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(71) Applicant: **Helvar Oy Ab**
03600 Karkkila (FI)

(72) Inventor: **Perkiö, Tuomas**
03600 Karkkila (FI)

(74) Representative: **Berggren Oy Ab**
P.O. Box 16
Eteläinen Rautatiekatu 10A
00101 Helsinki (FI)

(54) Hybrid control of a driver for light-emitting semiconductor devices

(57) A technique for providing output current for one or more light-emitting semiconductor devices is provided. According to an example embodiment, the technique comprises controlling supply of said output current from a power converter means for said one or more light-emitting semiconductor devices and regulating electrical characteristics of said output current in accordance with requested light output characteristics, said regulating comprising alternately enabling and disabling provision of said output current at a selectable duty cycle to provide duty cycle based output current limitation and controlling provision of said output current at a selectable current level to enable level based output current limitation, so as to regulate the output current to exhibit an average level that corresponds to said requested light output characteristics by a combination of the duty cycle based output current limitation and the level based output current limitation in dependence of a selected one of a plurality of different predefined mapping functions.

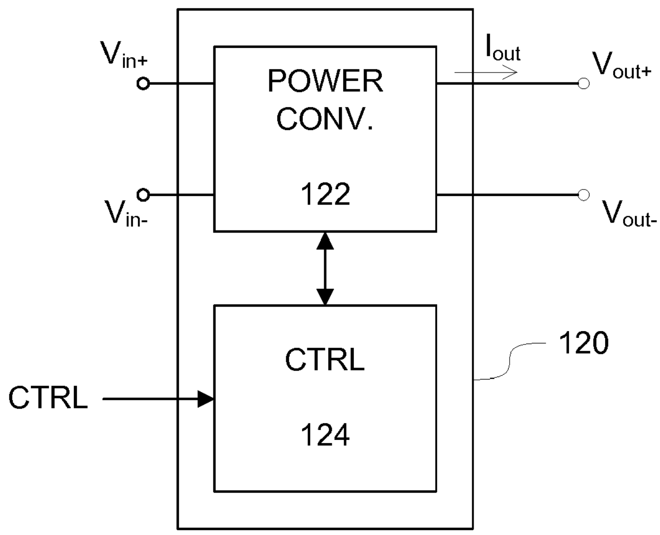

Figure 2

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Description

FIELD OF THE INVENTION

[0001] The example embodiments of the present invention relates to control of a driver device for operating one or more light-emitting semiconductor devices, such as light emitting diodes (LEDs). In particular, one or more example embodiments of the present invention relate to controlling operation of a driver device for operating one or more light-emitting semiconductor devices to provide an output current that causes light output at a desired level by using a suitable combination of duty cycle based control and level based control of the output current.

BACKGROUND OF THE INVENTION

[0002] Light fixtures that rely on light emitting semiconductor devices such as light emitting diodes (LEDs) as the source of light are typically provided with control means for adjusting the light output level of the light fixture. The adjustment is typically provided on basis of a control signal or command received via a user interface of the light fixture or via a central controller entity. In case of LEDs, such control means may be provided as part of a LED driver applied to operate the LEDs as current control means for regulating the characteristics of the output current provided from the LED driver such that light output at a desired light level is provided.

[0003] In this regard, the current control means in the LED driver may apply duty cycle based control of output current to cause alternately enabling and disabling provision of the output current from the LED driver in accordance with applied duty cycle and cycle frequency. Consequently, the output current is limited such that it (typically periodically or substantially periodically) varies between a nominal level (or a maximum level) and zero. With suitable selection of the duty cycle and cycle frequency a desired average level of the output current and, consequently, a desired light output level from the LEDs driven by the LED driver can be provided. Since the duty cycle based control results in alternately switching the light output from the LEDs on and off in accordance with the enabled and disabled periods of provision of the output current, the applied cycle frequency needs to be sufficiently high to ensure that no perceivable flickering or variations in the provided light level occur (especially at low duty cycles) due to periods of the light output from the LEDs being temporarily switched off. On the other hand, the cycle frequency needs to be sufficiently low to enable accurate control of light level.

[0004] As another example, the current control means in the LED driver may be arranged to limit the level of the output current to be lower than the nominal level set for the LED driver. Hence, the nominal level may be applied to provide the full light output level, whereas decreasing the level of the output current to a lower value decreases the provided light output level accordingly. Such control of light output level may be referred to as linear control or amplitude control. A challenge in the linear control is that color of light output provided from the LEDs typically varies with the variations in the level of the output current. Moreover, especially at low light output current levels the accuracy of the output current measurement and adjustment and, consequently, the accuracy of the control of the light output level may not be sufficient.

[0005] A hybrid control that makes use of both the duty cycle based control and the linear control may be applied in order to provide a balance between requirements pertaining to the allowable extent of possibly perceivable flickering of light output and allowable extent of changes in the color of light output. Known solutions in this regard typically make use of the duty cycle based control only at high light output levels, whereas a combination of the duty cycle based control and linear control is applied at low light output levels. However, known solutions only aim to keep perceivable flickering of light output at minimum in a general case while they fail to take into account specific requirements of a given lighting application.

SUMMARY OF THE INVENTION

[0006] It is an object of the present invention to provide a technique for operating one or more light-emitting semiconductor devices using a hybrid control in a more versatile and flexible manner.

[0007] The object(s) of the invention are reached by a driver device, by a lighting arrangement and by a method as defined by the respective independent claims.

[0008] According to a first example embodiment of the invention, a driver device for providing output current for one or more light-emitting semiconductor devices is provided, the deriver device comprising power converter means for supplying said output current via an output interface and control means for regulating electrical characteristics of said output current in accordance with requested light output characteristics, said control means comprising duty cycle control means for alternately enabling and disabling provision of output current from the driver device at a selectable duty cycle to enable duty cycle based output current limitation and level control means for controlling provision of the output current from the driver device at a selectable current level to enable level based output current limitation, wherein said control means is arranged to regulate the output current to exhibit an average level that corresponds to said requested light output characteristics by a combination of the duty cycle based output current limitation and the level based output current limitation in dependence of a selected one of a plurality of different predefined mapping functions stored in the driver device.

[0009] According to a second example embodiment of the invention, a lighting arrangement is provided, the lighting arrangement comprising a driver device according to the first example embodiment and light output means electrically coupled to said driver device.

[0010] According to a third example embodiment of the invention, a method for providing output current for one or more light-emitting semiconductor devices is provided, the method comprising controlling supply of said output current from a power converter means for said one or more light-emitting semiconductor devices and regulating electrical characteristics of said output current in accordance with requested light output characteristics. Said regulating comprises alternately enabling and disabling provision of said output current at a selectable duty cycle to provide duty cycle based output current limitation and controlling provision of said output current at a selectable current level to enable level based output current limitation, so as to regulate the output current to exhibit an average level that corresponds to said requested light output characteristics by a combination of the duty cycle based output current limitation and the level based output current limitation in dependence of a selected one of a plurality of different predefined mapping functions.

[0011] The exemplifying embodiments of the invention presented in this patent application are not to be interpreted to pose limitations to the applicability of the appended claims. The verb "to comprise" and its derivatives are used in this patent application as an open limitation that does not exclude the existence of also unrecited features. The features described hereinafter are mutually freely combinable unless explicitly stated otherwise.

[0012] Some features of the invention are set forth in the appended claims. Aspects of the invention, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of some example embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

Figure 1 schematically illustrates some components of a lighting arrangement in accordance with an example embodiment.

Figure 2 schematically illustrates some components of a light emitting diode (LED) driver in accordance with an example embodiment.

Figure 3 schematically illustrates some components of an exemplifying buck converter.

Figure 4a illustrates an example of a mapping function in accordance with an example embodiment.

Figure 4b illustrates an example of a mapping function in accordance with an example embodiment.

Figure 5a illustrates an example of a mapping function in accordance with an example embodiment.

Figure 5b illustrates an example of a mapping function in accordance with an example embodiment.

Figure 6 schematically illustrates some components of a light emitting diode (LED) driver in accordance with an example embodiment.

DETAILED DESCRIPTION

[0014] Figure 1 schematically illustrates at least some components of a lighting arrangement 100 comprising a LED driver 120 for operating a LED module 140 and the LED module 140 for providing the light output. The LED module 140 is detachably connectable to an output interface of the LED driver 120. The lighting arrangement 100 may include other components in addition to those depicted in Figure 1. The lighting arrangement 100 may be provided as part of any lighting device or lighting system that is configured to make use of light emitted from the LED module 140. Non-limiting examples of such devices or systems include a light fixture or a luminaire, a display arrangement, a headlight or taillight arrangement of a vehicle, etc.

[0015] The LED module 140 may comprise one or more LEDs, where the LEDs may be arranged e.g. as a string of one or more LEDs connected in series or as two or more strings of LEDs connected in parallel, where each string of LEDs comprises one or more LEDs connected in series. While described herein, for clarity and brevity of description, with references to the LEDs, the description generalizes into light output means of any type arranged to make use of one or more light-emitting semiconductor devices and the driver device that is suitable for operating such light-emitting semiconductor device(s). Examples of such light-emitting semiconductor devices of other type include laser diodes (LDs) and organic light-emitting diodes (OLEDs).

[0016] The LED driver 120 is arranged to generate a regulated output current I_{out} via an output interface of the LED deriver 120 under control of one or more control signals or commands provided to the LED driver 120 via a control signal input CTRL. The regulated output current I_{out} is provided by using electric energy brought to an input interface of the LED driver 120 via input nodes V_{in-} and V_{in+}. The output interface comprises at least two output nodes V_{out-} and V_{out+}. Typically, the node V_{out-} is at a ground potential while a higher potential is provided at the node V_{out+}. Some light output means may be driven, however, with alternating current (AC), in which case the potentials of the output nodes V_{out-} and V_{out+} of the output interface change polarity repeatedly.

[0017] Figure 2 schematically illustrates at least some components of the LED driver 120 to facilitate understanding of operation of various embodiments of the present invention. The LED driver 120 is arranged to continuously control or regulate the output current I_{out} such that it exhibits desired electrical characteristics in order to cause the LED module 140 to provide light output that exhibits requested light characteristics. The LED driver 120 comprises power converter means 122 for supplying the output current I_{out} and control means 124 for regulating electrical characteristics of the output current I_{out} in accordance with requested light output characteristics.

[0018] The power converter means 122 is arranged to generate electric current I_{pc}, referred to as a power converter output current or a converter current, for provision as or derivation of the output current I_{out} using the electric energy brought via the input nodes V_{in-} and V_{in+} of the input interface of the LED driver 120. As an example, the LED driver 120 may be arranged to provide the output current I_{out} as a direct current (DC) of desired characteristics exhibiting a desired average current level, wherein the average level of the output current I_{out} is regulated in accordance with the control signals or commands received via the control signal input CTRL and/or in accordance with an internal configuration of the LED driver 120.

[0019] The control means 124 comprises at least duty cycle control means for alternately enabling and disabling provision of the output current I_{out} from the LED driver 120 at a selectable duty cycle. The control means 124 further comprises level control means for controlling provision of the output current I_{out} from the LED driver 120, when the provision of the output current I_{out} is enabled, at a selectable current level. The duty cycle control means serves to enable duty cycle based output current limitation whereas the level control means serves to enable level based output current limitation. The duty cycle control means and the level control means jointly enable hybrid control of the output current I_{out}. The control means 124 is arranged to regulate output current I_{out} to exhibit an average level that corresponds to requested light output characteristics by using a combination of the duty cycle based output current limitation and the level based output current limitation. The combination of the duty cycle based output current limitation and the level based output current limitation is provided in dependence of a selected one of a plurality of mapping functions stored in the LED driver 120.

[0020] The control means 124 may comprise a processor, e.g. as a microprocessor, as a microcontroller or as a programmable device of other type, that is at least arranged to cause alternately enabling and disabling provision of the output current I_{out} and to control level of the output current I_{out} within periods during which the provision of the output current I_{out} is enabled, as will be described in the following in more detail. In this regard, the LED driver 120 (e.g. the control means 124) may further comprise a memory for storing a computer program comprising executable instructions that, when executed by the processor, cause the control means 124 to alternately enable and disable provision of the output current I_{out} and to control level of the output current I_{out} within periods during which the provision of the output current I_{out} is enabled.

[0021] Before describing the operation of the control means 124 in this regard in more detail, some details concerning operation of the power converter means 122 are described in the following in order to facilitate understanding the operation of the control means 124.

[0022] The power converter means 122 comprises one or more power converter entities. In case of two or more power converter entities are applied, they can be arranged in cascade, thereby constituting two or more power converter stages. A power converter entity is typically provided as a switched-mode power supply arranged to make use of controlled high-frequency switching operation of one or more switches in order to supply an output voltage of desired characteristics on basis of an input voltage provided thereto. The power converter means 122 may comprise also other entities, such as for example a rectifier (especially if the input nodes V_{in-} and V_{in+} are to be coupled to an AC input voltage), filters, fuses, signal transceivers, and the like.

[0023] The power converter means 122 further comprises driving means for operating the switch(es) of the one or more power converter entities and current measurement means arranged to observe the level of electric current that is descriptive of the level the converter current I_{pc} provided from the power converter means 122 and to provide a current feedback signal that is indicative of the observed current level to the driving means. The observed electric current may be the converter current I_{pc} or the observed electric current may be another electric current within the power converter means 122, which another electric current is descriptive of the level the converter current I_{pc}. It is also possible to measure some other quantity than an electric current, and use such measurements to indirectly make deductions about a level of the converter current I_{pc}. The converter current I_{pc} may be provided as the output current I_{out} as such or the converter current I_{pc} may be used as basis for deriving the output current I_{out}.

[0024] Switched-mode power converter entities and their use in generation of the converter current I_{pc} in LED drivers is known in the art. As an example, the power converter means 122 may comprise a buck converter, employed e.g. as a single power converter stage of the power converter means 122 or as the final power converter stage of a cascade of power converter entities. Although known in the art, in the following some basic operational principles of a buck converter are outlined in order to facilitate understanding of some aspects related to various embodiments of the present invention. A buck converter is arranged to convert a first DC voltage into a second DC voltage according to desired voltage conversion characteristics. The first DC voltage may be a voltage brought via the input nodes V_{in-} and V_{in+} (or e.g. a DC voltage supplied by another switched-mode power supply using the electrical energy received via the input nodes V_{in-} and V_{in+}) and the second DC voltage may be an internal voltage of the buck converter.

[0025] Figure 3 schematically illustrates some components of an exemplifying buck converter 222 that may be employed in the power converter means 122. The buck converter 222 comprises a switch S, a diode D, an inductor L and a capacitor C. The buck converter 222 further comprises driving means DRV for operating the switch S, and current measurement means 226 arranged to observe the level of the converter current I_{pc} and to provide, to the driving means DRV, a current feedback signal that is indicative of the observed level to the converter current I_{pc}. The converter current I_{pc} may be provided as the output current I_{out} from the LED driver 120.

[0026] The operation of the buck converter 222 is typically based on a control loop, wherein the driving means DRV is arranged to cause closing and opening the switch S in accordance with the current feedback signal. The operation of the control loop results in alternately closing and opening the switch S at a switching frequency f_{sw}, as will be described in the following. The switching frequency f_{sw} is typically in the order of a few tens or a few hundreds kilohertz. Suitable approaches for providing the driving means DRV are known in the art.

[0027] One commonly used current control scheme is the so-called current hysteresis control, in which the control loop operates such that when the switch S is closed, the converter current I_{pc} starts to increase and the switch S is kept closed until the current feedback signal indicates electric current that exceeds a high threshold I_{th1}. When the switch S is closed, the converter current I_{pc} is drawn from electrical energy received via the inductor L (while at the same the electrical energy received via the inductor L also charges the capacitor C, and energy is temporarily stored in the magnetic field of the inductor L). In response to the current feedback signal indicating electric current that exceeds the high threshold I_{th1}, the switch S is opened and the converter current I_{pc} is drawn from the energy that was temporarily stored in the magnetic field of the inductor L, as well as from electrical energy temporarily stored in the capacitor C. Consequently, the converter current I_{pc} starts to decrease since no more electrical energy is provided via the inductor L due to the switch S being open. The switch S is kept open until the current feedback signal indicates electric current that is lower than equal to a low threshold I_{th2}. In response to the current feedback signal indicating electric current that is lower than or equal to the low threshold I_{th2}, the switch S is again closed and, consequently, the converter current I_{pc} starts to increase since electrical energy is again provided via the inductor L (and at the same time the capacitor C is charged from the electrical energy received via the inductor L).

[0028] The resulting converter current I_{pc} hence varies in accordance with the thresholds I_{th1} and I_{th2}, which are set such that converter current I_{pc} is provided at a desired nominal level that is substantially constant. The relationship between the thresholds I_{th1}, I_{th2} and the nominal level of the converter current I_{pc} depends on the details of characteristics of the current feedback signal and/or other characteristics of the feedback loop.

[0029] Other kinds of current feedback schemes are possible, for example based on a filtered and buffered output current measurement that increases or decreases the duty cycle applied by the driving means. It is also possible to only have an upper threshold current value for opening the switch in the power converter, and to rely on a constant off-time or other features of the driving means DRV to time the closing of the switch. From the viewpoint of the present invention it is not significant, which particular scheme is used, as long as the value of the converter current I_{pc} can be controlled to assume a desired nominal level with sufficient accuracy during operation of the buck converter.

[0030] It should be noted that the while the electric current provided from the switch S to the inductor L may vary significantly, the electrical energy temporarily stored in the inductor's magnetic field together with the capacitor C slowing down any changes serve to keep the converter current I_{pc} at a sufficient level also when the switch S is in open state. Therefore, the converter current I_{pc} typically exhibits only a minor high-frequency ripple (at the switching frequency f_{sw}) that, when applied as the output current I_{out} of the LED driver 120, does not result in light output level variations that are perceivable by a human observer (either when observed directly or e.g. by viewing a video recording captured in an environment where the LED driver 120 is being operated).

[0031] As a variation of the example described above, instead of directly observing the level of the converter current I_{pc} the current measurement means 226 may be arranged to observe and provide a current feedback indicative of another electric current that is descriptive of the level the converter current I_{pc}. As examples in this regard, the current measurement means 226 may be arranged to observe and report in the current feedback signal the level of electric current supplied from the switch S to the inductor L, or the level of electric current supplied from the inductor L (towards the capacitor C) and the output of the buck converter 222. The current measurement means 226 could be located also between the load and ground potential, i.e. between the lower output node V_{out-} and the lower node of the capacitor C, or somewhere else along the various current paths in the circuit. Consequently, the thresholds I_{th1}, I_{th2} are set in view of the electric current observed and reported by the current measurement means 226 and its relationship with the converter current I_{pc}. In many cases it is more convenient to handle measurements and comparisons in voltage form, so that e.g. the momentary value of the converter current I_{pc} is measured as a voltage across a current-sensing resistor, and the thresholds I_{th1}, I_{th2} are actually voltage values to which the measured voltage is compared.

[0032] While described in the foregoing by using the buck converter 222 as an example of a power converter entity of the power converter means 122, switching operation and control loop of similar kind may be employed also in context of switched-mode power supplies of other kind to provide the converter current I_{pc} that exhibits constant or substantially constant nominal level. Thus, when the operation of the power converter means 124 is enabled, it is arranged to provide the converter current I_{pc} at a substantially constant level that approximates the nominal level.

[0033] The nominal current level may considered as the maximum effective level of the converter current I_{pc} in accordance of the applied configuration of the LED driver 120. The nominal current level may be a fixed predefined value that is set e.g. upon manufacturing of the LED driver 120 and/or the power converter means 122. Consequently, also the thresholds I_{th1} and I_{th2} may be fixed predefined thresholds. As another example, the nominal current level may be an adjustable value, e.g. a value that can be selected among a plurality of available values upon installation or during use of the LED driver 120 and/or the power converter means 122. Consequently, selection of the nominal current level also results in selection of values for the thresholds I_{th1} and I_{th2} accordingly, or the other way round: selecting a value for at least one of the thresholds I_{th1} and I_{th2} may result in essentially selecting a nominal current level. A fixed selection may be provided e.g. by equipping the LED driver with a control interface for connecting an identification component (e.g. a resistor), electrical characteristics of which indicate selection of the nominal current level according to a predefined selection rule.

[0034] As described in the foregoing, the control means 124 is arranged to employ the duty cycle control means and the level control means to impose a combination of the duty cycle based output current limitation and the level based output current limitation in accordance with the requested light output characteristics in dependence of a selected one of a plurality of mapping functions stored in the LED driver 120.

[0035] In this regard, the driver device 120 stores a plurality of mapping functions, wherein each mapping function defines a mapping of a plurality of values of a certain requested light output characteristic to a corresponding plurality of pairs of a duty cycle and a current level, thereby defining a respective combination of the duty cycle based output current limitation and the level based output current limitation for each of the plurality of values. The plurality values may cover one or more ranges of values of the certain requested light output characteristics. As an example, the requested light output characteristic may comprise a requested light output level, defined e.g. as a percentage of the full light intensity the LED driver 120 is capable of causing the LED module 140 to provide, and a mapping function may define a mapping between a requested light output level and a corresponding pair of a duty cycle and a current level for a plurality of requested light output levels that cover a predefined range (or predefined ranges) of light output levels (e.g. a range from 1 % to 100 % of the full light intensity the LED driver 120 is capable of causing the LED module 140 to provide). At least conceptually, such mapping function may define a first plurality of points that represent a first current limitation curve that indicates the extent of duty cycle based output current limitation as a function of the requested light output level over the desired range (or ranges) of light output levels and a second plurality of points that represent a second current limitation curve that indicates the extent of level based output current limitation as a function of the requested light output level over the desired range (or ranges) of light output levels. Each of the first plurality and second plurality of points preferably defines or approximates a respective curve that is a (typically monotonically increasing) function of the requested light output level.

[0036] A mapping function may be defined e.g. as a set of two interrelated, continuous functions, one for duty cycle and the other for current level, so that for any arbitrary requested light output level the corresponding duty cycle and current level values can be calculated from the definitions of said continuous functions. If a mapping function is defined as (discontinuous) sets of points (as described in the foregoing), so that the duty cycle and the current level values are defined only for a predefined set of requested light output levels, the mapping function may be provided as a mapping table (stored in a memory of the LED driver 120) comprising a table entry for each requested light output level of the predefined set, where a table entry defines a pair of the duty cycle and the current level associated with a respective requested light output level. A mapping table may be applied to derive the duty cycle and the current level for an arbitrary requested light level e.g. as the duty cycle and the current level associated with the table entry provided for the requested light level that is closest to an actually requested light output level. As another example, a mapping table may be applied to derive the duty cycle and the current level for an arbitrary requested light level by respective (e.g. linear) interpolation of the duty cycles and the current levels associated with those two table entries that are closest in value (i.e. the closest smaller value and closest larger value) to an actually requested light output level.

[0037] For a mapping function, the extent (or amount) of duty cycle based output current limitation may be defined as the corresponding duty cycle to be applied in alternately enabling and disabling the provision of the output current I_{out} from the LED driver 120, whereas the extent (or amount) of level based output current limitation may be defined as a percentage or a fraction of the nominal current level to be supplied from the LED driver 120 during periods when the provision of the output current I_{out} is enabled.

[0038] The plurality of mapping functions comprises two or more mapping functions that are alternatives to each other, so that a selection among them can be made, such that they each define a different mapping of the plurality of values of the light output characteristic to corresponding pairs of a duty cycle and a current level, where the plurality of values of the light output characteristic cover one or more predefined ranges of values. Consequently, the two or more mapping functions serve to provide two or more different combinations of the duty cycle based output current limitation and the level based output current limitation for the plurality of values of the light output characteristic. As an example, the two or more mapping functions may represent different ways of selecting the pair of a duty cycle and a current level as a response to the same requested light output level, for at least a range of requested light output levels.

[0039] As an example, a mapping function may be provided as a mapping function that results in applying the duty cycle based output current limitation to a larger extent than the level based output current limitation for at least at high percentages of the requested light output level. Such a mapping function serves to keep the nominal level of the converter current I_{pc} relatively high at least in a higher end of the requested light output levels in order to ensure no or only minor deviation from the desired color of light output from the LED module 140 at the expense of possibly perceivable flickering of light output. Such a mapping function may be referred to as a mapping function of a first type.

[0040] Figure 4a depicts a conceptual example of a mapping function of the first type, where the values on the x axis indicate fractions of the maximum available requested light output level and where the values on the y axis indicate fractions of both the maximum nominal current level and the maximum duty cycle. In Figure 4a the curve with diamond-shaped markers indicates the amount of duty cycle based output current limitation as a function of the requested light output level and the curve with square-shaped markers indicates the amount of level based output current limitation as a function of the requested light output level. In the example of Figure 4a the limiting effect caused by the duty cycle based output current limitation is larger than that of the level based output current limitation across the whole range of requested light output levels.

[0041] Figure 4b depicts another conceptual example of a mapping function of the first type. In the example of Figure 4b the limiting effect caused by the duty cycle based output current limitation (the curve with diamond-shaped markers) is larger than that of the level based output current limitation (the curve with square-shaped markers) for requested light output levels that exceed a predefined threshold L_{th_a}, which threshold in this example is approximately at requested light output level of 0.1 times the maximum available light output level, illustrated in Figure 4b as a dashed vertical line.

[0042] Another way to characterize a mapping function of the first type is to define a threshold value L_{th_d} of the requested light output level above which a change of a given amount in the requested light level results in a larger change in the duty cycle based output current limitation than in the level based output current limitation. As an example, in the example of Figure 4a the threshold L_{th_d} is approximately at requested light output level of 0.3 times the maximum available light output level and in the example of Figure 4b the threshold L_{th_d} is approximately at requested light output level of 0.45 times the maximum available light output level, shown in both figures as a solid vertical line.

[0043] As another example, a mapping function may be provided as a mapping function that results in applying the level based output current limitation to a larger extent than the duty cycle based output current limitation for at least at high percentages of the requested light output level. Such a mapping function serves to keep the duty cycle of the output current I_{out} relatively high (and hence to keep the duration of periods of disabled state of the output current provision from the LED driver 120 relatively short) at least in a higher end of the requested light output levels in order to ensure no or only minor perceivable flickering of light output from the LED module 140 at the expense of possibly perceivable deviation from the desired color of light output. Such a mapping function may be referred to as a mapping function of a second type.

[0044] Figure 5a depicts a conceptual example of a mapping function of the second type, where the limiting effect caused by the level based output current limitation (the curve with square-shaped markers) is larger than that of the duty cycle based output current limitation (the curve with diamond-shaped markers) across the whole range of requested light output levels. Figure 5b depicts another conceptual example of a mapping function of the second type, where the limiting effect caused by the level based output current limitation (the curve with square-shaped markers) is larger than that of the duty cycle based output current limitation (the curve with diamond-shaped markers) for requested light output levels that exceed a predefined threshold L_{th_a}, which threshold is approximately at requested light output level of 0.1 times the maximum available light output level, illustrated in Figure 5b as a dashed vertical line.

[0045] Another way to characterize a mapping function of the second type is to define a threshold value L_{th_d} of the requested light output level above which a change of a given amount in the requested light level results in a larger change in the level based output current limitation than in the duty cycle based output current limitation. As an example, in the example of Figure 5a the threshold L_{th_d} is approximately at requested light output level of 0.3 times the maximum available light output level and in the example of Figure 5b the threshold L_{th_d} is approximately at requested light output level of 0.45 times the maximum available light output level, shown in both figures as a solid vertical line.

[0046] The example mapping functions depicted in Figures 4a, 4b, 5a and 5b serve as conceptual examples, and the shape of the curves descriptive of the level based and duty cycle based output current limitations and/or the (x axis) position of the threshold value L_{th_d} may be different from the ones shown in these figures. Moreover, the (x axis) position of the threshold value L_{th_a} in Figures 4b and 5b may be different from the one shown in these figures.

[0047] The examples shown in Figures 4a, 4b, 5a, and 5b include an inherent assumption that each mapping function comprises a relatively large number of value pairs "duty cycle; current level", each associated with a corresponding requested light output level (or more generally: requested light output characteristic). As a consequence, in each of Figures 4a, 4b, 5a, and 5b two continuous (or substantially continuous) curves appear, so that the duty cycle curve consists of the points defined by the "duty cycle" part of each value pair, and the current level curve consists of the points defined by the "current level" part of each value pair. Indeed, as was explained earlier, it is possible to define a mapping function as a set of two interrelated, continuous functions, one for duty cycle and the other for current level, so that for any arbitrary requested light output level the corresponding duty cycle and current level values can be calculated from the definitions of said continuous functions.

[0048] However, it is also possible to define a mapping function using discontinuous sets of points, so that a value pair "duty cycle; current level" is defined only for a relatively limited number of requested light output levels (or other requested light output characteristics). For example, a first mapping function may be defined as:

- for 5% requested light output level: duty cycle 20%; current level 25%
- for 50% requested light output level: duty cycle 60%; current level 83%
- for 100% requested light output level: duty cycle 100%; current level 100%,

and a second mapping function may be defined as:

- for 5% requested light output level: duty cycle 25%; current level 20%
- for 50% requested light output level: duty cycle 83%; current level 60%
- for 100% requested light output level: duty cycle 100%; current level 100%.

[0049] Thus in this example a value pair "duty cycle; current level" is defined only for requested light output levels 5%, 50%, and 100%. Such a discontinuous definition of mapping functions may be quite sufficient particularly if the user interface of the lighting control system is such that it only allows the user to select among a limited number of different control commands (e.g. a limited number of possible requested light levels). Concerning the definition of mutually alternative mapping functions as representing different ways of selecting the pair of a duty cycle and a current level as a response to the same requested light output level for at least a range of light output levels, the term "range" means in this case the discontinuous set of allowable requested light output levels.

[0050] The plurality of mapping functions made available for selection in the LED driver 120 may depend on the intended usage of the LED driver 120. Typically, though, the available mapping functions include one or more mapping functions of the first type and one or more mapping functions of the second type.

[0051] In a straightforward example embodiment, a single mapping function of the first type and a single mapping function of the second type are provided for selection in the LED driver 120, thereby providing an option to select either a mapping function that serves to ensure minimizing a risk of deviation from the desired color of light output or a mapping function that serves to ensure minimizing the risk of perceivable flickering of light output.

[0052] In another example embodiment, two or more mapping functions of the first type and/or the second type with different values for the threshold L_{th_d} and/or for the threshold L_{th_a} (or in general: with different forms of the duty cycle based and level based limitation curves) are provided for selection in the LED driver 120, thereby providing an option to make use of a most suitable balance in terms of minimizing a risk of deviation from the desired color of light output and a risk of perceivable flickering of light output under the circumstances.

[0053] The selection of the mapping function in the control means 124 may be predefined such that the control means 124 may be configured upon installation of the LED driver 120 and/or upon installation of the lighting arrangement that makes use of the LED driver 120 to employ certain one of the mapping functions available in the LED driver 120. Configuring the control means 124 may take place for example by using a hardware-type control input, like selecting the position(s) of one or more switches, like DIP (dual inline package) switches or rotary switches, or by setting or removing jumpers, or by using a programming tool that connects to a dedicated component-level control input like a programming interface or debugging interface of a memory circuit or microcontroller. As another example, the control means 124 may be arranged to receive the selection of the mapping function as input control signal or command received via the control signal input CTRL or via another control or command input arranged in the LED driver 120.

[0054] Such approaches in selecting the mapping function to be employed enable selecting the most suitable one of the mapping functions available in the LED driver 120 for a specific usage scenario of the LED driver 120. As an example, in an environment and/or for an application where an emphasis should be on ensuring that no perceivable flickering occurs, a mapping function of the second type described above is likely the most preferable one, whereas in an environment and/or for an application where an emphasis should be on ensuring minimum deviation of the color of the light output, a mapping function of the first type described above is likely the most preferable one.

[0055] As a further example concerning selection of the mapping function, the selection of the mapping function from the plurality of mapping functions available in the LED driver 120 may depend on observed status or value of an operational parameter of the LED driver 120. As an example in this regard, the control means 124 may be configured to select the mapping function in dependence of a voltage across the output nodes V_{out-} and V_{out+} of the output interface. The relationship between this voltage and corresponding mapping function is predefined and it may map two or more different sub-ranges of a range of voltages into respective mapping function to be employed by the control means 124.

[0056] Alternatively or additionally, the control means 124 may be configured to select the mapping function in dependence of one or more measured temperatures, which may include a representative temperature of the LED driver 120 and/or a representative temperature of the LED module 140. Temperature sensors may be embedded in the LED driver 120 and/or the LED module 140 for measuring temperatures and communicating them to the control means 124. As an example, it may happen that a combination of a higher nominal level of the converter current I_{pc} and lower duty cycle produces more waste heat than a combination of lower nominal level of the converter current I_{pc} and higher duty cycle, even if the resulting light output is the same (or, depending on the practical implementation of the LED driver, the other way round). The control means 124 may be configured to respond to the detection of a particularly high temperature by changing towards a mapping function that would enable producing the same requested light output level with less waste heat.

[0057] Dependency on output voltage and dependency on temperature can be combined in selecting the mapping function, for example by using a measurement of output voltage as an indicator of LED temperature. LEDs may have a known temperature behavior; typically the forward voltage drop decreases by some millivolts per each degree of increasing junction temperature. If the LED driver includes output voltage detection means that are accurate enough, they may monitor changes in the output voltage during use of the LEDs and respond to an observed decrease in output voltage in the same way as was described above with respect to and observed increase in LED temperature.

[0058] If the dependencies between nominal level of the converter current I_{pc}, duty cycle, temperature, output voltage, and possibly other parameters are not straightforward enough to facilitate preprogrammed responses in the form of automatically selecting the most advantageous mapping function, the control means 124 may be configured to execute an optimization algorithm. This means that the control means 124 aims at producing the requested light output characteristics with a combination of nominal level of the converter current I_{pc} and duty cycle that best fulfils a preprogrammed optimization criterion, like a minimum increase in temperature. A simple optimization algorithm may involve testing all preprogrammed mapping functions and selecting the one that appears to best fulfil the criterion, while more advanced optimization algorithms may involve e.g. repeatedly making small changes towards a direction that appears to improve fulfilment of the optimization criterion.

[0059] As a further example, the selection of the mapping function may be made in dependence of presence or absence of perceivable flickering. In this regard, the LED driver 120 may comprise flicker detection means for detecting presence or absence of perceivable flicking of light output provided from the LED module 140. In particular, in case two or more mapping functions of the first and/or the second type with different values for the threshold L_{th_d} and/or for the threshold L_{th_a} (or in general: with different forms of the duty cycle based and level based limitation curves) are provided for selection in the LED driver 120, the control means 124 may be arranged to test the available mapping functions to find the mapping function that results in avoiding or minimizing perceivable flickering and select the mapping function that results in avoiding or minimizing the perceivable flickering for use by the LED driver 120.

[0060] The duty cycle control means may be arranged to affect the operation of the power converter means 122 and/or affect the provision of the converter current I_{pc} provided from the power converter means 122 as the output current I_{out} of the LED driver 120.

[0061] As an example, the duty cycle control means may are arranged to directly or indirectly affect the operation of the power converter means 122 such that the provision of the converter current I_{pc}, and hence the provision of the output current I_{out}, is alternately enabled and disabled in accordance with the duty cycle derived in dependence of the selected one of the mapping functions available in the LED driver 120 in view of the requested light output level. This duty cycle may be referred to as currently selected duty cycle. As an example in this regard, the duty cycle control means may be arranged to enable or disable the switching operation of a power converter entity of the power converter means 122 according to the currently selected duty cycle. In case of the buck converter 222 this may be provided by alternately enabling and disabling the operation of the driving means DRV with respect to closing or opening the switch S. In particular, the duty cycle control means may be arranged to enable switching operation in the buck converter 222 e.g. through the use of an enabling/disabling control signal brought to a dedicated ENABLE pin of an integrated circuit used as the driving means. As another example of alternately enabling and disabling provision of the converter current I_{pc} (and hence provision of the output current I_{out} from the LED driver 120), the duty cycle control means may be arranged to alternately enable and disable power supply to the power converter means 122 in accordance with the currently selected duty cycle.

[0062] As a further example, the duty cycle control means may be arranged to alternately enable and disable power supply from the power converter means 122 e.g. by alternately enabling and disabling provision of the converter current I_{pc} as the output current I_{out} in accordance with the currently selected duty cycle. The alternate enabling and disabling provision of the converter current I_{pc} as the output current I_{out} of the LED driver 120 may be provided e.g. by closing and opening, respectively, output switching means arranged between the power converter means 122 and the output interface of the LED driver 120 in accordance with the employed duty cycle.

[0063] As a yet further example, the duty cycle control means may be arranged to alternately open and close a bypass switch that makes the output current I_{out} of the LED driver 120 flow through a route that does not go through the light-emitting semiconductor devices (e.g. the LED module 140). Although in this case a converter current I_{pc} of certain magnitude flows out of the power converter means 122 all the time, no light output is produced during the time intervals when the bypass switch is closed, so for the purposes of this description it can be interpreted to equal a practice of alternately enabling and disabling provision of the converter current I_{pc} as the output current I_{out} of the LED driver 120 to the light-emitting semiconductor devices.

[0064] The duty cycle control means may be arranged to control the operation of the power converter means 122 or operate the output switching means by issuing a duty cycle based control signal that consists of alternate active signal periods (for enabling the provision of the output current I_{out}) and non-active signal periods (for disabling the provision of the output current I_{out}) such that the duty cycle based control signal exhibits the currently selected duty cycle. Such control signal may be provided as a rectangular wave signal, such as a pulse width modulation (PWM) signal, or as a signal that approximates a rectangular wave signal.

[0065] The level control means may are arranged to directly or indirectly affect the operation of the power converter means 122 such that the nominal level of the converter current I_{pc} from the power converter means 122 is limited in accordance with the level of electric current derived in dependence of the selected one of the mapping functions available in the LED driver 120 in view of the requested light output level. This level of electric current may be referred to as the target current level.

[0066] As an example in this regard, the level control means may be arranged to affect the operation of the control loop within a switched-mode power supply. In context of the exemplifying buck converter 222 described in the foregoing, such control may be provided e.g. by causing adjustment of at least one of the thresholds I_{th1} and I_{th2} towards a lower value such that the nominal level of the converter current I_{pc} is limited to the target current level. As another example, such control may be provided by processing the current feedback signal to indicate electric current that is higher than the one actually observed such that the nominal level of the converter current I_{pc} is limited to the target current level.

[0067] In many cases the integrated circuit that is used as the driving means in the switched-mode power supply of the power converter means 122 (e.g. the driving means DRV in the buck converter 222) exhibits a so-called analog dimming pin, for which the integrated circuit manufacturer has specified an input voltage range that corresponds to a range of current feedback signals. In such cases the control means 124 may comprise a processor with at least analog voltage output, from which the input voltage to the analog dimming pin of the driving means is derived. By varying the input voltage at the analog dimming pin within the specified range it is possible to control the value of the converter current I_{pc} from the power converter means 122 without having to pay attention to what exactly is the mechanism through which the desired effect is achieved.

[0068] Figure 6 schematically illustrates at least some components of a two-channel LED driver 320 to facilitate understanding operation of various example embodiments of the present invention. The two-channel LED driver 320 is arranged to continuously control or regulate a first output current I_{out1} provided via a first output interface (comprising at least two output nodes V_{out1-} and V_{out1+}) and a second output current I_{out2} provided via a second output interface (comprising at least two output nodes V_{out2-} and V_{out2+}). Each of the output currents I_{out1} and I_{out2} or output interfaces may be considered as a respective (output) channel of the multi-channel LED driver 320. The two-channel LED driver 320 is arranged to control or regulate the output currents I_{out1} and I_{out2} such that each output current I_{out1}, I_{out2} exhibits desired electrical characteristics in order to cause LED modules 140-1 and 140-2 that may be electrically coupled to the respective output interfaces to provide light output of desired characteristics.

[0069] The two-channel LED driver 320 comprises two power converter means 122-1 and 122-2 for providing respective converter currents I_{pc1} and I_{pc2}. Each of the power converter means 122-1, 122-2 may be an entity that is similar to the power converter means 122 described in the foregoing. Alternatively the two-channel LED driver 320 may comprise a common input stage (not shown), to which electric energy comes through the input nodes V_{in-} and V_{in+}, for producing an internal bus voltage that serves as the input voltage to the parallel output channels represented by the two power converter means 122-1 and 122-2. The two-channel LED driver 320 further comprises control means 324 for regulating electrical characteristics of the converter currents I_{pc1}, I_{pc2} and/or electrical characteristics of the output currents I_{out1}, I_{out2} derived on basis of the respective the converter currents I_{pc1}, I_{pc2} in accordance with requested light output characteristics. The requested light output characteristics concerning the average level (and possibly other characteristics) of the output currents I_{out1} and I_{out2} are received in respective control signals or commands obtained via control signal inputs CTRL1 and CTRL2.

[0070] Thus, the control means 324 of the two-channel LED driver 320 is arranged to control provision of each of the output currents I_{out1} and I_{out2} in a manner similar to described in the foregoing for the single output current of the LED driver 120. As an example, each of the output currents I_{out1} and I_{out2} may be provided for LED modules 140-1, 140-2 arranged to provide light output of different color and, consequently, suitable selection of the average current levels in the respective output currents I_{out1} and I_{out2} may be employed to provide combined light output exhibiting a desired color. As another example, each of the output currents I_{out1} and I_{out2} may be provided for LED modules 140-1, 140-2 arranged to provide (white) light output of different color temperature and, consequently, suitable selection of the average current levels in the respective output currents I_{out1} and I_{out2} may be employed to provide combined light output exhibiting a desired color temperature (in other words, to provide a LED driver that enables provision of so-called tunable white). As a further example, each of the output currents I_{out1} and I_{out2} may be provided for LED modules 140-1, 140-2 of similar characteristics (e.g. arranged to provide (white) light output at the same or similar color temperature or to provide light output at the same or similar color) and, consequently, can be applied to provide illumination for a larger area and/or at a higher combined light output level.

[0071] The description of the two-channel LED driver 320 generalizes into a multi-channel LED driver providing more than two output currents I_{outK} in accordance with control signals or commands received via respective control inputs, thereby enabling e.g. a more versatile approach for providing combined light output at a desired color or light output for further increased illuminated area and/or at still higher combined light output level.

[0072] In case of the two-channel LED driver 320 (or the multi-channel LED driver), for each channel the mapping function may be selected from the mapping functions available in the two-channel LED driver 320 (or in the multi-channel LED driver) independently of the other channel(s). The applied selection mechanism may be e.g. one of those described in the foregoing for the LED driver 120. As an example, for the two-channel LED driver 320 provided to enable combined light output at selectable color or color temperature, a mapping function that serves to keep the desired color unchanged at the expense of possibly perceivable flickering of light output (e.g. a mapping function of the first type described above) may be selected for both channels. As another example, for the two-channel LED driver 320 provided to enable illumination of larger area and/or at a higher combined light output level, a mapping function that serves to avoid perceivable flickering of light at the expense of possibly perceivable deviation from the desired color of light output (e.g. a mapping function of the second type described above) may be selected for both channels. As a further example, a mapping function that serves to keep the desired color unchanged may be selected for a first channel of the two-channel LED driver 320 and a mapping function that serves to avoid perceivable flickering of light may be selected for a second channel of the two-channel LED driver 320 in order to provide a compromise in terms of the color stability and flickering avoidance.

[0073] In the foregoing, various examples of structure and operation of the LED driver 120, 320 have been described. According to an example embodiment, the operation of the LED driver 120, 320 or any corresponding device or arrangement may be described as steps of a method. As an example in this regard, a method for providing the output current I_{out} for the LED module 140 (or, in general, for one or more light-emitting semiconductor devices) may be provided. The method comprises controlling supply of the output current I_{out} from the power converter means 122 for the LED module 140 and regulating electrical characteristics of the output current I_{out} in accordance with requested light output characteristics. The regulating comprises alternately enabling and disabling provision of the output current I_{out} at a selectable duty cycle to provide duty cycle based output current limitation, and controlling provision of the output current I_{out} at a selectable current level to enable level based output current limitation, so as to regulate the output current I_{out} to exhibit an average level that corresponds to said requested light output characteristics by a combination of the duty cycle based output current limitation and the level based output current limitation in dependence of a selected one of a plurality of different predefined mapping functions.

[0074] As described in the foregoing, a mapping function may define a mapping of a plurality of values of a requested light output characteristic to a corresponding plurality of pairs of a duty cycle and a current level, thereby defining a respective combination of the duty cycle based output current limitation and the level based output current limitation for each of the plurality of values. Moreover, the plurality of mapping functions may comprise two or more mapping functions that are alternatives to each other, wherein each of these two or more mapping functions defines a different mapping of the plurality of values to a corresponding plurality of pairs of a duty cycle and a current level, said two or more mapping functions thereby defining two or more different combinations of the duty cycle based output current limitation and the level based output current limitation for each of the plurality of values. As described in the foregoing, the requested light output characteristics may comprise a requested light output level.

[0075] The exemplifying method(s) outlined above may be (further) varied in a number of ways, for example in a manner described in the foregoing in context of the LED driver 120, 130.

[0076] Although functions have been described with reference to certain features, those functions may be performable by other features whether described or not. Although features have been described with reference to certain embodiments, those features may also be present in other embodiments whether described or not.

Claims

1. A driver device for providing output current for one or more light-emitting semiconductor devices, the driver device comprising
power converter means for supplying said output current via an output interface, and
control means for regulating electrical characteristics of said output current in accordance with requested light output characteristics, said control means comprising

    duty cycle control means for alternately enabling and disabling provision of output current from the driver device at a selectable duty cycle to enable duty cycle based output current limitation, and
    level control means for controlling provision of the output current from the driver device at a selectable current level to enable level based output current limitation,

    wherein said control means is arranged to regulate the output current to exhibit an average level that corresponds to said requested light output characteristics by a combination of the duty cycle based output current limitation and the level based output current limitation in dependence of a selected one of a plurality of different predefined mapping functions stored in the driver device.

2. A driver device according to claim 1, wherein the control means is arranged to receive an indication of said selected one of said plurality of different mapping functions via a control input.

3. A driver device according to claim 1, further comprising voltage determining means for determining a load voltage across a load coupled to said output interface, wherein the control means is arranged to select a mapping function from said plurality of different mapping functions in dependence of said load voltage.

4. A driver device according to claim 1, further comprising flicker detection means for detecting presence or absence of perceivable flickering of light in operating environment of the driver device, wherein the control means is arranged to select a mapping function from said plurality of different mapping functions in dependence of presence or absence of perceivable flickering of light.

5. A driver device according to any of claims 1 to 4, wherein a mapping function defines a mapping of a plurality of values of a light output characteristic to a corresponding plurality of pairs of a duty cycle and a current level, thereby defining a respective combination of the duty cycle based output current limitation and the level based output current limitation for each of said plurality of values.

6. A driver device according to claim 5, wherein said plurality of mapping functions comprises two or more mapping functions that are alternatives to each other, wherein each of said two or more mapping functions defines a different mapping of said plurality of values to a corresponding plurality of pairs of a duty cycle and a current level, said two or more mapping functions thereby defining two or more different combinations of the duty cycle based output current limitation and the level based output current limitation for each of said plurality of values.

7. A driver device according to any of claims 1 to 6, wherein said light output characteristics comprises a requested light output level.

8. A driver device according to any of claims 1 to 6, wherein said light output characteristics comprise a requested light output level, and said plurality of mapping functions include
at least one first mapping function that defines a mapping wherein, for requested light output levels that exceed a first predefined threshold, the effect of the duty cycle based output current limitation is larger than the effect of the level based output current limitation, and
at least one second mapping function that defines a mapping wherein, for requested light output levels that exceed a second predefined threshold, the effect of the duty cycle based output current limitation is smaller than the effect of the level based output current limitation.

9. A driver device according to any of claims 1 to 6, wherein said light output characteristics comprise a requested light output level, and said plurality of mapping functions include
at least one third mapping function that defines a mapping wherein, for requested light levels that exceed a third predefined threshold, a given change in the requested light output level results in a larger change in the duty cycle based output current limitation than in the level based output current limitation, and
at least one fourth mapping function that defines a mapping wherein, for requested light levels that exceed a fourth predefined threshold, a given change in the requested light output level results in a smaller change in the duty cycle based output current limitation than in the level based output current limitation.

10. A driver device according to any of claims 1 to 6, wherein said light output characteristics comprise a

requested light output level, and said plurality of mapping functions include at least one of the following

at least two fifth mapping functions that each define a mapping wherein, for requested light output levels that exceed a respective fifth predefined threshold, the effect of the duty cycle based output current limitation is larger than the effect of the level based output current limitation, wherein the fifth predefined threshold is different for each of said at least two fifth mapping functions, and

at least two sixth mapping functions that each define a mapping wherein, for requested light output levels that exceed a respective sixth predefined threshold, the effect of the duty cycle based output current limitation is smaller than the effect of the level based output current limitation, wherein the sixth predefined threshold is different for each of said at least two sixth mapping functions.

11. A driver device according to any of claims 1 to 6, wherein said light output characteristics comprise a requested light output level, and said plurality of mapping functions include at least one of the following:

at least two seventh mapping functions that each define a mapping wherein, for requested light output levels that are smaller than a respective seventh predefined threshold, a given change in the requested light output level results in a larger change in the duty cycle based output current limitation than in the level based output current limitation, wherein the seventh predefined threshold is different for each of said at least two seventh mapping functions, and

at least two eighth mapping functions that each define a mapping wherein, for requested light output levels that are smaller than a respective eighth predefined threshold, a given change in the requested light output level results in a smaller change in the duty cycle based output current limitation than in the level based output current limitation, wherein the eighth predefined threshold is different for each of said at least two eighth mapping functions.

12. A lighting arrangement comprising

a driver device according to any of claims 1 to 11, and light output means electrically coupled to said driver device.

13. A method for providing output current for one or more light-emitting semiconductor devices, the method comprising

controlling supply of said output current from a power converter means for said one or more light-emitting semiconductor devices, and

regulating electrical characteristics of said output current in accordance with requested light output characteristics, said regulating comprising

alternately enabling and disabling provision of said output current at a selectable duty cycle to provide duty cycle based output current limitation, and

controlling provision of said output current at a selectable current level to enable level based output current limitation,

so as to regulate the output current to exhibit an average level that corresponds to said requested light output characteristics by a combination of the duty cycle based output current limitation and the level based output current limitation in dependence of a selected one of a plurality of different predefined mapping functions.

14. A method according to claims 13, wherein said light output characteristics comprise a requested light output level and wherein a mapping function defines a mapping of a plurality of values of the requested light output level to a corresponding plurality of pairs of a duty cycle and a current level, thereby defining a respective combination of the duty cycle based output current limitation and the level based output current limitation for each of said plurality of values.

15. A method according to claim 14, wherein said plurality of mapping functions comprises two or more mapping functions that are alternatives to each other, wherein each of said two or more mapping functions defines a different mapping of said plurality of values to a corresponding plurality of pairs of a duty cycle and a current level, said two or more mapping functions thereby defining two or more different combinations of the duty cycle based output current limitation and the level based output current limitation for each of said plurality of values.

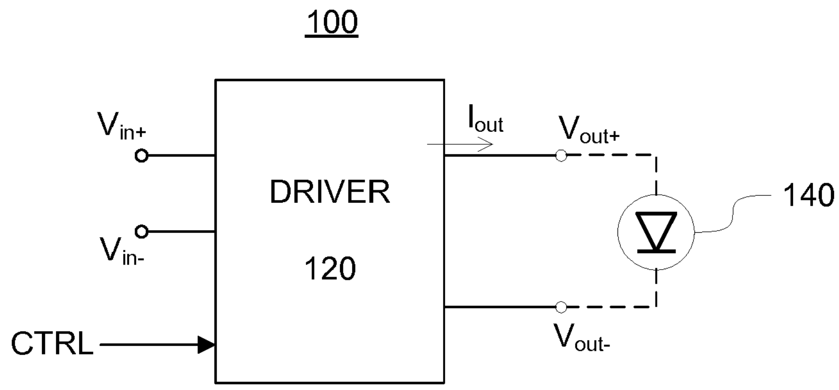

Figure 1

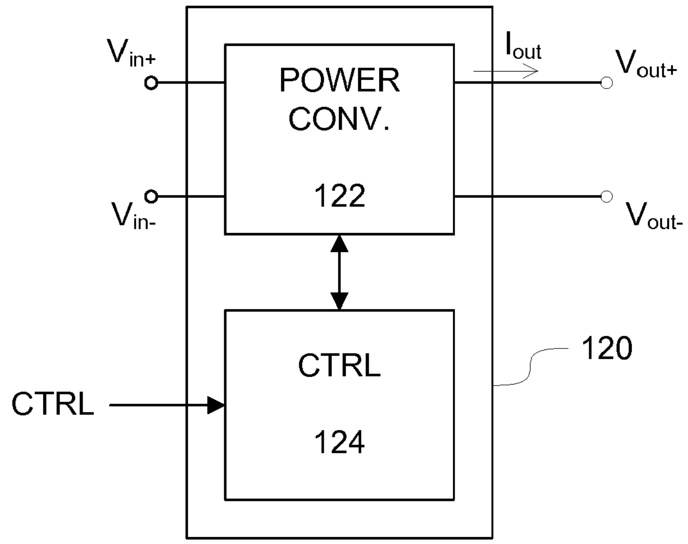

Figure 2

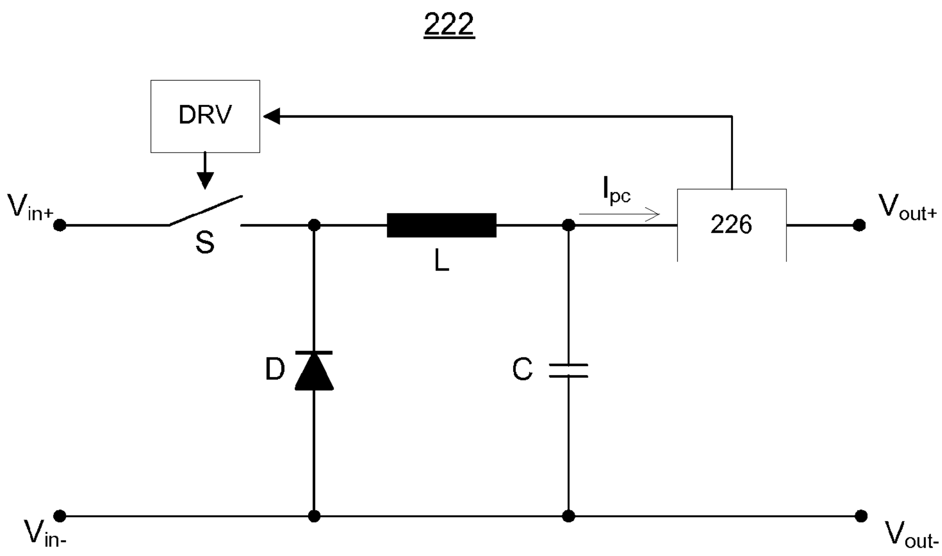

Figure 3

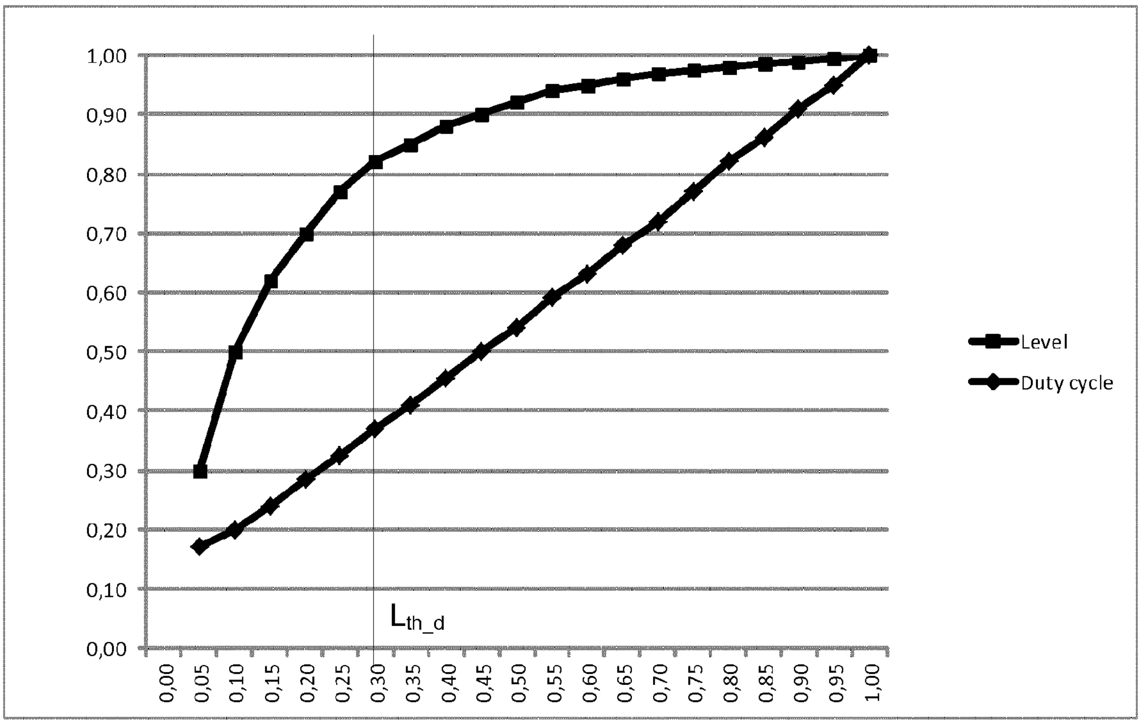

Figure 4a

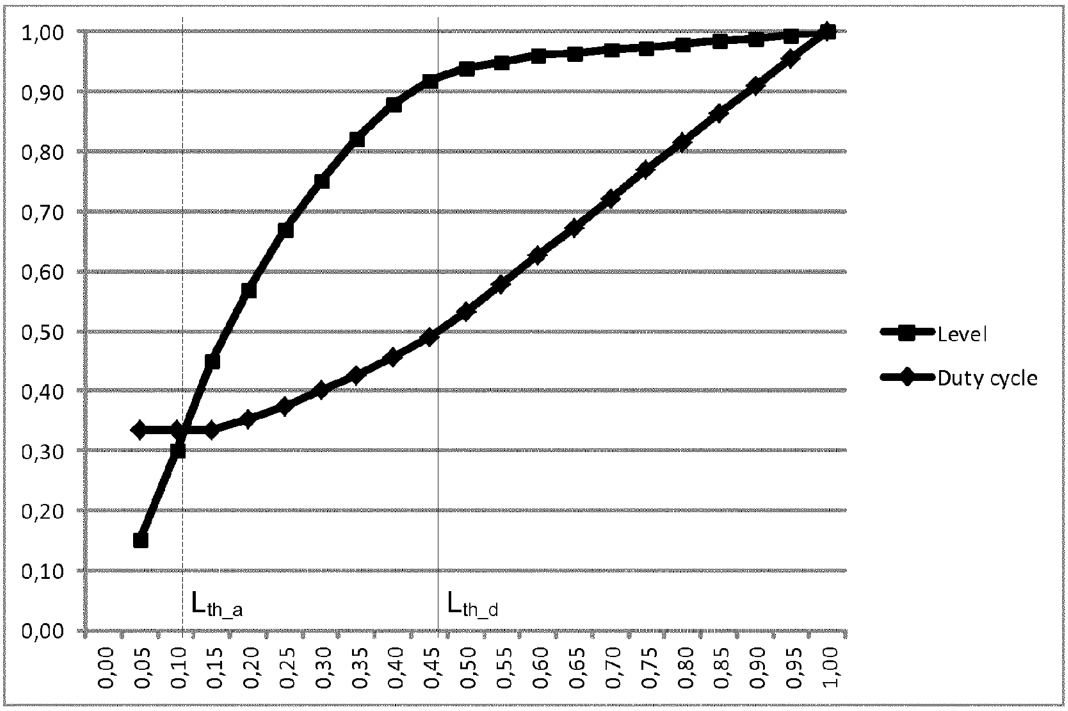

Figure 4b

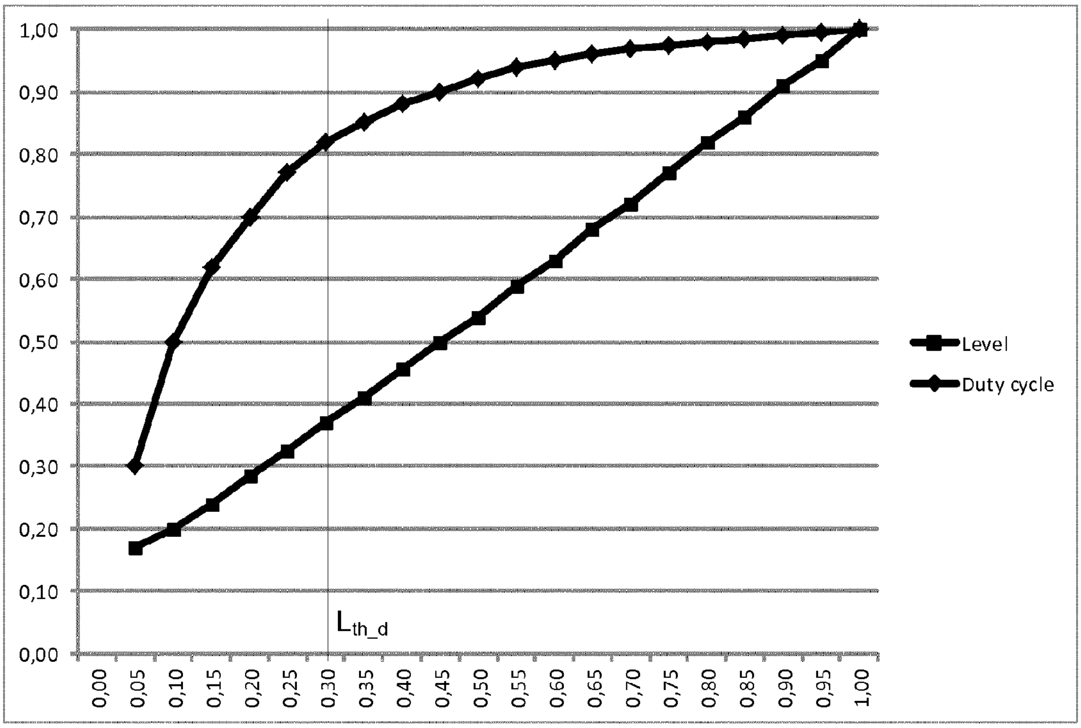

Figure 5a

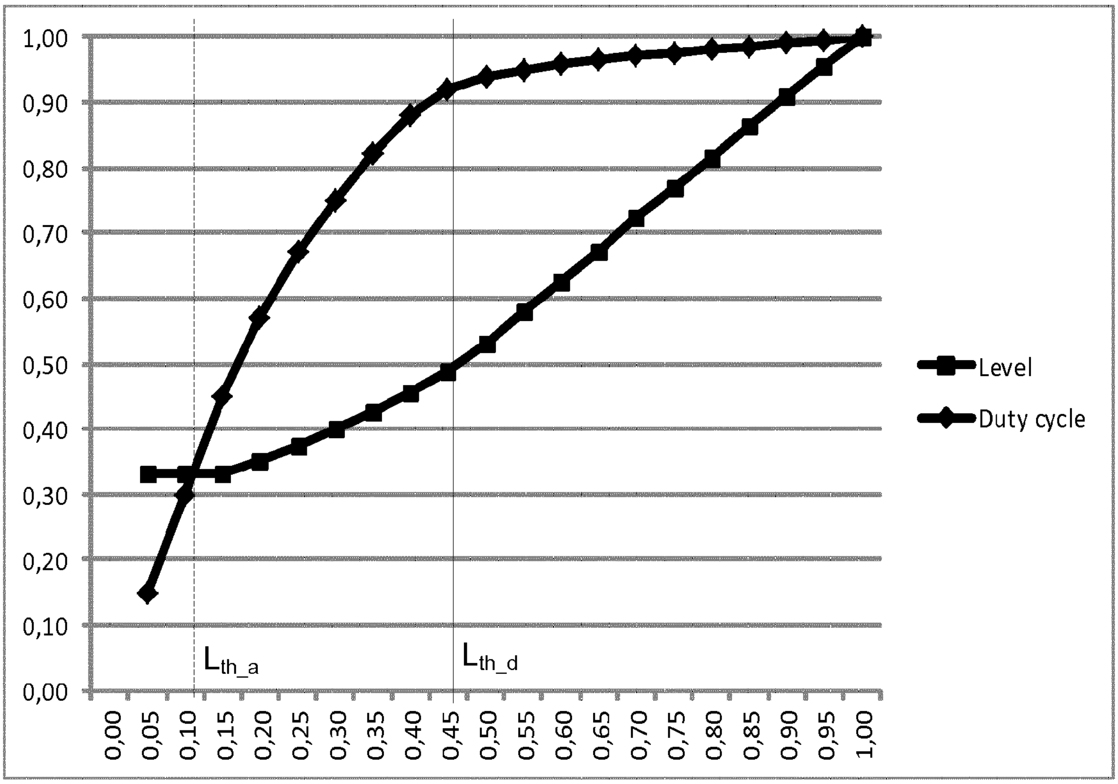
1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0,00 0,05 0,10 0,15 0,20 0,25 0,30 0,35 0,40 0,45 0,50 0,55 0,60 0,65 0,70 0,75 0,80 0,85 0,90 0,95 1,00
L_{th_a}
L_{th_d}
Level
Duty cycle

Figure 5b

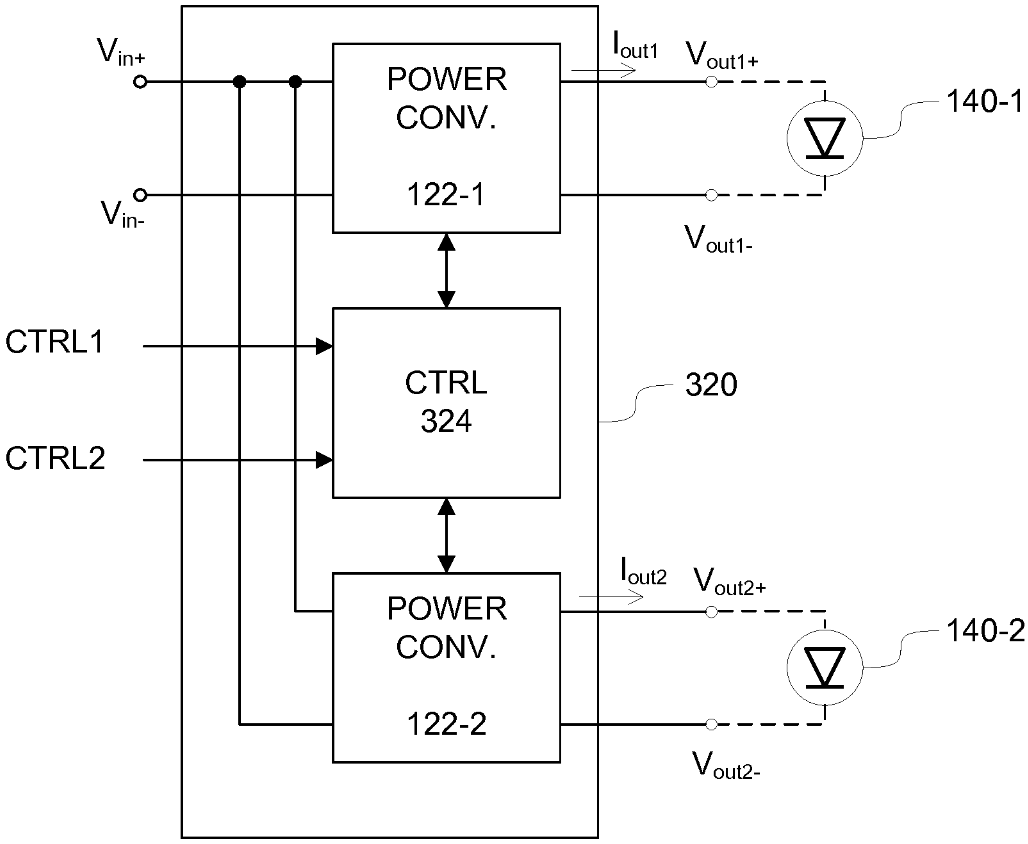
Vin+
Vin-
POWER CONV.
122-1
Iout1
Vout1+
Vout1-
140-1
CTRL1
CTRL2
CTRL 324
320
POWER CONV.
122-2
Iout2
Vout2+
Vout2-
140-2

Figure 6

Europäisches Patentamt
European Patent Office
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EUROPEAN SEARCH REPORT

Application Number
EP 14 19 3639

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	EP 1 689 212 A1 (PATENT TREUHAND GES FUER ELEKTRISCHE GLUEHLAMPEN MBH [DE]; OSRAM SPA [) 9 August 2006 (2006-08-09) * column 3, paragraph 16 - column 4, paragraph 21; figures 4-6 * * column 5, paragraph 29 - column 10, paragraph 63 * -----	1,2,5-7, 12-15 3,4,8-11	INV. H05B33/08
X A	US 2014/055045 A1 (RAVAL PRANAV [US] ET AL) 27 February 2014 (2014-02-27) * page 2, paragraph 19 - page 3, paragraph 24; figure 1 * -----	1-3,5,7, 12-14 4,6, 8-11,15	
X A	US 2006/273331 A1 (LIM KEVIN LEN L [MY] ET AL) 7 December 2006 (2006-12-07) * page 3, paragraph 33 - page 4, paragraph 39; claims 1-19; figures 4, 5 * -----	1,2,5,7, 12-14 3,4,6, 8-11,15	
A	WO 2010/067292 A2 (KONINKL PHILIPS ELECTRONICS NV [NL]; TER WEEME BEREND J W [NL]; TREURN) 17 June 2010 (2010-06-17) * page 6, line 14 - page 8, line 6; figures 1, 3 * * page 8, line 12 - page 12, line 24 * -----	1-15	TECHNICAL FIELDS SEARCHED (IPC) H05B H02M
A	WO 2008/112735 A2 (CIRRUS LOGIC INC [US]) 18 September 2008 (2008-09-18) * abstract; figures 4A, 5 * * page 5, paragraph 20 - page 7, paragraph 25 * -----	1-15	

1

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	27 April 2015	Brosa, Anna-Maria

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 14 19 3639

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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