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(54) Electric circuit and method for monitoring a temperature of a light emitting diode

(57) The present invention discloses an electric circuit 1 and method for monitoring a temperature of a light emitting diode 2. The inventive electric circuit 1 for monitoring a temperature of a light emitting diode 2 in a constant-current mode comprises a driver circuit 3 for supplying a predefined constant-current to the light emitting diode 2 to run the light emitting diode 2 in said constant-current mode, a storage 4 for storing a general dependency between a forward voltage of the light emitting diode 2 in said constant-current mode and the temperature of the light emitting diode 2, a voltage sensor 5 for measuring the actual forward voltage of the light emitting diode 2 in said constant-current mode and a calculator 6 for calculating the actual temperature of the light emitting diode 2 by using the detected general dependency and the measured actual forward voltage.

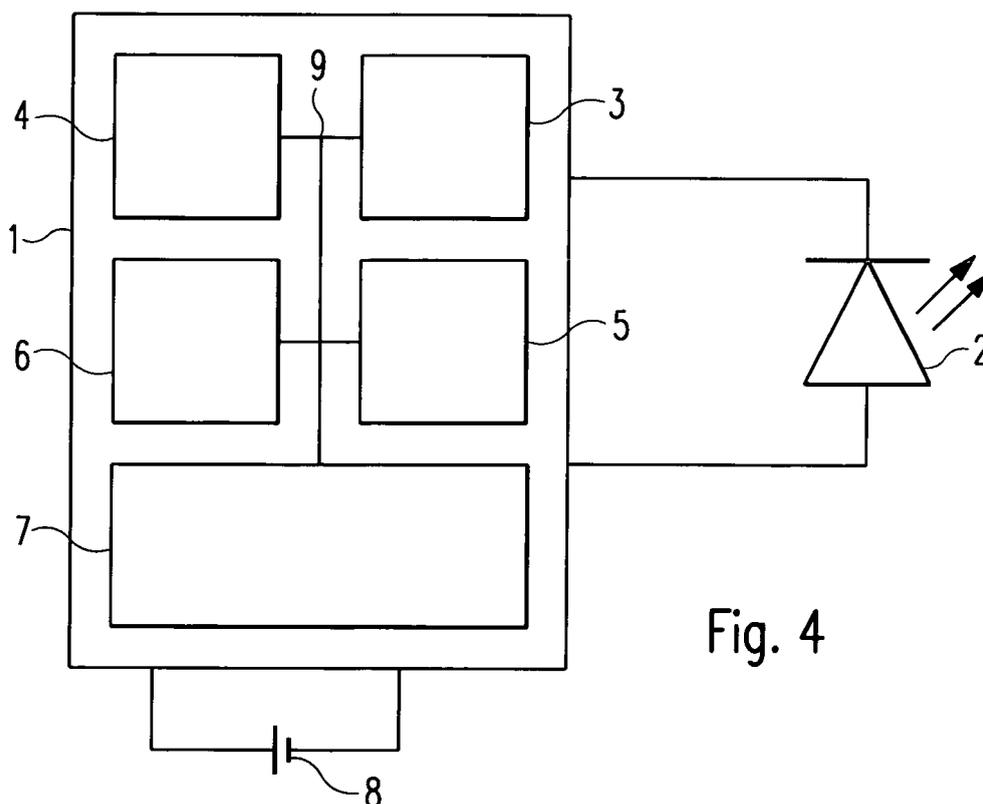


Fig. 4

Description

TECHNICAL FIELD OF THE INVENTION

5 **[0001]** The invention relates to an electronic circuit and method for monitoring a temperature of a light emitting diode that is driven in a constant-current mode.

[0002] In a plurality of electronic equipments and, especially, in portable radio communication equipments, light emitting diodes are used for lightening applications, e. g. as flash lights, background lights for displays or for lightening keys, etc.. Mayor reasons for the use of light emitting diodes are small size, low power consumption, high reliability and low heat generation in comparison to ordinary incandescent lamps.

10 **[0003]** Especially due to the increasing size of displays and use of colour displays in electronic equipment, there is a high demand for an increasing light intensity provided by said light emitting diodes.

[0004] In this respect, preferably white light emitting diodes are used.

15 **[0005]** Even though light emitting diodes remain relatively cold when producing light, even light emitting diodes generate heat during operation.

[0006] Since light emitting diodes are frequently integrated into mobile electronic equipment which have a rather compact structure, only few air circulation is provided for the light emitting diodes. Thus, the heat generated by the light emitting diodes becomes more and more problematic. This becomes even more dramatic since mobile electronic equipment frequently comprise a large number of integrated circuits that often are temperature sensitive.

20 **[0007]** Furthermore, since light emitting diodes are electronic semiconductors themselves, even the light emitting diodes might be damaged by their own heat.

[0008] In consequence, monitoring of the heat generated by light emitting diodes used in electronic equipment becomes more and more important.

25 **DESCRIPTION OF RELATED ART**

[0009] In this respect, Fig. 6 shows a solution according to the prior art frequently integrated into mobile phones. According to this solution, a light emitting diode 62 is driven by a drive circuit 61. The drive circuit 61 is connected to both a power supply 63 and the light emitting diode 62 and provides a constant current to the light emitting diode. The current supplied to the light emitting diode 62 is maintained constant to guarantee a constant brightness of the light emitting diode 62 during operation.

30 **[0010]** According to the prior art, a thermistor 64 is located as close as possible to the light emitting diode 62. The thermistor 64 is a resistant whose resistance changes proportional to the temperature of the thermistor. Thus, the thermistor is a temperature sensor. Therefore, the thermistor 64 is adapted to measure the temperature in an area surrounding the thermistor 64 and thus the temperature of the light emitting diode 62.

35 **[0011]** The thermistor 64 is connected to a microprocessor 65 for controlling the thermistor 64. Based on an output of the thermistor 64 the microprocessor 65 calculates a current temperature of the light emitting diode 62.

40 **[0012]** It is obvious that the thermistor 64 cannot exactly measure the temperature of the light emitting diode 62, since a sensing point of the thermistor 64 is not integrated into the light emitting diode 62. As it takes some time for the heat generated by the light emitting diode 62 to spread to the sensing point of the thermistor 64, a time delay with respect to the temperature measured by the thermistor 64 is inevitable.

[0013] Since the heat generated by a light emitting diode changes relatively fast, the time delay inevitable with temperature measurement by using a thermistor frequently causes a problem.

45 **[0014]** Furthermore, the thermistor is an additional element that has to be integrated to the mobile electronic equipment and has to be provided with energy. In portable electronic equipments, both energy and space are usually very limited.

OBJECT

50 **[0015]** Thus, it is the object of the present invention to provide an electronic circuit and method for monitoring a temperature of a light emitting diode that allows a very fast and accurate measurement of the temperature of the light emitting diode in an easy and reliable way.

SUMMARY

55 **[0016]** The above object is achieved by a method comprising the features of independent claim 1 and an electronic circuit comprising the features of independent claim 10, respectively. Preferred embodiments are defined in the dependent claims.

[0017] The above object is achieved by a method for monitoring a temperature of a light emitting diode that is driven

in a constant-current mode, the method comprising the following steps:

- detecting a general dependency between a forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode;
- 5 - measuring the actual forward voltage of the light emitting diode in said constant-current mode; and
- calculating the actual temperature of the light emitting diode by using the detected general dependency and the measured actual forward voltage.

10 **[0018]** The present invention bases on the principle that the forward voltage of a light emitting diode in a constant-current mode is approximately inverse proportional to the temperature of the light emitting diode. By detecting the general dependency between said forward voltage and the temperature of an individual light emitting diode in the constant-current mode, it is possible to calculate the actual temperature of the light emitting diode by using said general dependency by simply measuring the actual forward voltage of the light emitting diode.

15 **[0019]** Since the forward voltage of the light emitting diode is directly related to the current temperature status of said light emitting diode, there is no time delay between a temperature variation of the light emitting diode and a variation of the forward voltage.

[0020] Consequently, the inventive method provides a very quick, easy and reliable way to monitor a temperature of a light emitting diode.

20 **[0021]** Preferably, the step of detecting a general dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode comprises the steps of

- heating the light emitting diode to a first temperature;
- measuring the actual forward voltage of the light emitting diode in said constant-current mode at said first temperature;
- heating the light emitting diode to at least one second temperature different from said first temperature;
- 25 - measuring the actual forward voltage of the light emitting diode in said constant-current mode at said at least one second temperature; and
- calculating a linearised dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode by using the measured actual forward voltages at said different temperatures.

30 **[0022]** Since the forward voltage of a light emitting diode is approximately inverse proportional to the temperature of the light emitting diode, normally it is sufficient to measure the actual forward voltage of the light emitting diode in said constant-current mode at at least two different temperatures to calculate a linearised dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode. Thus, calibration to a certain individual light emitting diode can be performed in a very easy way by only two measurements.

35 **[0023]** In this respect it has to be emphasised that heating of the light emitting diode preferably is performed by the light emitting diode itself by simply using said light emitting diode in a constant-current mode.

40 **[0024]** According to a preferred embodiment, the step of detecting a general dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode comprises the steps of

- sequentially heating the light emitting diode to a plurality of different temperatures and measuring the actual forward voltage of the light emitting diode in said constant-current mode at said different temperatures; and
- 45 - generating a dependency table between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode by using said measured actual forward voltages at said different temperatures.

50 **[0025]** Said generation of a dependency table between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode is favourable to increase the accuracy of the general dependency for individual light emitting diodes. Although the forward voltage of a light emitting diode is approximately inverse proportional to the temperature of the light emitting diode, said dependency might not be accurate enough for certain temperature sensitive applications. Thus, the accuracy of calibration to an individual light emitting diode can be adapted to the requirement of the respective application.

55 **[0026]** Once again it is emphasised that heating of the light emitting diode preferably is performed by the light emitting diode itself by simply using said light emitting diode in a constant-current mode. Alternatively said heat might be provided by a separate heater.

[0027] According to an alternative embodiment the step of detecting a general dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode comprises

the steps of

- heating the light emitting diode to a known temperature;
- measuring the actual forward voltage of the light emitting diode in said constant-current mode at said known temperature;
- identifying a type of the light emitting diode; and
- calculating a linearised dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode by using the measured actual forward voltage at said known temperature and a predefined temperature curve inclination for the identified type of light emitting diode.

[0028] Thus, only one measurement of the actual forward voltage at a predefined or measured temperature has to be performed in case the temperature curve inclination for a certain identified type of light emitting diode is known. Said temperature curve inclination for a certain type of light emitting diode might be determined and provided by manufacturers of light emitting diodes, for example. In this respect, the linearised dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode is calculated by adjusting the position of the known temperature curve inclination for the identified type of light emitting diode in a temperature / forward voltage diagram according to the measured actual forward voltage at said known temperature. Since the above described calibration requires one measurement step, only, it is very quick and cheap.

[0029] Once again it is emphasised that heating of the light emitting diode preferably is performed by the light emitting diode itself by simply using said light emitting diode in a constant-current mode. Alternatively said heat might be provided by a separate heater.

[0030] As the temperature of the light emitting diode can increase very fast in a constant-current mode if nominal current is provided to the light emitting diode, it is beneficial if in said step of detecting a general dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode, the step of measuring the actual forward voltage of the light emitting diode in said constant-current mode is performed by supplying a current that is at least 10%, preferably at least 20%, more preferably at least 40 % and most preferably at least 60 % lower than nominal current of the light emitting diode to the light emitting diode.

[0031] Thus, the risk of damaging an individual light emitting diode during calibration can be reduced. The general dependency between the forward voltage of the light emitting diode in said constant-current mode at nominal current can be calculated by using the above calibration process and general characteristics of the light emitting diodes with ease.

[0032] Advantageously, the method further comprises the step of storing said calculated linearised dependency and / or said generated dependency table as a stored dependency, wherein said stored dependency further is used as detected general dependency for calculating the actual temperature of the light emitting diode.

[0033] Therefore, the calibration process has to be performed only once for an individual light emitting diode.

[0034] It is preferred that the method further comprises the steps of:

- detecting a general light dependency between the forward voltage of the light emitting diode in an open-circuit mode and ambient light irradiating the light emitting diode;
- measuring the actual forward voltage of the light emitting diode in said open-circuit mode; and
- calculating an amount of ambient light actually irradiating the light emitting diode by using the detected light dependency and the measured actual forward voltage.

[0035] The above embodiment bases on the principal that light emitting diodes are light sensitive elements. Therefore, light emitting diodes can be used as light sensors when not connected to a voltage source. Consequently, in an open-circuit mode, a light emitting diode generates a small voltage proportional to the light intensity irradiating the light emitting diode. As a result, by using the above method steps, the light emitting diode can be used as an ambient light sensor, e. g. for adjusting the intensity of light emitted by the light emitting diode in a very easy way. This can be performed e. g. when the light emitting diode is not in use or between two flash pulses of the light emitting diode.

[0036] In this case it is beneficial if the step of detecting a general light dependency between the forward voltage of the light emitting diode in said open-circuit mode and ambient light irradiating the light emitting diode comprises the steps of

- sequentially irradiating the light emitting diode with different intensities of ambient light and measuring the actual forward voltage of the light emitting diode in said open-circuit mode at different intensities of ambient light; and
- calculating a linearised light dependency and / or generating a light dependency table between the forward voltage of the light emitting diode in said open-circuit mode and the intensities of ambient light irradiating the light emitting diode by using said measured actual forward voltages at said different intensities of ambient light.

[0037] In consequence, calibration of an individual light emitting diode can be performed with ease and with sufficient

accuracy.

[0038] By storing said calculated linearised light dependency and / or said generated light dependency table as stored light dependency, calibration of the light emitting diode has to be performed only once for an individual light emitting diode.

[0039] In this respect it is preferred that the method further comprises the step of storing said calculated linearised light dependency and / or said generated light dependency table as a stored light dependency, wherein said stored light dependency further is used as detected general light dependency for calculating the amount of ambient light actually hitting the light emitting diode.

[0040] Furthermore, the above object is achieved by a computer program product directly loadable into the internal memory of a digital computer, comprising software code portions for performing the steps of one of the claims 1 to 8 when said product is run on a computer.

[0041] Moreover, the above object is achieved by an electric circuit for monitoring a temperature of a light emitting diode in a constant-current mode, comprising

- a driver circuit for supplying a predefined constant current to the light emitting diode in order to run the light emitting diode in said constant-current mode;
- a storage for storing a general dependency between a forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode;
- a voltage sensor for measuring the actual forward voltage of the light emitting diode in said constant-current mode; and
- a calculator for calculating the actual temperature of the light emitting diode by using the stored general dependency and the measured actual forward voltage.

[0042] Since the inventive electric circuit calculates the actual temperature of the light emitting diode by using the stored general dependency and the measured actual forward voltage, the temperature of the light emitting diode is monitored with high velocity, accuracy and reliability. Furthermore, as no additional elements such as thermistors are necessary to sense the temperature of the light emitting diode, the inventive electric circuit has a very easy and compact structure.

[0043] According to a preferred embodiment, the electric circuit further comprises a calibrator, said calibrator being adapted to control the voltage sensor in a way that the voltage sensor sequentially measures the actual forward voltage of the light emitting diode in said constant-current mode at different temperatures, to calculate a linearised dependency and / or a dependency table between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode by using the measured actual forward voltages at said different temperatures and to store said calculated linearised dependency and / or said generated dependency table as said general dependency in said storage.

[0044] Thus, calibration of the inventive electric circuit for monitoring a temperature of a light emitting diode to an individual light emitting diode can be performed with ease. Dependent on the requirements and on accuracy, either a linearised dependency by using at least two measured actual forward voltages of the light emitting diode in said constant-current mode at different temperatures or a detailed dependency table can be used. Since, said linearised dependency and /or said dependency table are stored in said storage, quick access to said dependency is guaranteed during the operation of the inventive electric circuit. Furthermore, said calibration has to be performed only once for an individual light emitting diode.

[0045] According to an alternative embodiment the electric circuit further comprises a calibrator, said calibrator being adapted to control the voltage sensor in a way that the voltage sensor measures the actual forward voltage of the light emitting diode in said constant-current mode at a known temperature, to identify a type of the light emitting diode, to calculate a linearised dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode by using the measured actual forward voltage at said known temperature and a predefined temperature curve inclination for the identified type of light emitting diode and to store said calculated linearised dependency as said general dependency in said storage.

[0046] By the provision of the above calibrator, only one measurement of the actual forward voltage at a predefined or measured temperature has to be performed to calibrate the inventive electric circuit for monitoring a temperature of a light emitting diode to an individual light emitting diode in case the temperature curve inclination for a certain identified type of light emitting diode is known. Thus, calibration is accelerated.

[0047] Advantageously, the calibrator is further adapted to control the driver circuit in a way that a current that is at least 10%, preferably at least 20%, more preferably at least 40% and most preferably at least 60% lower than nominal current of the light emitting diode is supplied to the light emitting diode in said constant-current mode during operation of said calibrator.

[0048] Since the calibrator of the inventive electric circuit is adapted to control the driver circuit in a way that a current that is lower than nominal current of the light emitting diode is supplied to the light emitting diode in said constant-current mode during the operation of said calibrator, it is ensured that the light emitting diode is not damaged during calibration.

The corresponding linearised dependency and / or dependency table for the light emitting diode at nominal current can easily be calculated by using the measurement results of the calibrator.

[0049] In the inventive electric circuit is further beneficial if said driver circuit is further adapted to run the light emitting diode in an open-circuit mode, said storage further stores a general light dependency between the forward voltage of the light emitting diode in said open-circuit mode and ambient light irradiating the light emitting diode, said voltage sensor is further adapted to measure the actual forward voltage of the light emitting diode in said open-circuit mode and said calculator is further adapted to calculate an amount of ambient light actually irradiating the light emitting diode by using the general light dependency and the measured actual forward voltage.

[0050] In case the driver circuit of the inventive electric circuit is further adapted to run the light emitting diode in an open-circuit mode, it is possible to use the light emitting diode as an ambient light sensor. Thus, the inventive electric circuit can be further used to adjust e. g. the intensity of light emitted by the light emitting diode.

[0051] In this respect, it is preferred that said calibrator is further adapted to control the voltage sensor in a way that the voltage sensor sequentially measures the actual forward voltage of the light emitting diode in said open-circuit mode at different intensities of ambient light irradiating the light emitting diode, to calculate a linearised light dependency and / or generate a light dependency table between the forward voltage of the light emitting diode in said open-circuit mode and the intensity of ambient light irradiating the light emitting diode by using said measured actual forward voltage at said different intensities of ambient light and to store said calculated linearised light dependency and / or said generated light dependency table as said general light dependency in said storage.

[0052] In consequence, calibration to an individual light emitting diode can be performed with ease. Since the result of the calibration is stored in said storage, said calibration has to be performed only once. Furthermore, quick access to the calculated linearised light dependency and / or generated light dependency table during the operation of the inventive electric circuit is ensured.

[0053] Advantageously, the circuit is comprised in a portable radio communication equipment.

[0054] Since the inventive electric circuit has a very compact and reliable structure, it is adapted to be implemented into a portable electronic equipment and especially a portable radio communication equipment like a mobile phone. In this respect, monitoring of the temperature of light emitting diodes used in a portable electronic equipment is very important, since said equipments frequently have a rather complex structure that is heat sensitive and prevents air circulation. Thus, these equipments are prone to heat accumulation.

[0055] It should be emphasised that the term 'comprises / comprising' when used in this specification is taken to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.

[0056] Furthermore, the term 'portable radio communication equipment', which herein after is referred to as a mobile radio terminal, includes all equipments such as mobile telephones, pagers, communicators, i. e. electronic organisers, smart phones or the like.

[0057] Moreover, in the above description reference has been made to individual light emitting diodes. It is obvious for a skilled person that the present invention further is applicable to groups of light emitting diodes connected in parallel or in series. In this case, an average temperature of the light emitting diodes of the group will be monitored.

BRIEF DESCRIPTION OF THE DRAWINGS

[0058] In the following, preferred embodiments of the present invention are explained by reference to the accompanying drawings, in which like reference characters refer to like parts. In the drawings

Figs. 1A, 1B show a preferred embodiment of the inventive method for monitoring a temperature of a light emitting diode;

Fig. 1C shows a modification of the inventive method for monitoring a temperature of a light emitting diode;

Figs. 2A, 2B show an example of a profitable possible completion of the preferred embodiment of the inventive method;

Fig. 3 shows a diagram of a measured dependency between a forward voltage of a light emitting diode in a constant-current mode and a temperature of the light emitting diode for three exemplary light emitting diodes;

Fig. 4 schematically shows a block diagram of the inventive electric circuit for monitoring a temperature of a light emitting diode;

Figs. 5A, 5B exemplarily show a dependency table and a light dependency table used in the inventive method and electric circuit; and

Fig. 6 schematically shows a block diagram of a temperature monitoring circuit for a light emitting diode according to the prior art.

DETAILED DESCRIPTION OF EMBODIMENT

[0059] Fig. 1A shows a flow diagram of a preferred embodiment of the inventive method for monitoring a temperature of a light emitting diode.

[0060] In a first step S11 a general dependency between a forward voltage of a light emitting diode in a constant-current mode and a temperature of the light emitting diode is detected. This step will be explained in more detail by reference to Figs. 1B and 1C, respectively.

[0061] Afterwards, in step S12 said light emitting diode is driven in said constant-current mode during ordinary operation of the light emitting diode to produce light.

[0062] During the operation of the light emitting diode, the actual forward voltage of a light emitting diode in said constant-current mode is measured in step S13. This measurement preferably is performed continuously. Alternatively a regular measurement at a predefined or variable time interval might be performed.

[0063] Afterwards, the actual temperature of the light emitting diode is continuously or regularly calculated in step S14 by using the detected general dependency and the measured actual forward voltage. Thus, the calculation step S14 preferably is closely linked to the measurement step S13.

[0064] The steps S12 to S14 are repeated as long as the light emitting diode is in a constant-current mode.

[0065] In the following, two preferred embodiments of the step S11 of detecting a general dependency between a forward voltage of a light emitting diode in a constant-current mode and a temperature of the light emitting diode are explained by reference to Figs. 1B and 1C, respectively.

[0066] Firstly, reference is made to the embodiment of Fig. 1B.

[0067] In a first step S111 a constant current that is at least 10 %, preferably at least 20 %, more preferably at least 40 % and most preferably at least 60 % lower than nominal current of the light emitting diode is supplied to the light emitting diode. The reason is that the risk of damaging the light emitting diode during calibration of the light emitting diode because of too high temperatures is significantly reduced by providing a lower current. Thus, the light emitting diode is driven in a constant-current mode.

[0068] Afterwards, in step S112 the light emitting diode is sequentially heated to a plurality of different temperatures by driving the light emitting diode in said constant-current mode. Since the light emitting diode generates heat during the production of light the light emitting diode is heated.

[0069] Alternatively an external heater might be used to heat the light emitting diode.

[0070] In the following step S113 the actual forward voltage of the light emitting diode that is driven in said constant-current mode is measured at said different temperatures. Thus, an actual forward voltage of the respective light emitting diode for a respective temperature is obtained. During the present calibration method, the actual temperature of the light emitting diode might be measured by any suitable temperature sensor.

[0071] Afterwards, in step S114 a linearised dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode is calculated by using the measured actual forward voltage at said different temperatures. In this respect, only two pairs of measured actual forward voltage and temperature values have to be provided for calculating said linearised dependency in order to obtain a good estimate. The reason is that the forward voltage of a light emitting diode is approximately inverse proportional to the temperature of the light emitting diode.

[0072] If a higher accuracy is required, a dependency table between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode can be generated in step S115 by using said measured actual forward voltages at said different temperatures. Thus, by choosing a suitable number of pairs of measured actual forward voltages and temperatures of the light emitting diode, the accuracy of the detected general dependency can be adapted to the requirements of a respective application.

[0073] In this respect it is obvious that the steps S114 and S115 can be performed alternatively or complementary.

[0074] Now, reference is made to the embodiment of Fig. 1C.

[0075] Similar to the embodiment shown in Fig. 1B, in a first step S111' a constant current that is at least 10%, preferably at least 20%, more preferably at least 40 % and most preferably at least 60% lower than nominal current of the light emitting diode is supplied to the light emitting diode.

[0076] Afterwards, in step S112' the light emitting diode is heated to a known temperature.

[0077] In step S113' the actual forward voltage of the light emitting diode in said constant-current mode at said known temperature is measured.

[0078] In step S114', a type of the light emitting diode currently used is identified. This can either be performed automatically by measuring certain component characteristics of the light emitting diode or based on a manual user input. Step S114' might be performed either before, in parallel or after steps S111', S112' and S113'.

[0079] Afterwards, in step S115' a linearised dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode is calculated by using the measured actual forward voltage at said known temperature and a predefined temperature curve inclination for the identified type of light

emitting diode.

[0080] After steps S114, S115 of Fig. 1B or step S115' of Fig. 1C, respectively, said calculated linearised dependency and / or said generated dependency table automatically is stored as a stored dependency.

[0081] Said stored dependency is used in step S 117, S 117' as detected general dependency for calculating the actual temperature of the light emitting diode in step S 14.

[0082] Thus, steps S11 and S111 to S 117 and S111' to S 117' have to be performed only once for calibrating the general dependency for an individual light emitting diode or a type of light emitting diodes. The reason is that the dependency of the forward voltage of a light emitting diode in a constant-current mode and the temperature spreads between different individual light emitting diodes of different types. Furthermore, the dependency of the forward voltage of a light emitting diode in a constant-current mode and the temperature might even spread between different individual light emitting diodes of the same types. This is accounted for by the calibration methods explained by reference to Figs. 1B and 1C, respectively.

[0083] In summary, by detecting the general dependency between said forward voltage and the temperature of the individual light emitting diode in the constant-current mode, it is possible to calculate the actual temperature of the light emitting diode by using said general dependency by simply measuring the actual forward voltage of the light emitting diode. Since the forward voltage of the light emitting diode is directly related to the current status of said light emitting diode, there is no time delay between a temperature variation of the light emitting diode and a variation of the forward voltage.

[0084] Consequently, the inventive method provides a very quick, easy and reliable way to monitor a temperature of a light emitting diode.

[0085] In the following, a profitable completion of the above described preferred embodiment of the inventive method for monitoring a temperature of a light emitting diode is explained by reference to Figs. 2A and 2B.

[0086] According to this embodiment, in a first step S21 a general light dependency between a forward voltage of a light emitting diode in an open-circuit mode and ambient light irradiating the light emitting diode is detected. This detection will be further explained by reference to Fig. 2B.

[0087] Afterwards, in step S22 said light emitting diode is driven in said open-circuit mode.

[0088] In the following step S23 the actual forward voltage of the light emitting diode in said open-circuit mode is measured.

[0089] In the last step S24 an amount of ambient light actually irradiating the light emitting diode by using the detected light dependency and the measured actual forward voltage is calculated.

[0090] The steps S22 to S24 are repeated as long as the light emitting diode is driven in said open-circuit mode and as long as a sensing of ambient light irradiating the light emitting diode is required.

[0091] In the following, the step S21 of detecting a general light dependency between a forward voltage of a light emitting diode in an open-circuit mode and ambient light irradiating the light emitting diode is further explained by reference to Fig. 2B.

[0092] In a first step S211 said light emitting diode is driven in said open-circuit mode. Thus, no external voltage is applied to the light emitting diode.

[0093] Afterwards, the light emitting diode is sequentially irradiated with different intensities of ambient light in step S212. Thus, the intensity of the irradiating light is known (either due to external measurement or due to a detailed knowledge of the light source).

[0094] In the following step S213 the actual forward voltage of the light emitting diode driven in said open-circuit mode is measured at different intensities of ambient light.

[0095] The steps S212 and S213 are repeated until sufficient numbers of pairs of measured actual forward voltages and corresponding intensities of irradiating ambient light are provided.

[0096] Afterwards, in step S214 a linearised light dependency is calculated and / or a light dependency table is generated. Both the linearised light dependency and the light dependency table relate to the dependency between the forward voltage of the light emitting diode in said open-circuit mode and the intensities of ambient light irradiating the light emitting diode. Both are provided by using said measured actual forward voltages at said different intensities of ambient light. While for the calculation of the linearised light dependency only two pairs of measured actual forward voltage and corresponding intensity of irradiating ambient light are necessary, the accuracy can be increased by using a higher number of pairs in a light dependency table.

[0097] In the preferred example, both said calculated linearised light dependency and / or said generated light dependency table are stored as a stored light dependency in step S215.

[0098] Said stored light dependency is used in step S216 as detected general light dependency for calculating the amount of ambient light actually hitting the light emitting diode. Thus, the calibration method described with reference to Fig. 2B above has to be performed only once for an individual diode or type of diodes.

[0099] As a result, by using the above method steps, the light emitting diode can be used as an ambient light sensor, e. g. for adjusting the intensity of light emitted by the light emitting diode in a constant-current mode in a very easy way.

This can be performed e. g. when the light emitting diode is not in use or between two flash pulses of the light emitting diode.

[0100] Fig. 3 is a diagram showing the general dependency between the forward voltage of three light emitting diodes D1, D2 and D3 in a constant-current mode and the temperature of the light emitting diodes D1, D2 and D3. Said diagram can be generated either by measuring a forward voltage value for each temperature value or by calculating a linearised dependency between the forward voltage of the light emitting diodes D1, D2, D3 in said constant-current mode and the temperature of the light emitting diodes D1, D2 and D3 by using two pairs of forward voltage T_{D11} , T_{D12} ; T_{D21} , T_{D22} ; and T_{D31} , T_{D32} , respectively.

[0101] With respect to Fig. 3, D1, D2 and D3 either can characterise different types of diodes or different individual light emitting diodes of one type.

[0102] Furthermore, the dependency described with respect to Fig. 3 is not limited to single light emitting diodes but is also applicable to several light emitting diodes connected in parallel or in series. In this case, the average temperature of the diodes would be monitored.

[0103] In the following, with respect to Fig. 4 a preferred embodiment of an electronic circuit for monitoring a temperature of a light emitting diode according to the present invention is described. Said electronic circuit is adapted to perform the above-described inventive method of monitoring the temperature of a light emitting diode.

[0104] The electronic circuit 1 is connected to a power supply 8 (in the present case a battery) and a light emitting diode 2 whose temperature has to be monitored. In the present case, said light emitting diode 2 is a conventional diode for white light. Alternatively said diode 2 could be a laser diode or a colour diode, for example. It is obvious that said light emitting diode 2 can be a single diode or several light emitting diodes connected in parallel or in series.

[0105] The electronic circuit 1 comprises a driver circuit 3, a storage 4, a voltage sensor 5, a calculator 6 and a calibrator 7.

[0106] The driver circuit 3 is adapted to supply a predefined constant current to the light emitting diode 2 to run the light emitting diode 2 in a constant-current mode. In the present embodiment, the driver circuit contains a voltage step-up converter to ensure that a constant current is applied to the diode 2 by correspondingly adapting the voltage applied to the diode 2.

[0107] Furthermore, the driver circuit 3 is adapted to run the light emitting diode 2 in an open-circuit mode and thus not to apply external voltage to the light emitting diode 2.

[0108] It is obvious that the light emitting diode 2 can be driven either in the open-circuit mode or in the constant-current mode.

[0109] The storage 4 stores a general dependency between a forward voltage of the light emitting diode 2 in said constant-current mode and the temperature of the light emitting diode 2. In the present example, the storage 4 further stores a general light dependency between the forward voltage of the light emitting diode 2 in an open-circuit mode and ambient light irradiating the light emitting diode 2. In the present example the storage 4 is an EPROM and thus a non-volatile memory. Alternatively any other non-volatile memory might be used.

[0110] The voltage sensor 5 is adapted to measure an actual forward voltage of said light emitting diode 2, wherein said diode 2 is driven either in the constant-current mode or in the open-circuit mode. In the present example, the voltage sensor 5 uses a differential amplifier for measuring the actual forward voltage and comprises an A/D converter to digitise the measured value.

[0111] The calculator 6 is a microprocessor adapted to calculate the actual temperature of the light emitting diode 2 by using the detected general dependency and the measured actual forward voltage when the diode is driven in said constant-current mode. Moreover, in the present example, the calculator 6 is adapted to calculate an amount of ambient light actually irradiating the light emitting diode 2 by using the general light dependency and the measured actual forward voltage.

[0112] All elements of the electric circuit 1, the driver circuit 3, the storage 4, the voltage sensor 5, the calculator 6 and the calibrator 7 are interconnected by a common bus system 9.

[0113] In the present example, the calibrator 7 is adapted to control the voltage sensor 5 in a way that the voltage sensor 5 sequentially measures the actual forward voltage of the light emitting diode 2 in said constant-current mode at different temperatures.

[0114] In this respect, the calibrator 7 is further adapted to control the driver circuit in a way that a current that is at least 10 % , preferably at least 20 % , more preferably at least 40% and most preferably at least 60% lower than nominal current of the light emitting diode 2 is supplied to the light emitting diode 2 in said constant-current mode during the operation of said calibrator 7.

[0115] Preferably, the different temperatures of the light emitting diode 2 are achieved by a self-heating effect of the light emitting diode 2, due to the operation of the light emitting diode 2. Alternatively, the light emitting diode 2 might be heated by using an external heater not shown in the figure. During calibration, the temperature of the light emitting diode 2 is measured by using an external temperature sensor (not shown in Fig. 4).

[0116] Starting from said measurements performed by using said reduced current of said light emitting diode 2 corresponding values for nominal current of said light emitting diode 2 automatically are calculated by said calibrator 7.

[0117] Based on the corrected actual forward voltages at said different temperatures, the calibrator 7 automatically calculates a dependency table between the forward voltage of the light emitting diode 2 in said constant-current mode and the temperature of the light emitting diode 2. An example of such a dependency table is shown in Fig. 5A.

[0118] In Fig. 5A the upper line indicates the measured actual forward voltage of said light emitting diode, and the lower line indicates the corresponding temperature value.

[0119] Alternatively, the calibrator 7 can calculate a linearised dependency as shown in Fig. 3 by simply using two pairs of voltage / temperature values for the light emitting diode 2.

[0120] According to an alternative embodiment, said calibrator 7 is adapted to control the voltage sensor 5 in a way that the voltage sensor 5 measures the actual forward voltage of the light emitting diode 2 in said constant-current mode only at one known temperature.

[0121] In this alternative embodiment, the calibrator 7 automatically identifies a type of the light emitting diode 2 by measuring component characteristics of the light emitting diode 2. Alternatively, said light emitting diode might be identified based on a manual user input.

[0122] According to the alternative embodiment a linearised dependency between the forward voltage of the light emitting diode 2 in said constant-current mode and the temperature of the light emitting diode 2 automatically is calculated by said calibrator 7 by using the measured actual forward voltage at said known temperature and a predefined temperature curve inclination for the identified type of light emitting diode 2. In this respect, predefined temperature curve inclinations for different types of light emitting diodes 2 preferably are stored in the storage 4 of the electronic circuit 1. Alternatively, said predefined temperature curve inclination might be input by a user.

[0123] Said calculated linearised dependency and / or said generated dependency table according to all embodiments is automatically stored by said calibrator 7 as a general dependency in said storage 4.

[0124] In the present example, said calibrator 7 is further adapted to control the driver circuit in a way that the light emitting diode 2 is driven in an open-circuit mode. Thus, no external voltage is applied on the diode 2.

[0125] Furthermore, the calibrator 7 controls the voltage sensor 5 in a way that the voltage sensor 5 sequentially measures said actual forward voltage of the light emitting diode 2 in said open-circuit mode at different intensities of ambient light irradiating the light emitting diode 2. Thus, a certain amount of ambient light has to be irradiated on the light emitting diode 2 in some way by using a light source not shown in the figures.

[0126] Moreover, said calibrator 7 preferably is adapted to calculate a linearised light dependency similar to the dependency shown in Fig. 3 but with the light intensity at the horizontal axis (x-axis) and / or to generate a light dependency table relating to the dependency between the forward voltage of the light emitting diode 2 in said open-circuit mode and the intensity of ambient light irradiating the light emitting diode 2 by using said measured actual forward voltage at said different intensities of ambient light. An example of such a light dependency table is shown in Fig. 5B.

[0127] In Fig. 5B the upper line indicates the measured actual forward voltage of said light emitting diode, and the lower line indicates the illuminance irradiating the light emitting diode.

[0128] Afterwards, said calculated linearised light dependency and / or said generated light dependency table are automatically stored by said calibrator 7 as said general light dependency in said storage 4.

[0129] During the operation of the light emitting diode 2 in a constant-current mode, said calculator 6 uses said general dependency stored in said storage 4 to automatically calculate the actual temperature of a light emitting diode 2 in real time by using the actual forward voltage measured by said voltage sensor 5.

[0130] In consequence, the inventive electric circuit 1 is adapted to reliably monitor a temperature of the light emitting diode with ease and high accuracy in real-time.

[0131] During the operation of the light emitting diode 2 in an open-circuit mode, the calculator 6 uses said general light dependency stored in the storage 4 for calculating an amount of ambient light actually irradiating the light emitting diode 2 by using the actual forward voltage measured by said voltage sensor 5.

[0132] Thus, by using the above-described electronic circuit 1 in addition to the capability to monitor the temperature of the light emitting diode 2 driven in a constant-current mode, the inventive electronic circuit 1 is adapted to monitor ambient light irradiating the light emitting diode driven in an open-circuit mode. In consequence, the inventive electronic circuit 1 can be used for adjusting the light intensity of the light emitting diode 2, for example.

[0133] In known applications, the light emitting diode usually is in an open-circuit mode when it is switched off or between two flash points when the light emitting diode is used as a flasher. Thus, the inventive electric circuit provides a further benefit without any extra costs or additional elements.

[0134] All elements of the inventive electric circuit 1 can be integrated into a circuit necessary to drive the light emitting diode 2. Thus, no additional components are needed.

[0135] In this respect, it is mentioned that ordinary driver circuits for driving light emitting diodes frequently have a sensing input for the output voltage of the light emitting diode at the anode side for use as over-voltage protection. Furthermore, known driver circuits for driving light emitting diodes often have an input for measuring the current through the light emitting diode or the current supplied to the light emitting diode at the cathode side. These inputs can be used as an input of the differential amplifier of the voltage sensor 5 of the above-described inventive electronic circuit 1.

[0136] Due to the compact structure and the ability to be integrated into drivers for light emitting diodes, the inventive electric circuit 1 is ideally suited to be used in portable radio communications equipments such as mobile phones. In this respect it is an advantage that the inventive electric circuit measures the temperature of the light emitting diode without a time delay and thus in real-time.

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Claims

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1. Method for monitoring a temperature of a light emitting diode that is driven in a constant-current mode, comprising the following steps:

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- (S11) detecting a general dependency between a forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode;
- (S13) measuring the actual forward voltage of the light emitting diode in said constant-current mode; and
- (S14) calculating the actual temperature of the light emitting diode by using the detected general dependency and the measured actual forward voltage.

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2. Method according to claim 1, **characterised in that** the step (S11) of detecting a general dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode comprises the steps of

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- heating the light emitting diode to a first temperature;
- measuring the actual forward voltage of the light emitting diode in said constant-current mode at said first temperature;
- heating the light emitting diode to at least one second temperature different from said first temperature;
- measuring the actual forward voltage of the light emitting diode in said constant-current mode at said at least one second temperature; and
- (S 114) calculating a linearised dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode by using the measured actual forward voltages at said different temperatures.

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3. Method according to claim 1 or 2, **characterised in that** the step (S11) of detecting a general dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode comprises the steps of

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- (S 112) sequentially heating the light emitting diode to a plurality of different temperatures and (S113) measuring the actual forward voltage of the light emitting diode in said constant-current mode at said different temperatures; and
- (S 115) generating a dependency table between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode by using said measured actual forward voltages at said different temperatures.

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4. Method according to claim 1, **characterised in that** the step (S11) of detecting a general dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode comprises the steps of

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- (S112') heating the light emitting diode to a known temperature;
- (S113') measuring the actual forward voltage of the light emitting diode in said constant-current mode at said known temperature;
- (S114') identifying a type of the light emitting diode; and
- (S 115') calculating a linearised dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode by using the measured actual forward voltage at said known temperature and a predefined temperature curve inclination for the identified type of light emitting diode.

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5. Method according to one of the claims 2, 3 or 4,

characterised in that

in said step (S11) of detecting a general dependency between the forward voltage of the light emitting diode in said constant-current mode and the temperature of the light emitting diode, the step (S113; S113') of measuring the actual forward voltage of the light emitting diode in said constant-current mode is performed by supplying (S111; S111') a current that is at least 10%, preferably at least 20%, more preferably at least 40% and most preferably at least 60% lower than nominal current of the light emitting diode to the light emitting diode.

6. Method according to one of the preceding claims,

characterised in that

the method further comprises the step (S116; S116') of storing said calculated linearised dependency and / or said generated dependency table as a stored dependency, wherein said stored dependency further is used (S117; S117') as detected general dependency for calculating the actual temperature of the light emitting diode.

7. Method according to one of the preceding claims,

characterised in that

the method further comprises the steps of:

- (S21) detecting a general light dependency between the forward voltage of the light emitting diode in an open-circuit mode and ambient light irradiating the light emitting diode;
- (S23) measuring the actual forward voltage of the light emitting diode in said open-circuit mode; and
- (S24) calculating an amount of ambient light actually irradiating the light emitting diode by using the detected light dependency and the measured actual forward voltage.

8. Method according to claim 7,

characterised in that

the step (S21) of detecting a general light dependency between the forward voltage of the light emitting diode in said open-circuit mode and ambient light irradiating the light emitting diode comprises the steps of

- (S212) sequentially irradiating the light emitting diode with different intensities of ambient light and measuring (S213) the actual forward voltage of the light emitting diode in said open-circuit mode at different intensities of ambient light; and
- (S214) calculating a linearised light dependency and / or generating a light dependency table between the forward voltage of the light emitting diode in said open-circuit mode and the intensities of ambient light irradiating the light emitting diode by using said measured actual forward voltages at said different intensities of ambient light.

9. Method according to claim 8,

characterised in that

the method further comprises the step (S215) of storing said calculated linearised light dependency and / or said generated light dependency table as a stored light dependency, wherein said stored light dependency further is used (S216) as detected general light dependency for calculating the amount of ambient light actually hitting the light emitting diode.

10. Computer program product directly loadable into the internal memory of a digital computer, comprising software code portions for performing the steps of one of the claims 1 to 9 when said product is run on a computer.

11. Electric circuit (1) for monitoring a temperature of a light emitting diode (2) in a constant-current mode, comprising

- a driver circuit (3) for supplying a predefined constant-current to the light emitting diode (2) to run the light emitting diode (2) in said constant-current mode;
- a storage (4) for storing a general dependency between a forward voltage of the light emitting diode (2) in said constant-current mode and the temperature of the light emitting diode (2);
- a voltage sensor (5) for measuring the actual forward voltage of the light emitting diode (2) in said constant-current mode; and
- a calculator (6) for calculating the actual temperature of the light emitting diode (2) by using the stored general dependency and the measured actual forward voltage.

12. An electric circuit (1) according to claim 11,

characterised in that the electric circuit (1) further comprises a calibrator (7), said calibrator (7) being adapted to control the voltage sensor (5) in a way that the voltage sensor (5) sequentially measures the actual forward voltage of the light emitting diode (2) in said constant-current mode at different temperatures,
 5 to calculate a linearised dependency and / or a dependency table between the forward voltage of the light emitting diode (2) in said constant-current mode and the temperature of the light emitting diode (2) by using the measured actual forward voltages at said different temperatures and
 10 to store said calculated linearised dependency and / or said generated dependency table as said general dependency in said storage (4).

13. An electric circuit (1) according to claim 11,
characterised in that the electric circuit (1) further comprises a calibrator (7), said calibrator (7) being adapted to control the voltage sensor (5) in a way that the voltage sensor (5) measures the actual forward voltage of the light emitting diode (2) in said constant-current mode at a known temperature,
 15 to identify a type of the light emitting diode (2),
 to calculate a linearised dependency between the forward voltage of the light emitting diode (2) in said constant-current mode and the temperature of the light emitting diode (2) by using the measured actual forward voltage at said known temperature and a predefined temperature curve inclination for the identified type of light emitting diode (2) and
 20 to store said calculated linearised dependency as said general dependency in said storage (4).

14. An electric circuit (1) according to one of the claims 11, 12 or 13,
characterised in
 25 **that** the calibrator (7) is further adapted to control the driver circuit (3) in a way that a current that is at least 10%, preferably at least 20%, more preferably at least 40 % and most preferably at least 60 % lower than nominal current of the light emitting diode (2) is supplied to the light emitting diode (2) in said constant-current mode during operation of said calibrator (7).

15. An electric circuit (1) according to one of the claims 11 to 14,
characterised in
 30 said driver circuit (3) is further adapted to run the light emitting diode (2) in an open-circuit mode;
 said storage (4) further stores a general light dependency between the forward voltage of the light emitting diode (2) in said open-circuit mode and ambient light irradiating the light emitting diode (2);
 35 said voltage sensor (5) is further adapted to measure the actual forward voltage of the light emitting diode (2) in said open-circuit mode; and
 said calculator (6) is further adapted to calculate an amount of ambient light actually irradiating the light emitting diode (2) by using the general light dependency and the measured actual forward voltage.

16. An electric circuit (1) according to claim 15,
characterised in
 40 said calibrator is further adapted
 to control the voltage sensor (5) in a way that the voltage sensor (5) sequentially measures the actual forward voltage of the light emitting diode (2) in said open-circuit mode at different intensities of ambient light irradiating the light emitting diode (2),
 45 to calculate a linearised light dependency and / or generate a light dependency table between the forward voltage of the light emitting diode (2) in said open-circuit mode and the intensity of ambient light irradiating the light emitting diode (2) by using said measured actual forward voltage at said different intensities of ambient light and to store said calculated linearised light dependency and / or said generated light dependency table as said general light dependency in said storage (4).
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17. An electric circuit (1) according to one of the claims 11 to 16,
characterised in
 55 **that** the circuit is comprised in a portable radio communication equipment.

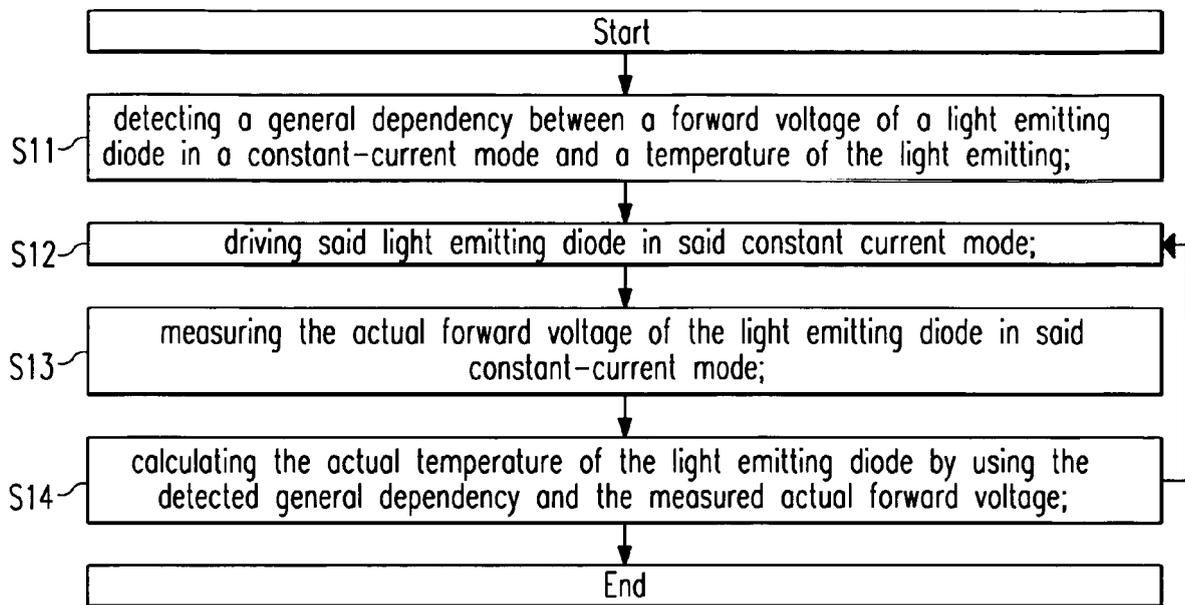


Fig. 1A

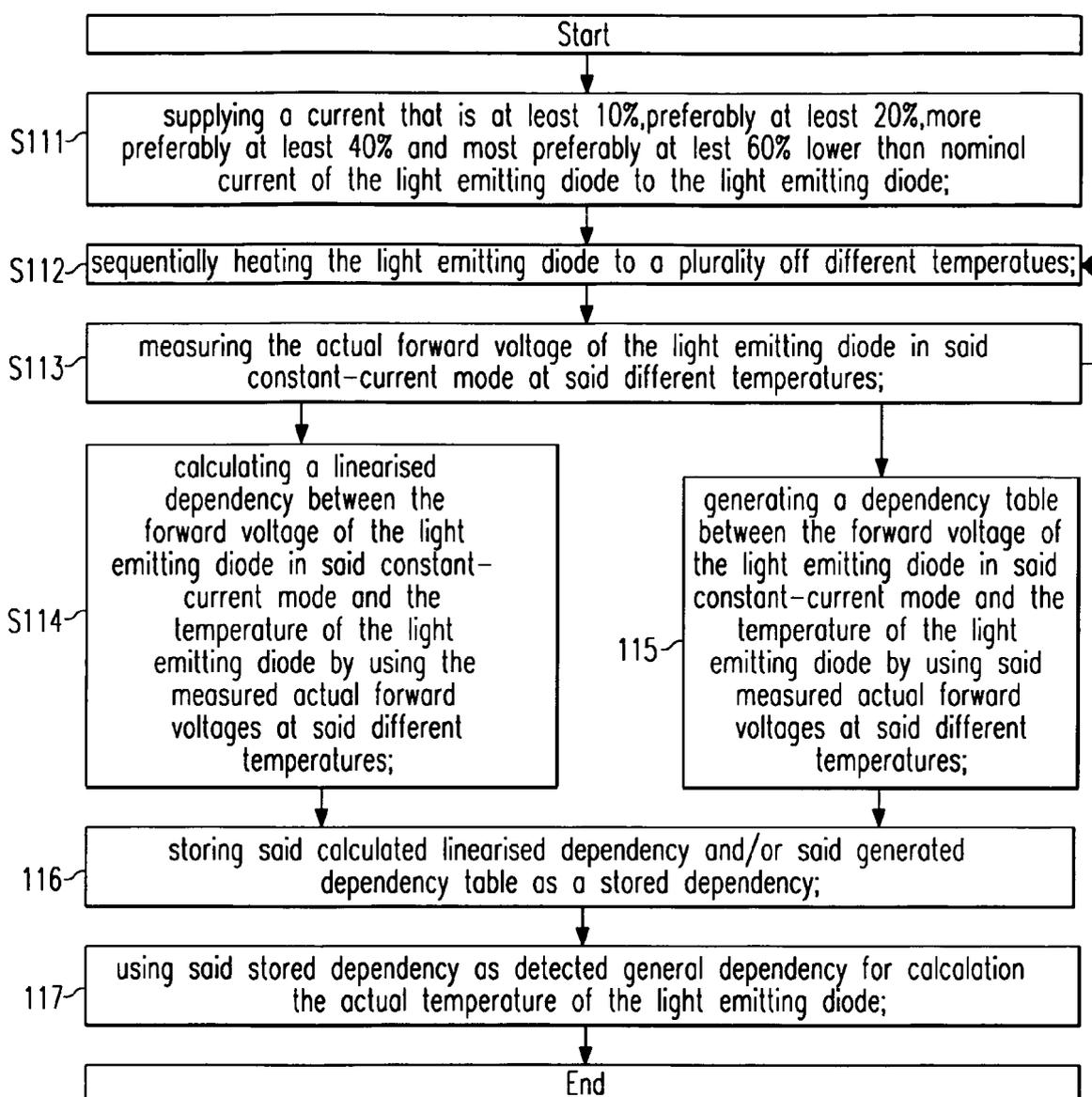


Fig. 1B

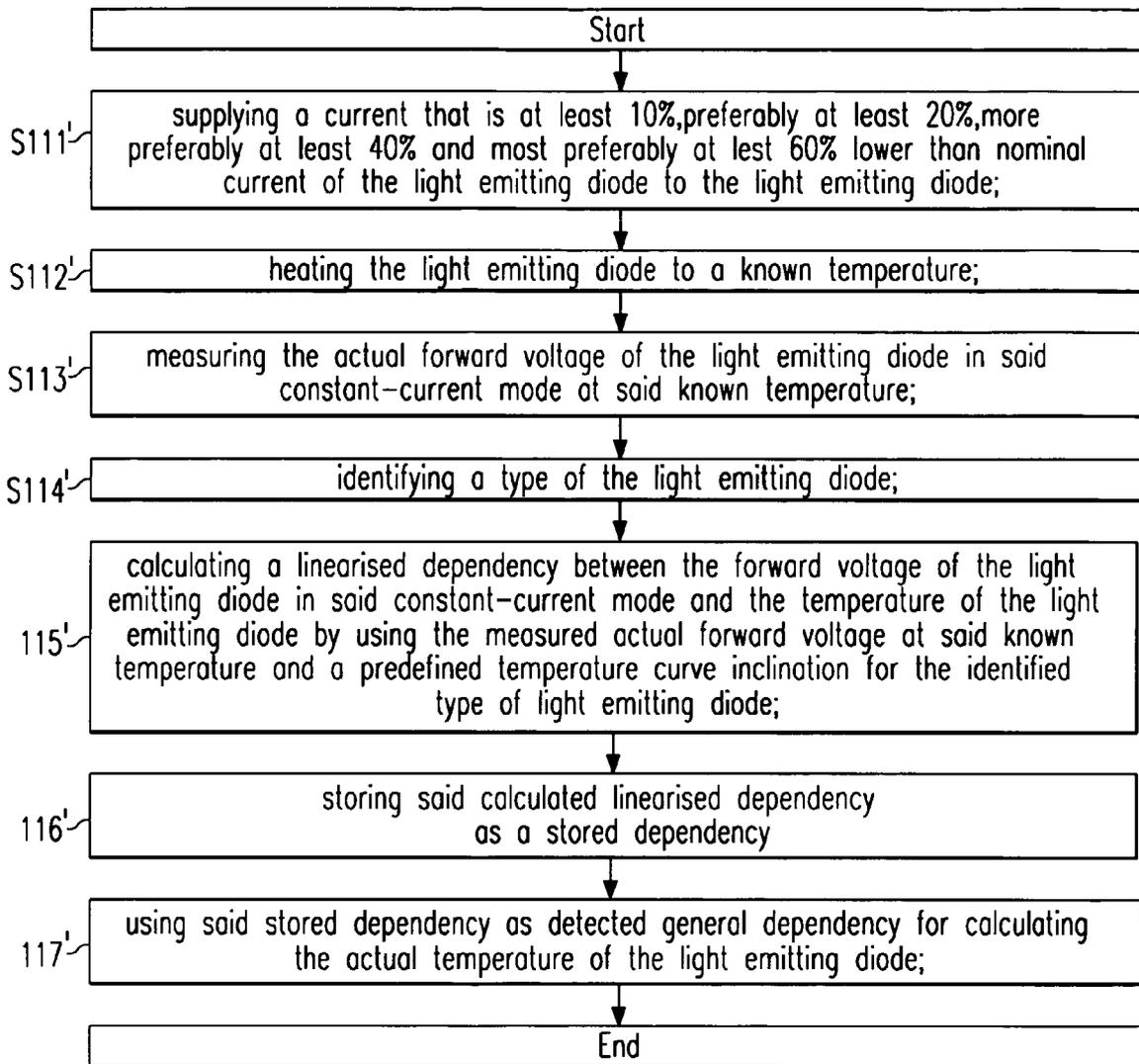


Fig. 1C

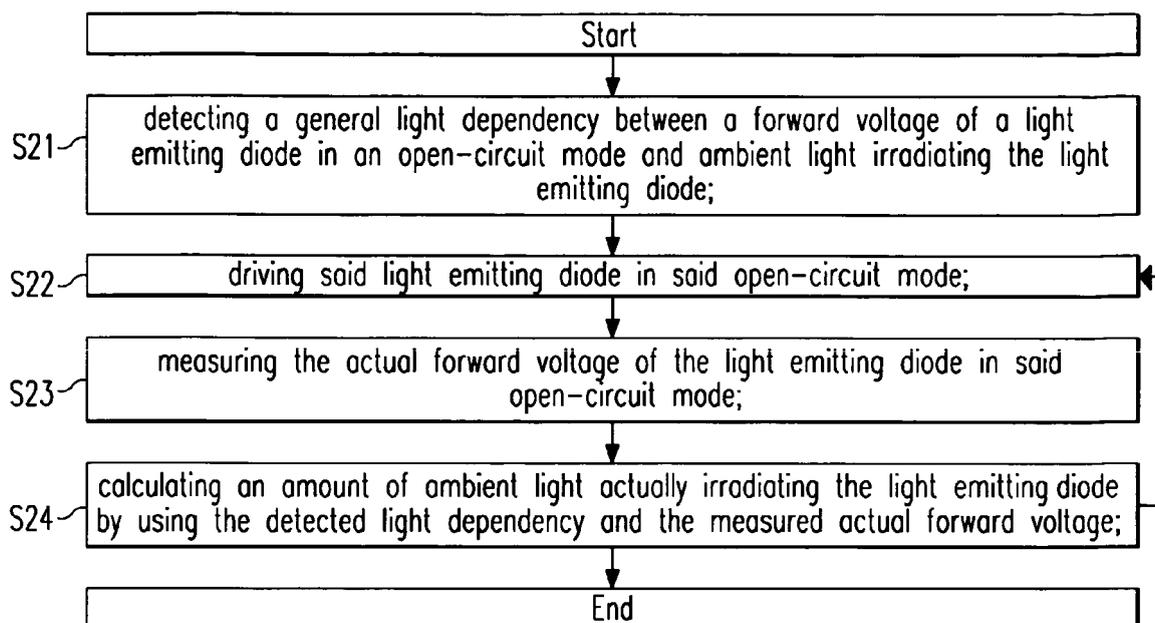


Fig. 2A

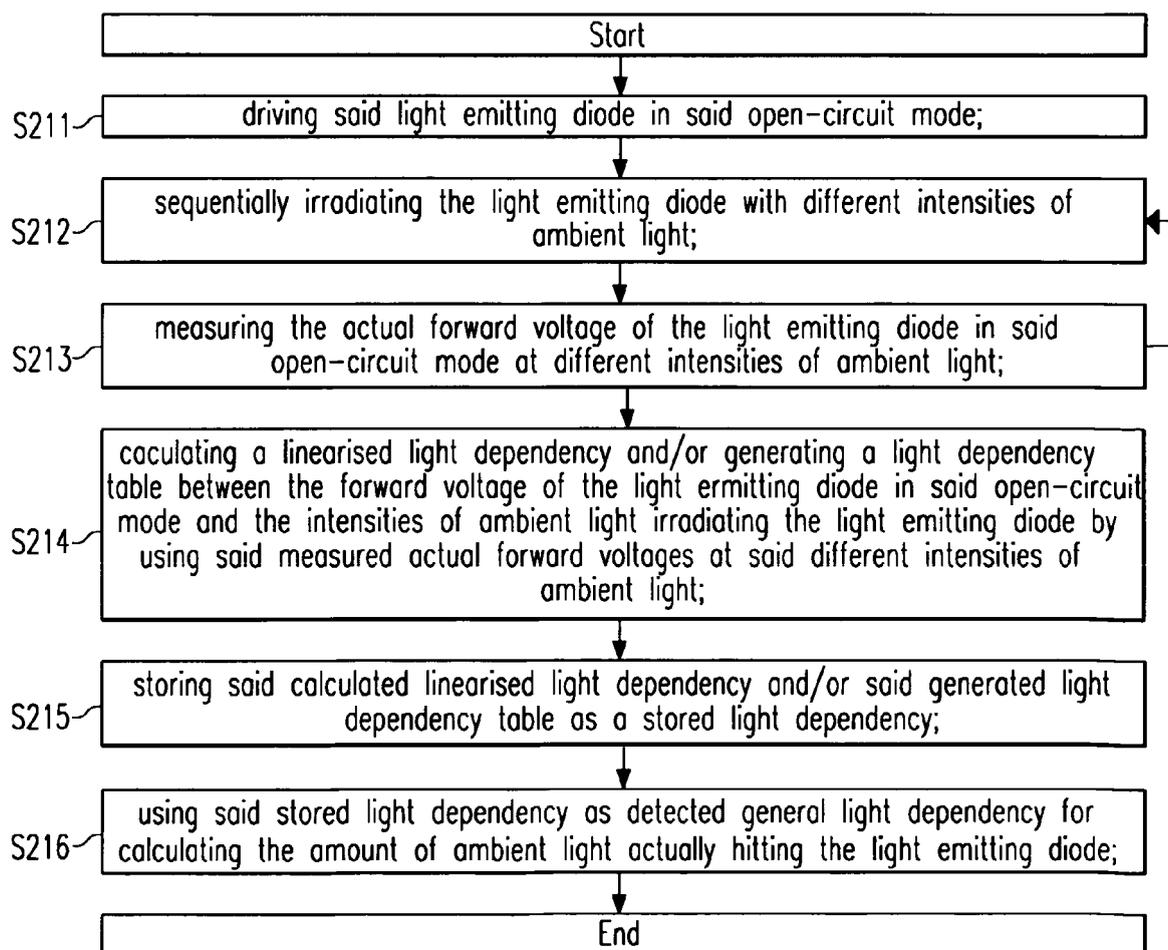


Fig. 2B

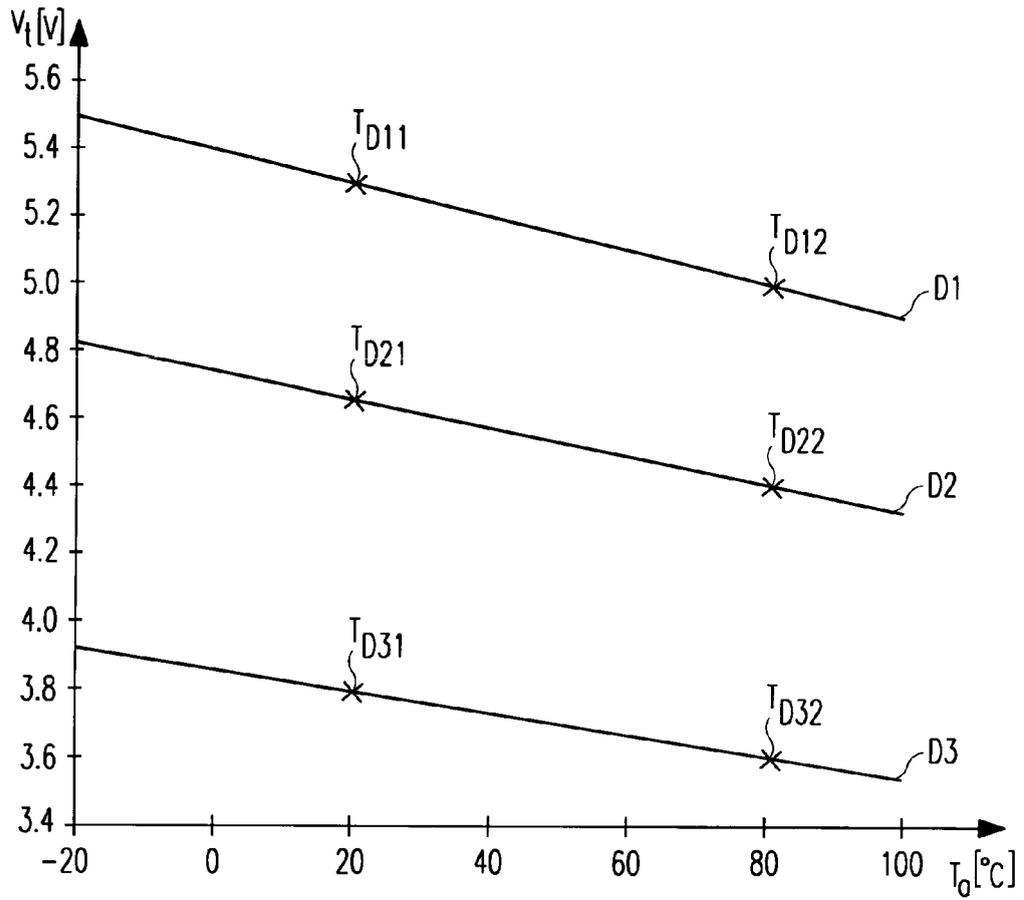


Fig. 3

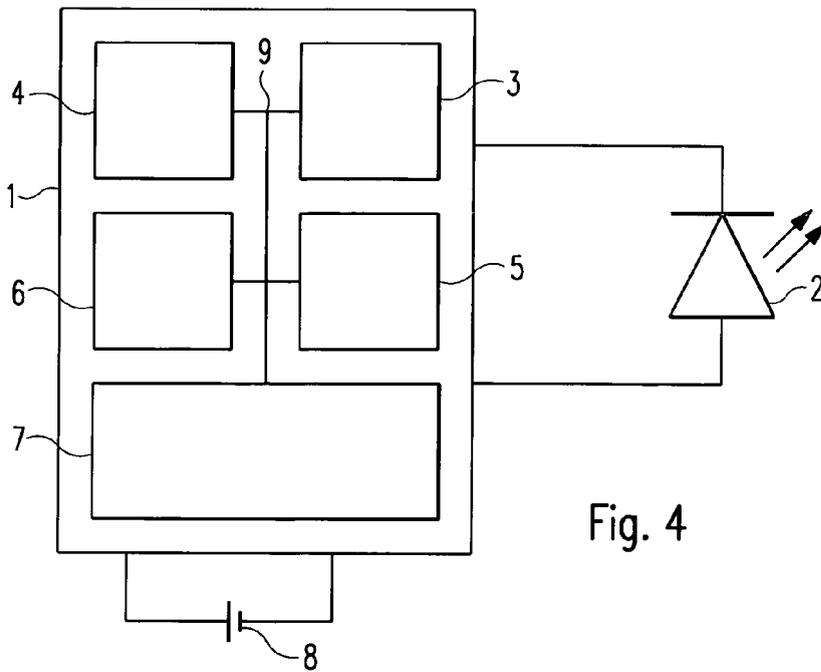


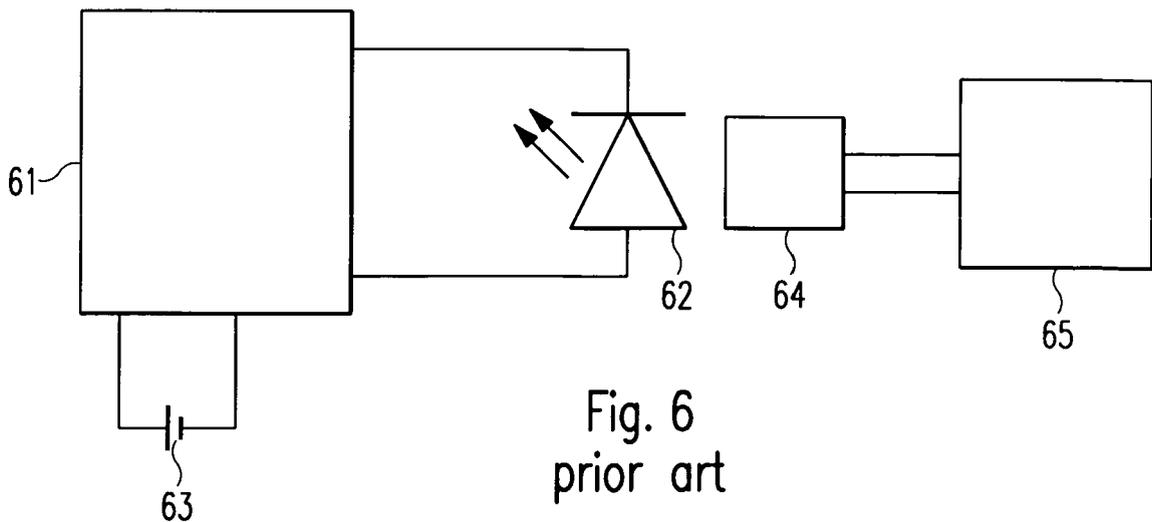
Fig. 4

V_t [V]	...	4.20	4.22	4.24	...	4.40	4.42	...
T [°C]	...	118	110	102	...	67	63	...

Fig. 5A

V_t [mV]	...	100	110	120	...
E [lx]	...	1000	1500	2000	...

Fig. 5B





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