

July 15, 1969

D. M. NEALE ET AL

3,455,632

METHOD OF CLASSIFYING PHOTOGRAPHIC MATERIAL

Filed Jan. 6, 1966

7 Sheets-Sheet 1

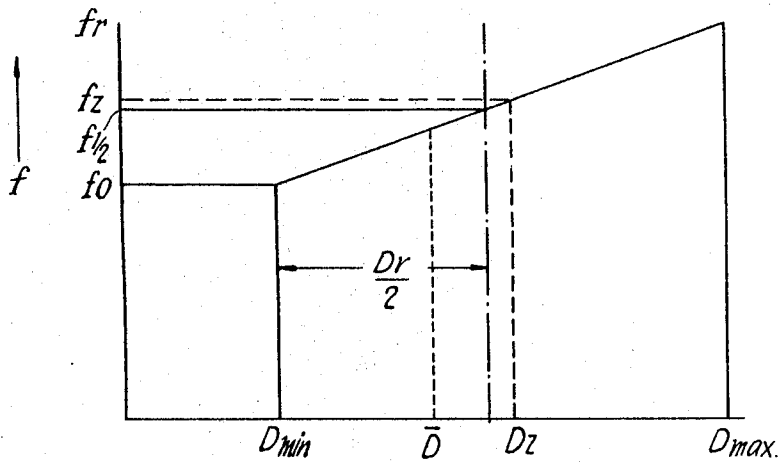


FIG. 1a

Density

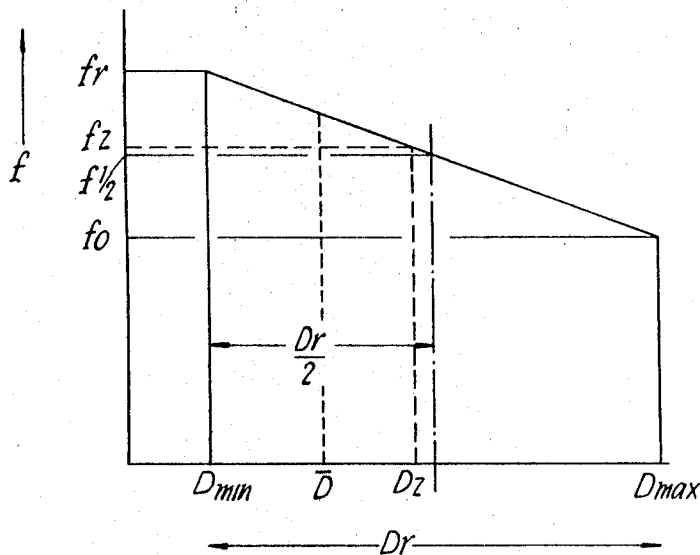


FIG. 1b

Density

Inventors

Denis M. Neale

Leslie J. H. Smith

By Cushman, Darby & Cushman
Attorneys

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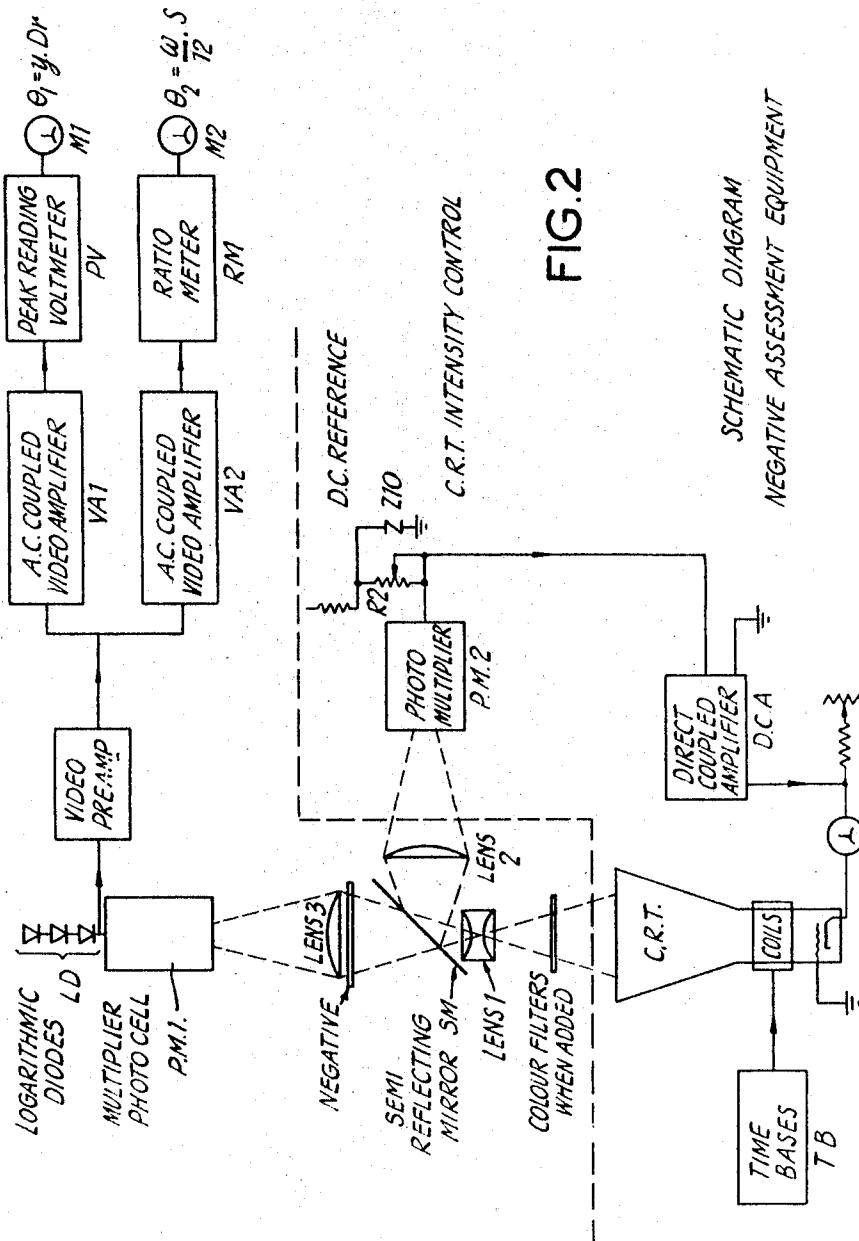
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7 Sheets-Sheet 2



Inventors
 Denis M. Neale
 Leslie J. H. Smith
 By Cushman, Darby & Cushman
 Attorneys

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7 Sheets-Sheet 3

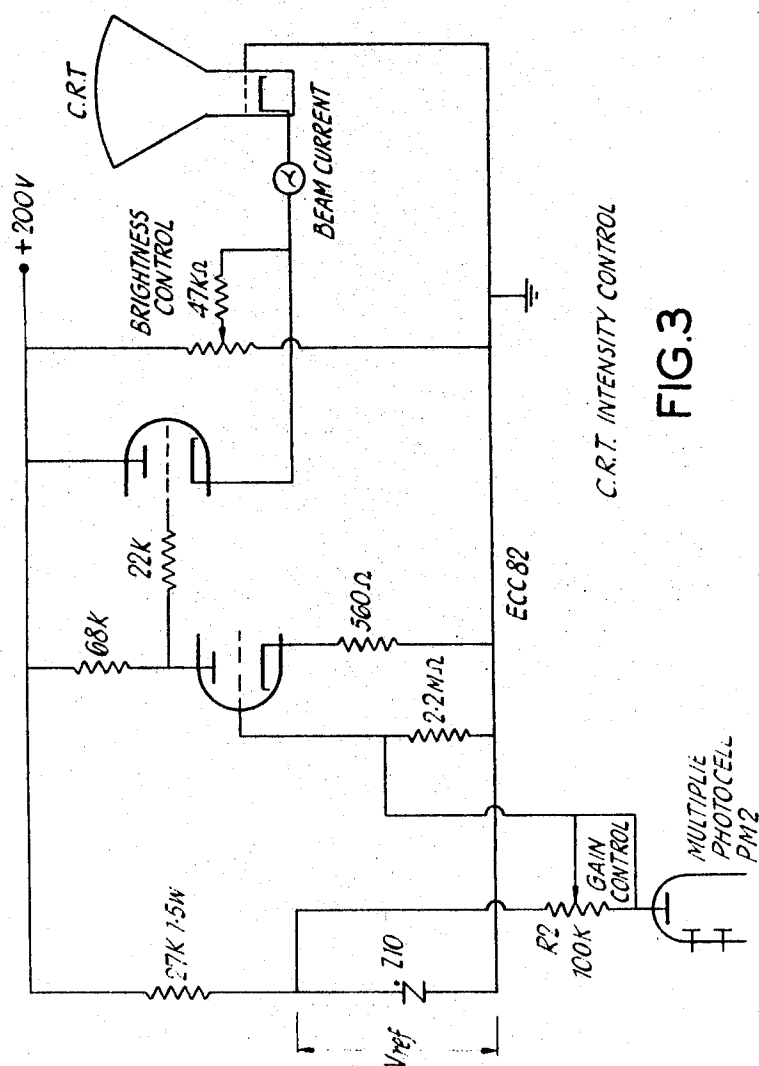


FIG. 3

Inventors
Benia M. Neale
Leddie J. H. Smith
By Cushman, Darby & Cushman
Attorneys

July 15, 1969

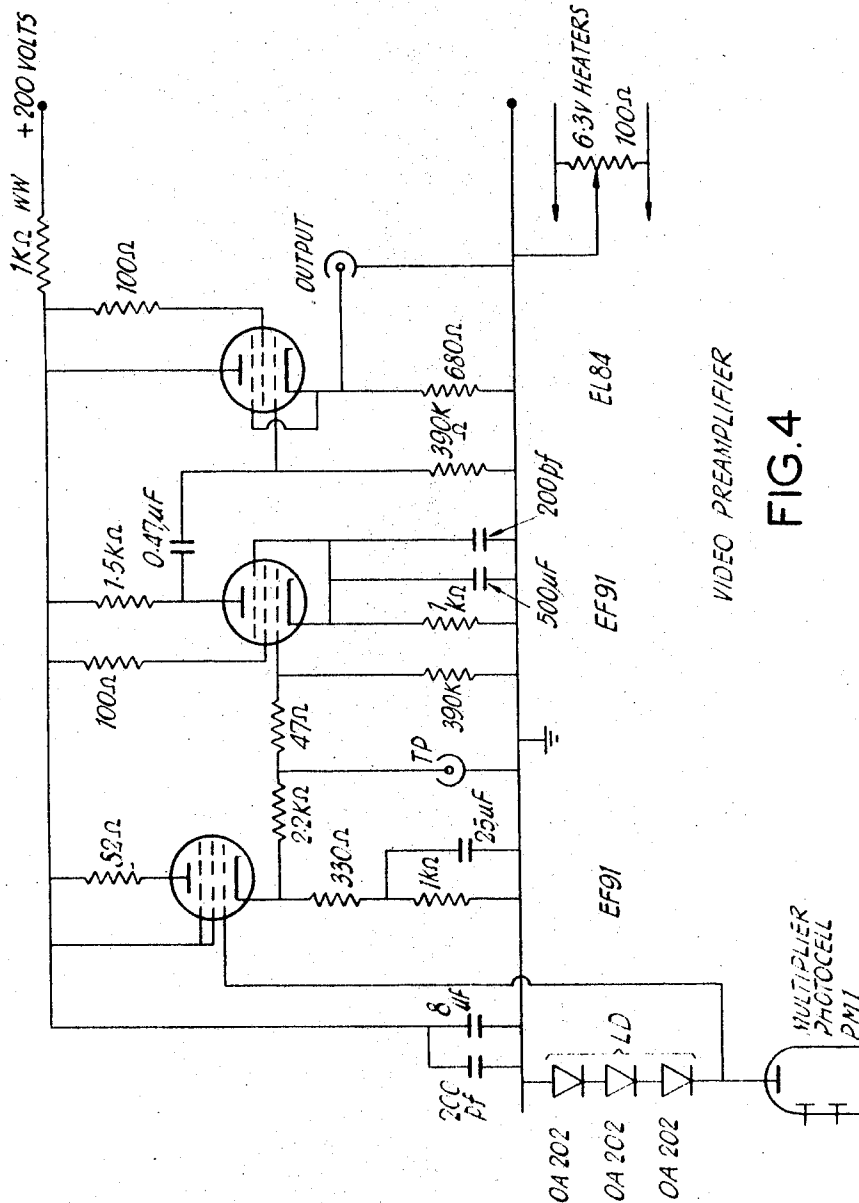
D. M. NEALE ET AL

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Filed Jan. 6, 1966

7 Sheets-Sheet 4



Inventors
 Denis M. Neale
 Leslie J. A. Smith

Denis M. Neale

Leslie J. A. Smith

By Cushman, Darby & Cushman
Attorneys

Attorneys

July 15, 1969

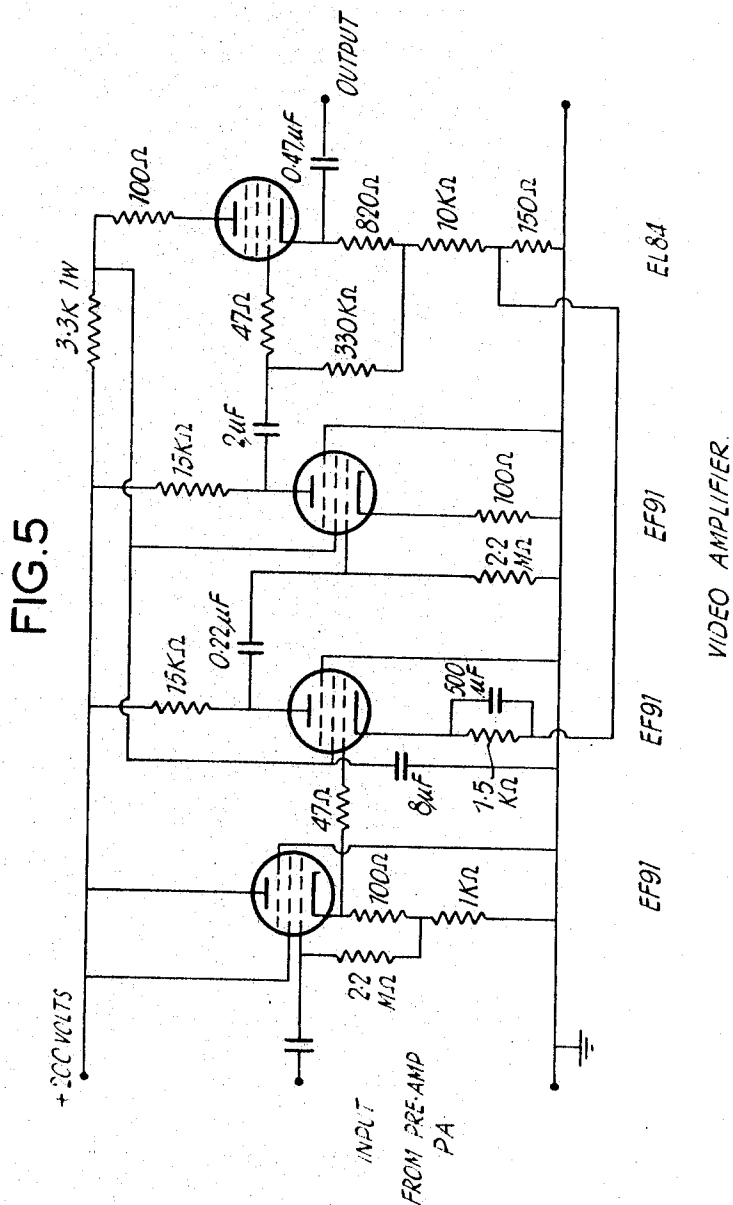
D. M. NEALE ET AL

3,455,632

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Filed Jan. 6, 1966

7 Sheets-Sheet 5



Inventors
 Denis M. Neale
 Leslie J. Smith
 By Cushman, Darby & Cushman
 Attorneys

July 15, 1969

D. M. NEALE ET AL

3,455,632

METHOD OF CLASSIFYING PHOTOGRAPHIC MATERIAL

Filed Jan. 6, 1966

7 Sheets-Sheet 6

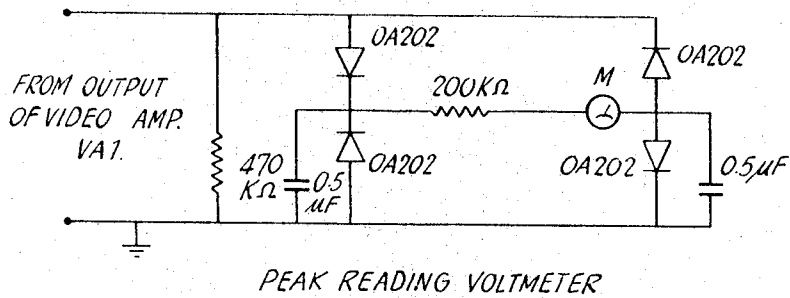
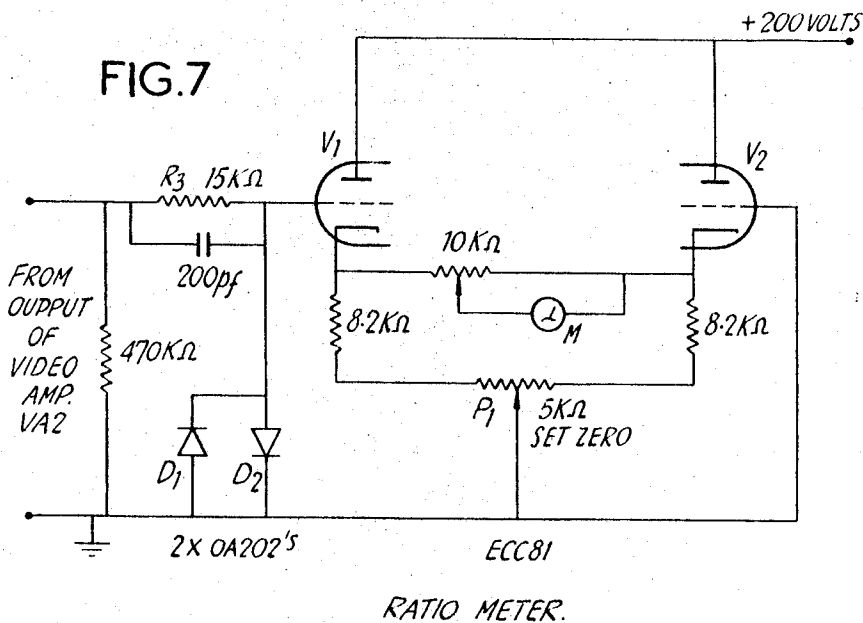


FIG. 6



Inventors
 Denis M. Neale
 Leslie J. A. Smith

By Cushman, Darby & Cushman
 Attorneys

July 15, 1969

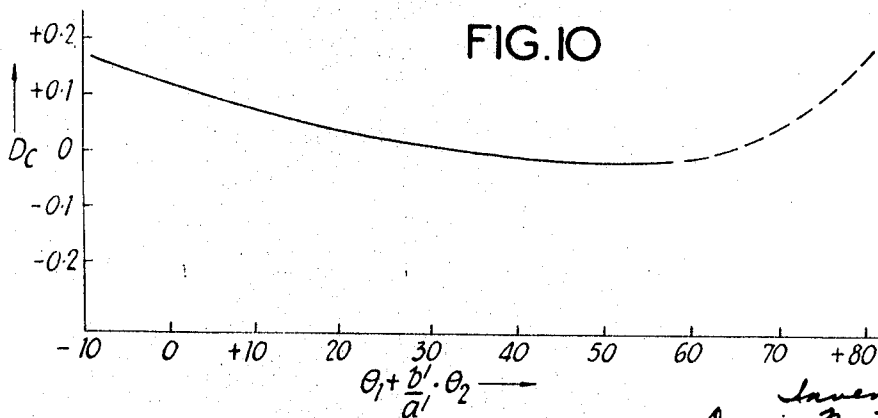
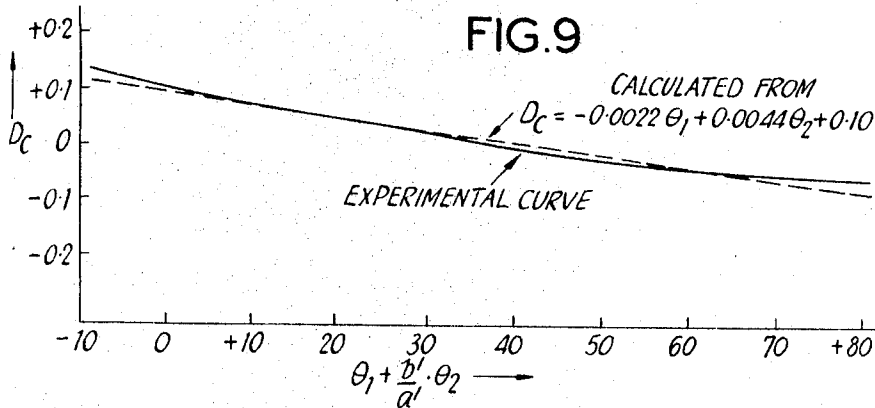
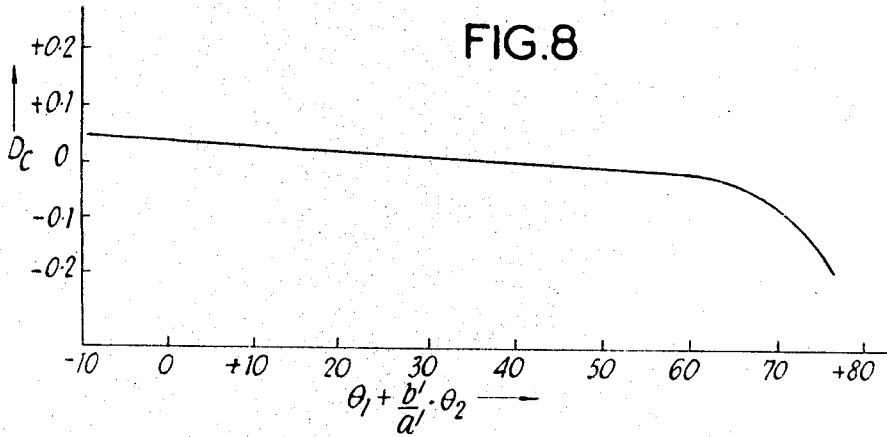
D. M. NEALE ET AL

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7 Sheets-Sheet 7



Inventors
Dennis M. Neale
Leslie J. H. Smith

By Cushman, Darby & Cushman
Attorneys

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3,455,632

METHOD OF CLASSIFYING PHOTOGRAPHIC MATERIAL

Denis Manktelow Neale and Leslie John George Smith, Ilford, England, assignors to Ilford Limited, Ilford, England, a British company

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Int. Cl. G03b 27/32

U.S. Cl. 355—77

6 Claims

ABSTRACT OF THE DISCLOSURE

A method of classifying photographic transparencies according to the optical density range of the transparencies as a step in the production of prints therefrom on photographic print material. The method consists of measuring by photoelectric means at least one of the following:

(1) The optical density range D_r between the highest and lowest densities in the area of the transparency.

(2) The optical density of at least ten area-elements of the transparency (such area-elements being distributed substantially uniformly over the total image area of the transparency). The proportion B is thereby determined by which the number of such area-elements of density greater than the average density D_z of the transparency exceeds the number of such area elements of density below the said average, thus generating an electrical signal. The signal is then utilised to effect an exposure correction (equivalent to the insertion between the print material and the image forming light of controlled and substantially constant integral of light flux against time) of the density.

This invention relates to the classification of photographic records.

In the printing of black and white photographic transparencies, and in particular in the printing of photographic negatives, it is known practice to expose the print material to image-forming light transmitted by said transparency until the integral against time of such light, as received by the print material, reaches a predetermined value. This method has the merit of providing compensation for a limited degree of over-exposure or under-exposure of individual photographic transparencies. As a result, a high proportion of prints made according to this criterion are found acceptable.

A minority of transparencies printed in this way provide prints which are unacceptable. These transparencies are then commonly printed a second time, the value of the predetermined exposure integral being adjusted to an alternative value.

It is also known practice to extend to the printing of photographic multicolour transparencies, and particularly to the printing of photographic multicolour negatives, the above-mentioned known black and white practice, said black and white practice being applied separately in respect of each colour of light, red, green and blue, to which the print material is selectively sensitised.

It is also known practice to make a visual examination of individual transparencies in order to assess any departure which may be required from the integral of light against time which is found to suit the majority of transparencies.

It is an object of the present invention to provide a method whereby this assessment may be made by photoelectric means.

According to the present invention there is provided a method of classifying photographic transparencies according to the optical density range of the transparencies

as a step in the production of prints therefrom on photographic print material, which comprises measuring by photoelectric means either the optical density range D_r between the highest and lowest densities in the area of the transparency, or the optical density of at least ten area-elements of the transparency (such area-elements being distributed substantially uniformly over the total image area of the transparency) and assessing the proportion B by which the number of such area-elements of density greater than the average density D_z of the transparency exceeds the number of such area-elements of density below the said average or carrying out both such measurements, computing a quantity A given by a weighted linear addition of D_r and B according to the formula $A = a \cdot D_r + 12b \cdot B + k$ where a , b and k are numerical constants, the value of a being from zero to minus 0.8 and being zero when D_r is not determined, the value of b being from zero to plus 0.07 and being zero when B is not determined, one of a and b being other than zero, and the value of k being determined by the setting of the printing apparatus used, and utilising the value of A so computed to determine a correction to the controlled and otherwise substantially constant integral against time of image-forming light directed to the print material, said correction being equivalent to insertion in the path of said image-forming light of a density D_c which is a function of both A and D_z .

According to a preferred form of the invention, when dealing with transparencies of substantially similar average density, the value of D_c is equivalent to the value of A where a is approximately minus 0.3 and b is approximately plus 0.03.

Substantial variations in procedure are permissible within the scope of the invention just defined and will now be described.

It has been observed that for each transparency, the adjustment required in the predetermined exposure integral is systematically related to the difference between maximum and minimum optical densities occurring in the image area of said transparency. This density difference will hereinafter be referred to as the density range of the transparency. It has been observed that for negatives of large density range, said exposure integral should in general be increased relative to the value appropriate for negatives of smaller density range.

It is proposed, therefore, to use photoelectric means to effect classification of the density range of transparencies before printing so that the predetermined exposure integral of the print material may be adjusted in accordance with said classification. By this means the proportion of unacceptable prints will be reduced.

According to one aspect of the invention, therefore, a method of classifying a photographic transparency prior to printing onto photosensitive print material comprises measuring by photoelectric means the highest and lowest optical densities of area-elements each covering not more than one-tenth of the area of the transparency, producing an electrical signal corresponding to the density range D_r which density range is the difference between said highest and lowest optical densities and classifying the transparency in accordance with the value of said electrical signal.

According to one specific embodiment of the invention a method of classifying photographic transparencies prior to printing onto photosensitive print material comprises scanning each transparency with a beam of light instantaneously covering not more than one-tenth of the area of the transparency, allowing the beam after transmission by the transparency to fall on a photocell, deriving from the electrical output of said photocell an electrical signal logarithmically related to the intensity of light incident

on said photocell, applying said electrical signal to a circuit responsive to the peak-to-peak variations in said signal and classifying the transparency in accordance with the response of said circuit.

It has been observed also that for each transparency the adjustment required in the predetermined exposure integral is systematically related to the density probability distribution, i.e. to the relative proportions of transparency area which have optical densities above and below the average value of optical density for that transparency. Thus if more elemental areas of the transparency exceed the average density than lie below it, the adjustment must represent a reduction in predetermined exposure integral below the value used for the majority of transparencies.

If the majority of elemental areas of the transparency have optical densities below the average value of density for that transparency, the adjustment required often represents an increase in predetermined exposure integral above the value used for the majority of transparencies.

It is proposed, therefore, to use photoelectric means to effect classification of transparencies according to density probability distribution before printing so that the predetermined exposure integral of the print material may be adjusted in accordance with said classification. By this means the proportion of unacceptable prints will be reduced.

According to this aspect of the invention, therefore, a method of classifying a photographic transparency prior to printing onto photosensitive print material comprises measuring by photoelectric means the optical densities of at least ten part-areas of the transparency, each part-area covering not more than one-tenth of the total area of the transparency, producing electrical signals corresponding to said optical densities, determining the proportion of all said signals by which those signals corresponding to more than average density exceed those signals corresponding to less than average density and classifying said transparency in accordance with said proportion.

According to another embodiment of this aspect of the invention, therefore, a method of classifying photographic transparencies prior to printing onto photosensitive print material comprises scanning each transparency with a beam of light instantaneously covering not more than one-tenth of the area of the transparency, allowing the beam after transmission by the transparency to fall on a photocell, deriving from the electrical output of said photocell an electrical signal logarithmically related to the intensity of light incident on said photocell, applying said electrical signal to one terminal of a capacitor, the other terminal of which is connected to a circuit providing an indication sensitive to asymmetry in the alternating component of said signal and classifying the transparency in accordance with said indication.

By "sensitive to asymmetry," it is intended to convey that the said circuit provides an indication sensitive to the phase of second harmonic present in an alternating component of electrical signal applied to said circuit. In one form, the circuit may comprise sub-circuits responsive respectively to positive and negative values of said electrical signal, said responses being substantially independent of signal amplitude.

In one form, the circuit may comprise sub-circuits rectifying positive-going and negative-going values of said electrical signal, the direct-current outputs obtained as a result of said rectification being of opposite polarity and being combined in an adding circuit. Said direct-current outputs substantially cancel in respect of electrical signals of symmetrical form such as, for example, a sine wave, or rectangular wave of equal mark-space ratio. When an electrical signal of asymmetric form, such as a rectangular wave of unequal mark-space ratio is applied through said capacitor to said circuit, the said direct-current outputs are unequal and do not cancel.

It is moreover to be understood that whereas the performance of said circuit has been defined in terms of electrical signals of relatively simple form, it is to be used with electrical signals of complex form, i.e. containing harmonics of high order.

Alternative known circuit configurations capable of providing an indication sensitive to asymmetry in the alternating component of a signal are the Schmitt trigger and the long-tailed pair.

Each of these configurations provides two outputs which are complementary. The difference between these outputs, averaged over a period of time, may be taken as indicating the extent by which the proportion of time during which the waveform is positive exceeds the proportion during which it is negative. Said difference between the two outputs will fall substantially to zero when the circuit is excited by electrical signals of symmetrical form such as, for example, a sine wave, or rectangular wave of equal mark-space ratio. When an electrical signal of asymmetric form, such as a rectangular wave of unequal mark-space ratio is applied through said capacitor to said circuit, said two outputs are unequal and a difference indication is obtained.

The prescribed procedure may be applied separately and independently in respect of light of any or all of the colours red, green and blue. Alternatively or additionally, classification may be effected with red, green and blue light falling simultaneously on the photocell, the red, green and blue printing exposures each being adjusted in accordance with the single classification process.

The theory underlying the process of this invention will now be described by way of further explanation:

In conventional automatic printers, photocells measure the integrated transmittance, $\bar{T}$, of each negative. The integrated transmittance, $\bar{T}$, is simply the mean of the individual transmittances, $T_1, T_2 \dots T_N$, of N elemental areas.

$$\bar{T} = [T_1 + T_2 + T_3 + \dots T_N] / N$$

Corresponding to the integrated transmittance, $\bar{T}$, there is a density, D_T , which is given by:

$$D_T = -\log_{10} \bar{T} \quad (2)$$

Consider now a hypothetical negative in which:

$D_{\min}$ = Minimum density,
 $D_{\max}$ = Maximum density,
 D_r = Density range [$= D_{\max} - D_{\min}$]
 n = Number of density levels in range D_r ,
 N = Number of elemental areas in picture.

Assume also a linear probability-density distribution, as in FIGS. 1a and 1b.

Thus, considering any particular density level, D , the frequency, f , with which that density occurs is given by:

$$f = m \cdot D + C \quad (3)$$

But, when

$$D = D_{\min} + \frac{1}{2} D_r$$

then

$$f_{1/2} = N/n \quad (4)$$

i.e. with the assumed linear probability-density distribution, the frequency with which a mid-range density,

$$\frac{1}{2}(D_{\max} + D_{\min}),$$

occurs is given by the number of picture elements N , divided by the number of density levels, n .

Substituting in (3),

$$f_{1/2} = N/n = m(D_{\min} + \frac{1}{2} D_r) + C$$

$$\therefore C = \frac{N}{n} - m(D_{\min} + \frac{1}{2} D_r) \quad (5)$$

5

$$\therefore f = \frac{N}{n} + m(D - D_{\min}) - \frac{m}{2} \cdot D_r \quad (6)$$

In a printer using photoelectric integration, the addition or subtraction of a uniform overall density has no effect on the resultant print. Consequently the minimum density in the negative plane, $D_{\min}$, may be subtracted from the value of each density level without affecting the validity of calculations concerned with the difference between optimum print exposure and that obtained on the "integrate-to-grey" criterion.

Hence, putting $D_{\min} = 0$,

$$f = \frac{N}{n} + m(D - \frac{1}{2}D_r) \quad (6A)$$

Let us now define a "subject key factor," S , such that S is the proportional change in probability frequency through the density range, D_r

Thus

$$S = m \cdot D_r / f_{1/2} = m D_r \cdot \frac{n}{N} \quad (7)$$

The integrated transmission of the negative is given by

$$\begin{aligned} \bar{T} &= \frac{1}{N} [f_1 \cdot 10^{-D_1} + f_2 \cdot 10^{-D_2} + f_3 \cdot 10^{-D_3} + \dots + f_n \cdot 10^{-D_n}] \\ &= \frac{1}{N} \sum_{R=1}^n [f_r \cdot 10^{-D_r}] \quad (8) \end{aligned}$$

Now for the R th term,

$$f_r = f_{1/2} + m \left(D_r - \frac{D_r}{2} \right) \quad (9)$$

and

$$D_R = \frac{R}{n} \cdot D_r$$

$$\begin{aligned} \therefore \bar{T} &= \frac{1}{N} \int_0^n \left\{ f_{1/2} + m \left(D_r - \frac{D_r}{2} \right) \right\} 10^{-D_r} dR \quad (10) \\ &= \frac{1}{2.303} D_r \left\{ \left(1 - \frac{m D_r}{2 f_{1/2}} + \frac{m}{2.303 f_{1/2}} \right) - \right. \\ &\quad \left. \left(1 - \frac{m D_r}{2 f_{1/2}} + \frac{m}{2.303 f_{1/2}} + \frac{m D_r}{f_{1/2}} \right) \cdot e^{-2.303 D_r} \right\} \quad (11) \end{aligned}$$

where $e = 2.718$ approx.

Substituting from (7),

$$\bar{T} = \frac{1}{2.303} D_r \left\{ \left(1 - \frac{S}{2} + \frac{S}{2.303 D_r} \right) (1 - 10^{-D_r}) - S \cdot 10^{-D_r} \right\} \quad (12)$$

$$\begin{aligned} \bar{D} = D_{\bar{T}} &= -\log_{10} \bar{T} = \frac{1}{2.303} \left[\log_e (2.303 D_r) - \right. \\ &\quad \left. \log_e \left\{ \left(1 - \frac{S}{2} + \frac{S}{2.303 D_r} \right) (1 - 10^{-D_r}) - S \cdot 10^{-D_r} \right\} \right] \quad (13) \end{aligned}$$

To comply with the mathematical model shown in FIG. 1, S must lie between -2 and $+2$.

For typical negative materials, the value of D_r may be assumed to lie between 1.0 and 2.0 . It may thus be shown that

$$\begin{aligned} \bar{D} &\approx \frac{2}{2.303} \left[\log_e 2.303 + \log_e D_r - \log_e (1 - 10^{-D_r}) - \right. \\ &\quad \left. \log_e \left(1 - \frac{S}{2} + \frac{S}{2.303 D_r} \right) \right] \quad (14) \end{aligned}$$

Whence

$$\bar{D} \approx \frac{1}{2.303} \left[0.334 + 0.5 D_r - 10^{-D_r} + S \left(\frac{1}{2} - \frac{1}{2.303 D_r} \right) \right] \quad (15)$$

If the printer is adjusted to print correctly a typical negative having $S = S'$, $D_r = D_r'$ and $\bar{D} = \bar{D}'$, then the same

6

highlight exposure will be obtained with other negatives if for each negative a density correction, D_c , is applied, given by

$$D_c \approx (D_r' - D_r) - (\bar{D}' - \bar{D}) \quad (16)$$

5 Substituting values of $\bar{D}$ and $\bar{D}'$ given by (15).

$$\begin{aligned} D_c &\approx 0.783(D_r' - D_r) + 0.435(10^{-D_r'} - 10^{-D_r}) - \\ &\quad 0.435 \left[S' \left(\frac{1}{2} - \frac{1}{2.303 D_r'} \right) - S \left(\frac{1}{2} - \frac{1}{2.303 D_r} \right) \right] \quad (17) \end{aligned}$$

Since the range of D_r is rather small and

$$R_r'$$

15 is approximately in the middle of this range,

$$D_c \approx 0.783(D_r' - D_r) - 0.435(S' - S) \left(\frac{1}{2} - \frac{1}{2.303 D_r'} \right) \quad (18)$$

Since D_r' and S' are constants, (18) has the form

$$D_c \approx a \cdot D_r + b \cdot S + k \quad (19)$$

where a , b and k are numerical constants.

The equation given at (19) suggests that the density correction required by any individual negative should be predictable from a weighted addition of measured values of density range, D_r , and subject key factor, S . The mathematical model leading to this conclusion is, however, somewhat artificial and several approximations have been made.

30 It should be noted, moreover, that although expression (19) has developed on the assumption that print highlights were to be exposed correctly, a lowered degree of correction can be computed by using proportionally reduced values of the numerical constants a , b , and k .

35 Practical tests with a large number of assorted negatives confirm that the equation given at (19) is substantially true. The practical tests also make it possible to determine suitable values of the constants, a , b and c .

Moreover practical tests confirm that if measurements of D_r and S are made separately for each of the colours red, green and blue, then by an extension of (19) the colour correction can be computed which will be necessary in a printer working on the "integration-to-grey" principle. Thus:

$$\begin{aligned} D_{\text{colour}} &= [(a \cdot D_r + b \cdot S)_{\text{red}} + \\ &\quad (a \cdot D_r + b \cdot S)_{\text{green}} + (a \cdot D_r + b \cdot S)_{\text{blue}}] \quad (20) \end{aligned}$$

50 where $r = \text{constant}$, and the arrows indicate vectorial quantities measured along axes mutually at 120° of angular rotation.

The invention will now be described with reference to the accompanying drawings in which:

FIGS. 1a and 1b represent density probability distributions for two hypothetical negatives. In FIG. 1a the negative represents a high-key subject, i.e. a subject containing a preponderance of lighter tones. In FIG. 1b the negative represents a low-key subject, i.e. a subject containing a preponderance of darker tones.

FIG. 2 is a schematic diagram representing a particular embodiment of apparatus according to the invention.

FIGS. 3 to 7 represent details of the apparatus of FIGURE 2 and are as follows:

FIG. 3 represents a feedback control regulating the intensity of light emitted by a cathode ray tube.

FIG. 4 represents a logarithmic current-to-voltage converter and A.C. coupled video pre-amplifier associated with a multiplier photocell receiving light transmitted by the transparency.

FIG. 5 represents a negative feedback video amplifier of known type.

FIG. 6 represents a voltmeter indicating the peak-to-peak value of an alternating voltage input.

FIG. 7 represents a circuit indicating the overall proportion by which the time for which an electrical input signal is of positive polarity exceeds the time for which the said signal is of negative polarity.

FIG. 8 is a plot of density correction D_c against a weighted sum of indications θ_1 and θ_2 obtained with the apparatus of FIG. 2 in respect of under-exposed negatives.

FIG. 9 is a similar plot in respect of correctly exposed negatives.

FIG. 10 is a further similar plot in respect of over-exposed negatives.

FIG. 2 is a schematic diagram of apparatus for making measurements on negatives. Cathode ray tube, CRT., lens 1, lens 3 and multiplier photocell PM1 are the principal elements of a flying spot scanner. Time bases TB energise deflection coils C in FIGURE 2 to cause the electron beam to explore a substantially rectangular area of the phosphor screen of the cathode ray tube. Lens 1 forms an image of said rectangular area upon the negative N_x in FIGURE 2 to be examined. Light transmitted by the negative is directed by lens 3 onto the photocathode of photocell PM1. Thus as the electron beam explores an area on the phosphor screen of the cathode ray tube, light passing lens L_1 explores the area of the negative and produces a variation in the collector current of photocell PM1.

A semi-reflecting mirror, SM, directs a proportion of light passing L_1 onto a lens L_2 and so to the photo-cathode of a multiplier photocell, PM2. The collector current of PM2 develops across a load resistance, R_2 , a voltage which is compared with a reference voltage, V_{ref} . Any difference between the two is amplified by a direct coupled amplifier, DCA shown in FIG. 3. The output of DCA controls the intensity of the electron beam of the cathode ray tube. In this way it is arranged that, despite lens vignetting and non-uniformities in the phosphor screen of the cathode ray tube, the intensity of light received by photocell PM2 is maintained substantially constant. This arrangement therefore represents an application of the invention described in British patent specification No. 736,899.

Lens 3 and photocell PM1 are positioned relative to mirror SM symmetrically with respect to lens 2 and photocell PM2. It follows that, in the absence of a negative N_x , photocell PM1 receives light of substantially constant intensity since the two photocells will then receive light in substantially constant proportion. When negative N_x is placed in the optical path as shown, light received by photocell PM1 is proportional in intensity to the transmittance T_x of that part of the negative N_x instantaneously receiving the image of the luminous spot on the phosphor screen of the cathode ray tube.

The collector current I_c drawn instantaneously by photocell PM1 is thus given by:

$$I_c = p \cdot T_x \quad (21)$$

where $p = \text{constant}$.

The collector current I_c passes through several semiconductor diodes, LD, connected in series. These diodes show a substantially logarithmic relation between voltage drop and forward current. It follows therefore that the voltage V_d developed across the diodes is given instantaneously by

$$\begin{aligned} V_d &= q \cdot \log_{10} I_c = q \cdot \log_{10} (p \cdot T_x) \\ &= u \cdot \log_{10} T_x = -u \cdot D_x \end{aligned} \quad (22)$$

where D_x is the optical density corresponding to transmittance T_x and q and u are constants.

The variations in the voltage V_d are then amplified in alternating current amplifiers PA in FIGURE 2, VA1 and VA2. The circuit of the video preamplifier is shown in FIG. 4. Video amplifiers VA1 and VA2 are each according to the circuit shown in FIG. 5. The output from VA1 is applied to a voltmeter shown at FIG. 6. This indicates the peak-to-peak value of alternating voltage output. The

indication θ_1 given by meter M1 is thus proportional to the extreme values of V_d for the negative N_x . Thus

$$\begin{aligned} \theta_1 &= y (D_{\max} - D_{\min}) \\ &= y \cdot D_r \end{aligned} \quad (23)$$

where y is a constant.

A high value of θ_1 therefore indicates a negative of high contrast. A low value of θ_1 indicates a negative of low contrast.

The alternating output voltage from amplifier VA2 is applied to the ratio meter RM, the circuit of which is shown at FIG. 7. Referring to FIG. 7, the potentiometer P1 is adjusted in the absence of input so that the centre-zero meter M2 in FIG. 7 indicates zero. Zero indication on M2 will thereafter indicate that the average potential of the grid of V1 is equal to the grid potential of V2. When the output from VA2 is positive, diode D2 conducts a current limited by the series resistance, R3. Over the range of current so passed, the voltage developed across D2 is 0.5 v. Thus while the output of VA2 is positive, the grid of V1 is held at +0.5 v. Similarly, while the output of VA2 is negative, diode D1 conducts and the grid of V1 is held at -0.5 v. It is evident that if VA2 delivers an alternating waveform of symmetrical waveform the grid of V1 will be held positive and negative for equal proportions of the time. The mean potential of the grid of V1 will then remain the equal to the grid potential of V2 and meter M2 will remain undeflected.

If, however, the output of VA2 is more often positive than negative, the meter M2 will be deflected in one direction. If the output of M2 is more often negative than positive, M2 will be deflected in the opposite direction.

It will now be shown that the deflection, θ_2 , of meter M2 is substantially proportional to the subject key factor, S.

Because the amplifiers PA, VA1 and VA2 include capacitor-coupled stages, their outputs represent departures of instantaneously measured negative density D from the average value D_z .

Because the amplifiers cannot transmit a direct current component of the signal, it follows that

$$\int_0^{D_r} f \cdot (D - D_z) dD = 0 \quad (24)$$

If all densities are measured above $D_{\min}$, then by substitution from (6) and (4),

$$\int_0^{D_r} \left(f_{1/2} + mD - \frac{1}{2} m \cdot D_r \right) (D - D_z) dD = 0 \quad (25)$$

whence

$$D_z = \frac{1}{2} D_r + \frac{1}{12} \frac{m \cdot D_r^2}{f_{1/2}} \quad (26)$$

Substituting from (7),

$$D_z = D_r \left[\frac{1}{2} + \frac{1}{12} S \right] \quad (27)$$

The value of S may thus be derived by comparison of measured values of D_r and D_z . Expressed mathematically,

$$S = 12(D_z - \frac{1}{2} D_r) / D_r \quad (27A)$$

The value of D_r is indicated by the deflection θ_1 of meter M1. The value of D_z may be observed by measuring the average direct voltage appearing at test point TP in FIG. 4. It will however be appreciated by those skilled in the art that measurement of such a relatively small direct voltage is subject to error and consequently it is not easy to measure S with adequate precision. Accordingly it is preferred to derive S from the deflection θ_2 provided by meter M2.

Referring to FIGS. 1a and 1b,

Number elements with density D above $D_z =$

$$N_a = \frac{(f_z + f_r)}{2} \cdot \frac{(D_r - D_z)}{D_r} \cdot n \quad (28)$$

Number of elements with density D below $D_z =$

$$N_b = \frac{(f_0 + f_z)}{2} \cdot \frac{D_z}{D_r} \cdot n \quad (29)$$

where

f_0 = number of elements in lowest density level,
 f_r = number of elements in highest density level.

Referring to the circuit shown in FIG. 7, the deflection θ_2 of meter M2 is given by

$$\frac{\theta_2}{w} = \frac{(N_a - N_b)}{N} = B \quad (30)$$

where w is a constant.

$$\begin{aligned} \therefore \frac{N}{w} \theta_2 &= \frac{(f_z + f_r)}{2} \cdot \frac{(D_r - D_z)}{D_r} \cdot n - \frac{(f_0 + f_z)}{2} \cdot \frac{D_z}{D_r} \cdot n \\ &= \frac{n}{D_r} \left[\frac{(f_z + f_r)}{2} \cdot D_r - \frac{(f_0 + f_z)}{2} D_z - f_z D_z \right] \end{aligned} \quad (31)$$

But,

$$\frac{f_0 + f_r}{2} = f_{1/2} \quad (32)$$

From (4) and (6),

$$f_z = f_{1/2} + m \frac{(D_r - D_z)}{2} \quad (33)$$

and also,

$$f_r = f_{1/2} + \frac{m \cdot D_r}{2} \quad (34)$$

Substitution from (32), (33) and (34) in (31), leads to

$$\frac{N}{w} \theta_2 = \frac{n}{D_r} [m D_z (D_r - D_z) - 2 f_{1/2} (D_z - \frac{1}{2} D_r)] \quad (35)$$

Substituting from (27)

$$\frac{N}{w} \theta_2 = S n f_{1/2} \left[\frac{1}{12} - \frac{S^2}{144} \right] \quad (36)$$

But $S^2 < 4$

$$\begin{aligned} \therefore \theta_2 &\approx \frac{w}{N} \cdot f_{1/2} \cdot \frac{S}{12} \cdot n = w \cdot \frac{S}{12} \\ \therefore \frac{\theta_2}{w} &\approx B \approx \frac{S}{12} \end{aligned} \quad (36)$$

It will be seen therefore that the subject key factor, S , as hereinbefore defined, is substantially equal to 12 times the proportion of all transparency elements by which the number of elements having optical densities above the average value of optical density exceeds the number having less than average value of optical density.

Expression (19) may thus be re-written in the form

$$D_c \approx a' \theta_1 + b' \theta_2 + k \quad (37)$$

S is here defined to be positive in FIG. 1a and negative in FIG. 1b. FIG. 1a represents a negative having more high density areas than low density areas. It therefore represents a "high-key" subject, e.g. a snow scene, a sandy beach scene or a white building.

FIG. 1b represents a "low-key" subject, e.g. a dark interior lit by a shaft of sunlight. In such a picture dark tones predominate.

The density correction, D_c , is the density equivalent to that which would be required in the printing path at such a point that the photoelectric exposure control would be unaffected by its insertion. (In practice it is usual to apply density correction by electrical modification of the photoelectric exposure control circuit.)

With these conventions, negatives with large values of D_r would be expected to require negative values of D_c . Negatives with positive values of S (high-key negatives) require positive values of D_c . Thus in (37) the constant a' will have a negative value and the constant b' will have a positive value.

From (18) it may be deduced that if the print highlights are required to receive always the same exposure, the weighting constants in (19) should have values

$$a \approx -0.78, \quad b \approx +0.07$$

However, it has been reported by C. M. Tuttle (Journal Franklin Institute, 224, No. 3, pp. 315-337, September 1937) that exposure in accordance with highlight densities is less successful than exposure in accordance with the value of D . Accordingly for most pictorial subjects the magnitudes of constants a and b should be less than half those mentioned above. In practice good results are obtained with $a \approx -0.3$, $b \approx +0.03$.

It remains now to describe the method of using the apparatus.

Initially a calibration must be performed by measuring values of θ_1 and θ_2 for each of a large and representative population of negatives. For each negative an approximate value of D_z is also deduced by measuring the average voltage appearing at the test point, TP, in FIG. 4.

It is found in practice that the interpretation of θ_1 and θ_2 in terms of required density correction, D_c , depends in some degree on the value of D_z . Accordingly the negative population is divided into three groups corresponding to three ranges of D_z . Alternatively, the division may be made into three ranges of $\bar{D}$ since there is a close correlation between $\bar{D}$ and $\bar{D}_z$.

For each such range, the accumulated data is analysed separately to determine the best values of a' , b' and k to be used in (37). From such analysis, FIGS. 8, 9, and 10 have been drawn relating to the three ranges of D_z respectively.

FIG. 9, which relates to values of D_z corresponding to correctly exposed negatives, shows that the experimentally determined characteristic agrees quite well with the linear relations predicted by (37).

FIG. 8 relates to negatives showing a value of D_z low enough to indicate some under-exposure. The characteristic calls for a relatively large density correction in respect of low key, high contrast negatives.

FIG. 10 relates to negatives showing a value of D_z high enough to indicate some under-exposure. The experimentally determined curve shows a considerable departure from one linear form of (37). This is because these negatives represent subjects including a very wide range of tone values, the lightest tones of which are of no interest because they are grossly over-exposed in the negative. An example of such a subject would be a portrait of a child taken indoors by daylight. If the exposure for the child is correct, the sky visible through the window behind the child will produce gross over-exposure. In printing the negative, the printing exposure must be chosen to produce an acceptable rendering of the child's face. The foregoing mathematical treatment has been based on the assumption that printing exposure should be determined by the relation between $D_{\max}$ and $\bar{D}$. In this case, however, the value of $D_{\max}$ is of no importance and accordingly it is not surprising that the experimental curve departs from the linear relation predicted by theory. That part of the curve drawn as a broken line is, therefore, a purely empirical result.

In one practical investigation, it was found that the corrections most useful in practice are approximately one-

third as large as those predicted by relation (19). This shows that, the relation between $D_{\max}$ and $\bar{D}$ is a better guide to printing exposure than either $D_{\max}$ or $\bar{D}$ alone.

Once a set of curves has been obtained corresponding to FIGS. 8, 9 and 10, further negatives may be classified as follows:

For each negative the values of D_z , θ_1 , and θ_2 are observed. According to the value of D_z , the appropriate curve is consulted. This then shows the density correction, D_c , to be used for the particular value of

$$\left(\theta_1 + \frac{b'}{a'}\theta_2\right)$$

When the negative is printed the indicated correction (or an approximation to it) is applied to the printer, e.g. a density correction button is pressed which modifies the value of photoelectric integral (or integrals) required to terminate exposure.

By introducing red, green and blue colour separation filters successively in the path of scanning light, the negative may be analysed separately for each of the said three colours. In accordance with relation (20), the statistically most successful colour correction is given by

$$D_{\text{colour}} = r \left[\left(\theta_1 + \frac{b'}{a'}\theta_2 \right)_{\text{red}} + \left(\theta_1 + \frac{b'}{a'}\theta_2 \right)_{\text{green}} + \left(\theta_1 + \frac{b'}{a'}\theta_2 \right)_{\text{blue}} \right] \quad (38)$$

In practice, the net correction is commonly computed by subtracting from the value of each of the three vector terms the magnitude of the smallest.

As a practical example, suppose $r = -0.01$ and $b/a = -2.0$. Suppose the values of θ_1 and θ_2 for a given negative were as follows:

	θ_1	θ_2
Red.....	49	+10
Green.....	48	+1
Blue.....	38	+3

The low value of θ_1 for blue indicates a relatively low blue contrast. This will require a reduction in blue printing exposure, i.e. a positive correction D_c to the blue component.

The relatively large positive value of θ_2 indicates a high-key red component, i.e. the subject is a red colour subject failure containing a high proportion of red areas. Correction of this abnormality will require a reduction in red printing exposure, i.e. a positive correction D_c to the red component.

It may thus be anticipated that the correction will comprise positive corrections to the red and blue components.

From the above data, the three vector terms are obtained.

$$\begin{aligned} \text{red} &= (49 - 20) = 29 \\ \text{green} &= (48 - 2) = 46 \\ \text{blue} &= (38 - 6) = 32 \end{aligned}$$

Subtracting the smallest value (red) gives

$$\text{red} = 0, \text{green} = 17, \text{blue} = 3$$

The colour correction to be used is thus:

$$\begin{aligned} D_{\text{colour}} &= -0.01 [17 \text{ green} + 3 \text{ blue}] \\ &= -0.17 \text{ density units to green light} \\ &\quad -0.03 \text{ density units to blue light.} \end{aligned}$$

It will be noted that the calculated colour correction is principally a reduction in density correction D_c to the green component. In terms of colour such a correction is equivalent to equal positive density corrections to the red and blue components. Thus the calculated correction conforms with the anticipated correction.

What is claimed is:

1. A method of classifying photographic transparencies according to the optical density range of the transparencies as a step in the production of prints therefrom on photographic print material, which comprises measuring by photoelectric means at least one of: (1) the optical density range D_r between the highest and lowest densities in the area of the transparency, and (2) the optical density of at least ten area-elements of the transparency, such area elements being distributed substantially uniformly over the total image area of transparency, and thereby measuring the proportion B by which the number of area-elements of density greater than the average density D_z of the transparency exceeds the number of such area-elements of density below the said average, generating an electrical signal corresponding to a quantity A given by a weighted linear addition of D_r and B according to the formula $A = a.D_r + 12b.B + k$ where a , b , and k are numerical constants, the value of a being from zero to minus 0.8 and being zero when step (1) is not carried out, the value of b being from zero to plus 0.07 and being zero when step (2) is not carried out, one of a and b being other than zero, and the value of k being determined by the setting of the printing apparatus used, and utilising the signal to effect an exposure correction equivalent to the insertion between the print material and the image-forming light of controlled and substantially constant integral of light flux against time, of a density D_c which is a function of both A and D_z .

2. A method according to claim 1 wherein $a=0$ which further comprises scanning each transparency with a beam of light instantaneously covering not more than one-tenth of the area of the transparency, allowing the beam after transmission by the transparency to fall on a photocell, producing from the electrical output of said photocell an electrical signal logarithmically related to the intensity of light incident on said photocell, applying said electrical signal to one terminal of a capacitor, the other terminal of which is connected to a circuit providing an indication sensitive to asymmetry in the alternating component of said signal and classifying the transparency in accordance with said indication.

3. A method according to claim 1 wherein the value of D_c is substantially equal to the value of A where the constant a has a value of approximately minus 0.3 and the constant b has a value of approximately plus 0.03.

4. A method according to claim 1 wherein $b=0$ which further comprises measuring by photoelectric means the highest and the lowest optical densities of the area elements, producing an electrical signal corresponding to the density range D_r , which is the difference between said highest and lowest optical densities, and classifying the transparency in accordance with the value of said electrical signal.

5. A method according to claim 1 wherein $b=0$ which further comprises scanning each transparency with a beam of light instantaneously covering not more than one tenth of the area of the transparency, allowing the beam after transmission by the transparency to fall on a photocell, deriving from the electrical output of said photocell an electrical signal logarithmically related to the intensity of light incident on said photocell, applying said electrical signal to a circuit responsive to the peak-to-peak variations in said signal and classifying the transparency in accordance with the response of said circuit.

6. A method according to claim 1 wherein $a=0$ which further comprises measuring by photoelectric means the optical densities of the area-elements, producing electrical signals corresponding to said optical densities, determining the proportion of all said signals by which those signals corresponding to more than average density exceed those signals corresponding to less than average density.

13

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14

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