

PATENT SPECIFICATION

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(19)



(54) EXPOSURE CONTROL APPARATUS

(71) We, EASTMAN KODAK COMPANY, a Company organized under the Laws of the State of New Jersey, United States of America of 343 State Street, Rochester, New York 14650, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to automatic exposure control circuits and in particular to an exposure control circuit in which a variable exposure interval in accordance with actual scene lighting conditions and a constant maximum exposure interval is obtained when the scene lighting conditions fall below a predetermined level.

Automatic exposure control apparatus for use in cameras have generally functioned to evaluate scene brightness and regulate one or more exposure control parameters such as exposure duration or aperture size in correspondence with the level of scene brightness. Scene brightness evaluation is most often performed with light measuring circuits utilizing one or more photosensitive elements positioned in the camera to receive scene illumination. When utilizing the apparatus to control exposure duration, the system typically integrates the output of a photosensitive circuit. When the integrated output reaches a predetermined level, the exposure is terminated. One circuit, for example, includes an R-C network, the resistor component of which is provided by a photocell, whose resistance is functionally related to scene brightness. Another system uses a photovoltaic cell and operational amplifier having capacitive feedback to provide an integrated output of the cell photocurrent. By activating either of the example integration circuits simultaneously with opening of a shutter, the arrangement generates a voltage at the output of the integration circuit that varies at a rate related to scene brightness. A voltage sensitive trigger circuit responsive to the

output of the integration circuit terminates the exposure when such voltage reaches a predetermined level.

When utilizing such automatic exposure control apparatus in very low light conditions, without the use of an auxiliary lighting unit or tripod, the resulting exposure time may well be beyond the limit of time that the average camera operator is capable of holding a camera steady, and blurred photographs may result. To prevent such inadvertent blurred photographs, a limited maximum exposure time is incorporated into some automatic cameras; that is, the exposure duration is permitted to vary from the shortest interval to, for example, an interval of approximately 1/30 sec. as scene brightness decreases. At lower levels of scene brightness, all exposures are accomplished at 1/30 sec.

The most general technique for limiting the exposure duration in such cameras, while permitting the interval to vary over a range of intervals between the minimum exposure interval and an exposure interval that corresponds to the hand-held limit is to employ two timing circuits. A first timing circuit utilizing a photosensitive element and capacitor integrates a current proportional to scene brightness to provide a voltage which reaches the triggering value at a time corresponding to the scene brightness. A second timing circuit uses a fixed resistance and a capacitor to provide a voltage that reaches the desired triggering value in a predetermined time. Whichever voltage reaches the triggering value first will terminate the exposure. Thus if scene brightness is normal, the exposure interval provided by the first timing circuit (integrated current proportional to scene brightness) will be shorter than that provided by the second timing circuit (integrated current proportional to the predetermined brightness) and the apparatus will operate to terminate the exposure prior to the maximum exposure interval. If scene brightness is lower than normal, the first timing circuit generates an exposure interval that is longer

than the maximum; however, the second timing circuit operates to terminate the exposure at the maximum exposure interval.

The direct comparison of the outputs of the two timing circuits permits a smooth transition between the variable exposure interval and the constant, maximum exposure interval. However, two timing circuits are required, each requiring a capacitor for integrating a current.

It is an object of the present invention to provide improved exposure control apparatus which permits the exposure interval to vary in accordance with actual scene brightness over a range of intervals between a minimum exposure interval and a maximum exposure interval related to a predetermined scene brightness, after which exposure is constant.

According to the present invention there is provided an exposure control apparatus comprising a first circuit providing a photocurrent corresponding to scene brightness incident thereon, and a second circuit providing a reference current corresponding to the photocurrent at a predetermined minimum scene brightness, the first and second circuits being connected to a switch so as to provide an output current from said switch equal to the difference between the reference current and the photocurrent when the reference current is greater than the photocurrent, and to provide no output current from said switch when the photocurrent is greater than the reference current and means for integrating the photocurrent and the switch output current and providing therefrom a signal for controlling the exposure time.

There is further provided a method of controlling photographic exposure comprising the steps of producing a photocurrent corresponding to scene brightness, producing a reference current corresponding to the photocurrent at a predetermined minimum scene brightness, producing an output current equal to the difference between the reference current and the photocurrent when the reference current exceeds the photocurrent, and producing no output current when the photocurrent exceeds the reference current, and integrating the photocurrent and the output current to provide an exposure time control signal.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

Fig. 1 shows an exposure control circuit of the present invention; and

Fig. 2 shows an operating curve of exposure time over a range of scene brightness produced by the circuit of Fig. 1.

An exposure control circuit in accordance with the present invention,

generates a timing signal for shutter control that is useful in cameras, printers or other apparatus requiring control of the operation of a shutter in relation to light intensity.

Referring to Fig. 1, a photometric section 1, in its basic configuration, includes a photovoltaic cell such as a silicon photodiode 10, that for example may be mounted upon a camera structure in order to evaluate light levels of the scene coincident with the field of view of the camera. The output of the photodiode 10 is connected to an input 11 of a current amplifier 12.

It is well known to couple a photodiode with an amplifier so that the output characteristics of the photodiode 10 may be considered linear and be useful in light level measurement. Conventionally, the photodiode 10 is coupled with an "operational amplifier" having a feedback system such that the photodiode 10 is "zero biased" i.e. no voltage drop appears across the photodiode 10 when the system is balanced. Such systems enable the short circuit current of the photodiode to be measured, and are commonly referred to as current-to-voltage converters. An example of such a system may be found in U.S. Patent No. 3,053,985. The amplifier 12 may be any one of a number of integrated circuit devices known for amplifying a current input thereto and having the feature of cooperating with the photodiode 10 such that the photodiode 10 is zero biased when the circuit is in a balanced state. Such amplifiers for use in the circuit of the present invention are preferably single-ended input devices with a single supply rail, VCC; however, the invention is not limited to single-ended input amplifiers. The amplifier 12 preferably has unity gain such that its output current is equal to the short circuit current of the photodiode 10.

To provide the current for zero biasing the photodiode 10 and current for use by a Current Processing Section 3 to develop a timing current, the output current from the amplifier 12 is coupled to the base 19 of a multicollector PNP transistor 20. The transistor 20, has its emitter 21 coupled to the supply rail VCC and each of the three collectors 22, 23, 24 has an equal percentage of the total emitter current flowing in the transistor 20. The two collectors 23, 24 are coupled back to the cathode of the photodiode 10 and provide a feedback current to the amplifier 12 and the photodiode 10 that is equal to twice the output current from the amplifier 12. The amplifier 12 is such that the current flowing in collectors 23, 24 will divide equally between the amplifier 12 and the photodiode 10, when the circuit is in balanced state, the photodiode 10 then

being zero biased. During an unbalanced state of the circuit, as when the light impinging on the photodiode 10 increases, the photodiode 10 will attempt to generate a higher short circuit current than the current at the output of the amplifier 12. As a result, the photodiode 10 begins to operate in a "photovoltaic" mode in which it exhibits a forward voltage, the cathode becoming slightly negative. The current distribution between the amplifier 12 and photodiode 10 will therefore become unequal. The currents in the collectors 23, 24 have not changed and provide twice the output current of the amplifier 12; thus a net increase in current appears at the input 11 of the amplifier 12 that creates a net increase in the current at the output of the amplifier 12. The net current at the output of the amplifier 12 biases the transistor 20 to increase the value of the current in the collectors 23, 24 until the division of current between the photodiode 10 and amplifier 12 again becomes equal, i.e. the circuit is balanced. The current in the collector 22 similarly is increased.

The current flowing in the collector 22 is considered to be the output of the Photometric Section 1, and is connected to an Amplification and Expansion Section 2. To amplify the current in the collector 22 to a "working" current level, the collector 22 is coupled to an amplifier 25 which may be a conventional current amplifier connected to the supply rail VCC. The current at the output of the amplifier 25 is coupled to the base 28 of a second multicollector PNP transistor 29, whose emitter 30 is connected to the supply rail VCC, and of which each of the two collectors 32, 24 carries an equal share of the current flowing in the emitter circuit. The current flowing in the emitter-collector circuit of the transistor 29 is functionally related to the short circuit current of the photodiode 10 by the gain factors in the Photometric and Amplification and Expansion Sections 1 and 2 respectively. Thus as may be seen, two equal photocurrents are available from the Amplification and Expansion Section 2 for use in the Current Processing Section 3 and these will hereafter be referred to as the photocurrent I_A .

Briefly, the Current Processing Section 3, couples a reference current source and a photocurrent source to a diode such that the diode conducts a current, which will be referred to as a difference current, only when the photocurrent is less than the reference current, and the difference current is then summed with an additional photocurrent which is then applied to an integrating circuit. Thus when the photocurrent is less than the reference current, a current equal to the reference

current is integrated; however, when the photocurrent is greater than the reference current, the photocurrent is integrated. The photocurrent source is the collector 34 of the transistor 29, coupled to a so-called "current mirror" comprising two NPN transistors 36, 37 that are coupled together base-to-base and emitter-to-emitter, the transistor 36 having its collector coupled to its base. Since the bases are emitters of the transistors 36, 37 are directly connected, transistor 37 will attempt to draw a collector current identical to that of transistor 36; i.e. I_A . Thus, a photocurrent flowing from the collector 34 through the collector of the transistor 36 is mirrored in the collector of the transistor 37. A PNP current mirror consisting of transistors 51, 52 is coupled to a Reference Current and Voltage Source 53. The Reference Current supplied by the source 53 is connected to the collector of the transistor 51, and is mirrored in the collector of the transistor 52 to provide the reference current, indicated as I_{ref} in Fig. 1. The reference current has a level proportional to the photocurrent at a predetermined scene brightness, and determines the "transition" point of the timing circuit, i.e., a point at which the exposure interval goes from a variable interval to a constant interval. To permit a smooth transition between the variable interval and the constant interval, the collectors of the transistors 37, 52 are coupled to the anode of a diode 48. The diode 48 passes a current that is equal to the difference between the reference current and the photocurrent when the magnitude of the reference current is greater than that of the photocurrent, and blocks the passage of current when the reference current is less than the photocurrent. The cathode of the diode 48 is coupled to a summing node 54, to which the collector 32 of the transistor 29 is also coupled. The node 54 is coupled to one terminal of a capacitor 55 that has the second terminal connected to ground. The capacitor 55, and thus the node 54 are shunted to ground by a normally closed switch S_1 . The timing cycle is initiated by opening the switch S_1 . It is apparent that the polarity of the elements such as the diode 48, PNP and NPN current mirrors, and other necessary elements may be reversed and then the capacitor 55 may be initially charged and permitted to discharge upon initiating the timing cycle.

The node 54 is also connected to one terminal of a trigger circuit 57. A second input terminal of the trigger circuit 57 is coupled to a reference voltage that is related to the threshold of the trigger circuit 57 and is supplied by the Reference Current and Voltage Source 53. The trigger circuit 57 may be a conventional high gain

differential comparator circuit having a single-ended output. The function of the trigger circuit 57 is to compare the voltage appearing at the node 54 with the reference voltage. When the voltage at the node 54 exceeds the reference voltage, the output of the trigger circuit 57 is switched to a nonconducting state thereby terminating the flow of current through a coil 58.

The operation of the exposure control circuit will be considered firstly when the scene brightness is above the predetermined level and the relative magnitude of the photocurrent is greater than that of the reference current. In such a case, the transistor 37 saturates because it cannot obtain sufficient operating current from the transistor 52, the potential at the anode of the diode 48 is lowered toward ground and the diode 48 becomes reverse biased. The diode 48, being reverse biased, does not pass current to the node 54, and only the photocurrent from the collector 32 charges the capacitor 55 after the switch S_2 is opened. An exposure of shorter duration than the predetermined maximum will result. On the other hand, if the scene brightness is below the predetermined level, the relative magnitude of the reference current exceeds that of the photocurrent. The collector of the transistor 52, which requires a current at least equal to the reference current to sustain its operation, can only obtain a current equal to the photocurrent, thus attempts to saturate. As the transistor 52 attempts to saturate, the potential at the anode of the diode 48 is increased toward VCC. The diode 48 thus becomes forward biased and passes a current to the node 54 that is equal to the difference between the reference current and the photocurrent. The photocurrent from the collector 32 also appears at the node 54. Upon opening the switch S_2 , the current that charges the capacitor 55 is therefore equal to $I_{ref} - I_{ph} + I_{ph}$, or is equal to the reference current. As previously stated, the reference current is of a level related to a predetermined scene brightness, being the brightness at which the maximum exposure interval is desired.

In the event that a limited time exposure is undesirable, such as during tripod mounting of the camera, a switch S_1 , coupled between the anode of the diode 48 and ground, shunts the anode of the diode 48 to ground and the only current available to charge the capacitor 55 is the photocurrent from the collector 32. The resulting exposure time may then exceed the predetermined maximum depending upon scene brightness.

A graph of exposure times provided by the circuit over a range of scene brightness

is shown in Fig. 2. During operation of the circuit when the switch S_1 is open, the timing signal follows the solid curve as scene brightness decreases. At some predetermined level, for example at approximately 100 Ft-lamberts illumination on the photodiode 10, the signal becomes constant at approximately the exposure duration equivalent to the duration (e.g. 1/30 sec.) that the camera may be handheld during the entire exposure. During operation of the circuit when the switch S_1 is closed, the timing signal does not become constant but continues in a straight line to provide an exposure in excess of the duration that the camera can be handheld steady. During operation along the dotted line, a tripod should be used.

WHAT WE CLAIM IS:—

1. An exposure control apparatus comprising, a first circuit providing a photocurrent corresponding to scene brightness incident thereon, and a second circuit providing a reference current corresponding to the photocurrent at a predetermined minimum scene brightness, the first and second circuits being connected to a switch so as to provide an output current from said switch equal to the difference between the reference current and the photocurrent when the reference current is greater than the photocurrent, and to provide no output current from said switch when the photocurrent is greater than the reference current, and means for integrating the photocurrent and the switch output current and providing therefrom a signal for controlling the exposure time.
2. An exposure control apparatus as claimed in Claim 1, wherein the switch includes a diode, the photocurrent and the reference current being connected to one terminal of the diode, and the photocurrent being connected to the other terminal of the diode.
3. An exposure control apparatus as claimed in Claim 2, wherein the switch further includes a first current mirror connected between the first circuit and the diode, and a second current mirror connected between the second circuit and the diode.
4. An exposure control apparatus as claimed in Claim 1, 2 or 3, wherein the integrating means includes a capacitor.
5. An exposure control apparatus as claimed in Claim 4, further comprising a trigger circuit connected to the capacitor and responsive to the charge on the capacitor to provide the signal for controlling the exposure time.
6. An exposure control apparatus as claimed in any preceding claim, wherein

5 differential comparator circuit having a single-ended output. The function of the trigger circuit 57 is to compare the voltage appearing at the node 54 with the reference voltage. When the voltage at the node 54 exceeds the reference voltage, the output of the trigger circuit 57 is switched to a nonconducting state thereby terminating the flow of current through a coil 58.

10 The operation of the exposure control circuit will be considered firstly when the scene brightness is above the predetermined level and the relative magnitude of the photocurrent is greater than that of the reference current. In such a case, the transistor 37 saturates because it cannot obtain sufficient operating current from the transistor 52, the potential at the anode of the diode 48 is lowered toward ground and the diode 48 becomes reverse biased. The diode 48, being reverse biased, does not pass current to the node 54, and only the photocurrent from the collector 32 charges the capacitor 55 after the switch S_2 is opened. An exposure of shorter duration than the predetermined maximum will result. On the other hand, if the scene brightness is below the predetermined level, the relative magnitude of the reference current exceeds that of the photocurrent. The collector of the transistor 52, which requires a current at least equal to the reference current to sustain its operation, can only obtain a current equal to the photocurrent, thus attempts to saturate. As the transistor 52 attempts to saturate, the potential at the anode of the diode 48 is increased toward VCC. The diode 48 thus becomes forward biased and passes a current to the node 54 that is equal to the difference between the reference current and the photocurrent. The photocurrent from the collector 32 also appears at the node 54. Upon opening the switch S_2 , the current that charges the capacitor 55 is therefore equal to $I_{ref} - I_A + I_A$, or is equal to the reference current. As previously stated, the reference current is of a level related to a predetermined scene brightness, being the brightness at which the maximum exposure interval is desired.

55 In the event that a limited time exposure is undesirable, such as during tripod mounting of the camera, a switch S_3 , coupled between the anode of the diode 48 and ground, shunts the anode of the diode 48 to ground and the only current available to charge the capacitor 55 is the photocurrent from the collector 32. The resulting exposure time may then exceed the predetermined maximum depending upon scene brightness.

60 A graph of exposure times provided by the circuit over a range of scene brightness

is shown in Fig. 2. During operation of the circuit when the switch S_3 is open, the timing signal follows the solid curve as scene brightness decreases. At some predetermined level, for example at approximately 100 Ft-lamberts illumination on the photodiode 10, the signal becomes constant at approximately the exposure duration equivalent to the duration (e.g. 1/30 sec.) that the camera may be handheld during the entire exposure. During operation of the circuit when the switch S_3 is closed, the timing signal does not become constant but continues in a straight line to provide an exposure in excess of the duration that the camera can be handheld steady. During operation along the dotted line, a tripod should be used.

WHAT WE CLAIM IS:—

1. An exposure control apparatus comprising, a first circuit providing a photocurrent corresponding to scene brightness incident thereon, and a second circuit providing a reference current corresponding to the photocurrent at a predetermined minimum scene brightness, the first and second circuits being connected to a switch so as to provide an output current from said switch equal to the difference between the reference current and the photocurrent when the reference current is greater than the photocurrent, and to provide no output current from said switch when the photocurrent is greater than the reference current, and means for integrating the photocurrent and the switch output current and providing therefrom a signal for controlling the exposure time.

2. An exposure control apparatus as claimed in Claim 1, wherein the switch includes a diode, the photocurrent and the reference current being connected to one terminal of the diode, and the photocurrent being connected to the other terminal of the diode.

3. An exposure control apparatus as claimed in Claim 2, wherein the switch further includes a first current mirror connected between the first circuit and the diode, and a second current mirror connected between the second circuit and the diode.

4. An exposure control apparatus as claimed in Claim 1, 2 or 3, wherein the integrating means includes a capacitor.

5. An exposure control apparatus as claimed in Claim 4, further comprising a trigger circuit connected to the capacitor and responsive to the charge on the capacitor to provide the signal for controlling the exposure time.

6. An exposure control apparatus as claimed in any preceding claim, wherein



the first circuit comprises a photodiode and means to zero bias the photodiode.

- 5 7. An exposure control apparatus substantially as hereinbefore described, with reference to and as illustrated in the accompanying drawings.

8. A photographic camera comprising an exposure control apparatus as claimed in any preceding claim.

- 10 9. A method of controlling photographic exposure comprising the steps of producing a photocurrent corresponding to scene brightness, producing a reference current corresponding to the photocurrent at a
15 predetermined minimum scene brightness, producing an output current equal to the

difference between the reference current and the photocurrent when the reference current exceeds the photocurrent, and producing no output current when the photocurrent exceeds the reference current, and integrating the photocurrent and the output current to provide an exposure time control signal. 20

10. A method of controlling photographic exposure as claimed in Claim 9 and substantially as hereinbefore described. 25

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