

Nov. 7, 1950

A. SIMMON
SENSITOMETRIC DEVICE

2,528,977

Filed March 27, 1948

3 Sheets-Sheet 1

Fig: 2

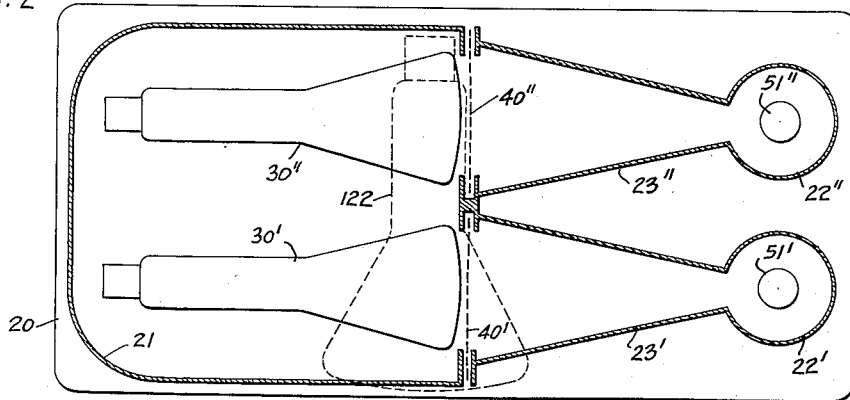
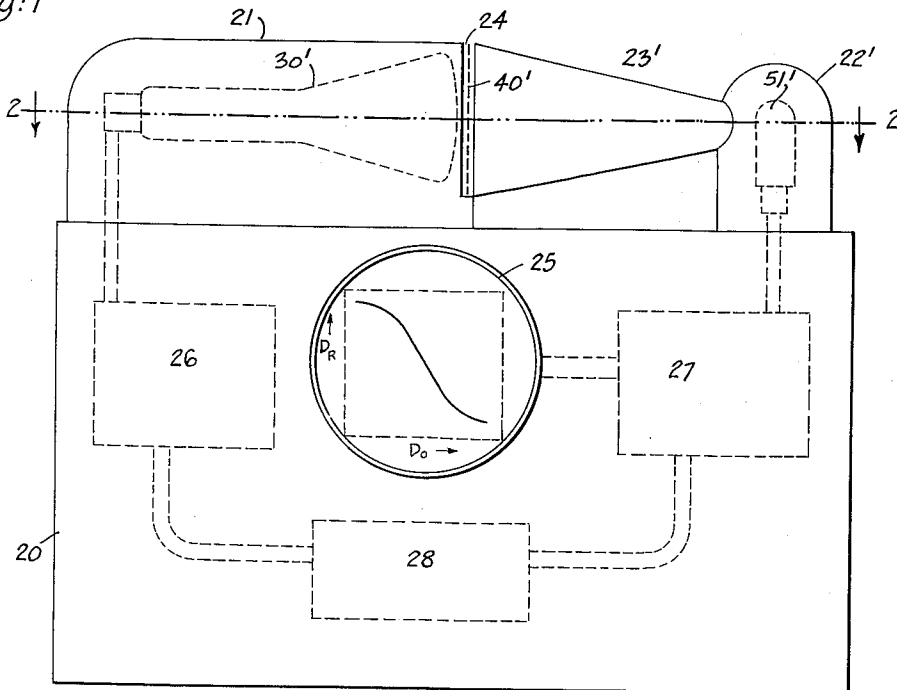


Fig: 1



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3 Sheets-Sheet 2

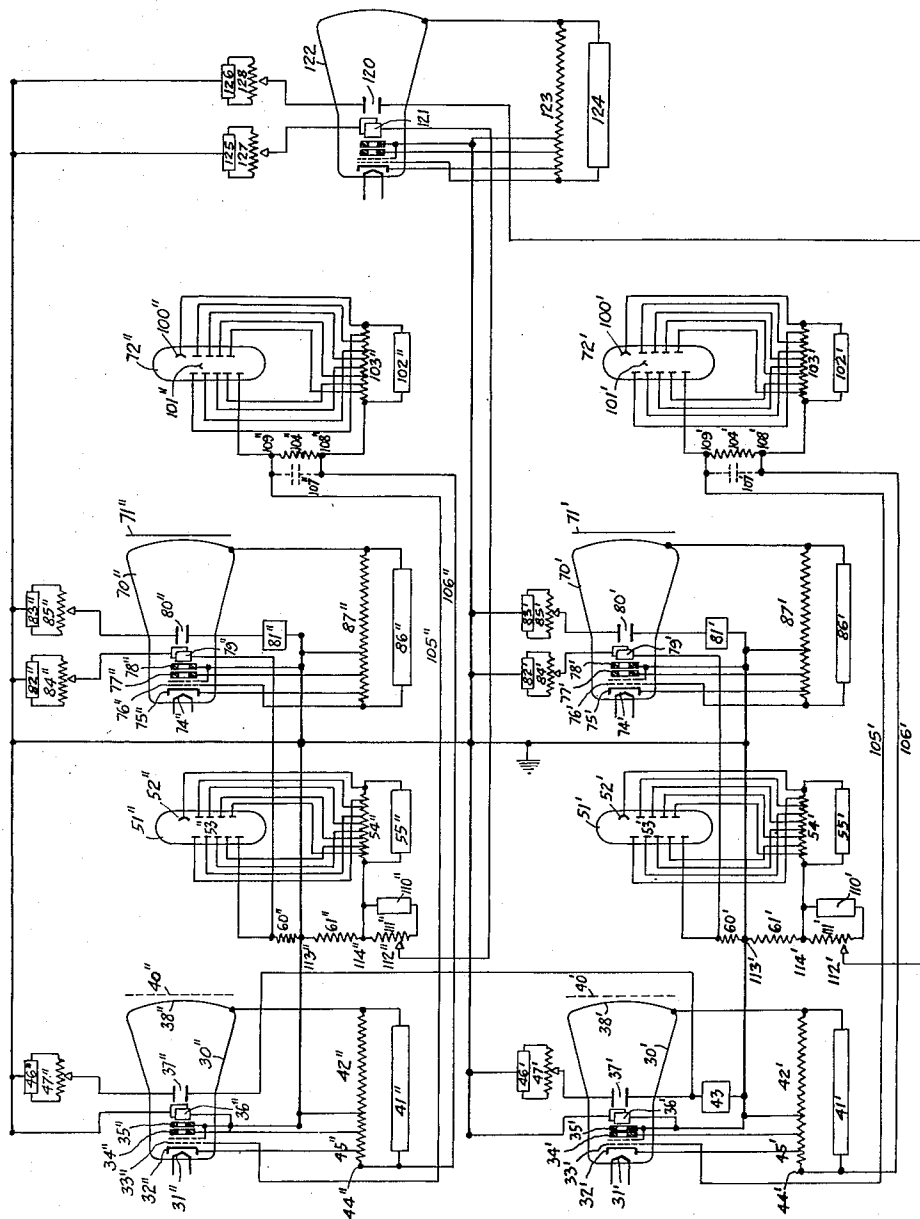


Fig. 3

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3 Sheets-Sheet 3

Fig: 4

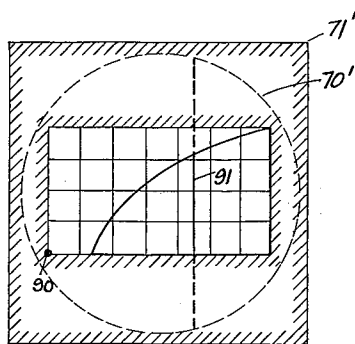
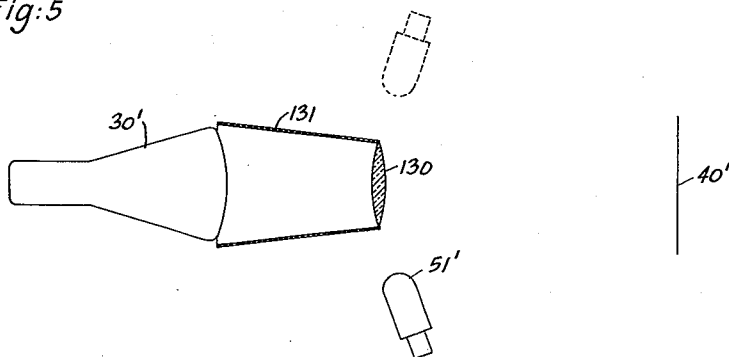


Fig: 5



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UNITED STATES PATENT OFFICE

2,528,977

SENSITOMETRIC DEVICE

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Application March 27, 1948, Serial No. 17,537

2 Claims. (Cl. 88—14)

1

The object of this invention is a sensitometric device or, more specifically, a device which plots automatically the density of points on a photographic reproduction as a function of the density of the corresponding points of an original object.

A preferred embodiment of this invention is illustrated in the accompanying drawings in which

Fig. 1 is a diagrammatic elevational view of the device also indicating the circuit in a more or less schematic form;

Fig. 2 is a horizontal cross-sectional view along the plane of line 2—2 in Fig. 1;

Fig. 3 is a detailed diagram of the electrical circuit;

Fig. 4 is a mask forming part of a modifying circuit by which certain photocell currents are rendered proportional to photographic densities; and

Fig. 5 is a schematic view of a modification of an illuminating device suitable for opaque test specimens.

Like characters of reference denote similar parts throughout the several views and the following specification.

Principle

An original object and a photographic reproduction made therefrom are scanned simultaneously by synchronized pencils of light in such a way that corresponding points of original and reproduction always receive illumination at the same time. Part of the light reflected or transmitted, depending upon whether one deals with opaque or transparent specimens, is made to impinge upon two photoelectric cells. By means of suitable modifying circuits the photocell currents are rendered proportional to photographic densities, and voltages corresponding to these currents are impressed upon the horizontal and vertical deflecting means, respectively, of a cathode ray tube. The curve appearing upon the screen of that cathode ray tube represents then directly the density of each point of the reproduction as a function of the density of the corresponding points of the original. This curve is substantially identical with the so-called H-D curve of the photographic material, differing from that curve only by a constant subtractive factor.

Representation of electrical circuits

In the interest of simplicity, voltage sources have in the following been represented by bat-

2

teries, but it will be understood that in reality these batteries can be readily replaced in the conventional manner by transformers, rectifiers, and condensers. Linear sweep circuits or saw tooth wave voltage generators are also shown only in block form since their detailed construction is well known and forms no part of this invention. Supply circuits for the various filaments for the cathode ray tubes have been omitted. These filaments are, in reality, either fed from small batteries or from filament transformers. All circuits used in this device are extremely sensitive to small voltage fluctuations and, therefore, automatic voltage regulators or stabilizers must be used in order to render all voltages independent of small changes of the line voltage. In the interest of clarity, these stabilizers have not been shown in the diagram of Fig. 3.

Structure

In its preferred embodiment the device comprises a cabinet-like housing 20, Fig. 3, on top of which is mounted a smaller housing 21 containing the two illuminating devices, two containers 22' and 22'' for the two photo-electric cells, and two light collecting elements 23' and 23'' which connect the illuminating devices with the photocell housings. A slot 24 is provided which permits the insertion of both the original and the photographic reproduction. It is preferable to add mechanical adjusting means by which the reproduction and the original can be shifted relative to each other until the two scanning beams of the illuminating device will strike corresponding points at all times. These adjusting means should preferably comprise means to shift either the original or the reproduction in two directions which are at right angles to each other and should also permit a certain amount of rotation. Mechanical adjusting means of this nature are well known and can be found, for example, on microscope stages and machine tools. Since the exact design of these adjusting means has no bearing upon the object of this invention, these mechanical means have not been shown.

The cabinet 20 serves not only as a base for the illuminating means and the photoelectric cells, but also as a housing within which the component parts of the various circuits can be mounted. The most important component part is a cathode ray tube 25 which is so mounted that its screen is visible through a corresponding aperture in the front wall of the cabinet

20. It is on this screen that later the curve appears which represents the function of the reproduction versus the original density.

The other component parts contained in the cabinet 20 are shown schematically since their exact position in this cabinet is unimportant. These component parts can be conveniently classified as the supply circuits 26 for the illuminating means, the supply circuits 27 for the photoelectric cells, and modifying circuits 28 connecting the two. These circuits will be described in detail in a later paragraph.

Original object and photographic reproduction

Both the original object and the reproduction made therefrom may be either opaque or transparent. For the investigation of negative materials, a transparent original is to be preferred since only in this manner can a sufficiently wide range of densities be provided, and the photographic reproduction made upon negative material is, of course, itself transparent. The reproduction may be made from the original in this case by a contact print or the original may be photographed with a camera upon the negative material to be investigated. In the latter case, the original, of course, has to be placed in front of a suitable source of light, i. e., illuminated from behind. An opaque original can be used if the contrast range to be investigated need not be very large and, if the material to be investigated is photographic positive material such as bromide paper, the reproduction will also be opaque. Depending upon whether transparent or opaque reproductions or originals are used, different optical systems for the illuminating means must be provided, as will be explained later. The original object may conveniently be a wedge or a wedge print, but this is not really necessary, and any other object will be satisfactory provided it contains the desired range of densities.

Illuminating and scanning means

The object and its reproduction are respectively illuminated by synchronously moving pencils of light. The light may be provided by any convenient source such as incandescent or carbon arc lamps and, likewise, scanning means of any convenient design are applicable such as, for example, rotating discs with suitable apertures on their periphery, or rotating or otherwise moving mirrors or lenses. In practice I prefer, however, to use cathode ray tubes because in this manner all mechanically moving parts are avoided and because the light output of a cathode ray tube can be most conveniently regulated by changing the voltage impressed upon a control grid. Therefore, illuminating and scanning means comprising two cathode ray tubes have been shown in the drawings, and will be described in the following paragraph.

Since the illuminating and scanning means used for the original and reproduction, respectively, are substantially identical, corresponding parts will be denoted by the same figures to which, in the case of the original, ' , and in the case of the reproduction, ' ' has been affixed. The same practice has been followed in the two following paragraphs describing the two photocells and their supply circuits and the two modifying circuits connected therewith, respectively.

Referring to Figs. 1 and 2, the two cathode ray tubes used as illuminating means are 30' and 30''. Their component elements are shown in

more detail in the diagram in Fig. 3 and comprise filaments 31' and 31'', indirectly heated cathodes 32', 32'', control grids 33', 33'', two focusing elements 34', 34'', 35', 35'' and two pairs of deflection plates 36', 36'' and 37', 37''. In front of the tubes are mounted in the usual manner light emitting fluorescent screens 38' and 38''. The original 40' and the reproduction 40'' are mounted in front of their respective tubes, it being assumed for the time being that both original and reproduction are transparencies. The modification necessary to accommodate opaque specimens will be described later.

The supply circuit for these two tubes is conventional, comprising batteries 41' and 41'', connected, respectively, to potentiometers 42' and 42''. These potentiometers have various taps connected to the elements of the cathode ray tubes in the usual manner as shown in Fig. 3.

For the purposes of this invention, only one set of deflection plates is really needed, and the second set has merely been shown because it is contemplated to use commercially available tubes which are always equipped with two sets. Therefore, the two pairs 36' and 36'' are connected to the ground or are in any other way rendered ineffective. The remaining plates 37' and 37'' are connected to a common sweep circuit 43. Due to this connection, the luminous spots upon the screens 38' and 38'' are driven synchronously by this common sweep circuit 43. The deflection plates 37' and 37'' are connected to additional biasing means which comprise batteries 46', 46'' and potentiometers 47', 47''. The purpose of this arrangement is to make it possible for the operator to adjust the starting point of the sweep circuit.

The control grids 33' and 33'' assume a certain negative potential relative to their respective cathode 32' and 32''. This negative bias consists of two parts, a fixed part which corresponds to the extreme left end of the potentiometer, i. e., to the voltage between points 44' or 45' and 44'' and 45'' and a variable part which is derived from the photoelectric cell through a modifying circuit which will be discussed in detail later.

Photoelectric cells and supply circuits

The two photoelectric cells 50' and 50'' may be of any desired type known in the art, but in practice I prefer the so-called photoelectric multiplier since additional amplifiers are usually unnecessary with this type of tube. Referring to Fig. 3, these cells comprise glass vessels 51' and 51'' within which the photo sensitive cathodes 52' and 52'' and nine additional electrodes 53' and 53'' are mounted. These elements are connected to respective points of the potentiometers 54', 54'' upon which a voltage is impressed by batteries 55', 55'' or equivalent sources of voltage. The cathodes 52', 52'' are connected to the most negative points at the extreme right of the potentiometers, and the last electrodes are connected to the extreme left point of their respective potentiometer so that they receive the most positive potential. The wire connecting the left end of each potentiometer to the last electrode is interrupted and two resistors 60', 60'', 61', 61'' are inserted in this circuit. During operation, voltages, depending upon the resistance values of these resistors and upon the current circulating in the last loop of the photoelectric multiplier circuit, are built up across these resistors.

The distance of the two photocells from their respective transparencies and from the respec-

tive screens of the cathode ray tubes must be sufficiently large so that all points of said transparency have substantially the same distance from said cell.

The light reaching the photoelectric cells from the screen of the cathode ray tubes can be magnified by placing suitably shaped light collecting elements between screen and photocell. These light collecting elements may, for example, be truncated cones or pyramids with an inner reflecting surface, or they may be solid bodies made from glass or transparent plastic in which case the light would be directed toward the photocell by total reflection along the boundaries.

Modifying circuit—general principle

The currents passing photocells 51', 51'' are proportional to the light intensities passing the specimens 40' and 40'', i. e., the reproduction and the original, respectively. Since it is desired to compare densities rather than light intensities, means must be provided to produce currents or corresponding voltages which are proportional to the densities to be measured. This is the purpose of the modifying circuits. Therefore, the modifying circuits may comprise suitable networks which have a non-linear response in such a way that the photocell currents fed into them are proportional to the intensity of the impinging light and that the currents or voltages delivered by these modifying circuits are proportional to the corresponding densities. Many networks with non-linear response are known, comprising non-linear resistors, vacuum tubes or similar elements, but regardless of the detailed designs, such an arrangement would suffer from the very serious disadvantage that the photocell currents themselves would have to be proportional to the light intensities and, if one measures densities up to 3, the light intensities and therefore with the photocell currents will vary in the proportion of 1:1000. It is very inconvenient if not impossible to design circuits which will satisfactorily cover such an exceedingly wide range. I prefer, therefore, to solve the problem in the following manner: The intensity of the light impinging any given point of the two specimens 40' and 40'' is modulated in accordance to the transmitted light intensity. This is done by the photocell current itself and a voltage which is a function of said photocell current is impressed upon the grid of the cathode ray tube, changing its light output. In this manner, the fluctuations of the light impinging upon the photoelectric cells 51' and 51'' are reduced, and it is even possible to modulate the light intensities in such a manner that the resulting photocell currents are now directly proportional to density values. The modifying circuit which accomplishes this function is described in the next paragraph.

Modifying circuits—mathematical basis

The photocell output currents or, more specifically, the voltages impressed upon resistances 60', 60'' are fed into two modifying circuits. The output voltages of these circuits are then impressed upon the grids of the respective cathode ray tubes and used there to modulate the brightness of the luminous spot formed on the screen. It is, therefore, clear that the modifying circuits must deliver output voltages which are definite mathematical functions of their input currents or voltages. This mathematical function will be derived in the following paragraph:

The current passing the cathode ray tube can be expressed within certain limits by the formula

$$I = I_{\max} - ae \quad (1)$$

I is the current passing the cathode ray tube at any given instance, and $I_{\max}$ is the maximum permissible cathode ray tube current. This value may be determined either as the maximum current that the screen of the tube will withstand without deterioration, or it may be the maximum value for which the linear relationship between cathode ray tube current and grid bias still holds true, or it may be determined by any other convenient consideration. Both I and $I_{\max}$ are conveniently expressed in micro amps (μA). e is the additional negative voltage impressed upon the control grids 33' and 33'' which is added to the voltage impressed upon these grids by the left end of potentiometers 42' and 42''. In other words, the left ends of potentiometers 42', 42'' impose a certain constant minimum negative voltage upon the grids at all times and the voltage e which is the output voltage of the modifying circuits will be added thereto. e is expressed in volts. a is a constant which depends upon the characteristics of the individual cathode ray tube and which has a dimension

$$\frac{\mu A}{\text{volts}}$$

The light intensity on screens 38', 38'' i. e., before the light has passed the reproduction or the original object, is again within reasonable limits directly proportional to the cathode ray tube current or

$$L_1 = bI \quad (2)$$

L_1 is expressed in foot candles, or any corresponding metric dimension, and b is a constant again depending upon the characteristic of the cathode ray tube, measured in

$$\frac{\text{foot candles}}{\mu A}$$

The light intensity after the light has passed the transparency, is expressed by

$$L_2 = L_1 \cdot 10^{-D} \quad (3)$$

where D is the density of the reproduction or original at the point which, at any given distance, is illuminated by the luminous spot of the cathode ray tube.

The light intensity in the plane of the photo sensitive cathode of the photoelectric cells 51', 51'' is proportional to L_2 but, of course, considerably smaller, depending upon the distance between the two tubes.

$$L_3 = dL_2 \quad (4)$$

d is a dimensionless constant.

The photocell current is again within wide limits proportional to the light impinging upon the photoelectric cell or

$$i = fL_3 \quad (5)$$

where f is a constant denoting the light sensitivity of the photoelectric cell in

$$\frac{\mu A}{\text{foot candles}}$$

I shall now impose the condition that the modifying circuit shall deliver e as a function of i , i. e., output voltage as a function of input current, in such a way that differences of photocell currents:

shall become directly proportional to density differences of the specimen to be measured, or

$$i_1 - i_2 = h(D_2 - D_1) \quad (6)$$

h is a proportionality factor which has the dimension of a current and which is expressed in μA .

D_1 and D_2 are the photographic densities of two points of the specimen, and i_1 and i_2 are the corresponding photocell currents, i. e., the currents which are measured when the luminous spot of the cathode ray tube is placed, respectively, behind the two points with the two densities D_1 and D_2 .

Equations 1, 2, 3, 4 and 5 can be combined and solved for D with the following result:

$$D = \text{LOG} \left[\frac{bdf}{i} (I_{\max} - ae) \right] \quad (7)$$

For $D = D_1$ there is, of course, $i = i_1$ and $e = e_1$ and likewise for $D = D_2$ there is $i = i_2$ and $e = e_2$. By substituting these values, I arrive at the following expression for $D_2 - D_1$:

$$D_2 - D_1 = \text{LOG} \left(\frac{I_{\max} - ae_2}{i_2} \right) - \text{LOG} \left(\frac{I_{\max} - ae_1}{i_1} \right) \quad (8)$$

$D_2 - D_1$ can also be computed from Equation 6:

$$D_2 - D_1 = \frac{i_1 - i_2}{h} \quad (9)$$

In the two Equations 8 and 9, e_2 becomes zero, and i_2 becomes $i_{\min}$ for $D_2 = \Delta_{\max}$, where $\Delta_{\max}$ is the highest density within the measuring range of the device. $\Delta_{\max}$ usually need not exceed the value 3.

$$\Delta_{\max} - D_1 = \text{LOG} \left(\frac{I_{\max}}{i_{\min}} \right) - \text{LOG} \left(\frac{I_{\max} - ae_1}{i_1} \right) \quad (8a)$$

$$\Delta_{\max} - D_1 = \frac{i_1 - i_{\min}}{h} \quad (9a)$$

These two equations can be combined and solved for e_1 with the following result:

$$e_1 = \frac{I_{\max}}{a} \left(1 - \frac{i_1 \cdot 10^{-\frac{i_1}{h}}}{i_{\min} \cdot 10^{-\frac{i_{\min}}{h}}} \right) \quad (10)$$

This is the mathematical function according to which the modifying circuits have to work, i. e., when the spot of a cathode ray tube passes a point with the density D_1 , a photocell current i_1 will be generated which, by the modifying circuit, will be changed into a voltage e_1 which is then impressed, in addition to a constant negative bias, upon the control grid of the cathode ray tube.

The value $i_{\min}$ which appears in Formula 10 is the minimum current which will pass the photocell when the density of a point illuminated by the cathode ray tube spot becomes $\Delta_{\max}$, which is the maximum density which the device shall be capable of measuring and which rarely, if ever, needs to exceed the value of 3. $i_{\min}$ can be computed from Formulae 1 to 5 by substituting $\Delta_{\max}$ for D and by making a zero, i. e.,

$$i_{\min} = bdf I_{\max} \cdot 10^{-\Delta_{\max}} \quad (11)$$

Modifying circuit—preferred design

The design of the modifying circuit itself is basically of no importance and any circuit which will modify an input current into an output voltage according to Formula 10 will be satisfactory. Circuits of this type are frequently networks using at least one non-linear resistance or imped-

ance element such as one of the so called semi-conductors or a device using a saturated iron core or one of the various types of vacuum tubes. A preferred modifying circuit, however, which is in many respect superior to these networks, has been disclosed in my co-pending application Serial No. 791,439 now Patent No. 2,474,380 and will be described as a preferred example in the following:

A modifying circuit built accordingly consists of three principal parts, cathode ray tubes 70', 70'', stationary masks 71', 71'' and photoelectric cells 72', 72''. It is emphasized that the cathode ray tubes 70', 70'' and the photoelectric cells 72', 72'' are in no way identical with elements 30', 30'' and 51', 51'' which have been described above. They are entirely independent therefrom and perform entirely different functions.

The broad principle of the modifying circuit is that in some suitable manner a luminous line is formed on the screen of the second cathode ray tubes 70', 70'' that the incoming signal, which in this case is the current passing the first photocells 51', 51'' is used to deflect this line in a direction at right angles to itself and that thereby, part of the light emitted by this line is cut off by the stationary masks placed in front of the luminous screen of tubes 70', 70''. The light permitted to pass these masks is then made to impinge upon the second photoelectric cells 72', 72'' forming part of the modifying circuit, but not upon tubes 51', 51''. The current passing these second photoelectric cells 72', 72'' or, more precisely, the corresponding voltage impressed upon a resistor of suitable magnitude, is then supplied as additional bias to the control grids 33', 33'' of the original cathode ray tubes 30', 30'' which scan the specimen in the manner described.

These circuits are shown in detail as the right half of Fig. 3. The cathode ray tubes 70', 70'' contain filaments 74', 74'', cathodes 75', 75'' heated thereby, control grids 76', 76'', two focusing members 77', 77'' and 78', 78'' including second control grids, two pairs of deflection plates 79', 79'' and 80', 80'' and a screen capable of light emittance.

A luminous line can be formed upon this screen by any desired means, for example, by giving the focusing elements 77', 77'' and 78', 78'' a proper configuration. I prefer, however, to use a conventional cathode ray tube which forms a luminous spot upon the screen which is transformed into a line by means of sweeps circuits 81', 81'' operatively connected to the deflection plates 80', 80''. This sweep circuit is a saw tooth wave generator of the customary type which has a high frequency compared to the frequency of the signal impressed upon the other pair of deflection plates. It can be seen that the other set of deflection plates 79', 79'' is operatively connected to resistance elements 60', 60'' upon which a voltage proportional to the current passing the first photocells 51', 51'' is impressed. Both sets of deflection plates 79', 79'' and 80', 80'' are biased by batteries 82', 82'' and 83', 83'' which are connected, respectively, to potentiometers 84', 84'' and 85', 85''. By means of this arrangement, the starting points of the two sweep circuits connected to deflection plates 79', 79'' and 80', 80'' can be adjusted.

The rest of the supply circuit for the second cathode ray tube is conventional. It consists of batteries 86', 86'' and potentiometers 87', 87'', the various points of which are connected to the

elements within the cathode ray tubes in such a way that the control grids 76', 76'' assume a fixed negative potential with respect to the cathodes 75', 75'', but that 77', 77'' have a positive potential with respect to 75', 75'', 78', 78'' a positive potential with respect to 77', 77'', and the screen finally a positive potential with respect to 78', 78''.

In front of the screen, and preferably immediately adjacent thereto are masks 71', 71'' which are again shown in Fig. 4. Each mask has an aperture which directly represents the mathematical function expressed in Formula 10. The mask is a thin plate made of opaque material such as black paper and sheet metal, and its vertical width varies as a function of the horizontal distance from a point of reference 90 in accordance with Formula 10. For convenience, the lower borderline of this aperture is made a straight line, but this is not necessary and both the upper and lower borders may be curved as long as the vertical width of the aperture is the desired function of the horizontal distance from the point of reference 90. It can be seen that only that part of the light emitted by the luminous line 91 which is behind said aperture can pass and that the other parts which are shown in dotted lines above and below this portion are blocked off. The light impinging upon the second photoelectric cells 72', 72'' is, therefore, proportional to the length of that portion of line 91 which appears behind the aperture or is a direct function of the shape of said aperture, in other words, varies in accordance with Formula 10, provided the aperture is fabricated correctly.

The respective distances between photoelectric cells 72', 72'' and cathode ray tubes 70', 70'' must, of course, be large enough so that all points of the luminous line have substantially the same distance from the photo sensitive cathode of the photoelectric cells 72', 72''. These cells may again be of any desired design and I have again shown photoelectric multiplier tubes because then complicated amplifiers can be avoided. Each cell again has photo sensitive cathodes 100', 100'', and nine additional electrodes 101', 101''. The supply circuit comprises batteries 102', 102'', and potentiometers 103', 103'', the various points of which are in the usual manner connected, respectively to elements 100', 100'' and 101', 101''. The wire between the extreme left point of each potentiometer 103', 103'' and the last electrode is again interrupted to receive resistance elements 104', 104''. The voltage impressed upon these resistance elements by the current passing it represents directly the value e_1 used in Formula 10. e_1 is then by means of two wires 105', 105'' and 106', 106'' fed back into the grid control of the first cathode ray tubes 30', 30'', i. e., voltage e_1 is added to the constant negative bias which control grids 33', 33'' have with respect to cathodes 32', 32''.

If the luminous line upon the screen of cathode ray tubes 70', 70'' is formed in the preferred manner by a voltage of high frequency impressed by saw tooth wave generators 81', 81'' upon deflection plates 80', 80'', means must be provided to keep the output current or voltage of the photoelectric cells 72', 72'' from being modulated accordingly. This can be done simply by connecting condensers 107', 107'', shown in dotted lines, of suitable magnitude across points 108', 108'' and 109', 109'', or a more complete filter formed in the usual manner of a network of capacitances and inductances can be connected

to points 108', 108'' and 109', 109''. A filter of this type has not been shown in detail since its design is well known and forms no part of this invention. If, however, the luminous line upon screen of tubes 70', 70'' is formed by other means, for example, by the proper configuration of the focusing elements 77', 77'' and 78', 78'', this filter means can be dispensed with.

Recording cathode ray tube

If the light output of the cathode ray tube which illuminates and scans the original and reproduction, respectively, are modulated by the output voltage of the modifying circuit in the manner described in the previous paragraph, differences of photocell currents are rendered directly proportional to differences of densities or, according to Equation 6

$$i_1 - i_2 = h(D_2 - D_1)$$

Of ultimate interest however, are not density differences but absolute values of densities, and these are obtained from a network which comprises resistors 61', 61'' carrying the photocell current of cells 51', 51'' and which is in series with potentiometers 111', 111'' each of which, in turn, receives a voltage from batteries or other source of voltage 110', 110''. The connection of these batteries must be so chosen that the polarity of potentiometer 111' is opposed to that of the resistors 61', 61'' or, in other words, the voltage between the sliding contacts 112', 112'' of the potentiometers and points 113', 113'' is the difference of the respective voltages impressed upon 111', 111'' and 61', 61''. The function of this network can be explained as follows:

Assuming that the resistance of 61', 61'' is R, and that the voltages corresponding to photocell currents i_1, i_2 are E_1 and E_2 , Equation 6 can be transformed to read:

$$E_1 - E_2 = hR(D_1 - D_2)$$

For $D_1 = 0$, E_1 will become $E_{\max}$, so we have

$$E_{\max} - E_2 = +hRD_2$$

This means that if I impress a voltage equal to $E_{\max}$ between points 112', 112'' and 114', 114'' which is opposed to the voltage impressed upon 61', 61'', that then the voltage between points 113', 113'' and 112', 112'' is directly proportional to the density D_2 of that point which at any given distance is illuminated by the scanning beam of the cathode ray tubes 30', 30''.

If one has transparent test specimens such as presupposed up to this time, the adjustment of the sliding contacts 112', 112'' of potentiometers 111', 111'' is particularly easy because all one has to do is to remove the test specimens 40', 40'' altogether so that one has zero density, and then adjust sliding contacts 112', 112'' until the voltage between points 113', 113'' and 112', 112'' becomes zero.

With an opaque test specimen this adjustment is a little more difficult because even a completely unexposed white piece of paper is not of zero density because it reflects less than 100% of the incident light. However, this reflectivity can be measured by other well known means, and the device can then be adjusted accordingly making proper allowance for the fact that the maximum reflection may be, for example, of the general order of 90%.

Contacts 112', 112'' are connected by wires 115', 115'' to the deflection plates 120', 120'', and 121', 121'' of the recording cathode ray tube 122'.

This cathode ray tube is of conventional design containing, in the usual manner, a glass vessel, a filament, a cathode, focusing members, control grid, and a luminous screen. These elements are connected in the usual manner to taps of a potentiometer 123 fed by a battery 124. Biasing means are provided for the deflection plates comprising batteries 125 and 126 and potentiometers 127 and 128 by means of which the zero points of the vertical and horizontal movements of the luminous spot upon the tube screen can be adjusted.

Operation

The function of the device will be obvious from the foregoing description. The test specimens of 40', 40'' are scanned and illuminated by the moving luminous spot appearing upon the screens of cathode ray tubes 30', 30''. Light transmitted by these test specimens impinges, respectively, upon photoelectric cells 51', 51''. The current passing these photocells as a result of the incident light, is modified by the modifying circuit which in a preferred embodiment of this invention, comprises second cathode ray tubes 70', 70'', and second photoelectric cells 72', 72''. Between the two last named elements, there are masks 71', 71'', and due to the coaction of the three last named parts, i. e., cathode ray tubes 70', 70'', photoelectric tubes 72', 72'' and masks 71', and 71'', a voltage is impressed upon the output resistors 104', 104'' which, when fed back into the control grids 33', 33'' of the two original cathode ray tubes 30', 30'', modulates their light output in such a way that differences of the currents passing the photocells 51', 51'' are rendered directly proportional to density differences of the test specimens 40', 40''. The networks comprising resistors 61', 61'' and potentiometers 111', 111'' convert these differences into voltages which are proportional to absolute density values. These voltages proportional to absolute density values are then impressed simultaneously upon the horizontal and vertical deflection plates 120', 120'', respectively, of the recording cathode ray tube 122. As a result of this arrangement there appears upon the screen of this last named cathode ray tube a luminous curve which is schematically shown in Fig. 1 and which directly represents the density D_r of points of the reproduction as a function of the densities D_o of the corresponding points of the original.

Opaque test specimens

It was pre-supposed up to this point that the test specimens, i. e., the original as well as the reproduction were transparencies. This will be true whenever the properties of films and plates suitable for photographic negatives are investigated. However, the investigation of opaque materials, such as bromide paper, is equally important, and in this case, I have to modify the arrangement slightly in order to adapt it to opaque specimens which will have to be tested with reflected rather than with transmitted light. Such an arrangement is schematically shown in Fig. 5. A lens 130 is placed at a suitable distance in front of the luminescent screen of the cathode ray tube 30' and projects an image of the luminescent spot appearing on the screen of said tube upon the opaque specimen 40' which may be either the original or the reproduction obtained therefrom. Opposite the test specimen 41 at a suitable distance is a photoelectric cell 51' which is adapted to accept part of the light diffusely reflected by 40'. Since unavoidable light losses

are incurred by the projection and reflection, it may be desirable to use more than one photoelectric cell and a second one has been indicated in Fig. 5 in dotted lines. It is important that the photoelectric cells be positioned in such a way that they intercept only diffusely reflected light and not a specularly reflected beam which, in the case of glossy photographic paper, may be of appreciable intensity. This, of course, would falsify the results completely.

It is advisable to place a shield 131 between the cathode ray tube 30' and the lens 130 which prevents light from the luminous screen of the cathode ray tube to reach the photoelectric cells directly.

Instead of the simple lens 130 which has been shown more or less schematically, it is, of course, possible to use more complex optical systems. A particularly efficient system has been developed lately which follows the so-called Schmitt camera and which consists of a light collecting reflector and an aspherical correction plate. Since a system of this type forms no part of the invention, it has not been shown.

Modifications

It has already been pointed out that many component parts of this invention can be changed freely. This has particularly been mentioned with regard to the modifying circuit, but other changes of this nature will occur readily to anybody skilled in the art without departing from the principles or sacrificing any of the advantages of the invention as defined in the appended claims. For example, while all cathode ray tubes have consistently been shown equipped with electrostatic deflection plates, it is also possible to use electromagnetic deflection means.

What I claim as new is:

1. A device for plotting the density of points of a photographic reproduction as a function of the density of the corresponding points of an original object, comprising means to illuminate said reproduction and said original, respectively, by two moving pencils of light, including means to synchronize the movements of said pencils of light whereby corresponding points of reproduction and original are always illuminated simultaneously, two photoelectric cells including electric circuits operatively connected therewith, and including means causing said cells to receive light coming from said two pencils and modified by the respective densities of said reproduction and said original, means to render the output voltages of said photocell circuits proportional to the respective densities of said reproduction and said original, a cathode ray tube including means to form a beam of electrons, first means to deflect said beam of electrons in one direction, second means to deflect said beam in a direction perpendicular to said first named direction, means to accelerate said electrons, and a screen capable of light emittance when struck by electrons, and means to actuate said two deflecting means, respectively, by the output voltages of said two photocell circuits, said means to illuminate said reproduction and said original, respectively, comprising two cathode ray tubes, each including means to form a beam of electrons, means, including a grid, to control the number of said electrons, means to deflect said beam of electrons, means to accelerate said electrons, and a screen capable of light emittance when struck by electrons, and said means to render the output voltages of said photocell currents proportional to

13

the respective densities of the reproduction and of the original, comprising two modifying circuits, each fed by the respective current of one of said photocells, and delivering an output voltage substantially according to the formula

$$e = A \left(1 - \frac{i \cdot 10^{-i}}{C} \right)$$

where

e is the output voltage of one of said circuits, i is the corresponding photocell current, and A , B and C are constants,

and means to impress the two output voltages, respectively, upon the two grids of said cathode ray tubes, whereby the brightness of the two luminous points on the two respective screens is automatically modulated in accordance with the respective densities of the two corresponding points of reproduction and original which are illuminated at any given instance.

2. A device for plotting the density of points of a photographic reproduction as a function of the density of the corresponding points of an original object, comprising means to illuminate said reproduction and said original, respectively, by two moving pencils of light, including means to synchronize the movements of said pencils of light whereby corresponding points of reproduction and original are always illuminated simultaneously, two photoelectric cells including electric circuits operatively connected therewith, and including means causing said cells to receive light coming from said two pencils and modified by the respective densities of said reproduction and said original, means to render the output voltages of said photocell circuits proportional to the respective densities of said reproduction and said original, a cathode ray tube including means to form a beam of electrons, first means to deflect said beam of electrons in one direction, second means to deflect said beam in a direction perpendicular to said first named direction, means to accelerate said electrons, and a screen capable of light emittance when struck by electrons, and means to actuate said two deflecting means, respectively, by the output voltages of said two photocell circuits, said means to illuminate said reproduction and said original, respectively, comprising two cathode ray tubes, each including means to form a beam of electrons, means, including a grid, to control the number of said electrons, means to deflect said beam of electrons, means

14

to accelerate said electrons, and a screen capable of light emittance when struck by electrons, and said means to render the output voltages of said photocell currents proportional to the respective densities of the reproduction and of the original, comprising two modifying circuits, each fed by the respective current of one of said photocells, and each comprising a cathode ray tube, independent of the cathode ray tubes named before, and with a screen capable of light emittance, a supply circuit for said independent cathode ray tube, including means to excite a straight line on said screen to light emittance, means to deflect said line substantially at right angles to itself in accordance with the current passing the photocell connected to this modifying circuit, an apertured mask made from opaque material placed in front of the screen of said cathode ray tube, the width of said aperture in a direction substantially parallel to said light emitting line varying substantially according to the formula

$$Y = D \left(1 - \frac{X \cdot 10^{-\frac{X}{E}}}{F} \right)$$

where

Y is the width of said aperture,

X the distance from a point of reference, in a direction at right angles to said light emitting line, and D , E and F are constants,

a photoelectric cell, independent of the cells named before, placed in front of said mask and connected to a supply circuit, and a resistor adapted to be passed by the current passing said independent photocell, the voltage thereby impressed upon said resistor being used to bias the control grid of one of the first named cathode ray tubes which are used as illuminating means.

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