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Gregg et al.

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[54] **SCANNING TYPE PHOTOGRAPHIC FILM DEVELOPING SYSTEM AND APPARATUS**

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[73] Assignee: **said Gregg, by said Pooley**

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[21] Appl. No.: **325,201**

Related U.S. Application Data

[63] Continuation of Ser. No. 214,924, Jan. 3, 1972, abandoned.

[52] **U.S. Cl.** ..... **95/89 R,** 95/96

[51] **Int. Cl.** **G03d 3/10**

[58] **Field of Search** ..... 95/89 R, 96, 97, 95/98

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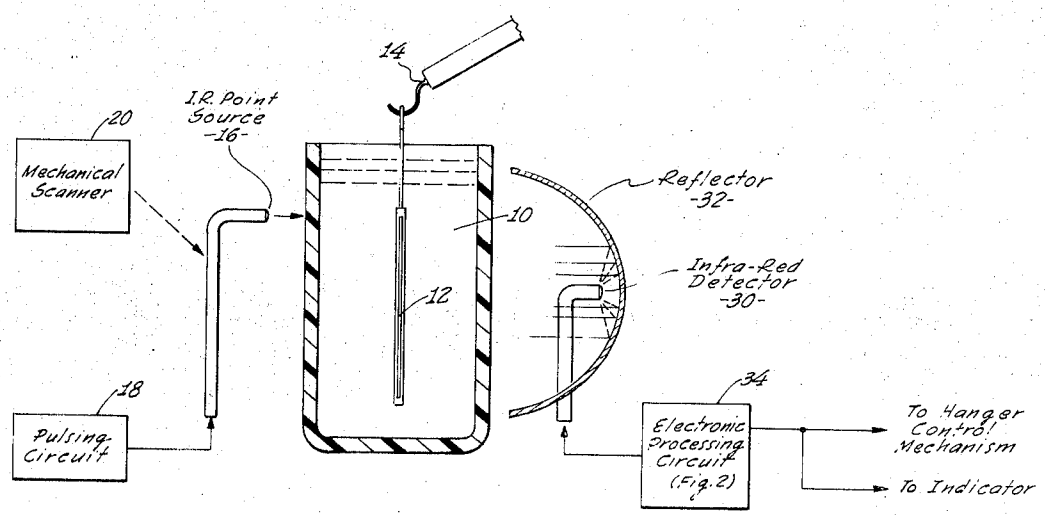
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[57] **ABSTRACT**

A system and apparatus is provided for developing photographic film such as X-ray film, for example, in a dental office, or in any other establishment. The system is capable of causing the film to be developed with any desired density, and within known limitations, regardless of whether the film has been over-exposed or under-exposed, and regardless of the temperature of the developing bath, and the age of the developing solution. The apparatus incorporates a control system which responds to the scanning of the exposed film in a developing solution by a radiant energy beam to which the particular film is relatively insensitive, and which causes the developing process to be terminated when a desired density is achieved. The system of the invention has a feature in that the very clear and very opaque areas, and other areas of no interest, are eliminated from the processing, and the desired density is established by processing the film between such minimums and maximums.

6 Claims, 4 Drawing Figures



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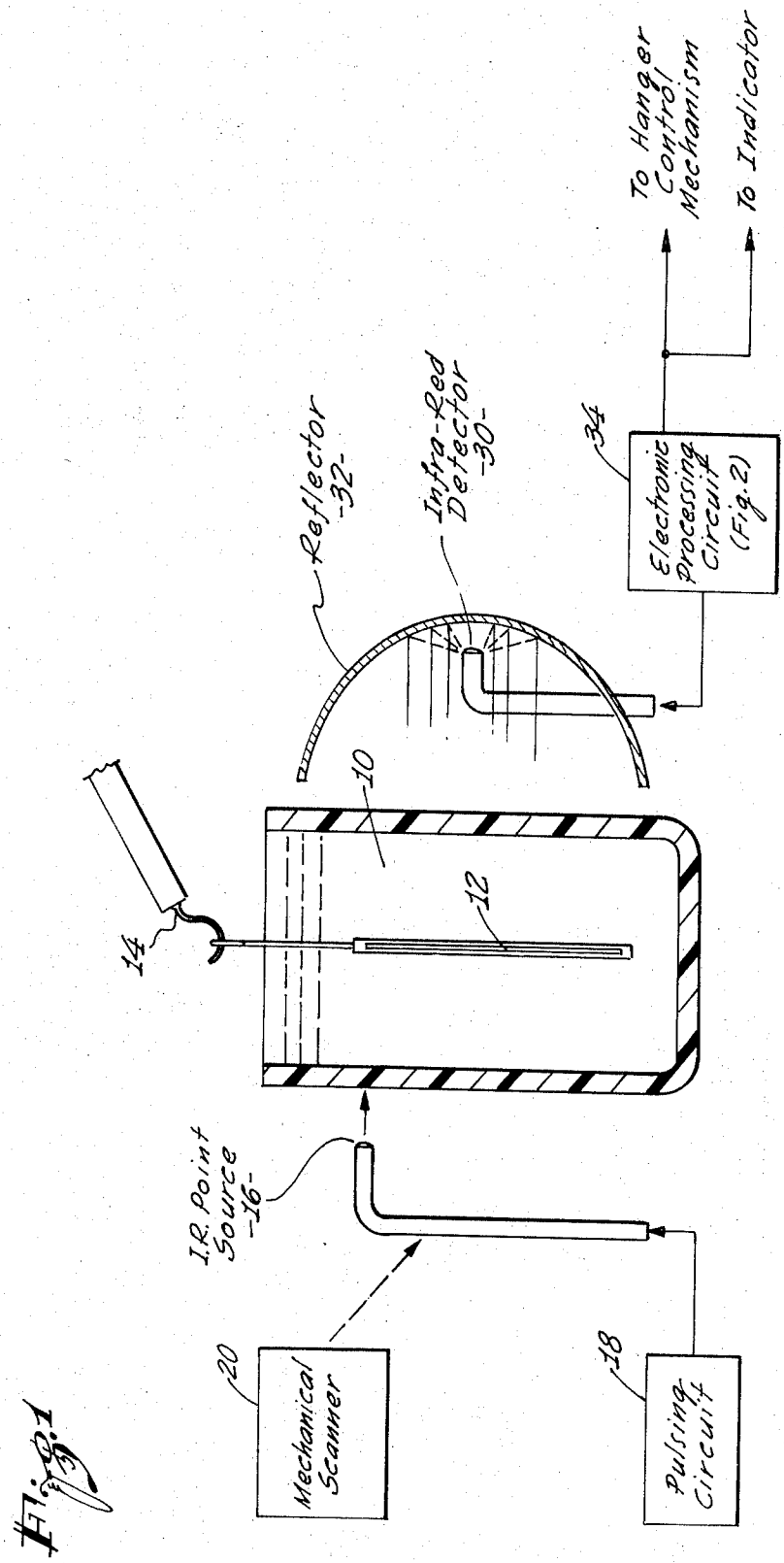


Fig. 1

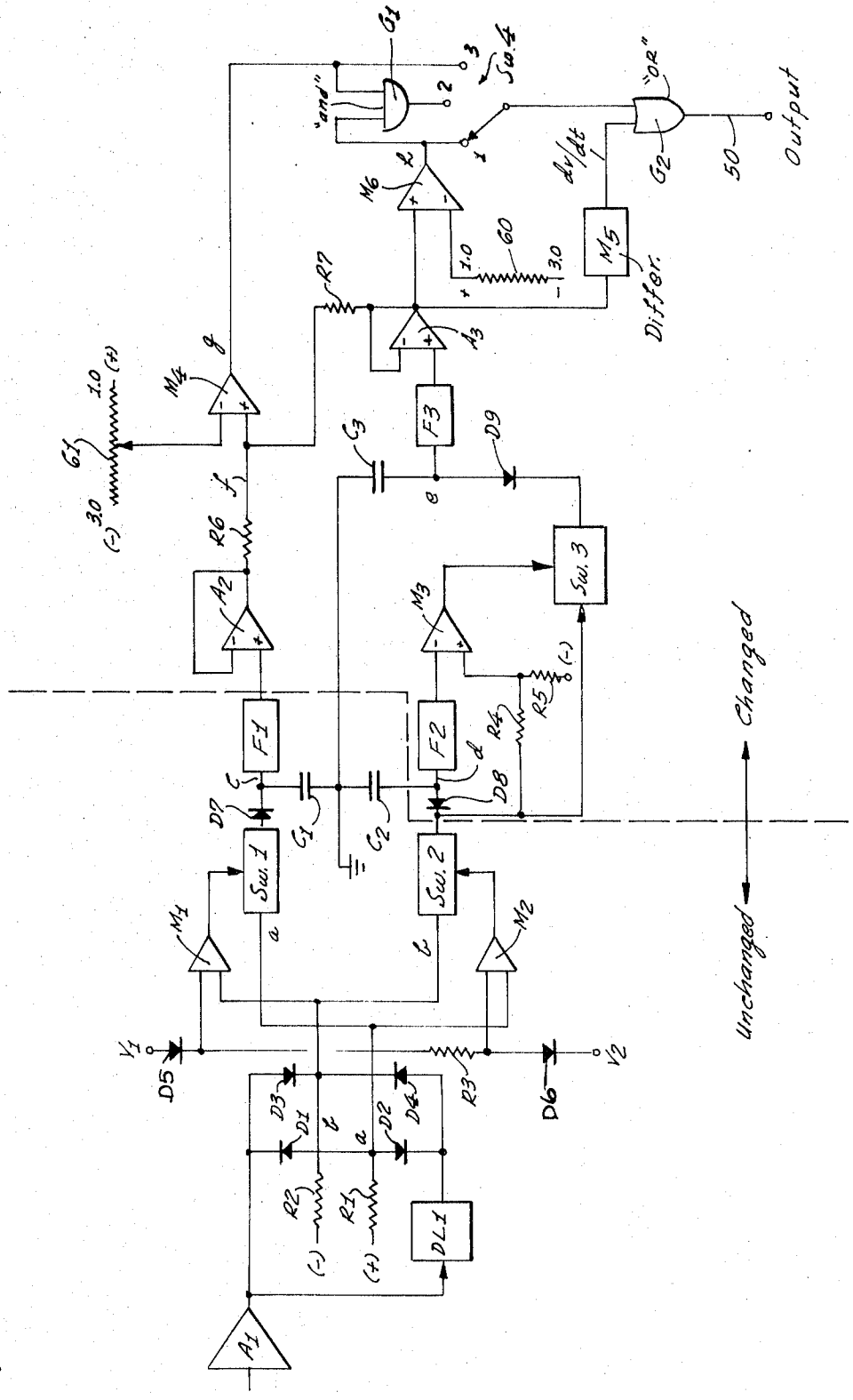
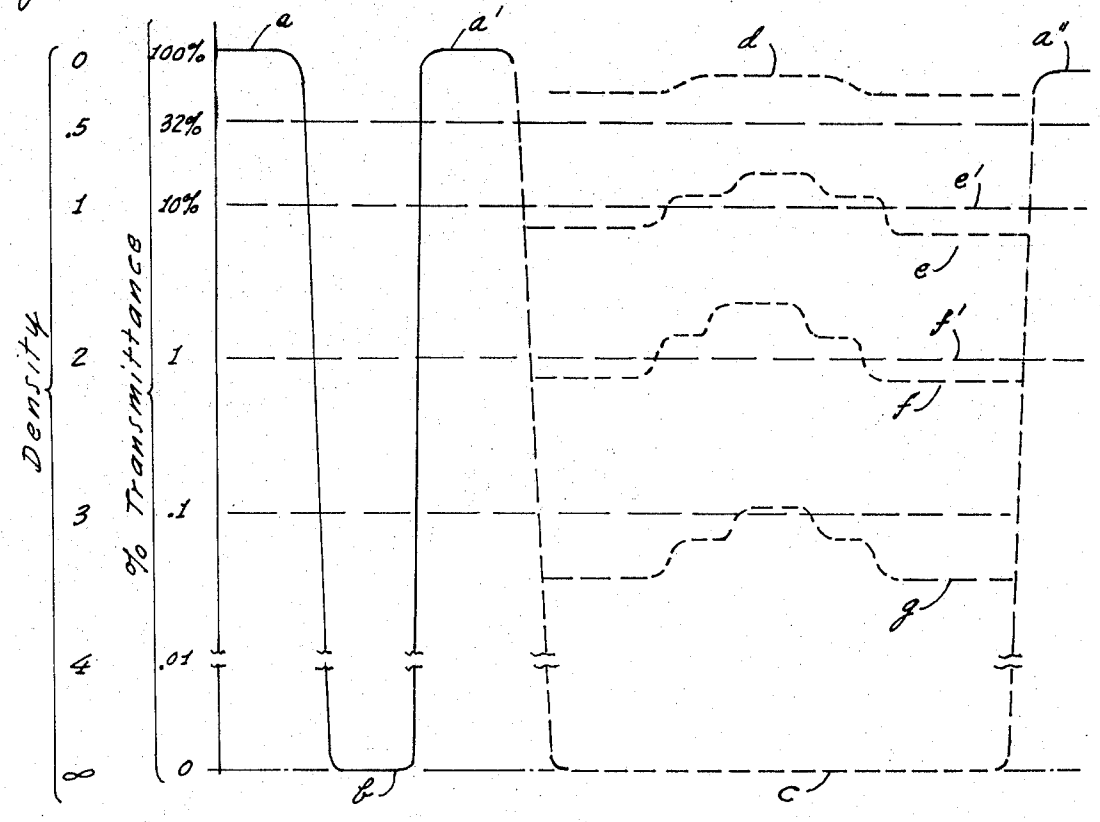

G1
"and"
"or"
Sw. 4
dv/dt
Differ.
M5
M6
A3
R7
60
1.0
3.0
G2
50
Output
M4
A2
R6
F3
G3
D9
F1
F2
R4
R5
M3
Sw. 3
Changed
Unchanged
D7
D8
C1
C2
Sw. 1
Sw. 2
M1
M2
V1
V2
D5
D6
R3
D3
D1
D2
D4
R2
R1
DLY
A1

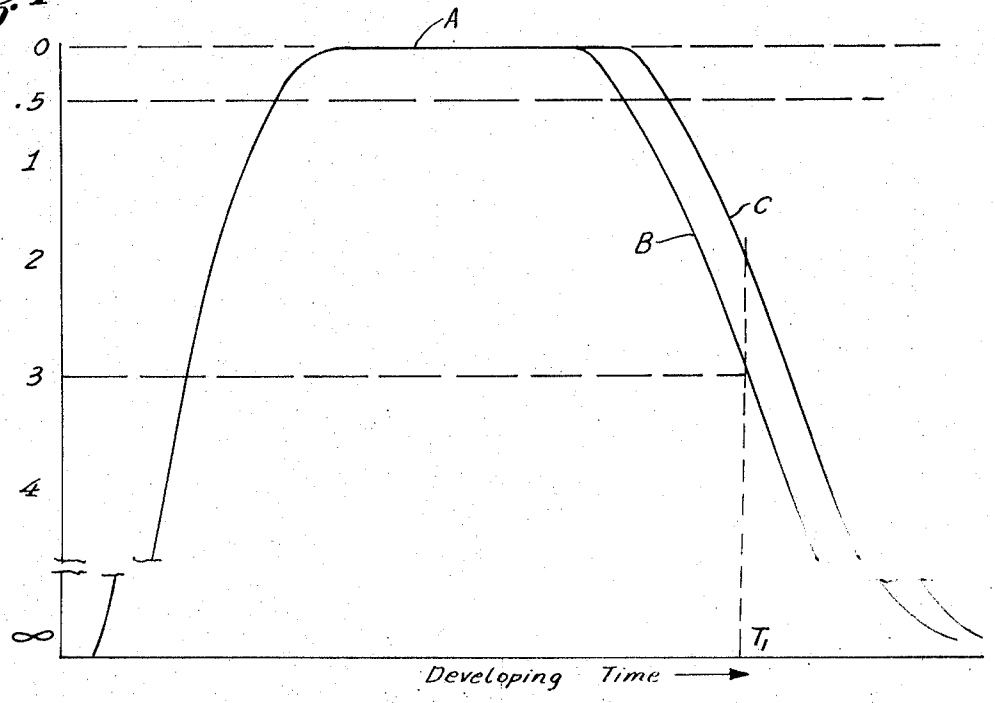
Fig. 2

Fig. 3



Video Signal During A Scan at Several Times During Development

Fig. 4



SCANNING TYPE PHOTOGRAPHIC FILM DEVELOPING SYSTEM AND APPARATUS

This application is a continuation of copending application Ser. No. 214,924 filed Jan. 3, 1972, and now abandoned, in the names of the present inventors.

BACKGROUND OF THE INVENTION

The photographic film developing system of the present invention is of the type described in copending application Ser. No. 141,538 which was filed May 10, 1971, and now abandoned, in the name of David Paul Gregg. The present system, however, involves scanning the film by means of a beam. The beam is derived, for example, from any appropriate radiant energy source to which the film is relatively insensitive; by subsequently transforming the energy in the beam passed through the film, and through the developer solution, into electrical signals; and by processing the electrical signals, as will be described. At present, light energy towards the red end of the visual spectrum has been found to be appropriate for the beam.

As pointed out in the copending application Ser. No. 141,538, a major problem in developing photographic film is the establishment of that developing time, which will permit a satisfactory density to be achieved, even though the film may have been over-exposed or under-exposed, even though the temperature of the developing solution may vary, or even when the age of the developing solution is unknown. This problem of proper density in X-ray films is especially prevalent in hospitals, clinics and dental offices, and it results in the technician's and doctors' either having to be satisfied with less than satisfactory density in the developed X-ray film, or his having to perform expensive and time-consuming retakes.

The system and apparatus described in the copending application Ser. No. 141,538 at present utilizes a red light beam as a basis for controlling the time in which the exposed X-ray film is actually submerged in the developing solution. Since the X-ray film is relatively insensitive to red light energy, there is little tendency for it to be fogged by the beam. Also, by pulsing the source, excessive heating of the source may be avoided.

The system of the present invention, as explained above, likewise uses an appropriate energy beam to which the film is relatively insensitive for controlling the time in which the X-ray film is actually to be submerged in the developing solution. As also explained, in the system of the present invention, the beam is scanned across the film, by any appropriate means, and the beam is subsequently detected and transformed into electrical signals, which are processed so that the appropriate control effects may be provided.

Therefore, in the practice of the present invention, an appropriate beam to which the film is relatively insensitive, which may be continuous or pulsed, is passed through the bath and developing solution and scanned across the film being developed within the bath. The bath is detected after it has passed through the developing solution and through the film, so that electrical signals may be produced whose amplitude corresponds to the local attenuation of the detected beam. When the film has been developed to a predetermined density, the amplitudes of the electrical signals reach a certain value. The electrical signals are used to provide a desired control effect, as will be described.

In the apparatus of the copending application Ser. No. 141,538, reflectors are used for directing the energy, so that it may be passed through the solution in the form of a beam whose cross-section approximates the area of the film being processed. In that case, the energy in the beam is averaged over the entire area of the film being developed, and local variations in the film density, such as are caused by tooth fillings, surgical clamps, and the like, have relatively little effect on the overall intensity of the beam. Under such conditions, the beam detected on the other side of the film has an amplitude determined by the overall contrast of the image being developed, as is desired.

In the system of the present invention, on the other hand, the beam has a small cross-section, and it is scanned across the film, and across the portions of the solution forming a margin around the film. The variations in the resulting electrical signals due to the aforesaid local variations which represent excessively opaque and transparent areas, are removed in the processing of the electrical signals, as are the variations in the electrical signals due to highly transparent areas, such as the areas of the developing solution around the margin of the film, as well as areas representing flesh. Specifically, the system is capable of detecting the presence of human flesh and of rejecting all other objects and transparent areas.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view, partly in block form, and somewhat schematically representing an appropriate system and apparatus for practicing the invention in one of its embodiments;

FIG. **2** is an electrical circuit diagram, partly in block form, showing the electrical processing system associated with the apparatus of FIG. **1**; and

FIGS. **3** and **4** are curves useful in understanding the operation of the system of the invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

As shown in FIG. **1**, the apparatus includes a transparent bath or tank **10** in which an appropriate developing solution is contained. An exposed photographic or X-ray film **12** is suspended in the solution in the tank **10** by a suitable film hanger **14.** The film hanger **14,** for example, may be part of an automatic film processing apparatus, whereby the film is carried from one bath to another during the developing process. An energy source **16** is provided. This source, for example, may be a red light emitting diode, a red laser, or any other appropriate type of energy source. The source may be pulsed, for example, at a rate of 1000 times a second by a suitable pulsing circuit represented by the block **18,** to prevent excessive heating. The pulse width may, for example, be of the order of 200 nanoseconds, although any appropriate parameters may be used. The source **16** is moved by any appropriate mechanical scanner indicated by the block **20,** or the film itself is moved, or both, so as to cause the beam from the source to be scanned across the tank **10** and across the film **12** within the tank. The scanning occurs, for example, in a series of repeated lines spaced slightly from one another until the entire film area is covered. The

resulting scanning rasters are repeated throughout the developing of the film.

The scanned beam, after it has passed through the transparent tank **10**, through the solution in the tank **10**, and through the film **12**, is detected by an energy detector and electrical transducer **30**. The scanning beam may be reflected to the detector from all its scanning positions by means, for example, of a reflector **32** of an ellipsoidal, or other suitable shape. The apparent source of the beam is always at one focus point of the imaginary whole ellipsoid and the detector is always at the other focus point. The reflector **32** is positioned on the opposite side of the tank **10** from the scanning source **16**. The detector **30**, for example, may be a silicon photo diode, or any other appropriate sensor may be used.

The electrical output from the energy detector **30** is applied to an electrical processing circuit designated **34** and which is described in detail in FIG. **2**. The output from the processing circuit **34** may be used, for example, to activate any appropriate indicator when a desired density has been achieved during the developing process of the X-ray film; or to operate an associated mechanism to cause the film **12** to be withdrawn from the tank **10** automatically at that time.

The electronic processing circuit **34** of FIG. **2** includes, for example, an amplifier A_1 which receives the electrical video signal from the IR detector **30**. The amplifier output is connected to a delay line DL_1, and also to a pair of diodes D_1 and D_3. The diodes D_1 and D_3 are connected in circuit with further diodes D_2 and D_4 at the output of the delay line DL_1, and with a pair of resistors R_1 and R_2, as shown. The resistor R_1 is connected to a positive potential source, and the resistor R_2 is connected to a negative potential source.

The diode circuit is connected to a pair of differential comparators M_1 and M_2, the comparators each having a second input terminal, one of which is connected through a diode D_5 to a source V_1, and the other being connected through a diode D_6 to a source V_2. The second input terminals of the comparators are interconnected by a resistor R_3. The outputs of the differential comparators M_1, and M_2 control respective electronic switches designated SW_1 and SW_2. The switch SW_1 switches a point *a* in the aforesaid diode circuit to a diode D_7, and the switch SW_2 switches a point *b* in the diode circuit to a diode D_8. The diode D_7 is connected at a point *c* to a grounded capacitor C_1, and to a low pass filter F_1; and the diode D_8 is connected at a point *d* to a grounded capacitor C_2 and to a low pass filter F_2. The filters are also connected to ground.

The output of the low pass filter F_1 is connected to a unity gain amplifier A_2, the output of which is connected by means of R_6 to the positive input of the comparator M_4. The low pass filter F_2 is connected to the negative input of comparator M_3, the output of which controls switch SW_3. The output signal at SW_2 is applied to the input of SW_3, and, through R_4, to the positive input of comparator M_3. A resistor R_5 is connected from the positive input of M_3 to a negative potential source. The output of SW_3 is connected to a diode D_9, and capacitor C_3, in a manner like SW_1 and SW_2, the output *e* is connected to a low pass filter F_3, which is in turn connected to the unity gain amplifier A_3, whose output is connected by R_7 to the positive input of M_4.

The output *h* of comparator M_6 is connected to an "and" gate G_1 and to one terminal of a rotary switch SW_4. The output of G_1 is connected to a second terminal of the switch SW_4. The output *g* of the comparator M_4 is connected to gate G_1 and to a third terminal of SW_4. The output dv/dt of the differentiator M_5 is connected to an "or" gate G_2, and the movable arm of the switch SW_4 is also connected to the gate G_2. The output from the processing circuit **34** appears at an output terminal **50** which is connected to the output of the gate G_2.

The processing circuit **34** of FIG. **2** converts the output of the amplifier A_1 into two signals, one undelayed and the other delayed in the delay line DL_1 by a small fraction of a single scan across the film **12**. Then, during each scan, the lesser of the two signals from the amplifier A_1 (delayed or undelayed) at any given moment appears at the junction "**1**" between the diodes D_1 and D_2; and the greater of the two signals (delayed or undelayed) at the same moment during each scan appears at the junction "**2**" of the diodes D_3 and D_4.

The comparator M_1 changes its output to render the switch SW_1 conductive when its input "**2**" is less than the voltage V_1. The voltage V_1 corresponds, for example, to a density of 0.5, or about 32 percent of the maximum transparency brightness that the film negative can achieve. Therefore, whenever the transparency exceeds the 32 percent level, the switch SW_1 is switched off, and such values do not affect the measurement of the film density. When the signal "**2**" applied to the comparator M_1 is less than the voltage V_1, however, the switch SW_1 is rendered conductive by the comparator M_1, so as to pass the lesser of the two signals appearing at the point "**1**." This lesser signal is passed through the diode D_7 to charge the capacitor C_1 positively. The capacitor C_1 is connected as a peak detector, and it follows the peak amplitude of the signal "**1**," as the scan continues. At the end of each scan, the charge on the capacitor C_1 holds, and it corresponds to the peak amplitude of the signal "**1**" during the preceding scan.

At the same time, the comparator M_2 changes its output to render the switch SW_2 conductive whenever the lesser of the two signals at point "**1**" is greater than the voltage V_2. The voltage V_2 is selected to represent a voltage corresponding, for example, to 0.1 percent of the maximum transparency value, or a density of 3.0. Therefore, any object which is encountered which makes the lesser voltage crop below the 0.1 percent value, during any scan, causes the switch SW_2 to be turned off, so that the density of that object is not included in the measurement of the average contrast. However, as long as the signal at point "**1**" is greater than the 0.1 percent level, as represented as V_2, the switch SW_2 is rendered conductive by the comparator M_2, and passes the greater signal at the point "**2**" through the diode D_8 to charge the capacitor C_2 negatively with respect to ground. The capacitor C_2 also is connected as a peak detector, and it measures the negative peaks of the signal at the point "**2**" during each scan.

Therefore, at the end of each scan, the charge across the capacitor C_1 is a positive value with respect to ground, and appears at a point "**3**" as representative of the lightest value of the scanned line, whereas the negative voltage developed across the capacitor C2 at the end of each scan represents the darkest value encountered during the scan, the latter signal appearing at the

point "4." The signals at the points "3" and "4" are filtered by the respective filters F_1 and F_2 which, as indicated, are low pass filters. The resulting signals at the outputs of the low pass filters F_1 and F_2 have a long time constant as compared with the scanning frame rate, so that maximum and minimum brightness over the entire film area is represented by such signals, with spurious changes due to opaque objects or excessive transparent areas being removed.

The negative-going, or maximum density signals are furthermore switched by SW_3 by the output of M_3. The inputs to M_3 are the maximum density determined as described above, and appearing at F_2, and the instantaneous result of SW_2, with a small fixed bias applied by R_4 and R_5 in such a way that the two inputs of M_3 are at the same potential when the signal from SW_2 is, say, a factor of 2 lighter, or showing a density of 0.3 less, than the maximum density value held at C_2 (signal *d*).

The switch SW_3 then switches on only when the value is 0.3 or more less dense than the peak density, this being then rectified by D_9 and stored in capacitor C_3 as signal *e*. This signal represents the darkest area which is at least 0.3 less dense than the densest portions of the image. For example, the background air surrounding an X-rayed subject, the darkest part of the film, is rejected from further processing.

With reference to FIG. 3, for example, scanning values are represented thereby as the developing process continues. For example, for each scan, a maximum brightness occurs at the part *a* of the curve as the beam passes through the solution surrounding the film negative. Then, a maximum dark line appears as the curve drops to *b*, as the beam encounters a bracket or support, or other opaque object. The beam then rises to a peak again as it moves to the margin of the film, the latter peak being designated *a'*. Then, early in the scanning process, and while the film is still coated with the opaque coating which is usual for such films, the scanning beam drops in intensity to the level represented as *c*, and this continues for each scanning line until the margin of the film is reached, and the beam again rises to the maximum brightness level, as represented by *a''*, as it again encounters the transparent solution.

It will be appreciated that for the initial part of the developing process, the effect of the beam is to continue to produce output signals corresponding in amplitude to the curve c, until the opaque coating is dissolved. Then, the film negative is revealed in its undeveloped and highly transparent state, so that the scanning beams exhibit a brightness for each scan as represented by the dotted curve *d*. This condition continues until the development starts, and the film negative begins to darken. Then the resultant of the scans drops to the level represented, for example, by *e*. As the developing process continues, the detected beam intensity then further drops to the values represented by *f*. If the developing process is continued too long, the whole film negative blackens, and the resultant intensity of the detected scanning beam drops to the value shown, for example, as *g*.

The circuit of FIG. 2, as thus far described, follows the curves *d*, *e*, *f*, and *g*, for example but rejects the peaks *a*, *b*, *a'*, *a''* and *c*, as being either less dense than 0.5, or more dense than 3.0 and subsequently rejecting those portions of the signal which pass the first criterion but which lie within, for example, 0.3 of the darkest portion, the limit being 3', and *f'* for *e* and *f* in FIG. 3. The outputs from the filters F_1 and F_2 as the developing process progresses, are represented by the curve of FIG. 4. For example, at the beginning of the developing process, during which any opaque coating which might or might not be present has not been dissolved from the film negative, the resulting dark signal results in corresponding signals from the filters F_1 and F_2. As any such coating is dissolved, the effect of the transparency rises to the peak A, and both the filters F_1 and F_2, during this interval, generate essentially the same amplitude signals, since no density has as yet been established. However, as the developing process progresses still further, and as the images are developed on the film negative, the two signals from the filters F_1 and F_2 decrease. However, the signal from the filter F_1, as represented by the curve C is of greater amplitude than the signal from the filter F_2, as represented by the curve B. Therefore, on the negative slope of the curves B and C, the difference in amplitude at any time, such as the time T_1 between the two curves represents the contrast. As the developing process is further continued, both curves drop to the minimum value, as the film becomes completely darkened.

The circuit of FIG. 2 may be adjusted in different ways to stop the developing process for different criteria. For example, if the switch SW_4 is set to terminal **1**, the output of the differential comparator M_6 is used to produce the output signal at the output terminal **50**, and this occurs when the darkest portion of the picture area being evaluated reaches a predetermined level, as determined by the setting of a potentiometer **60**. The differentiator M_5 assures that an output will be developed only in the presence of the increasing darkness, or increasing density, so as to prevent spurious outputs during the initial part of the developing process, and when the curve of FIG. 4, for example, is rising, rather than falling. This is implemented by applying the output of the differentiator M_5 to the "or" gate G_2, so that the "or" gate is enabled to permit an output to be produced, only at times of decreasing output from the filter F_2.

When the switch SW_4 is set to the terminal **3**, the output of the differential comparator M_4 is used to develop the output at the terminal **50**. In the latter case, the outputs from filters F_1 and F_3 are, with the aid of unity gain amplifiers A_2 and A_3, averaged by R_6 and R_7 so that the potential of the input of M_4 represents a density intermediate between the lightest and darkest areas being processed. By means of potentiometer **61**, the level at which M_4 changes its output is adjusted to signal when the above determined average density reaches the point where development should stop.

When the developing switch SW_4 is set to the number **2** contact, the output from the comparator M_4 is checked against an arbitrary value from the comparator M_6, so that the developing process can be stopped when the output from either of the comparators M_6 or M_4 becomes zero.

As explained above, many X-ray films are coated with an opaque coating which dissolves in the developer, and which should not be confused with video information. The differentiator M_5, as explained, develops a negative output when the slope of the dark curve (B in FIG. 4) is negative, indicating that the opaque coating has been dissolved, and the information is actu-

ally video information. Only during the latter condition is the stop command signal passed through the gate G_2 to the output terminal **50**. On the other hand, when the opaque coating is being dissolved, the darkness curve of FIG. **4** has a positive slope A, and the gate G_2 is disabled at this time, so as to prevent spurious outputs.

While the description is concerned with a linear type of X-ray negative whose transmittance is inversely proportional to the exposure, that is, the density is equal to the log of the exposure, which assumes the gamma to be **1**, the system can operate with films and developers giving a gamma other than **1**, whether by making the log amplifier A_1 adjustable, or making suitable allowances in the settings of potentiometers **60** and **61**.

Also, other combinations of indicators than the above illustrated average and maximum density of the selected picture can easily be used. For example, by filtering without peak deflection, the signals from SW_1 and SW_3, can be the RMS values of the lighter and darker densities, or some or all the signals could be passed through band pass filters and treated as AC signals, and finally be rectified and detected.

The invention provides, therefore, an automatic X-ray film developing system which permits a true optimum density, or any other percentage of contrast ratio, to be attained without the concomitant need for accurate control of the development bath temperature or of the developer solution. The system of the invention is advantageous in that it operates accurately with all sizes of X-ray film, since the light transmission through the marginal solution is not used in the determination of the contrast by the system. Moreover, the system also rejects any signals generated due to the presence of X-ray opaque materials, such as metallic prosthetics, dental fillings, and the like, and also background areas of air which surround many X-ray subjects, all of which otherwise would have a spurious effect on the determination of the desired image density. In addition, the system of the invention automatically compensates for under- or over-exposure of the X-ray film, as well as for variation in the sensitivity of the X-ray film from source-to-source and from lot-to-lot.

The foregoing features of the invention are accomplished by eliminating the time-of-development as the controlling factor of the developing process, and by substituting a continuous optical evaluation of the development quality as the developing process proceeds. This basic premise, together with the scanning technique, and associated electronics, enables the features of the invention to be achieved.

It is evident that although a particular embodiment of the invention has been shown as described, modifications may be made. It is intended in the following claims to cover all modifications which fall within the spirit and scope of the invention.

What is claimed is:

1. Photographic film developing apparatus and system including: a tank for a film developing solution; a source of radiant energy to which the film is relatively insensitive positioned to direct a beam of said energy through said solution in said tank; means for supporting a film to be developed in said tank in the path of said beam; scanning means coupled to said source for scanning said beam across said film; an energy detector positioned to receive the beam after it has passed through said flim for producing an electric signal representative of the intensity of said beam as received by said detector; and electrical circuit means coupled to said detector for developing an output indicative of when the density of the image developed on the film reaches a predetermined value, said circuitry including an input circuit coupled to said detector for developing a first signal which increases in amplitude as the brightness of the beam received by the detector increases from a reference level, and for developing a second signal which increases with amplitude as the brightness of the beam received by the detector decreases from a reference level, a first channel coupled to said input circuit for processing said first signal and including first peak detector means for producing a first output corresponding to the peak amplitude of the first signal, a second channel coupled to said input circuit for processing said second signal and including second peak detector means for producing a second output corresponding to the peak amplitude of the second signal; and an output circuit coupled to said first and second channels for developing the aforesaid output indicative of when the density of the image, or any portion of the image, developed on the film reaches a predetermined value.

2. The apparatus and system defined in claim **1**, and which includes first switching means included in said first channel for de-activating said first channel when the amplitude of said first signal exceeds a predetermined threshold, and second switching means included in said second channel for de-activating said second channel when the amplitude of said second signal exceeds a predetermined threshold.

3. The apparatus and system defined in claim **1**, in which said output circuit includes differential comparator means connected to said first and second channels for causing said output circuit to develop its output when the differential between said first and second signals reaches a predetermined level.

4. The apparatus and system defined in claim **1**, in which said output circuit includes differential comparator means connected to said second channel for causing said output circuit to develop said output when said second signal reaches a predetermined level.

5. The apparatus and system defined in claim **1**, in which said output circuit includes differential comparator means connected to said first channel for causing said output circuit to develop said output when said first signal reaches zero amplitude.

6. The apparatus and system defined in claim **1**, in which said output circuit includes differentiator means connected to one of said channels, and a gate circuit connected thereto, for preventing said output circuit from developing an output except during intervals when said first and second signals are decreasing in amplitude with time.

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