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(54) A feedback arrangement for a LED driver

(57) According to an example embodiment, a driver for operating one more LEDs is provided. The driver comprises an output for connecting the one or more LEDs, power source means for supplying power to said output, reference generation means for generating a common reference potential in dependence of a selectable component connectable to the driver, first feedback means for providing current feedback in dependence of said common reference potential, which current feedback is indicative of a level of an output current supplied to said output in relation to a nominal current level, second feedback means for providing voltage feedback in dependence of said common reference potential, which voltage feedback is indicative of an output voltage across nodes of said output in relation to an adaptive maximum output voltage, and control means for controlling the power source means based at least on said current feedback and said voltage feedback such that the power supplied to said output does not exceed a predefined maximum power.

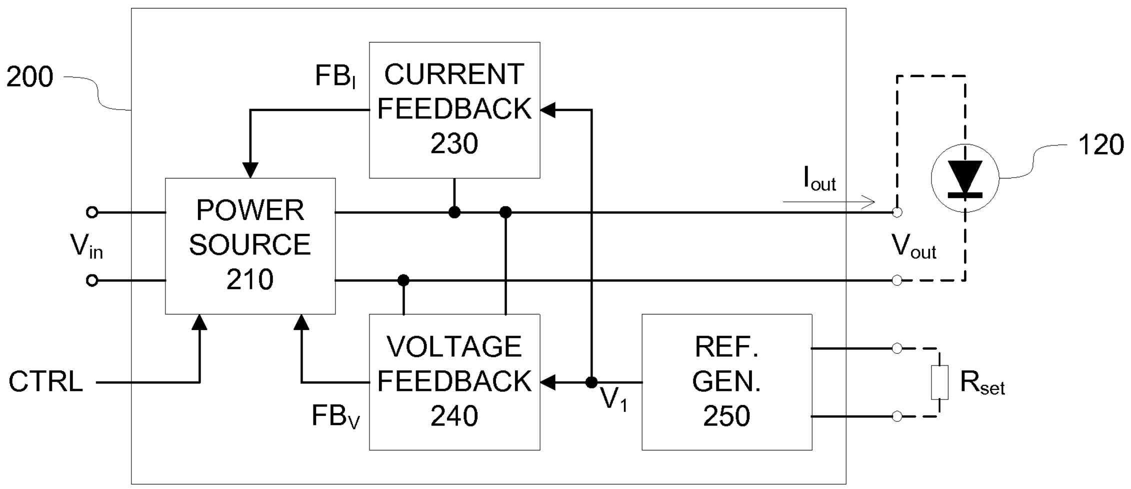

Figure 2

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Description

FIELD OF THE INVENTION

[0001] The example embodiments of the present invention relate to a feedback arrangement in a light emitting diode (LED) driver.

BACKGROUND OF THE INVENTION

[0002] LED drivers supply the LEDs with an output current, the value (or effective value, in case the current is pulsed or otherwise varies over time) of which determines the observed brightness of the LEDs. In order to limit the output current below a selected maximum level, a LED driver is typically provided with a current feedback mechanism that monitors the output current and produces a limiting signal when the output current reaches the maximum value.

[0003] The voltage across the LEDs connected to the output of the LED driver depends on characteristics of the employed LEDs, in particular on forward voltage(s) of the employed LEDs. As an example, for LEDs connected in series the voltage across the LEDs is the sum of the forward voltages of the employed LEDs. Herein, the voltage across the LEDs connected to the output of the LED driver is referred to as an output voltage of the LED driver.

[0004] Various standards may regulate the maximum allowable output voltage. As an example, the Safety Extra Low Voltage (SELV) regulations set a maximum output voltage drawn from the LED driver to 60 volts. In order to ensure meeting this voltage limit (or any other voltage limit) the LED driver may be provided with a voltage feedback mechanism that monitors the output voltage and a voltage control mechanism that limits the output voltage in accordance with the voltage limit.

[0005] Another reason for limiting the output voltage may arise from a design of the power source of the LED driver: the power source is typically designed for a certain maximum output power and with a selected output current the output power varies with the output voltage. Consequently, the voltage control mechanism may be, additionally or alternatively, arranged to limit the output voltage in accordance with a voltage limit set in view of the maximum output power of the LED driver.

[0006] LED drivers that are capable of selectively supplying the output current at one of multiple different nominal output current levels are known in the art. The selection of the desired nominal output current may be provided e.g. by connecting an external component of suitable characteristics to the LED driver, by using a switch arranged in a housing of the LED driver for selection of the nominal output current or by issuing an external control signal of suitable characteristics to select the desired nominal output current.

[0007] For such a LED driver the voltage limitation mechanism outlined above is likely to provide suboptimal performance due to the voltage limit applied by the voltage control mechanism failing to account for the applied nominal level of the output current.

SUMMARY OF THE INVENTION

[0008] It is an object of the present invention to provide a technique that facilitates limiting the output voltage in dependence of the selected nominal output current level in a flexible and cost-effective manner.

[0009] The object(s) of the invention are reached by a driver and by a method as defined by the respective independent claims.

[0010] According to an example embodiment of the invention, a driver for operating one more LEDs is provided. The driver comprises an output for connecting the one or more LEDs, power source means for supplying power to said output, reference generation means for generating a common reference potential in dependence of a selectable component connectable to the driver, first feedback means for providing current feedback in dependence of said common reference potential, which current feedback is indicative of a level of an output current supplied to said output in relation to a nominal current level, second feedback means for providing voltage feedback in dependence of said common reference potential, which voltage feedback is indicative of an output voltage across nodes of said output in relation to an adaptive maximum output voltage, and control means for controlling the power source means based at least on said current feedback and said voltage feedback such that the power supplied to said output does not exceed a predefined maximum power.

[0011] According to another example embodiment of the invention a method for operating one or more LEDs, using a driver comprising an output for connecting the one or more LEDs and a power source means for supplying power to said output is provided. The method comprises generating a common reference potential in dependence of a selectable component connectable to the driver, providing current feedback in dependence of said common reference potential, which current feedback is indicative of a level of an output current supplied to said output in relation to a nominal current level, providing voltage feedback in dependence of said common reference potential, which voltage feedback is indicative of an output voltage across nodes of said output in relation to an adaptive maximum output voltage, and controlling the power source means based at least on said current feedback and said voltage feedback such that the power supplied to said output does not exceed a predefined maximum power.

[0012] 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.

[0013] 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

[0014]

Figure 1 schematically illustrates some components of a LED driver known in the art.

Figure 2 schematically illustrates some components of a LED driver in accordance with an example embodiment.

Figure 3 schematically illustrates some components of a current feedback means according to an example embodiment.

Figure 4 schematically illustrates some components of a current feedback means according to an example embodiment.

Figure 5 schematically illustrates some components of a voltage feedback means according to an example embodiment.

Figure 6 schematically illustrates some components of a voltage feedback means according to an example embodiment.

Figure 7 schematically illustrates some components of a LED driver in accordance with an example embodiment.

Figure 8 schematically illustrates some components of a reference generation circuit according to an example embodiment.

Figure 9 illustrates a relationship between output current, output voltage and output power.

Figure 10 schematically illustrates some components of a LED driver in accordance with an example embodiment.

Figure 11 illustrates a method in accordance with an example embodiment.

DETAILED DESCRIPTION

[0015] Figure 1 schematically illustrates some components of a driver 100 for driving one or more LEDs 120. The driver 100 comprises a power source portion 110 for generating an output current I_{out} to an output of the driver 100 using electric energy brought to an input marked as V_{in} in Figure 1. The output current I_{out} may comprise a direct current (DC) of desired characteristics that may be provided to the one or more LEDs 120 that are connectable to an output of the driver 100.

[0016] In order to enable keeping the output current I_{out} at or below a desired level, the driver 100 further comprises a current feedback means 130 for providing current feedback FB_I that serves as an indication of a measured level of the output current I_{out} in relation to a target current level. As an example, the current feedback FB_I may indicate a difference between the measured output current I_{out} and the target current level, or the current feedback FB_I may become active, or assume a particular value or character, when the measured output current I_{out} reaches a predetermined maximum level. The current feedback means 130 is provided with connectors for connecting a selectable external component, e.g. a resistor R_{set} illustrated in Figure 1. The selectable external component adjusts the operation of the current feedback means 130 such that the target current level applied therein is derived in dependence of characteristics of the selectable external component, thereby providing a flexible and low-cost approach for selectively setting the target current level.

[0017] The driver 100 further comprises a voltage feedback means 140 for providing voltage feedback FB_V that serves as an indication of a measured level of an output voltage V_{out}, i.e. the voltage across nodes of the output of the driver 100. As an example, the voltage feedback FB_V may indicate a difference between a predefined reference voltage and the measured output voltage V_{out}, which predefined reference voltage represents a predefined maximum allowable output voltage V_{max}. Alternatively or additionally the voltage feedback FB_V may become active, or assume a particular value or character, when the measured output voltage V_{out} reaches the predefined maximum allowable output voltage V_{max}. The maximum allowable output voltage V_{max} may comprise e.g. a maximum voltage defined by a relevant safety regulation or standard or a maximum voltage set to prevent exceeding a maximum output power of the driver 100.

[0018] The power source portion 110 comprises one or more power converters for generating the output current I_{out} and a control means for controlling the operation of the power converter(s). In particular, the control means may be arranged to operate the power converter(s) to generate the output current I_{out} as the direct current (DC) of desired characteristics in accordance with control information received via the control input *CTRL* and in accordance with the current feedback FB_V. Moreover, the control means may be further arranged to operate the power converter(s) in accordance with the voltage feedback FB_V such that the predefined maximum allowable output voltage V_{max} is not exceeded.

[0019] Figure 2 schematically illustrates some components of a driver 200 for driving the one or more LEDs 120. Along the lines described for the driver 100, also the driver 200 comprises a power source portion 210 for generating an output current I_{out} to an output of the driver 200 using electric energy brought to an input marked as V_{in} in Figure 2. The output current I_{out} may comprise a DC current of desired characteristics that may be provided to the one or more LEDs 120 that are connectable to an output of the driver 200.

[0020] The driver 200 comprises a reference generation means 250 for generating a reference potential V_1. The reference generation means 250 is provided with connectors for connecting a selectable external component, e.g. a resistor R_{set} as illustrated in Figure 2. The selectable external component adjusts the operation of the reference generation means 250 such that the reference potential V_1 is derived in dependence of characteristics of the selectable external component.

[0021] The driver 200 comprises a current feedback means 230 for providing the current feedback FB_I. The current feedback means 230 may be arranged to provide the current feedback FB_I in dependence of the reference potential V_1 such that the current feedback FB_I is indicative of observed level of the output current I_{out} in relation to a selected nominal current level. The current feedback FB_I may be employed, for example, to operate the driver 200 as a constant current (CC) LED driver that is arranged to supply constant or substantially constant nominal current level as the output current I_{out}, or to limit the output current I_{out} below a predetermined maximum value.

[0022] The driver 200 further comprises a voltage feedback means 240 for providing the voltage feedback FB_V. The voltage feedback means 240 may be arranged to provide the voltage feedback FB_V in dependence of the reference potential V_1 such that the voltage feedback FB_V is indicative of the output voltage V_{out} in relation to a maximum allowable output voltage V_{max} which, for reasons explained in more detailed below, can be called an adaptive maximum output voltage in the circuit of Figure 2. The voltage feedback FB_V may be employed, for example, to operate the driver 200 such that the output voltage V_{out} is not allowed to exceed the adaptive maximum output voltage V_{max}.

[0023] The reference potential V_1 is hence a shared reference applied in both the current feedback means 230 and the voltage feedback means 240 and it is therefore (also) referred to as a common reference potential V_1. Hence, a single selectable external component, e.g. the resistor R_{set} illustrated in Figure 2, that is connectable to the driver 200 may be applied to set or select the common reference potential V_1 to a desired value. This, in turn, causes the current feedback means 230 being adjusted to operate such that the current feedback FB_I reflects a difference to a selectable target current level that depends on the common reference potential V_1 and the voltage feedback means 240 being adjusted to operate such that the voltage feedback FB_V reflects a difference to an adaptive maximum output voltage V_{max} that also depends of the common reference potential V_1. Instead or in addition to reflecting a difference, the current and/or voltage feedback may become active, or assume a particular value or character, when the measured output current or voltage reaches the predefined maximum allowable output current or voltage respectively.

[0024] Figure 3 schematically illustrates some components of an exemplifying current feedback means 330 that may be applied as the current feedback means 230 in the driver 200. The current feedback means 330 comprises current-to-voltage conversion means 332, e.g. a current-to-voltage conversion circuit, for deriving a potential V_I indicative of the level of the output current I_{out}. The current-to-voltage conversion means 332 may be arranged to derive the potential V_I as the voltage across a current sensing element (e.g. a current sensing resistor) arranged in the current path of the output current I_{out}. The current feedback means 330 further comprises a scaling means 334, e.g. a scaling circuit, for deriving a scaled reference potential V'_1 on basis of the common reference potential V_1. The scaling means 334 may be arranged to derive the scaled reference potential V'_1 by scaling (e.g. multiplying) the common reference potential V_1 by a predefined scaling factor k_1. The current feedback means 330 further comprises a comparator 336 for deriving the current feedback FB_I that is indicative of a difference between the scaled reference potential V'_1 and the potential indicative of the output current I_{out} level. This difference reflects the difference between the observed output current I_{out} and the nominal current level that would make the potential V_I equal to the scaled reference potential V'_1.

[0025] Figure 4 schematically illustrates some components of an exemplifying current feedback means 430 that may be applied as the current feedback means 230 in the driver 200. The current feedback means 430 comprises the current-to-voltage conversion means 332 for deriving a potential V_I indicative of the level of the output current I_{out}. The current feedback means 430 further comprises a scaling means 434, e.g. a scaling circuit, for deriving a scaled value V'_I of the potential V_I indicative of the level of the output current I_{out}. The scaling means 434 may be arranged derive the scaled potential V'_I as a combination of the potential V_I and the common reference potential V_1 or by scaling (e.g. multiplying) the potential V_I by an adaptive scaling factor k_2 that depends on the common reference potential V_1. The current feedback means 430 further comprises a comparator 436 for deriving the current feedback FB_I that is indicative of a difference between the scaled potential V'_1 and a predefined reference potential V_{ref}, which difference also reflects the difference between the observed output current I_{out} and the nominal current level that would make the scaled potential V'_1 equal to the predefined reference potential V_{ref}. The predefined reference potential V_{ref} is, preferably, provided internally in the driver 200, e.g. by a DC voltage source arranged to supply the reference potential V_{ref} at a desired voltage level.

[0026] Figure 5 schematically illustrates some components of an exemplifying voltage feedback means 340 that may be applied as the voltage feedback means 240 in the driver 200. The voltage feedback means 340 comprises a scaling means 344, e.g. a scaling circuit, for deriving a scaled potential V'_{out} of the output voltage V_{out}. The scaling means 344 may be arranged derive the scaled potential V'_{out} as a combination of the output voltage V_{out} and the common reference potential V_1 or by scaling (e.g. multiplying) the output voltage V_{out} by an adaptive scaling factor k_3 that depends on the common reference potential V_1. The voltage feedback means 340 further comprises a comparator 346 for deriving the voltage feedback FB_v that is indicative of a difference between the scaled output voltage V'_{out} and the predefined reference potential V_{ref}. This difference also reflects the difference between the observed output voltage V_{out} and the adaptive maximum output voltage V_{max} the occurrence of which at the output would make the scaled output voltage V'_{out} equal to the predefined reference potential V_{ref}.

[0027] The voltage feedback means 340 may be applied in the driver 200, for example, together with the current feedback means 330 or together with the current feedback means 430. In case a pair of the current feedback means 430 and the voltage feedback means 340 is applied, they may share the voltage source arranged to provide the predefined reference potential V_{ref}.

[0028] Figure 6 schematically illustrates some components of an exemplifying voltage feedback means 440 that may be applied as the voltage feedback means 240 in the driver 200. The voltage feedback means 440 comprises a scaling means 444, e.g. a scaling circuit, for deriving a scaled reference potential V'_{ref} on basis of the predetermined reference potential V_{ref}. The scaling means 444 may be arranged derive the scaled reference potential V'_{ref} as a combination of the reference potential V_{ref} and the common reference potential V_1 or by scaling (e.g. multiplying) the reference potential V_{ref} by an adaptive scaling factor k_4 that depends on the common reference potential V_1. The voltage feedback means 440 further comprises a comparator 446 for deriving the voltage feedback FB_v that is indicative of a difference between the scaled reference potential V'_{ref} and the output voltage V_{out}, which difference also reflects the difference between the observed output voltage V_{out} and the adaptive maximum output voltage V_{max} that would be equal to the scaled reference potential V'_{ref}.

[0029] The voltage feedback means 440 may be applied in the driver 200, for example, together with the current feedback means 330 or together with the current feedback means 430. In case a pair of the current feedback means 430 and the voltage feedback means 440 is applied, they may share the voltage source arranged to provide the predefined reference potential V_{ref}.

[0030] While there a multiple ways for implementing current feedback means 330, 430 and/or the voltage feedback means 340, 440 outlined in the foregoing, Figure 7 schematically illustrates some components of an exemplifying driver 300 comprising a current feedback circuit 530 and a voltage feedback circuit 540. Herein, the current feedback provides an exemplifying implementation of the current feedback means 330, whereas the voltage feedback circuit 540 provides an exemplifying implementation of the voltage feedback means 340.

[0031] In the example of Figure 7, the current feedback circuit 530 comprises resistors R_2, R_3, R_4 and R_{sense} together with the comparator 336, whereas the voltage feedback circuit 540 comprises resistors R_5 and R_6 together with the comparator 346.

[0032] In the current feedback circuit 530 the resistors R_3 and R_{sense} constitute the current-to-voltage conversion means to provide the potential V_I indicative of the level of the output current I_{out}. Furthermore, the resistors R_2 and R_4 form a voltage divider that constitutes the scaling means 334 and define the scaling factor k_1 (as $k_1 = R_2 / (R_2 + R_4)$) for providing the scaled reference potential V'_1 on basis of the common reference potential V_1 as $V'_1 = k_1 * V_1$. In the voltage feedback circuit 540 the resistors R_5 and R_6 form a voltage divider that constitutes the scaling means 344 and define the scaling for providing the scaled output voltage V'_{out} as a linear combination of the output voltage V_{out} and the common reference potential V_1, e.g. as $V'_{out} = (R_6 / (R_5 + R_6)) * V_{out} + (R_5 / (R_5 + R_6)) * V_1$).

[0033] In Figure 7 the power source portion 210 is depicted with control means 212 that is arranged to receive the current feedback FB_I and the voltage feedback FB_V and further arranged to adjust operation of the driver 300 according to one or more predefined rules.

[0034] Figure 8 schematically illustrates some components of an exemplifying reference generation circuit 350 that may be that may be applied as the reference generation means 250, for example, in the drivers 200 and 300.

[0035] The reference generation circuit 350 comprises resistors R_7, R_8, R_9 and R_{10} together with the voltage regulator IC_1. These components are arranged between an operating voltage source V_{cc} and a ground potential *GND*. In particular, resistor R_7 is connected between the operating voltage source V_{cc} and the cathode of the voltage regulator IC_1; resistor R_8 is connected between the cathode and the control input of the voltage regulator IC_1; and resistor R_9 is connected between the control input of the voltage regulator IC_1 and the ground potential *GND*, to which also the anode of the voltage regulator IC_1 is connected. Resistor R_{10} is connected between the control input of the voltage regulator IC_1 and a first coupling node for an external selectable component, and the second coupling node for the external selectable component is connected to the ground potential *GND*.

[0036] The voltage regulator IC_1 is configured to provide a cathode potential on basis of an internal reference voltage V_{int} of the IC_1 in dependence of a selectable control voltage V_{ctrl} applied in its control input. The voltage in the cathode of the IC_1 is supplied as the common reference potential V_1 for use by the current feedback means 230 and the voltage feedback means 240 described in the foregoing.

[0037] In particular, the IC_1 may be controlled to provide a desired value of the common reference potential V_1 on basis of its internal reference voltage V_{int} such that the common reference potential V_1 is selected between a minimum value V_{1_min} and a maximum value V_{1_max}. The selectable control voltage V_{ctrl} that causes selection of the common reference potential V_1 in the range defined by the values V_{1_min} and V_{1_max} is defined by the output of the voltage divider formed by the resistors R_8, R_9 and R_{10} of the reference generation circuit 350 and further by the external selectable component that may be coupled to the reference generation circuit 350, e.g. by the resistor R_{set} as illustrated in Figure 8.

[0038] In the exemplifying reference generation circuit 350 the relationship between the common reference potential V_1 and the external selectable component R_{set} may be expressed as

$$V_1 = V_{int} * (1 + R_8 * \frac{R_9+R_{10}+R_{set}}{R_9*(R_{10}+R_{set})}) \qquad [1]$$

[0039] Suitable selection of the resistors R_8, R_9 and R_{10} hence enables providing a predefined mapping between the resistance of the external selectable component, e.g. the resistor R_{set}, and the resulting common reference potential V_1.

[0040] The minimum value V_{1_min} of the common reference potential V_1 is obtained by leaving an open current path between the connectors for connecting the selectable external component (thereby providing an infinite resistance), while the maximum value V_{1_max} of the common reference potential V_1 is obtained by short-circuiting the connectors for connecting the selectable external component (thereby providing a zero resistance). This may be expressed e.g. as

$$V_{1\_max} = V_{int} * (1 + R_8 * \frac{R_9+R_{10}}{R_9*R_{10}}) \qquad [2]$$

$$V_{1\_min} = V_{int} * (1 + \frac{R_8}{R_9}) \qquad [3]$$

[0041] When the reference generation circuit 350 is applied in the driver 200 or 300, suitable selection of characteristics of the resistors R_7, R_8, R_9 and R_{10} may be applied to provide desired value range V_{1_min} to V_{1_max} of the common reference potential V_1 such that the minimum value V_{1_min} corresponds to the minimum setting for the nominal current level in the output current I_{out} and that the maximum value V_{1_max} corresponds to the maximum setting for the nominal current level in the output current I_{out}, whereas the external resistor R_{set} of suitable characteristics may be applied to select the desired value of the common reference potential V_1 from this range.

[0042] In the following, an exemplifying approach is considered for pre-selecting the resistors R_2 and R_4 in context of the driver 300 such that the current feedback FB_I indicates the difference between the observed output current I_{out} and the nominal current level that would make the potential V_I equal to the scaled reference potential V'_1 Moreover, an exemplifying approach is considered for selecting the resistors R_5 and R_6 in context of the driver 300 such that the voltage feedback FB_V indicates the difference between the observed output voltage V_{out} and the adaptive maximum output voltage V_{max} that corresponds to the common reference potential V_1.

[0043] Regarding the configuration of the current feedback circuit 530, as described in the foregoing, the scaled reference potential V'_1 provided to the lower input of the comparator 336 (in the illustration of Figure 7) may be obtained as

$$V'_1 = V_1 \cdot \frac{R_2}{R_2+R_4}, \qquad [4]$$

and the potential V_I provided to the upper input or inverting input of the comparator 336 (in the illustration of Figure 7) may be obtained as

$$V_\mathrm{I} = I_\mathrm{out} \cdot R_\mathrm{sense}. \qquad [5]$$

[0044] In case the driver 300 is employed as a LED driver, the control means 212 may be arranged to cause the power source portion 210 to continuously adjust its operation when the output current I_{out} flows, such that the current feedback FB_I indicates zero difference or a difference that is as close as possible to zero, which indicates that the measured output current I_{out} exhibits a level that is at or close to the selected nominal current level. In other words, the control means 212 may be arranged to cause the power source portion 210 to adjust its operation to keep the V'_1 and V_I equal. This corresponds to setting the right side of equation [4] equal to that of equation [5], which in turn enables deriving the following relationship between the output current I_{out} and the common reference potential V_1:

$$I_\mathrm{out} = V_1 \cdot \frac{R_2}{R_{sense} \cdot (R_2+R_4)}. \qquad [6]$$

[0045] In other words, nominal current level that is the desired level of the output current I_{out} is directly proportional to the common reference potential V_1 in accordance with the resistances of the resistors R_2, R_4 and R_{sense}.

[0046] Regarding operation of the voltage feedback circuit 540, at a given value of the common reference potential V_1 (and hence at a corresponding value of the nominal current level defined according to the equation [6]) the adaptive maximum output voltage V_{max} is defined according to equation [7] below. The voltage feedback FB_V at the output of the comparator 346 indicates the difference between the observed output voltage V_{out} and the adaptive maximum output voltage V_{max}.

$$V_{out} = V_\mathrm{ref} \cdot \frac{R_5+R_6}{R_6} - V_1 \cdot \frac{R_5}{R_6}. \qquad [7]$$

[0047] In this regard, the control means 212 may be arranged to cause the power source portion 210 to continuously adjust its operation such that the measured output voltage V_{out} does not exceed the adaptive maximum output voltage V_{max}. In other words, the control means 212 may be arranged to cause the power source portion 210 to adjust its operation such that the output voltage V_{out} is limited or reduced in response to the voltage feedback FB_V indicating an observed output voltage V_{out} that exceeds the adaptive maximum output voltage V_{max}. This may be provided e.g. by reducing the amount of electric energy delivered to the output of the driver 300, which may mean e.g. decreasing a duty cycle of a cyclically operated switch that controls operation of the power source portion 210 or performing some other action that has the desired effect.

[0048] In order to operation of the driver 300 to actually limit the output voltage V_{out} in accordance with the predefined maximum output power P_{max}, the following condition must be encountered.

$$P_{\max} = V_{\text{out}} \cdot I_{\text{out}}. \qquad [8]$$

[0049] This is illustrated in Figure 9 that depicts as the bold solid line a curve that indicates the maximum allowable output voltage V_{out} (the y axis) as a function of the output current I_{out} (the x axis) in order to ensure adhering to the maximum output power P_{max}. In Figure 9 the output voltage V_{max1} represents the adaptive maximum output voltage V_{max} that corresponds to the maximum setting for the output current I_{out1}, the output voltage V_{max2} represents the adaptive maximum output voltage V_{max} that corresponds to the minimum setting for the output current I_{out2}, while the pair of V_x and I_x indicates an exemplifying point between the end points of the range(s) for the output current I_{out} and the maximum output voltage V_{max}.. The curve that indicates the P_{max} as a function of the output current I_{out} is a hyperbola. However, when a relatively narrow range of output currents I_{out} is considered, the hyperbola can be approximated at a reasonably good accuracy with a straight line (not shown) that passes via the end-points defined by the coordinates (I_{out1}, V_{max1}) and (I_{out2}, V_{max2}).

[0050] In view of the equation [8] and in consideration of the minimum and maximum values for the adaptive maximum output voltage V_{out} and the output current I_{out}, we get

$$V_{\max1} \cdot I_{\text{out1}} = V_{\max2} \cdot I_{\text{out2}} \rightarrow \frac{V_{\max1}}{V_{\max2}} = \frac{I_{\text{out2}}}{I_{\text{out1}}}. \qquad [9]$$

[0051] When we further denote the ratio between the minimum and maximum output currents I_{out} as *rng* we can write

$$rng_I = \frac{I_{\text{out2}}}{I_{\text{out1}}} = \frac{V_{1\_min}}{V_{1\_max}}. \qquad [10]$$

[0052] Using the equation [7] we can rewrite the equation [10] into

$$rng_I = \frac{V_{\text{ref}} \cdot \frac{R_5+R_6}{R_6} - V_{1\_\max} \cdot \frac{R_5}{R_6}}{V_{\text{ref}} \cdot \frac{R_5+R_6}{R_6} - V_{1\_\min} \cdot \frac{R_5}{R_6}} = \frac{V_{\text{ref}} \cdot \frac{R_5+R_6}{R_6} - \frac{V_{1\_\min}}{rng_I} \cdot \frac{R_5}{R_6}}{V_{\text{ref}} \cdot \frac{R_5+R_6}{R_6} - V_{1\_\min} \cdot \frac{R_5}{R_6}} \qquad [11]$$

and further into

$$rng_I \cdot \left(V_{\text{ref}} \cdot \left(1 + \frac{R_5}{R_6}\right) - V_{1\_\min} \cdot \frac{R_5}{R_6}\right) = V_{\text{ref}} \cdot \left(1 + \frac{R_5}{R_6}\right) - \frac{V_{1\_\min}}{rng_I} \cdot \frac{R_5}{R_6}, \qquad [12]$$

$$V_{1\_\min} \cdot \frac{R_5}{R_6} \cdot \left(\frac{1}{rng_I^2} - 1\right) = V_{\text{ref}} \cdot \left(\frac{1}{rng_I} - 1\right) \cdot \left(1 + \frac{R_5}{R_6}\right), \qquad [13]$$

$$V_{1\_min} \cdot \frac{R_5}{R_6} \cdot \left(\frac{1}{rng_I} + 1\right) = V_{ref} \cdot (1 + \frac{R_5}{R_6}), \text{ and} \quad [14]$$

$$\frac{R_5}{R_6} = \frac{1}{\frac{V_{1\_min}}{V_{ref}} \cdot \left(\frac{1}{rng_I}+1\right)-1}. \quad [15]$$

[0053] Based on the equation [7] we can find another way of presenting the ratio of the resistances of the resistors R_5 and R_6:

$$V_{max2} = V_{ref} \cdot \frac{R_5+R_6}{R_6} - V_{1\_min} \cdot \frac{R_5}{R_6} \rightarrow \frac{R_5}{R_6} = \frac{V_{max2}-V_{ref}}{V_{ref}-V_{1\_min}}. \quad [16]$$

[0054] Since both the equation [15] and the equation [16] may be applied to calculate the ratio of the resistances of the resistors R_5 and R_6, by setting these two equations equal we get

$$\frac{1}{\frac{V_{1\_min}}{V_{ref}} \cdot \left(\frac{1}{rng_I}+1\right)-1} = \frac{V_{max2}-V_{ref}}{V_{ref}-V_{1\_min}}. \quad [17]$$

[0055] The equation [17] enables computing the required predefined reference voltage V_{ref} as

$$V_{ref} = \frac{V_{max2} \cdot V_{1\_min} \cdot (\frac{1}{rng_I}+1)}{V_{max2}+V_{1\_min} \cdot \frac{1}{rng_I}} = \frac{V_{max2} \cdot (V_{1\_max}+V_{1\_min})}{V_{max2}+V_{1\_max}}. \quad [18]$$

[0056] Now we can choose suitable values V_{1_min} and V_{1_max} e.g. such that the potential V_{1-min} = 3 V corresponds to the lowest selectable output current I_{out2} at 1.05 A and that the potential V_{1_max} = 4 V corresponds to the highest selectable output current I_{out1} at 1.4 A. Consequently, assuming that the maximum allowable output power P_{max} is set to 50 W we find that V_{out2} = 50 W / 1.4 A = 35.7 V, which results in the predefined reference voltage

$$V_{ref} = \frac{V_{max2} \cdot (V_{1\_max}+V_{1\_min})}{V_{max2}+V_{1\_max}} = \frac{35.7 \cdot (3+4)}{35.7+3} V = 6.46\,V \quad [19]$$

and in the ratio of the resistances of the resistors R_5 and R_6

$$\frac{R_5}{R_6} = \frac{V_{max2}-V_{ref}}{V_{ref}-V_{1\_min}} = 11.88. \quad [20]$$

[0057] Consequently, the adaptive maximum output voltage V_{max} set in accordance with the resistors R_5 and R_6 and the reference voltage V_{ref} in dependence of the common reference potential V_1 can be arranged to follow the respective (constant or substantially constant) output current I_{out} at the nominal current level defined by the resistors R_2 and R_4 (see the equation [6]) (also) in dependence of the common reference potential V_1.

[0058] In the following, an exemplifying driver 400 employed as a LED driver is described. The driver 400 is based on the driver 300 and only differences to the driver 300 are described in the following. Figure 10 schematically illustrates some components of the driver 400. In the driver 400 the comparator 336 is embodied as an operational amplifier (op-amp) 536 where the scaled reference potential V'_1 is provided to the non-inverting input of the op-amp 536 and where the potential V_I indicative of the level of the output current I_{out} is provided to the inverting input of the op-amp 536. Moreover, the output of the op-amp 536 is fed back to the inverting input of the op-amp 536 via an impedance Z_{fb1}, producing the familiar inverting amplifier configuration. With such an arrangement the output of the op-amp 536 is configured to go the more negative, the more positive goes the potential in its inverting input.

[0059] Along similar lines, in the driver 400 the comparator 346 is embodied as an op-amp 546 where the scaled output voltage V'_{out} is provided to the inverting input of the op-amp 546 and where the predefined reference potential V_{ref} is provided to the non-inverting input of the op-amp 546. The output of the op-amp 546 is fed back to the inverting input of the op-amp 546 via an impedance Z_{fb2}, again producing the inverting amplifier configuration in which the output of the op-amp 546 goes the more negative, the more positive goes the potential in its inverting input.

[0060] In the driver 400 a galvanically isolated feedback path to the control means 212 is provided. A current path from a voltage source V_{cc} to the output of the op-amp 536 includes, in this order, a resistor R_1, a light source of an optoisolator O_1, and a diode D_2. A current path from the voltage source V_{cc} to the output of the op-amp 546 includes, in this order, the resistor R_1, the light source of the optoisolator O_1, and a diode D_3. The sensor side of the optoisolator O_1 is coupled to the control means 212, which is provided as part of the power source portion 210.

[0061] The galvanically isolated feedback path comprising the voltage source V_{cc}, the resistor R_1, the optoisolator O_1 and the diodes D_2 and D_3 is configured to operate such that an electric current flows from the voltage source V_{cc} towards the op-amp 536 in response to the current feedback FB_I indicating observed output current I_{out} that is higher than the selected nominal current level and towards the op-amp 546 in response to the voltage feedback FB_V indicating observed output voltage V_{out} that is higher than the adaptive maximum output voltage V_{max}. Consequently, the current flowing through the light source of the optoisolator O_1 invokes an electric current in the sensor side of the optoisolator O_1 and hence provides the control means 212 in the power source portion 210 with an indication that the amount of electric energy delivered to the load should be reduced. The indication thus takes the form of either current feedback FB_I or voltage feedback FB_V.

[0062] The arrangement of Figure 10 serves as a non-limiting example of making use of the current feedback FB_I and the voltage feedback FB_V for controlling operation of the driver 200, 300, 400. As an example, the feedbacks FB_I and FB_V may be provided to the control means 212 included in the power source portion 210 (along the lines depicted in Figure 7), and the control means 212 may be configured to adjust the operation of the power source portion 210 according to one or more predefined rules in view of the received feedback FB_I and FB_V. These rules may involve, for example, controlling the power source portion 210 to reduce the amount of electric energy delivered to the load in response to the current feedback FB_I indicating observed output current I_{out} level that is higher than the nominal current level, and/or in response to the voltage feedback FB_V indicating observed output voltage V_{out} that is higher than the adaptive maximum output voltage V_{max}.

[0063] At least some of the operations, procedures and/or functions assigned to the structural units described in the context of the driver 200, 300, 400 may be provided as steps of a method. As an example of this regard, Figure 11 illustrates a method 600 for operating the LEDs 120 using a driver apparatus that comprises at least the output for connecting the LEDs and the power source portion 210 for supplying output power to the output of the driver apparatus. The method 600 may be embodied e.g. in the driver apparatus or in a control module or control apparatus arranged control operation of the driver apparatus.

[0064] The method 600 comprises generating the common reference potential V_1 in dependence of a selectable component, e.g. the resistor R_{set}, that is connectable to the driver apparatus (block 610). The method 600 further comprises providing the current feedback FB_I in dependence of the common reference potential V_1 such that the current feedback FB_I is indicative of a level of the output current I_{out} supplied to the output of the driver apparatus in relation to a nominal current level (block 620) and providing the voltage feedback FB_V in dependence of said common reference potential V_1 such that the voltage feedback FB_V is indicative of the output voltage V_{out} across nodes of the output of the driver apparatus in relation to the adaptive maximum output voltage V_{max} (block 630). The method 600 further comprises controlling the power source portion 210 based at least on the current feedback FB_I and the voltage feedback FB_V such that the power supplied to the output of the driver apparatus does not exceed the predefined maximum output power P_{max}. (block 640).

[0065] The method 600 outlined above may be varied in a number of ways, for example in accordance with the examples described in the foregoing in context of the driver 200, 300 and 400. Moreover, the steps of the method 600 may be provided in an order different from that illustrated in Figure 11.

[0066] A particular advantage of the embodiments of the invention described above is the ease at which a limitation of maximum output current can be combined with limiting also maximum output power. Simply connecting one selectable external component (like the resistor R_{set} in the embodiments described above) sets the nominal output current I_{out}, and simultaneously also sets the adaptive maximum output voltage V_{max} so that the product of I_{out} and V_{max} remains substantially constant. In other words, the higher value is selected for the nominal output current I_{out}, the lower becomes the adaptive maximum output voltage V_{max}, and vice versa, within certain range that is determined by internal components of the driver, 200, 300, 400. The interdependence between the output current I_{out} and output voltage V_{out} allows dimensioning the power source portion 210 so that it does not need to be able to deliver more electric power to the load than what is obtained as the product of I_{out} and V_{max}.

[0067] The manufacturer of a driver may provide a dedicated connector that is easily accessible from outside the driver, so that for example during the process of manufacturing a LED luminaire the luminaire manufacturer can install the selectable external component simply by pushing its leads to the dedicated connector. If the LEDs are to be coupled to the driver in the form of a LED module, the selectable external component may also be part of the LED module, in which case it becomes coupled to the driver at the same time when also other connections between the driver and the LED module are made.

[0068] The selectable external component does not need to be a resistor, although taken that the reference generation means typically generate a constant reference potential, the use of a resistor as a selectable external component is very straightforward. The selectable external component could be some other kind of passive component; for example, if the reference generation means handles oscillating signals, the selectable external component could be a capacitor or inductor that has a role in defining some resonance frequency, which in turn translates into a reference potential. A zener diode with a particular breakdown voltage can be used as a selectable external component. Also active components can be used as selectable external components, if their role in generating the reference in the reference generation means can be made unambiguous and accurate enough.

[0069] The embodiment of Figure 10 was based on the selection that the current feedback FB_I and the voltage feedback FB_V are only used in a limiting sense, so that excessive output current and/or excessive output voltage cause the light source in the optoisolator to light up and trigger the control means 212 to invoke a limiting action. However, a feedback signal from the output (i.e. the output current feedback or output voltage feedback) can also be used in enhancing mode, so that a feedback signal indicating that the measured quantity is smaller than a desired respective target value causes the amount of delivered electric energy to be increased. Such an approach is particularly applicable to the embodiment illustrated in Figure 7, where the control means 212 receives directly and separately the signals FB_I and FB_V.

[0070] 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 (200, 300, 400) for operating one or more light emitting diodes (120), LEDs, the driver (200, 300, 400) comprising,
an output for connecting the one or more LEDs (120),
power source means (210) for supplying power to said output,
reference generation means (250, 350) for generating a common reference potential (V_1) in dependence of a selectable component (R_{set}) connectable to the driver (200, 300, 400),
first feedback means (230, 330, 430, 530) for providing current feedback (FB_I) in dependence of said common reference potential (V_1), which current feedback (FB_I) is indicative of a level of an output current (I_{out}) supplied to said output in relation to a nominal current level,
second feedback means (240, 340, 440, 540) for providing voltage feedback (FB_V) in dependence of said common reference potential (V_1), which voltage feedback (FB_V) is indicative of an output voltage (V_{out}) across nodes of said output in relation to an adaptive maximum output voltage (V_{max}), and
control means (212) for controlling the power source means (210) based at least on said current feedback (FB_I) and said voltage feedback (FB_V) such that the power supplied to said output does not exceed a predefined maximum power (P_{max}).

2. A driver according to claim 1, wherein the first feedback means (230, 330, 430, 530) is arranged to derive the current feedback (FB_I) as an indication of one of the following:

   a difference between a first reference potential (V'_1) and a potential (V_I) indicative of the level of said output current (I_{out}), wherein said first reference potential (V'_1) is derived in dependence of said common reference

potential (V_1), and
a difference between a first reference potential (V_{ref}) and a potential (V'_I) indicative of the level of said output current (I_{out}), wherein said potential (V'_I) indicative of the level of said output current (I_{out}) is derived in dependence of said common reference potential (V_1).

3. A driver according to claim 2, wherein said first feedback means (230, 330, 430, 530) is arranged to carry out one of the following:

derive said first reference potential (V'_1) by scaling said common reference potential (V_1) by a predefined scaling factor, and
derive said potential (V'_I) indicative of the level of said output current (I_{out}) by combining said common reference potential (V_1) with a voltage (V_I) across an output current sensing element (R_{sense}).

4. A driver according to any of claims 1 to 3, wherein the second feedback means (240, 340, 440, 540) is arranged to derive the voltage feedback (FB_V) as an indication of one of the following:

a difference between a predefined reference potential (V_{ref1}) and a second reference potential (V'_{out}), wherein said second reference potential (V'_{out}) is derived in dependence of said common reference potential (V_1) and said output voltage (V_{out}), and
a difference between a predefined reference potential (V_{ref1}) scaled in dependence of said common reference potential (V_1) and a second reference potential indicative of said output voltage (V_{out}).

5. A driver according to claim 4, wherein said second feedback means (240, 340, 440, 540) is configured to carry out one of the following:

derive said second reference potential (V'_{out}) by combining a potential indicative of said output voltage (V_{out}) with said common reference potential (V_1) and
scale said predefined reference potential (V_{ref1}) by combining it with said common reference potential (V_1).

6. A driver according to any of claims 1 to 5, wherein said reference generation means (250, 350) comprises a voltage regulator (IC_1) arranged to generate the common reference potential (V_1) in dependence of a selectable control potential (V_{ctrl}) that is selectable in dependence of the selectable component (R_{set}).

7. A driver according to claim 6, wherein said control potential (V_{ctrl}) is defined by an output potential of a voltage divider arrangement, wherein the output potential of the voltage divider arrangement is set in dependence of the selectable component (R_{set}).

8. A driver according to any of claims 1 to 7, wherein said control means (212) is arranged to
control the power source means (210), on basis of said current feedback (FB_I), to supply constant or substantially constant output current (I_{out}) at said nominal current level as a response to said voltage feedback (FB_V) indicating an output voltage (V_{out}) that does not exceed said adaptive maximum output voltage (V_{max}), and
control the power control means (210) to reduce the amount of electric energy delivered to its output as a response to said voltage feedback (FB_V) indicating an output voltage (V_{out}) that exceeds said adaptive maximum output voltage (V_{out}).

9. A method for operating one or more light emitting diodes (120), LEDs, using a driver (200, 300, 400) comprising an output for connecting the one or more LEDs (120) and a power source means (210) for supplying power to said output, the method comprising
generating a common reference potential (V_1) in dependence of a selectable component (R_{set}) connectable to the driver (200, 300, 400),
providing current feedback (FB_I) in dependence of said common reference potential (V_1), which current feedback (FB_I) is indicative of a level of an output current (I_{out}) supplied to said output in relation to a nominal current level,
providing voltage feedback (FB_V) in dependence of said common reference potential (V_1), which voltage feedback (FB_V) is indicative of an output voltage (I_{out}) across nodes of said output in relation to an adaptive maximum output voltage (V_{max}), and
controlling the power source means (210) based at least on said current feedback (FB_I) and said voltage feedback (FB_V) such that the power supplied to said output does not exceed a predefined maximum power (P_{max}).

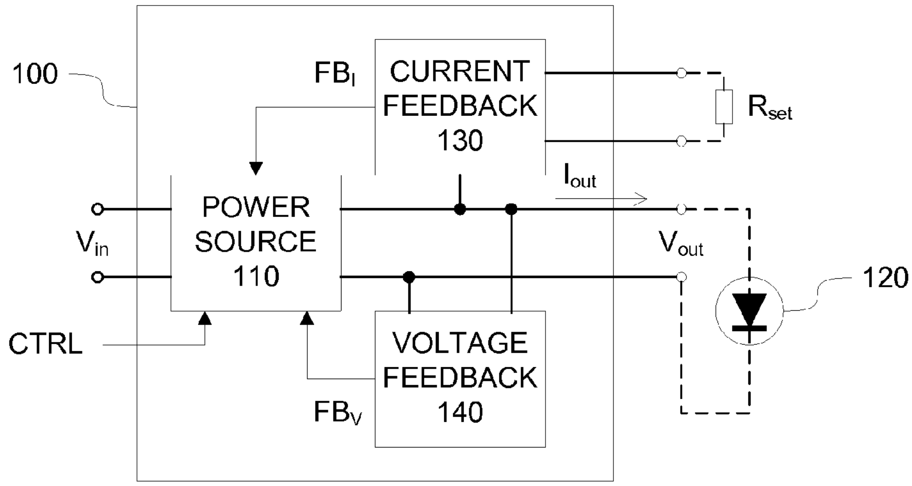

Figure 1

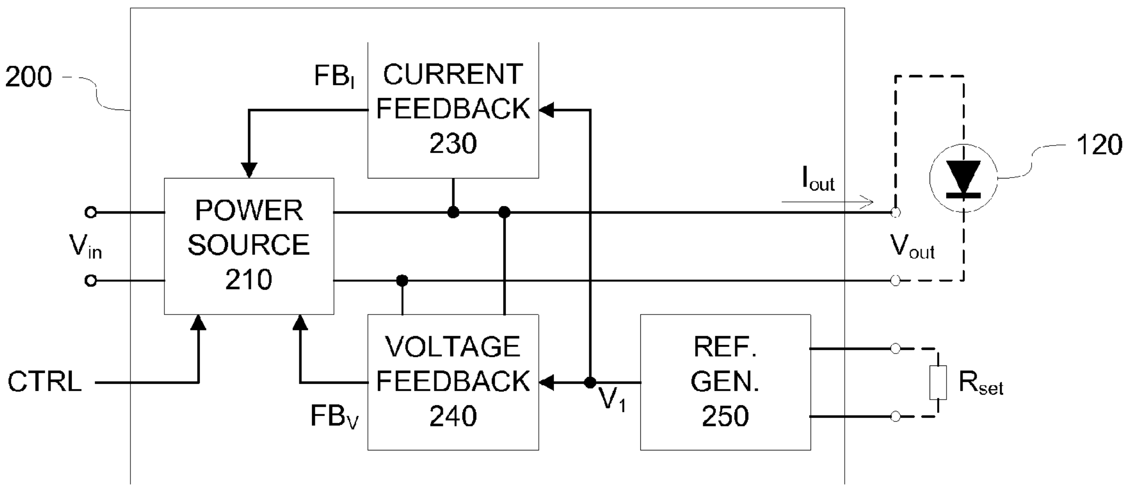

Figure 2

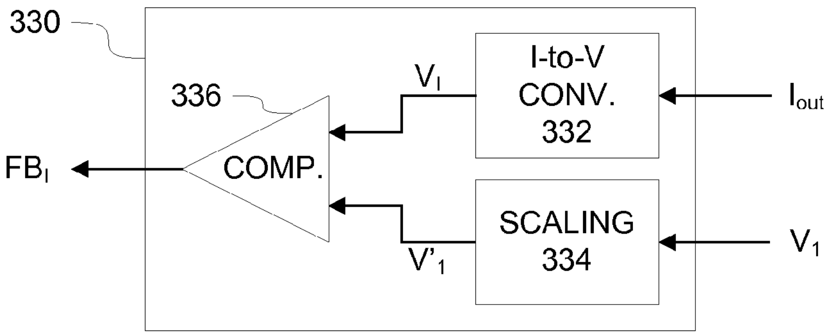

Figure 3

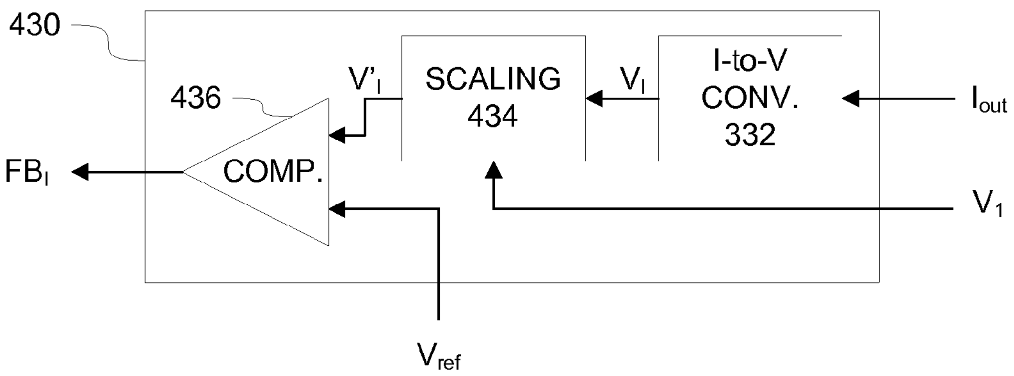

Figure 4

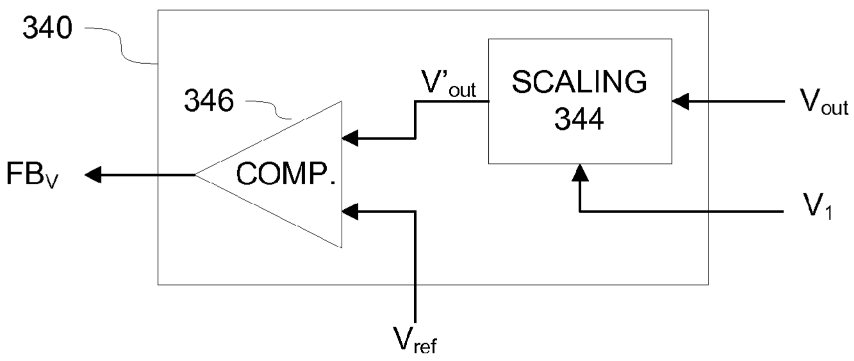

Figure 5

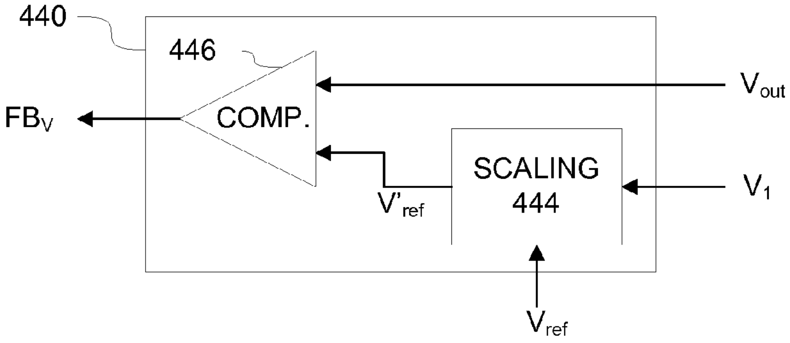

Figure 6

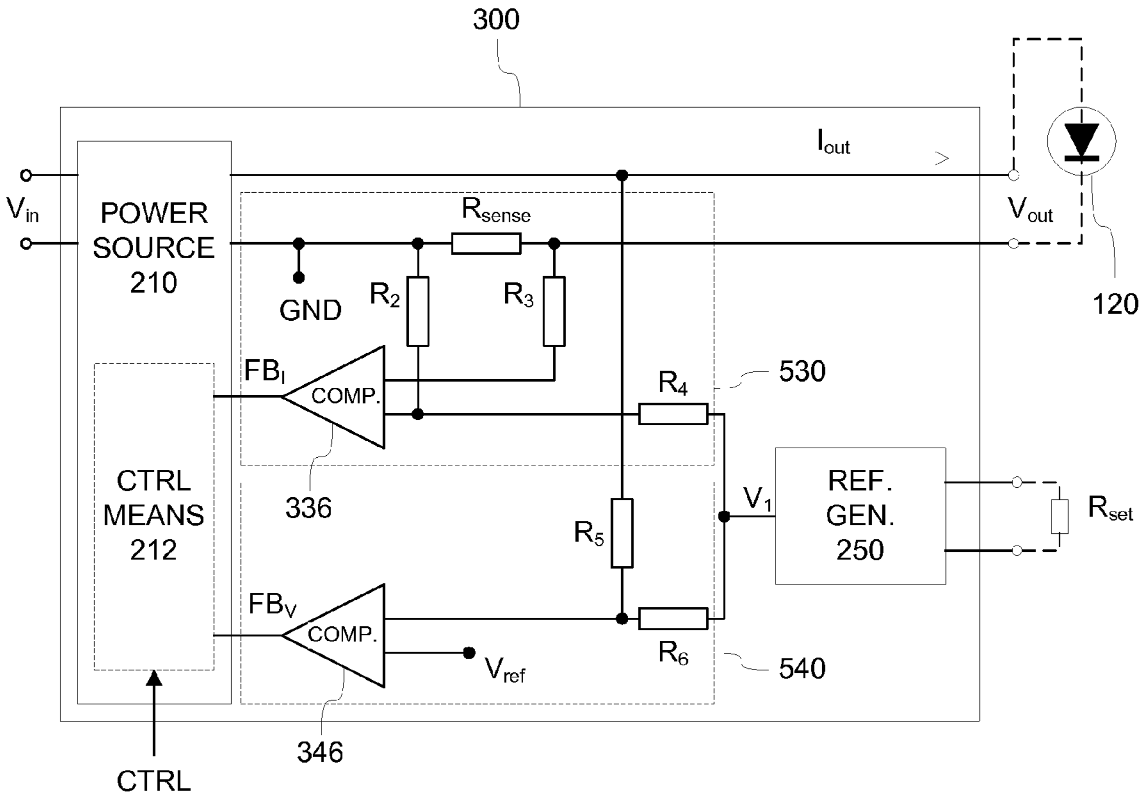

Figure 7

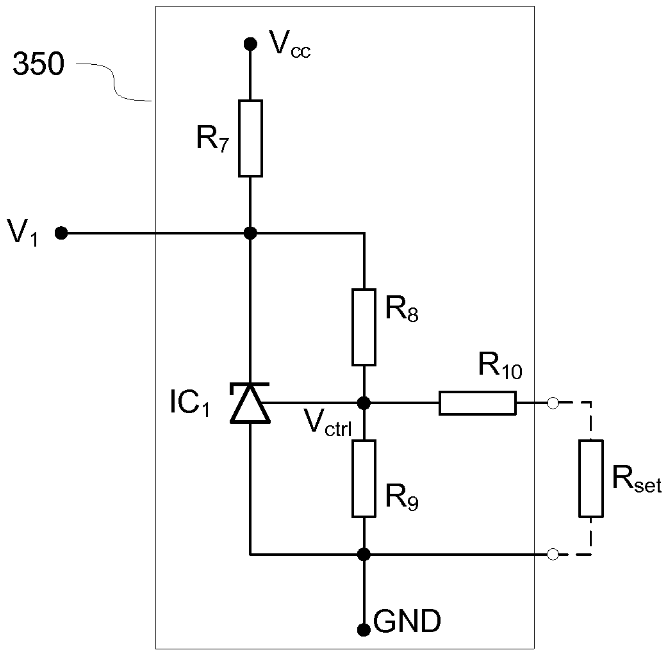

Figure 8

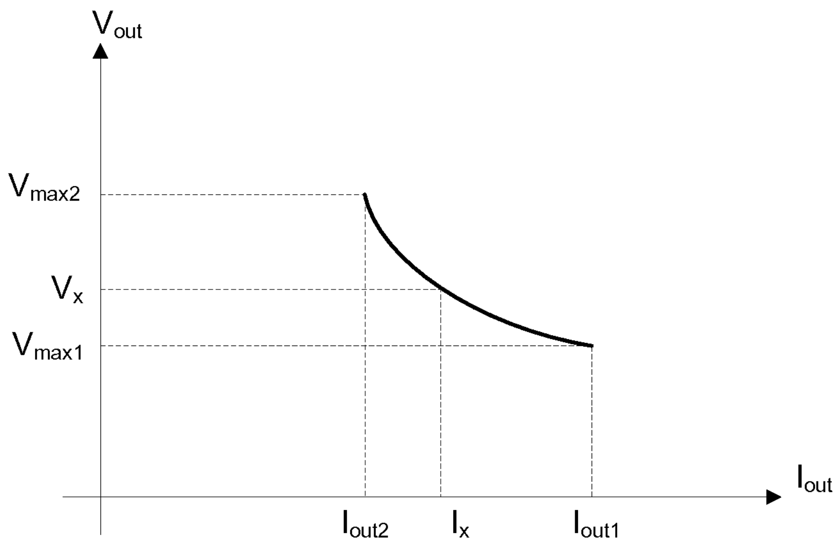

Figure 9

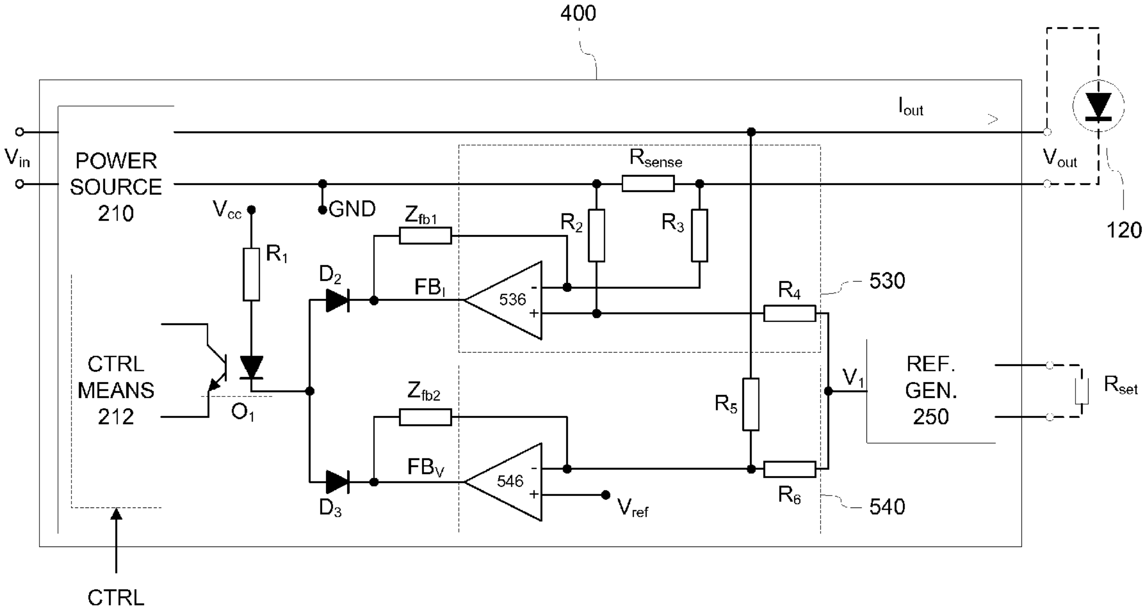
400
I_{out}
V_{in}
POWER
SOURCE
210
V_{cc}
GND
R_{sense}
V_{out}
120
Z_{fb1}
R_2
R_3
R_1
D_2
FB_I
536
530
R_4
CTRL
MEANS
212
O_1
V_1
REF.
GEN.
250
R_{set}
Z_{fb2}
R_5
FB_V
546
D_3
V_{ref}
R_6
540
CTRL

Figure 10

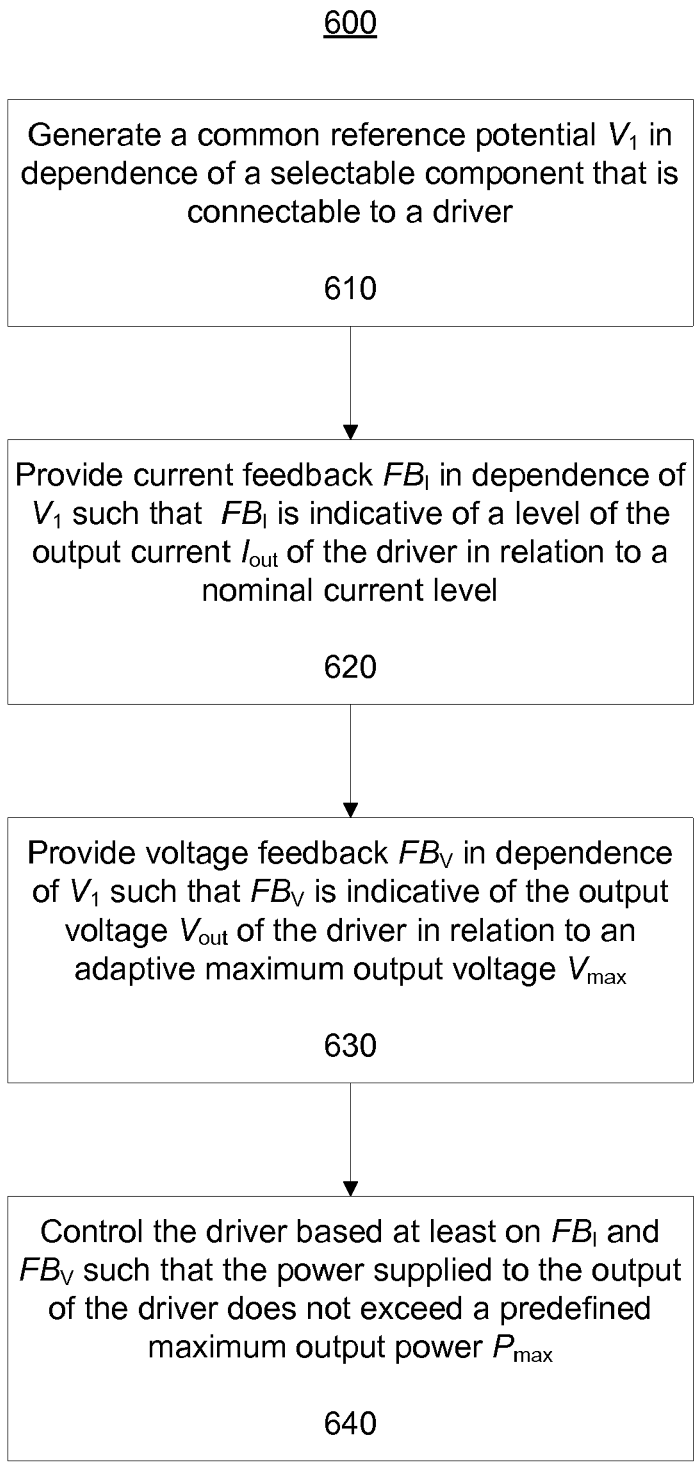
600
Generate a common reference potential V_1 in dependence of a selectable component that is connectable to a driver
610
Provide current feedback FB_I in dependence of V_1 such that FB_I is indicative of a level of the output current I_{out} of the driver in relation to a nominal current level
620
Provide voltage feedback FB_V in dependence of V_1 such that FB_V is indicative of the output voltage V_{out} of the driver in relation to an adaptive maximum output voltage V_{max}
630
Control the driver based at least on FB_I and FB_V such that the power supplied to the output of the driver does not exceed a predefined maximum output power P_{max}
640

Figure 11

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EUROPEAN SEARCH REPORT

Application Number
EP 14 17 2955

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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H05B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	1 December 2014	Morrish, Ian

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 14 17 2955

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01-12-2014

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82