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Shutter speed measurement techniques

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SHUTTER SPEED MEASUREMENT TECHNIQUES

BY

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Thesis

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II. INTRODUCTION

As the art of photography has progressed through the years into its present high technical state, the need for accurate methods of testing and standardizing shutter speeds has become increasingly important. The necessity for taking photographs of fast-moving objects under adverse lighting conditions has prompted research in the fields of film emulsions and in the design of faster and different types of camera shutters. And even now the camera shutter is being made obsolete for certain types of photography by the advent of stroboscopic lighting.

Due to the growing popularity of color photography, and the increased dependence of both amateur and professional photographers upon the photoelectric exposure meter, the need for accurately calibrated shutters has become strikingly apparent. Because of the wide latitude of sensitivity in black and white film, an exposure of double or half the desired length can be effectively remedied by adjusting the length of development of the negative, and exposure and development of the print. However, color film, such as Eastman Kodachrome, has a much narrower latitude of exposure under a given set of lighting conditions than does its black and white counterpart. So, to avoid needless waste of color film, which is relatively expensive, the true shutter speed of the camera should be known.

This paper will deal in brief with a great many methods for testing camera shutters, both between-the-lens and focal plane. It will deal in detail with two methods which I feel are comparatively simple and easy to set up and operate in the average physics laboratory, and with one device which any electronically-inclined photographer could construct himself for approximately twenty-five dollars.

III. DEFINITIONS OF TERMS USED[1]

1. Actual time open or total open time of a between-the-lens shutter is the time interval from the beginning of the opening period to the end of the closing period.

2. Efficiency of a between-the-lens shutter at a particular diaphram opening and exposure setting is the ratio of the amount of light transmitted by the shutter to the amount that would have been transmitted had the shutter been wide open for the entire exposure.

3. Effective speed or effective exposure time of a between-the-lens shutter with characteristics of efficiency E and total open time T, as defined above, is defined as that time of exposure which would permit a quantity of light equal to that actually transmitted by the shutter to pass through the full aperture.

4. Effective f stop of a lens-shutter combination is that f stop which would allow as much light to pass during the total time of exposure as is passed by the lens and shutter during the exposure.

5. Actual time open or total open time of a focal plane shutter, operating in a camera and with a lens, for a given point in the focal plane is the total time of exposure of that point.

6. Efficiency of a focal plane shutter is the ratio of the actual time of

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[1] Amron Katz, "Camera Shutters", Abstract presented at symposium at Boston University Optical Research Laboratory on July 18, 1947.

exposure, were the shutter in the focal plane, to the actual time of exposure as defined above.

7. Effective speed or effective exposure time of a focal plane shutter is that time of exposure which, at maximum illumination by the lens, would yield the same exposure as that obtained in the actual time open. It is equal to the actual time open T times the efficiency E.

8. Exposure variation of a focal plane shutter is defined as the difference between maximum and minimum curtain velocities in the focal plane, divided by the minimum curtain velocity.

The following discussion should add to the clarity of definitions 5, 6, 7, and 8 above. The focal plane shutter consists of an opaque cloth curtain containing a narrow slit. This curtain, mounted in the vicinity of the focal plane, moves across the focal plane, exposing successive strips of the film through the open slit, as with the between-the-lens shutter, the three pertinent characteristics are actual open time, effective shutter speed, and shutter efficiency. In the sketch below P is the image of a point focused on the sensitized film. The shutter curtain, moving down across the cone of light, takes longer to cut this cone at C than it would were the curtain and slit directly in the focal plane.

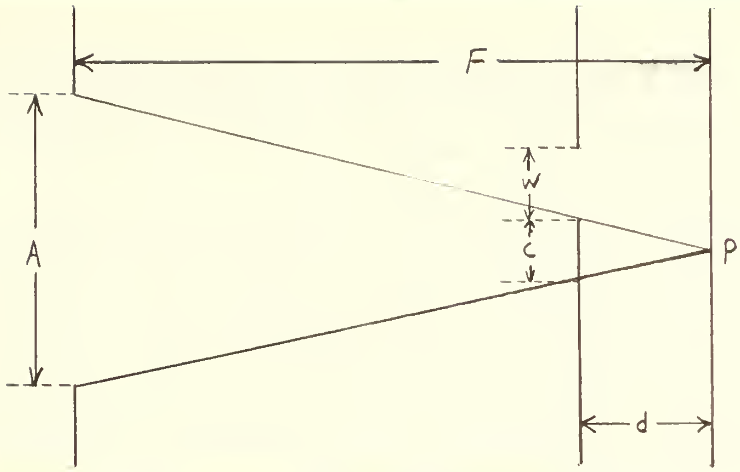
A = lens aperture

F = focal length

d = distance from shutter to focal plane

W = width of shutter aperture

C = diameter of cone of light at shutter position



Reference to the above sketch will show that in order for the slit, of width W, to completely traverse the cone of light, diameter C, the shutter must move C + W. If the shutter were exactly in the focal plane, it would have to move only the distance W to completely traverse the cone apex. Thus the definition of efficiency leads to the following, where f is the stop of the lens:

$$E = \frac{W}{W + C} = \frac{W}{W + \frac{d}{F/A}} = \frac{W}{W + \frac{d}{f}}$$

IV. BRIEF DESCRIPTION OF VARIOUS METHODS USED, PAST AND PRESENT, FOR TESTING CAMERA SHUTTER SPEEDS

Much work has been done on the development of both mechanical and electronic means for analyzing shutter operation, dating from as early as 1882. This paper will deal largely with electrical and electronic methods with brief reference to some of the simpler mechanical processes.

Rotating Camera Method

By mounting the camera on a motor-driven turntable and photographing a small fixed light source, the approximate speed of a between-the-lens shutter may be obtained. The length of the trace on the exposed film would be measured, as would the focal length of the lens system, the distance from lens to light source, and the speed of revolution of the camera. By using this information, the angle through which the camera turned while the shutter was open would be determined, as would the time interval during which the shutter was open.

A modification of this method would use a stroboscopic light as the light source, and manual rotation of the camera during exposure would be permitted. From a knowledge of the frequency of the flashing light, and the number of dots appearing on the exposed negative, the shutter speed could be computed.

Neither of these methods gives information as to the time of opening or closing of the shutter, but only the total time interval from the beginning of the opening of the shutter until it is completely closed. Also it is easy to imagine that a great number of trials would often be necessary in order to insure that the beginning and end of the trace

appear on the film. Too rapid rotation would cause the trace to start or finish off the film, and too slow rotation would give a trace so short as to make analysis difficult. And too, if using the motor-driven rotator, difficulty might be encountered in devising a satisfactory means of tripping the shutter mechanism. In the light of more modern electronic methods neither of the above mentioned methods are particularly practical or satisfactory.

The Fuller Electronic Chronometer

One of the first methods devised for measuring total-open-time without the need of film was devised by A. B. Fuller[2] and reviewed by Duffield and Lankes[3].

The now-common principal of interposing a shutter between the light source and a photocell was used. A motor-driven commutator was arranged to light a series of neon glow lamps in a known sequence when the necessary starting potential was applied by the photocell circuit. Once initiated, sufficient voltage was applied to maintain the lamps lighted even after the shutter closed and the photocell ceased to conduct. This gave sufficient time to count the number of lighted lamps and thus determine approximately the total-open-time. Widespread use is made of many variations of this fundamental scheme of measuring total-open-time.

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[2] A. B. Fuller, Electronic Chronometer, U. S. Pat. 1,954,313 (1934)

[3] S. H. Duffield and L. R. Lankes, "Testing Photographic Shutters" ELECTRONICS, pp. 82-87, August, 1948.

Methods of Kelley and Penther[4]

J. D. Kelley[5] devised a photoelectric means of measuring average open-time by establishing a photoelectric current proportional to shutter opening and utilizing this current to charge a capacitor. By means of a transfer process, comparison is made with that current which measures maximum area of shutter opening. The indicator is a vacuum tube voltmeter circuit. In using this system the shutter speed is obtained only after manually adjusting a resistor or otherwise balancing the circuit branches. During this time the charge stored in the capacitor is subject to leakage.

C. J. Penther[6] suggested improvements in Kelley's method by means of some circuit modifications to simplify the operation and to make the instrument direct reading. Both Kelley's and Penther's basic circuits are given in the footnoted references. A method similar to theirs will be dealt with in Part VI of this paper.

Oscillographic Systems

A realization of the inherent advantages of the oscillograph as a device for measuring the brief intervals of time dealt with in camera shutters came very early, at a time when oscillographs depended not on a stream of moving electrons but on the moving elements of a mirror galvanometer. Reich and Marvin[7] devised a two stage direct coupled amplifier

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[4] *Ibid.* S. H. Duffield and L. R. Lankes (Reviewed by)

[5] J. D. Kelley, Camera Shutter Tester, U. S. Pat. 2,168,994,(1937)

[6] C. J. Penther, Timing Device and Method, U. S. Pat. 2,376, 162, (1945)

[7] H. J. Reich and G. S. Marvin, REVIEW OF SCIENTIFIC INSTRUMENTS, December, 1931.

giving a linear current output of from 30 to 90 m.a. for input voltages between -3 and -11 volts. The input voltage was secured across the load resistor of a photocell, and the output current was allowed to flow through a G. E. type EM electromagnetic oscillograph. The light from an incandescent lamp was allowed to pass through the camera shutter and hence to the photocell. The oscillograph element consequently responded to the length of time and amount of light reaching the photocell.

They obtained fairly satisfactory results in the following respects:

a. the time of exposure is obtained by the length of the oscillogram, a 60-cycle timing wave being used as a time comparison scale.

b. the area under the curve is proportional to the total light flux admitted. The ratio of this area to that of a rectangle which just encloses the curve is a measure of the light efficiency of the shutter.

c. the shape of the curve shows at a glance the speed with which the shutter opens and closes.

Widespread use and improvement of the above-mentioned method awaited the development of the electrostatic deflection cathode ray tube, which is especially suited for the measurement and study of transient phenomena in electrical circuits because of the extremely low inertia of the electron beam.

A typical adaption of the cathode ray oscilloscope to the method of Reich and Marvin would briefly be as follows: The vertical deflection

plates of the cathode ray tube are coupled, either directly or though an amplifier, to the load resistor of the phototube. The shutter under test is interposed in the usual manner between the light source and the phototube. The horizontal deflecting plates are coupled to a source of a sawtooth voltage which may be triggered by the opening of the shutter. Thus a graph is produced on which the ordinates are proportional to the light passing through the shutter, and the abscissas are proportional to time.

Van Liempt and de Vriemd[8] in 1935 devised a cathode ray tube technique using but a single pair of deflection plates. They obtained their time base axis by providing linear motion of the photographic plate in the camera with which they photographed the trace. This method is much less satisfactory than the method utilizing two sets of deflection plates, especially under the present conditions when commercially designed oscilloscopes are available with the single triggered sweep feature incorporated into the instrument.

In Part V of this paper an oscillographic test will be discussed in detail, and the results presented and analyzed.

H. M. Ross[9, 10] in 1946 proposed the use of a logarithmic time base instead of the conventional linear sawtooth time base. His contention

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[8] J. A. M. Van Liempt and J. E. de Vriemd, "A New Method for Examining Photographic Shutter Speeds," Zeitschrift fur Physik, Vol. 98, 1935.

[9] H. M. Ross, "Nonlinear Time Bases for Testing Shutters and CRO Equipment," Private Communication from Research Laboratories, Kodak Ltd., Harron, England, September, 1946.

[10] S. H. Duffield and L. R. Lankes (Reviewed by) op. cit.

was that in a linear system it was possible to test only a limited range of speeds. If the horizontal sweep is suitable for viewing slow speeds, the pattern for a high speed will be crowded and too small to measure properly. And, if the sweep is adequate to observe the high speeds, the traces for the slow speeds occupy more than the available screen space. In using the logarithmic sweep, equal percentage differences appear as equal displacements. According to Ross, a speed range of 20 to 1 is easily covered with no appreciable loss in accuracy.

Blake and Lankes[11] in 1946 described their version of the cathode ray tube method in which they take advantage of a twin gun cathode ray tube. They provide the same time-base voltage to both sets of horizontal plates, and they feed the shutter pulse to one set of vertical plates and the pulse from a flash bulb synchronizer to the other set of vertical plates. Thus they obtain an accurate check of both the shutter speed and the synchronization mechanism.

Production Test for Shutters

Redemske[12] devised a versatile instrument for the production testing of large numbers of shutters for military cameras at the Fairchild Camera and Instrument Company. His equipment made possible rapid tests of between-the-lens shutters, focal plane shutters, and special night photography shutters. The speed of the focal plane shutter was tested at the start, center, and end of its motion across the photographic plate. The

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[11] S. H. Duffield and L. R. Lankes. op. cit.

[12] R. F. Redemske, "Electronic Shutter-Testers," ELECTRONICS, February, 1946, p. 128.

results were immediately available on teledeltos paper, which has the property of carbonizing and forming a dark line when a stylus energized with sufficient voltage is drawn against it.

Iconoscope Used for Focal Plane Shutter Testing[13]

The moving slit of a focal plane shutter can be imaged on the mosaic of an iconoscope to give a measure of integrated exposure, element by element, over the picture area. The signal from the iconoscope is fed to the vertical deflection plates of a cathode ray oscilloscope and a graph is thus plotted of integrated exposure against shutter displacement. This method is possibly abnormally complicated and expensive to set up.

Blake, Dixon, and Lankes[14] have simulated the mosaic of an iconoscope by constructing a phototube mosaic of as many as 25 miniature 1P42 phototubes. These tubes are placed in a row and aligned with the travel of the shutter slit. This device has been found useful and satisfactory, but the iconoscope itself offers a more complete answer to the problem.

Hurd Test for Focal Plane Shutters

The Hurd tester[15] consists of a cylindrical transparent plastic drum, open on one end, and driven at the rate of 1000 R.P.M. by a

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[13] S. H. Duffield and L. R. Lankes op. cit.

[14] S. H. Duffield and L. R. Lankes op. cit.

[15] A. H. Katz, "A.S.A. Standard Test for Focal Plane Shutters," (Monograph), published by Photographic Laboratory, Wright Field, Dayton, Ohio, December, 1944.

synchronous motor. It is manufactured by the Mark Hurd Manufacturing Company. A slit, parallel to the axis of rotation of the drum, is arranged so that it opens simultaneously with the starting of the motor. The shutter to be tested is placed over the slit in such a manner that the curtain is as close to the tester as possible and the shutter travel is in a direction parallel to the axis of rotation of the drum. A 100-watt lamp is placed on the far side of the shutter. A strip of film is placed in the drum, emulsion side out, and is held tightly against the inner surface of the drum by centrifugal force.

The actual test procedure is relatively simple:

a. with lights out the slit in the tester is opened and the motor is started. It reaches synchronous speed in less than one second.

b. the light source is turned on.

c. the shutter is tripped.

d. the slit in the tester is closed, turning off the motor.

e. the test film is developed and analyzed.

The photographic trace produced is a diagonal pattern which is the resultant of two motions: motion of the film past the slit and motion of the shutter at right angles to the film motion. By analyzing this trace according to procedures outlined in the reference, the actual time open, the effective exposure, and the efficiency may be computed.

Stroboscopic Method for Focal Plane Shutters[16]

The stroboscopic test for focal plane shutters is the simplest

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[16] *Ibid.*

test to carry out in the average laboratory, and consequently I am dealing with it in detail in Part VI of this paper.

V. OSCILLOGRAPHIC SHUTTER TEST

A great many variations of the basic oscillographic method have been devised, as indicated in Part IV of this paper. I will now describe the particular equipment, manner of operation, and results of the method which I set up in the laboratory.

Description of Equipment

My method is basically that described by Katz[17] as the American Standards Association's Standards for Testing Between-the-Lens Shutters. The circuit which I used is shown in Figure I. The phototube can be any high-vacuum type tube possessing characteristics similar to the RCA929 or 925. The oscilloscope used in this test must be provided with the single triggered-sweep feature. The Dumont Type 175A or 247 and the Tektronix Type 511A prove very satisfactory. If very slow shutter speeds are to be tested, the oscilloscope must have a sweep speed as low as one per second. The photographs included as a part of this paper were made while using a Dumont Type 175A. The Tektronix Type 511A makes possible the testing of the slower shutter speeds.

The audio oscillator used to modulate the Z-axis of the oscilloscope can be any available laboratory instrument. The wave form which it produces (sine or square) is not important, but for accurate timing of the shutter its frequency scale should be calibrated.

In order to make a permanent record of the test, the trace on the oscilloscope screen must be photographed. Satisfactory photography of the

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[17] A. H. Katz, "A.S.A. Standards for Testing Between-the-Lens Shutters", (Monograph) published by Photographic Laboratory, Wright Field, Dayton, Ohio, December, 1944.

OSCILLOGRAPHIC TEST
FOR
BETWEEN - THE - LENS
SHUTTERS

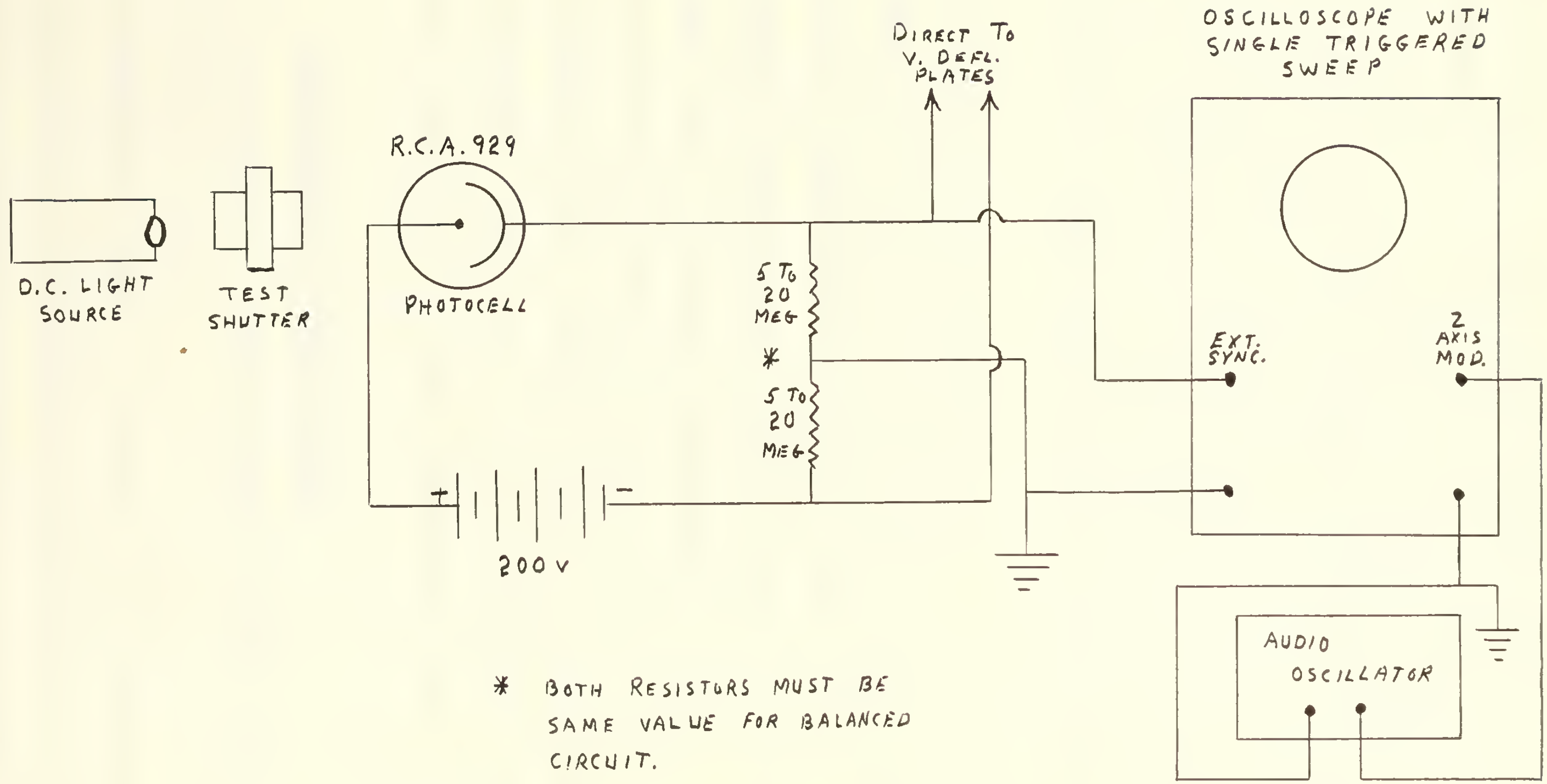


Figure I.

shutter characteristic curve can be made without special equipment. Exposures are bulb exposures made with any fast film and developed in a developer such as D-19 or D-72. No camera synchronization is needed. Since the camera and scope screen must be shielded from light, the bulb exposure is begun, the test shutter tripped, and the bulb exposure terminated. In the one or two seconds during which the film is exposed, not enough extraneous light enters the lens to cause any fogging, and the only light affecting the film is the brief single trace on the oscilloscope screen.

The light source used in the test must be operated from a d.c. source in order to avoid a.c. ripple in the shutter characteristic curve. The effect of using an a.c. light source is shown in Plates 7 and 8.

My only variation from the set-up described by Katz is the fact that I applied the signal from the photocell directly to the vertical plates of the oscilloscope through a balanced resistor network. Katz applied the signal developed across a 1-megohm resistor to the vertical amplifier of the oscilloscope. This method I found unsatisfactory due to the charge and discharge time involved in the coupling capacitors of the amplifiers.

Description of Test Procedure

The shutter to be tested is mounted between the light source and the photocell as indicated in Figure I.

The audio oscillator is coupled to the grid of the cathode ray tube (Z-axis modulation) and the beam intensity, oscillator gain, and Z-axis gain are adjusted so that clearly spaced timing dots are produced on

the trace. Each dot represents an interval of time equal to the reciprocal of the oscillator frequency.

Visual tests will determine the sweep frequency adjustments needed to adequately display the shutter characteristic curve. The method of adjusting the single sweep circuit of the oscilloscope will be found in the manual of instructions which accompanies the instrument. When this adjustment is properly made the beam is at rest and blanked out at the right side of the screen. When the test shutter is tripped, a signal is fed to the external synchronization binding post of the oscilloscope. This signal initiates the single sweep from left to right across the screen.

When all circuits are properly adjusted, you have merely to follow the method of photographing the trace which I have already outlined.

Calculation of Shutter Characteristics

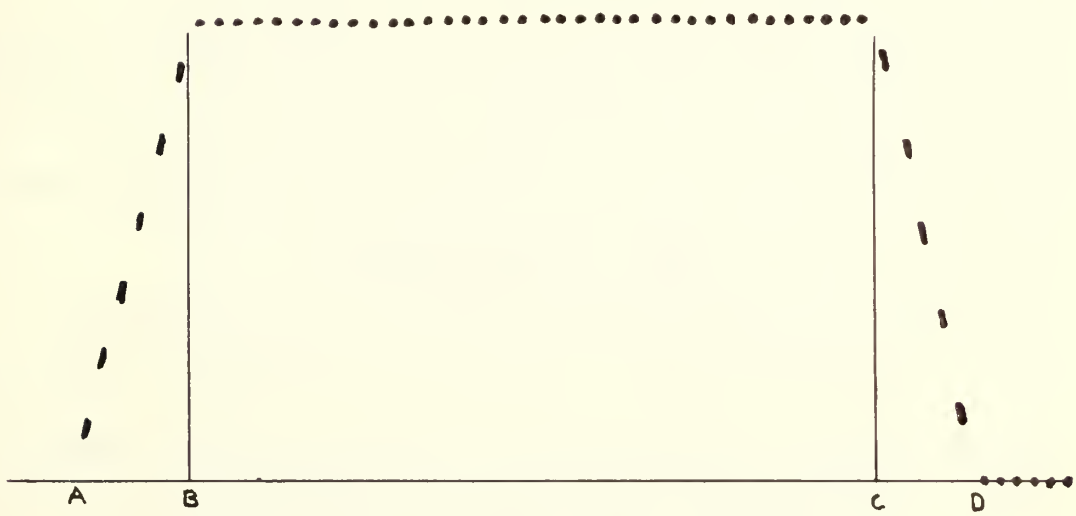
In general the shutter trace will appear as a trapezoidal pattern. When this is the case, the area under the curve, which is the integral of shutter area and time, represents the exposure. This may be found by elementary geometrical methods.

A typical oscillograph record and the accompanying calculations are found in Figure II. The shutter trace shown is the full aperture characteristic. If the aperture were stopped to half the area of its maximum opening, the horizontal top of the trace would be lowered half way to the axis. Thus the efficiency at half-area would increase half way to 100 percent from its previous value of 88 percent. Therefore, the half-area efficiency is 94 percent. The actual time open has, of course, remained unchanged. The A.S.A. speed is defined as the effective speed

Figure II.

Typical Oscillograph Trace and Calculations

Using Speed Graphic Camera



T_n = 1/50 second

f = 2000 cps

$T_a = N_{ad}/f$ = 47/2000 = 1/43 second

$$E = \frac{N_{ab}/2 + N_{bd} + N_{cd}/2}{N_{ad}} = \frac{6/2 + 36 + 5/2}{47} = 88\%$$

$T_e = E(T_a)$ = .88/43 = 1/49 second

T_n = Nominal (marked) speed

f = Frequency of dots

T_a = Actual time open (motion - stopping time)

E = Efficiency

T_e = Effective (exposure) speed

N_{ad} = Number of dots from A to D

ASA Speed = Effective speed at half aperture = .94/43 = 1/46 second

at half aperture, and is given by the formula:

A.S.A. Speed = (Efficiency at half aperture) (actual time open)

A much more detailed analysis of the mathematics and concepts involved in connection with the total open time, effective exposure time, and efficiency is presented by A. H. Katz in the paper already referred to which he presented at Boston University on July 18, 1947.

Actual Results of Tests

Sample tests on two cameras are shown in Plates 1 through 6. It can easily be seen that at slow shutter speeds the patterns are essentially trapezoidal. However the tests at 1/250 and 1/500 second using the shutter from the Zeiss Ikonta A camera deviate markedly from a trapezoid. As already mentioned, Plates 7 and 8 make obvious the necessity of using a direct current source of illumination.

The results of the analysis of Plates 1 though 6 is tabulated in Table I. The Zeiss camera was fairly new and in excellent condition, and yet the tests clearly show that the shutter speeds are abnormally lower than the speeds marked on the camera.

Oscillographic Test on Between-the-lens Shutter

Using Ansco View Camera

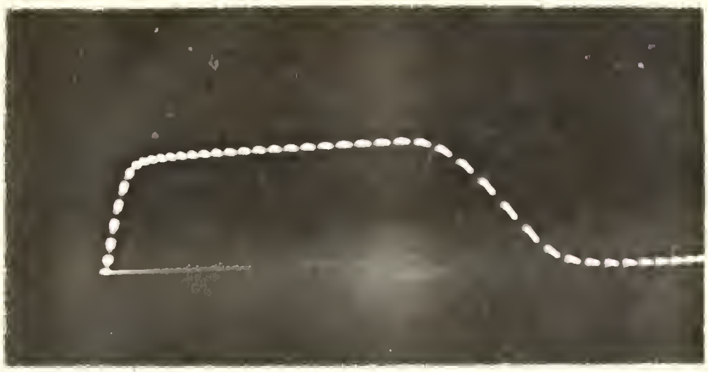


Plate 1. 1/50 second

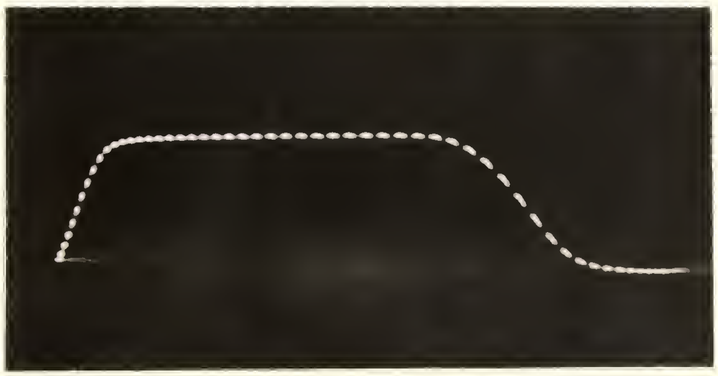


Plate 2. 1/75 second

Plate 3. 1/100 second

Oscillographic Test on Between-the-lens Shutter

Using Zeiss Ikonta A Camera

Plate 4. 1/100 second

Plate 5. 1/250 second

Plate 6. 1/500 second

Oscillographic Test on Between-the-lens Shutter

Using Ansco View Camera

Plate 7. 1/75 second

A. C. Light Source

Plate 8. 1/75 second

A. C. Light Source

Table I. - Results of Oscillographic and Electronic Tests

Camera	Nominal (marked) Speed	Audio Oscillator Frequency	t_a (by oscillograph)	Efficiency	t_e (by oscillograph)	t_a (electronically)
	$\frac{1}{100}$	2000 cps	$\frac{1}{67}$	88%	$\frac{1}{76}$	$\frac{1}{68}$
Zeiss Ikonta A (see plates 4,5,6)	$\frac{1}{250}$	4000 cps	$\frac{1}{160}$	74%	$\frac{1}{216}$	$\frac{1}{150}$
	$\frac{1}{500}$	5000 cps	$\frac{1}{192}$	69%	$\frac{1}{278}$	$\frac{1}{190}$
	$\frac{1}{50}$	2000 cps	$\frac{1}{57}$	80%	$\frac{1}{71}$	$\frac{1}{61}$
Ansco View (see plates 1,2,3)	$\frac{1}{75}$	3000 cps	$\frac{1}{67}$	79%	$\frac{1}{85}$	$\frac{1}{65}$
	$\frac{1}{100}$	3000 cps	$\frac{1}{75}$	75%	$\frac{1}{100}$	$\frac{1}{78}$

VI. A SIMPLE ELECTRONIC SHUTTER SPEED METER

The device about to be described was designed by Westburg[18] and is similar to the methods of Kelley and Penther discussed earlier in this paper. It was constructed partially from surplus materials at a cost of about $12, and could easily be duplicated by anyone interested for approximately $30 using entirely new parts, readily obtainable from any good radio wholesale house.

Construction of Tester

The schematic diagram is presented in Figure III. The phototube used is an RCA 929 or any other similar type. By using a high value of load resistance for the phototube the need for a high gain d.c. amplifier is eliminated. Three 10-megohm resistors in series make up this load resistor, and they must be enclosed in shielded braid to shield against 60-cycle pickup. The buffer, detector, and amplifier stages are all direct coupled in order to eliminate the leakage and charging problems of coupling capacitors. A 1/4-watt neon bulb is used to stabilize the anode voltage on the phototube. The 5,000-ohm potentiometer is used as a zero adjustment for the meter, and the 10,000-ohm potentiometer is used for the initial calibration of the instrument. The various charging resistors vary from 7 megohms to 4,000 ohms in value, and may be mounted directly on the single-pole eleven position switch. The indicating meter itself is a 0-500 microampere movement. Two 6SN7 tubes are utilized in the circuit.

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[18] Vernon B. Westburg, "A Simple Shutter Speed Meter," RADIO NEWS, p. 58, July, 1948.

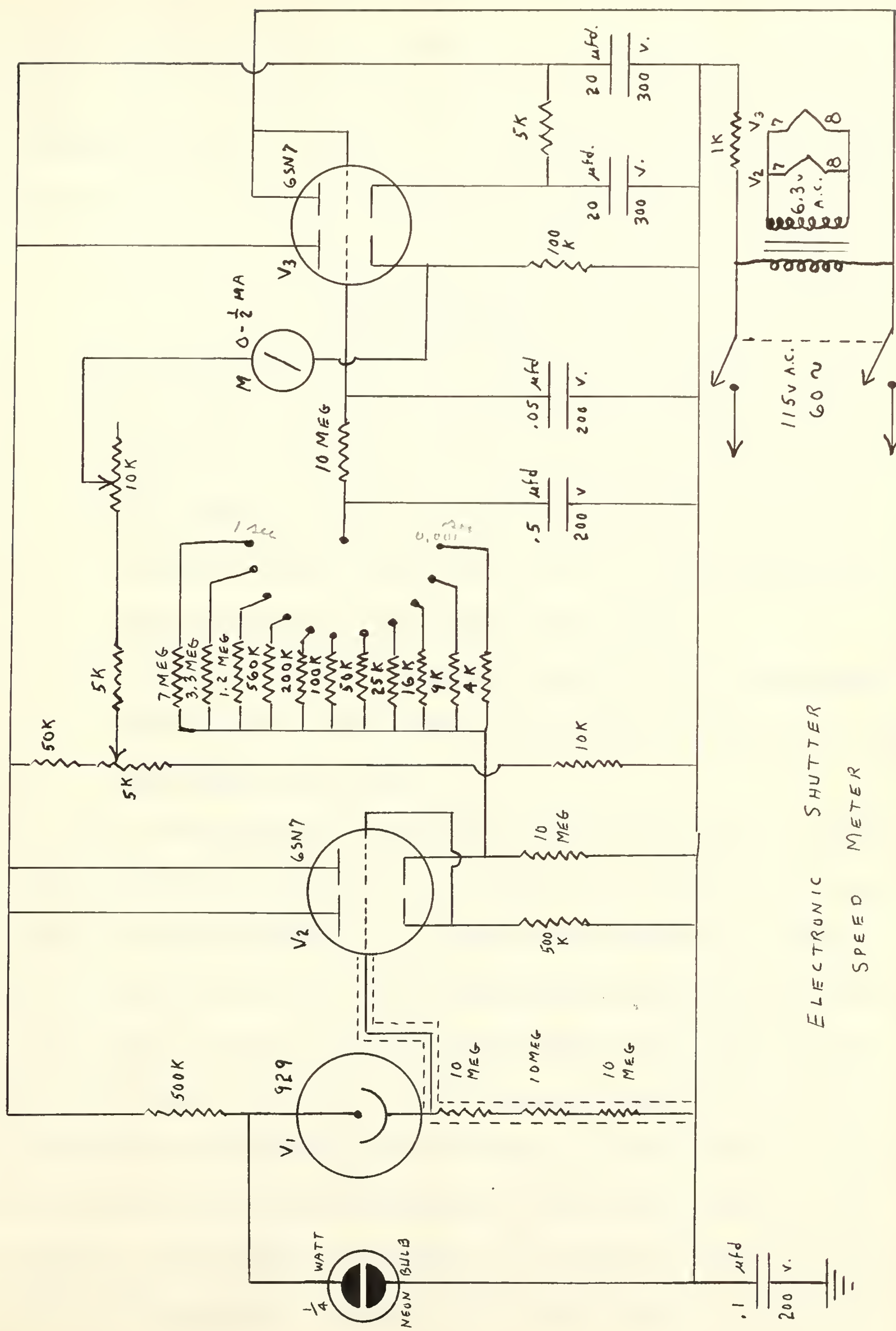

ELECTRONIC SHUTTER SPEED METER
V1
929
V2
6SN7
V3
6SN7
M
0-½ MA
10 MEG
.05 mfd 200 V.
.5 mfd 200 V
20 mfd 300 V.
20 mfd 300 V.
5K
1K
100 K
6.3V A.C.
115V A.C. 60~
10K
10K
5K
5K
50K
7 MEG
3.3 MEG
1.2 MEG
560K
200K
100K
50K
25K
16K
9K
4K
10 MEG
500 K
500K
10 MEG
10 MEG
10 MEG
¼ WATT
NEON BULB
.1 mfd 200 V.

Figure III.

V_2 acts as a buffer and detector, while V_3 acts as an amplifier and a rectifier. A 6.3 volt filament transformer is used to supply the necessary filament voltage. The entire unit can be mounted in a metal cabinet as small as 7 x 5 x 4 inches, thus making it readily applicable for portable use.

Circuit Operation

In brief the operation of the circuit is as follows:

a. the pulse of light which has passed through the shutter strikes the phototube and is converted into a voltage pulse.

b. this pulse of voltage is eventually applied to an RC circuit, so that the final voltage across the 0.5 microfarad capacitor is proportional to the length of the pulse.

c. a meter is used as a ballistic galvanometer in discharging this capacitor. The swing of the needle is proportional to the length of the pulse.

Let us investigate the operation of the circuit more in detail. The voltage pulse from the phototube is limited to a constant amplitude when the light flux, which strikes it, is above about two-tenths of a lumen. A 100-watt frosted bulb provides ample illumination to satisfy this requirement. This pulse is fed to the left hand section of V_2, which acts as a buffer stage (cathode follower). This stage is necessary since the phototube can supply but negligible power and cannot possibly drive the detector stage, which draws appreciable grid current. The right hand half of V_2 also acts as a cathode follower detector. It allows the charging of the RC circuit (the appropriate resistor of the eleven available and the 0.5

microfarad capacitor is applied to the grid of the third cathode follower, V_3, which serves as a power amplifier to deliver sufficient power to operate the meter. Because of the aforementioned slow discharge path, energy is stored long enough to allow a peak indication to be read on the meter. If the shutter is open too long, the capacitor will have time to charge beyond the proper voltage, and the milliammeter reading will be too high. If the shutter is not open long enough, the capacitor will not have enough time to charge to the proper voltage and the meter reading will be too low. The correct constants in the timing circuit for the various shutter speeds to be tested are obtained by switching any one of the eleven resistors into the charging circuit. The values have been picked so as to compensate for the high internal resistance of the detector at high shutter speeds and the effect of the overdamping of the meter. The shutter speeds measureable with these resistors are: 1, 1/2, 1/5, 1/10, 1/25, 1/50, 1/100, 1/200, 1/300, 1/500 and 1/1000 second. Intermediate speeds can be measured by interpolation.

Calibration and Operation

For calibration purposes a camera whose one second speed is known to be accurate is needed. The usual photocell technique is followed, namely, a 100-watt lamp bulb about 6 inches from the phototube and with the shutter placed between them. Permit the circuit to warm up, and then adjust the 5,000-ohm potentiometer for zero reading with no direct light falling on the phototube. We will arbitrarily establish 0.8 of full scale as the proper reading for a test shutter that tests in 100 percent agreement with the switch position used. With the aperture wide open, trip the shutter and

note the peak reading of the meter. By several trials, adjust the 10,000-ohm potentiometer until the meter swings to 0.8 of full scale. Naturally, the switch is on the 1 second position. When this 1 second calibration is completed, the higher speeds are automatically correct. Limits of minus and plus 25 percent of the rated time interval can be read on the scale at 0.6 and 1.0 of full scale. If you like, a new scale could be made on which various marks from 50 percent to 125 percent of rated values could be placed. For any test the average of several trials should, of course, be used.

Accuracy and Results of Test

Westburg determined the eleven resistor values by a series of calibration checks using more intricate methods. The time constants of the eleven R.C. charging circuits would be expected to follow the same progression as the eleven shutter speeds to be tested. Westburg found that the four highest value resistors should be larger than this regular progression would indicate in order to compensate for the effect of the overdamping of the meter circuit. Also the 3 lowest value resistors must be somewhat smaller in value than indicated by the progression in order to compensate for the internal resistance of the detector at fast shutter speeds. These values are plotted on the graph on page 30b.

Westburg's resistance values might not be exactly right for another instrument which uses a slightly different meter movement, but the accuracy seems more than sufficient for all normal photographic use. This method gives the total open time, and not the effective exposure time. For a much more complete view of the operation of a between-the-lens shutter, the

the oscillographic method is much to be preferred.

The results of tests on two cameras are presented in Table I. As compared with the total time open determined oscillographically, there seems to be very close agreement. Figure 4 shows how very much a new Speed Graphic shutter was in disagreement with the marked values.

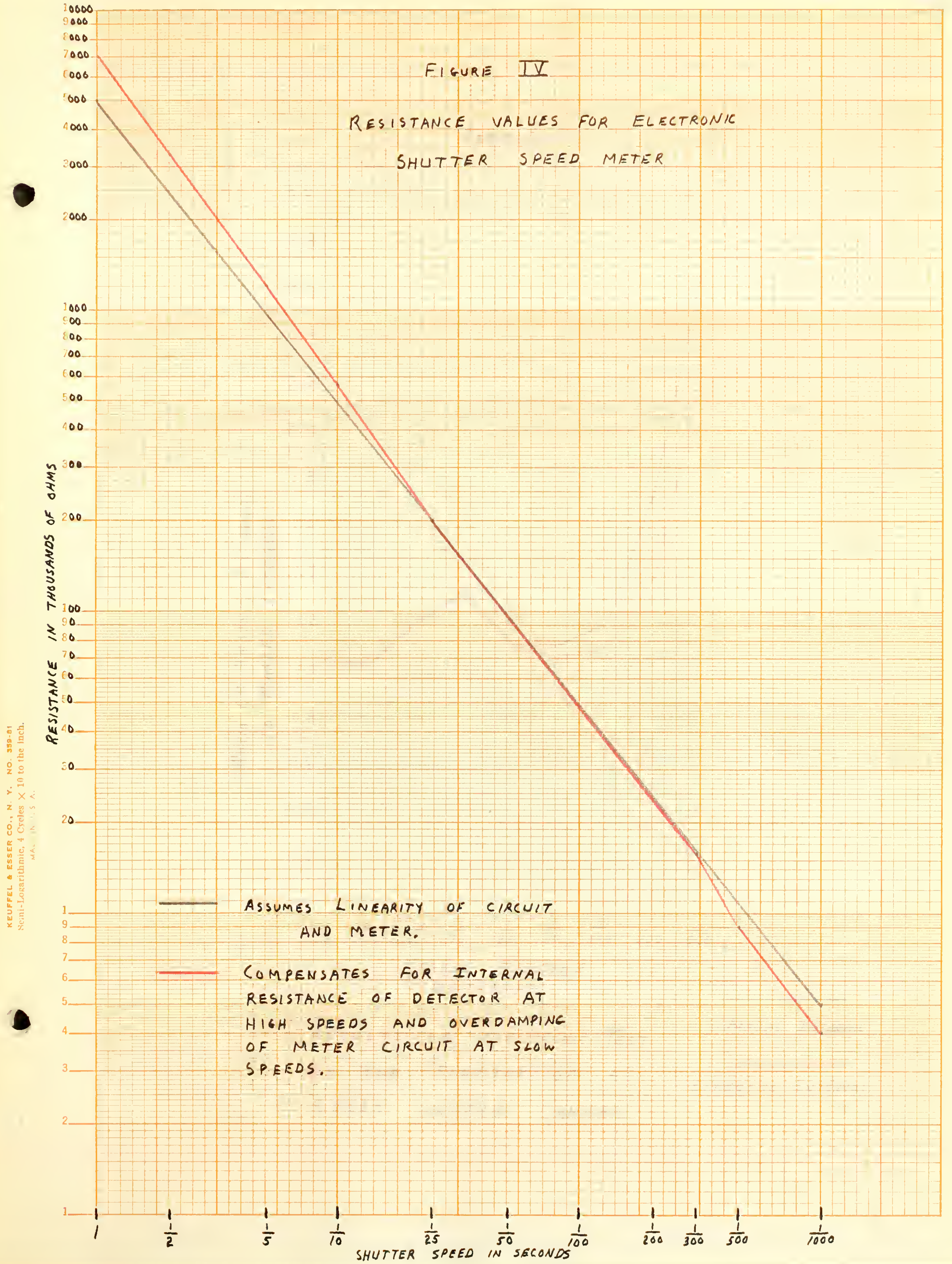
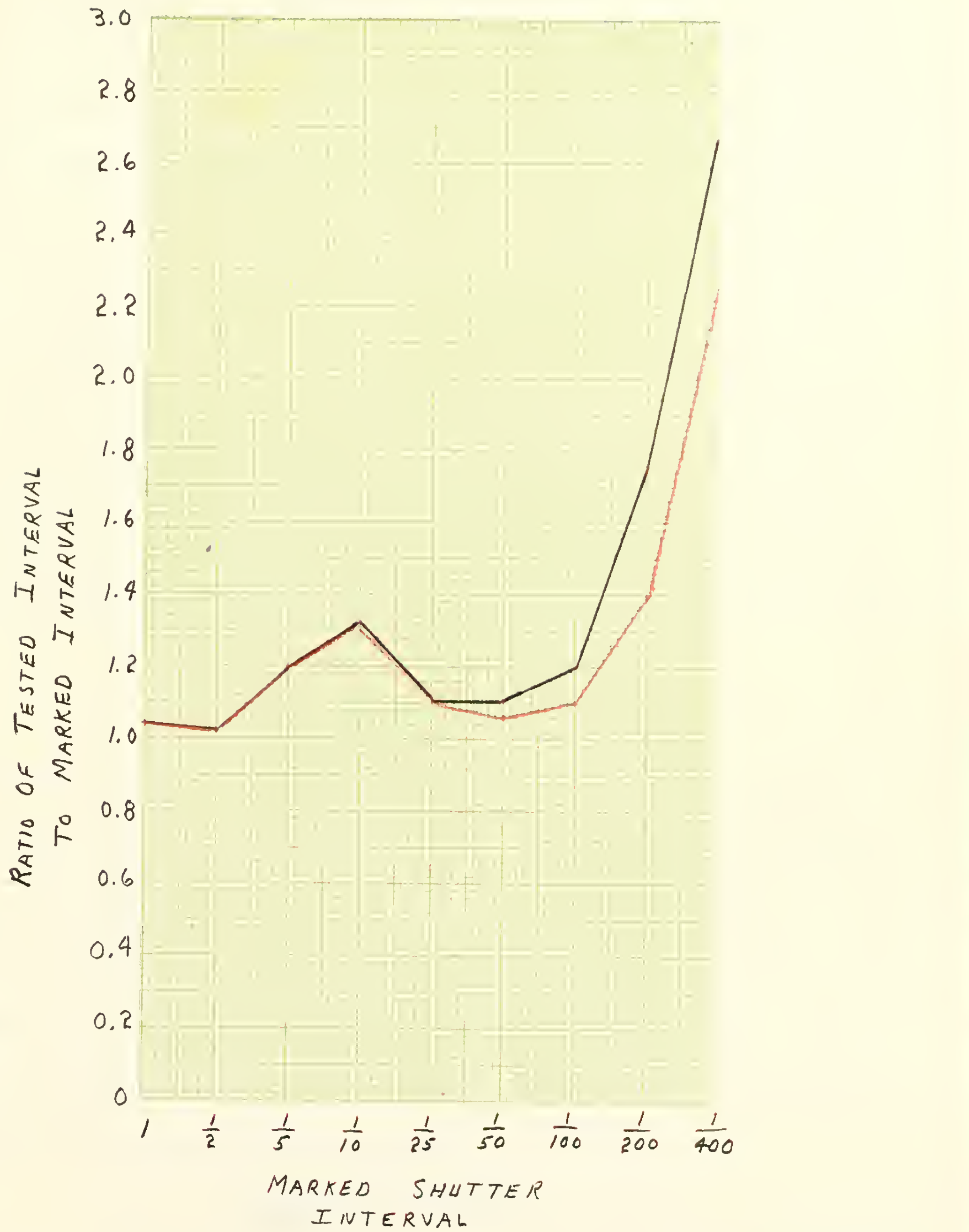


FIGURE IV
RESISTANCE VALUES FOR ELECTRONIC SHUTTER SPEED METER
RESISTANCE IN THOUSANDS OF OHMS
SHUTTER SPEED IN SECONDS
1 1/2 1/5 1/10 1/25 1/50 1/100 1/200 1/300 1/500 1/1000
10000 9000 8000 7000 6000 5000 4000 3000 2000 1000 900 800 700 600 500 400 300 200 100 90 80 70 60 50 40 30 20 1 9 8 7 6 5 4 3 2 1
ASSUMES LINEARITY OF CIRCUIT AND METER.
COMPENSATES FOR INTERNAL RESISTANCE OF DETECTOR AT HIGH SPEEDS AND OVERDAMPING OF METER CIRCUIT AT SLOW SPEEDS.
KEUFFEL & ESSER CO., N. Y. NO. 359-61
Semi-Logarithmic, 4 Cycles X 10 to the Inch.
MADE IN U.S.A.

Figure V.



Results of Electronic Test on the Shutter of a Speed Graphic Camera

VII. STROBOSCOPIC TEST FOR FOCAL PLANE SHUTTERS[19]

A relatively simple method for checking the characteristics of a focal plane shutter is possible if a rather intense flashing light of known frequency is available. A General Radio Strobotac operating in conjunction with a General Radio Strobolux is ideal for this test, but a stroboscope constructed by interrupting the light from an incandescent bulb by a rotating disc would prove adequate. The Strobolux is capable of flashing rates from 10 to 240 flashes per second, each flash being of extremely short duration. It is, therefore, very simple to make a series of shadowgraphs of the slit in the focal plane shutter as it passes across the film plane. An analysis of this picture gives complete information as to the curtain speed, actual time open, effective exposure time, efficiency, and exposure variation.

Test Procedure

The shutter under test is placed, without lens or aperture, as far away from the Strobolux as is convenient and consistent with adequate film exposure. A distance of five feet or more should be used. The flashing frequency is adjusted to the maximum frequency that will show clearly spaced images on the ground glass when the shutter is tripped. The ground glass is then replaced by the film, and the shutter tripped. Photographs, such as Plates 9, 10, and 11, will result.

Analysis of Results

The analysis of the resulting shadowgraphs is relatively simple.

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[19] A. H. Katz, op. cit., December, 1944 ("A.S.A. Standard Test for Focal Plane Shutters").

Stroboscopic Test on Focal Plane Shutter

of Speed Graphic Camera

Plate 9. 1/125 second

Plate 10. 1/250 second

Stroboscopic Test on Focal Plane Shutter

of Speed Graphic Camera - (Concluded)

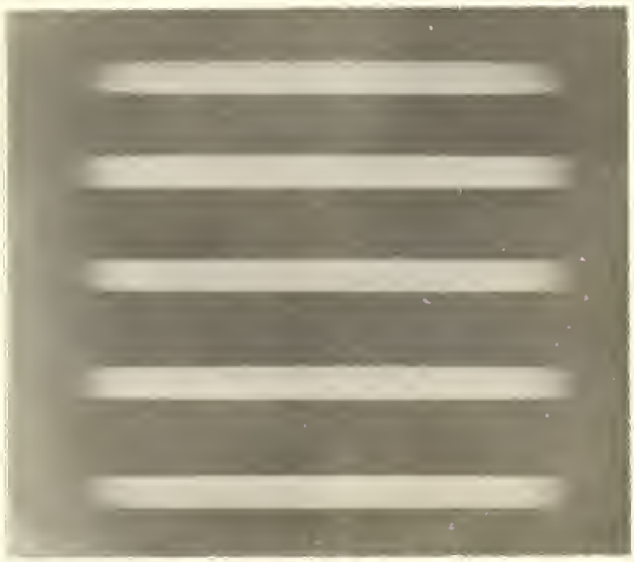


Plate 11. 1/1000 second

A sample set of calculations is shown in Figure V. The following formulas are used:

$$T_e = \frac{W}{n \cdot a}$$

where
T_e = effective speed
W = slit width
n = flash frequency in flashes per second
a = distance between corresponding edges of adjacent slit images

$$E = \frac{W}{W + \frac{d}{f}}$$

where
W = slit width
d = distance from film to curtain
f = f stop of aperture
E = efficiency

$$T_a = \frac{T_e}{E}$$

where T_a = actual time open

The complete development of these formulas is too lengthy to be adequately covered in this paper. However the paper, already referred to, which was presented July 18, 1947 at Boston University by A. H. Katz thoroughly develops the necessary concepts and equations.

The particular shutter analyzed in Figure V was that of a brand new Speed Graphic. The marked speed was 1/250 second, and the results indicate that in reality it is not as fast as claimed by the manufacturer.

Calculation of Focal Plane Shutter Characteristics
from Strobotac Record

Computation of Efficiency at f 4.7

$$\text{Efficiency} = \frac{W}{W + d/f}$$

W = width of slit = 11 mm.
d = distance of film to shutter=8.5 mm.
f = f stop = 4.7

$$= \frac{11}{11 + \frac{8.5}{4.7}} = 86\%$$

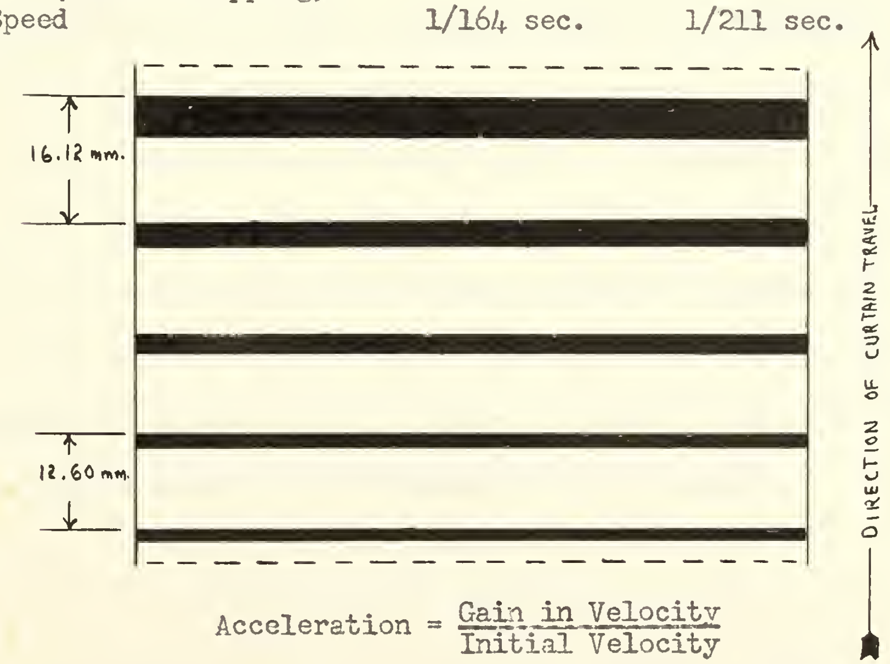
Strobotac Frequency = 167 flashes per second

$$\text{Effective speed at start} = t_s = \frac{11}{167\,(12.60)} = \frac{1}{191}\ \text{sec.}$$

$$\text{Effective speed at end} = t_e = \frac{11}{167\,(16.12)} = \frac{1}{245}\ \text{sec.}$$

$$\text{Actual (motion stopping) Speed} = \frac{\text{Effective Speed}}{\text{Efficiency}}$$

	Start of Travel	End of Travel	Average
Effective (exposure) Speed	1/191 sec.	1/245 sec.	1/215 sec.
Actual (motion stopping) Speed	1/164 sec.	1/211 sec.	1/185 sec.



$$\text{Acceleration} = \frac{\text{Gain in Velocity}}{\text{Initial Velocity}}$$

$$= \frac{16.12 - 12.60}{12.60} = 27.9\%$$

Figure VI.

VIII. ELECTRONIC COUNTER METHOD

I am proposing the following method of testing the total-time-open of a between-the-lens shutter as one which might prove satisfactory even though somewhat difficult to construct.

My plan would be to utilize the existing counter circuit from a Geiger-Mueller Counter. A scale of 100 circuit using the small 1/4 watt neon tubes would be preferable. A variable timing pulse would be needed, and could easily be obtained by peaking and clipping the variable frequency output of a multivibrator.

The operation would be as follows: A pulse of light would pass through the shutter and strike a photocell. The change in voltage across the photocell load would cause the timing pulses to be applied to the counter circuit. These pulses would only be counted as long as the photocell was exposed to the light, and thus, knowing the frequency of the timing pulse, one could readily determine the total time-open of the shutter.

This method is essentially a modern refinement of Fuller's Electronic Chronometer. The main difference is that the motor-driven commutator and its associated neon lamps would be replaced by a multivibrator type of electronic counting circuit. This device would directly and accurately indicate total open time, but would give no information as to the effective speed or the efficiency of the shutter.

IX. FINDINGS AND CONCLUSIONS

Since the purpose of this paper was to survey the various methods of testing shutters, both past and present, and to experimentally set up and try those methods, which the time and materials available permitted, there are no real conclusions, as such, that can be reached. I can, however, make a few general remarks on the relative merits of the methods tested.

To perform a comprehensive test upon a between-the-lens shutter, the oscillographic method is certainly the most satisfactory. It gives not only the total time open, but also the effective exposure time, the efficiency, and the A.S.A. exposure time. Any well-equipped college physics laboratory should be able to quickly assemble and set-up the necessary equipment to carry out such a test. The serious amateur or the professional photographer would certainly not have the equipment available to perform such a test, and he might very well be satisfied with the results of the electronic method as set forth by Westburg. Such a method would immediately detect, and with fair accuracy, any shutter that was in radical disagreement with the marked speed. A device such as this should prove useful in any up-to-date camera shop as a service to its customers.

As to the focal plane shutter, the Stroboscopic test is fairly simple, and it too could easily be performed in the average college physics laboratory. The Hurd test requires specialized equipment, as does the iconoscope or simulated mosaic methods.

My general conclusion, as a result of tests conducted in whole or part on a dozen cameras, is that even the most reputable manufacturers

seem to take no pains in making their cameras live up to the speeds with which they mark their shutters. All manufacturers should try and make the marked speeds mean something, and there should be reached an agreement as to whether the marked speed is supposed to mean actual time open, effective exposure time, or A.S.A. exposure time.

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BOSTON UNIVERSITY

GRADUATE SCHOOL

An Abstract of a Thesis

SHUTTER SPEED MEASUREMENT TECHNIQUES

by

Robert S. LaRue

(A.B., Michigan State Normal College, 1942)

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submitted in partial fulfilment of the

requirements for the degree of

Master of Arts

1949

Photography has rapidly progressed from the days of the pin-hole camera to its present highly technical state. During this development better and faster film emulsions were perfected, new and better lenses produced, and faster and more accurate shutters devised.

Hand in hand with the production of faster shutters came the need for accurately testing and calibrating their speeds. This necessity for shutter calibration has become increasingly important with the increased popularity of color film, which possesses a much narrower latitude of exposure than do black and white emulsions.

It is the author's purpose in writing this thesis to briefly describe some of the many methods, past and present, that have been and can be used to measure shutter speeds. Those methods which appeared the most feasable have been set up in the laboratory, various types of shutters tested, and the equipment, manner of use, and results set forth in detail.

Devices for the testing of shutter speeds date from as early as 1882. These first methods were largely mechanical, and this paper will deal mainly with electrical and electronic methods.

An early method used in testing between-the-lens shutters was the mechanical rotation of the camera while photographing a small fixed light source. By knowing the geometry of the set-up, the speed of revolution of the camera, and the length of trace on the film, the approximate shutter speed could be determined. This method could be modified by using a stroboscopic light for timing purposes. This would permit manual rotation of the camera.

In 1934 A. B. Fuller constructed a device consisting of a motor-

driven commutator connected to a series of neon glow lamps and a photocell. The light from an ordinary incandescent bulb would pass through the shutter under test to the photocell, and the number of neon lamps which glowed would be proportional to the open-time of the shutter.

J. D. Kelley devised, and C. J. Penther modified a method involving the use of phototube current to charge a capacitor. The voltage to which the capacitor charged was proportional to the open-time of the between-the-lens shutter and could be read with a vacuum tube voltmeter.

Many systems have been devised involving the use of the oscilloscope. Early methods used the electromagnetic mirror type of oscillograph, and present day techniques utilize the cathode ray oscilloscope. Basically the method is to allow a strong light to pass through the test shutter and strike a phototube. The voltage pulse developed across the load resistor of the phototube is fed to the vertical deflection plates of the oscilloscope. The beginning of the horizontal sweep must be synchronized with the opening of the shutter, and some timing base must be provided.

The calibration of focal plane shutters involves entirely different methods, inasmuch as the shutter itself inherently differs from the between-the-lens shutter. One method involves the focusing of the slit image on the sensitive mosaic of an iconoscope. Another method involves the focusing of the slit image on a mosaic of miniature phototubes. A commercial tester manufactured by the Mark Hurd Manufacturing Company consists of a rotating transparent cylindrical drum with a piece of film mounted around its inner circumference. The shutter slit moves in a direction parallel to the axis of rotation, and a diagonal pattern results

on the film which can easily be analyzed.

A stroboscopic method proposed by A. H. Katz at Wright Field, Dayton, Ohio, as an A.S.A. standard for testing focal plane shutters was set up in the author's laboratory. It is simple, inasmuch as the only equipment needed is a stroboscope of fairly high intensity. The lens and aperture is removed from the camera, the stroboscope placed in operation at a suitable frequency about eight feet from the camera, and the shutter allowed to travel across the sensitized film. The resulting shadowgraph is used in calculating the total open time, effective exposure time, and the efficiency of the shutter.

A version of the oscillographic method, similar to the A.S.A. standard test for between-the-lens shutters set up by Katz, was tried. The only expensive piece of equipment needed is an oscilloscope with the single triggered sweep feature. Light is allowed to pass through the shutter and strike a phototube. The voltage pulse developed across the load resistor is observed on the oscilloscope, whose single sweep is triggered by the opening of the shutter. The time interval is determined by intensity modulation of the electron beam by an audio oscillator. If a permanent record is desired, this trace on the oscilloscope must be photographed, but no specialized equipment is necessary to do this. This method yields excellent results since it gives you the time of opening and closing of the shutter as well as the total open time. An analysis of the pattern also allows you to compute the effective exposure time and the efficiency of the shutter.

The third device built and tested by the author for the measure-

ment of between-the-lens shutter speeds was designed by V. B. Westburg and published in the July, 1948, edition of Radio News. It uses the effect of a pulse of light striking a phototube in charging a capacitor. The charge stored is proportional to the light reaching the phototube, and this is proportional to the total open time of the shutter. The charge on the capacitor is indicated on a milliammeter serving essentially as a ballistic galvanometer. This method is not as accurate or useful as the oscilloscopic method, since it gives only the total open time. But the equipment is compact, portable, and easy, as well as inexpensive, to construct and deserves wide usage where extreme precision is not required.