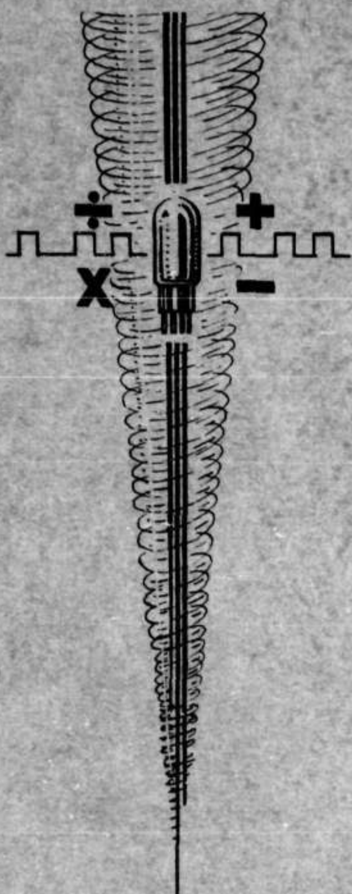

PROJECT

WHIRLWIND

Contract N5ori60

SUMMARY REPORT NO. 2

VOLUME 20

ICONOSCOPE STUDIES

SERVOMECHANISMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH

SPECIAL DEVICES CENTER

PROJECT WHIRLWIND
Summary Report No. 2
November, 1947

ICONOSCOPE STUDIES

Volume 20 of 22 volumes

Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

CONTENTS

INTRODUCTION

The thesis by Essigmann is included for its value on circuits, pulsed lights, laboratory techniques and the iconoscope tube. The study was begun as a possible high-speed input method for digital computers. Because of the progress in electrostatic storage tube research, the pulsed light method of reading punched cards is no longer considered significant as a data input method. However, the techniques and basic information presented in this text can be applied to research in electronic circuits and storage tubes.

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PHOTOSENSITIVE DEVICES AS DATA CONVERTORS for ELECTRONIC DIGITAL COMPUTERS

by

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B.S. in E.E.
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June, 1938

Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science

from the

Massachusetts Institute of Technology
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February, 1947

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Chairman of Departmental Committee on Graduate Students /s/ Harold L. Hazen

The author is sincerely indebted to Professor Henry J. Zimmermann for supervising this thesis; to Mr. Patrick Youtz and all other members of the Project Whirlwind (D.I.C. 6345) Staff for their continued interest and assistance in the work; and to Professor Gordon S. Brown and Mr. Jay W. Forrester for making available the facilities of the Servomechanisms Laboratory.

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INTRODUCTION

1. The Computer Problem

Any computation problem can be solved by arithmetical processes, given sufficient time; and results can be obtained to as good an approximation as desired. For those applications where complex mathematical problems are to be solved with considerable precision, and where solutions are required in times of the order of small fractions of a second, automatic digital computers are being developed. The manually-operated calculator can not be used for these applications.

Since the operator of the manually-operated type of calculator carries the program of solution in his head - or reads it from a schedule - and controls all the manipulations at the time that they are made, he sets the upper limit of speed. This method is not practicable in a problem where time is the independent variable, and the requirements of the problem are such that the solution must be obtained in real time. This means that the units of time in which the problem is defined cannot be stretched to simplify the computation.

Contemporary computers are based upon either analogue or digital principles. This investigation is concerned only with the digital type of computer. Digital computers have been built to operate on purely mechanical principles. A simple example is the ordinary adding machine. Mechanical computers, such as this, involve moving cams, relays, and so forth. The motion of physical parts limits the speed of operation to rates slow compared to those required in certain applications where the time scale is non-transformable. This undesirable characteristic can be partly eliminated by using electronic circuits; since, for example, the plate current of a vacuum tube can be turned on and off much faster than a relay can operate, and the time delay involved in passing a signal through an electronic amplifier is much less than that involved in placing levers and cams in motion. The reaction times of the computer elements become matters of microseconds when the electronic circuits are used, compared to milliseconds when mechanical components are involved.

Mechanical digital computers normally use the decimal system and require ten positions of activity to cover each place in each number manipulated. In an electronic digital computer, considerable simplicity and accuracy of control is gained if a lower base than ten is used to indicate such quantities. A computer using the base two, or operating in the binary system, requires only two conditions of activity to represent any binary digit.

This is true since zero and one are the only binary digits. They can be well represented, in the electronic computer, by the off and on conditions of plate-current flow in a vacuum tube. An electronic computer using a base larger than two would probably employ some type of proportional system involving voltage pulses whose heights corresponded to numerical magnitudes. The difficulty involved in accurately controlling the heights of these voltage pulses in vacuum-tube circuits is one of the main reasons why the binary system is one well adapted to electronic computing.

For a computer to operate at the speeds under consideration, the plan of solution, or program, must be made up in advance; and orders must be fed into the computer at appropriate times to control its operation. The programming unit controls the sequence in which the computer receives, stores, and manipulates the data, and then delivers the answer. This thesis concerns only the portion of the programming process in which data and sequence orders are obtained from prepared schedules and converted into electrical impulses.

2. The Program Unit

There are several possible methods of storing data in anticipation of the reading process which converts the data into electrical impulses for use by the computer.

In applications using the binary-number system, the data may be stored on cards having rows of punched holes. The order and spacing of the holes are used to represent the number. Other possibilities are lantern slides or motion-picture film having transparent areas carrying this same information. Bases higher than two can be used by shading the density of film, or by controlling the widths of holes in cards. In all cases, light is allowed to shine through the holes or shaded areas and some type of photosensitive device is used to convert the stored data into electrical impulses. If shading is used, the operation will probably not be precise.

The time required to read one binary digit determines the repetition rate of a computer using the binary system. In this case the repetition rate is the reciprocal of the length of the time interval during which one "on" or "off" condition can be represented. At the present time, the speeds of response of practical electronic circuits limit this to between one and five megacycles per second. The computer for which this thesis was undertaken is intended to operate at a one-megacycle-per-second rate. This means that each digit of a binary number must be converted in a time of one microsecond. In order that sufficient time be allowed between the occurrence of pulses indicating an "on" and "off" condition, this computer is to use one-fourth-microsecond pulses. This leaves a three-fourths-microsecond interval before the next digit begins.

Drawing B-30256 shows a block diagram of the proposed data reader for this computer. The components essential to this discussion are the electronic switch, the projectors containing pulsed-light sources and data slides, and the pick-up unit. The electronic switch receives projector-selection signals from the computer. These signals determine the order in which the lamps are turned on, and thus the order in which the images of the various slides are projected to the pick-up unit. At the pick-up unit, the images are displayed upon the photosensitive surface of some type of data converter to be described later. A line-selection signal is received by the pick-up unit, and the data contained on the line desired is removed electronically by a method determined by the type of data converter used. The electrical impulses thus generated are transferred through gated amplifiers to appropriate parts of the computer.

For the system shown, the number of projectors needed is the same as the number of cards of data to be read. It has been estimated* that a computer which will solve a large variety of problems must have data-storage facilities capable of handling at least 10,000 numbers. If each binary

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* This estimate was given by Professor Hartree of the University of Manchester, Manchester, England, in a seminar at the Massachusetts Institute of Technology.

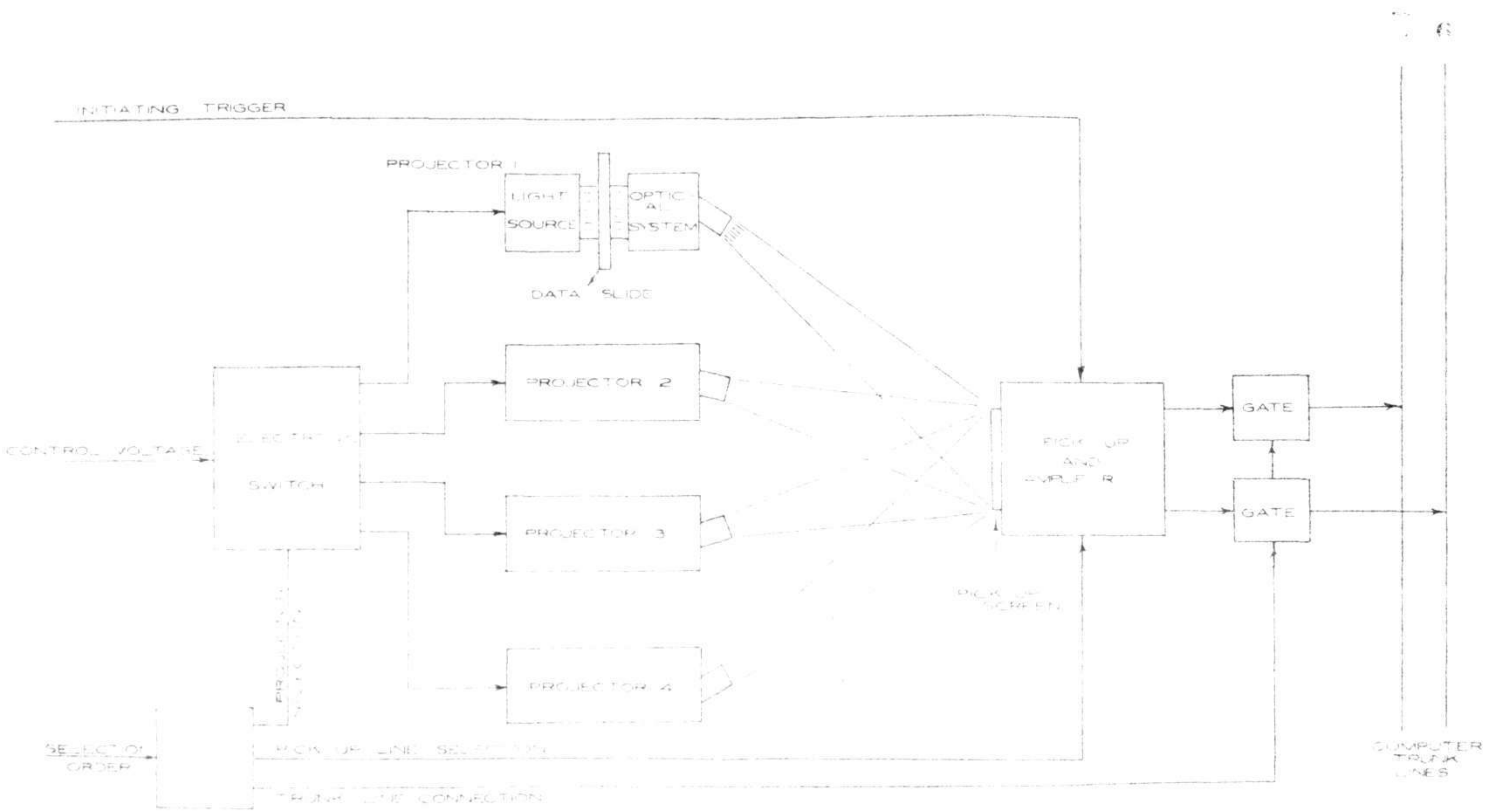

FIGURE 1 PROPOSED DATA READER — SIMPLIFIED BLOCK DIAGRAM

number is to contain thirty digits, then 300,000 binary digits must be stored. Assuming that each number takes up one line and that forty lines are contained on a card, then 250 cards and projectors are required.

Several possible types of photosensitive pick-up units have been considered as data converters. Pick-up devices which might be used include the iconoscope, the image dissector, the image orthicon and a matrix of photocells. The television-type tubes would be used under conditions of scan somewhat different than those in their normal application. The matrix of photocells would require complicated electronic switching circuits to remove the information contained thereon.

This thesis was originally undertaken to investigate the application of the television-type tubes and the matrix of photocells to the data-conversion problem. Initial investigation showed that the image orthicon has more sensitivity than is needed but a time lag that is probably too long. The image dissector is probably the best suited of the television tubes to this application because its time lag is the smallest of the types considered. The investigation was, however, started with the iconoscope, since an iconoscope tube and its associated deflection circuits were readily obtained.

The initial plan of the thesis involved constructing the necessary auxiliary equipment for use with the television tubes named above, and performing the necessary tests on these tubes, so that quantitative information could be obtained to indicate the suitability of each type to the data-conversion problem. As the thesis progressed, however, it became evident that the amount of original work involved was too much for the time available. Television-type circuits were not directly applicable, and there was no pulsed-light source fulfilling the requirements of the problem. In addition, published information did not describe sufficiently the various phenomena encountered to allow anticipation of, the types of compensating circuits required to correct for the spurious signals encountered. It was decided that the original objective should be narrowed to the extent that the iconoscope alone would be studied. The information desired concerning each of these types of tubes is the same; and the equipment used, and the techniques developed, for the iconoscope tests are applicable, with only minor modification, to the testing of the image dissector and image orthicon.

As a result of this revised objective, certain quantitative and qualitative conclusions have been reached concerning the application of the iconoscope to the data-conversion problem. These are indicated in the body of this thesis report.

The application of a matrix of phototubes is at present under study by others. The main limitation of this system seems to be the physical size of the matrix required if the effects of distributed and tube capacitances are to be kept to tolerable values.

One other possible way of converting data that does not require a projector system has already been investigated by others. It utilizes a data card placed at the face of a cathode-ray tube. The beam of the tube is swept across a row of coded holes in the card and the resulting light pulses are picked up by a photomultiplier tube. This method is considered uneconomical because of the large numbers of cathode-ray tubes, and their attendant complicated deflection circuits, required. Difficulty is experienced in stabilizing the deflection circuits to the degree required by the number of lines of data it is desired to store on a given card. The precision desired was not attained.

CHAPTER I

BASIC THEORY OF ICONOSCOPE OPERATION

1. Physical Description

Figure 2 shows the construction and circuit connections of the type of iconoscope tubes used in this thesis. This tube contains an electron gun consisting of a cathode with its associated heater, a control grid, an accelerating anode and a focusing anode. A second accelerating anode, called the collector, is an aquadag coating over a portion of the inside wall of the glass envelope. Magnetic deflection of the electron beam is used to position the beam on the target. The target (called the mosaic) consists of a sheet of mica, of from 0.001 to 0.003 inch in thickness, coated on one side with a conducting film, and on the other with globules of silver made photosensitive by treatment with cesium.

2. Secondary-Emission Effects

Before an explanation of the operation of the iconoscope is undertaken, it is advisable to consider the fundamental phenomena that occur when a material surface - either metallic or dielectric - is bombarded by electrons of various velocities. It is well known that under such bombardment the surface of the material emits electrons. The number of electrons emitted per impinging electron depends upon, but is not proportional to, the velocity of the impinging electron.

Consider the simplified form of a tube of the cathode-ray type shown in Fig. 3. The target is a slab of insulating material backed with a conductive coating. The front surface is arranged so

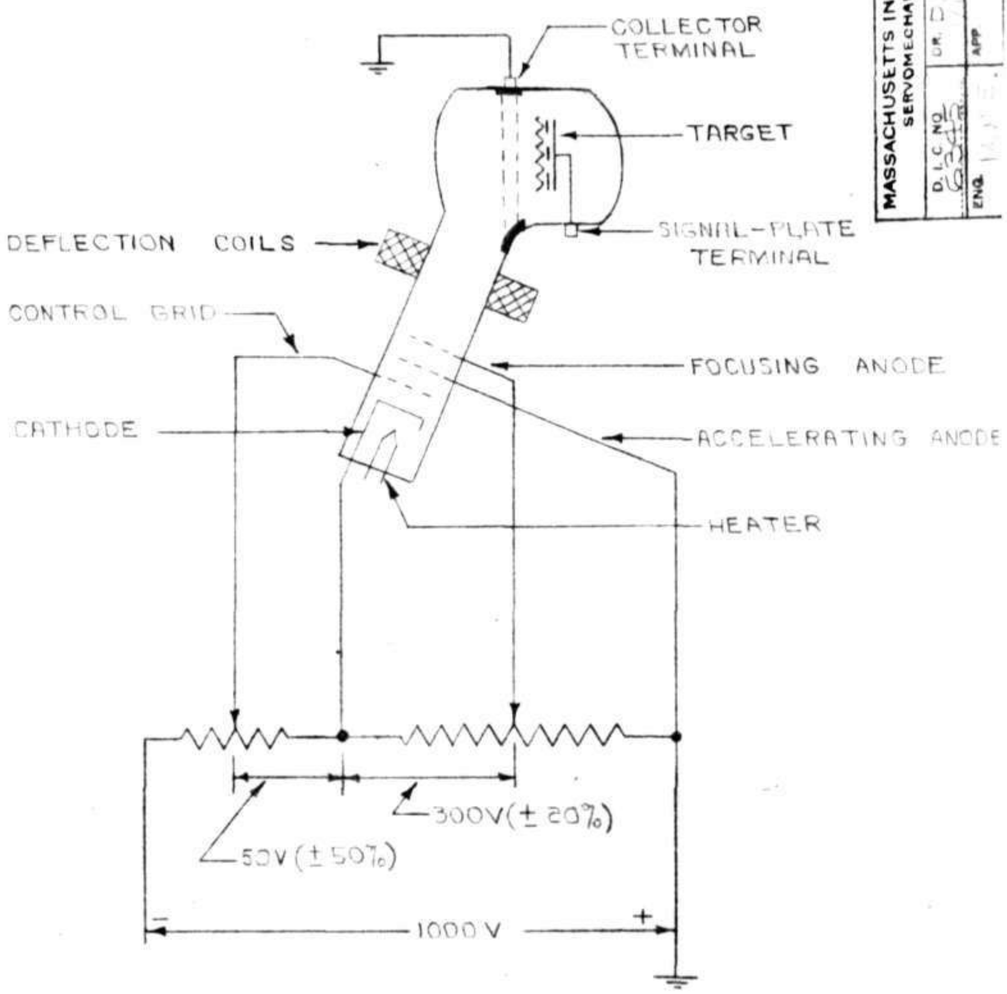

FIGURE 2. ICONOSCOPE TUBE AND CIRCUIT CONNECTIONS.

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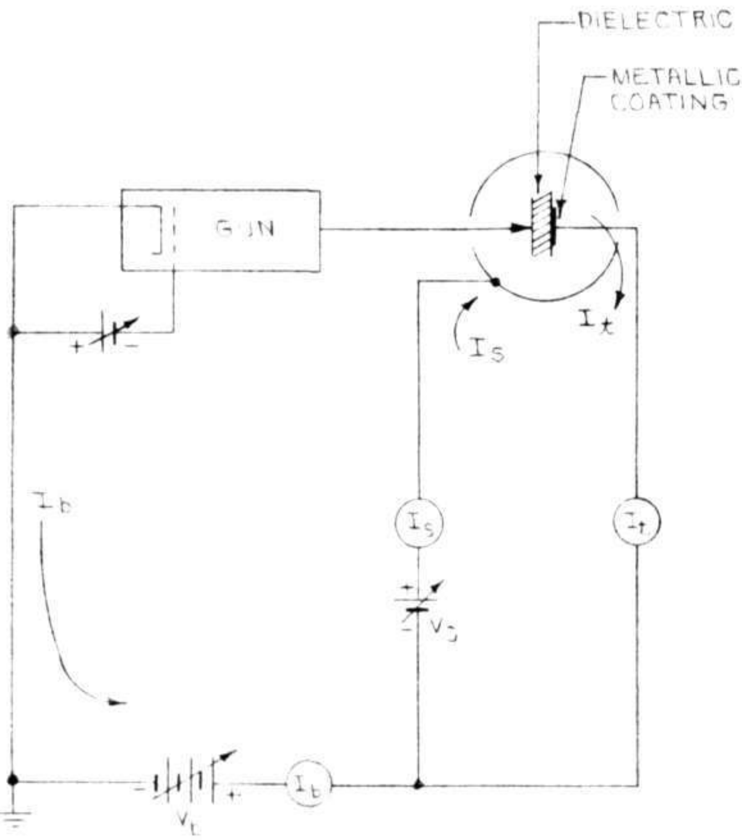

FIGURE 3 TUBE AND CIRCUIT FOR SHOWING SECONDARY-EMISSION EFFECTS

that the electron beam supplied by the gun strikes it perpendicularly. The beam is allowed to remain in one position; hence, only one point is under bombardment. Ammeters are provided to read the various currents, and a variable voltage, V_c, of reversible polarity can be inserted in series with the collector terminal. Under all conditions of operation, the three currents shown are related by the equation

$$I_s = I_c + I_b \qquad (1)$$

If, with V_c at zero volts, V_b is varied from zero to a large positive value and $\frac{I_s}{I_b}$ is plotted as a function of V_b, the curve obtained is that of Fig. 4a. The symbols I_s and I_b represent the secondary-emission and primary-beam currents, respectively. The curve shows that their ratio, called the secondary-emission ratio and represented here by the symbol δ, varies with beam voltage over three distinct ranges. In Ranges I and III δ is less than 1, and, in Range II, it is greater than 1. The foregoing statement is true for most materials, and typical curves for nickel, glass Al_2O_3, and Cs - CsO - Ag surfaces are shown in Fig. 4b.* The last-mentioned surface is the one used in the iconoscope. While all the surfaces named have secondary-emission ratios that exceed unity, this is not true for all materials. The secondary-emission ratio of carbon, for example, never reaches unity.

The following statements explain qualitatively the general shape of the curves shown. Under the impetus of the voltage V_b, each

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*Curves A,B, and C, are from Reference 1. Curve D is from Reference 2. A list of numbered references is given at the end of this thesis.

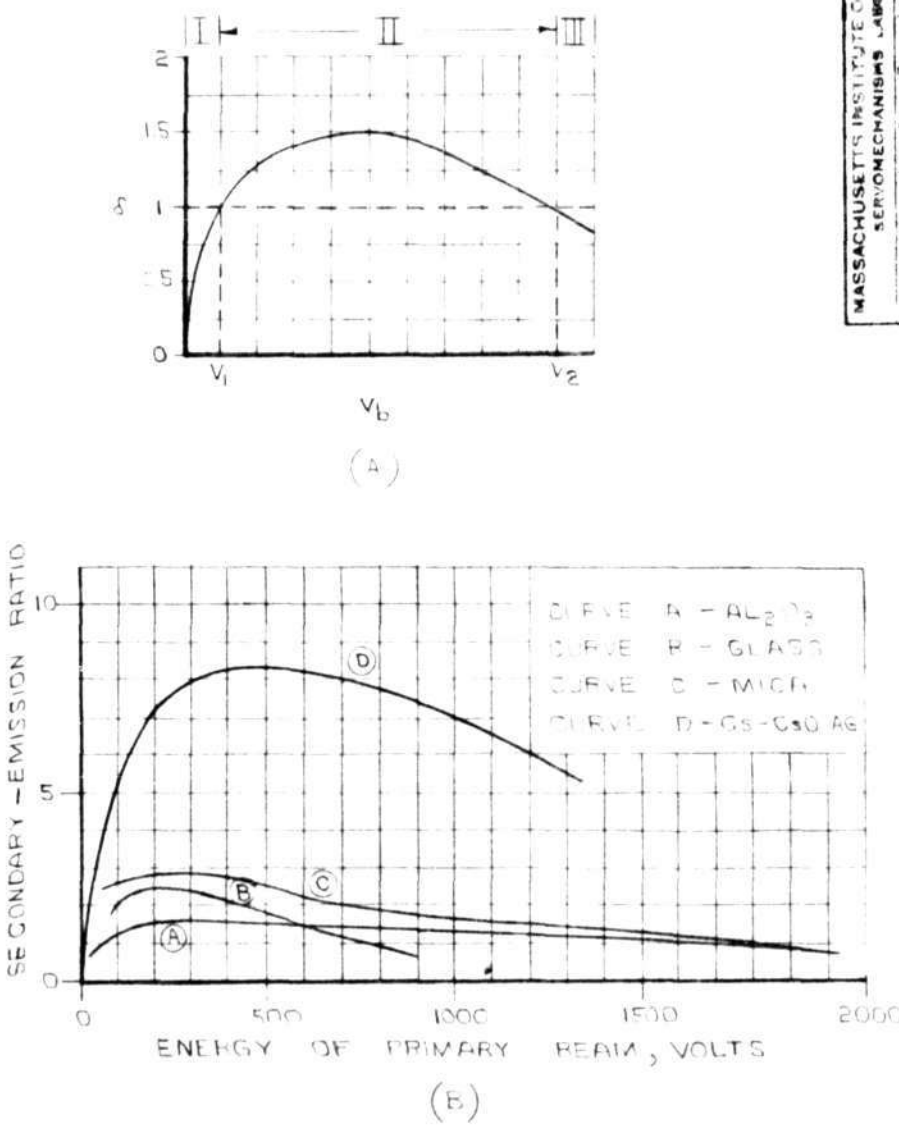

FIGURE 4. (A) AND (B). VARIATION OF SECONDARY-EMISSION RATIO WITH BEAM VOLTAGE.

USED IN MWE THESIS

primary electron penetrates into the surface of the material and imparts its energy to several electrons which may then be capable of leaving the surface. If the beam voltage is at the lower end of Range II, the primary electrons have energies corresponding to only a few hundred volts, and the number of emitted electrons is small. As the voltage V_b is increased, the primary electrons have increased velocity and a larger number of emitted electrons result. In addition, the increased velocity allows the primary electrons to penetrate further into the material. The secondaries so produced within the material have further to go to reach the surface; and the chance of losing their energy by collision with other electrons increases in proportion to the penetration. After a certain critical increase in voltage has taken place in Range II, the loss of energy due to collision becomes greater than the increase in energy due to the higher voltage, and the secondary-emission ratio is decreased.

In Range I the velocity of the beam electrons is insufficient to cause δ to reach unity. In Range III the secondary-emission ratio is less than unity because the electrons penetrate too far into the material.

The electrons produced by secondary emission have energies corresponding to a relatively few volts. In addition to these low-velocity electrons leaving the surface, there are additional ones having velocities at or close to the beam voltage. These are, perhaps, electrons of the main beam that have been reflected at the surface. The velocity distribution of all the electrons leaving the surface can be shown as in Fig. 5. It has been found experimentally that about 85 per cent* of the emitted electrons have velocities of three volts or less, and only a very

*See Reference 2

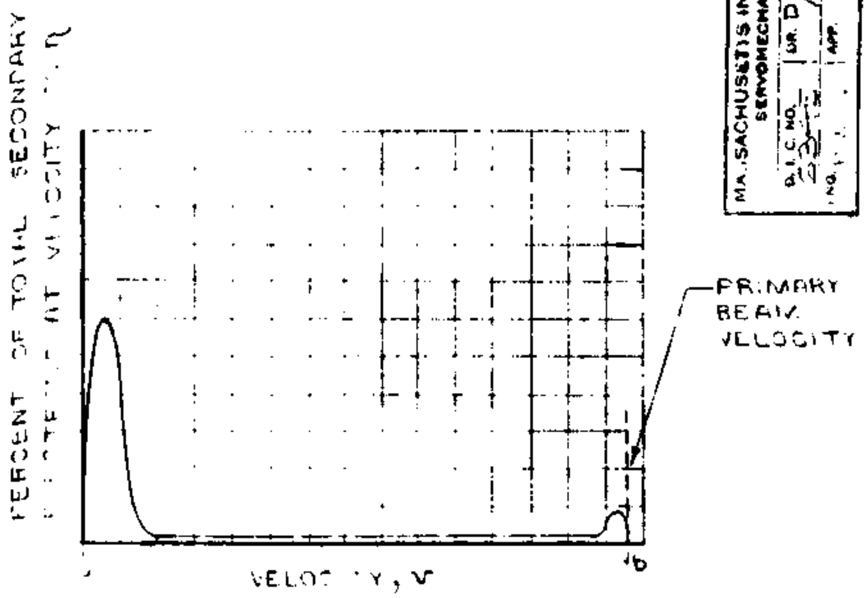

FIGURE 5 VELOCITY DISTRIBUTION OF SECONDARY ELECTRONS.

few have velocities of the order of the beam voltage. If E_{bm} is the total number of primary electrons, the total number of electrons having velocities less than that corresponding to a voltage V_1 is given by

$$E_{bm} \int_0^{V_1} \frac{n}{100} \, dv \qquad (2)$$

where n is the per cent of the total number of electrons leaving the surface with the velocity v .

3. Sticking Effects

The discussion thus far has not taken into account the build up with time of charge at the point of bombardment, and its resultant effect upon the net number of electrons that leave the surface. If δ is greater than unity at any instant, the potential of the spot bombarded is changing in a positive direction with respect to the neighboring electrodes. The number of the emitted secondary electrons that return to the spot of their origin is therefore increasing and the net number of electrons escaping to other elements is decreased. As a result, a final equilibrium potential is sought by the point of bombardment such that the number of escaping electrons just equals the number of electrons arriving in the beam. At this point in the discussion it is necessary to introduce a new term, that of the secondary-escape ratio, to give the ratio of the net current leaving the mosaic at any instant to the arriving beam current.

For the experimental tube shown in Fig. 3 there are three possible conditions of equilibrium depending upon whether V_b falls within Range I, II, or III of Fig. 4a. Assume first, for simplicity, that the collector voltage V_c is zero. If V_b is in Range I,* the secondary

*See References 7, 8, 9.

emission ratio δ is less than unity and the spot charges negatively to the cathode potential. If V_b is in Range III, δ is again less than unity and the spot again charges negatively. This time, however, it stops at V_2, the voltage at which δ equals unity. At these points of equilibrium, the potential of the spot is said to "stick" to the value given.

If V_b is in Range II, δ is greater than unity and the current I_s flows in such a direction as to increase the positive charge at the point under bombardment. As the potential of the point under bombardment becomes more positive, the secondary electrons which constitute I_s and normally flow to the collector are attracted by the positive charge at this point and the secondary-escape ratio decreases to unity. This equilibrium condition exists usually with the target potential at about three volts higher than V_b above the cathode, or ground, potential.

The process by which this equilibrium potential at the point of bombardment is established when the collector potential, V_c, is not the same as that of the target can be best explained by considering two different types of operation. With the system in the steady state (i.e., the target and its dielectric medium uncharged) the voltage V_b is applied. If the beam is held at cut off by proper adjustment of the bias voltage at the time V_b is applied, the potential of the front surface of the target rises to V_b above ground. Assume for the first type of operation that V_c is -100 volts. At the instant the beam is turned on, the target potential exceeds the collector poeontial by 100 volts, and the secondary electrons are, for the most part, attracted back to the surface. In other words, the secondary-escape ratio is less than unity. The target spot thus begins to charge negatively, and continues in this direction until the spot potential drops to a value sufficiently more positive than that of the collector to allow the secondary-escape ratio to increase to unity. Under this condition of equilibrium, the potential difference between collector and target is about 3 volts.

For the second type of operation, assume that the conditions are the same except that V_c is 100 volts. At the instant the beam is turned on, the secondary-escape ratio is greater than unity and the target spot begins to charge positively and continues in this direction until the potential of target is above that of the collector by about 3 volts. At this potential, the secondary-escape ratio is again unity.

In summarizing the preceding, it can be said that, regardless of the potential of the collector, if V_b falls within Ranges I or III, the potential of the target spot (with respect to ground) becomes, respectively, zero or V_2. If V_b falls within Range II, the equilibrium operating - or sticking - potential is that which places the target at about three volts positive with respect to the collector of electrons.

The velocity-distribution curve of Fig. 5 can be used to further define the value of the equilibrium potential of the target spot. If operation is in Range II of Fig. 4a, the value of the equilibrium potential V (with respect to ground) is given by the solution of

$$\int_{V-V_c'}^{\infty} \frac{n\,d\,v}{100} = 1 \qquad (3)$$

where V_c' is the collector voltage referred to ground. This is true since only electrons having equivalent velocities greater than $(V-V_c')$ can reach the collector; and the ratio of the number of these electrons to the total beam current must be unity.

In a practical pick-up tube circuit, the positive side of V_b is usually the grounded side. The discussions given must be modified to take this into account.

4. The Charging Phenomenon

In the foregoing discussion the target has been assumed to be a perfect insulator or dielectric and under this condition the charged region is localized to the area beneath the electron beam. In the case of the iconoscope, the target consists of a capacitor with mica dielectric, one side of which is coated with a conducting film of either graphite or silver to form the signal plate, and the other side is covered with tiny conducting photo-sensitive globules. These globules have diameters of approximately 0.0005 inch, and are separated by paths over the mica surface of high, but finite, resistance. The equivalent circuit of the mosaic, drawn for a cross-section passing through the beam axis, is shown in Fig. 6a. This equivalent circuit can be assumed to have circular symmetry about the beam axis (shown as AA'). When the electron beam impinges at Point P a voltage builds up across the mosaic. The area of the mosaic under charge at any instant of time, and the rate of charging of this area, is determined by the resistance and capacitance values, R_m and C_m.

Provided the surface resistance R_m is high, the mosaic can be assumed to be accurately represented by the magnitude of total C_m included under the beam cross-section when a brief pulse of beam current is applied to the globule at P. If the collector is at ground potential and the beam voltage is within Range II of Fig. 4a, then the voltage at

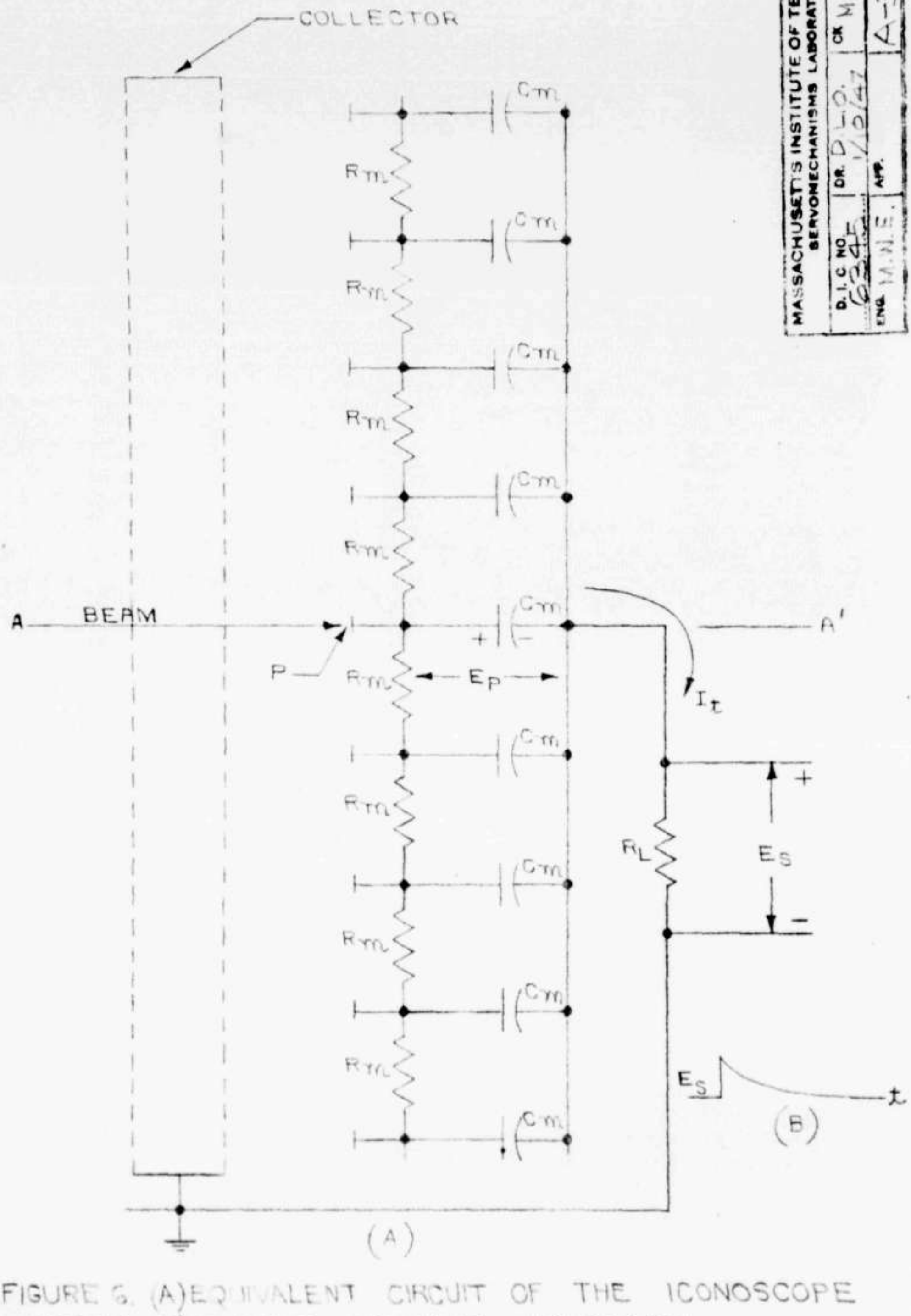

FIGURE 6. (A) EQUIVALENT CIRCUIT OF THE ICONOSCOPE MOSAIC. (B) OUTPUT - VOLTAGE WAVEFORM.

P, the point of bombardment, must rise to +3 volts with respect to ground (as discussed before) when a pulse of beam current is applied. With the resistor R_L in the circuit the capacitor C_m cannot change its charge instantaneously, and a voltage E_s is produced which is proportional to the charging current I_t. Consider the mosaic surface to be initially at ground potential, as it would be in the steady state with no beam current flowing, and allow a step-function of current to be applied at P. The current I_t flows in the direction shown and charges C_m to make E_p = +3 volts. The current I_t produces a positive voltage at E_s. This equilibrium is reached very quickly - in a time of the order of tenths of a microsecond if C_m is small - and the output-voltage waveform appears as in Fig. 6b. The mechanisms of the production of this waveform, and the derivation of its shape, is given the next section.

5. The Formation of the Signal Stored by Grid Modulation

It has been shown in the preceding sections that the secondary-escape ratio is decreased as the mosaic potential is made increasingly positive with respect to the collector, and reaches a final value of unity at about +3 volts for the Cs - CsO - Ag mosaic. For the circuit of Fig. 7, this potential is V and the secondary-escape ratio is given by $\frac{I_s}{I_b}$. An experimentally-determined curve relating variation of $\frac{I_s}{I_b}$ with V has been given by Maloff* and is reproduced in Fig. 8. If unity is subtracted from the ordinate of the curve of Fig. 8, the resulting relationship is that of $\frac{I_t}{I_b}$ vs. V**. This curve is shown

* See Reference 3.

**That this is true can be shown as follows. Since $I_t = I_s - I_b$, then $\frac{I_s}{I_b} - 1 = \frac{I_t}{I_b}$

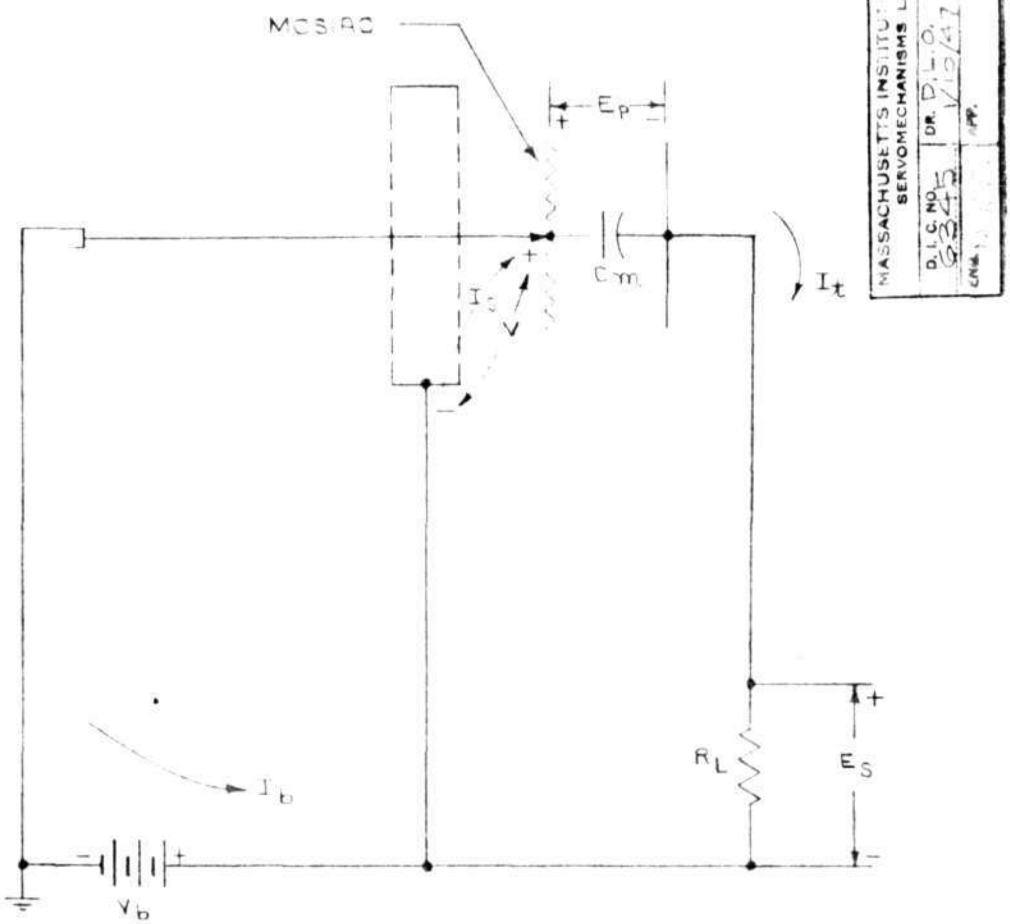

FIGURE 7 CIRCUIT FOR SINGLE SPOT CHARGING OF MOSAIC.

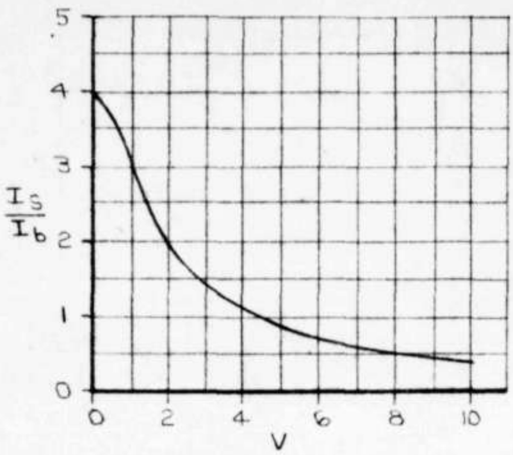

FIGURE 8. VARIATION OF SECONDARY-ESCAPE RATIO WITH MOSAIC-TO-COLLECTOR POTENTIAL.

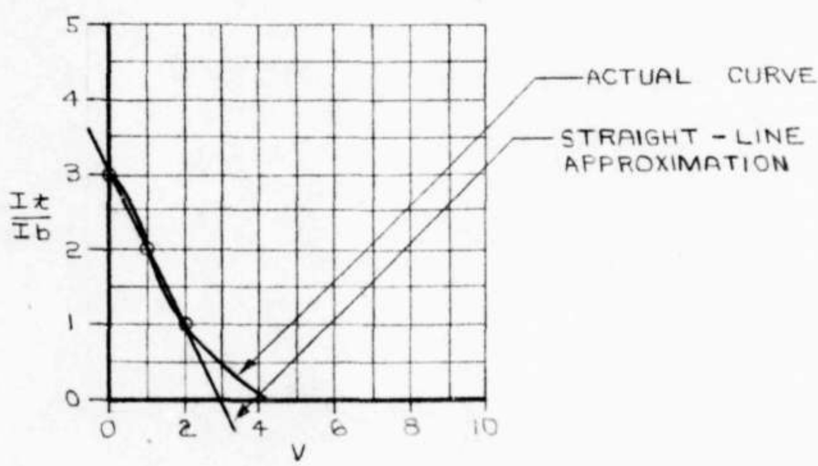

FIGURE 9. CURVE DERIVED FROM THAT OF FIGURE 8 BY SUBTRACTING UNITY FROM THE ORDINATE VALUES.

in Fig. 9, and inspection indicates that it can be considered to be a straight line having the equation

$$\frac{I_t}{I_b} = 3 - V \qquad (4)$$

Assume that a step function of I_b is supplied to the initially uncharged surface at time $t = 0$. The current flowing from the signal plate is the charging current of C_m and is related to E_p by the equation.

$$I_t = C_m \frac{dE_P}{dt} \qquad (5)$$

But $$E_P = V - I_t R_L \qquad (6)$$

and, therefore, $$I_t = C_m \frac{d(V - I_t R_L)}{dt} \qquad (7)$$

Also, $$E_s = I_t R_L \qquad (8)$$

Equations (4), (7), and (8), give three independent equations relating I_t, V, E_s, and t. These equations can be solved to give the variation of E_s with time. The initial conditions required are that at $t = 0$, $V = 0$.

Substituting I_t obtained from equation (4) into equation (7), and collecting variables, gives

$$\frac{dV}{V - 3} = - \frac{I_b}{C_m(1 + R_L I_b)}. \qquad (9)$$

The solution of equation (9) is

$$V = 3 + Ke^{-\frac{I_b}{C_m(1 + R_L I_b)} t} \qquad (10)$$

for only short interval of time, secondary emission is saturated and this method is not suitable. It is probable, however, that in the application at hand where only a single point is bombarded (beam not swept), and a large beam current is used that this method of attack is justified.

6. The Effect of Light

The foregoing discussion of the electronic phenomena existing at the surface of the mosaic has considered only the secondary-emission effects. In the case of the iconoscope, the surface has been chosen to provide high photo emission as well as secondary emission. When an area of the mosaic is illuminated, it emits electrons because of its photo sensitivity and as a result the potential of the illuminated area moves positively with respect to either the collector or the unilluminated regions.

This photo-emission is, in general, unsaturated since the collector is normally at ground potential and there is no positive gradient tending to draw off electrons from the region considered. If the surface is under scan, or if other adjacent portions are strongly illuminated, this is not the case since then there may well be positive gradients existing at this region. This point is of importance, since when emission is unsaturated the most positive potential reached at the point is independent of light intensity. When two neighboring regions are illuminated at different light intensities, the equilibrium potentials of these regions can be shown to be different in the following manner as described by Zworykin and Morton.*

* See Reference 4, pp. 283, 284.

Let the two intensities be L_1 and L_2, with L_2 greater than L_1. The variation of the photo-electron current flowing away from the surface at these two regions varies with the spot potential approximately as shown in Fig. 10. Photo-electrons that have left the immediate region of the illuminated areas return to other portions of the mosaic with a nearly uniform density. If I_r represents the magnitude of this redistribution-current flow, then the two equilibrium potentials are E_1 and E_2.

When an illuminated area is bombarded with a sufficiently dense beam of electrons it charges to the equilibrium potential described in Article 2 at which the secondary-escape ratio becomes unity. This is the same final potential reached by an unilluminated spot. There is, however, a difference of charge which must flow from these two regions and this difference appears as a variation in voltage across the load resistor. This voltage change is negative, under normal conditions, for an increase in illumination. It is the video signal generated in a television pick-up unit, and it is used to carry the video intelligence.

7. Single-Line Scanning Phenomenon

In neither the usual television nor the present computer application is the beam maintained stationary on the mosaic - as it has been considered to be in the foregoing discussion - but it is made to sweep across the surface in various ways. This scanning action causes a time-varying charge distribution on the mosaic that depends upon many parameters such as average beam current, instantaneous beam current, spot coordinates on the mosaic, beam voltage and collector potential.

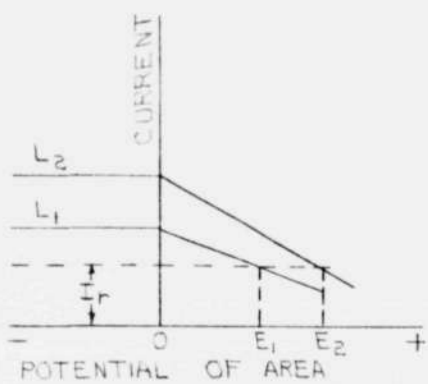

FIGURE 10. PHENOMENON OCCURING WITH DIFFERENT ILLUMINATIONS ON MOSAIC SURFACE.

The resulting signal-voltage waveform produced across the load resistor is, therefore, very complex. Inasmuch as all the tests made in this investigation that used a scanning beam have involved only a single line, the explanation to be given will be for this type of operation. Furthermore, the literature* covers completely the scanning of a field in the form of a series of adjacent lines, but the charge distributions involved are considerably different than for single-line conditions.

The waveform produced when the unilluminated mosaic is scanned is called the dark-spot signal. The dark-spot signal is a function of repetition rate. In the explanation of this waveform to follow, it is assumed, for simplicity, that a non-repetitive sweep is used and that initially the whole iconoscope is in a steady-state condition with the mosaic surface unilluminated and at the collector potential. Consider first a spot of the same area as the electron beam and near the center of the mosaic. The beam is held below cutoff for the time taken to sweep from the left-hand edge of the mosaic to a point three beam diameters from the spot, and it is then held at a constant current value until it is three beam diameters on the other side of the spot. At this point the beam is cutoff. Thebeam is thus intensified for the time taken to pass over seven elements of the mosaic area with the spot under consideration in the center of the seven. If the beam current is sufficiently large as it moves across the mosaic, it raises the potentials of the points it passes over to equilibrium values placing them at about +3 volts with respect to the collector.

As the beam approaches the spot under consideration, the spot

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* For example, See References 4, 5, and 6.

receives redistribution electrons from the region of bombardment, and its potential changes negatively. Let it be assumed that redistribution electrons begin to be received when the beam is two beam diameters away from spot considered. As the beam progresses closer to the spot, the rate at which negative charge is accumulated increases, and the rate at which the spot potential changes is increased. As the beam passes over the spot, it rapidly changes the potential of the spot from a negative value to the positive equilibrium value. As the beam recedes from the spot, the spot receives a rain of redistribution electrons that decreases as the beam gets further away. This tends to reduce the positive potential at the spot. This reduction can be assumed to stop when the beam has reached a point two beam diameters away.

Figure 11 shows pictorially the change in voltage with time at the mosaic spot when the intensifier pulse applied to thebeam is phased to occur at different points along the scan with respect to the spot considered. At (a) the intensification stops when the spot is reached, and the charge accumulated due to the redistribution electrons remains on the surface. At (b) the beam current is cutoff as soon as the beam begins to leave the spot and the leveling effect of the redistribution electrons is absent. Pictures (c) through (h) are self-explanatory. At (i), the beam current is turned on at the instant the spot is reached and the charging process starts at zero.

The mosaic may be idealized and considered to be a group of capacitors having one common terminal connected to the load resistor as shown in Fig. 12. In order to derive the waveform to be expected

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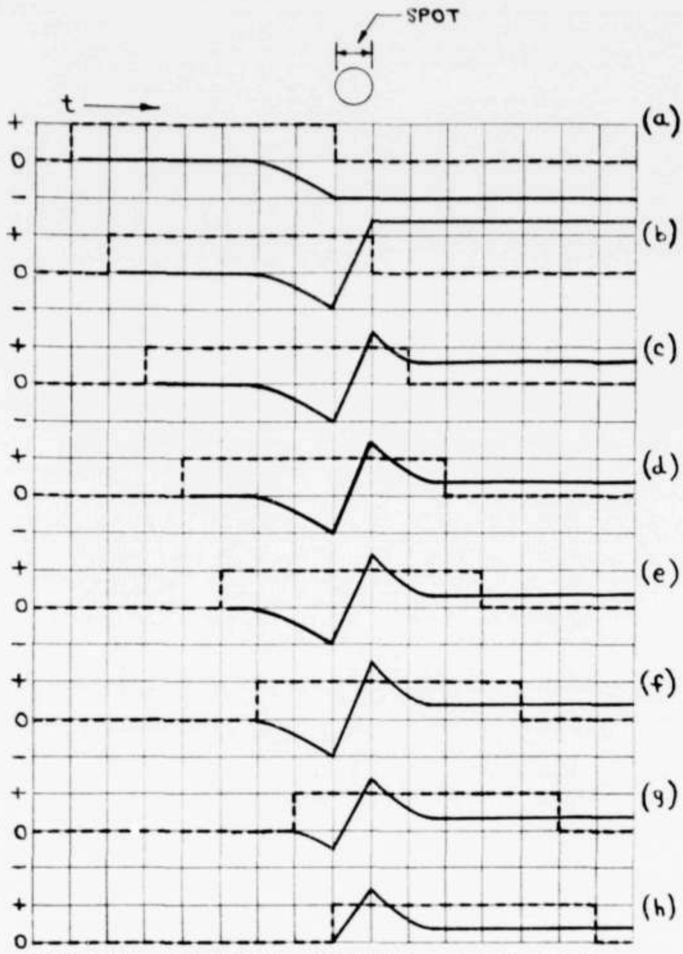

FIGURE 11. POTENTIAL VARIATION OF A SPOT ON MOSAIC WHEN PHASE OF INTENSIFIER PULSE IS CHANGED.

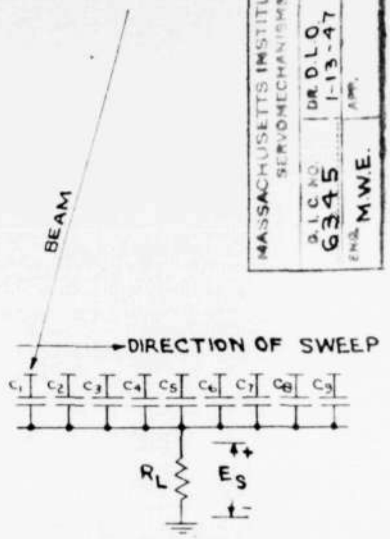

FIGURE 12. SIMPLIFIED FORM OF ICONOSCOPE TARGET CIRCUIT

- - - - ITENSIFIER PULSE
——— POTENTIAL OF SPOT

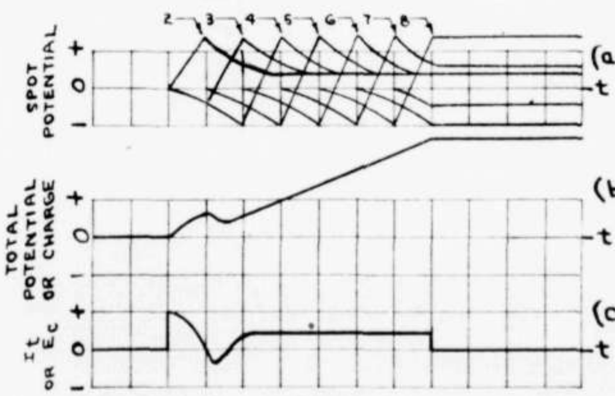

FIGURE 13. FORMATION OF DARK-SPOT SIGNAL BY LARGE BEAM CURRENT.

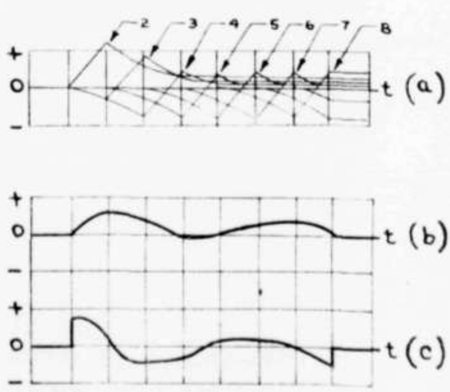

FIGURE 14. FORMATION OF DARK-SPOT SIGNAL BY SMALL BEAM CURRENT

at E_s, let the scan start from C_1, and the beam be intensified at C_2 and remain at constant value until cutoff at C_8. The voltage changes occurring across capacitors C_2 and C_8 are shown in the correspondingly-labeled curves of Fig. 13a. Since the voltage across C_2 to C_8 is proportional to the charge on these capacitors, the ordinate of these curves could just as well have been labelled "charge". If the eight curves of Fig. 13a are added, the resulting waveform is that of the variation of total charge on the mosaic with time (see Fig. 13b). The time rate of change of charge (or the instantaneous slope of Fig. 13b is the current I_t flowing to produce E_s. The result obtained by graphically differentiating the curve of Fig. 13b is shown in Fig. 13c. T is is the waveform of E_s.*

If the beam current is assumed to be of smaller magnitude than that used in the foregoing, then the equilibrium potential is not reached during the time the beam is on a spot. It may be assumed, however, that the total change in potential is the same for each of the elementary capacitors of Fig. 12 during this time. The voltages across the capacitors C_2 to C_8 are shown in Fig. 14a, and the same process as described for the larger beam current can be applied here to derive the waveform of E_s given in Fig. 14c.

When a portion of the mosaic is illuminated, the rise of voltage across the capacitance, i.e. from the area illuminated to the signal plate, is limited to a smaller value and a negative output-voltage indication is obtained. The method used above can be modified

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* Compare with Fig. 27(f) of Chap. V

to derive this waveform. Consider that an area equal to that of the beam cross-section is illuminated at the location of C_5 on the mosaic, and that the mosaic is scanned at the beam current used in Fig. 13. The waveforms of voltage across C_2, C_3, C_4, C_6, C_7, and C_8 are, to a first approximation, not effected by the light; but, the initial voltage across C_5 is slightly positive, and the beginning part of this waveform is raised by this amount. These waveforms are shown in Fig. 15a. At the instant when the beam reaches C_5, its potential is driven to the same positive potential as the other capacitors, and from this time on its shape is the same as shown in Fig. 13a. The result of adding these seven waveforms is given at (b), and differentiation of this variation of charge produces the waveform E_s at (c).*

* Compare with Fig. 29 (g) of Chap. V.

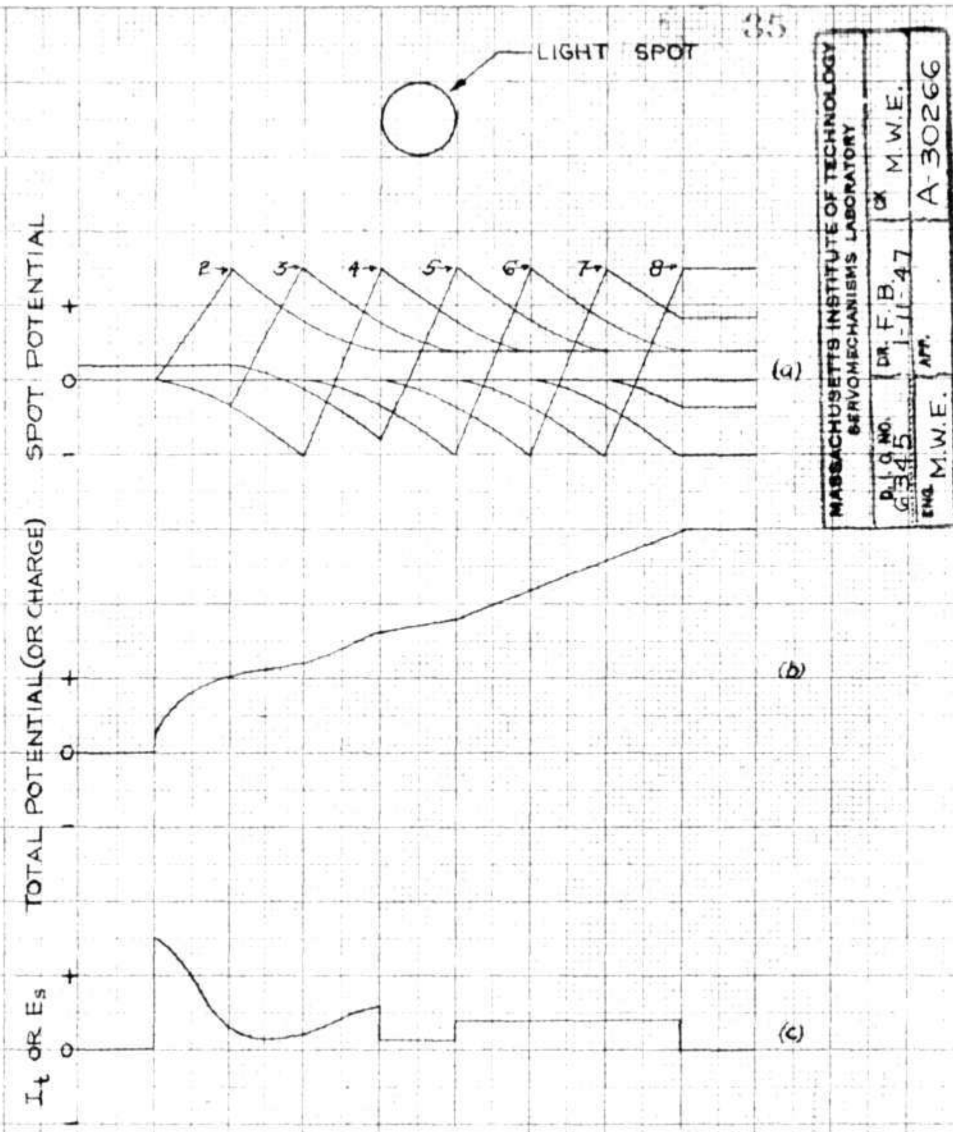

FIG. 15. FORMATION OF SIGNAL DUE TO LIGHT AT LARGE BEAM CURRENT

USED IN M.W.E. THESIS

CHAPTER II

DISCUSSION OF THE REQUIREMENTS OF THE PICK-UP PROBLEM

1. General Requirements:

It has been stated in the Introduction that the computer application for which this thesis was undertaken requires the reading of data from cards, slides, or films. These data are stored in lines assumed here to contain sixty basic elements, where each basic element corresponds to a place in a binary number. Each element is one microsecond long and may or may not contain a one-fourth microsecond pulse depending upon the binary number of which it is a part. A plot of voltage vs. time at the output of an ideal data converter is shown in Fig. 16. The arrangement of pulses included between the times (1) and (2) corresponds to the binary equivalent of the decimal number fifty-four.

In the case of the iconoscope, there are many reasons why the output may not have the ideal waveform shown in Fig. 16. The most important of these are:

a) Spurious signals will exist due to thermal agitation noise, inadvertant transfer of intensifying pulses through the inter-electrode and stray-wiring capacities, and the peculiar phenomenon produced by stray secondary electrons in forming the "dark spot" signal.

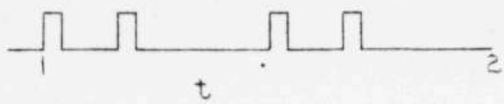

FIGURE 16. IDEALIZED VIDEO SIGNAL RESULTING FROM READING THE NUMBER FIFTY FOUR.

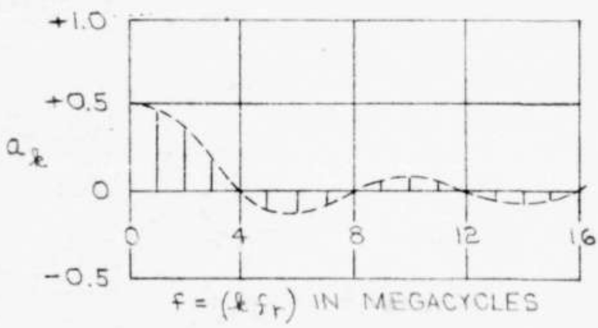

FIGURE 17. FREQUENCY SPECTRUM SHOWING AMPLITUDE COEFFICIENTS INVOLVED IN REPEATED PULSES.

b) The video amplifier can spoil the waveform of its gain and phase vs. frequency characteristics are not of the proper shape.

c) The light source may not evenly illuminate the mosaic surface so that the pulses do not all have the same height.

After a line has been scanned, or "read", it is essential that all information contained thereon shall have been - or shall be - removed in order that the surface be ready to receive another light impression of an entirely different nature. If erasure is to take place after the line has been read, this process shall not take more than a few micro-seconds to perform. If it is to take place during the scan, it must not adversely affect the signal stored, or cause either temporary or permanent loss of sensitivity of the iconoscope.

Since it is desired to keep the "dead-time" between line elements to a minimum, the light source must be of a type that can be turned on and extinguished rapidly. The light output waveform must be fairly constant during the time the lamp is on in order that a series of signal pulses having uniform height be possible. As will be discussed later, if a light source of sufficient peak intensity is available, it may be possible to flash the image on the mosaic during a time small in comparison to the 60-microsecond sweep period, and rely upon the storage phenomenon at the mosaic to retain the potential pattern until the line is scanned.

Because there will always be the undesired voltage pulses of the types discussed above along with the desired signals, some means must be devised for separating these components. The method presently considered consists of amplifying and clipping the mixed signal waveforms to remove the spurious outputs of the iconoscope. In order that the desired precision of not more than one error in some 10^{10} operations be obtained, it is desirable that the ratio of peak signal voltage to rms noise voltages be at least five before these shaping operations are performed.

2. Bandwidth Considerations

The most stringent bandwidth requirement is met when the waveform of Fig. 16 contains all ones. Under this condition, the spectrum of harmonics involved is given by *

$$a_k = 2E_o \delta f_r \frac{\sin \pi k f_r \delta}{\pi k f_r \delta} \qquad (1)$$

where a_k represents the amplitude coefficients of the Fourier-series expansion for this waveform as given by

$$e_s = \frac{a_o}{2} + a_1 \cos \omega_r t + a_2 \cos 2 (\omega_r t) + \dots a_k \cos k (\omega_r t) + \dots \qquad (2)$$

In the above, E_o is the peak pulse amplitude in volts, δ is the pulse width in seconds, (0.25×10^{-6} seconds), f_r is the pulse repetition rate (10^6 cycles per second), and e_s is the

*See Chapter IV of Reference 11.

equation of the voltage variation with time. A plot of a_k vs frequency is shown in Figure 17. It is seen that there are zeros occuring at values of k which make k f_r equal to $1/\delta$, $2/\delta$, $3/\delta$, etc., and that there are three harmonic components contained within each loop. In order that the peak pulse height be reached the bandwidth of the video amplifier must pass the frequency components contained within the first loop or up to 4 Mcps. Present expectations are that the over-all bandwidth should include all harmonics up to the frequency corresponding to $2/\delta$, or 8 Mcps, in order that the slopes of the leading and trailing edges be reasonably steep. If this bandwidth is used, a waveform showing the shape of the output for a rectangular pulse at the input of the video amplifier would appear as in Fig. 18b. This is true only under the conditions, however, that the gain-vs-frequency curve is "flat" from zero frequency up to 8 Mcps, and then drops vertically to zero; and that the phase-vs-frequency curve is constant over this range. This type of curve is neither possible nor particularly desirable because it produces the undesirable variations indicated in the figure. Also shown for comparison is the output for the case where the bandwidth extends to 4 Mcps.

The input coupling circuit from the iconoscope is also involved in the video-amplifier problem. As will be

FIGURE 18. EFFECT OF BANDWIDTH ON PULSE SHAPE
(A) BANDWIDTH TO 1/8 (B) BANDWIDTH TO 2/8

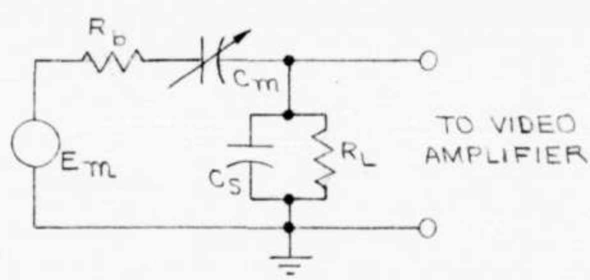

FIGURE 19. EQUIVALENT OUTPUT CIRCUIT OF ICONOSCOPE.

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shown later, the iconoscope simulates a voltage source of high internal impedance, this impedance appearing in series with the load resistor. It has been shown by others* that this impedance is made up of series resistance R_b and capacitance, C_m where the value of the resistance is of the order of ten to fifteen megohms and the capacitance may be within a few hundredths of a micro-microfarad to several thousand micro-microfarads depending upon such quantities as the surface area under scan, the beam current, and the repetition rate of the scan. There is also appreciable stray capacitance, C_s , in shunt with the load resistor as shown in Fig. 19 which represents the equivalent generator and coupling circuit at the input to the amplifier. The frequency response of this circuit must be considered along with that of the amplifier in determining the waveform of the output voltage corresponding to a given light distribution on the mosaic surface.

3. Spurious Outputs

In Article 7 of Chapter I, the formation of the so-called "dark-spot" signal by stray electrons falling before and after the scanning beam was discussed in considerable detail. This produces a base of variable height upon which are superposed the desired pulses. As has been mentioned, this undesired signal must be either eliminated or minimized before the pulse shaping processes described in Article 1

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*See Reference 3.

can be applied. Usual television practice corrects for this effect by inserting "shading" voltages of the proper waveforms into the video channel.

In addition to the dark-spot signal, another form of undesired output exists in the thermal agitation noise produced at the input to the video amplifier. The magnitude of this noise voltage is given by the well-known expression

$$E_n = \sqrt{4K\ T\ R_L \Delta f} \text{ rms volts.} \qquad (3)$$

In this equation, K is Boltzman's constant, T is the absolute temperature in degrees Kelvin, R_L is the resistance across which the noise voltage is produced, and Δf is the bandwidth of the video system in cycles per second. For the particular circuit used in the iconoscope investigation, this voltage is of the order of magnitude of 0.00003 volts. A possible signal voltage appearing across the load resistor is 0.0002 volts, a value roughly fifteen times as large as the noise voltage. Since a signal-to-noise ratio of five is considered satisfactory, it is seen that statistical noise of this type is not very important.

4. Light Requirements

From the standpoint of sensitivity in this application where degrees of brightness are not involved, it is desirable that the photoemission be unsaturated* so that all signal heights will be the same. This is also the condition for

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*See Article 6, Chapter I

maximum signal-to-noise ratio: and this maximum value, as has already been stated, must be at least five. Measurements with steady light indicate that the equilibrium potential resulting from unsaturated emission is reached at approximately 10 foot candles*; and that the signal-to-noise ratio under this condition is 7.5*. For a signal-to-noise ratio of five, the intensity required is about 3.5 foot candles.

The time lag of the mosaic is not considered a major problem since the time taken for the liberation of photoelectrons from the illuminated surface is of the order of only 3×10^{-9}** seconds. A more serious problem does exist, however, in the finite rate of rise of the light-output pulse produced by available lamps. These two characteristics determine another requirement: namely, that of setting the minimum time necessary following the flashing of the lamp before signals will be received at the input to the video amplifier.

Since the iconoscope is a storage device in which light output is integrated over a period of time, the peak intensities required from a pulsed-light source are much larger than those from a constant light source. Measurements indicate that of the order of 10,000 foot candles are required at the mosaic if the light pulse is to last

*See Article 5, Chapter VI
**See Reference 2, Page 480

for 60 microseconds, or for the length of one sweep. A still higher intensity is required if the pulse is to last for a shorter period of time.

For a period of several microseconds following the application of a light pulse, or the starting of the sweep, transient conditions exist at the mosaic surface and prevent readable signals from being obtained from the iconoscope. These are due to the random effects produced by the redistribution electrons. For this reason, it seems desirable that both the sweep and the light be started a sufficient length of time before the output signals are used to allow conditions to stabilize.

5. Storage Removal

Among the possible methods of insuring at the start of a scan that there is no stored signal remaining on the mosaic from a previous reading period are:

a) The illumination of the mosaic with ultraviolet light during the period between scans,

b) The illumination of the mosaic with a steady bias light of sufficient intensity that the photoelectrons so produced will redistribute themselves in such a manner as to bring the mosaic to a constant potential, and

c) The scanning of the mosaic with a value of beam current such that erasure of the stored signal is accomplished as the pulses are being read. Of the several methods listed, the last-named seems to be the most promising.

CHAPTER III

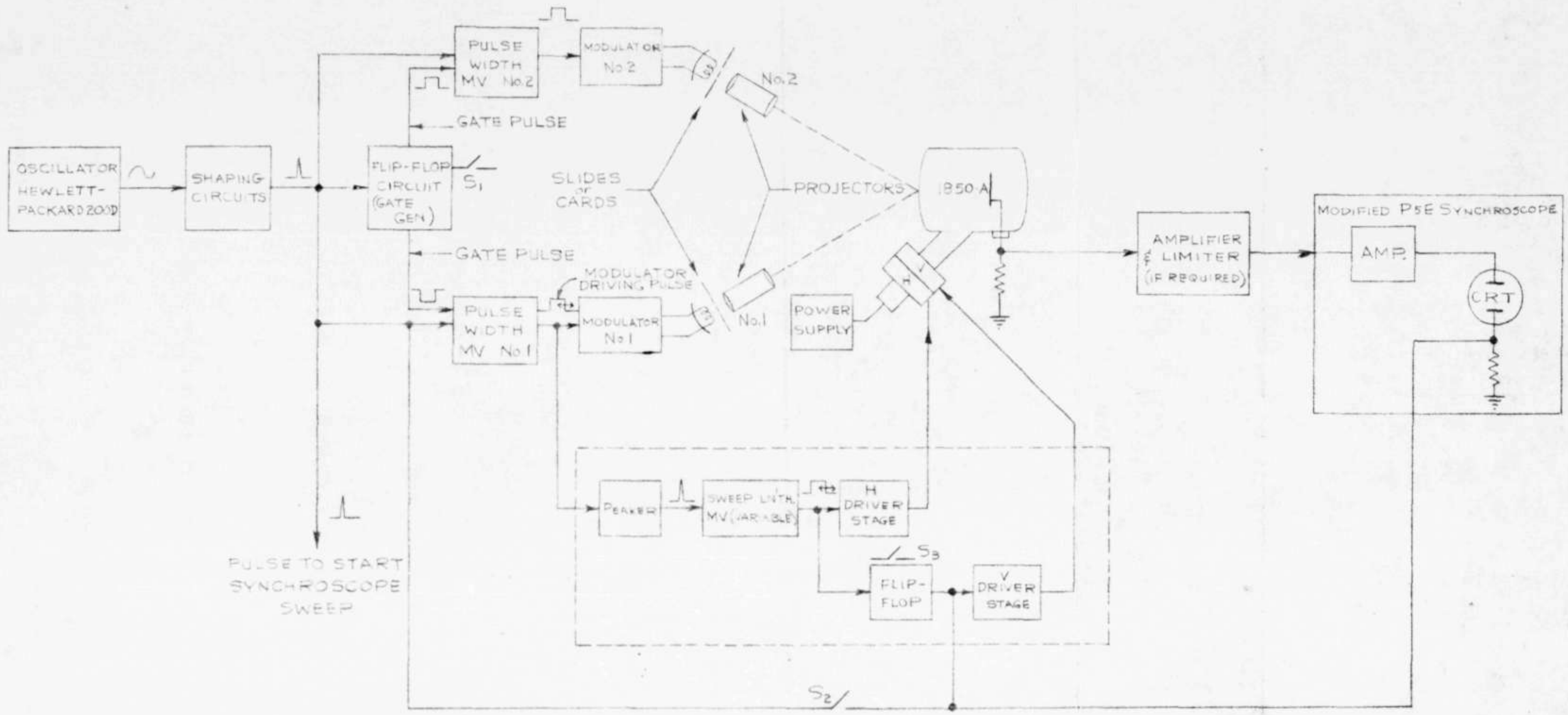
OBJECTIVES AND OUTLINE OF PROCEDURE

1. Original Plan

At the outset of this investigation it was planned to design, construct, and investigate the operational limitations of the data-input section of, an electronic digital computer using different types of television tubes as the data converter elements. A system was devised to allow the necessary tests to be made on an iconoscope tube. This system, shown in a block diagram form in Fig. 20, is arranged for alternate pulsing of either of two projection lamps at repetition rates from zero to 20,000 cycles per second. It was planned to try various compensating devices at the video amplifier and sweep-deflection-driver circuits to provide output indications - when punched cards were scanned - fulfilling the requirements outlined in Chapter II.

2. Initial Investigation

The feasibility of using an iconoscope as a data reader was investigated by selecting one line from the video-output signal of a factory-built television pick-up unit while it was scanning the image of a card having alternate light and dark areas. This investigation is covered in Chapter IV. The image dissector and matrix-of-photocell methods discussed in the Introduction were considered



SWITCHING KEY:

S_1 CLOSED, S_2 OPEN, S_3 OPEN; ONLY SLIDE NO.1 READ, SWEEP ALTERNATES BETWEEN 2 LINES

S_1 CLOSED, S_2 OPEN, S_3 CLOSED, ONLY SLIDE NO.1 READ, SWEEP ALWAYS ON SAME LINE

S_1 OPEN, S_2 CLOSED, S_3 CLOSED; SLIDES READ ALTERNATELY, LINES READ ARE AT DIFFERENT LEVELS ON THE MOSAIC FOR THE TWO CARDS, AND ARE PRESENTED AT DIFFERENT LEVELS ON THE SYNCHROSCOPE SCREEN.

(NOTE: S_1 AND S_3 ARE DISABLING SWITCHES THAT CAUSE THE FLIP-FLOP CIRCUITS TO REMAIN IN ONE CONDITION)

FIG. 20. BLOCK DIAGRAM OF EQUIPMENT FOR CYCLIC ICONOSCOPE 1850-A TESTS

(REPRODUCED FROM THESIS PROPOSAL)

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quantitatively and qualitatively, but not tested by experiment. During this time a search was made through the literature and manufacturer's catalogues to find information on available pulsed-light sources. When it became evident that none of the available lamps was suitable, and that the problem was a major one, it was decided to omit the light study from the thesis. This problem was then assigned to another investigator.

3. Pulsed-Light Tests

While the investigation of pulsed lamps and their modulator circuits was not one of the objects of this thesis, a circuit was designed and constructed for pulsing the Glow Tube R_{1130B}*. Its operation with the iconoscope was studied by scanning the image of a coded slide illuminated by this light source. The tube was found to have a crater too small for the field it was desired to illuminate; and it gave insufficient light to provide a readable signal at the iconoscope.

Tests similar to those described for the R_{1130B} were made with the R_{1131} Glow Tube, the SN4 Stobotron Tube, and the R_{4330} Flash Lamp. The only lamp tested that gave sufficient light for the iconoscope was the R_{4330}. This tube is of the cold-cathode constricted-arc type, and its operation is limited to very low frequencies. This limitation is set both by the lamp and by its modulator. The

*Appendix B, Page 138, is devoted to a detailed description of this and other types of pulsed lamps used.

manufacturer's rating for maximum frequency is six flashes per minute. During the tests the lamp was used at repetition rates up to two cycles per second with no obvious deleterious results. The circuit used with this lamp is described in Cahpter V. In all tests made, only a single line - and not a whole frame - was scanned.

4. Revised Objective and Plan

The signal waveforms obtained at first were incorrect, and a long series of modifications of the video-amplifier system was begun to eliminate distortion in this part of the circuit. After the amplifier system was perfected several peculiar effects were noted. Among these effects were the dark-spot signal (described in Chapter I), and an apparent reversal of signal polarity which occured under certain conditions where the beam current was increased or the light intensity was decreased. Since the pulsed-light sources were not available to allow the tests described in Art. 1 to be made, and since the effects observed in the single-line tests gave waveforms not readily explainable by theories described in the literature, it was decided that the original objective should be broadened to include certain basic studies of the behavior of the iconoscope mosaic to various types of pulsed-beam and pulsed-light excitations. Such work was also considered timely because of parallel contemporary work of others using special tubes for the temporary storage of data.

It was decided that if the number of variable parameters involved in the excitation studies could be reduced the explanation might be arrived at more readily. In line with this philosophy, the beam was placed at one position on the mosaic surface - not scanned - and the output signal observed when the beam was pulsed with and without light present. Tests were also made under scanning conditions to determine (a) how long the light had to be on before readable signals could be obtained, (b) the effect scanning at different beam currents had on the dark-spot signal, (c) the effect increased light had on the output signal amplitude, and (d) the possible methods of storage removal.

In order that quantitative measurements of light output be possible, it was necessary to calibrate the light sources, and the fixed and variable light attenuators, used to determine the proper value of light intesnity and beam current for a satisfactory signal-to-noise ratio.

CHAPTER IV

LINE-SELECTOR TESTS

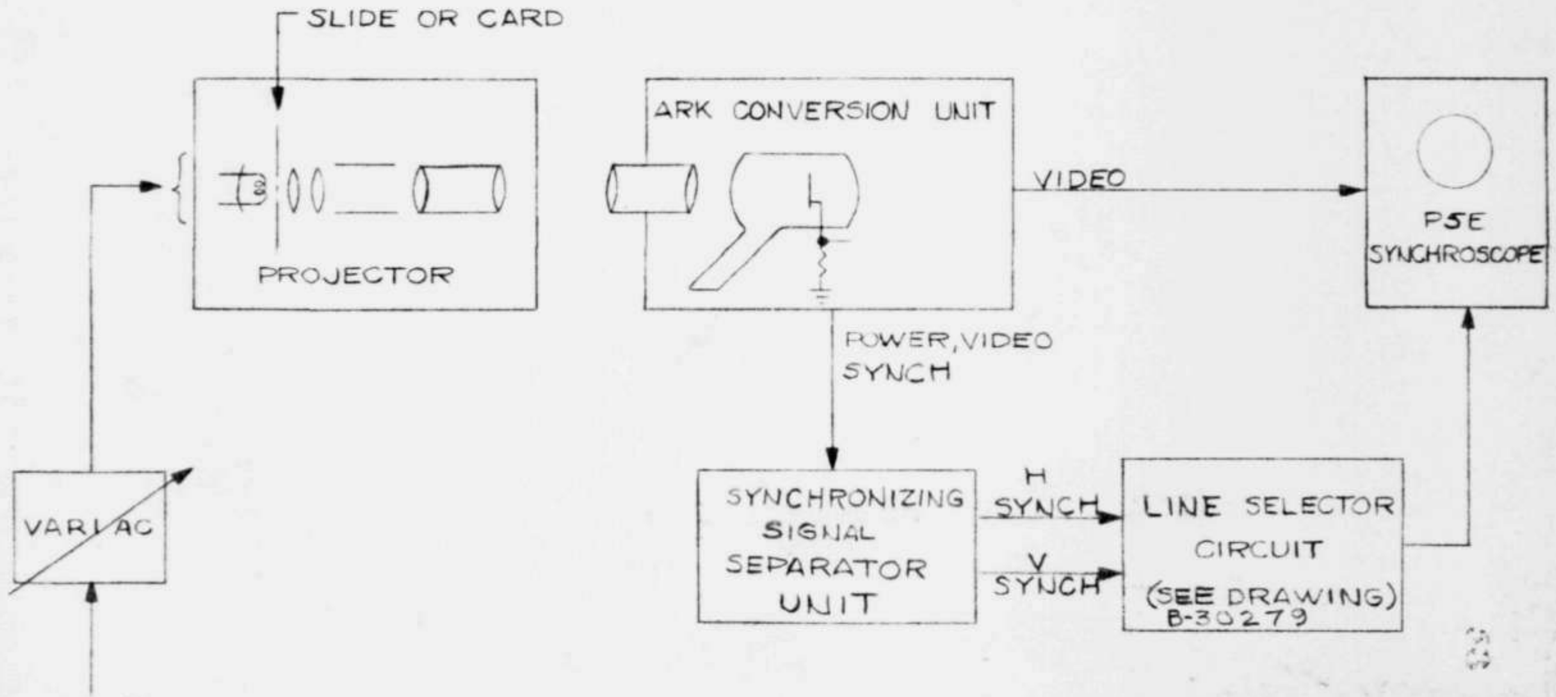
1. Purpose

The reasons for making these tests were twofold. First, familiarity with the use and adjustment of the iconoscope circuit could be obtained; and second, the feasibility and practicability of using such a device for converting signals stored on coded cards or slides into electrical impulses of sufficient readability for the computer problem would be demonstrated. In addition to the above objects, a rough indication of the amount of light required was determined for both steady and pulsed sources; and certain of the well-known but little-reported peculiarities of the behavior of the iconoscope were observed.

2. Equipment Details

In the block diagram shown in Fig. 21, a projector is arranged to project the image of a test slide - with markings of the type reproduced in Fig. 22 - onto the mosaic of the iconoscope contained in the Conversion Unit of the Navy Aircraft Equipments ATK and ARK. A schematic drawing of the circuit of this unit is reproduced in Fig. 23*. It contains its own master-oscillator and supplies horizontal

*See Reference 10.



BLOCK DIAGRAM OF CIRCUIT USED TO SELECT AND VIEW ONE LINE OF VIDEO FROM ARK CONVERSION UNIT

FIG. 21

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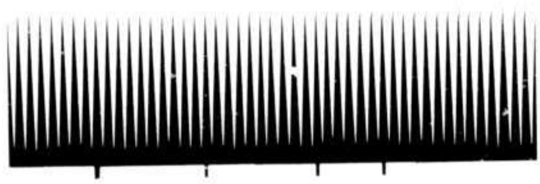
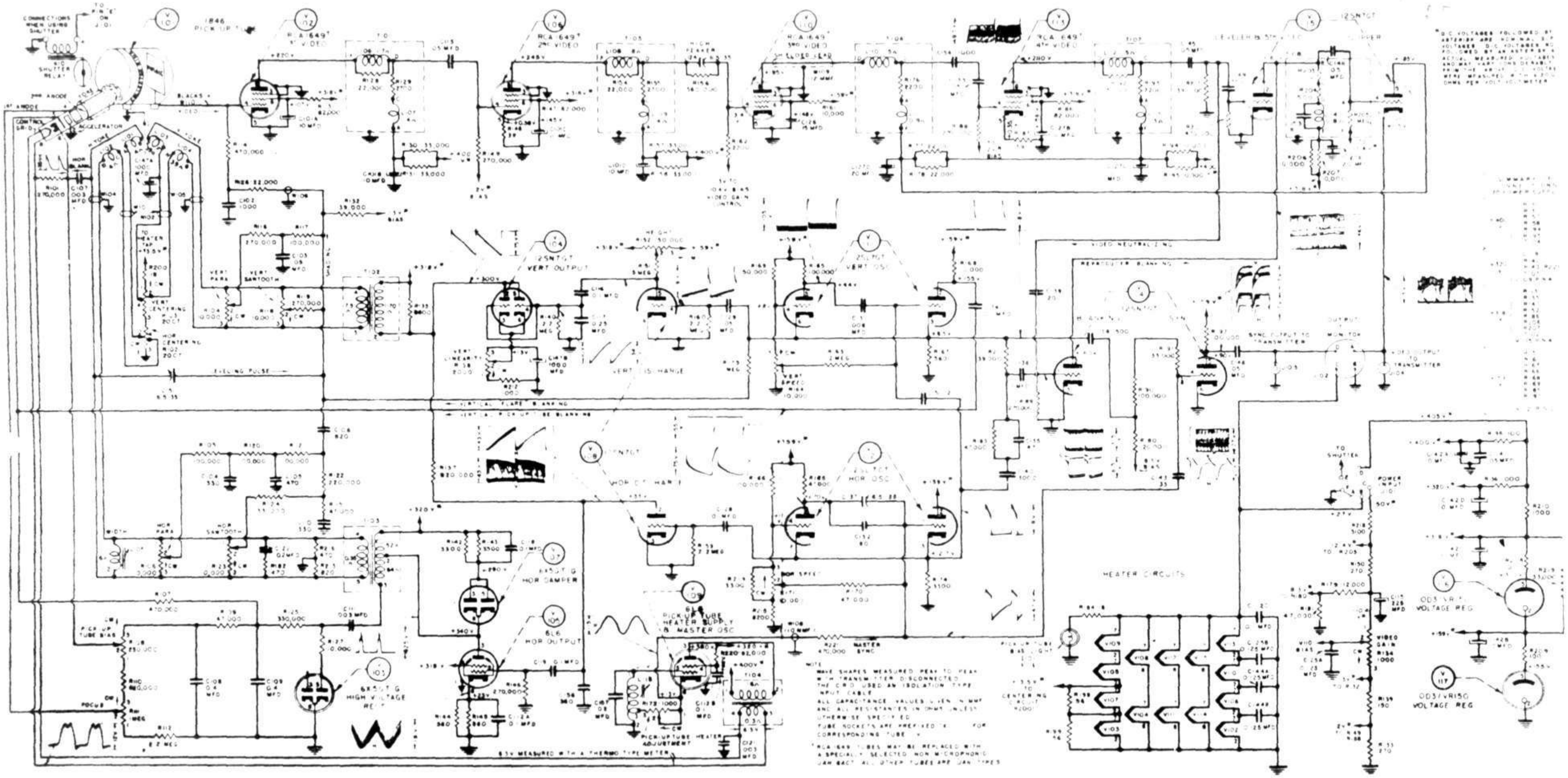


FIGURE 22
REPRODUCTION OF TEST SLIDE USED IN LINE-SELECTION TESTS



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[illegible]
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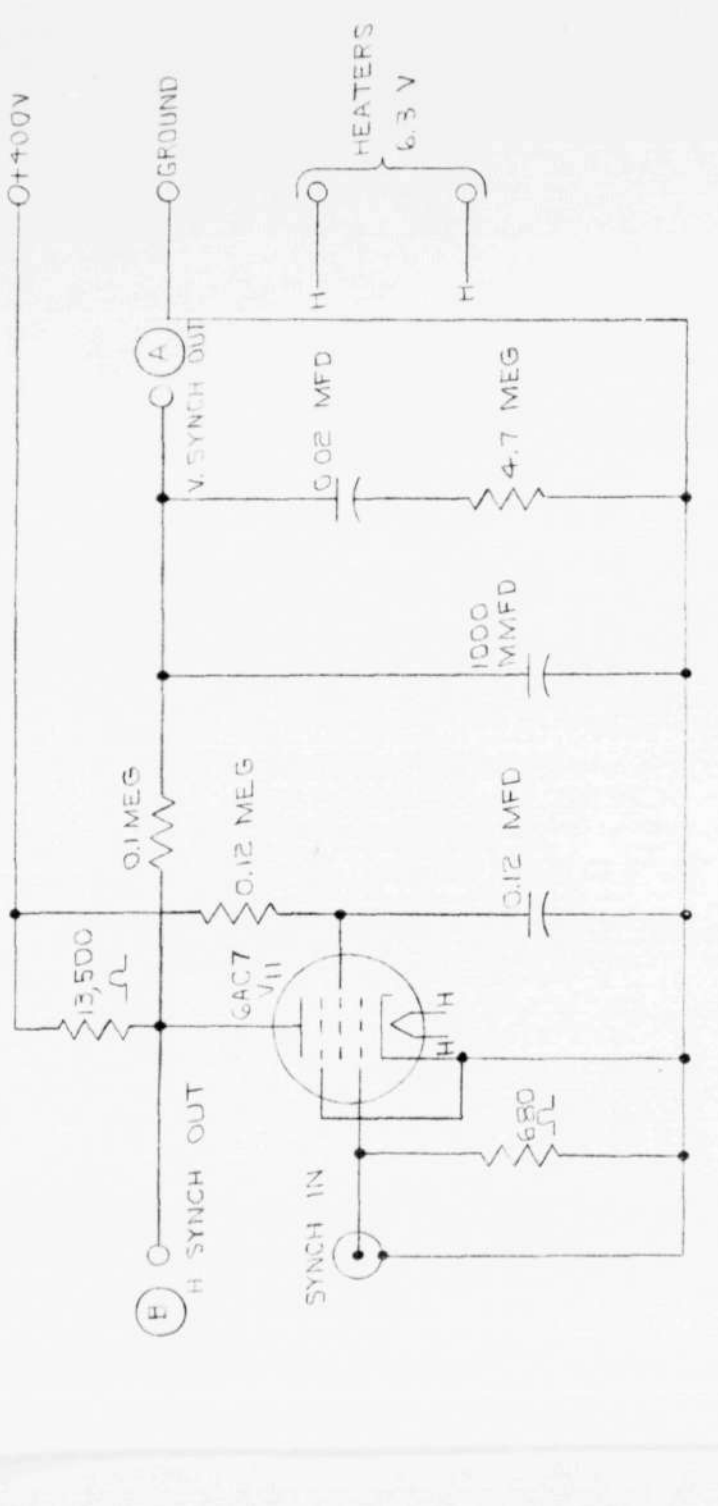
and vertical synchronizing signals, all combined at the same output jack, to the synchronizing-signal-separator circuit shown in Drwg. A-30275. Trigger pulses are thus obtained at the input to the separator corresponding in time to the start of each frame, and to the start of each line in the frame. The function of the separator is such that triggers at the frame repetition rate appear at Terminal A; and triggers at the line repetition rate appear at Terminal B. The sweep-selector circuit (schematic shown in Drwg. B-30279) supplies one trigger per frame to the synchroscope. The signal output of the iconoscope passes through several video-amplifier stages to finally reach the vertical-deflection plates of the cathode-ray tube in the synchroscope. Waveforms reproduced on the screen of the synchroscope are derived from the same portion of the mosaic for each sweep of the cathode-ray-tube beam, and this sweep occurs only once in each frame period.

3. Circuit Operation

Briefly, the circuits function as follows: The synchronizing signal obtained from Terminal A of the signal-separator unit (Drwg. A-30275) contains large amplitude frame synchronizing signals at a repetition rate of about 40 cps. These signals are applied through a buffer cathode-follower stage (V_1) and a blocking oscillator (V_2) to the control grid of the normally cut-off tube of the Wide-Pulse-Width-Multivibrator.



SYNCHRONIZING - SIGNAL SEPARATOR UNIT

USED IN MVE THESIS

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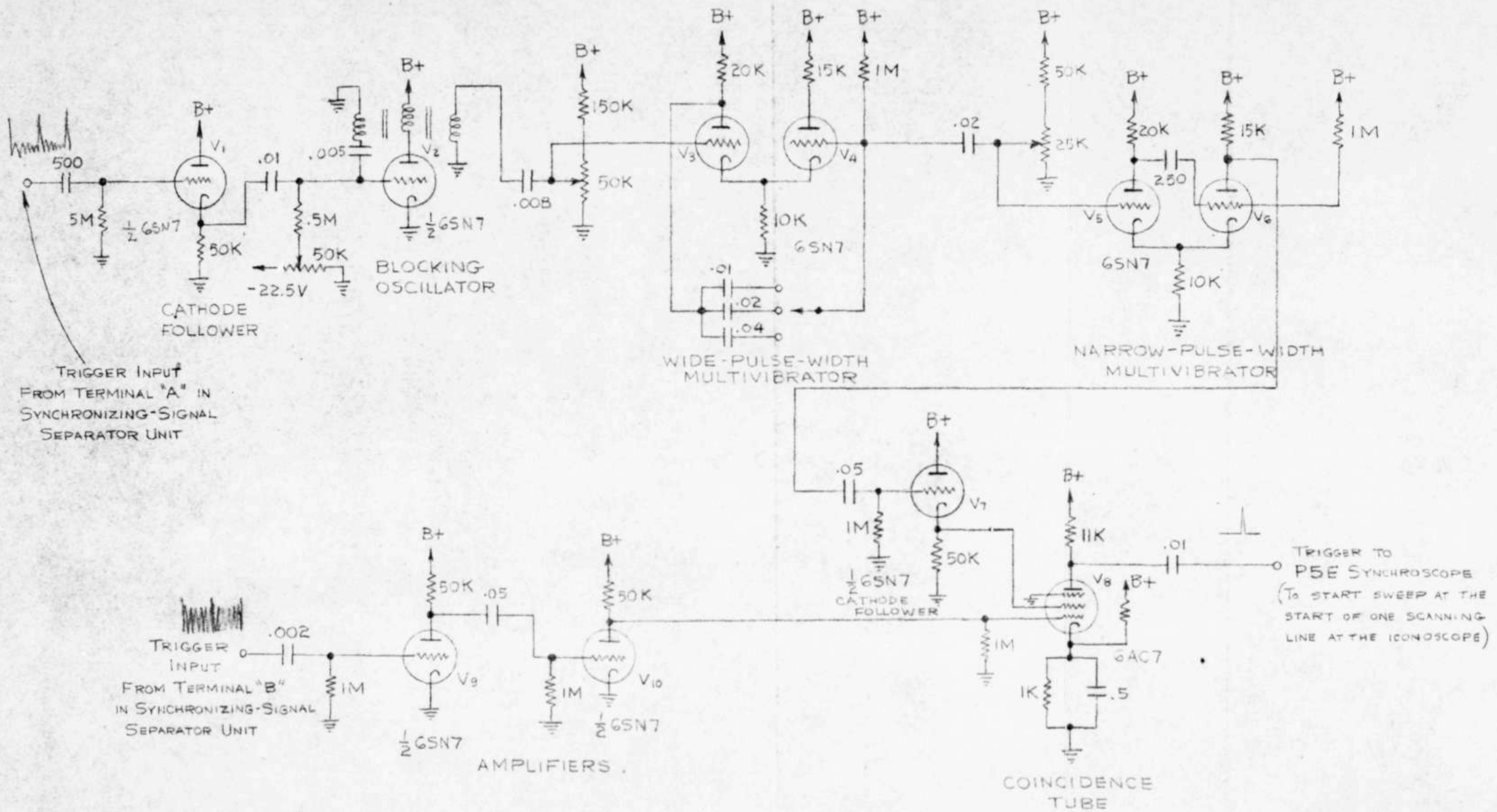
CHK. M.W.E. | APP. |
A-30275

TEST CIRCUIT FOR SELECTING A SINGLE LINE OF VIDEO FROM ARK CONVERSION UNIT



REVISION OF DRAWING MADE FOR THESIS PROPOSAL

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The width of the gate produced by this tube is adjusted both by means of changing the bias on the normally off tube and by changing the size of the coupling capacitor. This width is generally about 10,000 microseconds so that the trailing edge of the gate produced occurs at about the same time that the scan at the iconoscope is half-way up the mosaic. The output waveform of this multivibrator is differentiated and the positive pulse occuring at the time of the trailing edge is used to control the start of the switching action of the Narrow-Pulse-Width Multivibrator. The width of the gate generated by this multivibrator is also adjustable, but in this case the width must be less than the time taken for the scanning of one line. Thisgate is applied through a cathode-follower stage to the screen grid of the Coincidence Tube, V_8.

Triggers at the line-scan frequency, 14,000 cps, are applied to Terminal B. After passing through the pulse-shaping amplifiers V_9 and V_{10}, they are applied to the control grid of the Coincidence Tube. These pulses can produce an output at the plate of the Coincidence Tube only when the positive gate from the Narrow-Pulse-Width Multivibrator is present on the screen grid. The output is, therefore, a positive pulse occuring at the time of the start of a particular scan at the mosaic, and occurs only once during each frame interval. This positive output is used to trigger the sweep circuit of the synchroscope. Under these conditions, the beam of the cathode-ray tube in the synchroscope scans once each frame period, and during this scanning period the video signals generated by the iconoscope are displayed upon the cathode-ray-tube screen.

4. Results and Conclusions

Waveforms of the signal appearing on the screen of the synchroscope were observed when the mosaic was illuminated through the slide of Fig. 22. The pulses stood well above the noise level when the shading and bias controls were properly adjusted, and the level of illumination was of the order of one foot candle at the mosaic. The optimum operating condition as signified by maximum signal-to-noise ratio, was obtained when the illumination was 3.5 foot candles. During these tests the signal was also displayed on the screen of the kinescope contained in the Monitor Unit of the ARK/ATK system. It was found that the conditions of optimum readability for the deflection-modulated synchroscope corresponded exactly to the conditions of optimum readability for the intensity-modulated kinescope.

Two peculiar effects were observed during the conduct of these tests. The first was that the picture-signal polarity suffered a reversal (that, is, the picture became a "negative") when the beam current increased beyond a certain value. The second effect was a reversal of this same type when pulsed light from a SN4 Strobotron tube was allowed to fall on the mosaic with sufficient intensity. These same phenomena were met repeatedly in the more refined tests to be described in subsequent chapters.

The conclusion drawn from this preliminary investigation was that the iconoscope offered sufficient promise as a data converter to warrant further investigation along the lines described in Chapters III, V, and VI.

CHAPTER V

SINGLE-LINE TESTS

1. Purpose

Tests were made on the iconoscope to study the effects of sweeping a single line on its mosaic under varying conditions of beam current, illumination, and repetition rate. This was to provide information, not previously described in the literature, concerning (a) the phenomenon of the formation of the dark-spot signal produced by low-velocity secondary electrons, (b) the necessary light intensities required for the desired readability, (c) the methods possible for insuring erasure of signal information after one reading, and (d) the response of the mosaic to high-intensity pulsed light. Data so obtained was used in formulating and checking the theories of iconoscope operation given in Chapter I.

2. Equipment Details

It was necessary to modify certain existing equipment and to build some new equipment in order that the required experiments be possible. The following* briefly describes those components used that are other than standard test equipment or laboratory power supplies.

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*This list also contains equipment used in the investigations to be described in Chapter VI.

(a) Iconoscope Test Unit

This piece of equipment was adapted from the ATK/ARK Conversion Unit discussed in Chapter IV. The modified circuit used in this thesis is shown in Dwg. D-30249. The original sweep-generating circuits were isolated by removing certain tubes; and the necessary leads were broken to eliminate shading and blanking pulses. The bleeder supplying variable and fixed voltages to the various elements of the iconoscope was kept intact, as was the iconoscope heater-supply source. Since this original unit did not contain usable power supplies, a 1000-volt regulated supply is included in the circuit, and external connections to a 405-volt, 265-ma., regulated supply are indicated. A bank of five 6-volt storage batteries was used to supply 28.5 volts (nominal) to the filament and centering circuits. The video-amplifier and deflection circuits of the test unit were different than the ones in the ARK system; but the Type 1846 iconoscope, lens and shutter system, and deflection coils used were those of the original Conversion Unit. The vertical-deflection coils were used only for centering, since at no time in the tests of this, and the following chapter, was vertical deflection required.

A special sweep-voltage generator was constructed for horizontal deflection of the beam. Its circuit, as

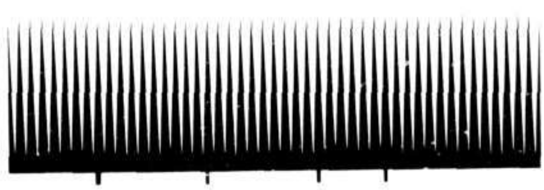
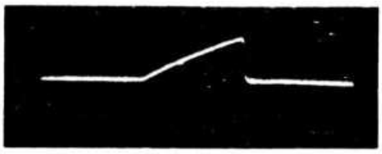


FIGURE 22
REPRODUCTION OF TEST SLIDE USED IN LINE-SELECTION TESTS

shown in the drawing, uses tubes V_3 and V_4. Tube V_{3A}, and the screen-grid, control-grid, cathode portion of V_4 are parts of a start-stop multivibrator that serves as a gate generator to control the plate current flow of V_4. When this tube is heavily conducting, as it is during the between-pulse period, the plate of V_4 is at a low positive potential with respect to ground. During the gated period, V_4 is cut off, and the voltage at the plate terminal rises exponentially as the 330-$\mu\mu$f sweep capacitor charges through the 1-Meg plate-load resistor. The voltage waveform produced by this circuit is shown in Fig. 24a. The unconventional use of electron coupling here demonstrated reduces the time delay between the trigger pulse and the start of the sweep waveform.

The three-winding pulse transformer allows the circuit to be triggered by a wide variety of waveforms. For example, either positive or negative pulses can be used at Trigger Input B, and these pulses can have large overshoots of the opposite polarity. The isolating diode prevents these overshoots from controlling the operation of the multivibrator. Where the trigger source has a high impedance, and its waveform a particularly fast rise time with no serious overshoots, Trigger Input A at the grid of the normally-off tube of the multivibrator is used to provide freedom from excessive jitter. These different



(A) SWEEP WAVEFORM

(B) INTENSIFIER-PULSE WAVEFORM

FIG. 24 PHOTOGRAPHS SHOWING SWEEP–VOLTAGE AND INTENSIFIER–VOLTAGE WAVEFORMS GENERATED FOR ICONOSCOPE methods allow the flexibility required by the large assortment of sources used.

Also obtained from the sweep generator is the 24-volt rectangular pulse reproduced in Fig. 24b. This voltage is used as an intensifier, and is applied to the control-grid of the iconoscope gun to cause the beam current to flow only during the sweep time. Because of the peculiar phenomenon produced by secondary electrons, no way of measuring the magnitude of this beam current at the mosaic is possible. As an alternative, the value of the variable grid-to-cathode bias-supply voltage is read on the voltmeter provided, and the net grid-to-cathode voltage is used as an indication of beam current. As estimated from characteristic curves obtained by others who used tubes with special electrodes having low secondary-emission ratios for collecting the beam electrons, and by comparison of the manufactuser's gun data for the Type 1846 tube with data for the bubes used by the others, the probable variation of beam current with grid-to-cathode voltage has been determined. This curve is included in Appendix D.

(b) Video-Amplifier Circuits

Either of two video amplifiers was available to amplify the signal produced by the iconoscope tube. One was a modified version of the ARK circuit; and its circuit* is shown and described in Appendix C.

*See Drwg. C-30254

The purposes of the changes made in the original circuit were to place the various tubes at operating points preventing limiting of signal amplitudes, and to eliminate shading, blanking and levelling voltages used originally in compensating for the dark-spot signal and preventing the transmission of microphonics through the amplifier. The frequency response of this circuit was designed to compensate for the poor high-frequency characteristics of the iconoscope and its connected load circuit. The resulting over-all system including both the iconoscope and its amplifier thus has nearly constant over-all gain with varying frequency. The phase-vs-frequency characteristics, however, is such that a measurable delay results in signals passed through the amplifier.

The other amplifier used was made up of three identical general-purpose units*. Each unit contains a video-amplifier stage having some high-frequency shunt compensation, and a cathode follower to allow driving the capacitance of the connecting cable without causing appreciable loss of the high-frequency components of the waveforms passed. Further details of these amplifiers, including the measured response curves, are given in Appendix C.

(c) Light Projector and Attenuators

The light-projection system used is shown in

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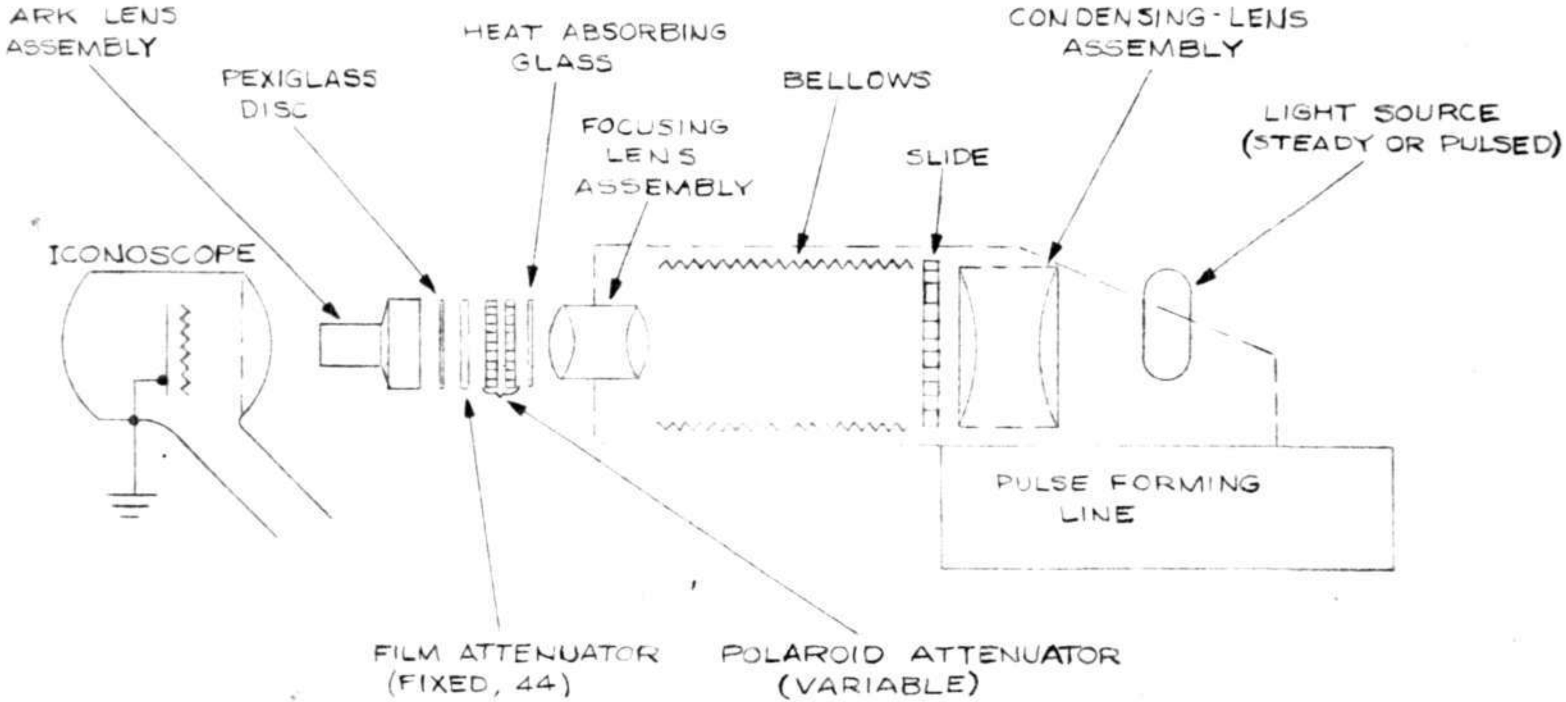
*The circuit diagram of one of these units is shown in Drwg. C-30255 in Appendix C.



PROJECTOR SYSTEM

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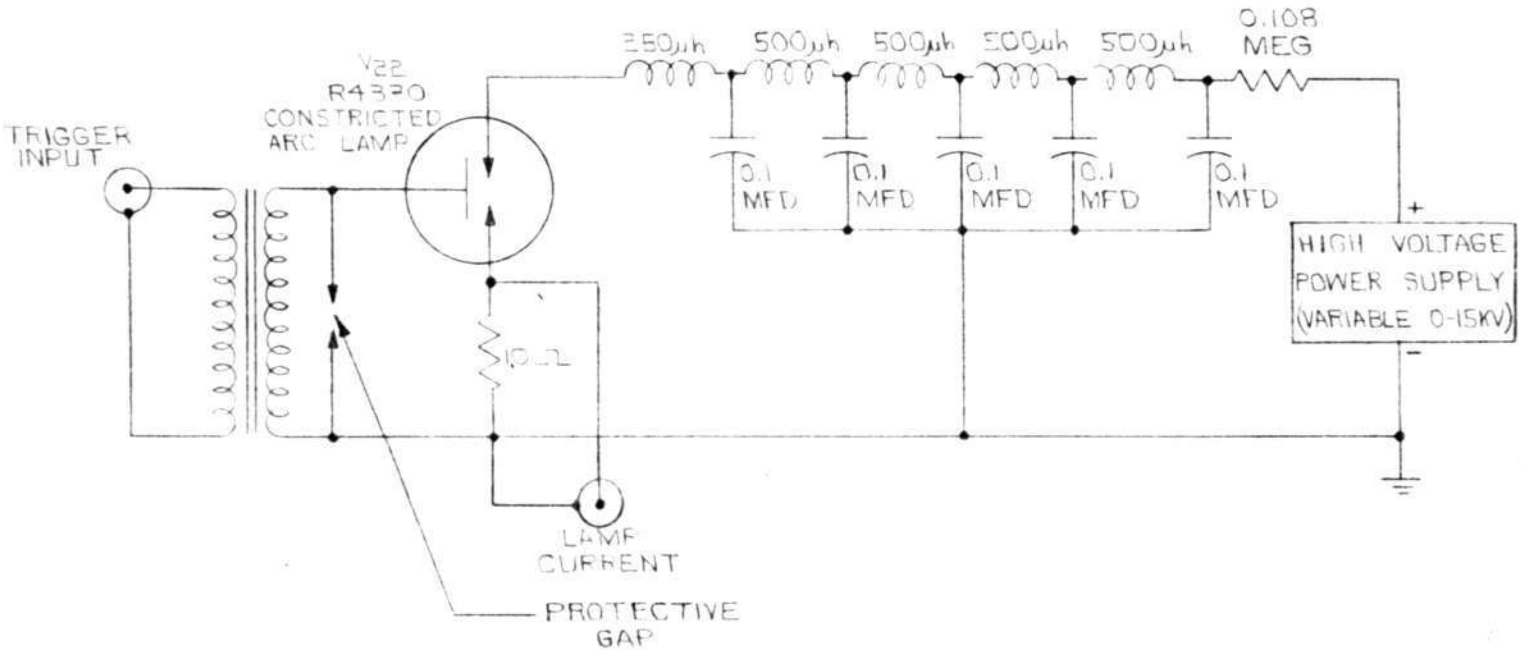
USED IN MWE THESIS

Drwg. A-30250. The drawing shows a standard lantern-slide projector mounted on a box containing a pulse-forming network. The physical arrangement is such that either a standard 115-volt projection lamp, or a Type R_{4330} pulsed lamp, can be used as a light source. Details of this arrangement and reasons for the various additional components are given in Appendices A and B. The fixed film attenuator was arranged to be removable so that when pulsed light sources were used, advantage could be taken of the limited amount of light power available. Focusing was possible either at the ARK lens assembly or at the projector. During the tests and calibrations made, these adjustments were kept fixed to preserve the accuracy of the illumination measurements.

(d) Pulsed-Light Sources

Two major pulsed-light sources were used in the course of this investigation. The most commonly used one, and the one used in taking the data reported in this thesis, employs a Type R_{4330} Flash Tube. The modulator used with this tube was designed by others for another purpose and is shown in Drwg. A-30251. It consists of a five-section artificial line charged from a variable high-voltage supply of standard design. The line is charged slowly through the 108-K resistor, and then discharged through the lamp. The constants of the line were adjusted in the design to provide



PULSER CIRCUIT FOR CONSTRICTED-ARC TUBE

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ENG. M.W.B. | | A-30251

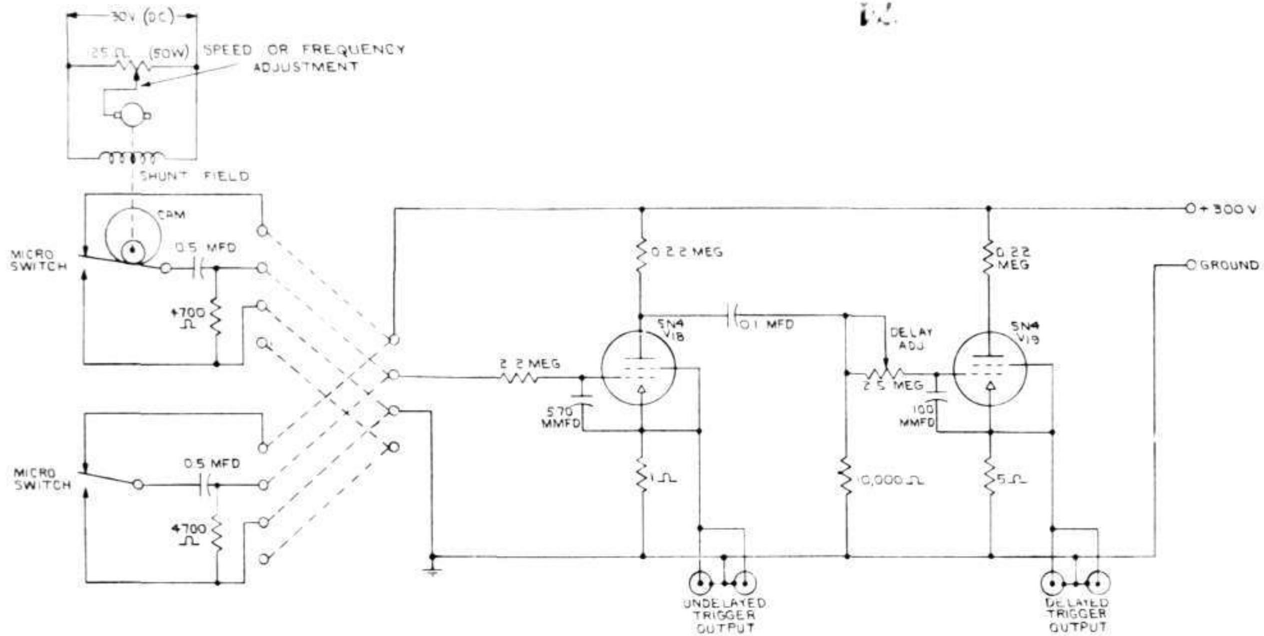
a 50-microsecond pulse having a minimum amount of reflection produced by the firing of the lamp. The time at which the pulse-forming line begins to discharge through the lamp is determined by a trigger applied to the ionizing electrode of the lamp. The high voltage required to initiate the arc -of the order of 15 kv is required - is obtained by means of an induction coil. Specific details concerning the design of modulators of this type are given in Appendix B.

The circuit just described is intended for use with a high-intensity lamp of the arc type. A different modulator problem arises when low-powered lamps of the glow-tube type are considered. For tests made, but not specifically reported in this thesis, using the R_{1130B} and R_{1131} tubes, a special modulator was constructed. The discussion of this circuit is left to Appendix B.

(e) Synchronizing-Pulse Generators

All tests made required some source of synchronizing pulses. The particular method used in generating these pulses depended upon the characteristics of the load, the frequency ranges desired, and the steepness and final amplitude of the trigger required. Operation of the R_{4330} was limited to frequencies below 3 cps, and the fact that an induction coil was driven made necessary a large current and fast rise time. The glow-tube modulator, and the sweep and intensifier circuits designed for use with the Iconoscope Test Unit, were sufficiently flexible so that almost any type of pulse source was satisfactory insofar as repetitive tests were concerned. Certain of the investigations made, however, were under non-repetitive, or single-shot, conditions and a source of this type of triggers was required.

The circuit used for generating both non-repetitive triggers, and triggers at repetition rates up to 5 cps, is shown in Drwg. C-30252. This is the only circuit used with the flash-lamp modulator. Either a motor-driven or a manually-operated microswitch is arranged to provide positive pulses to the first grid of the strobotron tube V_{18}. At the instant this grid is driven positive, the tube conducts, and a large amount of current flows through the one-ohm cathode resistor. The high current passed is due to the stored charge on the 0.1μf capacitor. A positive pulse appears across the 10-K coupling resistor; and, after a variable delay produced by the 2.5-Meg rheostat and the 100μμf capacitor, the second strobotron is fired. Thus a delay, variable up to about 200 microseconds, exists between the outputs at the two cathodes. The one- and five-ohm cathode resistors provide low impedances for rapidly charging the connecting-cable capacities. Although, as stated, this circuit is limited by the storage capacitors



SINGLE-SHOT AND LOW-FREQUENCY PULSE GENERATOR

USED IN MWE THESIS

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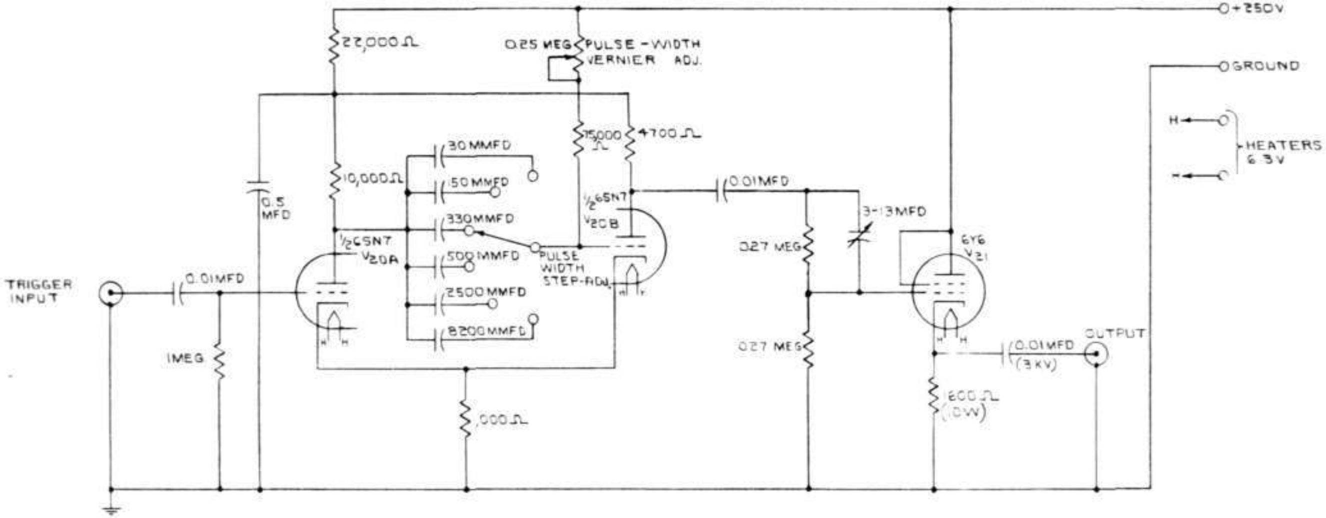
to frequencies below 5 cps, it covers fully the range of repetition rates possible with the R_{4330} flash lamp.

The requirements of the circuits using triggering frequencies in excess of 5 cps were such that the internal oscillator of the DuMont 256B Oscilloscope was a satisfactory source over its available range of 80 to 2000 cps. This was the source used with the glow-tube modulator. The horizontal-sweep generator of a DuMont Type 208 Oscilloscope provided a convenient source of triggers for the interim range of 3 to 80 cps. The horizontal-sweep voltage was passed through a single cathode-follower stage, and the return portion of this waveform was used as the synchronizing pulse.

(f) Variable-Width Intensifier-Pulse Generator

A source of intensifier pulses having widths variable from 0.5 to 700 microseconds was required for the tests to be described in Chapter VI. The circuit designed and built to fulfill these requirements is shown in Drwg. C-30273. The two sections of V_{20} are connected to form a conventional cathode-coupled multivibrator. The positive rectangular pulse generated by this tube is passed through a cathode-follower stage. A triode-connected 6Y6 tube was chosen for use in the output stage in order to preserve as much as possible the steepness of the leading edge of the pulse.



VARIABLE-WIDTH INTENSIFIER-PULSE GENERATOR

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ENG. M.W.E.	APP.	C-50273

USED IN MWE THESIS

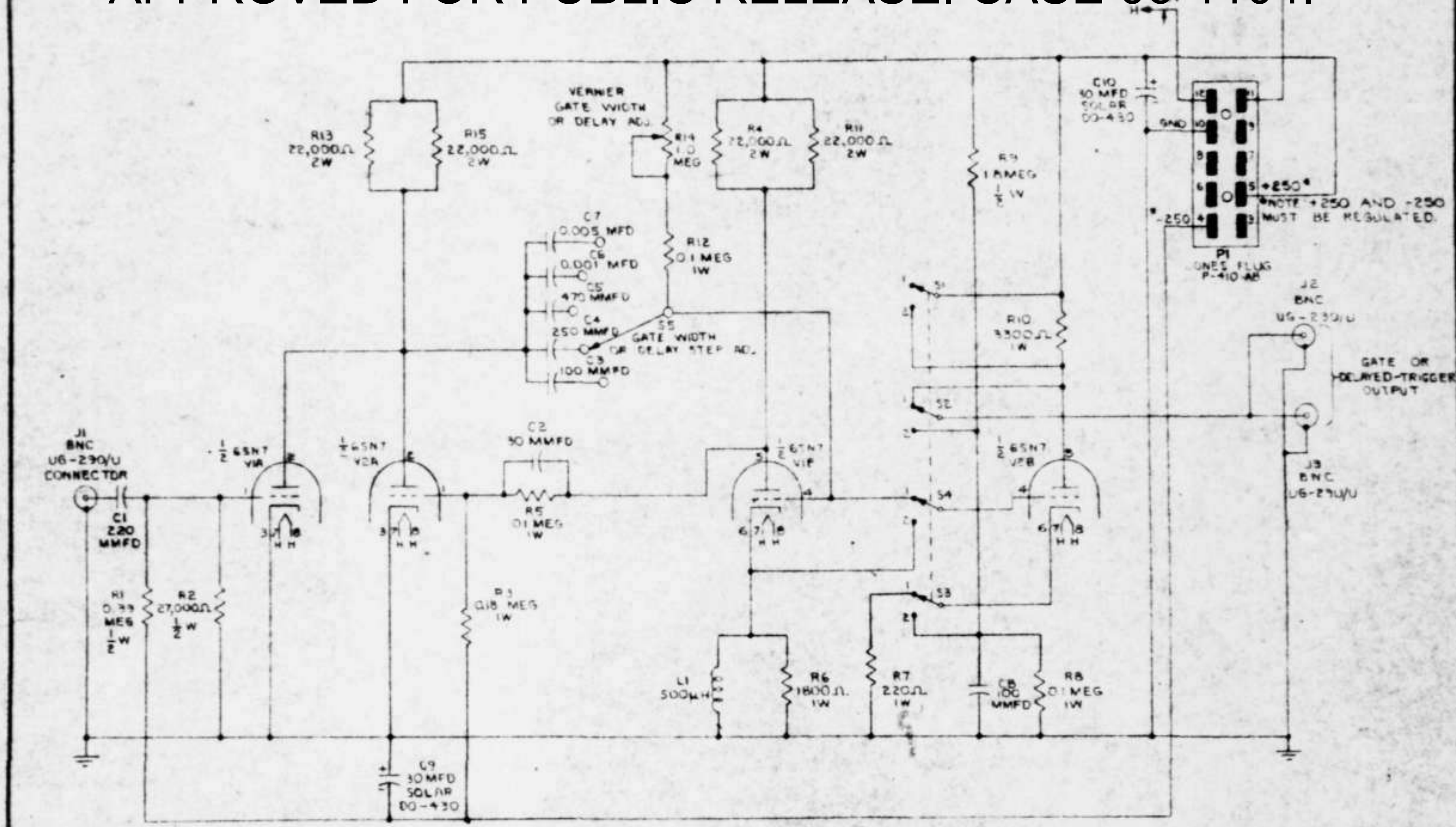
The coupling circuit between the multivibrator and the cathode follower contains a compensated voltage divider included to provide the proper pulse height at the output. The pulse so produced has an amplitude of 14 volts. The circuit shown in the drawing is limited by its elements to widths of less than 70 microseconds. Provision was made, however, for increasing the widths to 700 microseconds by inserting a 1.7-Meg resistor in the grid circuit of V_{20B}.

(g) Gate and Delayed-Trigger Generator

In some of the pulsed-light tests it was necessary to delay the reading period for some time after the light impression was made. This required a variable delayed-trigger source. The circuit diagram of such a generator is shown in Drwg. C-30253. The unit used in this thesis contained two such generators mounted on one chassis. The circuits were arranged so that the two generators could be triggered from the same source or operated in cascade. Thus two controlled delays with respect to the same time reference were possible.

The tubes V_{2A} and V_{1B} constitute a biassed, or single-shot, multivibrator. The length of the gate so produced is variable from about 3 to 5000 microseconds. Tube V_{2B} operates as a degenerative amplifier, and provides a variable-width gate when the ganged switch is in Position I. This same tube operates as a cathode follower to provide a positive trigger at the time of the trailing edge of the variable-width gate when the switch is in

C-30253-3



NOTES:

SWITCH POSITION 1 GIVES A GATE.
SWITCH POSITION 2 GIVES A DELAYED POSITIVE TRIGGER.
IN SOME CASES, TWO OF THESE UNITS ARE BUILT ON THE SAME CHASSIS, USING A COMMON POWER PLUG (P1).
IN SOME UNITS, C9 AND C10 ARE MALLORY BS-74 16 MFD CAPACITORS.
FOR FURTHER INFORMATION SEE 6345 ENGINEERING NOTES NO E-38

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LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY DIVISION OF INDUSTRIAL COOPERATION PROJECT NO. 6345			
GATE AND DELAYED-TRIGGER GENERATOR			
SCALE	DR D.L.O. 4-9-46		C-30253-3
6/1/47	4/13/47		

Position 2.

Figure 25 shows photographs of the equipment used in the single-line tests. These pictures also include all equipment used in the tests to be described in Chapter VI.

3. Effect of Sweeping the Unilluminated Mosaic at Various Beam Currents

(a) Circuit Used

The block diagram of Fig. 26 shows the interconnections of the equipment used in most of the tests involving a sweeping beam. Where any difference occurs in the set-up for a particular test, only minor changes are necessary and these will be indicated in the text. The output signals from the mosaic were, in all cases, passed through the internal amplifier of the synchroscope. The external trigger source was the strobotron circuit for single-shot and repetitive tests up to the frequencies of 3 cps. This source was replaced by the DuMont 208 operated as described in Art. 2 (e) for the range from 3 to 80 cps. The internal oscillator of the DuMont 256B was used at 80 cps and all higher frequencies.

The purpose of this first series of tests is to study the formation of the spurious output signal generated while the mosaic is under scan. The video amplifier used should, therefore, be the one that shows with greater

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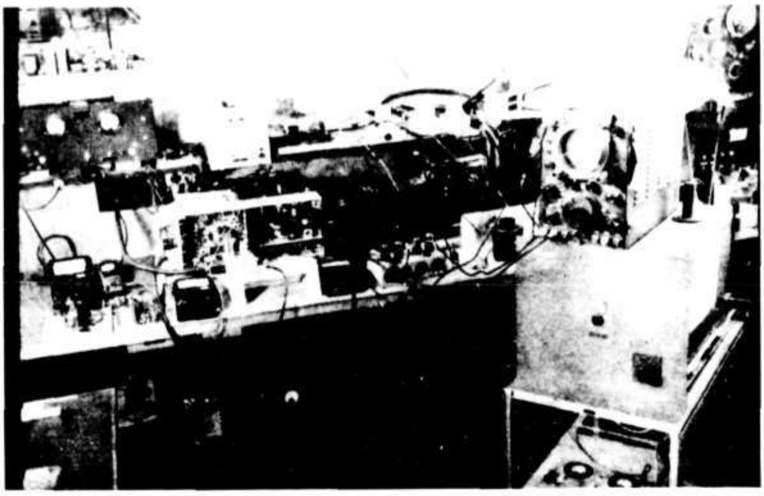
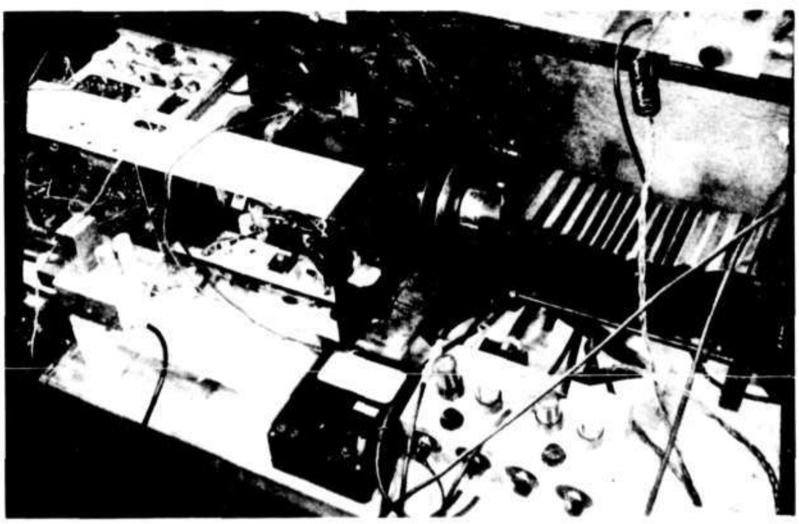
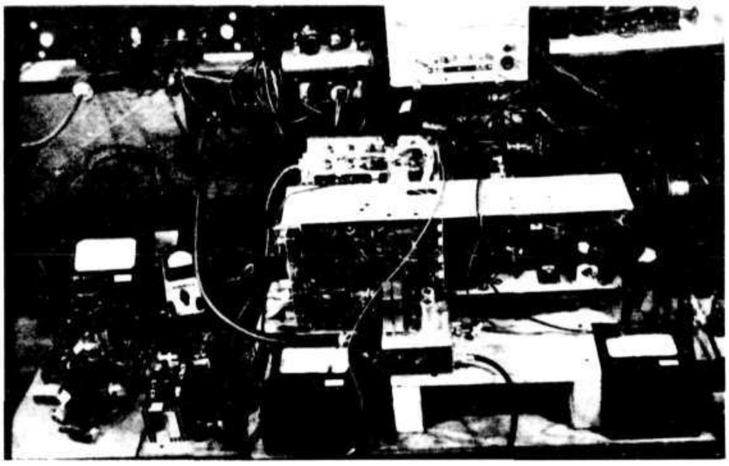


(A) OVERALL VIEW

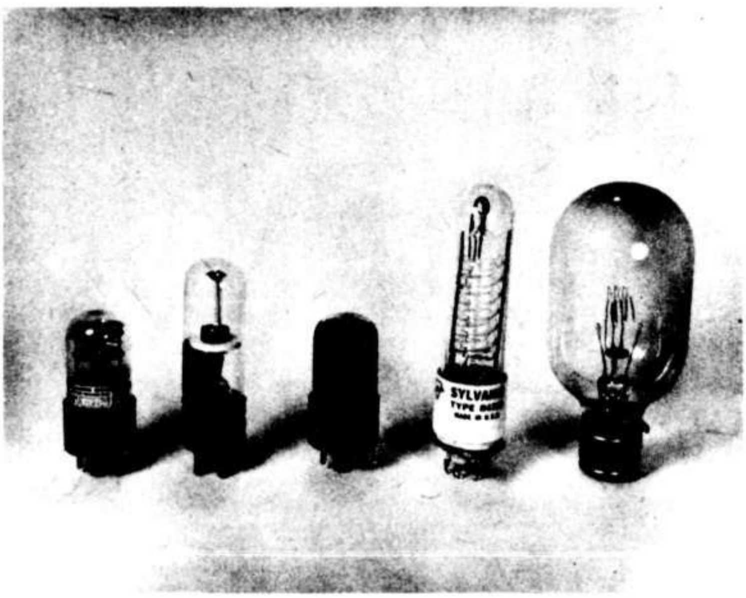


(B) CLOSE-UP VIEW OF EQUIPMENT

FIG. 25. PHOTOGRAPHS OF EQUIPMENT USED IN SINGLE-LINE AND SINGLE-SPOT TESTS



(C) CLOSE-UP VIEW OF EQUIPMENT



(D) LAMPS USED IN THE INVESTIGATION

FIG. 25. PHOTOGRAPHS OF EQUIPMENT USED IN SINGLE-LINE AND SINGLE-SPOT TESTS.

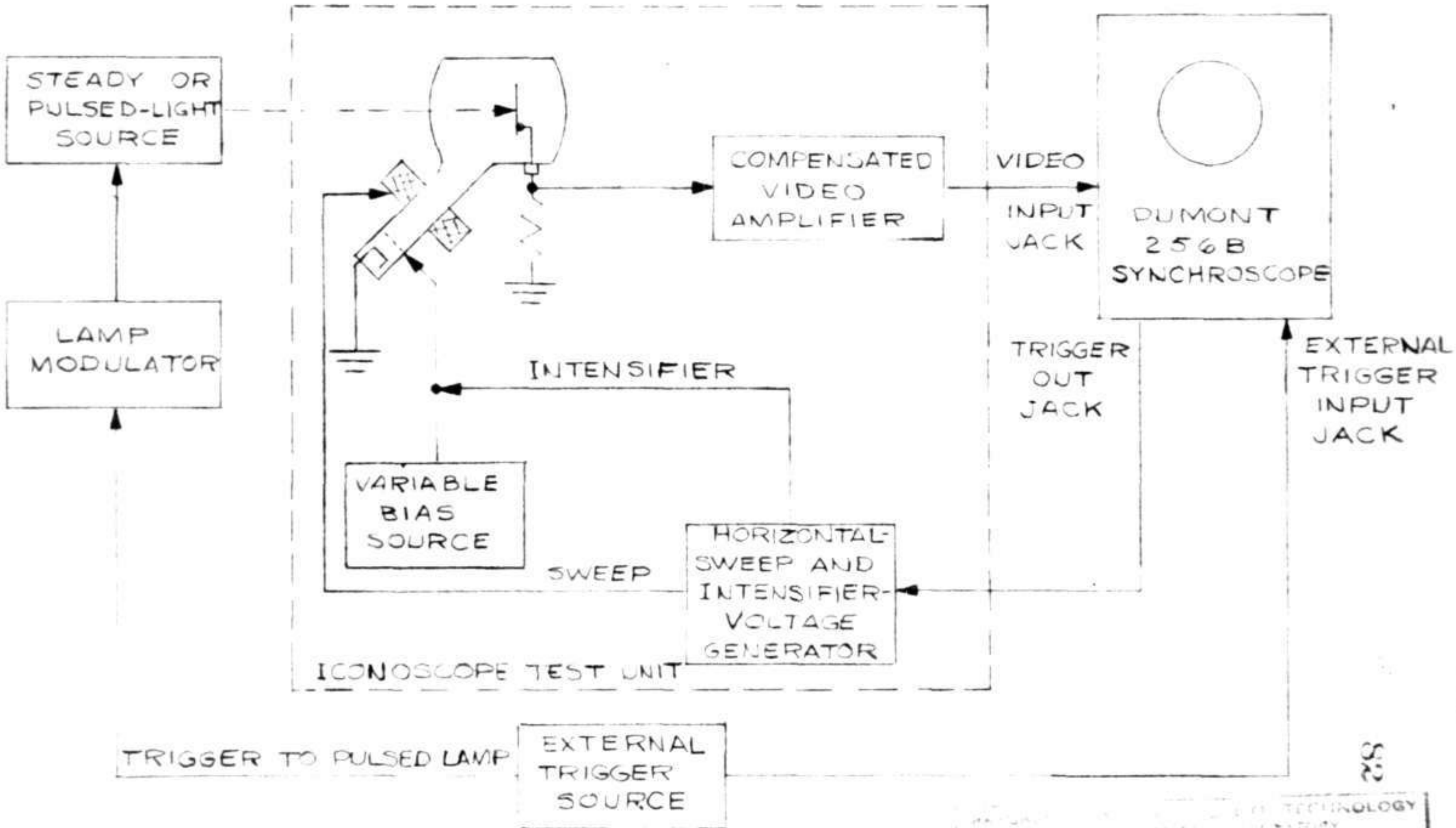


FIG 26. BLOCK DIAGRAM OF EQUIPMENT USED IN SINGLE-LINE TEST

fidelity the phenomena occurring at the mosaic. This is the modified ARK amplifier described in Art. 2(b). Another reason for this particular choice is that in the next article where the reading of light pulses is described, the use of this amplifier is mandatory if the high-frequency components of the pulses are to be reproduced. Since this is desired, and the spurious signals produced in both cases are to be compared, the same amplifier is used for both tests.

The sweep circuit is that shown in the Iconoscope Test Unit, Drwg. D-30249, and the intensifier pulse used is that produced by this circuit so that the intensification occurs for the full length of the line.

The bias light normally used in the ARK Conversion Unit was disconnected for these tests to eliminate all sources of electrons other than those produced by beam bombardment.

(b) Test Procedure and Results

Waveforms were first recorded of the video output signal of the mosaic for various beam currents under single-shot conditions. In this type of operation, sufficient time was allowed between successive scans to insure that no important charge pattern had been left on the mosaic from previous scans. The time required was a function of the beam current used and varied between 5 and 30 seconds in these tests. Samples of the waveforms observed are reproduced in Figure 27. In these, and all waveforms to follow using this amplifier, about 0.05 inches (peak-to-peak) of noise was present on the oscilloscope screen. Inspection of these waveforms show that the most striking phenomenon occuring is that of a decrease in signal amplitude, and an eventual reversal of polarity, at the start of the sweep. For low values of beam current the slope is negative over the complete sweep time, and its polarity is positive over the greater portion of the length of the scan. At high values of beam current, the waveshape is the reverse. As explained in Art. 2(a) above, decreasing bias-voltage values give an indication of increasing beam current.

The increased drop in signal voltage E_s, and the disappearance of the initial positive spike, can be explained in terms of the theory developed in Chapter I involving the returned low-velocity secondary electrons. Following the method outlined in Art. 7 of Chapter I, the volt-time curves of Fig. 28 have been drawn to cover a greatly increased beam-current value compared to that used for Fig. 13. The potential at a given spot is shown going negative for a longer period of time before being reached by the beam, and is shown as reaching a larger negative value than in Fig. 13. When the waveform of E_s in Fig. 28, as derived from the other two waveforms in this figure, is compared with Fig. 13, it is seen that the increase in charge returned

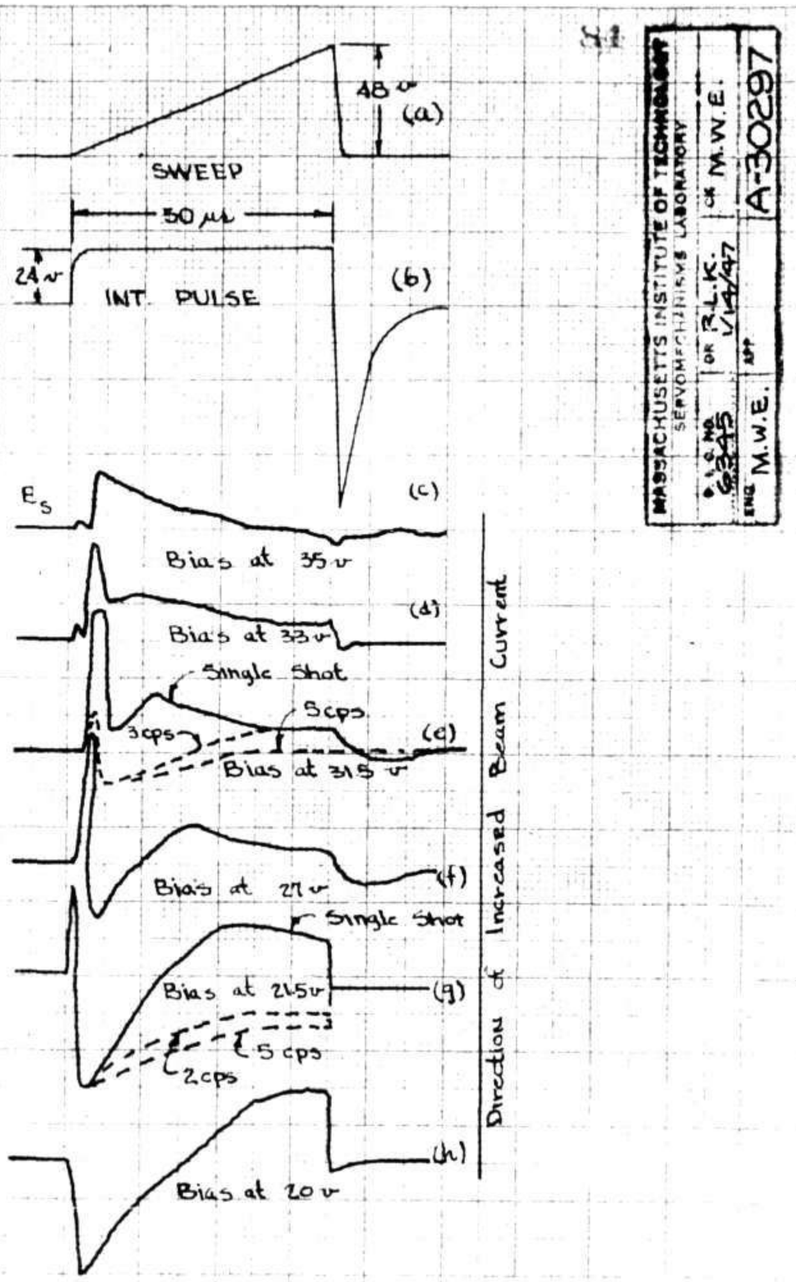


Fig. 27 - Waveforms Indicating Effect of Beam Current on Dark-Spot Signal

Full line curves - Single Shot
Dashed line curves - at rep rate given

USED IN M.W.E. THESIS

(WAVEFORMS REPRODUCED FROM 1MWE113)

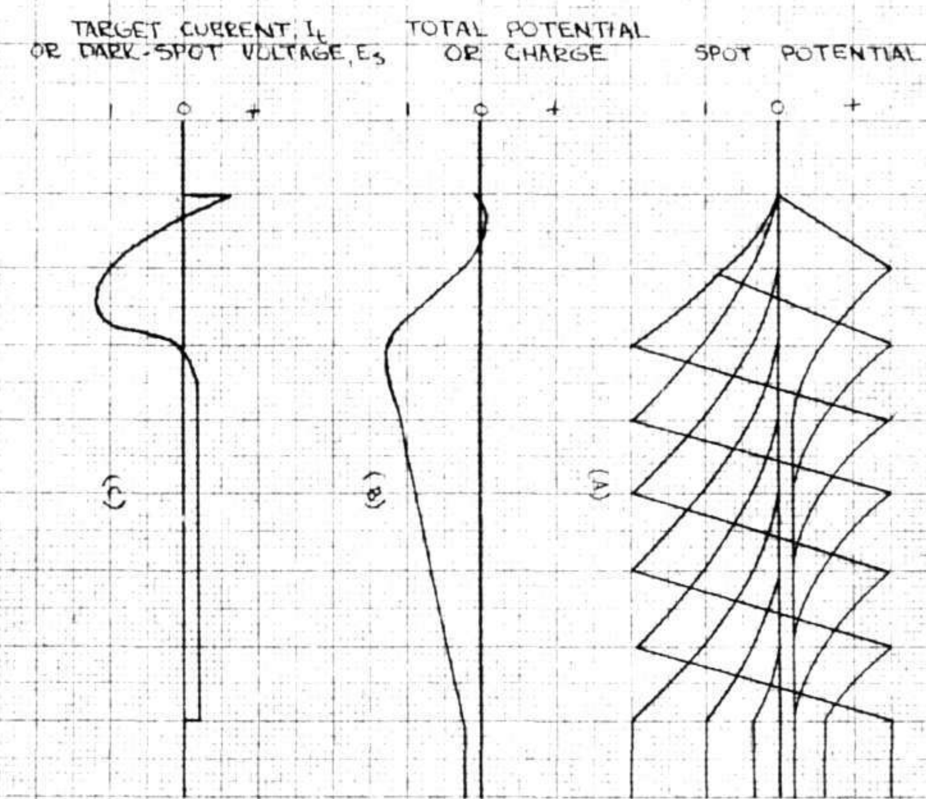


FIG. 28. GRAPHICAL ILLUSTRATION OF THE FORMATION OF THE DARK-SPOT SIGNALS SHOWN IN FIG. 27 FOR LARGE BEAM CURRENTS

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to the mosaic causes the output voltage to drop faster, and to a more negative value, and to stay down for a longer period of time. The initial positive spike produced by the lack of pre-bombardment returned secondary electrons at the start of the intensification is reduced in width and height.

The delay observed at the start of the waveforms is probably due to the finite rise time of the intensifier pulse. This delay is shown as decreasing with a decrease in bias voltage. Since the intensifier pulse had a constant height, and was added to a variable-level direct voltage, it is reasonable that adjustment of this level will produce the effects noted if the leading of the intensifier pulse is sloping. Manufacturer's data for the Type 1846 Iconoscope Tube give the normal operating grid-to-cathode voltage as approximately -40 volts. Thus, the operating conditions shown at (c) in Fig. 27 closely represent those used in television. The negative slope of this waveform is cancelled in the television application by addition of a compensating, or shading, voltage of positive slope to the signal passing through the video-amplifier.

This dip in the output-voltage waveform becomes more pronounced when the repetition rate is increased. The dashed-line curves of Figs. 27 (e) and (g) illustrate this phenomenon. A possible explanation is that the mosaic starts with some initial positive charge when the pre-bombardment electrons begin to arrive. These areas are consequently better collectors of electrons than corresponding areas on an uncharged mosaic. This results in increased flow of electron current to the mosaic, and hence through the iconoscope load resistor to ground. The positive equilibrium potential reached during bombardment is probably unchanged with these rather large values of beam currents flowing. Thus, there is an increase in the net flow of electrons to ground; either a reduction in positive value, or a negative value of voltage, is expected for E_s.

Examples of the effects produced on the dark-spot signal by repetition rates higher than 5 cps will be given in the next section.

4. Effect of Sweeping the Mosaic with a Single Spot on the Line Illuminated by Steady Light

(a) Circuit

The circuit used for this test was the same as that for Art. 3. Operation was the same except that the incandescent lamp was used in the projector, and that the image of a card bearing a 1/8-inch diameter hole was displayed upon the mosaic. The vertical-centering circuit was adjusted so that the sweep passed through the center of the light spot.

(b) Test Procedure and Results

The sketches shown in Fig. 29 were made from the original recorded waveforms. They illustrate the effect on the signal waveform produced by increasing the beam current under non-repetitive operation. The illumination on the mosaic was maintained constant at 10.6 foot candles. An apparent increase in sensitivity of the iconoscope is noted for increasing values of current over the lower range of bias voltages. The sensitivity reaches a maximum at a bias voltage of 27.5 volts; and, for larger beam currents than correspond to this, the pulse height is decreased. The polarity of the signal produced by the light is that predicted in Chapter I.

The behavior of the spurious output upon which the signal pulse appears is seen to be essentially the same as for the unilluminated mosaic. The only difference noted between the waveforms taken with and without light, for times other than when the beam was on an illuminated region, is a slight reduction in magnitude. This is due, possibly, to light dispersion around the edge of the hole, and to redistributed photoelectrons. This effect is illustrated by the dashed-line curve of Fig. 29 (h) which shows the dark-spot signal produced by scanning the unilluminated line.

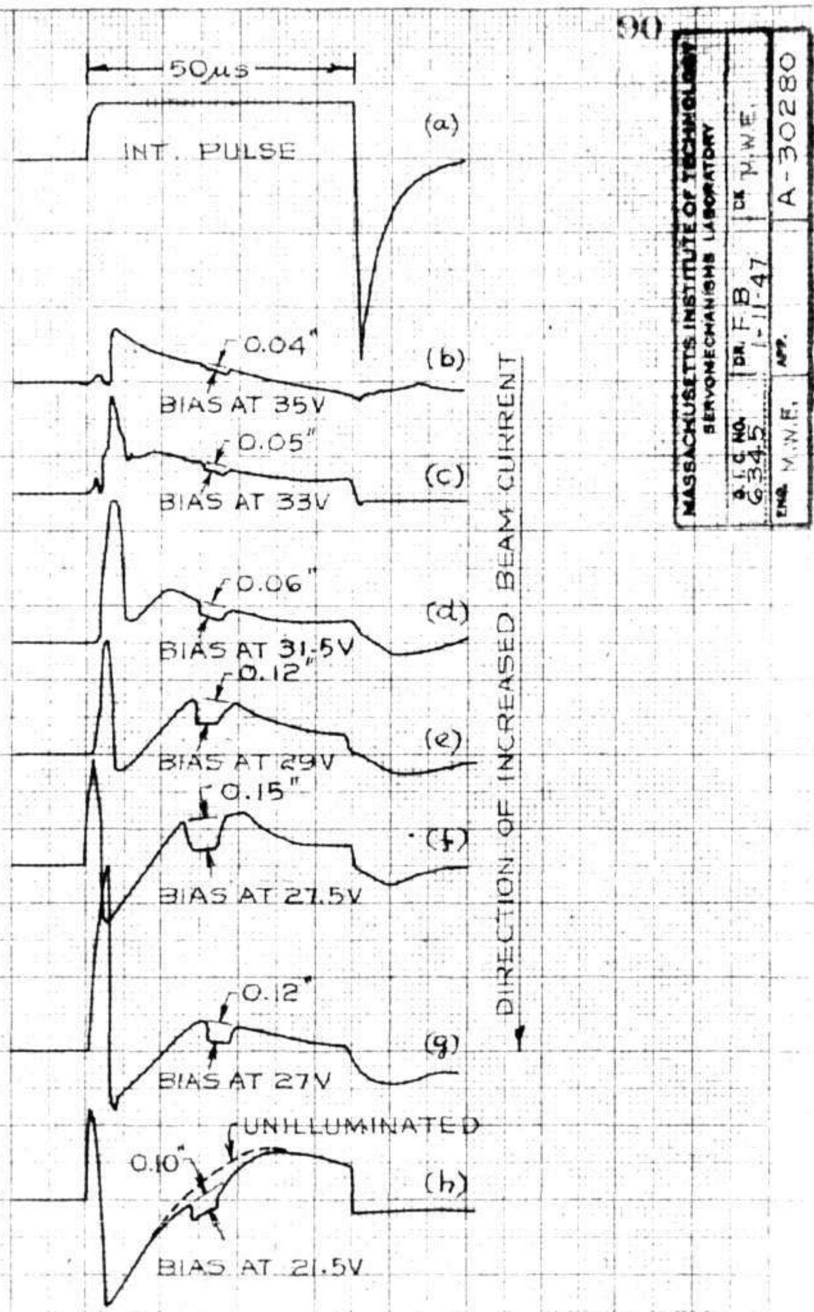

FIG. 29. EFFECT OF SCANNING A SPOT UNDER CONSTANT ILLUMINATION OF 10.6 FOOT-CANDLES AT VARIOUS BEAM CURRENTS, NON-REPETITIVE.

USED IN M.W.E. THESIS

The waveforms of Fig. 29, just described, were for a non-repetitive scan, constant illumination at the mosaic, and varying beam current. Those shown in Fig. 30 are for a non-repetitive scan, constant beam current, and varying illumination. The current value is that corresponding to a 38.5-volt bias voltage. In obtaining this data, the gain of the video amplifier was adjusted to a higher value than that used previously hence the observed magnitudes of Fig. 30 cannot be directly compared with those of Figs. 27 and 28.

The effect of increased light is seen to be an increase in signal height. This is in agreement with the explanation of Chapter I provided the intensity is sufficiently small so that the photoemission can be assumed to be saturated. As the light intensity is increased, however, a condition of unsaturated emission is reached wherein practically all the photoelectrons are returned to the mosaic. At this intensity, further increase in light should cause little or no increase in signal amplitude. This point of transition, as measured, occurs at an illumination of 3.8 foot candles.

It has been observed that if, under the conditions of Fig. 30, the beam current is increased, not only is the sensitivity increased as has been noted in Fig. 29, but

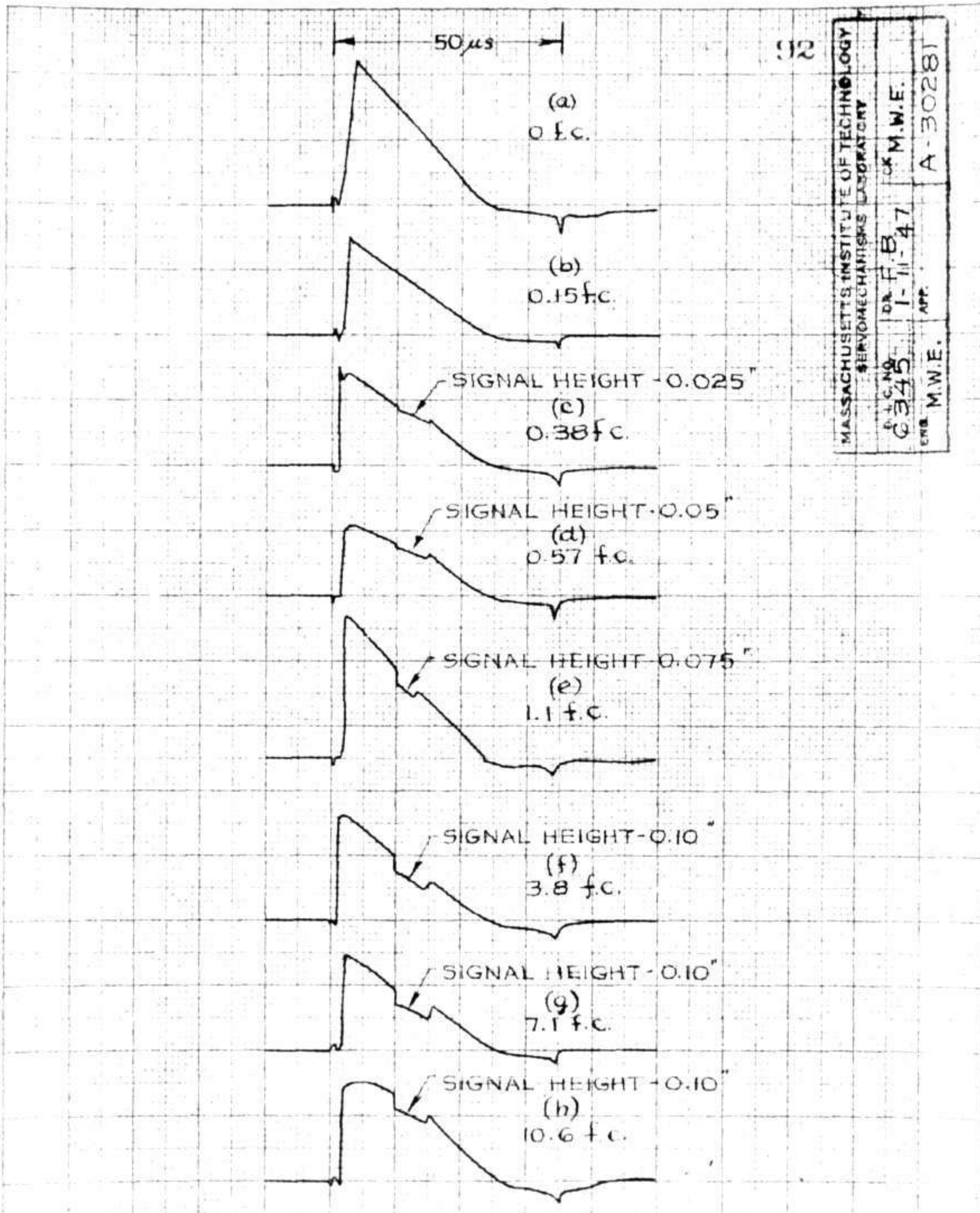

FIG. 30. EFFECT OF INCREASED LIGHT INTENSITY ON SIGNAL HEIGHT WHEN SCANNING AT LOW BEAM CURRENT. NON-REPETITIVE. BIAS VOLTAGE AT 38.5 V.

USED IN M.W.E. THESIS

the signal polarity is inverted to become positive when low light intensities are used. This effect has been illustrated by waveforms not shown in this thesis. Above one foot candle the polarities and shapes were those expected. Below one foot candle the polarity was the reverse of that expected, and the shape was somewhat rounded. An exact explanation of these effects is unknown to the author. The bias at which this reversal took place, however, was observed to be that for which the waveforms of Fig. 29 show maximum sensitivity.

The waveforms produced when the mosaic is scanned at varying repetition rates, but with a constant spot illumination of 10.6 foot candles, are shown in Fig. 31. The spurious signal upon which the pulse due to light appears behaves in the same way as for the unilluminated mosaic. The signal polarity is that expected for frequencies up to 90 cps. The polarity reverses for higher frequencies and the signal pulse becomes positive. Very little change takes place in either the spurious or desired signal outputs when the frequency is increased above 160 cps. It was found that if the illumination was reduced sufficiently below 10.6 foot candles at any frequency lower than 90 cps, the pulse polarity was reversed and the signal became positive.

The effects of scanning the mosaic at various

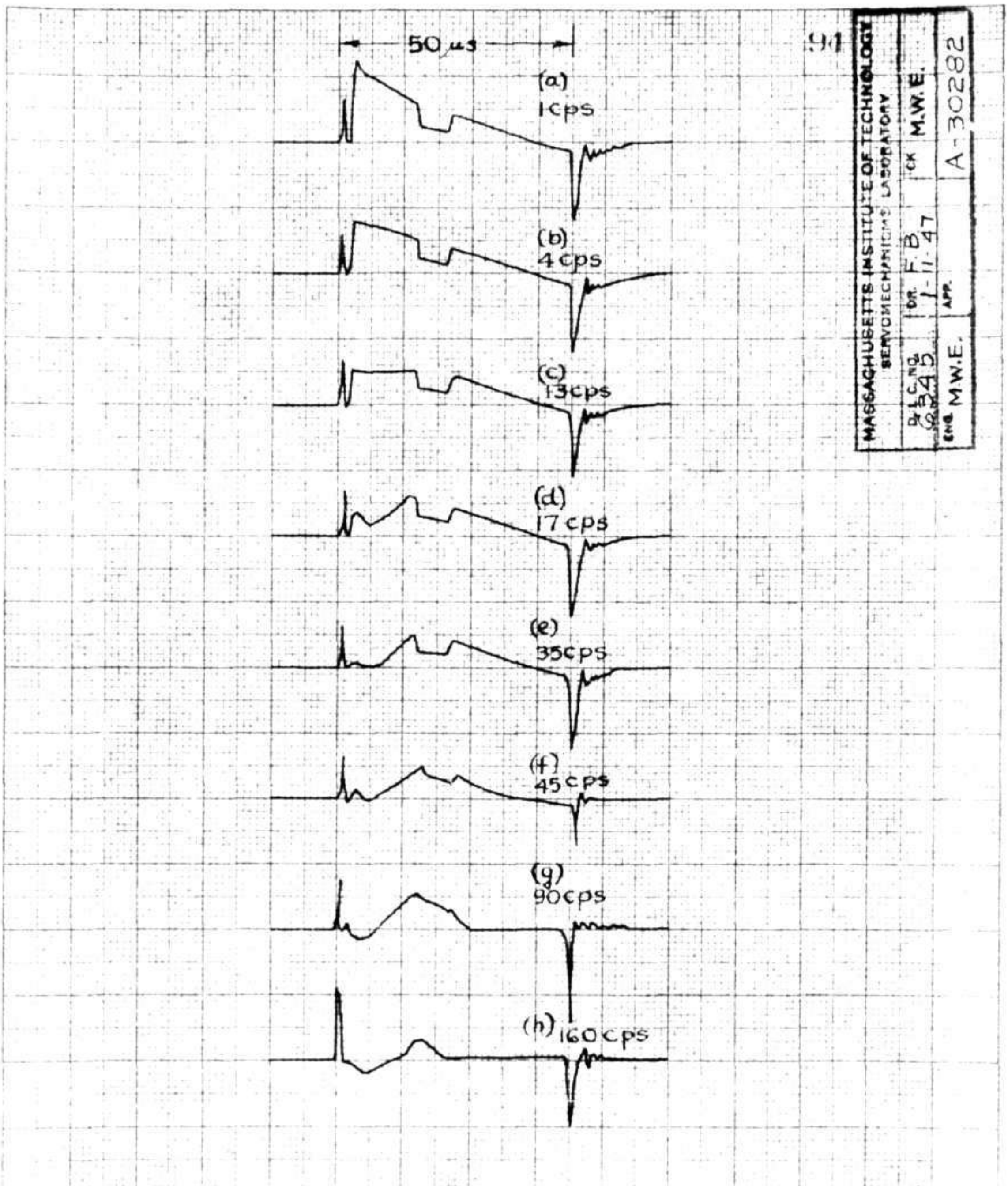

FIG. 31. EFFECT OF SCANNING AT CONSTANT LIGHT INTENSITY OF 10.6 f.c AND LOW BEAM CURRENT. REPETITION RATE VARIABLE. BIAS VOLTAGE AT 38.5V.

USED IN M.W.E. THESIS

light intensities and beam currents, but at a constant repetition rate of 80 cps, are illustrated by the waveforms of Fig. 32. For beam currents of the order of magnitude used in television the waveforms for bias values of 36 volts apply. The waveforms produced by this beam current are different from those expected from the explanation of Chapter I in that a positive signal pulse is indicated for low illumination. The results are, however, in agreement with observations made previously for non-repetitive operation at an increased value of beam current. The waveforms drawn in Fig. 32 for the two larger values of beam current indicate not only a reversal of polarity at low light intensities, but a definite change of signal shape at the higher intensities.

It is thus seen that the amplitude and polarity of the signal produced by scanning across an illuminated spot is a function of beam current, repetition rate, and light intensity. The trend of the variation of signal polarity with variation of each of these parameters can be summarized as follows:

(a) At constant repetition rate and light intensity, an increase in beam current from zero results in a polarity change from negative to positive. The crossover point can be made to occur at a higher beam current by decreasing the

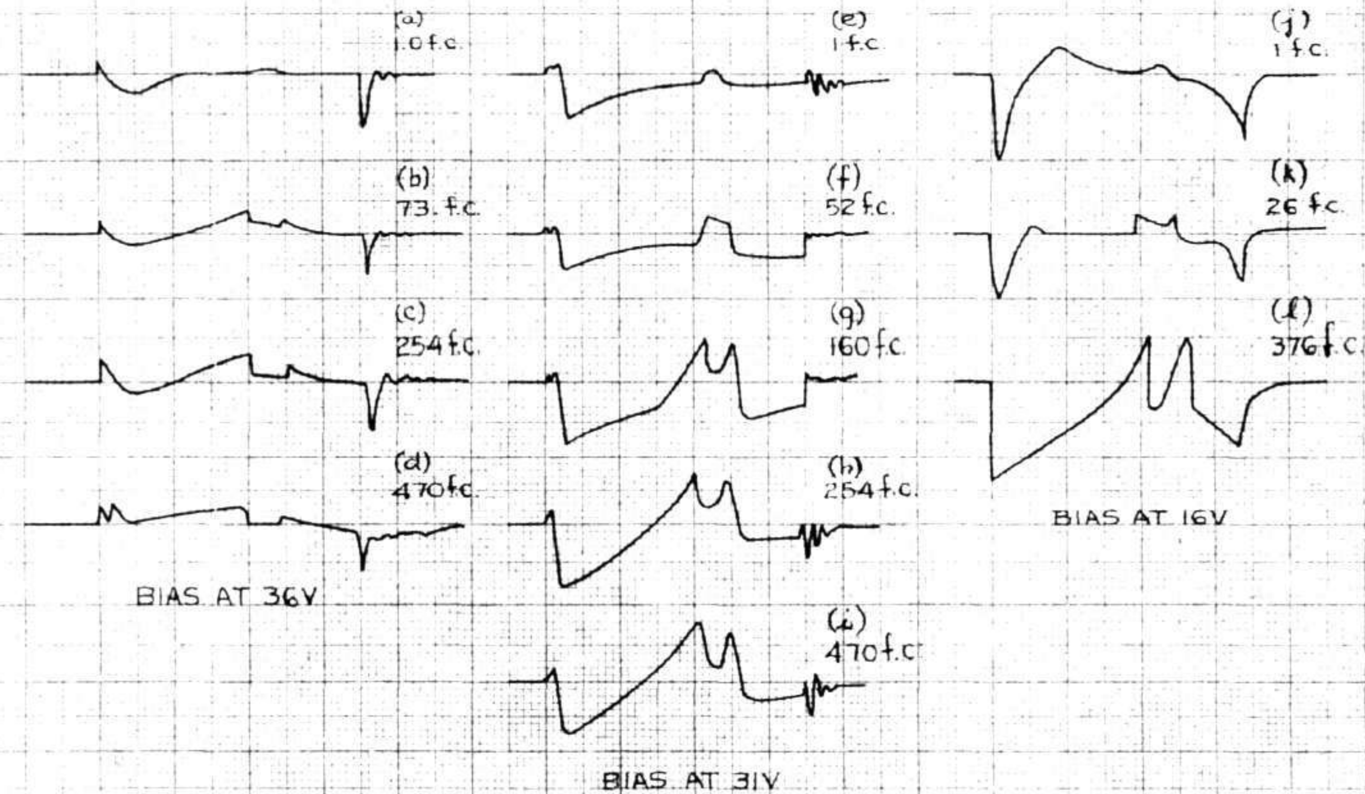

FIG. 32 EFFECT OF SCANNING AT VARYING LIGHT INTENSITIES AND BEAM CURRENTS. REPETITION RATE CONSTANT AT 80 CPS.

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repetition rate, or increasing the illumination.

(b) At constant beam current and light intensity, an increase in repetition rate results in a polarity change from negative to positive. The crossover point can be made to occur at a higher repetition rate by increasing the illumination or decreasing the beam current.

(c) At constant beam current and repetition rate, an increase in light intensity results in a polarity change from positive to negative. The crossover point can be made to occur at a higher value of illumination by increasing the current or repetition rate.

The effect of changing the time, during the sweep, at which the light area is scanned was investigated. This was accomplished by changing the setting of the horizontal-positioning control at the iconoscope. It was found that the pulse could be moved in to within 10 microseconds of the start of the sweep and not be measurably affected in amplitude. The pulse height decreased consistently as the delay was adjusted to smaller values than 10 microseconds, and the pulse disappeared entirely at about 5 microseconds. This phenomenon was not, within the precision of any measurements that could be made, a function of repetition rate or beam current.' This observation, of course, excludes the major effects on amplitude and polarity discussed above. Quantitative statements cannot be made in this instance because the deflections compared were of the order of 0.10 inches and less; and, while magnitudes can be estimated with certainty, rates at which the magnitudes change cannot.

Figure 33 shows waveforms photographed from the cathode-ray-tube screen illustrating the various effects described. The captions describe the conditions existing when the photographs were taken.

5. Effect of Sweeping the Mosaic with Single-Spot Illumination Produced by the Pulsed-Light Source

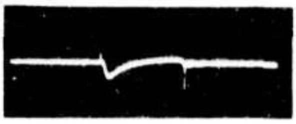
(a) Circuit

The circuit and equipment for the pulsed-light tests were essentially the same as those for steady illumination. The R_{4330} Flash Tube was used in place of the incandescent lamp; and, as a result, the Strobotron trigger box shown in Drwg. C-30252 was required for all tests. The two film attenuators used in the lamp projection system were removed since considerably more light intensity was required for this type of operation.

(b) Test Procedures and Results

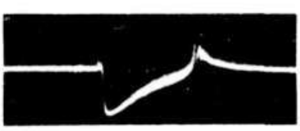
The mosaic was swept while illuminated at a spot by a light intensity (during the pulse) of 10,400 foot candles. With this illumination as a constant parameter, the beam current was changed and the waveforms of Fig. 34 observed under non-repetetive* conditions. With this large value of light intensity, the polarity of the signal at low values of current is that which is expected from the theory

*A time of at least 20 seconds was allowed between successive readings.



BIAS AT 38.5 VOLTS

BIAS AT 38.5 VOLTS
LIGHT INTENSITY AT 16.4 F.C.



BIAS AT 36 VOLTS

(A)

BIAS AT 38.5 VOLTS
LIGHT INTENSITY AT 4.7 F.C.

(B)

FIG. 33. WAVEFORMS OF SIGNALS PRODUCED BY SCANNING THE ICONOSCOPE MOSAIC. (A) WITH NO LIGHT PRESENT. (B) WITH LIGHT SPOT AT INTENSITY GIVEN. ALL PICTURES AT A REPETITION RATE OF 80 CPS.

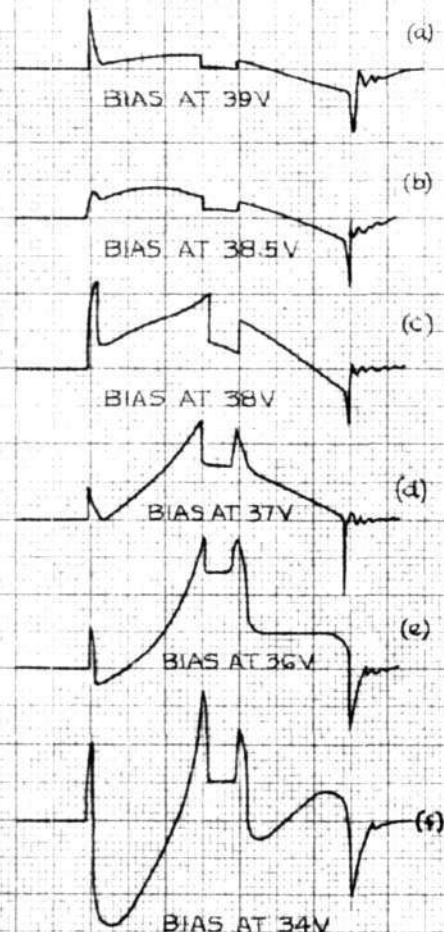


FIG. 34. RESPONSE DUE TO PULSED LIGHT.
LIGHT INTENSITY CONSTANT AT 10,400 f.c.
NON-REPETITIVE VARIABLE CURRENT

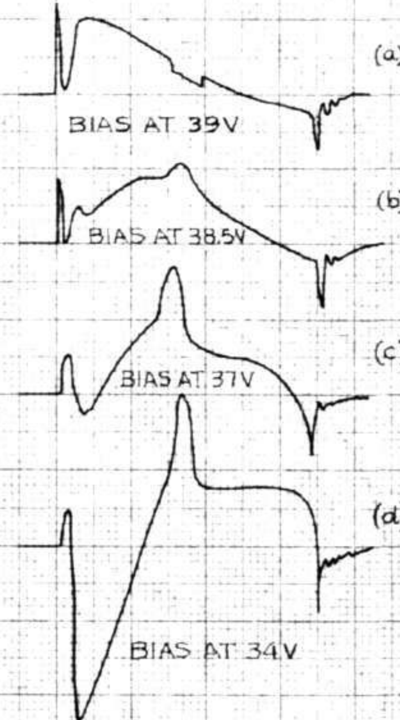


FIG. 35 RESPONSE DUE TO PULSED LIGHT. LIGHT INTENSITY CONSTANT AT 2190 f.c. NON-REPETITIVE VARIABLE CURRENT. (THE VIDEOGAIN WAS SLIGHTLY HIGHER HERE THAN FOR FIG. 34)

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outlined in Chapter I. An increase in beam current results in an increase in sensitivity, just as did increasing the beam current when steady illumination was used. It was also found that by increasing the repetition rate sufficiently the signal polarity could be made to reverse. The higher the frequency, the lower the beam-current value at which this reversal takes place.

When the illumination during the pulse was reduced to 2190 foot candles, it is found that the polarity was negative at only very low values of beam current. Signal polarity varies with beam current at this light intensity as shown in Fig. 35. These last results are in agreement with those made in Art. 4 for steady illumination, with the exception that the intensities of the pulsed light are many hundreds of times larger.

This last observation is explained by the fact that an integrating action takes place in producing the build-up of the potential distribution due to light on the mosaic surface. This also illustrates the reason for calling the iconoscope a storage device. Experimental confirmation of this fact was observed in several other ways. It was found that if the bias and intensity were respectively set to 37 volts and 2190 foot candles, the conditions corresponding to (c) in Fig. 35, the pulse polarity could be made negative by first flashing the lamp a few times without sweeping the beam. If a sufficient number of flashes were made, the waveforms as a function of beam current behaved as in Fig. 34. This phenomenon was also the reason why the signal polarity reversed, in the case of steady illumination, when the repetition rate was increased. Less time between sweeps allows less time for the stored signal to build up when the light intensity is constant. The photographs of Figure 36 illustrate some of the phenomena just described.

It having thus been experimentally proved that a single flash from the pulsed lamp is capable of building up a readable potential distribution on the surface of the mosaic, and that this potential distribution remains on the mosaic for a long period of time, the problem arises as to how this stored signal can be removed so that the surface will be ready for a new impression in as short a time as possible. Two methods have been tried experimentally.

In the first method, a lantern-slide projector was arranged to illuminate the mosaic with varying light intensity of constant spectral characteristics. The Gate and Delayed-Trigger Generator* was connected into the circuit between the TRIGGER OUT jack of the synchroscope and the trigger input jack of the sweep-voltage generator. Operation was adjusted so that the sweep circuit was triggered at a time

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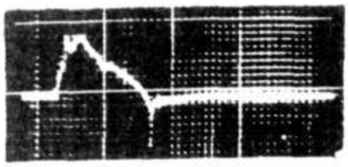
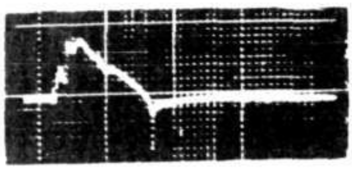
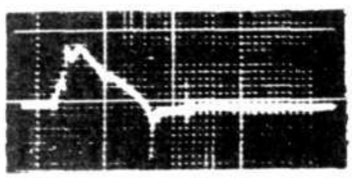
* This unit is described in Section 2 (g) of this chapter.



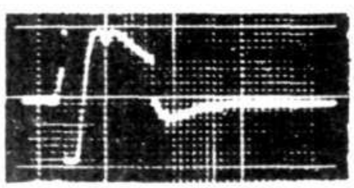
BIAS AT 38.5 V



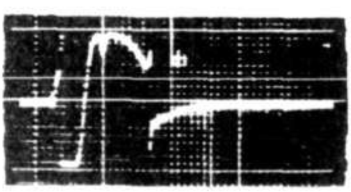
BIAS AT 36 V



BIAS AT 31 V



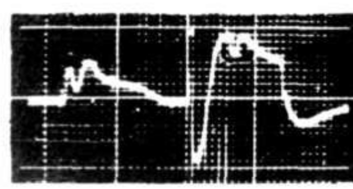
BIAS AT 26 V



BIAS AT 21 V
LIGHT INTENSITY - 2190 F.C.
SWEEP PHASED TO START
WHEN LIGHT IS FLASHED

BIAS AT 38.5 V

BIAS AT 36 V



BIAS AT 31 V
SWEEP PHASED TO START 63
LIGHT INTENSITY - 2190 F.C.
(LEFT
WHEN
INATE

900 microseconds after the lamp had started to flash. The resulting signal obtained in sweeping across the spot on the mosaic that had been illuminated was observed on the 4000-yd delayed sweep of the synchroscope.

The curve of Fig. 37 illustrates the variation in amplitude of the signal pulse as a function of a stray-light intensity. For physical reasons, no convenient method was available for determining the actual magnitude of this illumination in foot candles; hence, only relative values of intensity are given*.

The fact that storage removal is possible by this method is clearly demonstrated by this curve. This storage removal is probably due to the redistribution of the large number of photoelectrons produced by the auxiliary light source. These electrons serve to neutralize any potential variations on the surface, provided sufficient time is allowed. This method is not suitable, however, when storage removal must be affected in the time of a few microseconds, since even after a long period of 900 microseconds there still remained a signal of about twice the noise amplitude. It would be interesting to investigate this method of storage removal by placing an additional high-intensity source, similar to the R_{4330}, near the mosaic, and pulsing it for a time of 5 or 10 microseconds.

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* It was estimated, however, by comparison with the known output of the calibrated projection lamp, that the peak light intensity was approximately 50 foot candles.

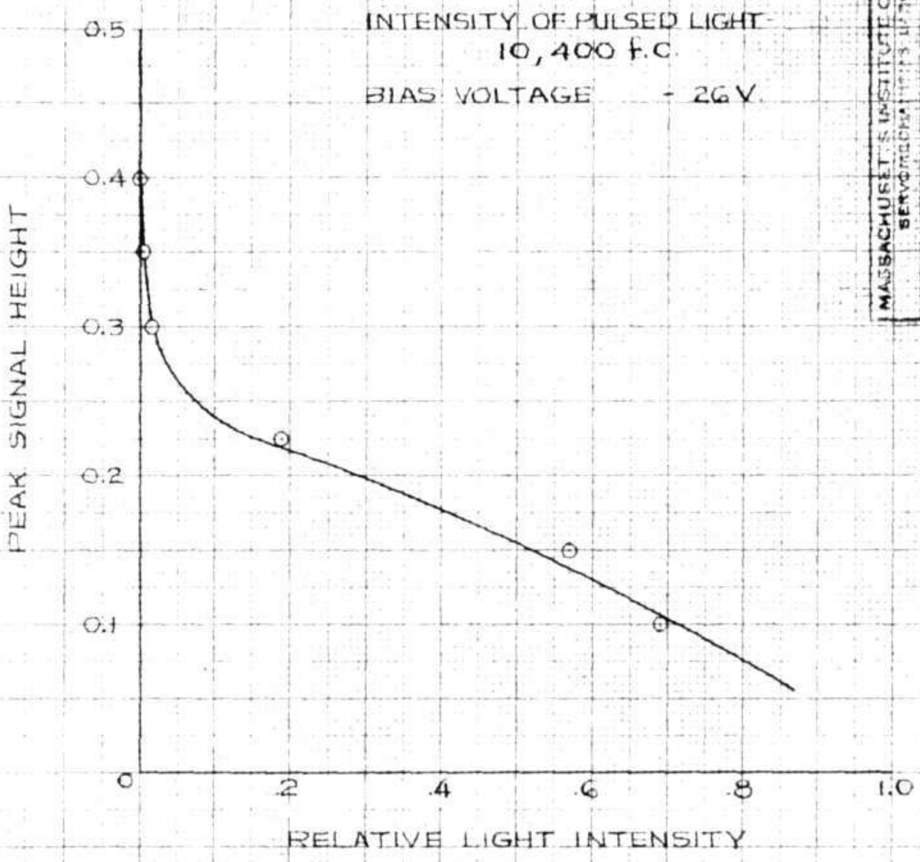

FIG. 37. EFFECT OF VARYING AMOUNTS OF STRAY LIGHT IN REMOVING SIGNAL STORED BY PULSED LIGHT. A DELAY OF 900 MICRO-SECONDS EXISTED BETWEEN THE TIMES WHEN THE LIGHT WAS FLASHED AND THE MOSAIC WAS SCANNED.

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The second method of storage removal investigated required sweeping the mosaic at a large value of beam current during the reading time. One means of studying this effect involved triggering the sweep-generator circuit twice for every flash of the lamp. This was accomplished by feeding the triggers from the synchroscope into both inputs of the Gate and Relayed-Trigger Generator. The two pulse outputs were mixed at the trigger input jack of the sweep generator. The two delays were adjusted so that the two sweeps occured at times 245 and 595 microseconds respectively after the light was flashed. A sample of the resulting waveforms observed on the 200,000-yard range of the synchroscope is shown in Fig. 38. The signal polarity was positive at the repetition rate and beam current used. Figure 39 describes the variation of the ratio $\frac{\text{peak signal amplitude on second sweep}}{\text{peak signal amplitude on first sweep}}$ with bias voltage. This curve indicates that no signal remains on the mosaic if the beam current used is that corresponding to a bias of 21 volts.

This same value of bias required for complete storage removal has been determined by an entirely different method. A single delay of about 70 microseconds was used in the trigger path to the sweep-voltage generator; and this circuit was operated at 80 cps as controlled by the internal oscillator of the synchroscope. A single flash of the R_{4330},

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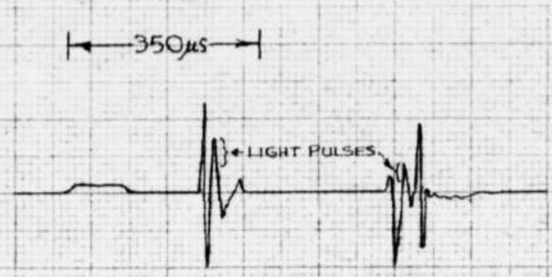

FIG. 38. WAVEFORM ILLUSTRATING REDUCTION OF STORED SIGNAL BY SCANNING AT INCREASED BEAM CURRENT.

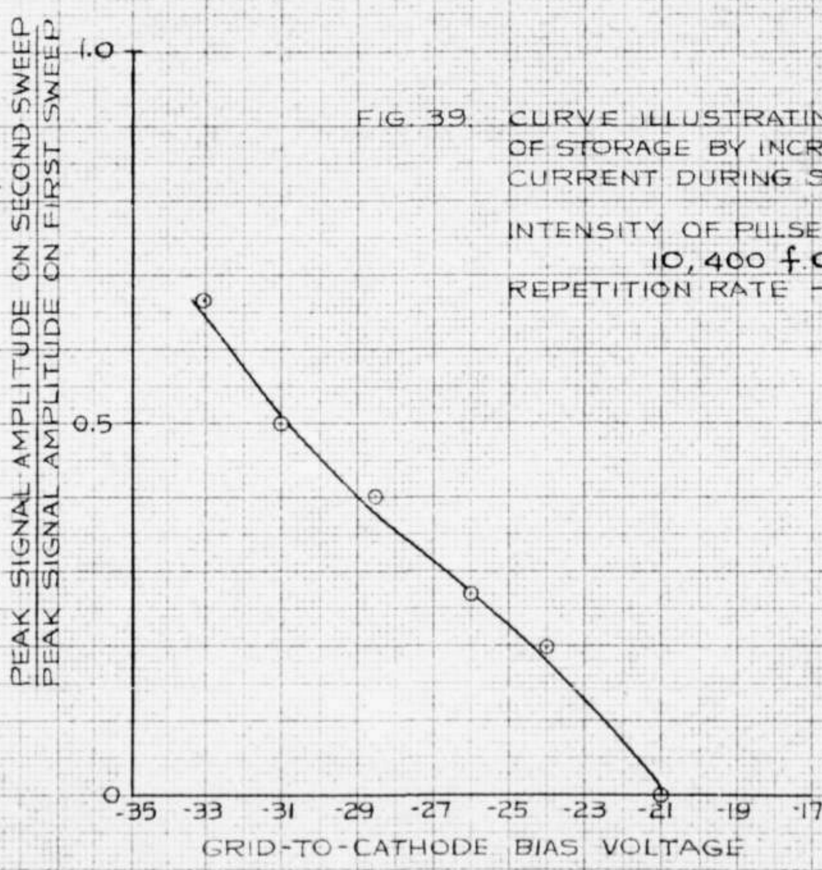

FIG. 39. CURVE ILLUSTRATING REDUCTION OF STORAGE BY INCREASED BEAM CURRENT DURING SCAN.

INTENSITY OF PULSED LIGHT - 10,400 f.c.
REPETITION RATE - 2.4 cps

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triggered by the strobotron circuit, was allowed to illuminate the spot on the mosaic. The resulting pattern on the synchroscope screen for a bias of 21 volts is shown in Fig. 40. It is seen that, at this voltage, the stored signal is removed by one scan. When the bias is greater than 21 volts, several scans are required. A plot showing the number of scans required for various bias voltages is given in Fig. 41.

LIGHT INTENSITY - 10,400 fc
BIAS VOLTAGE - 21 V

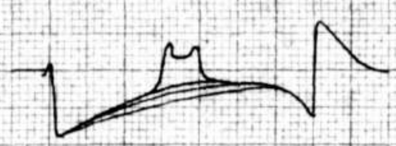

FIG. 40. WAVEFORM OF OUTPUT VOLTAGE WHEN MOSAIC IS SCANNED AT 80 cps, AND A SINGLE FLASH OF LIGHT OCCURS.

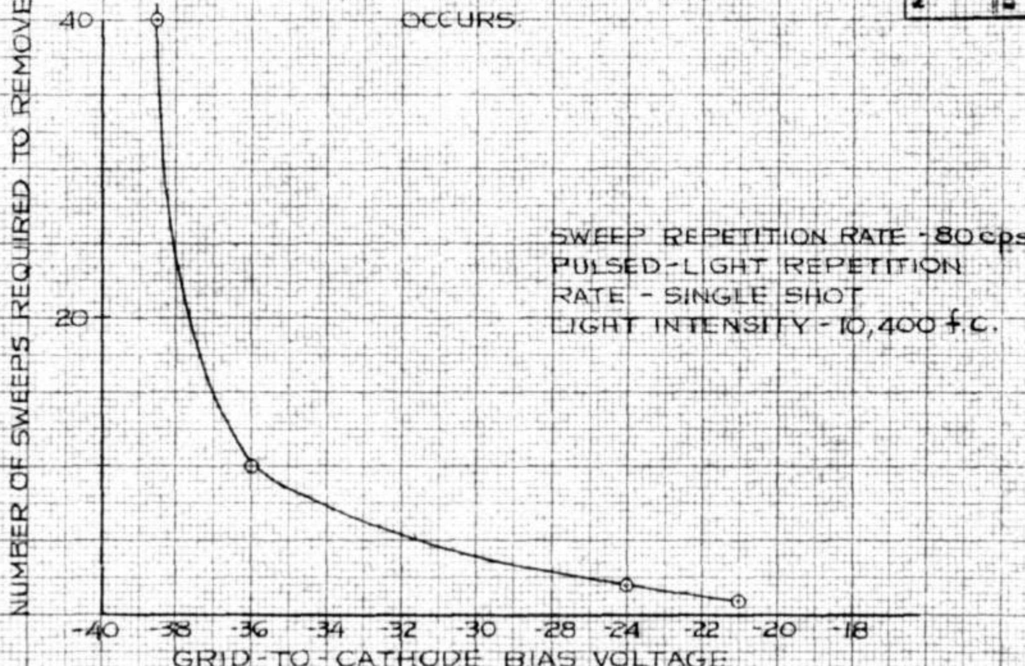

FIG. 41. CURVE SHOWING NUMBER OF SWEEPS REQUIRED AT BIAS VOLTAGE GIVEN TO REMOVE SIGNAL STORED BY PULSED LIGHT.

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CHAPTER VI

SINGLE-SPOT TESTS

1. Purpose

Tests were made with the beam stationary to obtain data concerning the behavior of the mosaic when the variable effects of a sweeping beam were eliminated. As has been discussed in Chapter V, the greatest sensitivity to projected light was observed to occur at large beam currents. No reason could be given for this, and it was hoped that some might develop from these static tests.

2. Block Diagram

All equipment shown in the block diagram of Fig. 42 has been discussed in Chapter V. The video-amplifier system uses the three units having good frequency response so that the waveforms obtained are those of the voltage across the iconoscope load resistor. Compared to the waveforms obtained in the tests of Chapter V, the polarities indicated on the synchroscope screen are reversed because an odd number of amplifiers are involved. Arrangement was made so that either the pulsed- or steady-light source could be used. For single-shot and low-repetition-rate studies, the source of triggers used was the strobotron circuit; and for higher frequencies the source was the internal oscillator of the synchroscope.

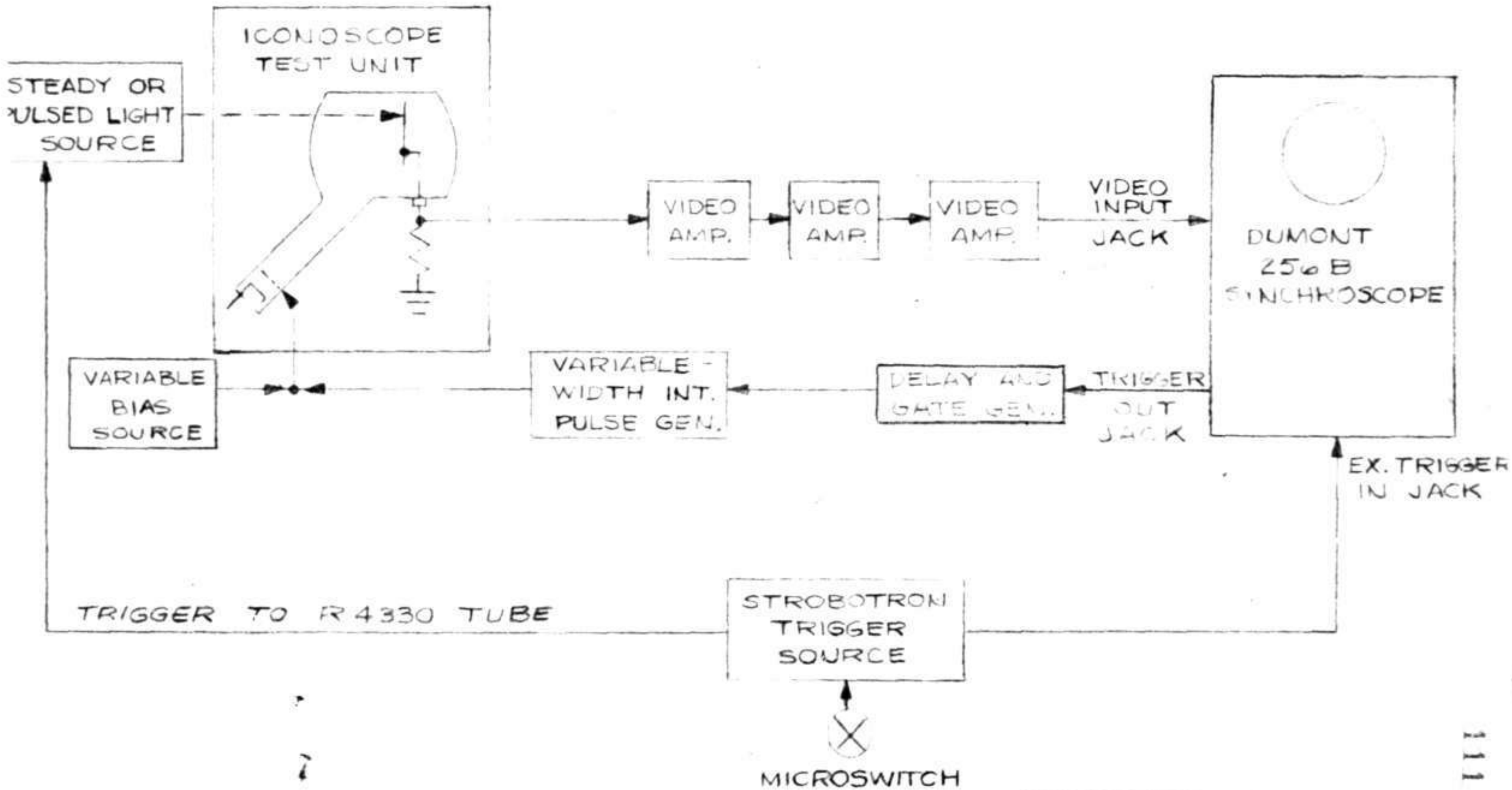

FIG. 42. BLOCK DIAGRAM OF EQUIPMENT USED IN SINGLE-SPOT TESTS

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3. General Features

The minimum width of the pulse produced by the intensifier-pulse generator was 0.6 microsecond. Its shape under this condition was more nearly triangular than rectangular. In the usual tests made in this section, the amplitude of this pulse was kept at 14 volts and beam current was varied by changing the level of a direct voltage to which this was added. Thus, the time at which beam current started to flow was a function of the setting of this bias level. Results, therefore, must be modified in the discussion to follow to correct for the delay so produced.

An attempt was made at using a more closely rectangular pulse than this to study the mosaic response. A pulse generator operating with gas tubes and capable of providing rise times of the order of 0.05 microseconds was tried. It was found that the combination of this fast rise time and the video-amplifier response characteristic resulted in ringing oscillations several times the amplitudes of the changes under observation. Sufficient information was obtained, however, using this generator to corroborate the results obtained using the triangular pulse.

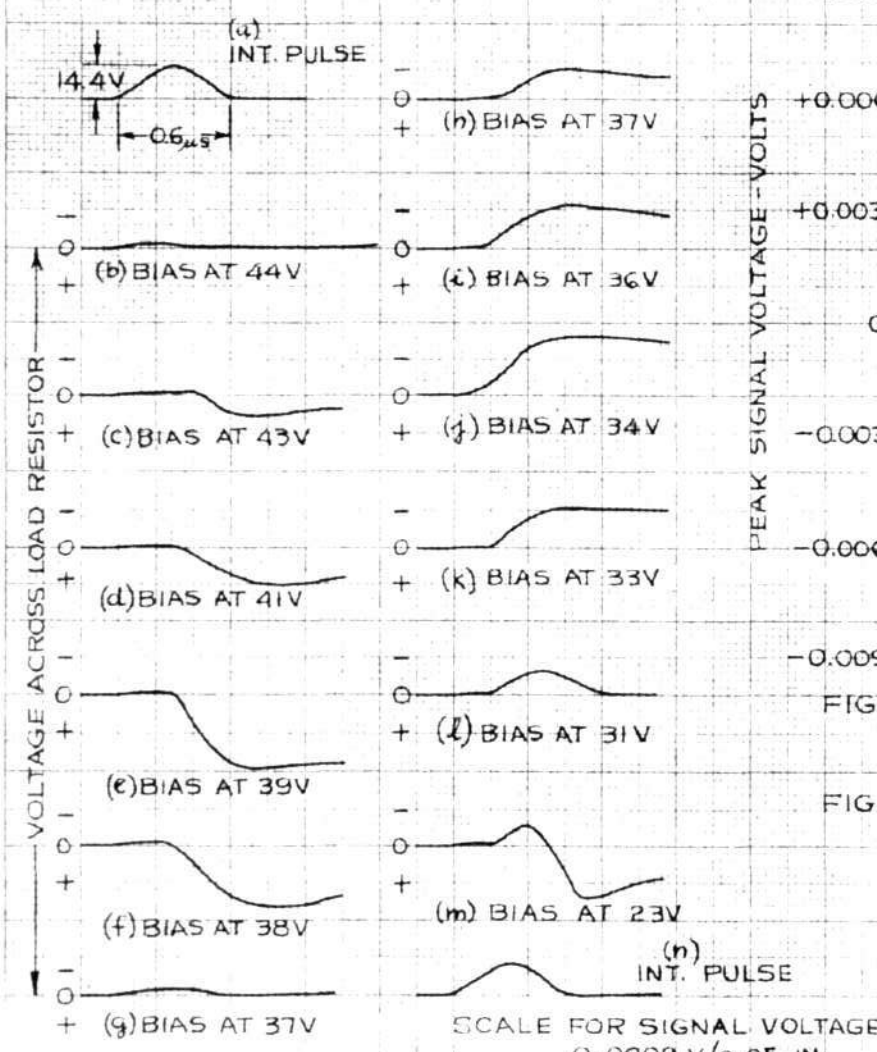
The reason for using a 0.6 microsecond pulse was that this corresponds closely to the time the beam will be on a given spot in the normal computer sweep. Assume that the length of the scan is to be 6 centimeters, and is to occur in 60 microseconds. The spot then travels at a speed of 0.1 centimeters per microsecond. The beam diameter is of the order of 0.025 centimeters. The time taken for the beam to pass over a given spot is then $\frac{0.025}{0.1}$ or 0.25 microsecond. Since the pulse is triangular, its effective length is approximately this value.

4. Effect of Variation of Beam Current with No Illumination

The beam was focused and positioned at a spot on the mosaic, and pulsed with the 0.6 microsecond pulse. The video output signal was observed as the beam current was changed, and the waveforms recorded are reproduced in Fig. 43. It is to be noted that the polarity for low beam currents is that expected*. A secondary-escape ratio of about 3 exists at the instant the beam strikes the mosaic, and there are more electrons leaving the surface than arrive. This causes the signal plate to become positive with respect to ground. Figure 44 shows a plot of peak signal amplitude and polarity as a function of bias voltage.

The shapes of the waveforms shown can be justified as follows: In Chapter I it was shown that if a step-function of beam current was allowed to bombard the mosaic at a single spot, the output voltage E_s could be described

*Note that a reversal of polarity takes place in the amplifier system.



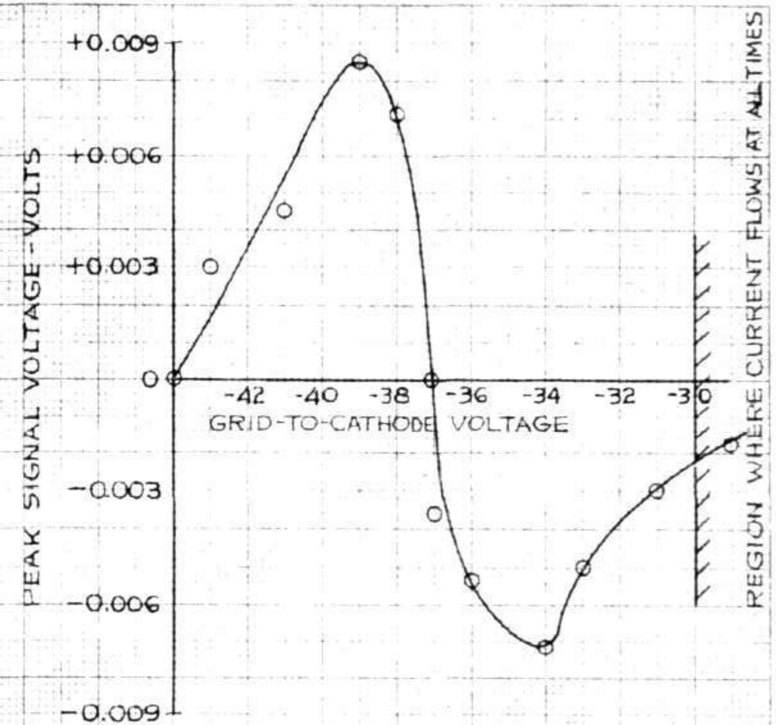


FIG. 44. (ABOVE) CURVE OF SIGNAL AMPLITUDE AND POLARITY VS. BIAS VOLTAGE.

FIG. 43. (LEFT) WAVEFORMS OF SIGNAL VOLTAGE AS BEAM CURRENT IS VARIED.

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$$E_s = 3\ I\ \ R_L \varepsilon^{-\frac{t}{T}} \tag{1}$$

where I_b was the beam current maguitude, R_L was the load resistor, and T is the time constant of the resulting change. Certain assumptions were made in this derivation that must be considered in an exact analysis. These assumptions were (a) that the beam current rises instantaneously to a steady value, (b) that only the mosaic capacitance directly under the beam is charged, (c) that the surface has infinite resistivity, (d) that the effects of space charge are negligible, (e) that redistributed electrons are returned only to the point under bombardment, and (f) that the stray capacitance shunting R_L is negligible.

An exact analysis of the circuit including all the variables which were neglected would be difficult, and would not give meaningfull results because of the assumptions that would have to be made regarding magnitudes. The general trend of the results that would be obtained can, however, be estimated and compared with the experimentally-determined waveforms.

Consider first the curves shown in Fig. 43, parts (b) through (e). These curves begin to rise slowly shortly after the start of the intensification, reach a maximum

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*See equation 13 of Chapter I.

value at the end of the intensifier pulse, and then decrease with a measured time constant of about 10 microseconds. This waveform is considerably different than that indicated by the equation given above; but, the reason for this difference can be seen if one considers the application of a rising current to the R-C network of Fig. 45, and determines the waveform of output voltage, e_s. In terms of Laplace Transforms, with the initial conditions given that at $t = 0$, $i_b = 0$ and the capacitors are uncharged, the following equation can be written.

$$E_s(s) = \frac{k}{2} \times \frac{R_L}{1 + sR_L C_s} = \frac{k}{C_s} \frac{1}{s^2\left(s + \frac{1}{R_L C_s}\right)} \qquad (2)$$

The solution of this equation is*

$$e_s = k R_L^2 C_s \left[\varepsilon^{-\frac{t}{R_L C_s}} + \underline{\qquad} - 1 \right] \qquad (3)$$

A sketch illustrating the general form of e_s given by equation (3) is shown in Fig. 46. It is assumed in drawing this waveform that the flow of i_b is suddenly stopped at the time t_1 . The voltage decreases exponentially with a time constant of $R_L C_s$ for times greater than t_1.

In light of the results of this derivation for a circuit similar to the iconoscope but under simpler excitation, and with no redistribution electron effects to consider, it is reasonable that the waveforms of Fig. 43 have the proper

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*By Transorm No. 2.103 in Reference 23.

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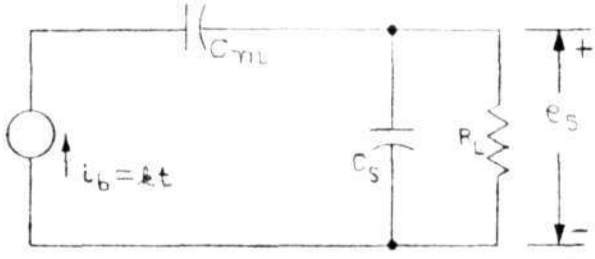

FIGURE 45. CIRCUIT SIMILAR TO THAT OF ICONOSCOPE.

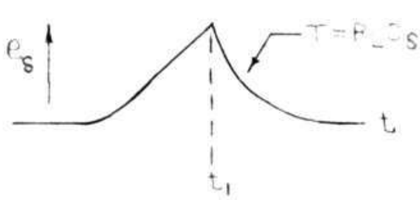

FIGURE 46. WAVEFORM OF e_S PRODUCED BY CIRCUIT OF FIGURE 45.

shapes. The time constant of the decrease in voltage following the end of the intensifier pulse has been measured to be about 10 microseconds. Assuming a stray capacitance of 20 $\mu\mu$f shunting the 470-K load resistor, a time constant of 9.4 microseconds can be calculated to compare favorably with this measured value.

That the peak amplitude reached is of the correct order of magnitude can be checked by assuming a mosaic capacitance* of 100 $\mu\mu$f per square centimeter, a beam diameter of 0.025 centimeters, and computing the drop across the stray capacitance C_s. At the frequencies involved in the 0.6-microsecond pulse, the resistor R_L can be neglected, and a capacitive voltage divider can be formulated by placing the capacitance of the mosaic spot under bombardment in series with C_s. The spot capacitance will be $100 \times \frac{\pi}{4} \times (0.025)^2 = 0.0491 \mu\mu f$. The voltage applied across this divider is the approximately three-volt change occuring to cause the secondary-escape ratio to drop to unity. Assuming C_s to be 20 $\mu\mu$f, the signal voltage appearing across C_s is

$$e_s = 3 \times \frac{0.0491}{20.05} = 0.0075 \text{ volts.}$$

In view of the assumptions made, this figure compares favorably with the measured value of 0.0085 volts.

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* See Reference 4, page 279.

Up to now, no mention has been made of the reversal of signal polarity with increased beam current as indicated in Figs. 43 and 44. This is an effect not mentioned in the literature, but observed to occur* by television authorities. The only reasonable explanation arrived at, as a result of this investigation, is that it is due to the effects of increased space charge in the region outside the mosaic surface when the beam current is increased. With a secondary-emission ratio of four, or possibly even greater than four, there will be a large number of slow-moving-electrons receding from the mosaic. The space charge so produced will create a dip in the potential-distribution curve between the mosaic surface and the various elements that serve as collectors of electrons. The effect of this negative gradient will be such as to limit the number of electrons that are able to leave the mosaic.

It is reasonable to expect that if the beam current is increased sufficiently, a value will be reached at which more electrons will arive at the mosaic in the beam than leave it to travel to other elements of the tube. In other words, the secondary-escape ratio is decreased below unity. As a result, the electron current flows down from the signal plate and the signal polarity becomes negative. The overall effect is that as beam current is increased from zero,

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*See Article 4 of Chapter IV.

the signal amplitude increases to a maximum, decreases, passes through zero, and goes negative. This variation is shown in Fig. 44.

5. Effect of Varying the Intensity of Steady Light at the Cross-Over Point

For the computer application, it is desirable to operate the iconoscope under conditions of optimum signal-to-noise ratio. It has been noted in Chapter V that maximum sensitivity occurs at a high value of beam current. It was also observed, however, that the peak-to-peak amplitude of the dark-spot signal increases as the beam current is increased. The observation of the reversal-of-polarity effect led to the conclusion that the best signal-to-noise ratio with light present might be obtained with the bias set to the cross-over value given by Fig. 44. This is the bias at which the polarity reversal takes place.

Tests were undertaken to investigate this pehnomenon. The calibrated incandescent lamp was used as a source and varying amounts of light were allowed to fall on the mosaic with the grid-to cathode bias voltage adjusted to the cross-over value. The variation of the ratio of peak signal amplitude to peak-to-peak noise amplitude determined from the test results is shown in Fig. 47. The effect of repetition rate on this ratio was also noted and the resulting curves are included in this figure. The variation

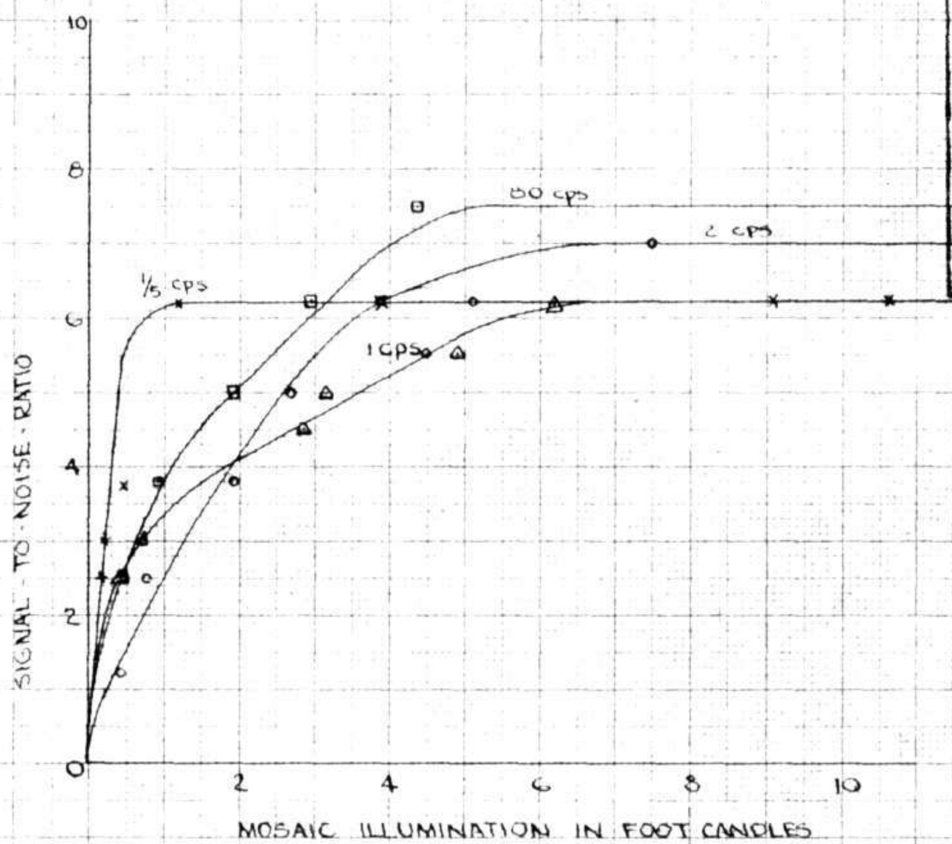

FIG. 47. VARIATION OF SIGNAL-TO-NOISE RATIO WITH LIGHT INTENSITY AND REPITITION AT THE CROSSOVER POINT INDICATED IN FIG 44

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to signal-to-noise ratio with light intensity shows the expected results. The fact that the curves level off is in agreement with the results of other tests wherein sufficient light was obtained to result in unsaturated photoemission. Because of the poor precision of the measurements made, no attempt is made at comparing the curves obtained at the various repetition rates. Amplitudes were read from the face of a cathode-ray tube and at no time did the deflection exceed 0.3 inch. While changes in magnitudes in a given run can give significant results, comparison of rates of changes between different runs cannot be made.

CHAPTER VII

CONCLUSIONS and SUGGESTIONS FOR FUTURE STUDY

1. Conclusions

This investigation has not been carried far enough to allow a definite statement to be made as to whether or not the iconoscope, or any of the other types of pick-up devices, will make a satisfactory data converter for an electronic computer. Quantitative answers can be given, however, to some of the problems that arise in this application when a Type 1846 iconoscope is used. A few of the more important conclusions are presented below.

Tests have indicated that it is possible to use a pulsed-light source to illuminate the iconoscope mosaic provided sufficient time is allowed for building up of the stored signal. If, during the pulse, an illumination of 10,000 foot candles (at the mosaic) is used, a readable signal is obtained after about ten microseconds. If the light intensity is reduced the minimum time required before a readable signal is obtained is increased.

The signal stored by light can be completely removed by scanning the mosaic with the proper value of beam current during the reading period. For the tube tested, this was shown by several methods to be that current corresponding to a grid-to-cathode bias voltage of -21 volts. The method of using extraneous light to provide a sufficient number of stray electrons to remove these stored signals has been shown to be impractical because a long time is required. There are, however, two disadvantages to using a large beam current during scan. A large spurious signal is involved that must be compensated for in the video amplifier; and a normal, well-defined, signal is not obtained with reasonable values of light intensity. It has been found that the pulse polarity changes from negative to positive, and its shape becomes rounded, as the beam current is increased.

When an image projected on the mosaic is to be scanned, the sweep must be timed to start sufficiently before the video amplifier signals are required. This is to allow the peculiar effects produced by returned secondary electrons to reach a steady-state condition. For a 0.1-centimeter-per-microsecond sweep, the sweep must be started at least 0.5 centimeters in front of the first light image it is desired to read.

The illuminations required for readable signals when steady light is used are much lower than for pulsed light. Such operation, while not directly applicable to the computer problem, was investigated. For non-repetitive and low-frequency operation, maximum readability is obtained when the illumination at the mosaic is about four foot candles. Readability is decreased when the repetition rate is increased. This is expected when the storage phenomenon occuring is considered. At 40 cycles per second, a common television frequency, the minimum light for a signal barely perceptible in the noise is about one foot candle.

There is at present no pulsed-light source that satisfies the high-repetition-rate and intensity requirements of the computer, insofar as the use of an iconoscope as a data converter is concerned. The R_{4330} Flash Lamp is a satisfactory lamp for studying the response of the iconoscope at repetition rates up to about two cycles per second. The glow tubes can be operated at the frequencies required, but the light available is insufficient. Provided a sufficiently intense light is obtained, all indications are that operation of the iconoscope as a data converter is possible. It may well be, however, that the intense light required will damage the photosensitive surface, but this is not anticipated.

2. Suggestions for Further Study

Development of pulsed light sources should be carried on until lamps are obtained that are capable of operation of 20,000 cycles per second with duty cycles of 90 per cent, and that provide illuminations at the mosaic of approximately 10,000 foot candles. When these lamps have been perfected, it is recommended that the tests indicated in Chapter III be made using the block diagram of Fig. 20. Design of the vertical-deflection circuits required for selecting any given line on the projected card image, and modification of the video-amplifier system to compensate for the dark-spot signal, will be problems involved in this investigation.

The use of the Kerr Cell as a means of pulsing a beam of light under the conditions required by the computer can be investigated. The design and test of the driver system should prove interesting, and radar techniques are well adapted to the problem. Quantitative measurements need to be made on sources of pulsed light other than the glow and arc tubes. The ordinary cathode-ray-tube with its beam defocused and operated at higher than normal voltage should be given special consideration, and its application with the more sensitive types of television tubes such as the image dissector can be studied.

The relatively new pulsed techniques used in this thesis in testing the iconoscope can be applied to testing the other types of television tubes. The phenomena of spurious signal formation and polarity inversion require further study to determine their causes. Such a study would yield information aiding in the design of new tubes, and in the design of compensating circuits for correcting for these effects.

A steady-state method of determining the sizes of the elements in the iconoscope equivalent circuit has been described by Maloff*. This same data can probably be obtained by using a pulse technique similar to that used in the single-spot tests reported in this thesis. It would be advisable to make these tests on a specially-built iconoscope tube. This tube could well have a circular mosaic, to simplify mathematical analysis. It should contain a suitable collector of beam electrons so that measurement of beam current is possible. In addition, a screen grid should be located close to the mosaic to allow control of the space-charge effects in the tube. The propogation of charge outwards from the point of bombardment can be studied by using intensifier pulses of various lengths. These results may be interpreted to give an idea of the effective capacitance charged when the beam is on a given spot. An interesting mathematical problem is involved that is similar to the two-dimensional problem in which charge is built up on a long d-c transmission line. The mosaic would involve a third dimension and would be solved in polar coordinates. Because of the configuration

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* See Reference 3.

and symmetry, the solution would probably be in terms of Bessel functions.

Results of the iconoscope investigation indicate that the image dissector and orthicon-type tubes should be studied. The difficulties due to spurious signals in the iconoscope are practically non-existent in the case of the orthicon tube. This tube, as designed by Iams and Rose*, uses a scanning beam of low-velocity electrons and the secondary emission resulting is negligible. Hence, the cause of the dark-spot signal is eliminated. The storage efficiency of this tube is twenty times that of the iconoscope for the television application. Considerable increase in sensitivity might possibly be gained by using the orthicon instead of the iconoscope for the single-line operation required by the computer.

The question of precision of the data converter has not been considered in this investigation. When the electronic data converter is further advanced in its development than it is at the present time, some means will be required to determine if any of the pulses are missed during the reading process. One possible method uses a high-speed recording oscillograph. The design of this oscillograph and its use in testing the data converter are suggested for study.

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* See Reference 25.

APPENDIX A

LAMP AND LIGHT ATTENUATOR CALIBRATIONS

It was necessary that the light sources and attenuators used in the various tests be calibrated in order that the magnitude of the light intensity on the mosaic could be known. The light system shown in Drwg. A-30250 and described in Chapter V was under the same conditions of focus for all tests; and, in the calibration procedure, the loss in the lens system was not measured since it was a fixed quantity.

1. Projection Lamp Calibration:

The projection lamp and lens system was first calibrated by direct measurement to provide a value of illumination on a surface the same distance from the iconoscope lens as the mosaic was in the tests made. The photocell unit of a Weston 603 Illumination meter was placed on this surface corresponding to the position of the mosaic, and the intensity at this point was read with the polaroid attenuators in the uncrossed position. In this and all other tests made using the incandescent projection lamp, the lamp voltage was adjusted to its rated value of 115 volts to insure that the spectral distribution of the light was constant. The effective light output, on the surface described above, was measured to be 470 foot candles.

2. Polaroid Attenuator Calibration:

The polaroid attenuator was calibrated by rotating one of the lenses and reading the illumination meter. The plot of Fig. 48 relates the attenuation factor (defined as the number by which the light intensity with the attenuator lenses in the uncrossed position must be multiplied to give the actual illumination with the lens axes partially crossed) to the angle of lens rotation from the crossed position.

3. Pulsed-Lamp Calibration:

Calibration of the R_{4330} Flash Lamp was a somewhat more difficult problem because this lamp could be operated only under pulsed conditions. The method used involved the photo tube cathode-follower circuit shown in Drwg. A-30292, two of the video amplifier boxes described in Chapter V and shown in Drwg. C-30255*, and a DuMont 256B Oscilloscope.

In the photo tube cathode-follower circuit, the photo tube (a Type 929) operates into the cathode-follower stage arranged to have sufficiently low output impedance so that the capacitance of the cable connecting it to the video amplifier does not seriously affect the pulse shape. The 10-K rheostat allows adjustment of the bias voltage on this stage so that it operates in its linear range. When properly adjusted, the drop across the 101-ohm cable-terminating and cathode-load resistor is 1.05 volts. This corresponds

* This drawing is included in Appendix C.

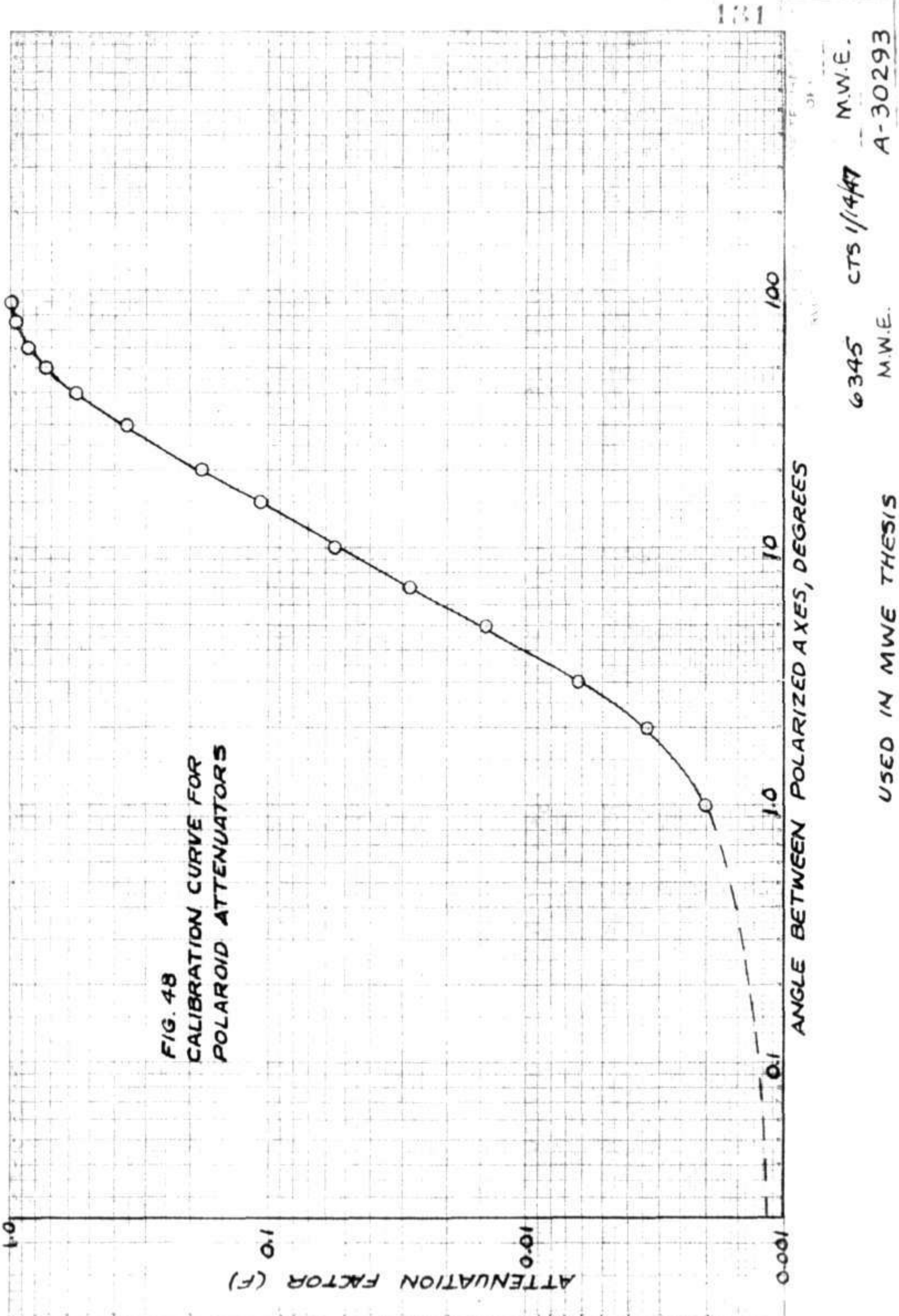
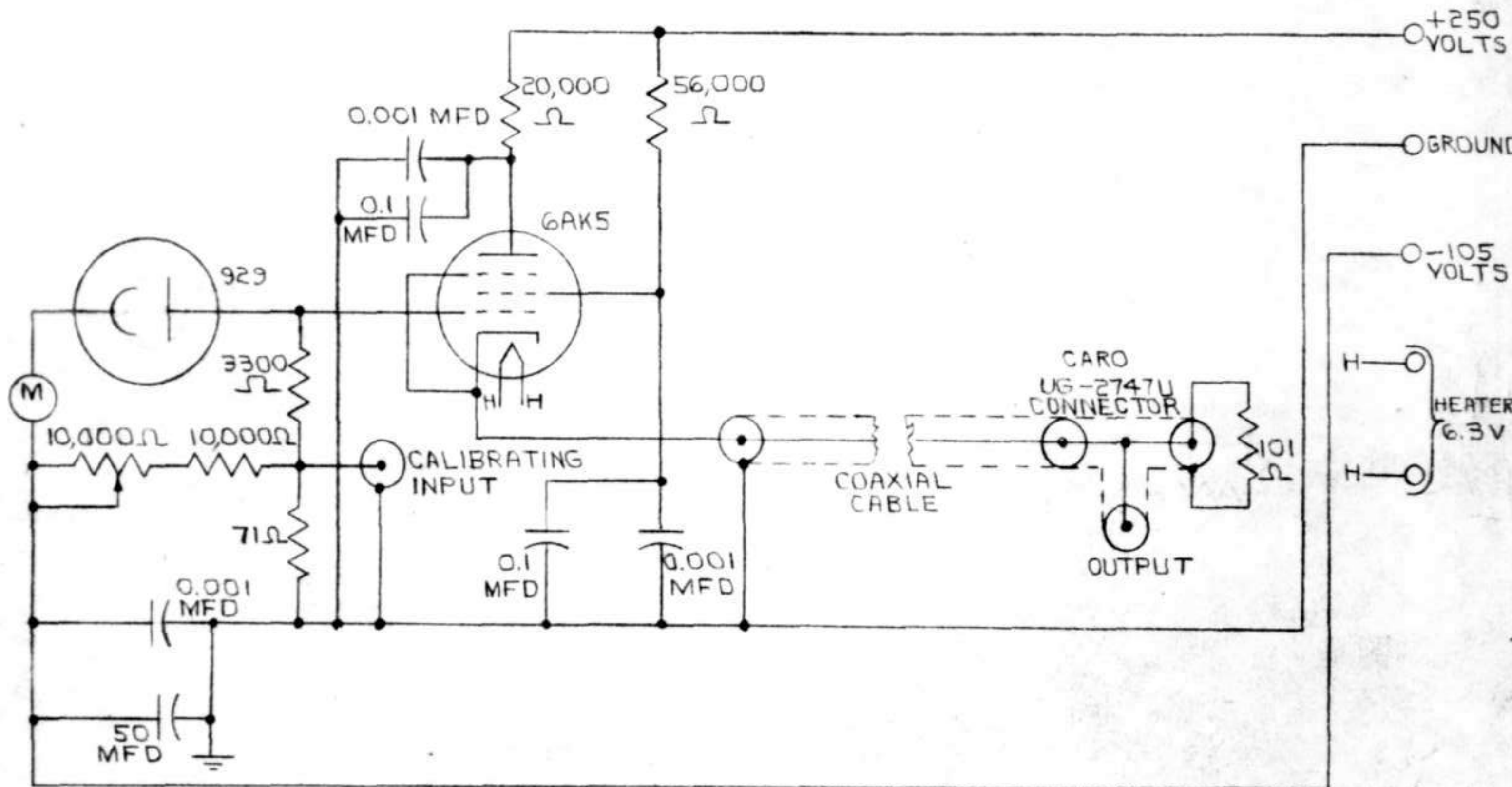


FIG. 48
CALIBRATION CURVE FOR
POLAROID ATTENUATORS

to a tube current of approximately 10 milliamperes.

The cathode of the phototube was located the same distance from the iconoscope lens as the mosaic is in the actual test set-up. The output of the cathode follower was connected to the input of the first of two of the video-amplifier units mentioned above, and the output of the second of these amplifiers was connected to the VIDEO INPUT Jack of DuMont 256B oscilloscope. The gain of the complete amplifier system was obtained by feeding the output of an LP-5 signal generator set to 50 kcps into the calibrating input jack of the photo tube unit. The input voltage required for an oscilloscope beam deflection of 0.6 inches peak-to-peak was measured as 0.05 volts rms. These data give a value of $\frac{0.6}{0.5 \times 2 \times \sqrt{2}} = 4.25$ for the system sensitivity in inches deflection at the oscilloscope screen per volt applied between grid and ground of the cathode-follower tube.

The phototube cathode was then illuminated with steady light of variable intensity as provided by the projection lamp and polaroid attenuator. Readings were taken of phototube current (read on a 50-microampere instrument in series with it) as a function of light intensity. The resulting current readings were multiplied by 3.61K - the measured resistance from the phototube anode to ground - to obtain the voltage at the input to the cathode follower.



PHOTOTUBE AND CATHODE-FOLLOWER CIRCUIT.

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When this voltage is multiplied by the video-amplifier sensitivity of 4.25 inches/volt, sufficient data has been obtained to plot the curve of Fig. 49 relating inches of deflection at the oscilloscope screen and light intensity at the phototube cathode. This curve is reasonably linear and has a slope of 376 foot candles/inch.

The projection lamp was replaced by the R4330 flash lamp. This lamp was pulsed at various voltages and the resulting waveforms recorded. Two of these waveforms are shown in Fig. 51 properly aligned in time with the lamp-current pulse of Fig. 50. Using the data given on this figure, the peak light intensity falling on the phototube cathode when the lamp is pulsed at 3.0 kv is $0.4 \times 376 \times \frac{1}{0.11} = 1370$ foot candles. The corresponding value at 3.5 kv is $0.7 \times 376 \times \frac{1}{0.36} \times 3 = 2190$ foot candles. These are the two values of applied voltage used in the tests. The loss in the polaroid attenuator with the lenses in the uncrossed position was measured to be 79%. The peak intensity at the mosaic when the attenuators are not used is, therefore, $\frac{1370}{0.21} = 6510$ foot candles for a lamp voltage of 3.0 kv, and $\frac{2190}{0.21} = 10,400$ candles for a lamp voltage of 3.5 kv.

It is noted from Fig. 48 that considerable light is passed with the polaroid lenses in the crossed-axes position. For tests involving very low light intensities this leakage may be more than the maximum light used. To

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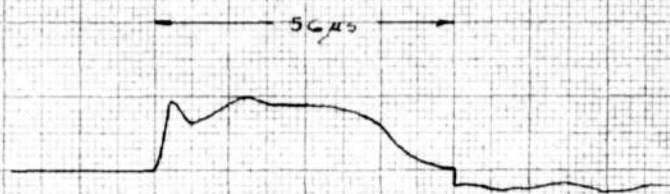

FIG. 50 LAMP - CURRENT PULSE

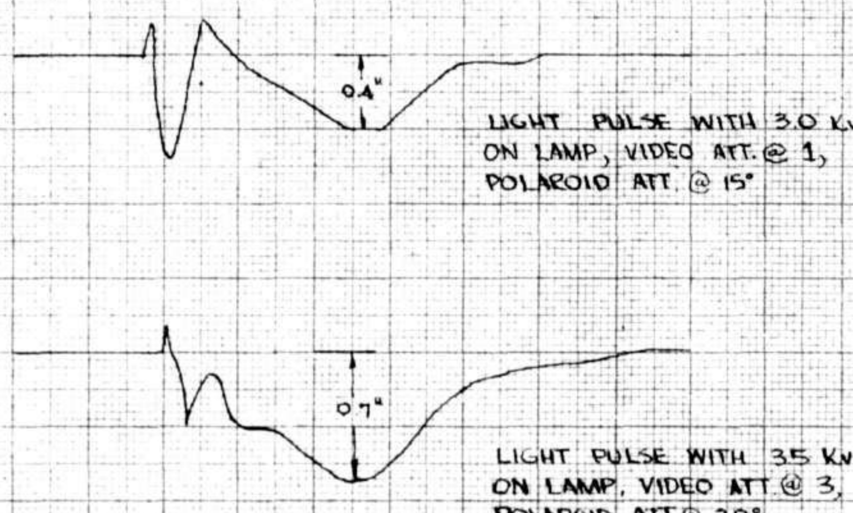

FIG 51 R4330 PULSED LAMP CALIBRATION DATA

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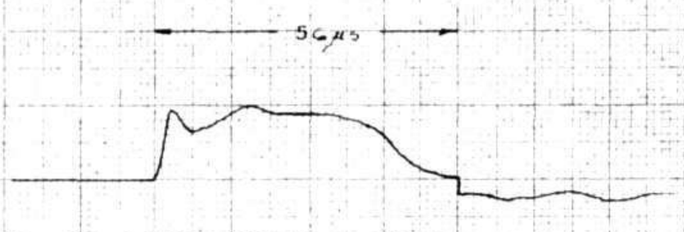

FIG. 50 LAMP CURRENT PULSE

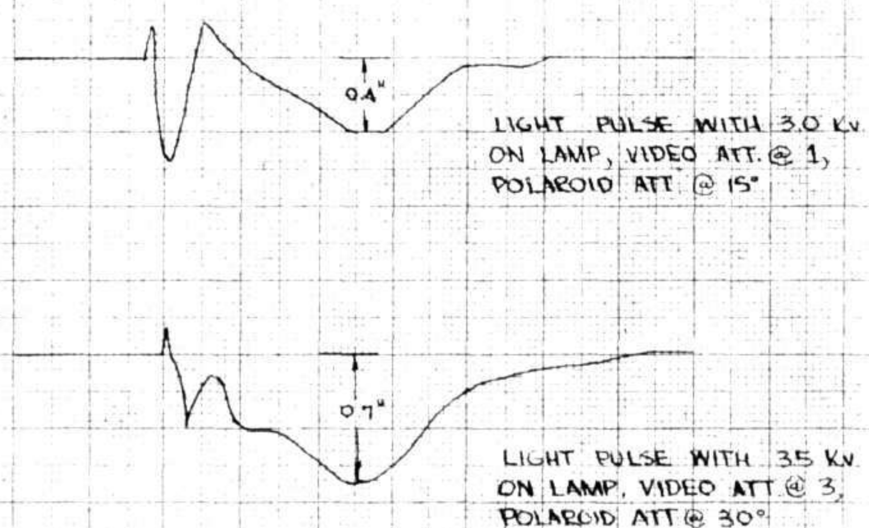

FIG 51 R4330 PULSED LAMP CALIBRATION DATA

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allow lower intensities to be obtained without reducing the lamp voltage - undesirable because the spectral distribution of the light output changes with voltage - a series of neutral filters were made from photographic film. This film was exposed to a cloudy sky in accordance with the schedule given in Table I. It is believed that this is the best readily available method of reducing all frequency components of the light by the same amount. The attenuation factors were measured by a substitution method in the set-up used to obtain the data for Fig. 49. Attenuation factors for the various films are given in Table I.

Table I - Data on Film Attenuators

Number	Exp. Time (Secs.)	Att. Factor
12	3	0.002
9	1/5	0.0104
8	1/10	0.142
7	1/20	0.194
6	1/40	0.222
5	1/70	0.668
4	1/150	0.424
3	1/240	0.571
2	1/1000	0.678

Camera - Speed Graphlex

Lens opening - f/3.2

Film - Super XX

Developed for 6 mins in D-11 Developer

Fixed for 15 mins

APPENDIX B

PULSED-LIGHT TECHNIQUES

1. Lamps Available as Pulsed-Light Sources

Four lamps* were available and used in investigating the response of the iconoscope to pulsed light. These were the Sylvania Types R_{1130B}, R_{1131}, R_{4330} and the SN4 strobotron. The R_{1130B} and R_{1131} are tubes designed to operate at low anode voltages, and the light produced results from a glow discharge located near the cathode. The R_{4330} is a cold-cathode constricted-arc lamp capable of considerable peak light output. The strobotron can be operated under either glow or arc conditions, and its light output falls between those of the R_{1131} and constricted-arc types.

The light intensities available from any of the tubes operating under conditions of glow discharge were not sufficient to provide a response from the mosaic. When the R_{1130B}, R_{1131} and Strobotron tubes were operated in the arc regions of anode voltage, a slight indication of the presence of light was given. In all cases, however, the size of the source was such that, with the projection system used, the area illuminated was very small. Since continued operation of the R_{1130B} and the R_{1131} tubes under arc conditions would have damaged them, these tests were not continued.

The R_{4330} Flash Tube gave sufficient light to allow

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*Photographs of these lamps are shown in Fig. 25 of Chapter V.

study of the response of the iconoscope at low repetition rates. The size of the source was sufficiently large so that the whole mosaic could be illuminated. Manufacturer's data for these different types of tubes follow:

For the R_{1130B} Tube:

Crater diameter - 0.050"

Operating voltage - 140v (max)

Operating current - 5 to 35 ma

Starting voltage - 225v (max)

Useful light range - 3500 to 6500 Angstroms

Modulation frequency range - 15 to 15,000 cps.

This tube has a relative light output that is practically in direct proportion to the tube current.

For the R_{1131} Tube:

The characteristics of this tube are similar to those given above for the R_{1130B} with the notable exception that the crater diameter is 0.093 inches.

For the R_{4330} Tube:

Forward anode voltage - 2000 volts min to 2250 volts max

Typical operating voltage - 2250 volts

Flashing rate - 6 flashes/minute

Discharge energy - 100 watt seconds max per flash

Trigger voltage - 15,000 volts min

Color of discharge - Blue-white

Light output (peak lumens) - 12,000,000 lumens

For the SN-4 Strobotron Tube:

Anode voltage - 300 volts max

Average cathode current - 50 ma max

Peak cathode current - 5 amps min

Cathode starting voltage - 80 to 125 volts

Control grid (grid No.1) voltage - 50 to +50 volts

Shield grid (grid No.2) voltage - -50 to +50 volts

Pulse frequency - 60 cps max

Tube voltage drop

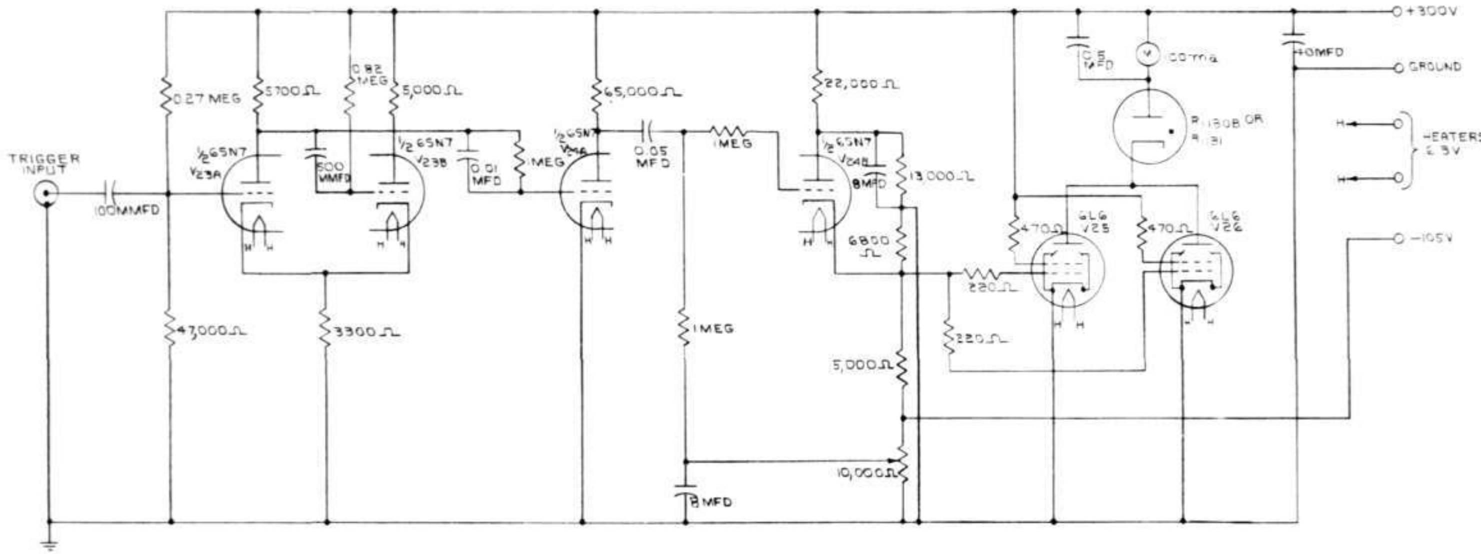
Glow discharge - 75 volts (approx)

Arc discharge - 20 volts (approx)

2. Modulation Sources for Pulsed Lamps:

Drawing C-30274 shows the modulator circuit used with the R_{1130B} and R_{1131} Glow Tubes. A positive pulse applied to the grid of V_{23A} triggers the multivibrator comprising tubes V_{23A} and V_{23B}. This multivibrator generates a negative gate of the same time duration of the desired light pulse. This gate is inverted and amplified by V_{24A}. The resulting positive rectangular pulse is applied through the cathode-follower stage V_{24B}, to the lamp modulator tubes V_{25} and V_{26}.

The method described above of obtaining the pulse current from ordinary amplifier tubes, such as Type 6L6's, is not applicable in the case of the arc lamps. This is because the high pulse currents - of the order of 50 or 100 amperes - cannot be obtained from the cathode emission



MODULATOR CIRCUIT FOR GLOW TUBES

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of these tubes. In such cases it is necessary to use modulators containing storage elements. Radar modulators are of this type. Unfortunately, however, radar applications involve duty cycles of the order of 0.1 per cent, and the design problems arising are very much simpler under these conditions than in the computer application where the duty cycle may approach 90 per cent.

There is no apparent solution seen to the problem where the light must be on for the full time of one sweep (60 microseconds), then be extinguished, but be ready for reflashing within as short a period as 5 microseconds. A possible method of solving the general problem is, however, to use an intense light for as short a period as possible, probably not more than 5 microseconds, and rely upon the memory of the mosaic to retain enough of the impression received during this time to provide a readable signal. A modulator circuit that might be made to work under the still stringent, but relaxed, conditions of this relatively high duty cycle is shown in Fig. 52.

The pulse-forming network is the storage element in this circuit. It is charged during the period between flashes to the voltage required by the lamp. The charging diode is included to complete the charging path since the lamp is not conducting during this interval. The lamp is made to conduct at the proper time by simultaneously

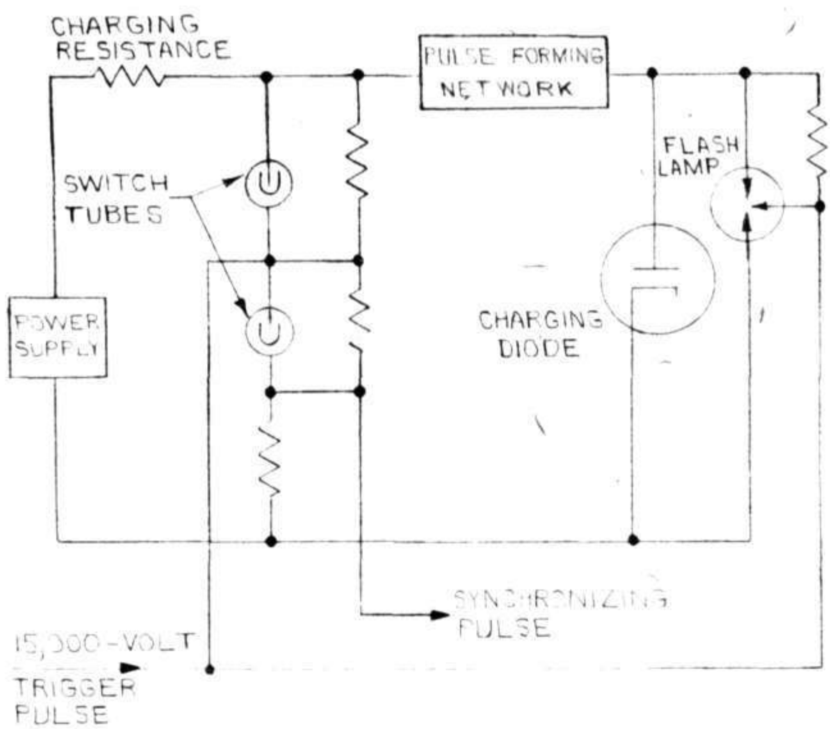

FIGURE 52. LINE-PULSING TYPE OF LAMP MODULATOR

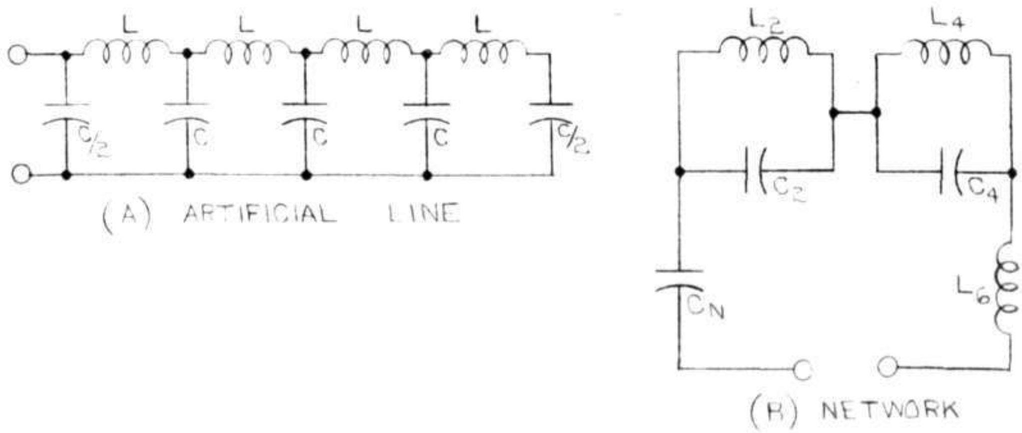

FIGURE 53. TWO FORMS OF PULSE-FORMING NETWORKS USABLE IN A LINE-PULSING TYPE OF LAMP MODULATOR

triggering both the switch-tube circuit and the ionizing electrode of the lamp. The network then delivers the charge accumulated upon it to the lamp, causing it to emit light. The polarity with which the diode is connected into the circuit prevents it from conducting while the lamp is on.

The pulse-forming network may have one of many configurations, two of which are shown in Fig. 53. The elements L and C included in the artificial line of Fig. 53a are, for optimum design, related to the pulse width desired and the given lamp resistance, by the equations*

$$L = \frac{\delta Z_L}{2N} \qquad (1)$$

and $$C = \frac{\delta}{2NZ_L} \qquad (2)$$

where   is the pulse width in seconds,

Z_L is the lamp resistance, and

N is the number of sections in the line.

Figure 53B illustrates a network that is more economical to use - from the standpoint of materials - than the artificial line described above. This network requires fewer circuit elements than the corresponding artificial line for the same quality of pulse shape. As given by Guillemin**, the sizes of the elements can be

* See Reference 11.
**See Reference 12.

calculated by means of the relationships

$$C_N = 0.415 \frac{\delta}{Z_L} \qquad L_6 = 0.1402\,\delta Z_L$$

$$C_2 = 0.232 \frac{\delta}{Z_L} \qquad L_2 = 0.0768\,\delta Z_L \qquad (3)$$

$$C_4 = 0.382 \frac{\delta}{Z_L} \qquad L_4 = 0.118\,\delta Z_L$$

There are many complications which arise in the design of this type of modulator for the pulsed-light application. One of the assumptions upon which the relationships given by equations (1) to (3) are based is that the characteristic impedance of the network must be equal to the resistance of load. Where the load is a lamp, its resistance is a function of the length of time the lamp has been conducting. This resistance is high at the start of the flash but decreases rapidly.

The switch tubes must be capable of practically instantaneous switching. This is not true of those types used in radar. A high-speed high-voltage trigger source is required capable of generating rise times of the order of 15,000 volts per microsecond. The charging resistance must be very low to allow fast charging of the network. Fast charging also involves the use of a high-powered high-voltage supply.

3. Light Valves:

An alternative to pulsing the lamp is to control the light beam by some type of light valve such as the Kerr Cell.

In its simplest form, the Kerr Cell consists of two parallel plates emersed in an organic liquid having the characteristic of losing its isotropic optical properties when subjected to an electric field. Examples of satisfactory liquids are carbon disulfide, chloroform, nitrobenzene, and acetone.

A voltage source is connected across the plates and a beam of polarized light is passed between the plates. As a result of the action of the electric field, the plane of polarization of the light emerging from the plates is different from that with which it entered. The amount by which the beam is rotated is given by the equation*

$$\phi = 2\pi B \ell E^2 \text{ radians} \qquad (4)$$

In this equation, B is the Kerr Constant of the liquid in esu, ℓ is the length of the light path in centimeters, and E is the field strength in the liquid in abvolts/cm.

A typical arrangement for pulsing a beam of light is shown in Fig. 54. The polaroid lenses are adjusted to the crossed-axis position, so that with no liquid in the cell the emerging light is a minimum. The function of the liquid is then to rotate the beam, polarized by lens A, so that it can pass through lens B. The amount of light emerging from the system is thus a function of the voltage impressed across the cell. The form of this function is such that as the voltage is continually increased, the intensity of the

*See Reference 4, pp 245-251

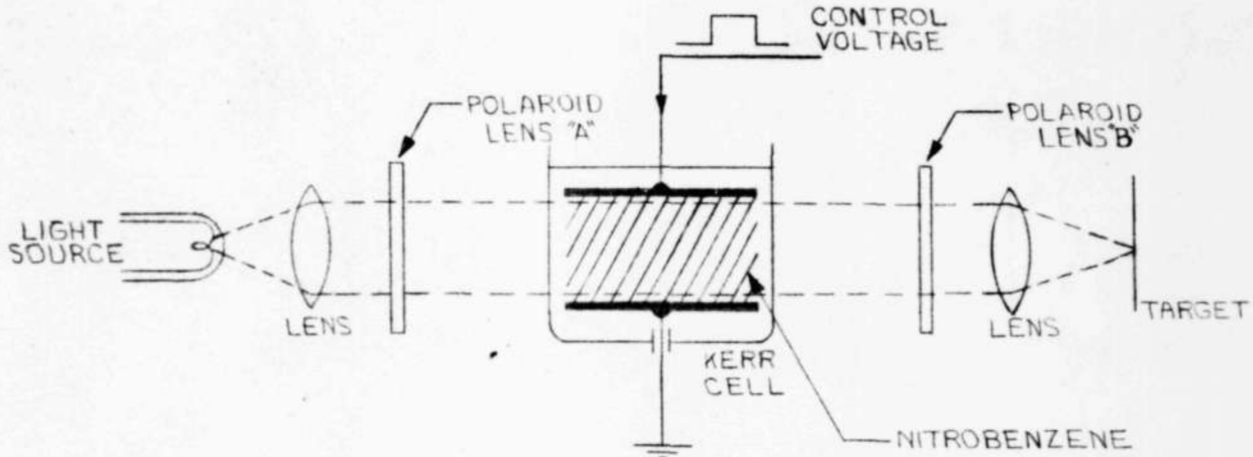

FIGURE 54. METHOD OF USING KERR CELL FOR PULSING A BEAM OF LIGHT.

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emerging light alternates between maximum and minimum values. The first maximum, as derived by Zworykin and Morton, occurs at a voltage given by the equation

$$V_{max} = d\sqrt{\frac{1}{2B\lambda}} \text{ volts} \qquad (5)$$

In this equation d is the spacing between the plates, in centimeters, and the other factors are as defined for eq.4.

There are several disadvantages to this method of pulsing the light beam. Considerable capacitance must be charged by the signal source, and the response of the output is hence limited to slow rise times. The amount of polarization is considerably dependent upon temperature. The spacing required for a usable rotation by a reasonable voltage is small.

This last-named disadvantage can be illustrated by considering the design of a Kerr Cell to be operated at 2000 volts. Assuming the plate lengths to be limited to 5 centimeters, and the liquid to be nitrobenzene, the Kerr constant of which is 41.0×10^{-6}, the spacing as given by eq. 5 is

$$d = V_{max}\sqrt{2B\lambda} = \frac{2000}{300}\sqrt{2 \times 41 \times 10^{-6} \times 5} = 1.35 \text{ mm.}$$

This is an unreasonably small spacing to be conveniently used in the application considered. Variations of this basic method involve stacking cells of this type to increase the cross-sectional area presented to the light.

These variations, however, also tend to increase the capacitance of the cell, and complicate the driving problem.

4. Cathode-Ray Tubes as Light Sources:

Another type of pulsed-light source considered, but not investigated by experiment, is the cathode-ray tube operated with its beam defocused and at several times rated anode voltage. Unpublished findings of others indicate that tubes having either P_5 or P_{11} screens, when operated at voltages between 5 and 50 kv, can be pulsed at the repetition rates and duty cycles required by the computer problem. While no quantitative information concerning the light output of such devices is available, it is not probable that this is sufficient to excite the mosaic of the iconoscope.

APPENDIX C

VIDEO AMPLIFIER REQUIREMENTS AND RESPONSE CURVES

The equivalent circuit for the iconoscope and its connected load impedance is shown in Fig. 19 of Chapter II. In this figure, R_b and C_m are the a-c resistance and capacitance, respectively, appearing at the output of the tube. These equivalent elements are in series with the voltage E_m generated at the mosaic surface. R_L is the load resistance that must be used with the iconoscope in order that a signal voltage be obtained, and C_s is the stray shunting capacitance that exists across the output.

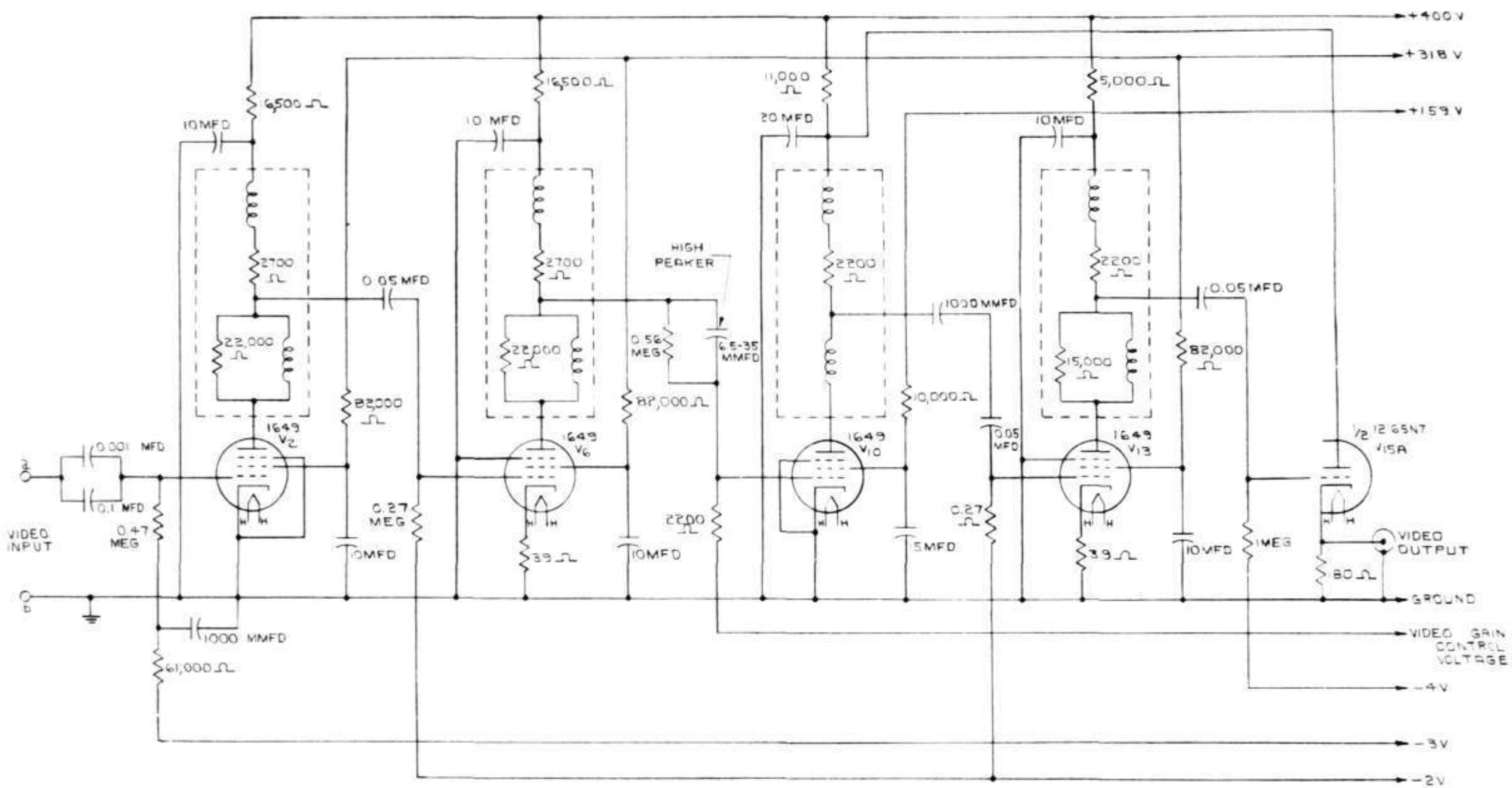
The resistance R_b is both non-linear and a function of frequency. Over the usual operating range, its value is of the order of 10 to 20 megohms*. The magnitude of C_m varies greatly with frequency. For slow changes, or low frequencies, it approaches a value approximating that of the whole mosaic. This is about 1000μμf for the Type 1846 iconoscope. For fast changes, or high frequencies, the limiting value is that of the capacitance of an area on the mosaic equal to the beam cross section, or about 0.1μμf. The equivalent voltage E_m is a function of frequency, light intensity, beam current, and any sources of free electrons within the tube.

The components R_L and C_s form an integrating

*See Reference 3.

network. They thus effect the high-frequency response of the iconoscope circuit by reducing the output voltage and introducing a lag in the response. Since C_s is fixed by the circuit, any improvement in high frequency response must be obtained by reducing the size of R_L . While values of R_L down to 10,000 ohms have to be used in television, common practice uses a larger value to take advantage of the improved signal-to-noise ratio. The resistance used in the experimental equipment was approximately 250,000 ohms and the estimated shunting capacitance C_s was 40$\mu\mu$f. This circuit has a phase shift of 45° at a frequency given by $\frac{1}{2\pi \times 0.25 \times 10^6 \times 40 \times 10^{-12}}$ or approximately 16,000 cps. At a frequency of 160,000 cps the reactance of C_s becomes so small that the resistance R_L need not be considered. For this and higher frequencies, the output circuit becomes a capacitance type of voltage divider.

In order to compensate for the poor high-frequency characteristic of the iconoscope, the response of one of the two video-amplifier systems used was adjusted, in its design, to provide a gain that consistently increases with an increase in frequency. The circuit of this amplifier, as shown in Drwg. C-30254 is a modification of that used in the ARK Conversion Unit. The coupling circuits between various stages form filters of the constant-K type. Their purpose is to



NOTE: PLATE, SCREEN, HEATER, AND BIAS-VOLTAGE SOURCES ARE SHOWN ON DRAWING B-30249

MODIFIED ARK VIDEO AMPLIFIER

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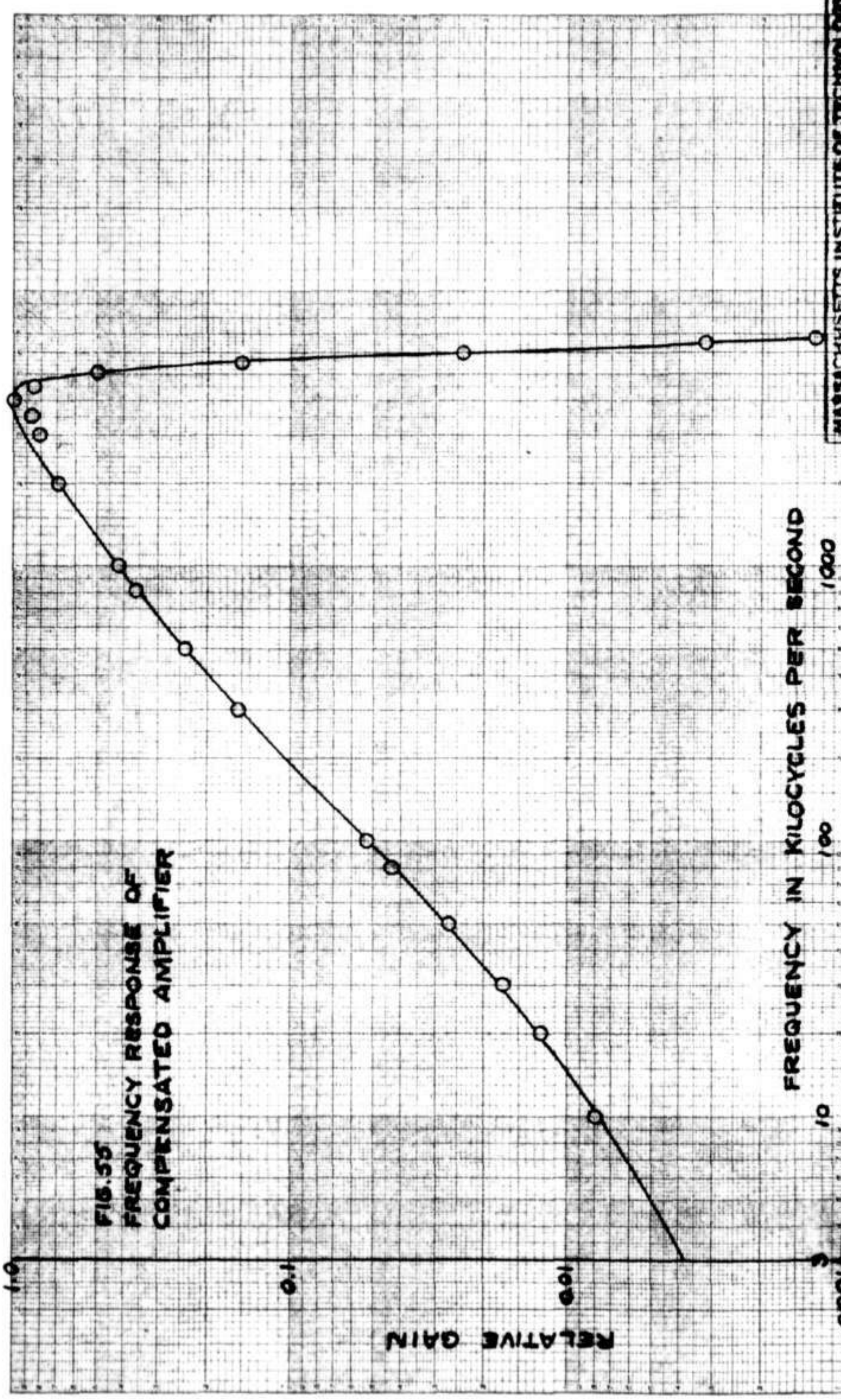
provide relatively constant gain at frequencies up to 1 Mcps and a rising response from this value up to about 4 Mcps. A peaking circuit is included between the second and third stages. Its constants are such that the low-frequency gain is reduced by a factor of about 250 to 1, and its purpose is to provide the compensation made necessary by the poor high-frequency response of the iconoscope load circuit. The measured frequency response of this amplifier, with the iconoscope disconnected, is shown in Fig. 55. Since this amplifier has a variable gain control, the numerical magnitude of gain is not given.

In the single-spot tests made, the amplifier required was one that had a flat response from low to very high frequencies. This was made necessary by the fact that the over-all response of the iconoscope was desired and C_s and R_L are a necessary part of the device. This amplifier, as has been described in Article 2 (b) of Chapter V, consists of three identical units connected in cascade. Its measured response curve is shown in Fig. 56, and the circuit schematic for one of the three units is shown in Drwg. C-30255.

Signals were observed on the screen of the DuMont 256B Oscilloscope. In all cases the internal amplifier of this piece of equipment was included in the circuit. The measured response of the compensated amplifier does not



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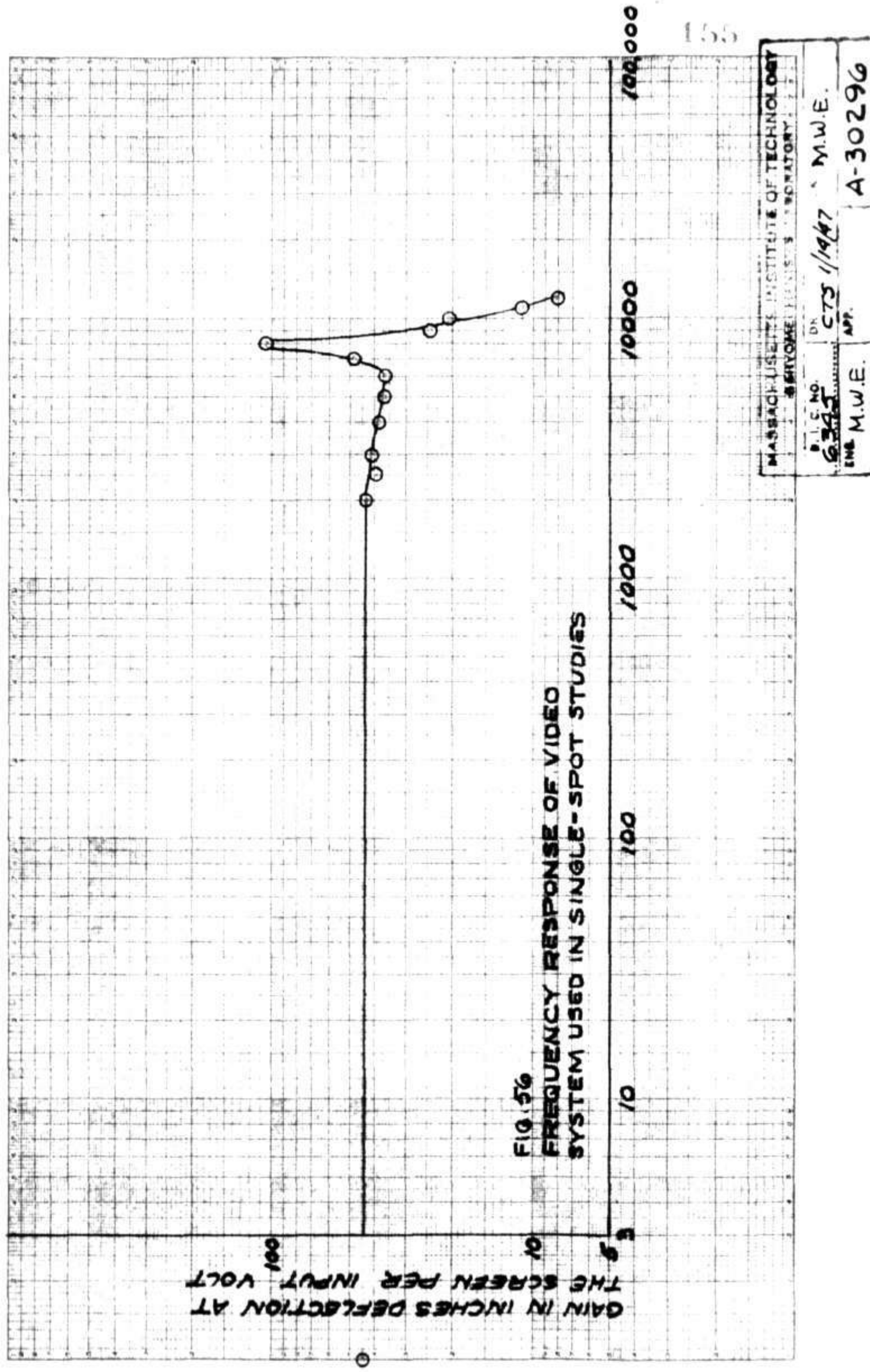

FIG. 56
FREQUENCY RESPONSE OF VIDEO SYSTEM USED IN SINGLE-SPOT STUDIES

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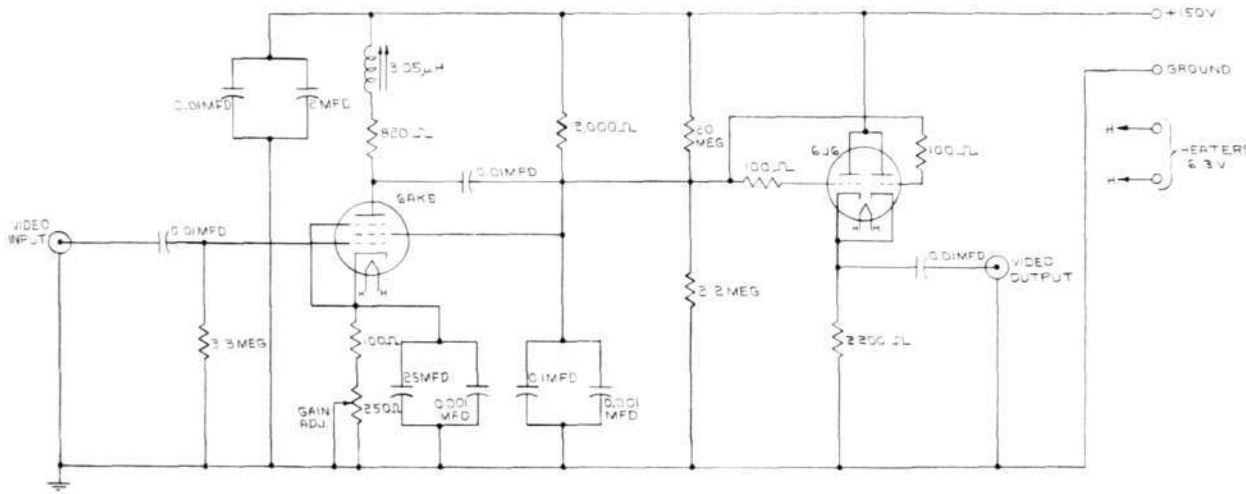

VIDEO AMPLIFIER UNIT

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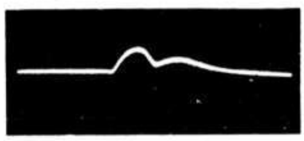
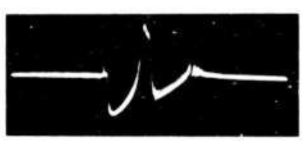
include the response of the oscilloscope amplifier. The measured response of the wide-band amplifier, however, does include the effect of this amplifier and the gain is given in terms of inches deflection at the oscilloscope screen per volt change at the input to the first of these three separate units.

Waveforms of a particular signal as observed on the synchroscope screen are shown in Fig. 57 for the alternate use of the two amplifiers. The effect of the compensated amplifier in increasing the definition of the pulse is clearly indicated. It is to be noted that a polarity reversal takes place in the amplifier system used to obtain Fig. 57a. This reversal must be considered in comparing the two waveforms.



(A) OUTPUT SIGNAL OBTAINED USING THE AMPLIFIER HAVING FLAT RESPONSE



(B) OUTPUT SIGNAL OBTAINED USING THE AMPLIFIER COMPENSATING FOR THE POOR HIGH-FREQUENCY RESPONSE OF THE ICONOSCOPE

FIG. 57 WAVEFORMS FOR COMPARING THE TWO VIDEO-AMPLIFIER SYSTEMS

APPENDIX D

CHARACTERISTICS OF THE TYPE 1846 ICONOSCOPE

1. Electronic Data

The following pertinent data are reproduced from the RCA application sheet for the Type 1846 iconoscope.

Mosaic size ------------------------------ 2 3/16" by 2 7/8"

Heater voltage---------------------------- 6.3 volts

Direct interelectrode capacitances:

Signal electrode to collector ----- 10 $\mu\mu$f (approx)

Grid No. 1 to all other electrodes- 6.5 $\mu\mu$f

Focusing method ---------------------------- Electrostatic

Deflection method -------------------------- Magnetic

Maximum Ratings, absolute values:

Signal electrode voltage -----------1320 (max) volts

Collector voltage -----------------1320 (max) volts

Grid No. 3 voltage ----------------495 (max) volts

Grid No. 2 voltage ----------------1320 (max) volts

Grid No. 1 voltage range ----------0 to -125 (max) volts

Typical Operation:

Signal electrode voltage --------- 1000 volts

Collector voltage ---------------- 1000 volts

Grid No. 3 voltage (focus) -------- 240 to 360 volts

Grid No. 2 voltage ---------------- 1000 volts

Grid No. 1 voltage for cut off ---- 50 volts

Collector current ----------------- 0.15 μa

General:

The RCA - 1846 is similar in size and characteristics to the RCA - 1848 but its spectral response and electrical characteristics are subject to wider variations between tubes.

2. Characteristic Curve

Figure 58 shows the estimated* variation of beam current with grid-to-cathode voltage for the Type 1846 iconoscope.

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* See Art. 2 (a), Chapter V.

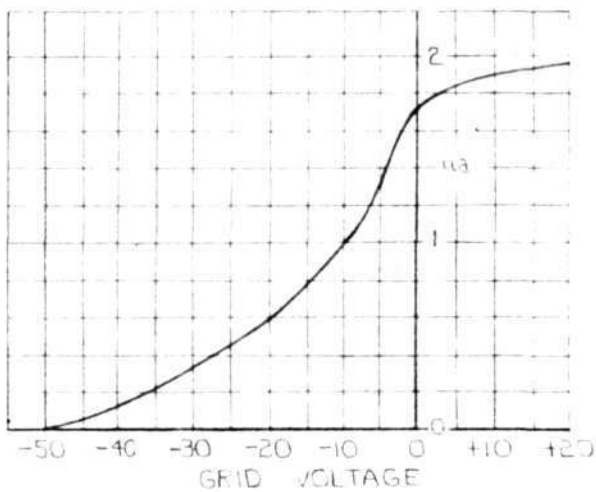

FIGURE 58 ESTIMATED VARIATION OF BEAM CURRENT WITH BIAS VOLTAGE FOR THE TYPE 1846 ICONOSCOPE.

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LIST OF ILLUSTRATIONS

List of Illustrations(Cont'd.)