_1 and the lamp are the same.

After a series of tests, the unregulated D.C. voltage at the input to the current regulator was insufficient. This caused a low collector-emitter voltage (V_{ce}) at transistor Q_1, which was saturated and not operating linearly. By increasing the input voltage to the current regulator from about 8.5 volts D.C. to about 14 volts D.C., transistor Q_1 was able to operate linearly and the power supply performed as intended. In order to accomplish this, the Stancor P-6309 power transformer was replaced by a Stancor P-8669, which increased the A.C. voltage to the rectifier, which was then changed from a full wave bridge to a full wave center tapped configuration.

The unit was constructed using standard construction procedures for electronic equipment. The components were chassis mounted and housed within a BUD cabinet.

Figure V : Given Lamp Power Supply

C_1	16,000 uf., 10WVDC
C_2,C_3	22,000 uf., 75WVDC
P_1	2-prong household plug
Q_1-Q_4	NPN power transistor, 2N3055
R_1	10 ohm, 5watt, potentiometer
R_2	43 ohm, 2 watt
R_3-R_{10}	0.1 ohm, 1 watt
$RECT_1$	Bridge rectifier, 40208, 40208B

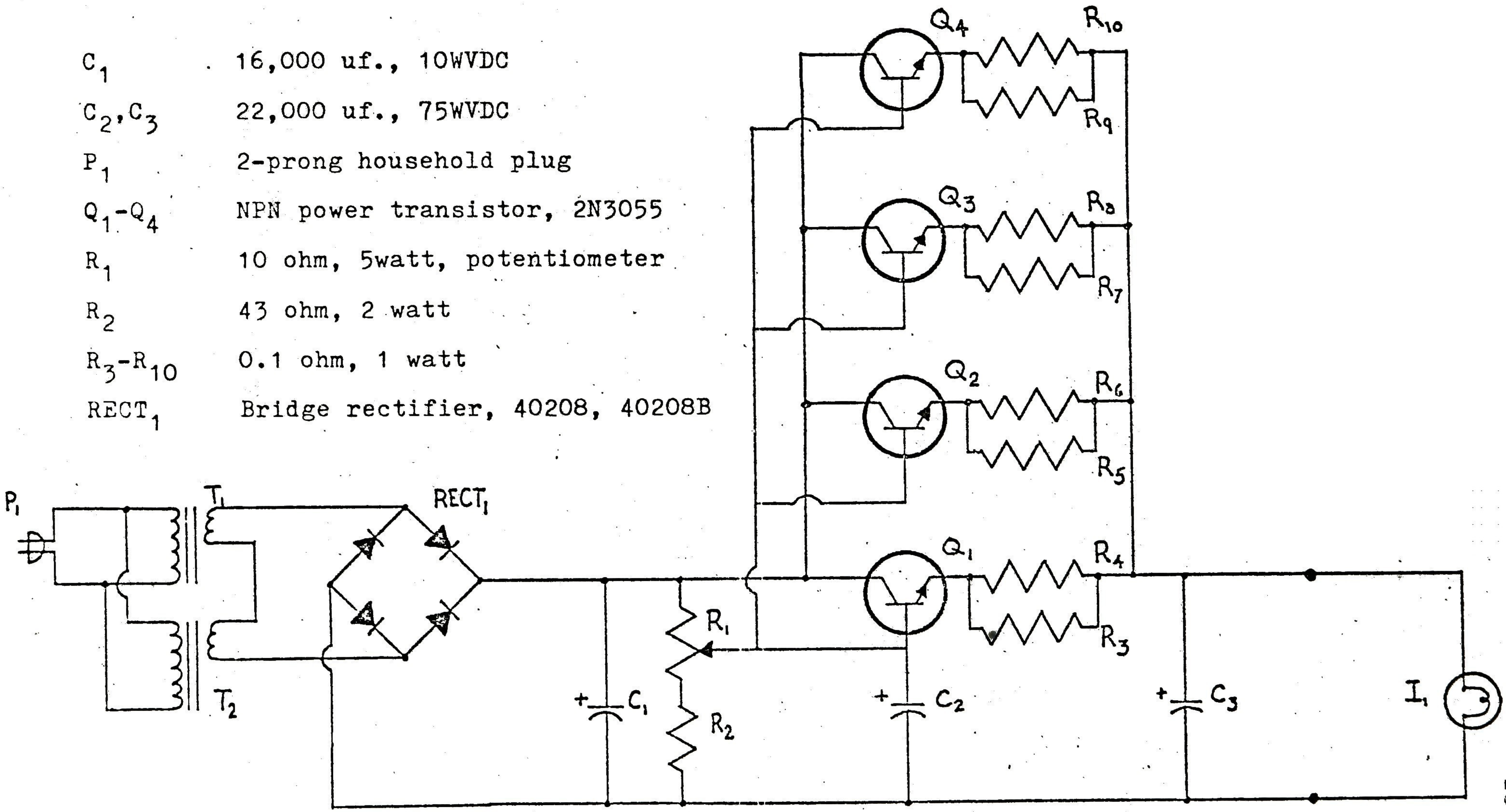
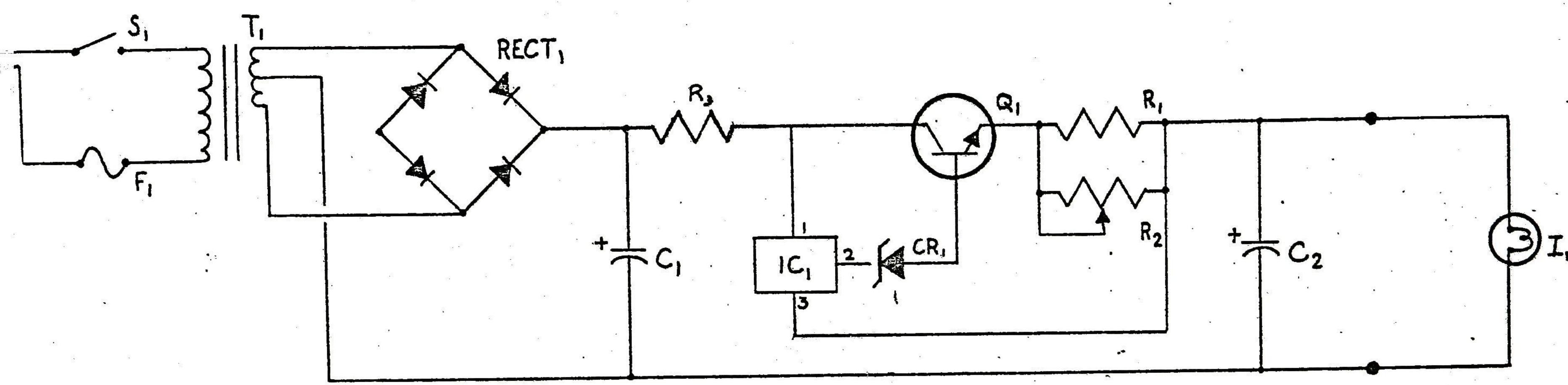


Figure VI: Current Regulated Power Supply (5 Ampere)



C_1, C_2	22,000 uf., 75WVDC	R_1	0.083 ohm, 2 watt
CR_1	1N5335B, 3.9 V. zener diode	R_2	rheostat, 4 ohm, 3.54 amp.
F_1	3 amp. fuse	R_3	0.75 ohm, 60 watt
I_1	Olympus lamp, 5 amp.	$RECT_1$	400 PIV, 6 amp. bridge rectifier
IC_1	National LM309K 5 v. regulator	S_1	SPST toggle switch
P_1	2-prong household plug	T_1	Pri.: 117 volts Sec.: 28 volts center-tapped
Q_1	NPN power transistor, 2N3055		

Influx and Efflux Optics:

The influx and efflux microscopes are mirror images of each other consisting of Rolyn tubes; Bausch and Lomb, 10X N.A. 0.25 achromat objectives and two Bausch and Lomb, 10X Huygens eyepieces.

Sample Stage:

The existing rotating sample stage was used. The rotor was machined from a 6-inch-diameter 1-inch-thick brass disk. It is a ring, the bore of which is seized to the outer diameter of a 209T precision bearing manufactured by SKF. The inner bore of the bearing is seized to a thin walled brass bushing mounted to the carrier assembly.[1]

Motor Drive:

A fractional horsepower synchronous motor was bought, type (MYC-12R) manufactured by Bodine Motors. This motor operates at 150 volts A.C. at 60 Hz. The horsepower is rated at 1/125 HP with a torque of 1.2 lbs./inch. The motor is gear reduced from 1800 rpm. to 300 rpm.

Detection System:

A 4" x 5" x 9" minibox was used to enclose the detection system. A drawing showing the placement of components within the housing is shown in Figure VII.

The N.D. wedge and its sliding holder are much the same as they were originally constructed. The mounting system was changed from the optical bench mount to an aluminum bracket for mounting within the housing. A bracket was added to the slide which will mate with a threaded rod and will permit adjustment of the wedge from outside the housing.

The efflux apertures chosen were 4.8 mm., 2.4 mm., 1.0 mm., and 0.5 mm., to give effective scanning apertures of 48 um., 24 um., 10 um., and 5 um., respectively. The apertures were photo-fabricated from a single piece of thin brass stock and mounted such that the apertures can be readily changed by sliding the aperture plate to position the correct aperture. The aperture plate and its sliding mount were mounted on the same mounting base as the N.D. wedge, as indicated in Figure VII.

The photo-multiplier tube is an RCA 931A unit, with a 100 K per stage dynode chain. Power input and signal output from the detector is via a pair of BNC type jacks

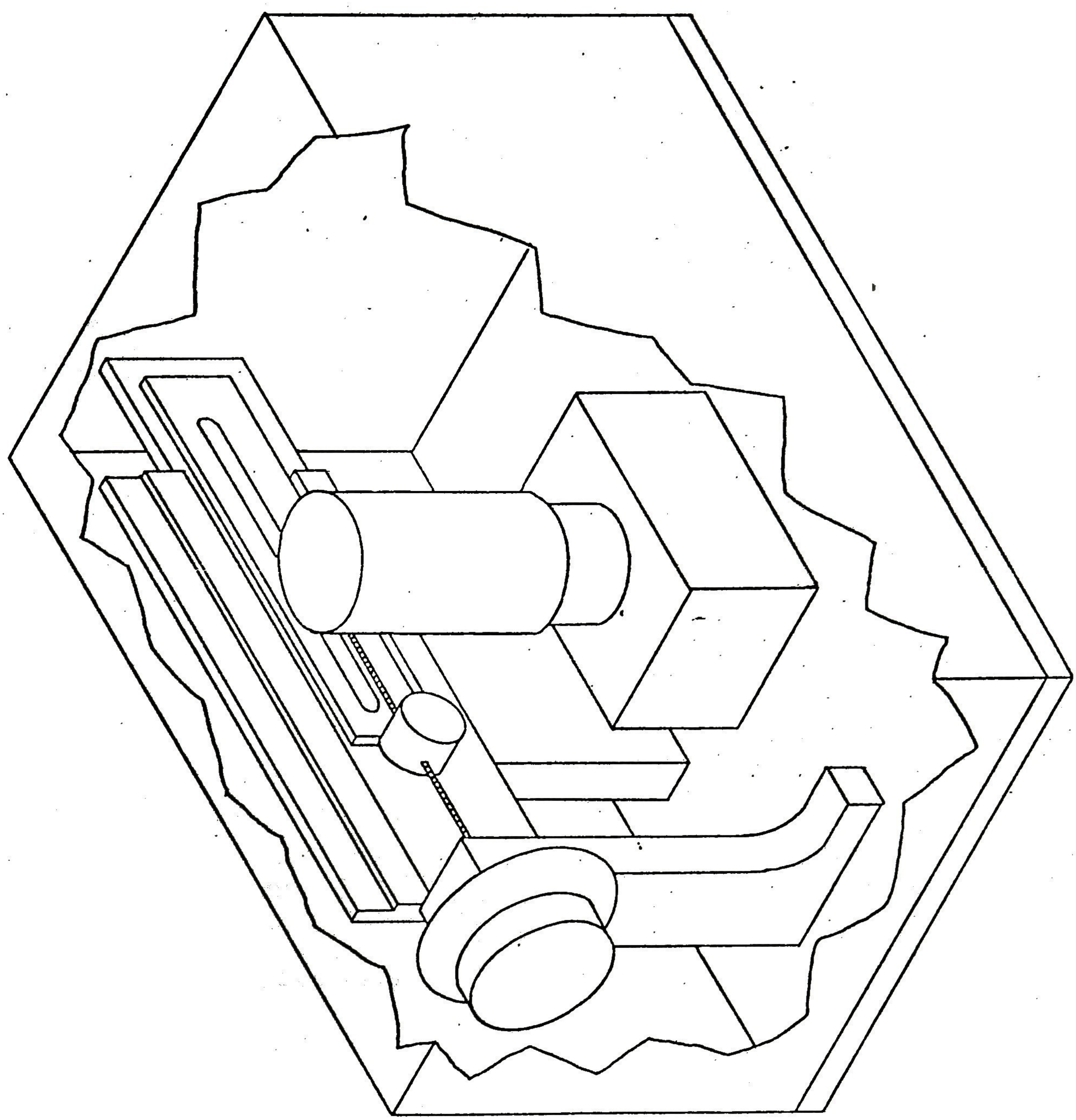


Figure VII: Detection System

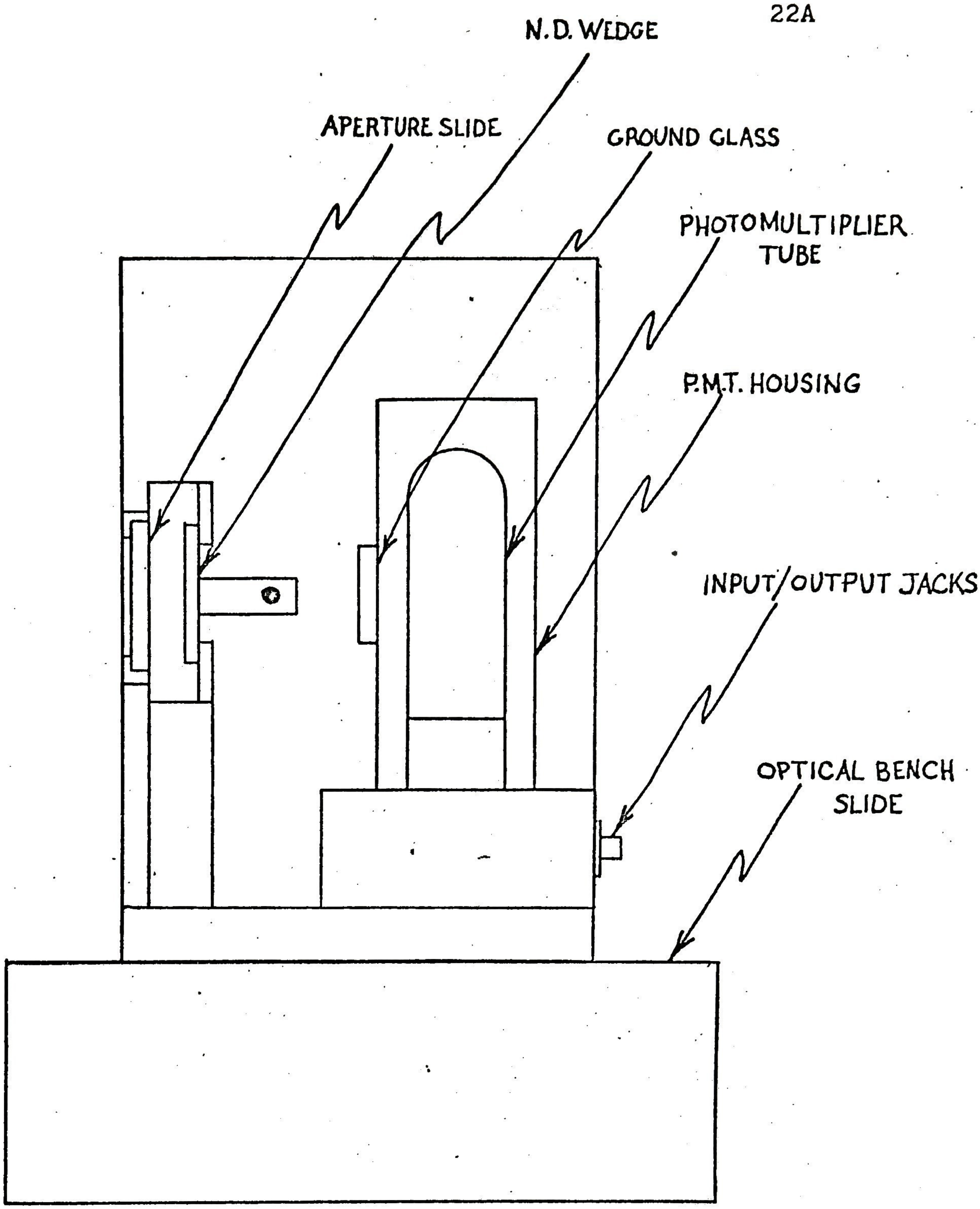


Fig. VIIA: Detection System Side View

mounted on the rear of the housing. A ground glass was mounted over the entrance aperture of the tube shield to diffuse the light across the photo-cathode of the tube and to facilitate in aligning the detector.

PMT Power Supply:

The PMT power supply was bought, manufactured by Kepco Inc. Model ABC 1500M SR# E77927. It is a regulated D.C. supply with an A.C. input of 105 volts to 125 volts or 210 volts to 250 volts (selectable). The output is 0 to 1500 volts at 0 to 10 milliamps.

RMS AC Voltmeter:

The Fluke Model 931 RMS AC Voltmeter was connected to the system on a semi-permanent basis with minor modification. The modification consisted of removing the probe which is at present permanently attached to the front panel and replacing it with a BNC jack. A short length of RG/58U cable can then be run from the PMT housing to terminate in a BNC plug which connects to the voltmeter. This type of connection eliminates many problems due to noise and stray voltages picked up by induction.

FOOTNOTES FOR CHAPTER 3

[1]Melvin E. Pollard, M.S. Thesis, "An Instrument for Rapid Determination of Granularity in Photographic Film Samples", 11/15/71, p. 20.

CHAPTER 4

DISCUSSION AND CONCLUSION

The PMT detection system and power supply are now improved, which will extend the linear range of the measurements. This improvement will allow for higher density than 1.0 N.D. to be read. The PMT power supply now allows a more sensitive control of the anode to dynode potential.

A very good current regulated and ripple free power supply for the lamp reduces the photomultiplier $V_{d.c.}$ output flucuations.

An improved lamp and lamp housing reduces attenuation of radiant flux emitted from the filament and also makes it possible for quick replacement of the actual lamp when replacement is necessary.

The motor used to drive the stage is synchronous. The stage R.P.M. was measured by means of a strobotac unit. The R.P.M. was found to be 90 R. P. M. with very little drift. The drift was not detectable visually. With this motor drive configuration and narrow band pass filters, a power spectrum may possibly be investigated.

Recommendations

The limitations of time and resources prevented us to make a further study and evaluation of the instrument. Therefore, before the instrument is used for the study of RMS granularity, the instrument should be calibrated.

A calibration scheme may follow as indicated. Evenly exposed and processed film samples between the density of 0.8 to 1.0 N.D. are first scanned with a conventional microdensitometer. Off the microdensitometer scan traces, data is taken and a statistical method is used to obtain the RMS granularity value. The same patches are then scanned with the RMS granularity meter using the same optics for efflux and influx and scanning apertures as was used on the microdensitometer. A RMS voltage value is read off the RMS voltmeter (931P Fluke). Then a calibration constant is calculated as shown in Chapter 2. When the RMS value in RMS voltage is read, it can be calibrated so that it will correspond to RMS granularity. Theory indicates a linear relationship between RMS A.C. voltage read on the RMS voltmeter and RMS granularity. This linear relation should be in the form of:

$$\sigma_D \approx k(V_{rms}) \propto \sigma_T$$

σ_D = Rms granularity

k = Constant

V_{rms} = RMS voltage

$\propto$ = Proportional

σ_T = RMS transmittance

Further recomendations to improve the function of the granularity meter are addition of possible slit apertures to correlate studies with the circular apertures, and also variable influx aperture to further reduce flare and stray light from the condenser system.

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APPENDICES

APPENDIX A

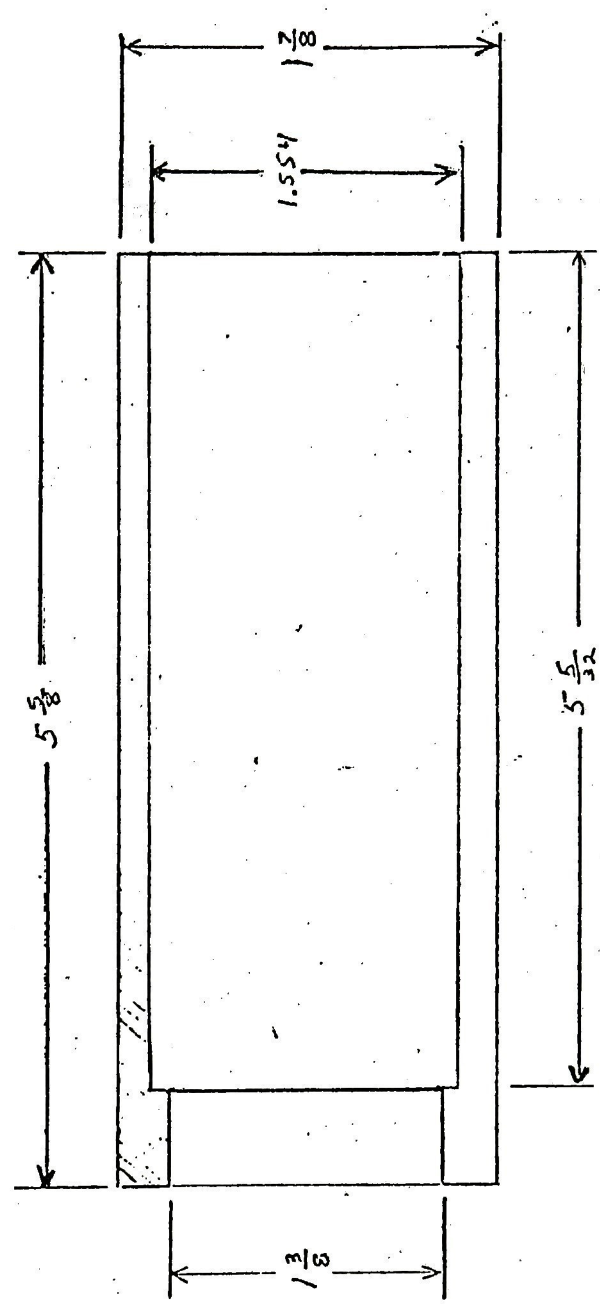


FIGURE A-1
LENS EXTENSION TUBE
BASIC SHELL 1 7/8 DIA. 2024 ALUMINUM
SCALE 1:1

APPENDIX B

The dynode chain (R_1-R_{10}) for the RCA 931A photomultiplier is constructed using 100K resistors between each dynode This will give good stability with an idler current of about 1 ma. with a 1 KV. power supply.

The output signal is measured across the anode load resistor (R_L) with the Fluke 931 RMS AC Voltmeter. The load resistor must be chosen so that signals from higher spatial frequencies on the sample will not be greatly attenuated due to the inherent capacitance of the instruments.

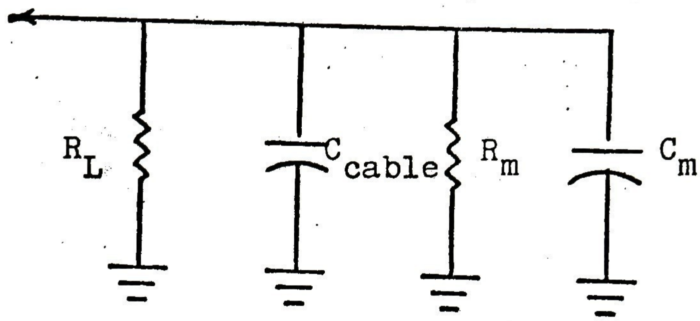
Since the smallest effective aperture expected to be used with this instrument is a 1 μm. slit, then the maximum spatial frequency that can be scanned on the sample is 1000 cycles/mm.. The stage speed was measured at 1.50 revolutions/sec., and the scan path is 29.6 mm./revolution.[1] The maximum frequency of the output signal from the photomultiplier tube is:

$$f_{max} = (1000\text{cyc./mm.})\ (1.50\text{rev./sec.})\ (29.6\text{mm./rev.})$$

$$f_{max} = 44.4 \text{ KHz.}$$

[1] Melvin E. Pollard, M.S. Thesis, 11/15/71, p. 53.

to anode



where R_L = Anode load resistor

C_{cable} = Cable capacitance

R_m = Meter input resistance

C_m = Meter input capacitance

which acts as a low-pass filter. The frequency (f) at which the signal is attenuated by 3db. is given by:

$$f = \frac{1}{2\pi RC}$$

where
$$R = \frac{R_L R_m}{R_L + R_m}$$

$$C = C_m + C_{cable}$$

If we are to have f_{max} attenuated 3db. or less, then the maximum value for R is:

$$R_{max} = \frac{1}{2\pi f_{max} C} = 39.4\ K\Omega$$

Since R_m is fixed, we can determine the maximum value for R_L:

$$\frac{1}{R_L} = \frac{1}{R_{max}} - \frac{1}{R_m}$$

$$R_L \doteq 41.0\ K\Omega$$

The value used is the nearest commercial value, 39K

With R_L = 39K , we can calculate the actual value of R:

$$R = \frac{R_m R_L}{R_m + R_L} \doteq 37.5\ K\Omega$$

The actual frequency at 3db. attenuation is:

$$f_{-3db.} = \frac{1}{2\pi RC} = 46.6\ KHz$$

At f_{max} = 44.4 KHz, the attenuation is:

$$-10\log\ (1+W^2R^2C^2) = -2.80db.$$

where $w = 2\pi f_{max}$.

The bandwidth of the detector circuitry is sufficient for effective apertures as small as 1 μm, with a maximum attenuation of -2.80db. at 1000 cycles/mm..

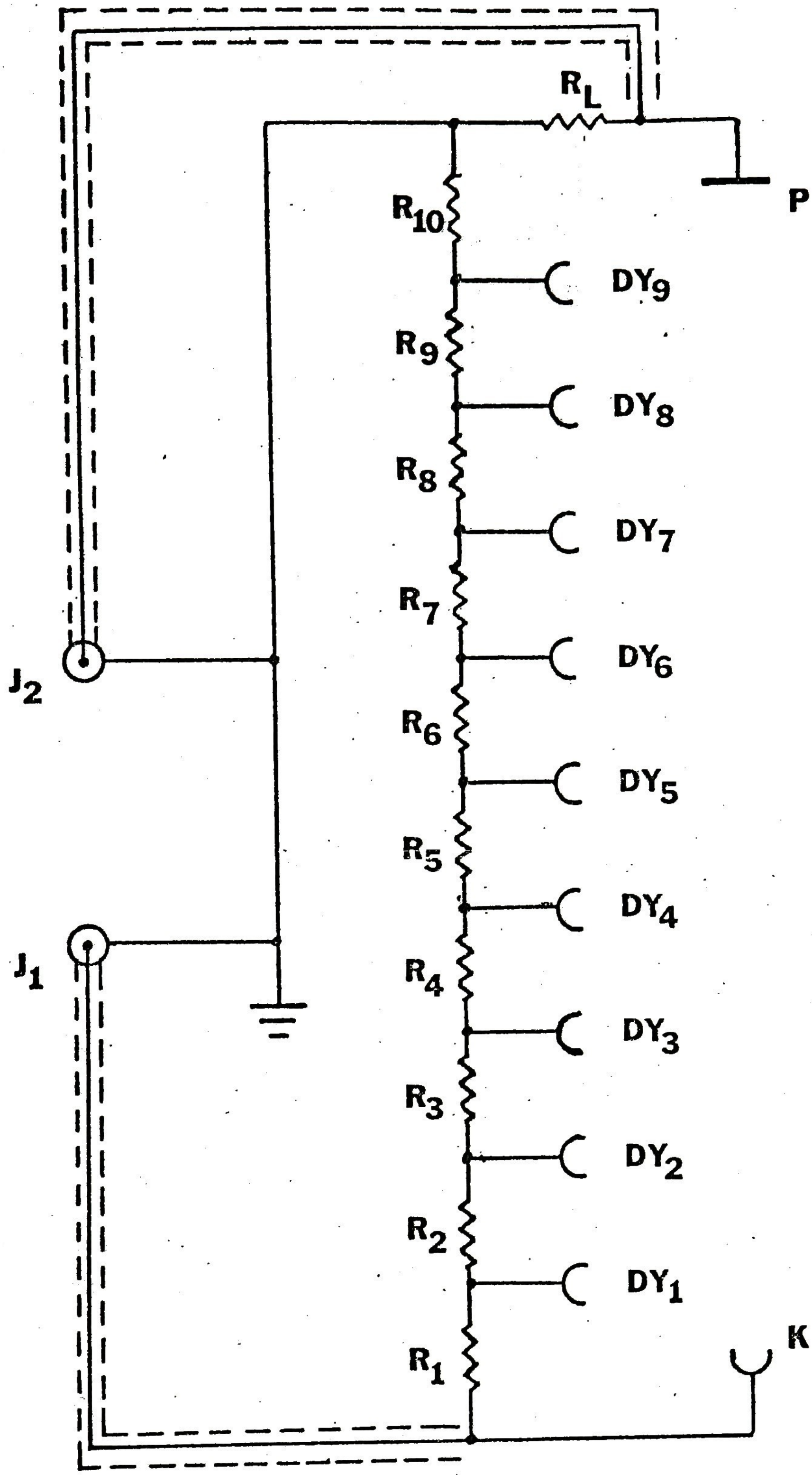


Fig. B·1: Photo-Detector

LEGEND FOR FIGURE B-1:

$R_1 - R_{10}$	100KΩ $\frac{1}{2}$ watt resistors
R_L	39KΩ $\frac{1}{2}$ watt resistors
J_1	BNC Jack, Power input
J_2	BNC Jack, Signal output
$DY_1 - DY_9$	Dynodes 1-9 on 931A PMT
K	Photo Cathode on 931A PMT
P	Anode on 931A PMT