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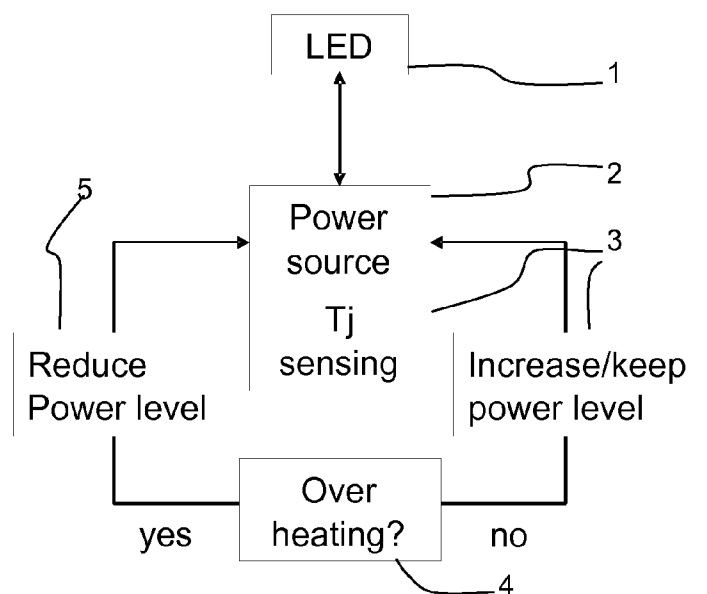
(54) **Title:** LIGHTING UNIT WITH TEMPERATURE PROTECTION

FIG. 1

(57) **Abstract:** A method of operating a light emitting diode (1) comprises operating the light emitting diode to provide a desired brightness output and estimating the junction temperature of the light emitting diode based on electrical drive parameters of the light emitting diode. A threshold is derived which determines if there is overheating, and the light emitting diode is operated within the threshold. This method uses junction temperature estimation to implement a system which provides protection from overheating. The method allows an LED to be used at its maximum potential in term of light generation whilst avoiding the need for external temperature measurement.



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DESCRIPTION

LIGHTING UNIT WITH TEMPERATURE PROTECTION

5 This invention relates to lighting devices using light emitting diodes (LEDs), and particularly to the control of such devices to provide temperature protection.

 Lighting using solid-state devices such as LEDs is gaining momentum.
10 The use of LEDs for lighting has several advantages over the use of conventional light sources, including a better light output/dimension ratio, improved quality of light, the ability to change light color as well as the long life time of the LED devices (50000 hours as compared to 2000 hours of incandescent light bulb).

15 LED light emission efficiency is also approaching that of conventional light sources.

 However, LED lighting has one intrinsic problem. Without proper control of the drive signals, the lifetime and the performance of the LED device can be seriously compromised. The main problem is that the performance
20 deteriorates as the temperature at the junction of the LED increases. Like many other electronic devices, when an LED operates at higher nominal temperature, it will have a shorter life time.

 The light output intensity of a LED can be controlled by either:

- (a) regulating the amplitude of the current through the LED, or
- 25 (b) regulating the frequency and duty cycle of the current pulse through the LED.

 A combination of both techniques can also be used. In an ideal LED device, the amount of light output should be linearly dependent on the amount of input power.

30 During operation, the LED temperature increases and this influences the amount of light output of the LED as well as the dominant wavelength of the output light.

It has been recognised that either temperature measurement or optical analysis of the light output is desirable to provide feedback for use in controlling the LED driver conditions, for example to provide a constant light output level. This feedback can compensate both for temperature dependent effects and for ageing of the LED.

However, this feedback results in more power being fed to the LED, making it even hotter and becoming even less efficient. This can result in a thermal runaway situation where all the additional power turns directly into heat that heats up the LED. Operating at high temperature not only degrades the light generation efficiency of the LED but also drastically reduces the LED life time.

The most common method to guarantee constant light output level of a LED without this thermal runaway problem is to use an LED with higher power rating than necessary. In this way, there is a relatively large safety margin from a thermal runaway situation. This method is relatively expensive especially for lighting fixture that requires several LEDs.

Another popular method to prevent thermal runaway is to use a thermal sensor closely positioned to the LED. Upon the detection of overheating, the amount of power sent to the LED is automatically reduced. The use of an external sensor has disadvantages: it requires extra wiring and a discrete sensor that increases the total cost of the system. Furthermore, the sensor does not give the temperature value at the LED junction, which is most representative of the thermal condition of the LED. The real temperature at the LED junction is usually higher. This can result in overheating at the LED junction for a period of time before it is detected. This is especially problematic for LEDs in an environment that has poor thermal dissipation design.

There is therefore a need for a low cost and simple apparatus and method which provides protection for thermal runaway in an LED lighting unit.

According to the invention, there is provided a method of operating a light emitting diode, comprising:

operating the light emitting diode to provide a desired brightness output;

estimating the junction temperature of the light emitting diode based on electrical drive parameters of the light emitting diode;
deriving a threshold which determines if there is overheating; and
operating the light emitting diode within the threshold.

5 This method uses junction temperature estimation to implement a system which provides protection from overheating. The method allows an LED to be used at its maximum potential in term of light generation. The invention provides a low cost solution for LED protection and at the same time lifetime improvement, by using junction temperature estimation based on the
10 electrical conditions of the LED. This avoids the need for external temperature measurement.

Deriving a threshold can comprise setting a threshold temperature level, and operating the light emitting diode within the threshold then comprises monitoring the temperature in use, and lowering the power drive level when
15 overheating is detected. This provides an active temperature sensing and control loop which can function during operation of the LED.

In an alternative approach, deriving a threshold can comprise deriving a maximum power level from a junction temperature during normal operation, and operating the light emitting diode within the threshold then comprises
20 using a power drive level below the threshold. This "normal operation" can then be a stabilised drive condition established during a calibration step. In this way, the overheating protection does not require any feedback loop during use of the LED- instead modelling of the LED characteristics has taken place during calibration.

25 Deriving a maximum power level can comprise driving the light emitting diode at a constant power, and determining a thermal power of the light emitting diode, and setting a maximum power based on the maximum allowed junction temperature.

Estimating the junction temperature of the light emitting diode, based on
30 the electrical characteristics, can comprise:

driving a forward bias current through the diode, the current comprising a square wave which toggles between high and low current values, the high

current value comprising an LED operation current, and the low current comprising a non-zero measurement current;

sampling the forward bias voltage drop, and determining the forward bias voltage drop at the measurement current; and

5 deriving the temperature from the determined forward bias voltage drop.

This method uses measurement current pulses for driving the LED with a low non-zero current. This allows the LED temperature measurement to take place while the LED is in operation (either in use or as part of the stable calibration phase). The low measurement current pulses are alternated (in a square wave pulse sequence) with high current LED drive pulses.

10 The low measurement current pulses may have a current less than or equal to 1mA.

Preferably, determining the forward bias voltage drop comprises analysing the samples to find a forward bias voltage drop which corresponds to a peak in the number of occurrences of that voltage drop.

15 In this way, the samples are analysed to detect a local peak in the number of occurrences of measured voltage drops. The detected peak corresponds to the voltage drop associated with the fixed low measurement current. There may be other peaks corresponding to the drive current, but the voltage drop corresponding to the low current will be the peak at the lowest voltage. Analysing the samples can comprise deriving a histogram.

The use of multiple pulses and a histogram helps to average out the variations in measurement current and therefore improve the accuracy of the measurement. In this method, no extra temperature sensor is required and therefore it lowers the cost of the system as a whole.

25 The invention also provides a system for operating a light emitting diode, comprising:

a driver for operating the light emitting diode to provide a desired brightness output;

30 a system for estimating the junction temperature of the light emitting diode based on electrical drive parameters of the light emitting diode; and

means for deriving a threshold which determines if there is overheating, wherein the driver is operable to control the light emitting diode within the derived threshold.

The system for estimating the junction temperature of the light emitting diode can comprise:

means for driving a forward bias current through the diode, the current comprising a square wave which toggles between high and low current values, the high current value comprising an LED operation current, and the low current comprising a non-zero measurement current;

means for sampling the forward bias voltage drop, and determining the forward bias voltage drop at the measurement current; and

means for deriving the temperature from the determined forward bias voltage drop.

Examples of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a first overheating protection circuit of the invention;

Figure 2 shows a second overheating protection circuit of the invention;

Figures 3A to 3D are graphs to explain the junction temperature estimating method of the invention; and

Figure 4 shows the system of the invention.

The invention provides a method of protecting an LED from overheating, based on estimation of the junction temperature of the LED. Two different approaches are proposed: (i) in-situ detection and control; and (ii) initial determination of the thermal resistance of the system and a maximum allowed electrical drive power.

Figure 1 is a block diagram of a system based on the first approach above, which comprises an active junction temperature detection and control circuit for a LED in accordance with the invention.

The circuit comprises the light emitting diode (LED) 1, an LED driver 2 and a system 3 for estimating the junction temperature of the LED.

The system 3 is described further below, and allows junction temperature measurement based on electrical measurements relating to the signals flowing in the power supply wires to the LED.

A closed loop control is provided to protect the LED from overheating. This control loop comprises comparing the estimated junction temperature with a threshold to detect overheating, as shown by block 4. If overheating is detected, the power used to electrically drive the LED is reduced (block 5), or else the power is maintained (block 6). If the power level has been reduced, and the temperature has stabilised, the power can be increased in block 6.

The system may of course be applied to multiple LEDs which are working in unison, such as in a backlight for an LCD TV. If an overheating event is detected on one LED cluster, an overall power reduction of all the LED clusters in the system may be triggered. In this way, uniformity (color and flux) of light output across the whole set can be maintained.

This method thus provides direct comparison of the junction temperature with a threshold during operation of the LED.

An alternative approach is to use the junction temperature estimation to enable a model of the LED characteristics to be derived, which can then be used to set an electrical threshold, which does not require monitoring during use of the LED.

Figure 2 shows an example of this approach. By driving the LED at a constant power and measuring its junction temperature when it is stable, for example in a calibration phase, the thermal resistance of the system which includes the LED can be determined, by:

25

$$h = P(1-\eta)/(T_j - T_{\text{ambient}}) \quad (1)$$

where h is thermal resistance between the LED junction and the ambient environment, P is the electrical input power, η is a luminous efficiency factor and T_{ambient} is the temperature of the ambient environment.

Based on this data, a maximum allowed power to be supplied to the LED can be deduced:

$$P_{\max} = h \cdot (1/(1 - \eta)) \cdot (T_{j-\max} - T_{\text{ambient}}) \quad (2)$$

where $T_{j-\max}$ is the maximum allowed junction temperature of the LED to
5 ensure a long lifetime.

This maximum power level sets the threshold for power feeding to the
LED.

As shown in Figure 2, the system comprises the LED 1, power source 2
and junction temperature sensing system 3, and a processor (not shown)
10 which determines the thermal resistance of the system (block 7) and the
maximum allowed power (block 8). This is then used to control the LED driver
2.

The temperature sensing and calculations (i.e. all functions enclosed by
dotted line 9) can be part of a calibration stage. By enabling the required
15 measurements and calculations as a calibration stage, a lower cost version of
overheating protection is provided.

Although all LEDs have a specification sheet in which the maximum
allowed power is specified, such data are measured from LEDs in totally
different conditions than the LEDs in a specific system with its associated heat
20 sink and neighboring devices. Thus, the approach described provides greatly
improved overheating protection.

An example of method (and apparatus) to measure the junction
temperature of a LED with good accuracy will now be described. The example
of method described uses square wave current pulses, in which the high level
25 (I_{high}) is an operational current of the LED and the low level is a measurement
current. Of course, trapezoidal pulse shapes with two distinctive current levels
will work equally well.

By monitoring the forward voltage (V_f) of the LED over time, two
dominant values will be found (if the operational current is constant over the
30 monitoring period), one of which is representative of the real temperature at
the LED junction during operation. A histogram of the forward voltage drops
can be used for the data analysis.

Figures 3A to 3D are graphs which schematically represent an example of junction temperature estimation method which can be used.

Figure 3A shows the drive current applied to the LED. A pulsed current source is used to drive the LED. The pulses drive a forward bias current through the diode, and the current is in the form of a square wave which toggles between high and low current values.

The low current value is a measuring current, preferably smaller or equal to 1mA. More preferably this current is less than 500 μ A, more preferably less than 100 μ A, even more preferably less than 50 μ A and even more preferably less than 10 μ A, for example in the region of 5 μ A.

A low measurement current (for example less than 1mA) is desired for two main reasons. Firstly, if a LED is driven at large current, the self-heating effect starts, which means a less accurate measurement is obtained. The self-heating effect has been found by the applicant to be significant above currents of 1mA. The self-heating effect depends on the thermal design of the LED package, and is therefore different for different LED designs.

Secondly, the larger the current, the brighter the LED. In an application such as 2D dimming TV, the minimum light level emitted from the backlight should not be more than 1% of the maximum illumination level. This 2D dimming system is a backlight control method in which only parts of the backlight are illuminated so that improved contrast between bright and dark areas of an image can be obtained.

The desire for low light output for the measurement phase means that the lowest possible current is required, but the current needs to be sufficient for the LED to be forward biased so that the voltage can be measured.

These considerations will all be taken into account when selecting the measurement current, and the value will depend on the intended use of the LED, the thermal properties of the packaging, and the LED characteristics.

Figure 3B shows the resulting forward bias voltage drop V_f across the diode.

The forward bias voltage drop is sampled at regular intervals, and the sampling instants are shown as filled circles in the plot of Figure 3B.

At each sampling instant, the voltage is measured, and a histogram counter monitors this LED voltage V_f , and determines the dominant value of voltage drop.

This is achieved by creating the histogram as shown in Figure 3C. As shown, there are two peaks in the count number. The peak in the count number corresponding to the higher voltage drop derives from the drive current (as this has been shown as constant in Figure 3A). The peak in the count number corresponding to the lower voltage drop derives from the measurement current, and this peak represents the forward bias voltage drop at the low current measurement value.

The LED junction temperature can be determined by relating the dominant forward bias voltage drop corresponding to the measurement current with a calibrated curve or an analytical model of the relationship between forward bias voltage V_f and temperature T . This relationship is shown schematically in Figure 3D.

The LED performance is determined by the temperature at its junction.

An analytical function is used to define the relationship shown in Figure 3D, giving very low memory requirement. The output flux of the LED is controlled by the high current value of the current drive sequence, as well as the pulse frequency and the duty cycle. However, the measurement current value is unchanged throughout the operation.

At the operational current, the LED junction is heated up leading to the so-called self heating effect. Measurement using this current is therefore much less accurate (the measured temperature is always more or less than the actual temperature in this dynamic situation). An error in the temperature determination will of course have a large impact on the accuracy of the control scheme. At the operation current, especially for high power LEDs (~ 100mA drive current) the contact and wiring resistance to the LED plays an important role. The variation of contact and wiring resistance can cause the forward bias voltage drop to vary typically by a few tens of mV at the operational current, which in turn gives errors to the junction temperature determination. Typically, the slope of the V_f vs. T curve is only few mV per degree Celsius.

For different currents, the slope of the V_f vs. T curve will be different. Thus, if the LED temperature is to be determined by the forward bias voltage drop at operational currents, the control will be difficult because when different output flux of the LED is required, the drive current has to be changed.

5 It is computationally not practical to provide an analytical model of the forward bias voltage drop both as a function of temperature and drive current.

The approach above provides a constant measurement current so that a model of the relationship between the corresponding forward bias voltage drop and temperature can be easily derived and stored, avoiding the need for
10 look up tables, which introduce unwanted discretisation.

Another advantage of measuring the voltage drop (and therefore temperature) at low current (for example less than 1mA) is that in some applications, such as backlighting for an LCD panel, it enables a dimming operation to be implemented, where a fast dynamic response to a requirement
15 for a light output change, and high contrast between light and dark, is required. The light output can be altered by changing the duty cycle of the current waveform, and the low measurement current results in very little light emission, so that good dark performance can be obtained.

Figure 4 shows a system for estimating the junction temperature using
20 the method described above.

A current source circuit 10 is used for driving a forward bias current through the diode 11, and this current comprises the square wave described above. Any suitable current source circuit can be used for this purpose.

The forward bias voltage drop is sampled by a voltage measurement
25 circuit 12, and the samples are provided to a processor 14. The processor 14 stores the analytical function representing the voltage-temperature characteristics, and determines the forward bias voltage drop at the measurement current based on the histogram analysis described above. The processor derives the temperature from the determined forward bias voltage drop using the function.
30

The invention can be used to determine LED junction temperature for LED performance control. For example, for this purpose, Figure 4 shows the

current source 10 under the control of the processor 14, so that a control loop is implemented. The measured junction temperature is then used for controlling the diode 11 so that the light output is accurately controlled to a desired level with the effects of temperature being compensated.

5 As mentioned above, the luminous flux of a LED can essentially be controlled in two ways (or a combination of these):

(i) the amplitude of a constant current,

(ii) a pulsed current (between a constant operation current and zero) and variable duty cycle.

10 In general, a LED is driven by the second method for a number of reasons. As a result of a constant operational current, the dependency of the LED peak wavelength on the current is eliminated, and thus controlling the LED colour point is easier.

For a given colour point and desired luminous flux, the task of the control loop model is to calculate the appropriate currents for red, green and blue LEDs based on the junction temperature information from the LEDs. This invention is not concerned with the way in which temperature measurement can be used to provide a feedback control for the LED output characteristics, and is only concerned with the overheating protection. Thus, further details
15 are not provided.

For lighting purposes, the current frequency has to be high enough so that human eye can not see the flickering, particularly if the temperature determination is carried out during normal operation (not only in a calibration phase). This minimum frequency is around 24 Hz, but in practice the pulsing
25 frequency will typically be between 300Hz and 1,5 kHz, but it can be even higher. For TV backlight applications, the most common frame rate now is 120Hz. and this sets the minimum frequency for the LED pulsing.

An LED module can have any number of LEDs, not only three mentioned above.

30 Various modifications will be apparent to those skilled in the art.

CLAIMS

1. A method of operating a light emitting diode (1), comprising:
operating the light emitting diode to provide a desired brightness output;
5 estimating the junction temperature of the light emitting diode based on
electrical drive parameters of the light emitting diode;
deriving a threshold which determines if there is overheating; and
operating the light emitting diode within the threshold.
- 10 2. A method as claimed in claim 1, wherein deriving a threshold
comprises setting a threshold temperature level, and operating the light
emitting diode (1) within the threshold comprises monitoring the temperature in
use, and lowering (5) the power drive level when overheating is detected.
- 15 3. A method as claimed in claim 1, wherein deriving a threshold
comprises deriving a maximum power level from a junction temperature during
normal operation, and operating the light emitting diode within the threshold
comprises using a power drive level below the threshold.
- 20 4. A method as claimed in claim 3, wherein deriving a maximum
power level comprises driving the light emitting diode at a constant power, and
determining a thermal power of the light emitting diode, and setting a
maximum power based on the maximum allowed junction temperature.
- 25 5. A method as claimed in any preceding claim, wherein estimating
the junction temperature comprises:
driving a forward bias current through the diode, the current comprising
a square wave which toggles between high and low current values (I_{high} , I_{low}),
the high current value (I_{high}) comprising an LED operation current, and the low
30 current value (I_{low}) comprising a non-zero measurement current;
sampling the forward bias voltage drop (V_f), and determining the
forward bias voltage drop ($V_{f_{low}}$) at the measurement current (I_{low}); and

deriving the temperature from the determined forward bias voltage drop.

6. A method as claimed in claim 5, wherein the measurement current (I_{low}) is less than or equal to 1mA.

5

7. A method as claimed in claim 5 or 6, wherein determining the forward bias voltage drop (V_f) comprises analysing the samples to find a forward bias voltage drop which corresponds to a peak in the number of occurrences of that voltage drop.

10

8. A method as claimed in claim 7, wherein analysing the samples comprises deriving a histogram.

9. A system for operating a light emitting diode (1), comprising:
15 a driver (2) for operating the light emitting diode to provide a desired brightness output;
a system (3) for estimating the junction temperature of the light emitting diode based on electrical drive parameters of the light emitting diode; and
means for deriving a threshold which determines if there is overheating,
20 wherein the driver is operable to control the light emitting diode within the derived threshold.

10. A system as claimed in claim 9, wherein the system (3) for estimating the junction temperature of a light emitting diode comprises:
25 means (12) for driving a forward bias current through the diode, the current comprising a square wave which toggles between high and low current values, the high current value (I_{high}) comprising an LED operation current, and the low current (I_{low}) comprising a non-zero measurement current;
means (14) for sampling the forward bias voltage drop (V_f), and
30 determining the forward bias voltage drop ($V_{f_{low}}$) at the measurement current (I_{low}); and

means (14) for deriving the temperature from the determined forward bias voltage drop.

11. A system as claimed in claim 10, wherein the measurement
5 current (I_{low}) is less than or equal to 1mA.

12. A system as claimed in claim 10 or 11, wherein the means (14)
for sampling comprises means for analysing the samples to find a forward bias
voltage drop which corresponds to a peak in the number of occurrences of that
10 voltage drop.

13. A system as claimed in any one of claims 10 to 12, wherein the
means (14) for deriving the temperature from the determined forward bias
voltage drop comprises a memory storing a transformation function that
15 represents the voltage-temperature characteristics at the measurement
current.

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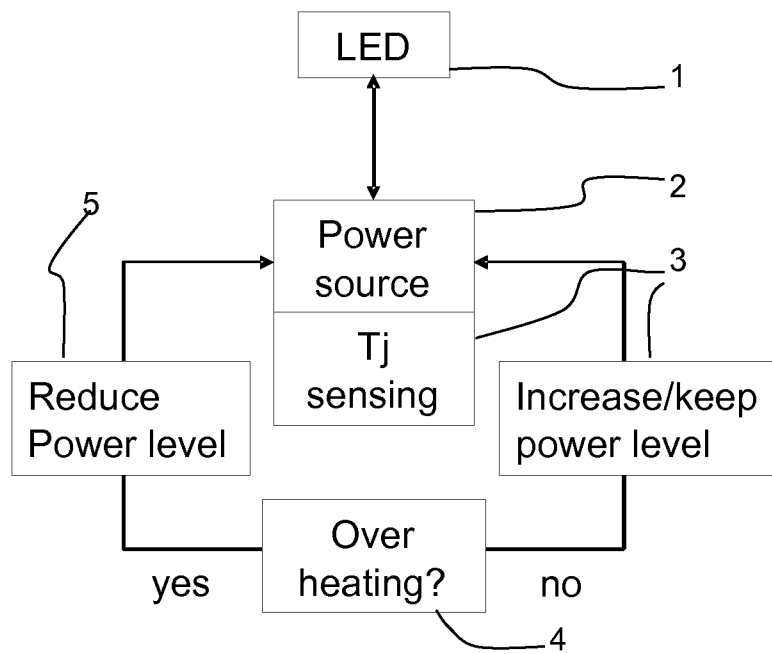


FIG. 1

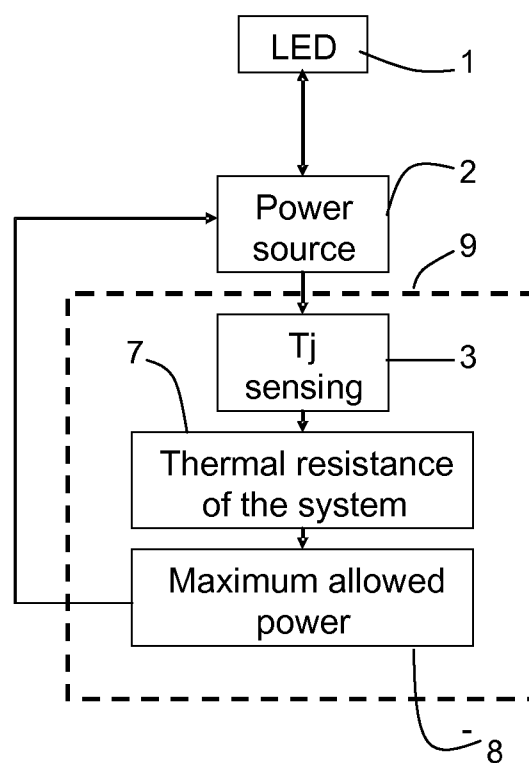
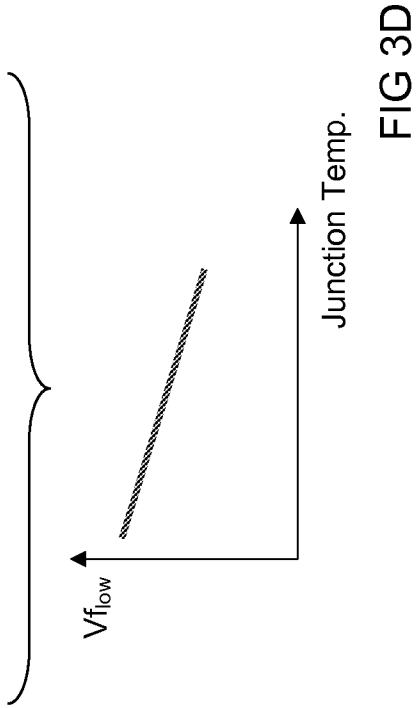
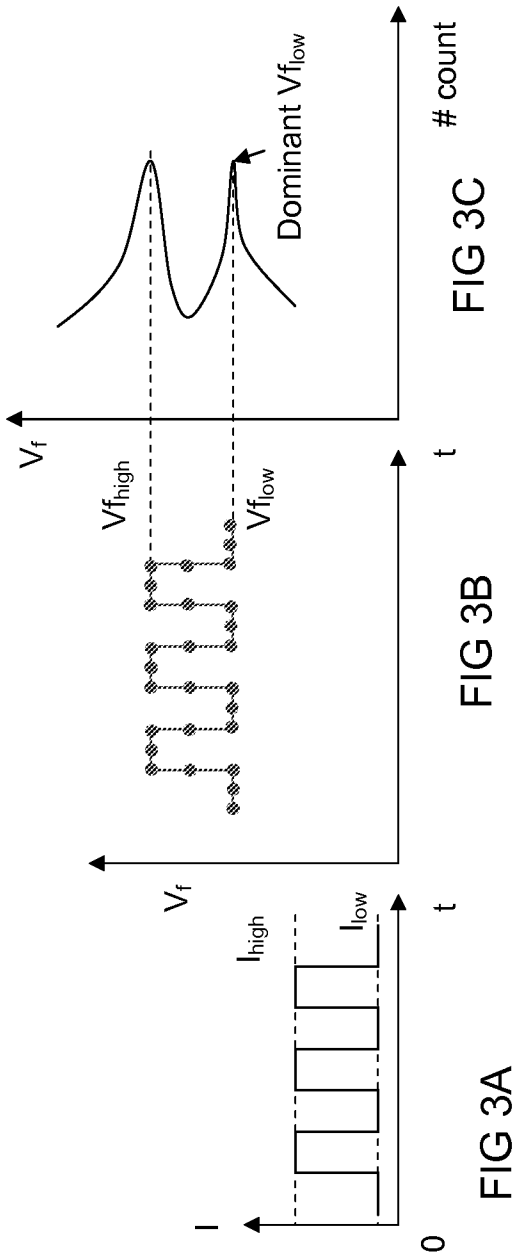


FIG. 2



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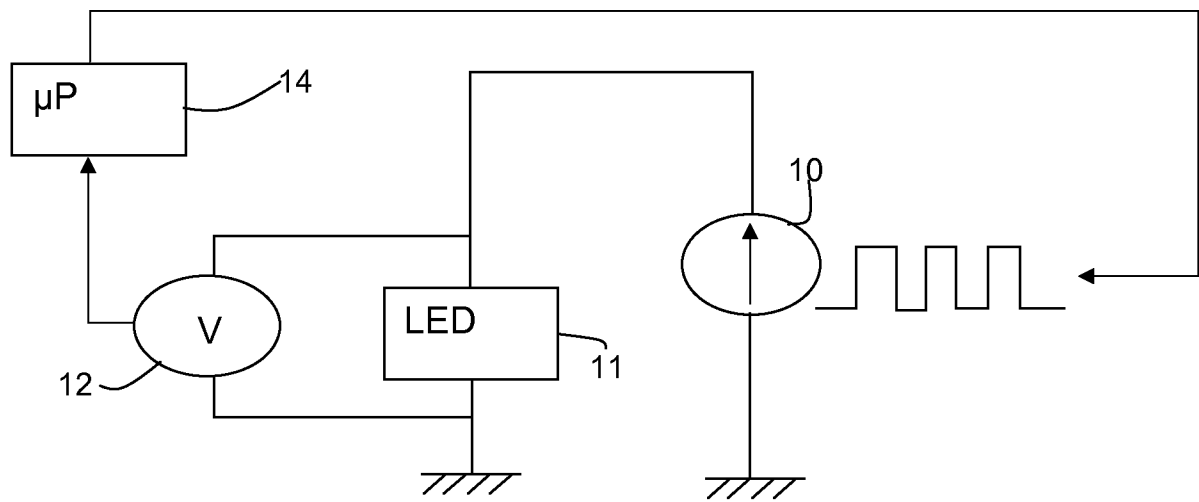


FIG 4