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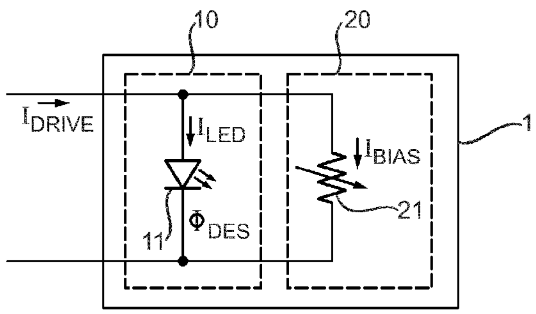
FIG. 1



(57) Abstract: The invention describes an LED module (1) for a lighting arrangement (2), which LED module (1) comprises an LED unit (10) comprising a number of LED light sources (11) and a current regulation unit (20) comprising a current regulating means (21), which current regulating means (21) is realized to divert a portion (I_{BIAS}) of a drive current (I_{DRIVE}) from the LED unit (10) such that the remainder current (I_{LED}) is sufficient to drive the number of LED light sources (11) to emit a desired light output (ODES). The invention further describes a lighting arrangement (2) comprising an LED unit (10) comprising a number of LED light sources (11); a driver realized (30) to supply a drive current (IDRIVE) to an LED unit (10); and a current regulation unit (20) comprising a current regulating means (21), which current regulating means (21) is realized to divert a portion (I_{BIAS}) of the drive current (I_{DRIVE}) from an LED unit (10) such that the remainder current (I_{LED}) is sufficient to drive the number of LED light sources (11) to emit a desired light output (Φ_{DES}). The invention also describes an automotive lighting unit comprising such a lighting arrangement (2); and a method of operating such a lighting arrangement (2).

WO 2015/000863 A1

LED module

FIELD OF THE INVENTION

The invention describes an LED module, a lighting arrangement, an automotive front lighting arrangement, and a method of operating a lighting arrangement.

BACKGROUND OF THE INVENTION

Continuing developments in the field of LED (light-emitting diode) technology have made it possible for LEDs to be used instead of conventional light sources in many applications. High-power LEDs can deliver 80 or more lumen per Watt, so that such LEDs are becoming attractive for use in applications such as automotive front lighting. In such applications the light source used must be able to generate a fixed light output in order to assure that the minimum and maximum beam intensity for the headlamp stays within given limits. The requirements are relatively easily fulfilled by a light source such as a filament lamp, which is operated at a given test voltage. The qualities of the light to be delivered by certain types of replaceable light sources (e.g. filament lamps, high-intensity discharge lamps, etc.) are governed by the appropriate regulations, for example the ECE regulations. When such a light source fails, it can simply be replaced by an equivalent light source, since each light source of a certain type is manufactured to deliver a certain quantity of luminous flux.

The process control in LED manufacturing is not sufficient to guarantee one of the key performance parameters, namely the luminous flux (light output) at a given test current. Relatively large variations in luminous flux can occur, even among LEDs of a single type and manufactured under the same conditions. Since the flux is strongly dependent on the drive current, the light output can be adjusted by adapting the drive current, i.e. the current at the output of the driver. There are various ways of achieving this result. For example, LEDs can be pre-grouped in 'bins' according to the luminous flux they deliver at a given test current, and the LEDs of a particular bin can be matched to a driver that is realized to deliver an appropriate drive current for an LED of that bin. The input to such a driver is often a fixed voltage or a voltage range. If the LED should fail, the lighting arrangement can only deliver the same light output if an LED of the same bin is used as a replacement. Clearly, it is expensive to ensure a supply of replacement LEDs for each bin.

To make the design more flexible, some approaches make use of a bin-code resistor assigned to an LED. The bin-code resistor effectively identifies the bin to which an LED belongs, and is connected to the driver so that the resistance of the bin-code resistor can be 'read' by the driver. The driver can then adjust its output current accordingly. However, this approach is also associated with a relatively high effort in matching bin-code resistors to LEDs, by the added wiring that is necessary to connect the bin-code resistor to the driver, and by the additional driver circuitry that is necessary to evaluate and respond to the current through the bin-code resistor.

Furthermore, the continuous effort to improve the efficiency of LEDs, i.e. to obtain more lumen per Watt, results in a greater efficiency. In other words, the 'newer' LEDs of a certain type deliver more luminous flux than the 'older' versions. If the efficiency of an LED type improves significantly over the life time of an application based on that LED type, it may become necessary to redesign the driver to adapt to the lower drive currents needed by the more efficient LEDs. Clearly, this adds significantly to the overall cost of the application. However, from the point of view of the manufacturer, it is important to be able to provide a replacement light source product that will continue to comply with the applicable regulations and that will not also require a consumer to replace a part that still functions when in fact a different part (e.g. a failed LED) is being replaced. In particular in automotive lighting applications, it is desirable to be able to offer a stable system configuration over the manufacturing period of the vehicle, and for at least another ten years beyond that.

Therefore, it is an object of the invention to provide an improved design of an LED lighting solution, avoiding or overcoming the problems mentioned above.

SUMMARY OF THE INVENTION

The object of the invention is achieved by the LED module of claim 1, by the lighting arrangement of claim 10, by the automotive lighting unit of claim 14, and by the method according to claim 15 of operating a lighting arrangement.

According to the invention, the LED module for a lighting arrangement comprises an LED unit comprising a number of LED light sources and a current regulation unit comprising a current regulating means, which current regulating means is realized to divert a portion of a drive current from the LED unit such that the remainder current is sufficient to drive the number of LED light sources to emit a desired light output.

Here, the term 'drive current' is to be understood to mean a pre-set or constant current that is output by a driver, in other words the drive current delivered by such a driver is not adapted to the load, in this case the LED module, but is directly used by the load without any driver-side adjustment. An advantage of the LED module according to the invention is that it can be realized for use with any driver that delivers a fixed drive current, i.e. the LED module according to the invention can be used with essentially any such driver, since the current regulating means ensures that the LED(s) of the LED unit receive a level of current that will drive them to emit the desired light output.

The term 'remainder current' is to be understood as the current remaining after a portion of the drive current has been diverted by the current regulation unit. The term 'light output' is to be understood to mean the luminous flux produced by the light source(s), usually expressed using the lumen SI unit.

The LED module according to the invention does away with the need to adapt or adjust the driver current to the requirements of the LEDs being used, as outlined in the introduction. In contrast to the prior art, therefore, the LED module according to the invention is essentially driver-independent, i.e. an LED module of a certain type will always deliver the desired luminous flux, as long as it is connected to a driver that is capable of supplying the fixed drive current.

According to the invention, the lighting arrangement comprises at least one LED unit comprising a number of LED light sources;; a current regulation unit comprising a current regulating means, which current regulating means is realized to divert a portion of a drive current from the LED unit such that the remainder current is sufficient to drive the number of LED light sources to emit a desired light output; and a driver unit comprising a driver realized to supply the drive current.

An advantage of the lighting arrangement according to the invention is that driver can simply be realized to deliver a certain fixed current, and does not have to include circuitry for adjusting a drive current to suit a load, which is a problem in the prior art realizations. In other words, the driver will deliver the fixed or constant current, regardless of the load that is connected across its output. Here, the 'load' is given by the LED unit and current regulation unit. The driver delivers its output current, i.e. the fixed drive current to the LED unit and current regulation unit. The driver is preferably a constant current driver, capable of accommodating the input voltage variation typical for its application, and capable of providing a certain range of output voltage depending on the load, e.g. the number of LEDs to be driven in series. The current regulation unit diverts some of the current so that the remaining current is enough to drive the LED(s) of the LED unit to deliver the desired light output.

According to the invention, the automotive lighting unit comprises such a lighting arrangement, i.e. a lighting arrangement with an LED module comprising an LED unit and a current regulating unit, realized such that the current regulation unit diverts as much current as necessary from a fixed drive current delivered by a driver, so that the LEDs of the LED unit always emit a desired light flux.

An advantage of the automotive lighting unit according to the invention is that it can be realized in a very straightforward way, since the driver does not need to be hard-wired to a bin code resistor in order to determine the amount of current it should deliver. Instead, the driver can simply be realized to deliver a certain fixed or constant current, regardless of the load connected across its outputs, and the current regulating unit of the LED module ensures that the driver current is then adjusted if necessary, i.e. by diverting a portion away from the LED unit, so that the LED unit only receives the current it requires in order to emit the desired amount of light.

According to the invention, the method of operating a lighting arrangement comprising an LED unit with one or more LED light sources comprises the steps of supplying a drive current and diverting a portion of the drive current from the LED unit such that the remainder drive current is sufficient to drive the number of LED light sources to emit a desired specific light output.

An advantage of the method according to the invention is that it is much easier to simply divert an 'excess' current from the LED unit, thus leaving the required LED current as a 'remainder', than it is to ensure that precisely that LED current is supplied by the driver in the first place. This makes it easy to drive multiple LED modules, for example a series configuration LED modules, using only a single driver, giving an advantageously simple design for a lighting application.

The dependent claims and the following description disclose particularly advantageous embodiments and features of the invention. Features of the embodiments may be combined as appropriate. Features described in the context of one claim category can apply equally to another claim category.

As indicated above, LED light sources (or simply 'LEDs') are generally operated by connecting them to a driver, which delivers the necessary current, usually a DC current. The driver can comprise any regulating and conversion circuitry required to deliver a steady current to the LED light sources. As mentioned in the introduction, prior art drivers are generally also connected to some kind of bin code resistor or other circuitry that provides information about the LED light source(s) to be driven, so that the driver can adjust the output current to suit the requirements of the LED(s). The LED module according to the invention does away with the need for such a driver-side adjustment. In the following, therefore, it may be assumed that the drive current supplied by the driver unit comprises a fixed drive current, i.e. the driver is preferably realized to essentially always deliver a certain current. For example, in one embodiment of a front lighting arrangement comprising an LED module according to the invention, where the lighting arrangement is to be used to generate a front beam, the driver can simply be realized to deliver a constant DC current of 1.0 A. This is more than enough to drive an LED unit with five high-power LEDs of typically 1.0 mm^2 surface area in order to obtain a luminous flux of 1000 lm.

An LED module according to the invention can comprise an LED unit with any number of LED light sources. Preferably, an LED module according to the invention comprises an LED unit with a series arrangement of up to ten LED light sources, more preferably a series arrangement of up to six LED light sources. The number of LED light sources is preferably chosen to provide a luminous flux of 150 lm – 3000 lm, more preferably 250 lm – 2000 lm. For example, a luminous flux of 150 lm might be achieved by a single LED light source in the LED unit of an LED module. A luminous flux of 2000 lm or more might be achieved by a string of series-connected LED light sources in the LED unit of a single LED module, or by arranging several LED modules in a series-connected string, or by using several LED modules, each driven by a separate driver. Depending on the desired luminous flux, the drive current to the LED module(s) is preferably in the range of 100 mA to 2.0 A, more preferably in the range of 700 mA to 1.5 A. Any driver capable of delivering such a current could be used to drive one or more LED modules according to the invention in order to achieve the desired luminous flux.

In a particularly preferred embodiment of the invention, the portion of the drive current diverted from the LED unit by the current regulating means comprises a bias current, and the remainder of the drive current comprises an LED current. The current regulating means is preferably realized such that the bias current diverted by the current regulating means results in a specific current through the number of LED light sources of the LED unit. In other words, the current regulation unit diverts enough current from the drive current so that only a desired or necessary current remains, thus ensuring that the LED(s) are driven at the correct LED current for that application.

The number of LEDs of an LED module is preferably be chosen so that most of the drive current is used to generate light and so that the bias current is relatively low compared to the LED current. Should the efficiency of the LEDs increase during the lifetime of a lighting application that uses those LEDs, the LED current can be reduced by increasing the bias current accordingly. In this way, the lighting arrangement according to the invention makes it possible to maintain an essentially constant overall efficiency as regards light generation. This allows consideration of the requirements of lighting applications such as automotive lighting, which may need to keep the efficiency constant once a lighting system has been designed. This is in contrast to other conventional lighting applications, which tend to welcome an increased efficiency of the light sources.

With the LED module, lighting arrangement, and method according to the invention, a later generation of an automotive lighting unit can benefit from an increased LED efficiency by defining a higher desired light output for the same fixed drive current; by using less LEDs to generate the same desired light output at the same fixed drive current; or by defining a lower fixed drive current to generate the same desired light output with the same number of LEDs. However, since it is advantageous and more economical to keep the driver of an automotive lighting unit as universal as possible, preferred embodiments of the invention are realized for use with improved generations of LEDs as well as a stable or essentially unchanging driver design.

The LED module can be realized in any appropriate way. For example, the current regulation unit can be realized as a simple parallel resistor of appropriate size, assuming that the relevant voltage to calculate the resulting bias current is defined by the forward voltage of the LED(s) in the LED unit. Preferably, the current regulation unit is connected in parallel with the LED unit in the manner of a shunt regulator.

The current regulation unit can be realized in any appropriate way to divert a portion of the drive current from the LED(s) of the LED unit. Basically, the current regulation unit can be realized to maintain an essentially constant current across the LED unit. This can be achieved by varying a resistance of the current regulation unit according to a voltage drop across the LED(s) of the LED unit. For example, one batch of LEDs may be characterized by a certain efficiency, requiring a specific LED current in order to emit a desired quantity of light. A later batch of LEDs can be characterized by a higher efficiency, so that the same LED current will result in a higher light output. This effect is undesirable in certain applications, for example in automotive front lighting applications, in which the light output to be delivered by a light source is strictly regulated, and deviations are not permitted. Therefore, to avoid a light output that is actually brighter than desired, the current regulation unit of the LED module according to the invention is adjusted to the efficiency of the LED(s) of the LED unit, ensuring that enough bias current is always diverted from the driver current so that the LED(s) always deliver only the desired light output. The current regulation unit can be realized to function as a variable resistor, so that its resistance can adjust according to the load presented to it by the LED module. In a particularly preferred embodiment of the invention, the current regulation unit comprises a linear regulator. Since such components are easily realized, for example as an integrated circuit, in a preferred embodiment of the invention the current regulation unit comprises an off-the-shelf linear regulator component.

As indicated above, the developments in LED technology are continually leading to improvements in the performance of the LEDs, so that the efficiency of the LEDs of a 'later' batch can be expected to exceed the efficiency of an 'earlier' batch of the same type of LED. A significant increase in efficiency can be achieved for a type of LED within the space of a several months. These developments are generally perceived as positive, since it is usually better when a light source such as an LED can be manufactured to delivers more light flux without consuming more power. In household or commercial lighting applications, for example, an increase in LED efficiency is generally advantageous. However, a negative side-effect is observed in applications that require a constant light flux. For example, in automotive front lighting applications, very strict standards apply to the light output that is to be delivered by a lighting arrangement. Therefore, in a further preferred embodiment of the invention, the current regulation unit comprises a power dissipation arrangement realized to dissipate a portion of the power available to the current regulation unit. In this way, the current regulation unit can effectively dissipate 'excess power', i.e. the power that is no longer needed by this type of LED in order to deliver the desired light flux.

The light output of an LED can depend to a certain extent on its junction temperature. During operation, the junction temperature of the LED(s) in the LED unit can increase. This results in a drop in efficiency for most LEDs. Therefore, the light output by an LED can decrease at higher temperatures. However, a requirement of a regulation such as an automotive front lighting regulation is that the light output remains stable over a wide range of operating temperatures. A prior art driver may include a module designed to compensate for the reduction of light output with increasing operating temperature. For example, a temperature sensor based on a component such as a negative-temperature coefficient thermistor can be placed next to the LED and any temperature-related change in resistance is detected by the driver. The prior art driver is calibrated for that combination of thermistor and LED, so that a certain alteration in the current through the thermistor indicates to the driver by how much the LED drive current must be adjusted. This allows the driver to respond to changes in the resistance of the thermistor by increasing or decreasing the LED drive current as appropriate. However, if the LED must be replaced at some time, the driver would have to be re-calibrated for the new combination of thermistor and LED. Therefore, in a particularly preferred embodiment of the invention, the current regulation unit comprises a temperature compensation arrangement realized to adjust the bias current according to a local temperature of the LED(s) in the LED unit. In this way, the light output of the LED module can be maintained at an essentially constant level, with the LED(s) delivering an essentially constant desired light output over a relevant temperature range. The temperature compensation arrangement can comprise a suitable arrangement with a thermistor or equivalent. The temperature compensation arrangement is preferably realized to adjust a resistance in the bias path of the current regulation means, so that the bias current is adjusted accordingly. The temperature at the temperature compensation arrangement will alter in a controlled manner according to the temperature of the LEDs, so that it is relatively straightforward to achieve a satisfactory realization of a temperature compensation arrangement.

The LED module according to the invention can itself comprise an inherently modular design. For example, an LED unit can be realized as an independent modular component of the LED module, so that such an LED unit can be replaced easily and without having to replace other components of a lighting arrangement in which the LED module is incorporated. Similarly, if an LED unit itself comprises several LED light sources, for example a series arrangement of several high-power LEDs, each such LED light source could be realized as an independent modular component of the LED module, so that such an LED can be replaced easily and without having to replace other components of a lighting arrangement in which the LED module is incorporated. Of course, the current regulation unit could be realized as an independent modular component of the LED module, so that it too could be replaced if necessary without having to replace other elements of a lighting arrangement.

Even though LEDs are generally long-lived and reliable light sources, it cannot be ruled out that an LED may fail for some reason. An LED failure can result in the LED appearing as a short circuit ("fail short"), or as an open circuit ("fail open"). When an LED (or an individual LED of a series arrangement of LEDs) fails open, the LED (or the series arrangement) will stop generating light, and a significant change in the current/voltage characteristic of the lighting arrangement occurs. When one LED of a series arrangement of LEDs fails short, the other LEDs will continue to generate light, but at a lower level than required. Depending on the number of LEDs in the series arrangement, there may only be a moderate alteration in the electrical characteristic of the LED arrangement. For example, the forward voltage across the series arrangement may drop slightly. A "fail short" failure is therefore more difficult to detect. However, particularly for lighting applications that require a constant specific luminous flux, it is important that such a failure is detected. Therefore, in a preferred embodiment of the invention, the LED module comprises a failure detection unit realized to detect a failure of an LED light source of an LED unit of the LED module and to bring the LED module into predefined state in the event of an LED failure. Preferably, the failure detection unit can be realized to force a controlled and pre-determined behavior of the LED module in the event of an LED failure. For example, if one of the LEDs fails open, the failure detection unit may shut off the drive current. This would result in an open failure of the entire LED module. In the event of an LED failing short, the failure detection unit could interrupt the drive current to the LED module. For example, the failure detection unit could open a switch in the input to the LED module to force an open failure of the entire LED module. Alternatively, the failure detection unit could be realized to conduct all drive current as 'bias' current, for example, by providing an additional current path that effectively bypasses the LED unit and protects the current regulation unit from damage. An LED failure can therefore be detected and dealt with in an easy and straightforward way. In another embodiment, the failure detection unit could also comprise a means to generate an output signal that can be read by an external failure detection unit. For example, the driver of a vehicle could be informed visually that a front lighting unit has failed and must be replaced.

As indicated above, the LED module according to the invention can be used as part of a front lighting arrangement in an automotive lighting application. Such lighting applications are subject to strict regulations concerning the luminous flux to be output, the color temperature of the light, etc. To satisfy any light color requirements, in a further preferred embodiment of the invention, the LED light sources of the LED unit are chosen to emit essentially white light with a certain color point or color temperature when used in a front lighting unit. The current regulation unit of the LED module according to the invention ensures that the LED module can deliver the required quantity of luminous flux. In this way, a very reliable lighting arrangement can be achieved with relatively little effort, and for which the quality of the light output is maintained even if the LED module must be replaced during its lifetime.

A method of performing maintenance on an automotive lighting unit according to the invention can comprise the steps of removing only an older LED unit from the automotive light unit; and replacing the older LED unit by a new LED unit, which new LED unit is characterized by a higher efficiency than the older LED unit.

Other objects and features of the present invention will become apparent from the following detailed descriptions considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for the purposes of illustration and not as a definition of the limits of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a schematic diagram of a first embodiment of an LED module according to the invention;

Fig. 2 shows a schematic diagram of a second embodiment of an LED module according to the invention;

Fig. 3 shows a schematic diagram of a third embodiment of an LED module according to the invention;

Fig. 4 shows a schematic diagram of a first embodiment of an LED lighting arrangement according to the invention;

Fig. 5 shows a schematic diagram of a second embodiment of an LED lighting arrangement according to the invention;

Fig. 6 shows a schematic diagram of a third embodiment of an LED lighting arrangement according to the invention;

Fig. 7 shows a schematic diagram of a fourth embodiment of an LED lighting arrangement according to the invention;

Fig. 8 shows a schematic diagram of a prior art LED lighting arrangement;

Fig. 9 shows a schematic diagram of another prior art LED lighting arrangement.

In the drawings, like numbers refer to like objects throughout. Objects in the diagrams are not necessarily drawn to scale.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Fig. 1 shows a schematic diagram of a first embodiment of an LED module 1 according to the invention. The LED module 1 comprises an LED unit 10 connected in parallel to a current regulation unit 20. The LED module 1 is realized for connection to a driver (not shown) so that a drive current I_{DRIVE} can be applied to the LED module 1. The LED unit 10 can comprise several LEDs 11 connected in series, but only one representative LED 11 is shown here for the sake of clarity. The current regulation unit 20 diverts a portion of the drive current I_{DRIVE} from the LED unit 10. The diverted portion is referred to as the bias current I_{BIAS}. The LED unit 10 draws the remainder of the drive current, and the current passing through the LED(s) 11 of the LED unit is referred to as the LED current I_{LED}. The current regulation unit 20 comprises a current regulating means 21 that determines the amount of bias current I_{BIAS} to divert from the drive current I_{DRIVE}. Here, the current regulating means 21 is shown symbolically as a variable resistor. Any suitable circuitry can be used to fulfill the purpose of diverting a suitable bias current I_{BIAS} so that the remaining LED current I_{LED} does not exceed the level at which the LED(s) 11 of the LED unit 10 emit a desired luminous flux Φ_{DES}. The desired luminous flux Φ_{DES} is the 'starting point' defining the realization of the LED module 1. Knowing the desired luminous flux Φ_{DES}, and knowing the LED current I_{LED} required to deliver that luminous flux Φ_{DES}, the amount of bias current I_{BIAS} that is to be diverted from the LED unit 10 can be determined. This information is then used to realize the 'variable resistor' function of the current regulation unit 20 in order to 'tune' the output of the LED(s), which would otherwise be too bright if driven directly by the drive current I_{DRIVE}.

Fig. 2 shows a schematic diagram of a second embodiment of an LED module 1 according to the invention. Here, the current regulation unit 20 is realized by incorporating an off-the-shelf linear regulator 210 into the current regulating means 21. For example, a component such as an LT3080 may be used (or any other suitable component) and the current drawn by the device 210 can be set, for example by appropriate choice of control resistors.

As mentioned above, the efficiency of an LED can decrease as the pad or board temperature increases. In order to correct such an efficiency drop at higher temperature, some kind of temperature compensation means can be included in the circuitry. This embodiment of the LED module 1 includes a thermistor arrangement R_{TH}, R_2, R_3 in addition to a control resistor R_2. The thermistor arrangement R_{TH}, R_2, R_3 can adjust the overall resistance of the current regulation unit 20 in direct proportion to an increase in temperature, so that the bias current I_{BIAS} decreases as temperature increases. As a result, the LED current I_{LED} increases at higher temperatures, so that the inherent drop in efficiency is effectively cancelled out or compensated, and the LED(s) 11 of the LED module 1 can consistently deliver the desired luminous flux Φ_{DES}.

Fig. 3 shows a schematic diagram of a third embodiment of an LED module 1 according to the invention. Here, the circuit of Fig. 2 above can be further modified to take into account the increasing efficiency of a future generation of LED that can be expected to replace the LED 11 used in the LED unit 10. Since a more efficient LED will require a lower

LED current to deliver the same desired luminous flux Φ_{DES}, this embodiment of the current regulation unit includes a power dissipation arrangement 211 for dissipating the excess power, thus increasing the bias current I_{BIAS} by the required amount. For example, the 'surplus' power may be expressed as the product of the forward voltage over the LED(s) in the LED unit and the bias current. This surplus power may be too high to be dissipated in a compact variable resistor as e.g. the linear regulator 210 in Fig. 2. Since the forward voltage is known for every LED design, and the required bias current I_{BIAS} can be determined knowing the desired luminous flux Φ_{DES} and the drive current I_{DRIVE}, it is relatively straightforward to determine a value for an additional resistance in the bias path that would ensure that the majority of the 'surplus' power is dissipated by the additional resistance, thereby ensuring also that the power dissipated by the variable resistor of the current regulation unit is comparably low. In this way, a favorably long lifetime can be achieved for the more sensitive type of component that is required to realize the variable resistor (for example a linear regulator). The bias resistance can be achieved by any suitable combination of resistors, for example a parallel arrangement of conventional resistors R_{BIAS1}, R_{BIAS2} as shown in the diagram. In this way, it is relatively easy to adapt the current regulation unit 20 to suit a newer, more efficient version of the LEDs that are used in the LED unit 10, so that a replacement LED module 1 will behave in essentially exactly the same way as an older LED module that is being replaced, and will deliver the same desired luminous flux Φ_{DES}.

Figs. 4 - 6 show various possible embodiments of an LED lighting arrangement 2 according to the invention. In Fig. 4, the LED module 1 comprises an LED unit 10 with several series-connected LEDs 11 chosen to provide a desired luminous flux Φ_{DES}. A single driver 30 provides a drive current I_{DRIVE} to the LED module 1. A single current regulation unit 20 diverts a bias current I_{BIAS} from the drive current I_{DRIVE} so that the LEDs 11 are driven using the remaining LED current I_{LED}.

In a simplified representation in Fig. 5, a driver 30 is used to provide a drive current I_{DRIVE} to an LED module 1 comprising a single LED 11 in its LED unit. Each LED module 1 also includes a current regulation unit 20 in the same manner as in Fig. 4, in parallel with the LED unit of the LED module 1, although this is not shown in the diagram. Three such combinations are arranged to collectively act as an LED lighting arrangement 2 that provides a desired luminous flux Φ_{DES} given by the sum of the luminous flux delivered by each of the LED modules 1.

In Fig. 6, a similar configuration is used, however in this case the driver 30 supplies a drive current I_{DRIVE} to three series-connected LED modules 1. Each LED module 1 also includes a current regulation unit 20 as shown in Fig. 4, in parallel with the LED unit of the LED module 1. Again, the LED modules 1 are chosen so that they collectively deliver a certain luminous flux Φ_{DES}. In each of the realizations shown above, any of the LED modules, LED units etc. may be replaced by a spare part that complies with the same current/flux specification.

Fig. 7 shows a further embodiment of a lighting arrangement 2 according to the invention. Here, the LED module 1 also comprises a failure detection unit 40 which comprises circuitry for detecting whether an LED of an LED unit 10 has failed open and/or for detecting whether an LED of an LED unit 10 has failed short. Here, in the event of an LED "fail open", the failure detection unit 40 can open a switch 41 (which is otherwise closed during normal operation of the LED module) in the input line to the LED module 1, so that the drive current I_{DRIVE} to the LED module 1 is interrupted completely. Such a realization can be useful in the configurations shown in any of Figs. 4 – 6, where each LED module 1 can comprise a failure detection unit 40 with this capability. The diagram also shows that the failure detection unit 40 can close a switch 42 (which is otherwise open during normal operation of the LED module) in an additional current path parallel to the LED unit 10 and the current regulation unit 20 so that, in the event of "fail short" failure of an LED in an LED module 1, the entire drive current I_{DRIVE} can be diverted through the switch 42 and the additional current path. This capability is useful particularly in the case of a series arrangement of several LED modules that are driven by a single driver, for example in a lighting arrangement such as that shown in Fig. 6. The failure detection and correction capability ensures that the remaining non-defective LED modules will still continue to produce light, and the defective module can clearly be identified and does not pose a risk to the overall lighting arrangement.

Fig. 8 shows a prior art approach to 'tuning' the light output by an LED lighting unit 70, for example in an automotive front lighting arrangement product. Such a lighting arrangement 70 may be based on a certain driver design, so that the same driver 72 is used in each lighting arrangement 70. Furthermore, the lighting arrangement 70 generally has to satisfy the automotive front lighting standards that apply in the country in which the product is to be implemented. Therefore, in a first step of manufacturing the prior art lighting arrangement, the LEDs 71 that are to be used are pre-grouped in 'bins' according to the level of flux they deliver at a nominal drive current specific for that type of LED. This nominal drive current may be different from the drive current required for them to deliver the required luminous flux Φ_{700}. The input to the driver is usually a fixed voltage or a fixed voltage range, so that the output drive current I_{DRIVE} of the driver 30 may or may not result in a desired luminous flux when the driver 30 is used as it is to drive a number of LEDs 71. To circumvent this problem, a so-called 'bin code resistor' R_{BIN} can be permanently assigned to the LEDs 71, and is chosen according to the performance characteristics of the LEDs 71 to which it is matched. During operation of the prior art lighting arrangement 70, the value of the bin code resistor R_{BIN} is 'read' by the driver, which then adjusts the drive current I_{DRIVE} in order to achieve a satisfactory LED current $I(R_{BIN})$. To achieve this, the driver arrangement 72 must include a bin code reader 73 for 'reading' the bin code resistor R_{BIN}, and current adjustment circuitry 74 for adjusting the drive current I_{DRIVE} as a function of the bin code resistor to give the required amount of current $I(R_{BIN})$. One disadvantage of the prior art approach is that considerable effort must be invested in sorting the LEDs 71 according to 'bin', and selecting the matching bin code resistors R_{BIN}. Another disadvantage is that the prior art lighting arrangement 70 does not allow for an easy replacement of a failed LED 71 at a later point in time. This is because the bin code resistor R_{BIN} is matched to the older, probably less efficient LEDs 71 used in the initial realization, and a later, more efficient LED with a different flux/current characteristic will result in a brighter light output, i.e. brighter than the allowed luminous flux Φ_{700}. Particularly in the case of an application such as automotive front lighting, this increased efficiency and improved light output is actually a serious disadvantage, since it can mean that the lighting arrangement would no longer fulfill the statutory regulations. If LEDs with the poorer current/flux characteristics are no longer available, it may be necessary to replace the entire lighting arrangement 70, even if only one LED 71 has failed. Clearly, the costs of ensuring that a supply of LEDs 71 with specific current/flux characteristics is kept available for several years will result in expensive replacement parts, thus making such a product unattractive from the point of view of the consumer.

Fig. 9 shows another prior art embodiment of a lighting arrangement 70'. Here, several LED modules 700' are used, each with its own driver 72. Each LED module 700' in this case comprises an LED unit which can comprise one or more LEDs in series. A bin code resistor R_{binA}, R_{binB}, R_{binC} is matched to each LED unit. Each driver adjusts its drive current so that each LED unit receives the necessary LED current $I(R_{binA})$, $I(R_{binB})$, $I(R_{binC})$ in order to collectively deliver the required luminous flux Φ_{700}. This arrangement may be used when several replaceable LEDs are to be used in a single application. Since all of the LEDs require a 'tuning' of their light output to a specific target value, an individual driver 72 is required for each LED. However, this prior art realization has the same disadvantages as described under

Fig. 8 above, and, in general, it is not possible to drive several LED modules 700 with only one driver 72, in contrast to the embodiment shown in Fig. 6 of a lighting arrangement according to the invention.

Although the present invention has been disclosed in the form of preferred embodiments and variations thereon, it will be understood that numerous additional modifications and variations could be made thereto without departing from the scope of the invention.

For the sake of clarity, it is to be understood that the use of "a" or "an" throughout this application does not exclude a plurality, and "comprising" does not exclude other steps or elements. Use of the terms "unit" or "module" does not preclude the use of a plurality of units or modules, respectively.

CLAIMS:

1. An LED module (1) for a lighting arrangement (2), the LED module being configured to receive a drive current (I_{DRIVE}) and to emit a light output (Φ), and which LED module (1) comprises

- an LED unit (10) comprising a number of LED light sources (11) and
- a current regulation unit (20) comprising a current regulating means (21),

which current regulating means (21) is realized to divert a portion (I_{BIAS}) of a drive current (I_{DRIVE}) from the LED unit (10)

wherein

the current regulator is configured to divert, at a nominal drive current (I_{DRIVE}), such portion (I_{BIAS}) of a drive current (I_{DRIVE}) from the LED unit (10) that the remainder current (I_{LED}) is sufficient to drive the number of LED light sources (11) to emit a desired light output (Φ_{DES}) for that nominal drive current (I_{DRIVE}).

2. An LED module according to claim 1, wherein the portion of the drive current (I_{DRIVE}) diverted from the LED unit (10) by the current regulating means (21) comprises a bias current (I_{BIAS}), and the remainder of the drive current (I_{DRIVE}) comprises an LED current (I_{LED}).

3. An LED module according to claim 2, wherein the current regulating means (21) is realized such that the bias current (I_{BIAS}) diverted by the current regulating means (21) results in a specific current (I_{DES}) through the number of LED light sources (11) of the LED unit (10).

4. An LED module according to any of the preceding claims, wherein the current regulation unit (20) is connected in parallel with the LED unit (10).

5. An LED module according to any of the preceding claims, wherein the current regulating means (21) comprises a linear regulator (210).

6. An LED module according to any of the preceding claims, wherein the current regulation unit (20) comprises a power dissipation arrangement (211) realized to dissipate a portion of the power available to the current regulation unit (20).

7. An LED module according to any of the preceding claims, wherein the current regulation unit (20) comprises a temperature compensation arrangement realized to adjust the diverted current portion (I_{BIAS}) according to a temperature of an LED light source (11) of the LED unit (10).

8. An LED module according to any of the preceding claims, wherein the LED unit (10) comprises an independent modular component of the LED module (1) and/or wherein an LED light source (11) of the LED unit (10) comprises an independent modular component of the LED module (1).

9. An LED module according to any of the preceding claims, comprising a failure detection unit (40) realized to detect a failure of an LED light source (11) of an LED unit (10) of the LED module (1) and to bring the LED module (1) into a predefined state in the event of an LED light source failure.

10. A lighting arrangement (2) comprising

- an LED module according to claim 1; and
- a driver (30) realized to supply the drive current (I_{DRIVE})

11. A lighting arrangement according to claim 10, wherein an LED unit (10) and a current regulation unit (20) are realized as an LED module (1) according to any of claims 1 to 9.

12. A lighting arrangement according to claim 11, comprising an arrangement of two or more LED modules (1) connected in series, and a single driver (30) for supplying the drive current (I_{DRIVE}) to the series-connected LED modules (1).

13. A lighting arrangement according to claim 11 or claim 12, wherein an LED module (1) comprises a failure detection unit (40) realized to detect a failure of an LED light

source (11) of an LED unit (10) of that LED module (1) and to bring that LED module (1) into a predefined state in the event of an LED light source failure.

14. An automotive lighting unit comprising a lighting arrangement (2) according to any of claims 10 to 13.

15. A method of operating a lighting arrangement (2) comprising an LED unit (10), which LED unit (10) comprises a number of LED light sources (11), which method comprises the steps of

- supplying a drive current (I_{DRIVE}) to the LED unit (10); and
- diverting a portion of the drive current (I_{DRIVE}) from the LED unit (10) such that the remainder drive current (I_{LED}) is sufficient to drive the number of LED light sources (11) to emit a desired light output (Φ_{DES}).

FIG. 1

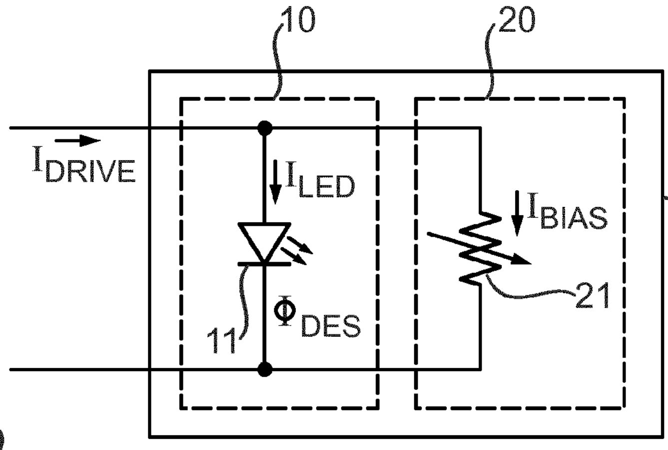


FIG. 2

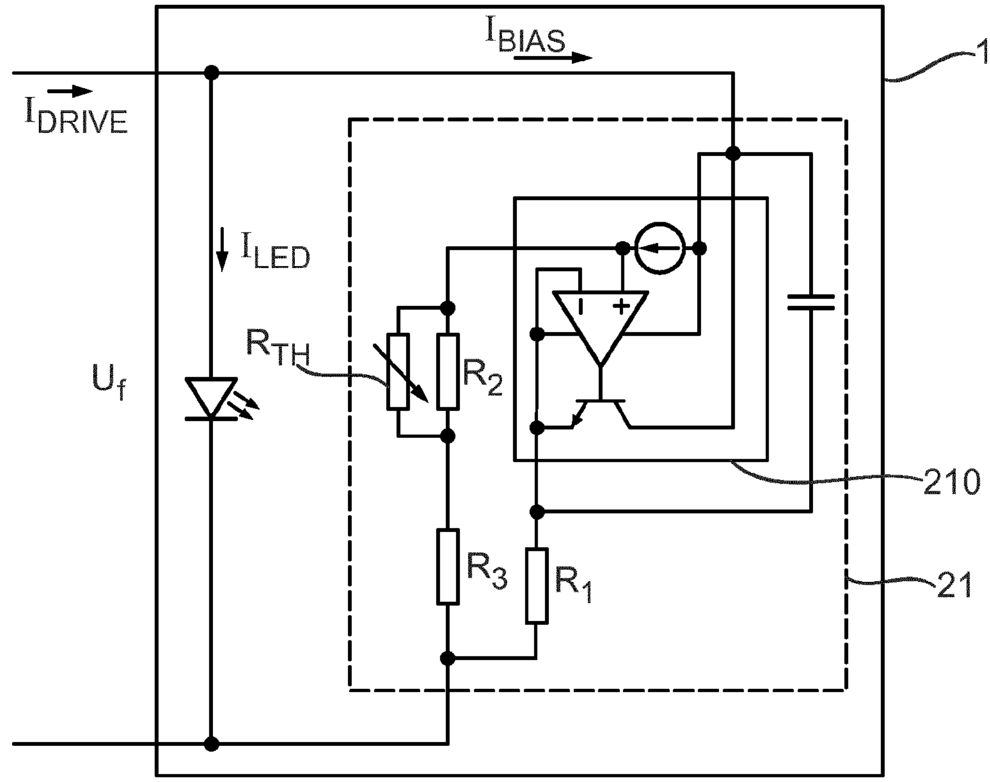


FIG. 3

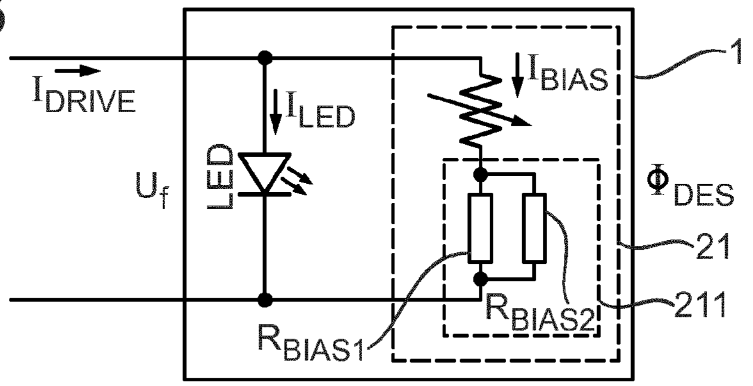


FIG. 4

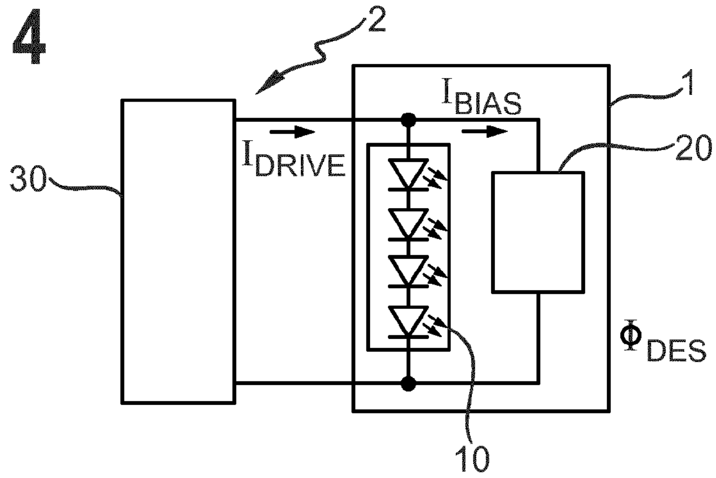


FIG. 5

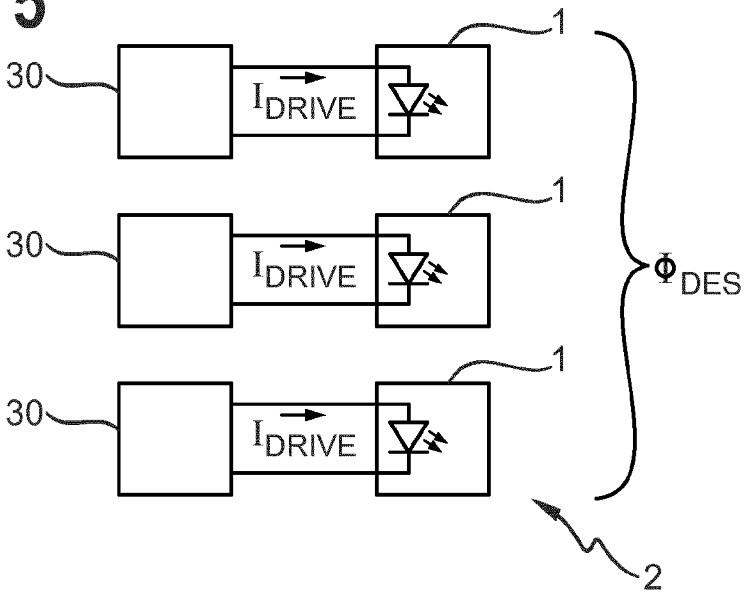


FIG. 6

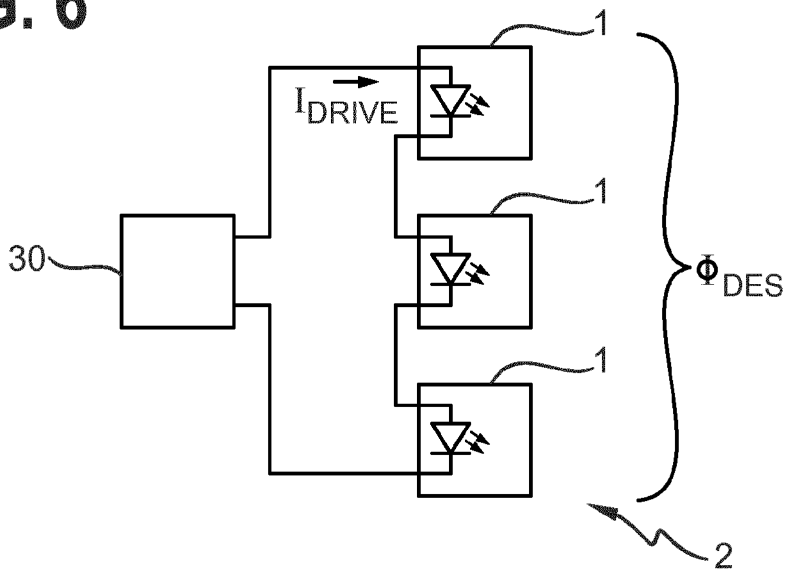


FIG. 7

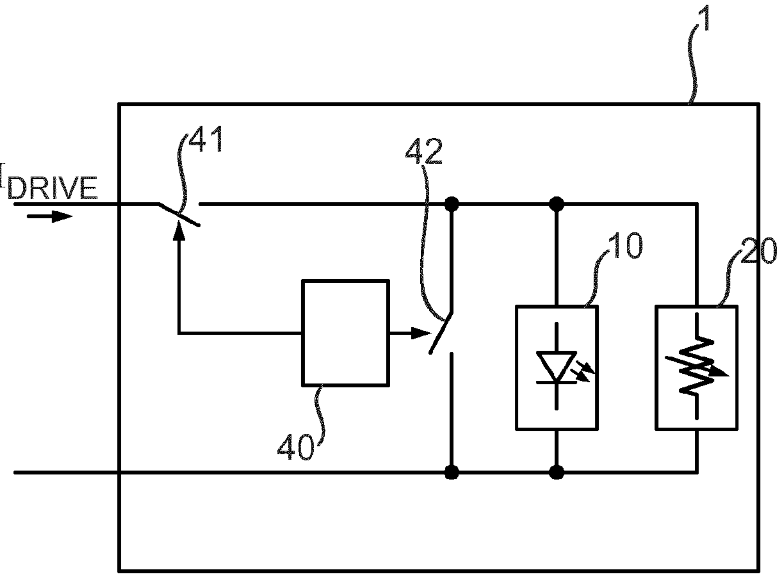


FIG. 8 PRIOR ART

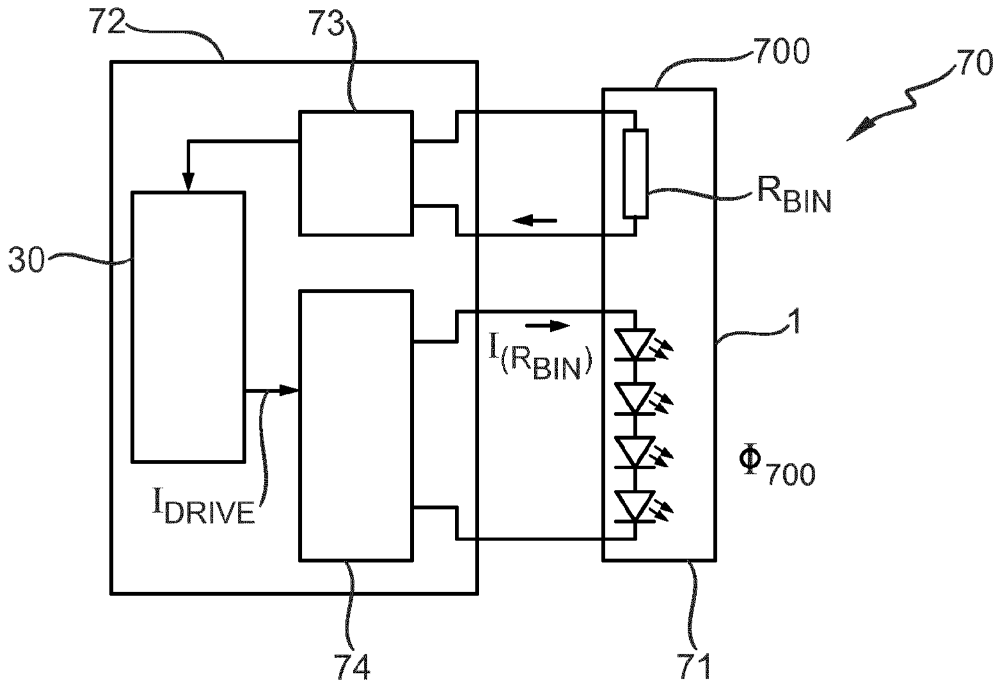
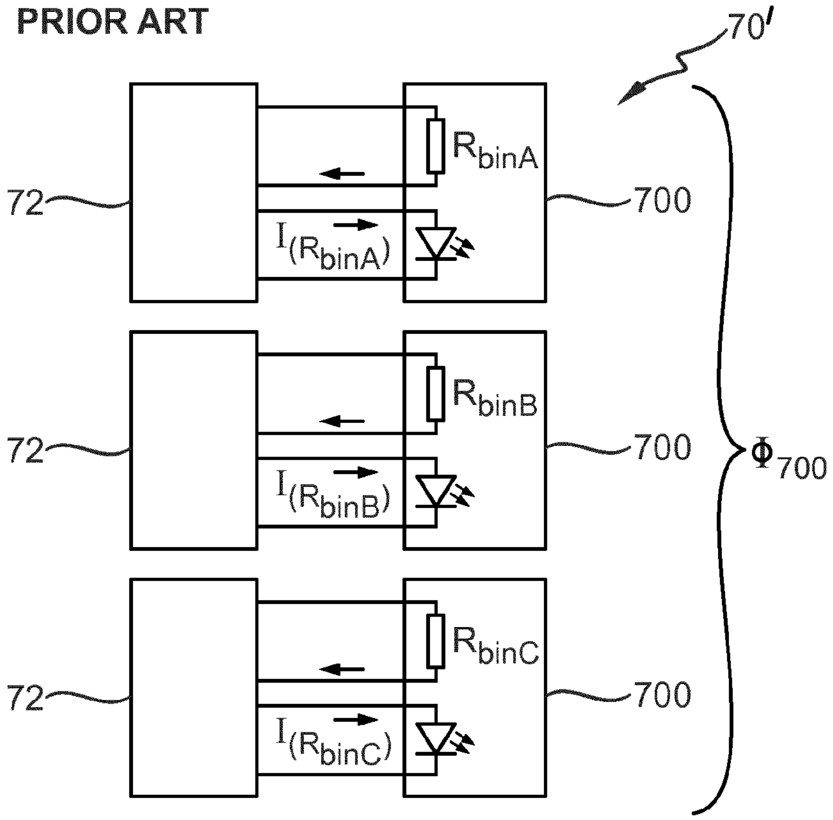


FIG. 9 PRIOR ART



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/063886

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B33/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/241549 A1 (WOOTTON GERALD R [CA]) 6 October 2011 (2011-10-06) paragraph [0172] - paragraph [0188]; figure 4	1-15
X	US 2011/068696 A1 (VAN DE VEN ANTONY P [HK] ET AL) 24 March 2011 (2011-03-24) paragraph [0066] - paragraph [0073]; figures 7B, 15	1-7, 10-12,15
X	US 6 127 784 A (GROSSMAN HYMAN [US] ET AL) 3 October 2000 (2000-10-03) columns 2-4; figure 1	1-7, 10-12,15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 July 2014	31/07/2014

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/063886

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