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(54) **A DRIVER DEVICE AND A METHOD OF CONTROLLING A POWER CONVERTER IN A DRIVER DEVICE**

(57) A driver device (210) for providing electric current to a light is provided. The driver device (210) comprises a power converter (213) arranged to provide an output voltage at a converter output. The driver device (210) further comprises a control circuit (214) arranged to control the operation of the power converter (213), and a feedback circuit (216) arranged to provide to the control circuit (214) a feedback signal (217) based on at least one measured value. The control circuit (214) is arranged to control the operation of the power converter (213) based on the value of the feedback signal (217). The driver device (210) further comprises a limiting circuit (223) coupled to the converter output and configured to provide a measured value indicative of the rate of change of the output voltage of the power converter (213) to the feedback circuit (216). Moreover, a corresponding method of controlling a power converter in a driver device for a light source is provided.

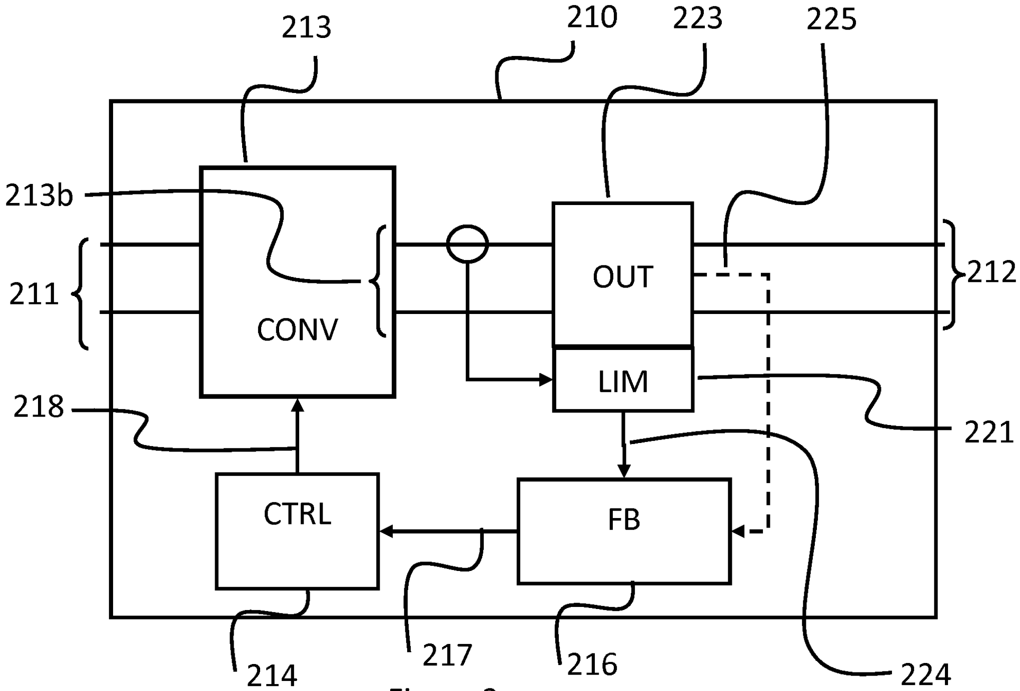

Figure 2

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Description

FIELD OF THE INVENTION

[0001] The invention relates to a control of operation of a driver device for providing electric current to a light source. In particular, the invention relates to a driver device and a method of controlling a power converter in a driver device.

BACKGROUND OF THE INVENTION

[0002] Driving current to a light source is typically provided by a driver device, which converts AC power provided by a mains power network into DC current suitable for the light source. Some light sources have highly non-linear voltage-current characteristics. For example, light emitting diodes (LEDs) have a threshold voltage, below which the LED is essentially non-conducting and above which a small increase in voltage may result in significant increase in current.

[0003] For simplicity, let us assume that a light source consists of a string of LEDs. When a driver starts providing operating power to the light source, the voltage over the LED string starts increasing but practically no current flows through the individual LEDs. Eventually, the voltage exceeds the sum of threshold voltages of the individual LEDs, and current starts passing through the light source and the light source starts emitting light. After the threshold voltage is exceeded, the current through the light source increases rapidly if voltage is further increased.

[0004] Usually, the driver device comprises at least one power converter stage and typically at least one of the power converter stages of the driver device is controlled by a feedback signal related to the current passing through the light source. For the feedback control, the threshold-behavior of current through the light source is problematic. As long as the voltage is below the threshold voltage, the feedback control requests the power converter to increase the output power as much as possible. Once the threshold voltage is exceeded and significant current suddenly starts passing through the light source, the feedback control does not react fast enough to reduce the power provided by the power converter and thus the current passing through the light source may become even high enough to cause some damage.

[0005] For these reasons, an improved driver device and method for controlling the driver device for a light source is needed.

SUMMARY OF THE INVENTION

[0006] It is an object of the present invention to provide a driver device and a method for controlling a power converter in a driver device with improved response when a light source connected to a driver device has a threshold voltage for producing light.

[0007] The objects of the invention are reached by a driver device and a method as defined by the respective independent claims.

[0008] According to a first aspect of the invention a driver device for providing electric current to a light source connectable to a driver output of the driver device is provided. The driver device comprises a power converter arranged to provide an output voltage at a converter output, which converter output is coupled to the driver output via an output circuit. The driver device further comprises a control circuit arranged to control the operation of the power converter and a feedback circuit arranged to provide to the control circuit a feedback signal based on at least one measured value in the output circuit. The control circuit is arranged to control the operation of the power converter based on the value of the feedback signal. The driver device further comprises a limiting circuit coupled to the converter output and configured to provide a measured value to the feedback circuit. The measured value is indicative of the rate of change of the output voltage of the power converter

[0009] According to a second aspect of the invention a method of controlling a power converter in a driver device for a light source is provided. The method comprises creating a voltage feedback signal proportional to a rate of change of an output voltage of the power converter, providing the voltage feedback signal as a feedback signal to a control circuit which controls operation of the power converter, and issuing, based on the feedback signal provided to the control circuit, control commands to the power converter.

[0010] 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.

[0011] The novel features which are considered as characteristic of the invention are set forth in particular in the appended claims. The invention itself, 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 detailed description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

Figure 1 illustrates a driver device according to the state of the art.

Figure 2 illustrates an exemplary driver device.

Figure 3 illustrates an exemplary embodiment of a driver device.

Figure 4 illustrates an exemplary embodiment of a driver device.

Figure 5 illustrates an exemplary limiting circuit and feedback circuit in a driver device.

Figure 6 illustrates an exemplary limiting circuit and feedback circuit in a driver device.

Figure 7 illustrates an exemplary limiting circuit and feedback circuit in a driver device.

Figure 8 illustrates an exemplary limiting circuit and feedback circuit in a driver device.

Figure 9 illustrates an exemplary limiting circuit and feedback circuit in a driver device.

DETAILED DESCRIPTION

[0013] Figure 1 illustrates an exemplary driver device 10 according to the state of the art. The driver device 10 is arranged to receive operating power from an external power source via power input 11. The driver device 10 is arranged to provide electric current to a light source which is connectable to a driver output 12. The driver device 10 comprises a power converter 13 which is arranged to convert input power received at power input 11 into converter output voltage at a driver output 12. The driver device 10 also comprises a control circuit 14 arranged to control the operation of the power converter 13 or at least one stage of the power converter 13. The driver device 10 further comprises a feedback circuit 16. The feedback circuit 16 is arranged to provide a feedback signal 17 to the control circuit 14. The control circuit 14 is arranged to control the operation of the power converter 13 based on the value of the feedback signal 17. The feedback signal 17 is based on a measured value at the driver output 12, such as on a measurement of a current passing through the light source.

[0014] A driver device 10 according to the state of the art is able to provide a relatively stable current to a light source during stable operation, in other words, when the light source is emitting light. However, light sources such as LED light sources exhibit non-linear voltage-current characteristics. Hence, a small increase in the voltage provided to the light source may result in a significant increase in the current passing through the light source. Typically, the response times of the feedback signal 17 and the control circuit 14 are not short enough to prevent a sizeable current overshoot. The current overshoot may in turn result in excess reduction of the current, and only after several oscillations the current passing through the light source may settle into its desired value. Such a behavior is expected when the output voltage of the power converter 13 is increased, for example during a start-up phase when the output voltage is increased from essentially zero to around the threshold voltage of the light source.

[0015] Figure 2 illustrates an exemplary driver device 210 according to an embodiment of the invention.

[0016] The driver device 210 is arranged to receive operating power from an external power source via a power input 211. The external power source may be an AC power source such as, for example, a mains power network. Alternatively, the external power source may be a DC power source such as a battery.

[0017] The driver device 210 is arranged to provide electric current to a light source which may be connected to a driver output 212. The light source may be an LED light source comprising one or more LEDs. However, the light source may be any light source exhibiting non-linear voltage-current relationship, such as a threshold voltage for conducting current.

[0018] The driver device 210 comprises a power converter 213 which is arranged to convert input power received at power input 211 into converter output voltage at a converter output 213b. Preferably, the power converter 213 is a switched mode power converter. Alternatively, the power converter 213 may be a regulator, a rectifier, or a transformer, wherein in addition to the regulator, rectifier or transformer the power converter 213 also comprises a separate, controllable switch. Suitable switched mode power converters are, for example, a buck converter or a boost converter. The power converter 213 may also be an isolated converter, such as a flyback converter or a resonant converter, such as an LLC converter. The power converter 213 may also comprise more than one power conversion stage. In other words, the power converter 213 may be a multi-stage power converter. If the power converter 213 comprises more than one power conversion stage, a first power converter stage may be a rectifier stage for rectifying input AC power. A power converter 213 may also comprise a power factor correction (PFC) stage, formed by, for example, a boost converter. A multi-stage power converter 213 may also comprise a transformer stage followed by or preceded by a non-isolated switched mode converter stage, such as a buck converter stage or a boost converter stage. However, in any case the power converter 213 comprises at least one controllable switch, wherein the output of the power converter 213 is arranged to be controlled by controlling the operation of the at least one controllable switch, or by controlling the operation of at least one of the controllable switches.

[0019] The converter output 213b is coupled to the driver output 212 via an output circuit 223. The output circuit 223 may comprise components that may modify the output of the power converter 213, and thus the voltage, current and/or power at the driver output 212 may be different from the voltage, current and/or power at the converter output 213b. For example, the output circuit 223 may comprise a capacitor for reducing ripple in the voltage provided to the driver output 212. However, in some cases such a capacitor may also be considered to be part of the power converter 213. As another example, the output circuit 223 may comprise a controllable switch to be used to control the intensity of light provided by a light source connected to the driver output 212 using, for example, pulse width modulation (PWM) to limit the relative duration of the time when operating power is provided to the light source. According to a third example, the output circuit 223 may comprise an additional power converter which converts a voltage at the converter output 213b into a voltage or current at the driver output 212. Alternatively or additionally, the output circuit 223 may comprise components for monitoring the output of the power converter 213 or for monitoring the output provided at the driver output 212. The output circuit 223 may comprise filtering components for filtering the output provided at the driver output 212. The output circuit 223 may further comprise protection components for protecting either a light source connected to the driver output 212 from sudden changes in the output provided to it, or for protecting components in the driver device 210.

[0020] The driver device 210 also comprises a control circuit 214 arranged to control the operation of the power converter 213 or at least one stage of the power converter 213. Typically, the control circuit 214 is arranged to control the operation of the at least one controllable switch of the power converter 213. The control circuit 214 controls the operation of the power converter 213 by issuing control commands 218 to the power converter 213. The control commands 218 may, for example, control the state of the at least one controllable switch of the power converter 213.

[0021] The driver device 210 according to an embodiment of the invention also comprises a feedback circuit 216. The feedback circuit 216 is arranged to provide a feedback signal 217 to the control circuit 214. The control circuit 214 is arranged to control the operation of the power converter 213 based on the value of the feedback signal 217. In other words, the control commands 218 or the timing of the control commands 218 depend at least in part on the value of the feedback signal. The control commands 218 may be, for example, be selected or timed such that the value of the feedback signal 217 remains below a preset limit, or such that the value of the feedback signal 217 is as close as possible to a predetermined target value.

[0022] The driver device 210 further comprises a limiting circuit 221. The limiting circuit 221 can be considered to be a part of the output circuit 223 or it can be considered to be independent of the output circuit 223. Some components of the limiting circuit 221 may be considered to be also components of the output circuit 223. The limiting circuit 221 is coupled to the converter output 213b and it is configured to provide a measured value 224 to the feedback circuit 216. The measured value 224 is indicative of the rate of change of the output voltage of the power converter 213. The feedback circuit 216 is arranged to provide the feedback signal 217 based on the measured value 224 indicative of the rate of change of the output voltage of the power converter 213. The feedback signal 217 is derived from the measured value 224 indicative of the rate of change of the output voltage of the power converter 213 such that the feedback signal 217 has a constant, fixed value when the rate of change of the output voltage of the power converter 213 remains constant. Thus, based on the feedback signal, the control circuit 214 is arranged to control the power converter 213 such that the rate of change of the output voltage remains constant until the output voltage reaches its target value. The target value of the output voltage of the power converter 213 is effectively the output voltage that provides at the driver output 212 a voltage corresponding to the threshold voltage of a light source connected to the driver output 212. Thus, the target voltage depends on the light source connected to the driver output 212. The driver device 210 is preferably arranged to accommodate a range of target voltages so that also a range of light sources are connectable to the driver output 212.

[0023] The feedback circuit 216 may have a fixed reference value to which the measured value 224 indicative of the rate of change of the output voltage of the power converter 213 is compared. The result of the comparison is provided as the feedback signal 217 to the control circuit 214. The fixed reference value may be provided to the feedback circuit 216 from an external source, or the fixed reference value may be an internal value of the feedback circuit 216. The reference value may be a voltage or it may be some other reference quantity.

[0024] Feedback to the control circuit 214 may also be based on two measured values 224, 225 in the output circuit 223. In such a case, the first measured value 224 is indicative of the rate of change of the output voltage of the power converter 213. The second measured value 225 may be, for example, related to a current provided to a light source connected to the driver output 212. However, considering that changes in the current provided to a light source connected to the driver output 212 are essentially caused by changes in the output voltage of the power converter 213, provision of a second measured value 225 related to a current provided to a light source, in addition to the measured value 224 indicative of the rate of change of the output voltage of the power converter 213, is optional.

[0025] Examples of arrangements wherein the feedback to the control circuit is based on two measured values are illustrated in Figures 3 and 4.

[0026] The driver device 310 in Figure 3 is an exemplary embodiment of a driver device wherein two feedback signals 317a, 317b are provided to control circuit 314. The power input 311, driver output 312, output circuit 323, limiting circuit 321 and measured value 324 correspond to the power input 211, driver output 212, output circuit 223, limiting circuit 221 and measured value 224 of Figure 2.

[0027] Feedback signal 317a corresponds to feedback signal 217 of Figure 2. A measured value 324 indicative of the rate of change of the output voltage of the power converter 313 is provided to feedback circuit 316a by a limiting circuit 321. The feedback signal 317a is obtained, for example, by comparing the measured value 324 with a reference value. The feedback signal 317a is provided to the control circuit 314, and the control circuit 314 is arranged to control the operation of the power converter 313, and in particular the rate of change of the output voltage of the power converter 313, based on the value of the feedback signal 317a.

[0028] The second feedback signal 317b in Figure 3 is similar to a feedback signal of prior art, such as feedback signal 17 in Figure 1. Typically, the feedback signal 317b is based on a measurement of a current provided to a light source connected to the driver output 312. The measurement can be a measurement of a current passing through the light source, or a measurement proportional to or related to a current passing through the light source. A signal 325 indicative of the measured current is provided to a feedback circuit 316b. Typically, the value of the signal 325 related to a current provided to a light source is compared to a reference value, which may be provided either externally to the feedback circuit 316b or which may internal to the feedback circuit 316b. The feedback circuit 316b is arranged to provide a feedback signal 317b to the control circuit 314 based on the comparison of the value of the signal 325 and the reference value. The control circuit 314 is arranged to control the operation of the power converter 313 based on the value of the feedback signal 317b. In particular, based on the value of the feedback signal 317b, the control circuit is arranged to maintain the current provided to the light source connected to the driver output 312 at a constant level. The external or internal reference value of the feedback circuit 316b is selected such that the constant level of the current corresponds to a predetermined or selected target current.

[0029] In the embodiment of Figure 3, the control circuit 314 receives two feedback signals, a feedback signal 317a related to rate of change of the output voltage of the power converter 313 and a feedback signal 317b related to the current provided to a light source connected to the driver output 312. During a start-up phase, when the output voltage of the power converter 313 is being increased towards the threshold voltage of the light source connected to the driver output 312, essentially no current is passing through the light source. Hence, the feedback signal 317b related to the current passing through the light source would indicate a need to significantly increase the output of the power converter 313 in order to reach a target value of the current. On the other hand, feedback signal 317a, related to the rate of change of the output voltage of the power converter 313 would aim to limit the rate at which the output voltage of the power converter 313 is allowed to increase, simultaneously limiting also the current provided to the light source connected to the driver output 312. Both signals, however, indicate a need to increase the output of the power converter, and the control circuit 314 needs to follow the one that is more restrictive, namely the feedback signal 317a limiting the rate at which the requested increase in output voltage of the power converter 313 is allowed to take place.

[0030] During steady-state operation, when a light source connected to the driver output 312 is providing light and where both the output voltage of the power converter 313 and the current provided to the light source connected to the driver output 312 remain essentially constant, the feedback signal 317a related to the rate of change of the output voltage of the power converter 313 would indicate a negligible rate of change in the output voltage and hence would not cause the control circuit 314 to limit the output of the power converter 313. Any small variations in the current provided to the light source connected to the driver output 312 would cause also variations in the corresponding feedback signal 317b and therefore would cause the control circuit 314 to adjust the operation of the power converter 313 in a manner that aims to return the current provided to the light source to its target value.

[0031] It is possible that during steady-state operation, an adjustment requiring considerable increase in the output voltage of the power converter 313 takes place. This might be due to, for example, a sudden increase in the threshold voltage of the light source connected to the driver output 312 because of an additional LED being activated in a LED string of the light source. However, the rate of change of the output voltage of the power converter 313 will be measured by the limiting circuit 321. The rate of change is then relayed to the feedback circuit 316a in a form of measured value 324 and thus the feedback circuit 316a will provide a feedback signal 317a to the control circuit 314 to limit the rate of change of the output voltage of the power convert 313.

[0032] Another embodiment of the invention is illustrated in Figure 4. In the embodiment of Figure 4, power input 411, power converter 413, output circuit 423, limiting circuit 421, measured value 424, control signal 418 and driver output 412 are as described in connection with corresponding parts of Figures 2 and 3. The difference between the embodiment of Figure 4 compared to that of Figure 3 is that in the embodiment of Figure 4, only one feedback signal 417 is provided to the control circuit 414, whereas in the embodiment of Figure 3, two feedback signals 317a, 317b are provided.

[0033] In the embodiment of Figure 4, a signal 425 related to a current provided to a light source connected to the driver output 412 is combined with the measured value 424 indicative of the rate of change of the output voltage of the power converter 413, and the combined signal is provided to the feedback circuit 416. In an alternate variation of the embodiment, both signal 425 and the measured value 424 are provided to the feedback circuit 416, and the combining of the two is performed within the feedback circuit 416. In both cases, the feedback circuit 416 provides one feedback signal 417 to the control circuit 414, wherein the value of the feedback signal 417 is based both on signal 425 related to a current provided to a light source connected to the driver output 412 and on the measured value 424 indicative of the rate of change of the output voltage of the power converter 414. The combining of the signal 425 related to a current provided to a light source and the measured value 424 indicative of the rate of change of the output voltage of the power converter 413 is performed such that the feedback signal 417 is dominated by the signal which is more restrictive. In other words, the signal which is more restrictive may determine the value of the feedback signal or it may limit the value of the feedback signal. In practice, during start-up phase when the output voltage of the power converter 413 is being increased towards a threshold voltage of a light source connected to the driver output 412, the measured value 424 indicative of the rate of change of the output voltage of the power converter 413 will dominate the feedback signal. During steady-state operation, when a light source connected to the driver output 412 is providing light, the signal 425 related to a current provided to the light source will dominate the feedback signal.

[0034] Based on the feedback signal 417, the control circuit 414 can control the power converter 413 such that the rate of change of the output voltage of the power converter 413 does not exceed a maximum allowed rate of change, and, during steady state operation, the current provided to a light source connected to the driver output 412 remains essentially constant.

[0035] Figure 5 illustrates an exemplary limiting circuit 521 and feedback circuit 516 in a driver device, such as driver devices 210, 310, or 410 described earlier with reference to Figures 2, 3 and 4, respectively. The limiting circuit 521 is connected to the converter output 513b. V_{CONV} represents the output voltage of a power converter comprised in the driver device. The converter output 513b is typically formed of two nodes having a potential difference which corresponds to voltage V_{CONV}. Thus, one of the nodes has a higher potential than the other one, and therefore the nodes may be named a high potential node and a low potential node. The potential at the low potential node is typically the circuit ground on the output side of the converter.

[0036] The exemplary limiting circuit 521 of Figure 5 comprises a capacitance C_L and a resistance R_L connected in series between the high potential node and the low potential node of the converter output 513b.

[0037] Preferably, the capacitance C_L and the resistance R_L are arranged in series such that the capacitance C_L is connected to the high potential node of the converter output 513b and the resistance R_L is connected to the low potential node of the converter output 513b. In other words, preferably a first terminal of capacitance C_L is coupled or connected to the high potential node of the converter output 513b, a second terminal of capacitance C_L is coupled or connected to a first terminal of resistance R_L, and a second terminal of resistance R_L is coupled or connected to the low potential node of the converter output 513b.

[0038] The limiting circuit 521 is connected across the converter output 513b, and in the example of Figure 5, there are no components of an output circuit other than those considered to be comprised in the limiting circuit 521. Hence, in the exemplary embodiment of Figure 5, when a light source is connected to the driver output 512, the limiting circuit 521 is connected in parallel with the light source. However, depending on the further components of the output circuit, it can generally be stated that the limiting circuit 521 is located in a circuit branch that is parallel to a circuit branch comprising the driver output 512, and, therefore, also a light source connected to the driver output 512 when a light source is connected to the driver output 512.

[0039] It should be noted that when the voltage at the driver output 512 is less than the threshold voltage of a light source connected to the driver output 512, essentially no current is passing through the light source, and, consequently, essentially all current is passing through the limiting circuit 521. On the other hand, when the voltage at the driver output 512 is more than the threshold voltage of a light source connected to the driver output 512 and hence the voltage V_{CONV} is kept essentially constant, the capacitance C_L is charged to voltage V_{CONV} and practically no current is passing through the limiting circuit and essentially all the current is passing through the light source connected to the driver output 512.

[0040] When the output voltage V_{CONV} of the power converter is being increased during a start-up phase, the voltage over the limiting circuit 521 increases correspondingly. However, the capacitance C_L limits the charging current which passes through the limiting circuit 521 and charges the capacitance C_L. The current passing through the limiting circuit 521 is equal to the product of the capacitance C_L and the rate of change of the output voltage V_{CONV} of the power converter.

[0041] The measured value 524 indicative of the rate of change of the output voltage V_{CONV} of the power converter is extracted from a node between the capacitance C_L and the resistance R_L. The series connection of the capacitance C_L and the resistance R_L thus forms an RC differentiator, wherein the rate of change of the input voltage to the RC differentiator is known to correspond to the voltage over the resistance R_L at frequencies significantly lower than $1/(R_L \cdot C_L)$. Thus, the measured value 524 indicative of the rate of change of output voltage V_{CONV} of the power converter is obtained as the voltage over the resistance R_L.

[0042] The exemplary feedback circuit 516 of Figure 5 corresponds to the feedback circuit 216, 316a and 416 of Figures 2, 3 and 4. The feedback circuit 516 comprises a comparator, wherein the measured value 524 indicative of the rate of change of the output voltage V_{CONV} of a power converter is compared to a fixed reference value V_{REF}. The result of the comparison is provided as a feedback signal 517 to a control circuit controlling the operation of the power converter. Thus, when there is a need to increase the output voltage of the power converter, based on the feedback signal 517 the control circuit will control the power converter such that the rate of change of the output voltage of the power converter will not exceed the maximum allowed rate defined by the reference value V_{REF} together with the capacitance C_L and resistance R_L.

[0043] The reference value V_{REF} is selected to correspond to a maximum allowed rate of change of the output voltage V_{CONV} of the power converter. Preferably, the reference value V_{REF} is selected to correspond to the voltage at the node between the capacitance C_L and the resistance R_L at the maximum allowed rate of change of the output voltage V_{CONV} of the power converter, given by $V_{REF} = (R_L \cdot C_L) \cdot dV_{MAX}$, wherein dV_{MAX} is the maximum allowed rate of change of the output voltage V_{CONV} of the power converter.

[0044] In addition to the components shown, the feedback circuit 516 may comprise further components, such as a feedback loop from the output of the comparator to an input of the comparator, as is known in the art. Such a feedback loop may comprise, for example, a series connection of a resistance and a capacitance.

[0045] Figure 6 illustrates a second exemplary limiting circuit 621 and feedback circuit 616 in a driver device according to an embodiment of the invention. The feedback circuit 616 is similar to the feedback circuit 516 of Figure 5. The limiting circuit 621 comprises, in addition to the capacitance C_L and resistance R_L also present in the limiting circuit 521 of Figure 5, a second resistance R_Z. The second resistance R_Z is connected in series with the capacitance C_L and resistance R_L. Preferably, the resistance R_Z is connected between the high potential node of the converter output 613b and the capacitance C_L. In other words, a first terminal of resistance R_Z is connected to the high potential node of the converter output 613b and a second terminal of resistance R_Z is connected to a first terminal of capacitance C_L. The second terminal of capacitance C_L is connected to a first terminal of resistance R_L and a second terminal of resistance R_L is connected to the low potential node of the converter output 613b. A measured signal 624 indicative of the rate of change of the output voltage V_{CONV} of the power converter is obtained from a node between the second terminal of the capacitance C_L and the first terminal of the resistance R_L.

[0046] The operating principle of the limiting circuit 621 is similar to that of limiting circuit 521 of Figure 5. The contribution of the additional resistance R_Z is twofold.

[0047] On one hand, a certain value of V_{REF} may be easier to obtain than other values thus making it a preferred value of V_{REF}, or the feedback circuit 616 may have a fixed value for V_{REF}. Hence, when there are two resistances R_L, R_Z in series in the limiting circuit 621, the total resistance of the limiting circuit 621 is divided between the two resistances R_L, R_Z. Therefore, the value of R_L may be selected such that at maximum allowed rate of change of the output voltage V_{CONV} of the power converter, the measured value 624 indicative of rate of change of the output voltage V_{CONV} of the power converter corresponds to the preferred or fixed value of V_{REF}. This is due to the fact that the measured value 624 indicative of the rate of change of the output voltage V_{CONV} of the power converter is equal to the product of the resistance R_L and the current passing through the limiting circuit 621.

[0048] On the other hand, the second resistance R_Z helps reduce high-frequency noise in the measured value 624 indicative of the rate of change of the output voltage V_{CONV} of the power converter. This high-frequency noise may be due to, for example, high-frequency variations in the output voltage V_{CONV} of the power converter due to operation of the power converter or interference in the input power to the power converter. For high-frequency signals with frequencies above $1/(R_L \cdot C_L)$, the series connection of C_L and R_L acts as a high pass filter. By including an additional resistance R_Z, the gain of the limiting circuit 621 for high frequency signals can be reduced. The contribution of the high-frequency noise is therefore reduced in the feedback signal 617 provided to the control circuit and hence it will not affect significantly the control signals issued by the control circuit to the power converter.

[0049] Figure 7 illustrates a third exemplary limiting circuit 721 and feedback circuit 716 in a driver device 210, 310, 410 according to an embodiment of the invention. The feedback circuit 716 is similar to the feedback circuit 516 and 616 of Figures 5 and 6, respectively. In addition to capacitance C_L, resistance R_L and optional resistance R_Z, the limiting circuit comprises a protection diode D. The protection diode D is arranged in series with the other components of the limiting circuit 721. For example, the anode of the protection diode D may be connected to a high potential node of converter output 713b and the cathode of the protection diode D may be connected to a first terminal of either the optional resistance R_Z, as shown in Figure 7, or to a first terminal of the capacitance C_L. The second terminal of the optional resistance R_Z is connected to a first terminal of the capacitance C_L. The second terminal of the capacitance C_L is connected to a first terminal of the resistance R_L, and the second terminal of the resistance R_L is connected to the low potential node of the converter output 713b.

[0050] The protection diode D serves to protect the feedback circuit 716 from excessive negative voltages, which may occur, due to, for example, the light source connected to the driver output 712 being suddenly short-circuited. In the case of a short-circuit and in the absence of the protection diode D, the charge stored in capacitance C_L would be discharged via the short-circuited light source, thereby causing also high negative voltage at an input of the feedback circuit 716.

[0051] Figure 8 illustrates an example of an arrangement according to Figure 4, wherein a single feedback signal 417, 817 based on two measured values in the output circuit is provided to the control circuit 414. The feedback signal 817 is formed by the feedback circuit 816 based on a signal which consists of a combination of a measured value indicative of the rate of change of the output voltage V_{CONV} of a power converter and a signal indicative of a current provided to a light source connected to the driver output 812.

[0052] The resistance R_S is on a current path of a current flowing though the light source connected to the driver output 812. Hence, the voltage over the resistance R_S is proportional to the current flowing through the light source connected to the driver output 812. In an alternate embodiment, only a part of the current passing through the light source connected to the driver output 812 may be passing through the resistance R_S.

[0053] The driver output 812 has two terminals: a high terminal coupled to the high potential node of the output of the power converter, and a low terminal coupled to the low potential node of the output of the power converter.

[0054] In the embodiment of Figure 8, the resistance R_S is located between a low terminal of the driver output 812 and the low potential node of the converter output 813b. The resistance R_L is connected to a node between the low terminal of the driver output 812 and the resistance R_S. Therefore, resistance R_S is also in the current path of the current flowing in the limiting circuit 821.

[0055] The measured value 824 is obtained based on two separate measurements in the circuit: the rate of change of the output voltage V_{CONV} of the power converter and the current passing through a light source connected to the driver output 812. However, one measurement dominates at a time. During a start-up phase, when the output voltage V_{CONV} of the power converter is being increased towards the threshold voltage of a light source connected to the driver output 812, essentially no current is flowing through the light source connected to the driver output 812. Hence, the potential at the node where the measured value 824 is extracted depends on the current in the limiting circuit, which is determined by the rate of change of the output voltage V_{CONV} of the power converter. On the other hand, once the threshold voltage of the light source connected to the driver output 812 has been reached, the output voltage V_{CONV} of the power converter remains essentially constant, and hence the measured value indicative of the rate of change of the output voltage V_{CONV} of the power converter will remain essentially zero. Thus the potential at the node where the measured value 824 is extracted depends on the voltage over the resistance R_S, in other words, on the current passing through a light source connected to the driver output 812.

[0056] Figure 9 illustrates a third exemplary limiting circuit 921 and feedback circuit 916 in a driver device 210, 310, 410 according to an embodiment of the invention. The feedback circuit 916 is similar to the feedback circuit 516 and 616 of Figures 5 and 6, respectively. In addition to capacitance C_L, resistance R_L and optional resistance R_Z, the limiting circuit comprises a Zener diode D_Z. The Zener diode Dz is arranged in series with the other components of the limiting circuit 921. For example, the cathode of the Zener diode D_Z may be connected to a high potential node of converter output 913b and the anode of the Zener diode D_Z may be connected either to a first terminal of the optional resistance R_Z, as shown in Figure 9, or to a first terminal of the capacitance C_L. The second terminal of the optional resistance R_Z is connected to a first terminal of the capacitance C_L. The second terminal of the capacitance C_L is connected to a first terminal of the resistance R_L, and the second terminal of the resistance R_L is connected to the low potential node of the converter output 913b.

[0057] Because of the Zener diode D_Z, current will not flow in the limiting circuit 921 until the output voltage V_{CONV} of the power converter has risen above the Zener voltage of the Zener diode D_Z. Hence, the rate of change of the output voltage V_{CONV} of the power converter is not limited until the Zener voltage of the Zener diode D_Z is reached. Thus, due to the higher rate of change of the output voltage V_{CONV} of the power converter, the output voltage V_{CONV} of the power converter reaches the level of the Zener voltage faster than if the rate of change was limited by the limiting circuit 921.

[0058] Preferably, the Zener voltage of the Zener diode D_Z is significantly lower than the lowest threshold voltage of a light source connectable to the driver output 912 so that the limiting circuit 921 is able to prevent an overshoot of the voltage and current provided to the light source when the threshold voltage of the light source is reached.

[0059] The limiting circuit 921 may also comprise a protection diode D as described in connection of Figure 7. In such a case, the Zener diode and the protection diode D can be connected in series with each other and the rest of the limiting circuit 921.

[0060] The operations, procedures and/or functions described hereinbefore in context of the driver device may also be expressed as steps of a method implementing the corresponding operation, procedure and/or function. The method may be arranged to control the operation of a power converter in a driver device for a light source.

[0061] The method comprises creating a voltage feedback signal proportional to a rate of change of an output voltage of a power converter. The voltage feedback signal is preferably based on a measured value at converter output indicative of the rate of change of the output voltage at the converter output, as described in relation to embodiments of Figures 2 to 8. Thus, the voltage feedback signal of the method corresponds to feedback signals 217, 317a, 417, 517, 617, 717, 817 illustrated in Figure 2, 3, 4, 5, 6, 7 and 8, respectively.

[0062] The method further comprises providing the voltage feedback signal as a feedback signal to a control circuit which controls the operation of the power converter. The method 900 also comprises issuing control commands to the power converter based on the feedback signal provided to the control circuit. The control commands correspond to control commands 218, 318, 418 illustrated in Figures 2, 3 and 4, respectively.

[0063] In a second method according to an embodiment of the invention, also feedback information relating to an output current is provided. In addition to the actions of the first method, the second method comprises measuring a current provided to a light source connected to the driver device, wherein the current is provided by the driver device. The current may be measured by a resistor arranged on a current path passing through the light source, as illustrated in Figure 8 with resistance R_S. The second method further comprises providing a current feedback signal based on the measured current to the control circuit which controls the operation of the power converter. The second method also comprises issuing control commands to the power converter based on the current feedback signal provided to the control circuit.

[0064] A third method according to an embodiment of the invention comprises combining the voltage feedback signal and the current feedback signal of the second method into a feedback signal. The third method further comprises providing the feedback signal to the control circuit which controls the operation of the power converter. The third method also comprises issuing control commands to the power converter based on the feedback signal provided to the control circuit.

[0065] Preferably, in the third method, the voltage feedback signal is arranged to dominate the feedback signal during a start-up phase of the driver device, and the current feedback signal is arranged to dominate the feedback signal during stable operation, in other words, when a light source connected to the driver output is providing light.

[0066] A method according to an embodiment of the invention may also comprise filtering high-frequency components from the voltage feedback signal.

[0067] An additional benefit of the invention is that it enables providing essentially two measurements from the output circuit to the control circuit with only one signal. The measured value indicative of the rate of change of the output voltage of the power converter already carries also information relating to the current provided to a light source connected to the driver output of the driver device. According to some embodiments of the invention, the current provided to a light source connected to a driver output is separately measured but a combined signal is provided to the control circuit.

Claims

1. A driver device for providing electric current to a light source connectable to a driver output of the driver device, comprising:

   - a power converter arranged to provide an output voltage at a converter output, which converter output is coupled to the driver output via an output circuit,
   - a control circuit arranged to control the operation of the power converter,
   - a feedback circuit arranged to provide to the control circuit a feedback signal based on at least one measured value in the output circuit, wherein the control circuit is arranged to control the operation of the power converter based on the value of the feedback signal, and
   - a limiting circuit coupled to the converter output and configured to provide a measured value to the feedback circuit, wherein the measured value is indicative of the rate of change of the output voltage of the power converter.

2. A driver device according to claim 1, wherein

   - the output circuit comprises a current measurement part arranged to provide a signal related to a measured current at the driver output and
   - a feedback circuit is arranged to provide a feedback signal to the control circuit based on the signal related to a measured current at the driver output.

3. A driver device according to claim 2, wherein the feedback signal is a combination of the measured value provided by the limiting circuit and the signal related to a measured current at the driver output.

4. A driver device according to claim 3, wherein the measured value provided by the limiting circuit is arranged to dominate the feedback signal during start-up phase of the driver device and the signal related to measured current at the driver output is arranged to dominate the feedback signal when the light source is providing light.

5. A driver device according to claim 2, wherein the control circuit is arranged to receive the feedback signal related to a measured current as a separate signal from the feedback signal based on a measured value indicative of the rate of change of the output voltage of the power converter.

6. A driver device according to claim 5, wherein the measured value provided by the limiting circuit is arranged to determine the response of the control circuit during start-up phase of the driver device and the signal related to measured current at the driver output is arranged to determine the response of the control circuit when the light source is providing light.

7. A driver device according to any previous claim, wherein the limiting circuit comprises a capacitance, which is coupled to receive electric charge from the converter output voltage, wherein the value of the capacitance determines the rate at which the converter output voltage is controlled to increase based on the feedback signal.

8. A driver device according to any previous claim, wherein the limiting circuit comprises a resistance in a current path from converter output via limiting circuit to output circuit, to limit the current through the capacitance.

9. A driver device according to any of the previous claims, wherein the limiting circuit comprises a protection diode.

10. A driver device according to any of the previous claims, wherein the limiting circuit comprises a Zener diode.

11. A driver device according to any previous claim, wherein the limiting circuit comprises a resistance connected in series with the capacitance to limit feedback gain for high frequency signals.

12. A driver device according to any previous claim, wherein the power converter is a switched mode power converter comprising one or more switches, and the control circuit is arranged to control the operation of the one or more switches.

13. A driver device according to any previous claim, wherein the power converter is a multistage power converter.

14. A method of controlling a power converter in a driver device for a light source, comprising:

- creating a voltage feedback signal proportional to a rate of change of an output voltage of the power converter,
- providing the voltage feedback signal as a feedback signal to a control circuit which controls operation of the power converter, and
- issuing, based on the feedback signal provided to the control circuit, control commands to the power converter.

15. A method according to claim 14, further comprising:

- measuring a current provided to a light source by the driver device,
- providing a current feedback signal based on the measured current to the control circuit which controls operation of the power converter, and
- issuing, based on the current feedback signal provided to the control circuit, control commands to the power converter

16. A method according to claim 15, further comprising:

- combining the voltage feedback signal and the current feedback signal into a feedback signal
- providing the feedback signal to a control circuit which controls operation of the power converter, and
- issuing, based on the feedback signal provided to the control circuit, control commands to the power converter.

17. A method according to any of claims 14 to 16, wherein the voltage feedback signal dominates the feedback signal during start-up phase of the driver device and the current feedback signal dominates the feedback signal when the light source is providing light.

18. A method according to any of claims 14 to 17, comprising also filtering high-frequency components from the voltage feedback signal.

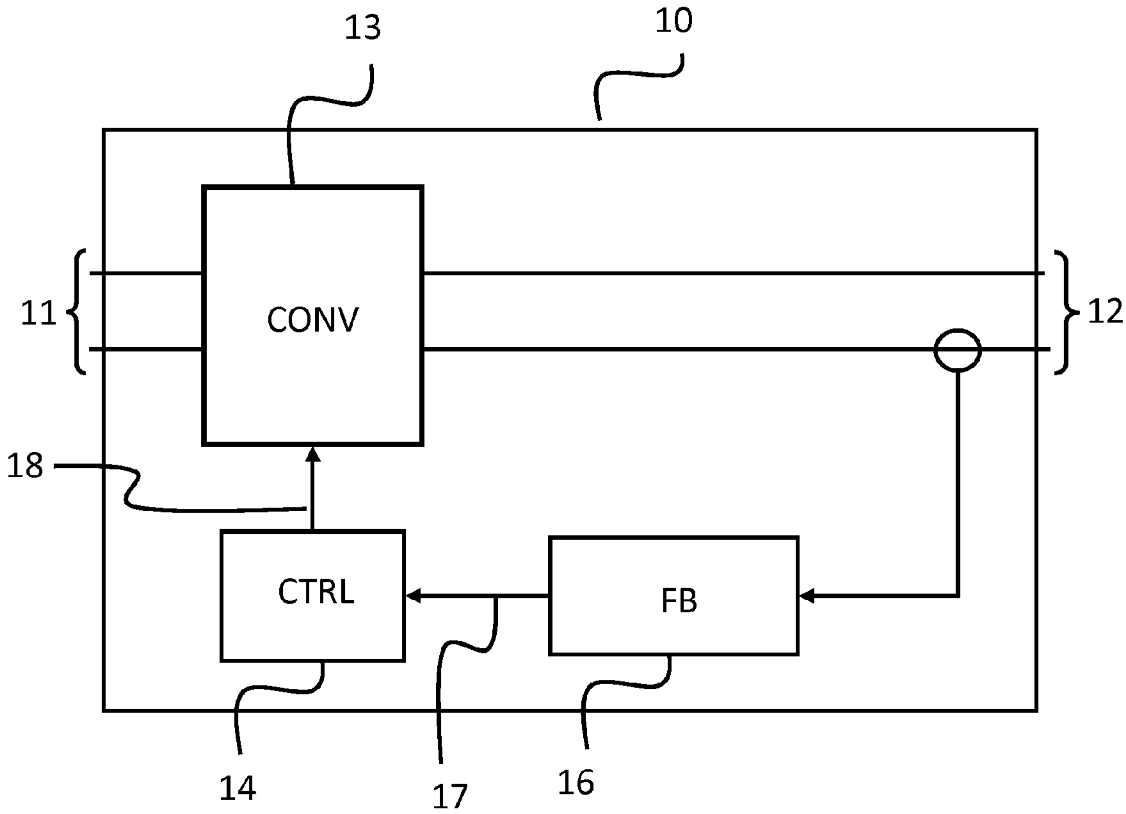

Figure 1

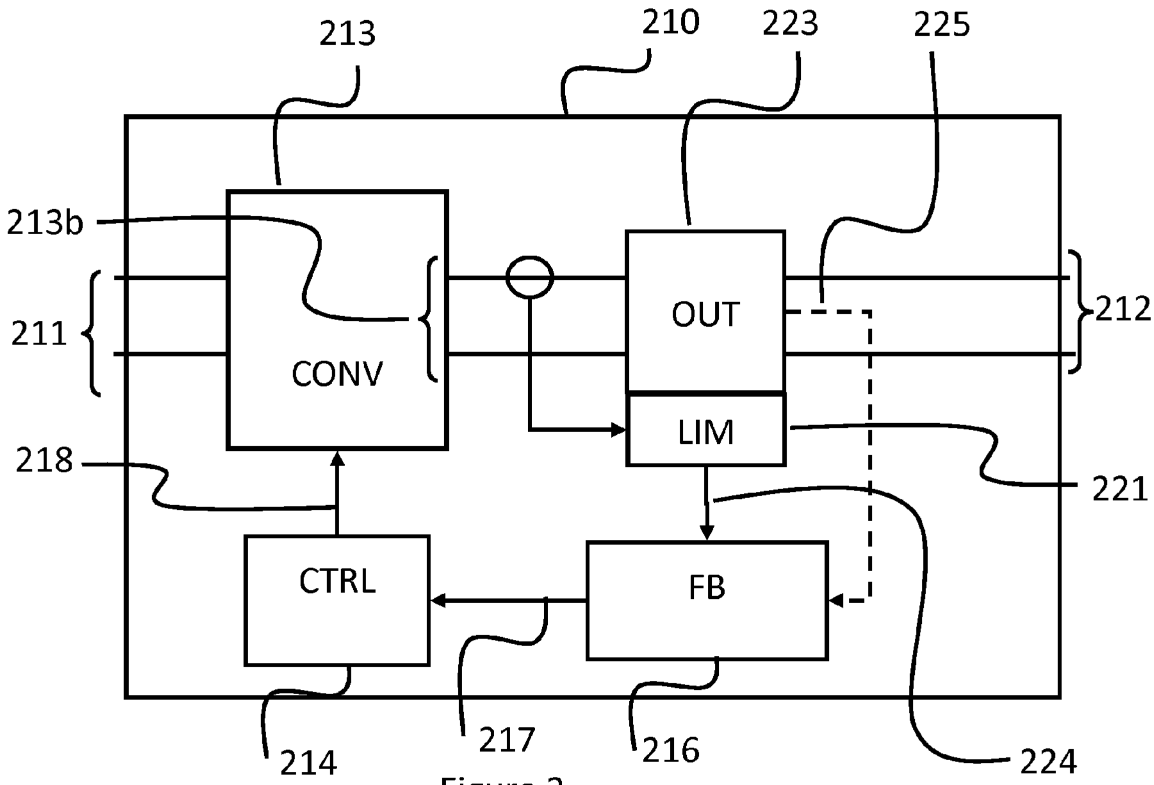

Figure 2

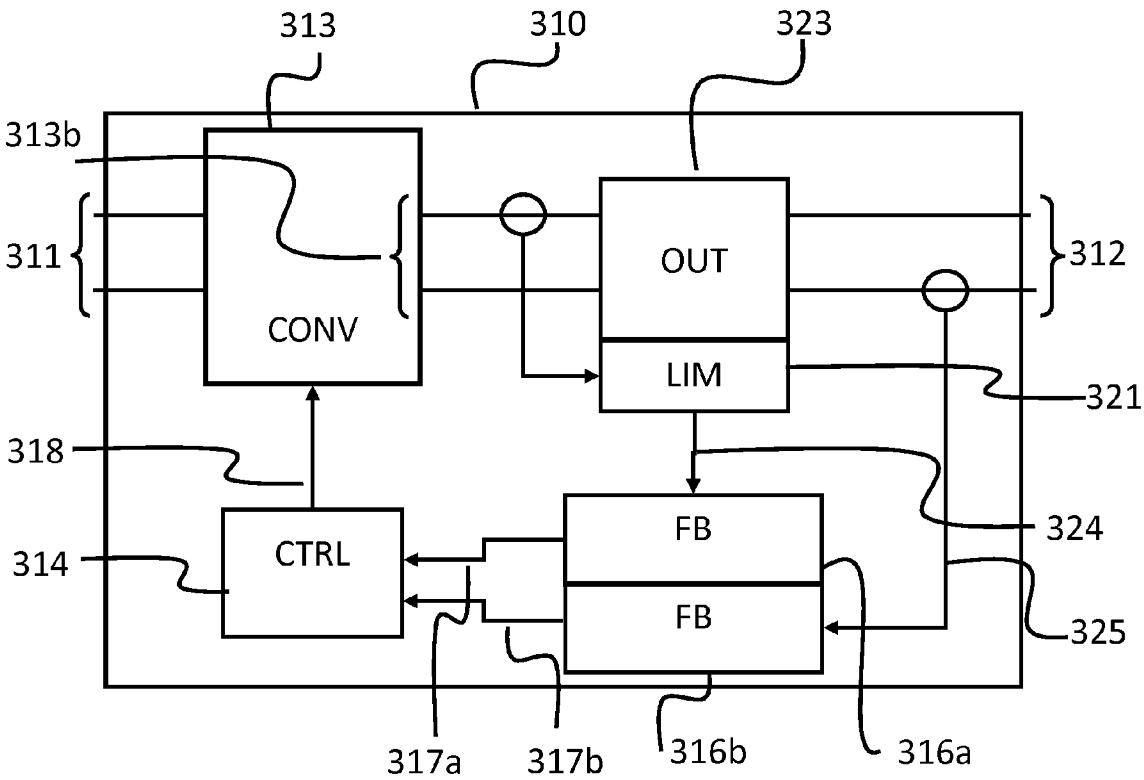

Figure 3

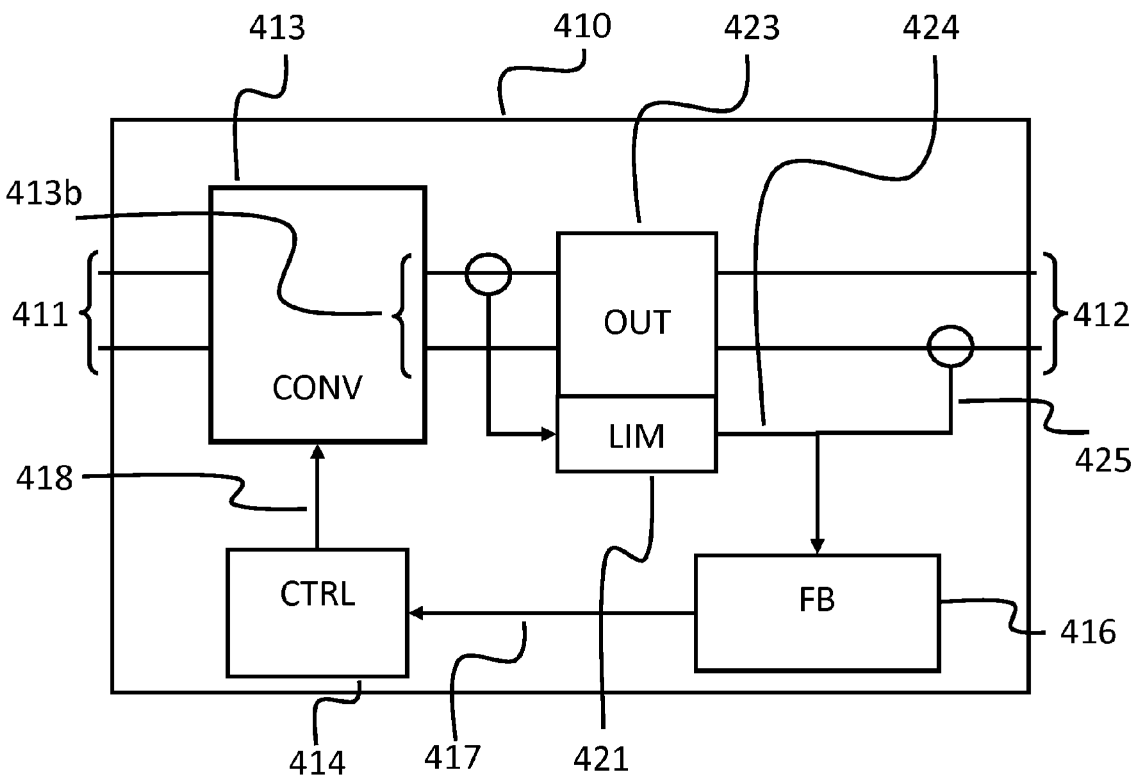

Figure 4

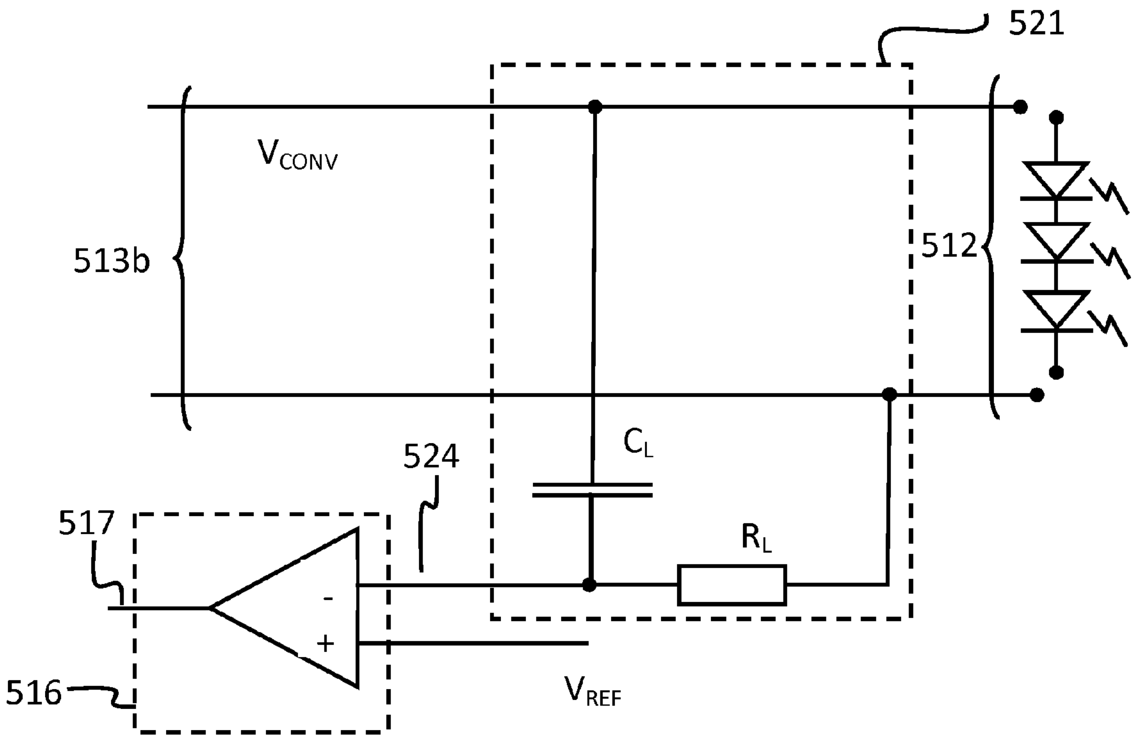

Figure 5

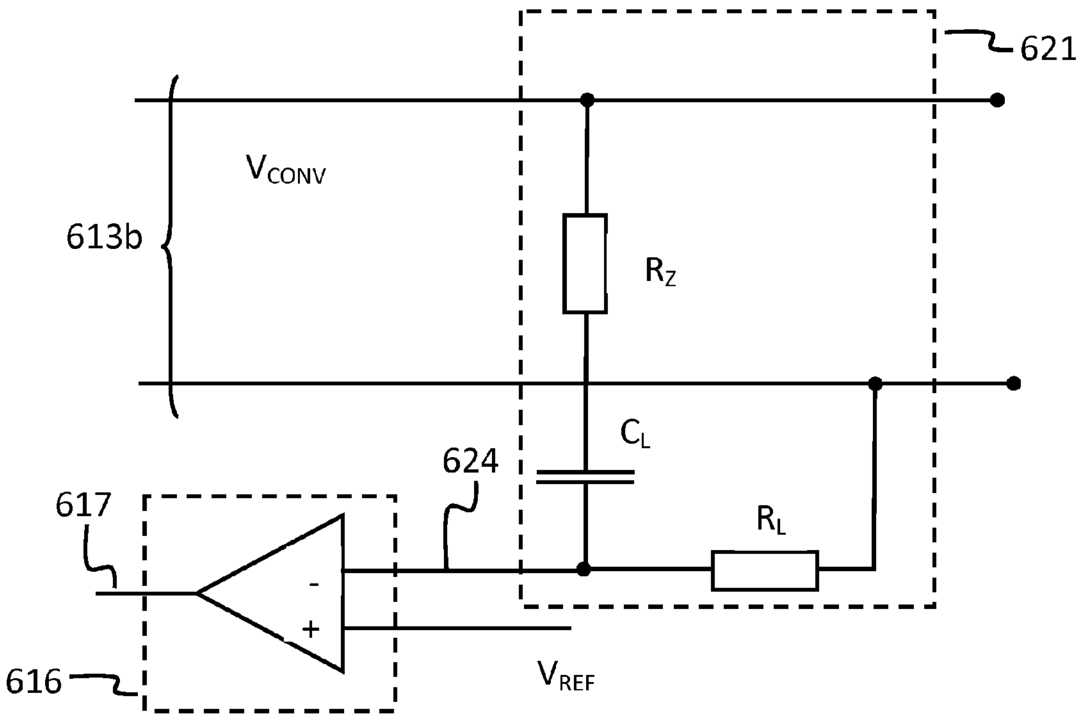

Figure 6

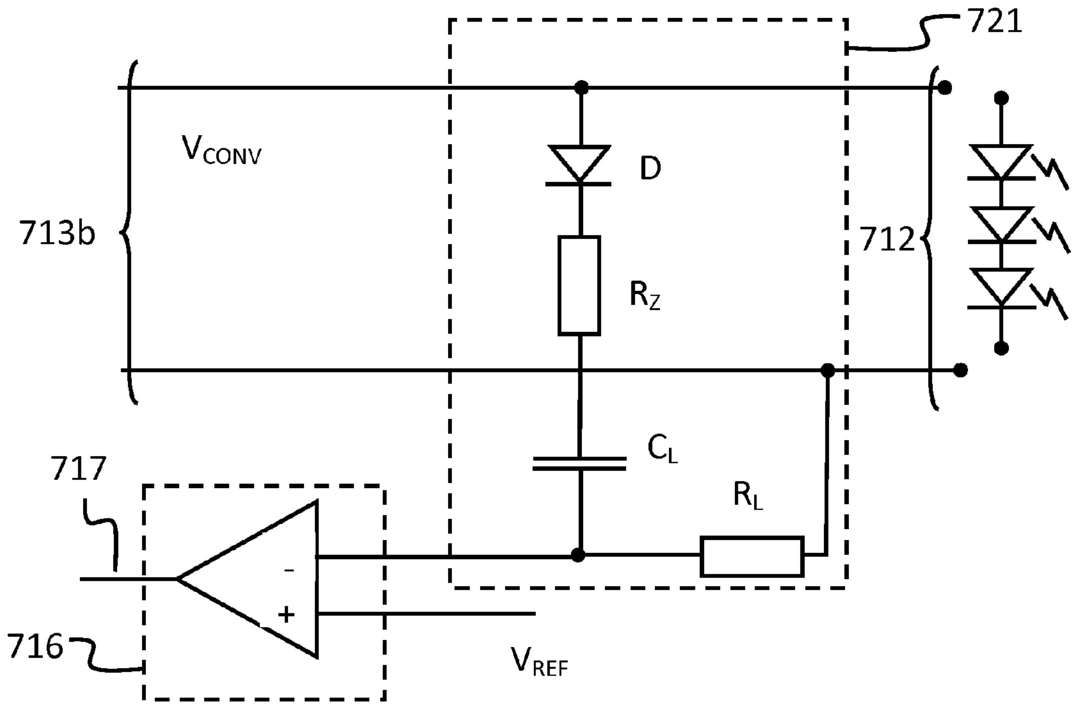

Figure 7

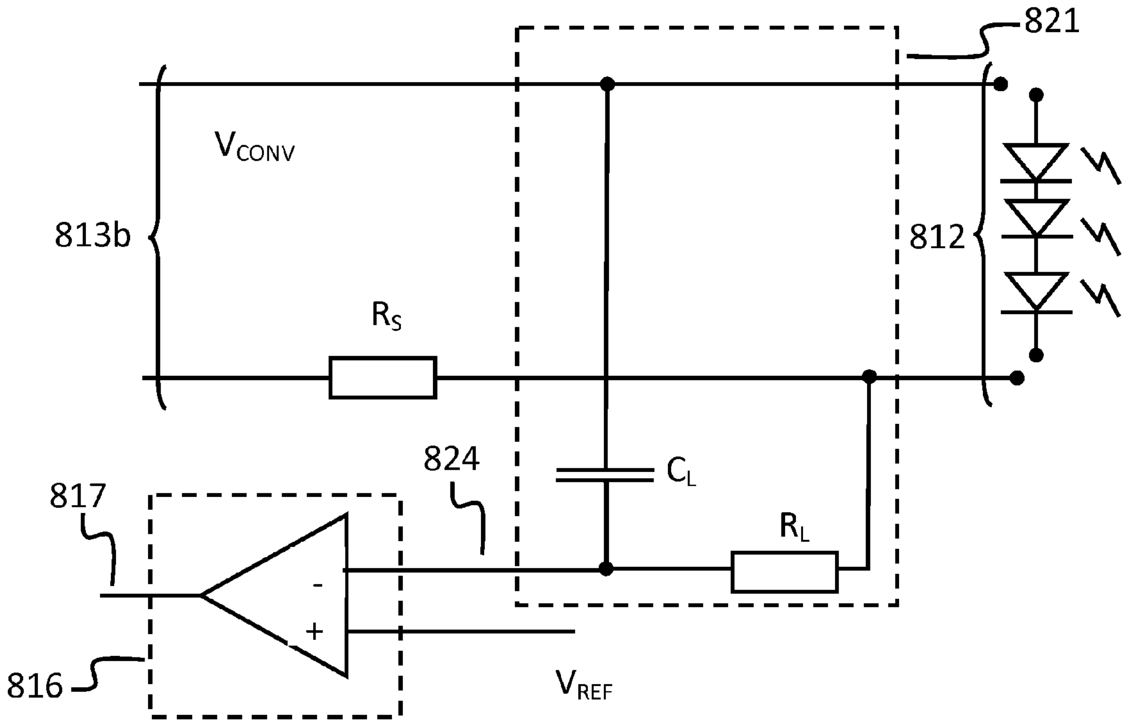

Figure 8

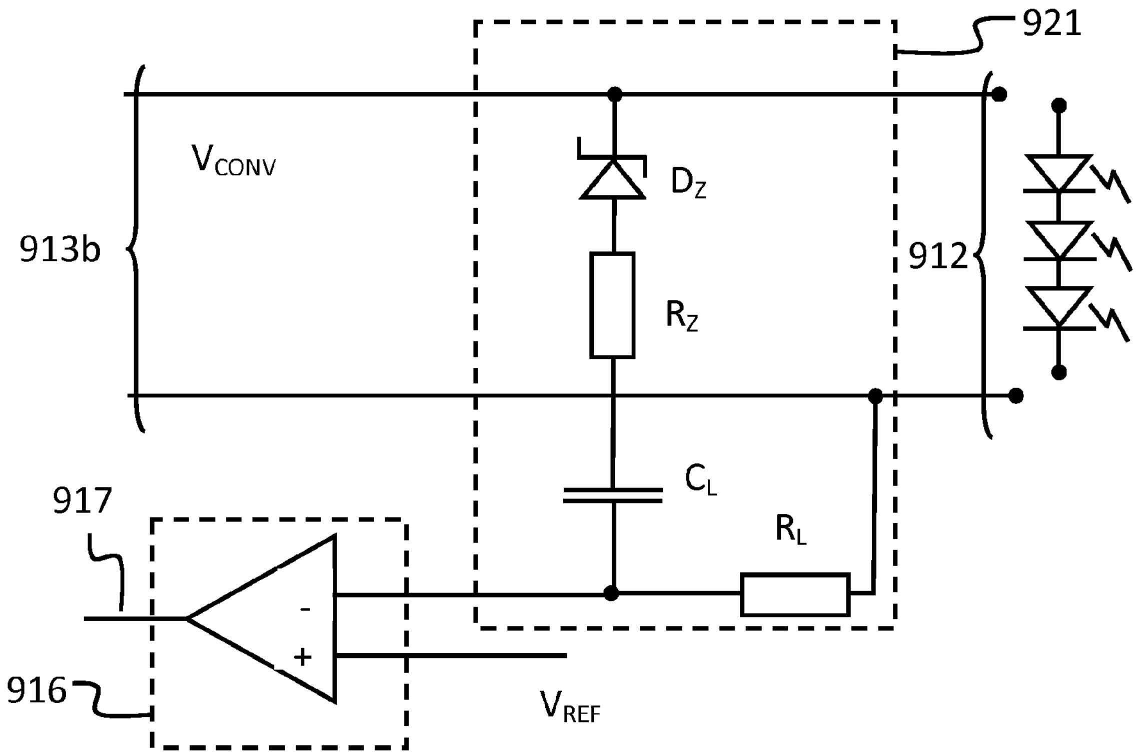

Figure 9

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EUROPEAN SEARCH REPORT

Application Number
EP 16 18 8309

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	WO 2006/046207 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; TRIPATHI AJAY [US]; UPADHYAY ANAN) 4 May 2006 (2006-05-04) * page 1, line 6 - page 8, line 27; figures 1,2 * -----	1-18	INV. H05B33/08
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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	14 February 2017	Burchielli, M

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