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(54) **Method and apparatus for dimming a light source**

(57) The invention provides an apparatus (1) and a method for dimming a light source (2) which transforms with a transformation curve (TC) adapted to compensate

a predetermined eye-sensitivity-curve (ESC) a varying input amplitude dimmer control signal (IADCS) provided by a dimmer (3) into an output amplitude dimmer control signal (OADCS) applied to said light source (2).

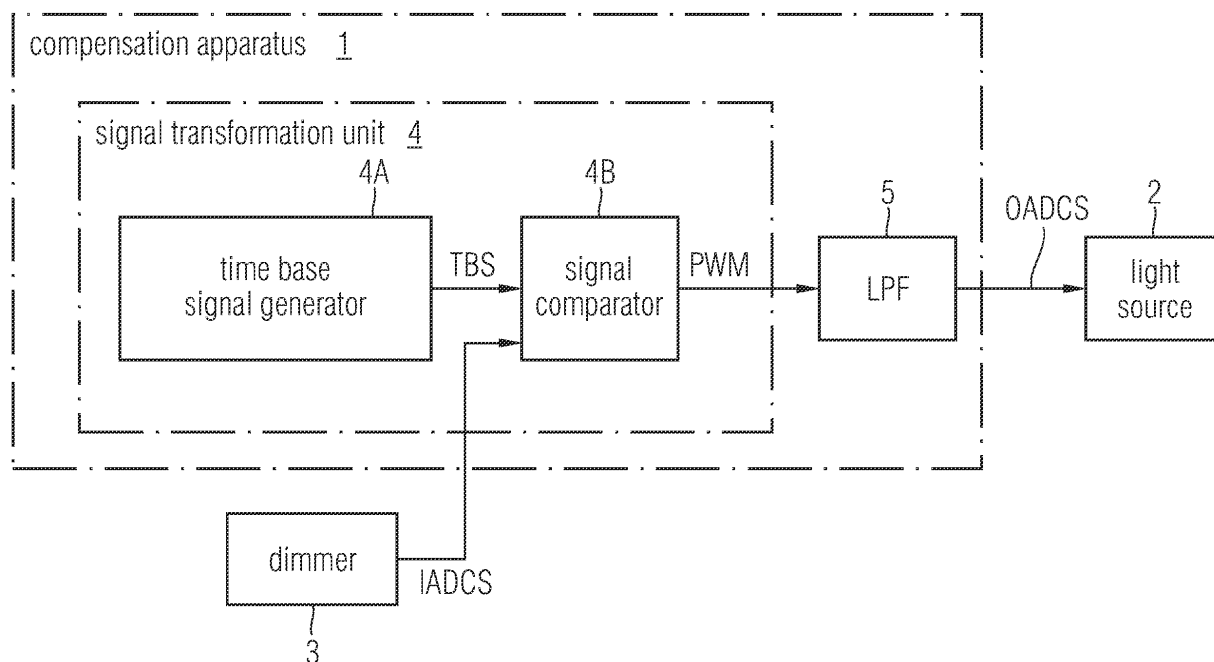


Fig. 1

Description

[0001] The invention relates to an apparatus and a method for dimming a light source in particular a linear light source comprising at least one light emitting diode LED or compact fluorescent lamp (CFL).

[0002] Conventional lamps such as incandescent lamps which transform heat into radiated light show a particular behaviour when dimmed by means of a dimmer such as a wall dimmer provided in a wall of a building. When reducing the light intensities of a light source, i.e. when dimming the light, the light intensity of the emitted light is reduced. At low light intensity the human eye is more sensitive for light variation. The eye-sensitivity of a human eye can be approximated by a logarithmic curve. With a linear light source doubling the amplitude of a control signal applied to this linear light source causes a doubling of the emitted light seen by the human eye. With a conventional incandescent lamp when a user entering for example a room within a building actuates a dimmer for example by turning a knob or moving sliding means of the dimmer for example halfway the user expects that the light level within the room will be reduced also by about 50%. With a conventional incandescent lamp transforming heat into emitting light the sensation of the user is indeed that the light level in the room is inherently about the half light level when comparing it with a light level before actuating the dimmer. Because of the logarithmic eye-sensitivity of the human eye if a conventional dimmer controlling a linear light source comprising for example light emitting diodes is actuated by a user entering a room for example halfway the caused light level which is perceived by the user in the room has a far too high light level.

[0003] Accordingly, it is an object of the present invention to provide an apparatus and a method for dimming a linear light source, wherein a linear variation of a user actuated dimmer controlling a linear light source causes a corresponding light level sensation for the eyes of the actuating user. This object is achieved by an apparatus comprising the features of claim 1.

[0004] The invention provides an apparatus for dimming a light source which transforms with a transformation curve adapted to compensate a predetermined eye-sensitivity curve a varying input amplitude dimmer control signal provided by a dimmer into an output amplitude dimmer control signal applied to said light source.

[0005] The light source can be formed by a linear light source which can comprise at least one light emitting diode LED or a compact fluorescent lamp CFL.

[0006] In a possible embodiment of the apparatus according to the present invention the transformation curve provided by the apparatus is formed by a transformation curve having an exponential shape adapted to compensate a logarithmic eye-sensitivity-curve of a human eye.

[0007] In a possible embodiment of the apparatus according to the present invention the apparatus comprises a signal transformation unit which transforms the varying input amplitude dimmer control signal into a pulse with modulated PWM-signal.

[0008] In a possible embodiment of the apparatus according to the present invention the apparatus further comprises a low pass filter which transforms the pulse with modulated PWM signal into the output amplitude dimmer control signal applied to the light source.

[0009] In a possible embodiment of the apparatus according to the present invention the signal transformation unit comprises a time base signal generator for generating a time base signal. In a possible embodiment of the apparatus according to the present invention the signal transformation unit further comprises a signal comparator which compares the generated time base signal with the varying input amplitude dimmer control signal to provide the pulse width modulated (PWM)-signal applied to the low pass filter.

[0010] In a possible embodiment of the apparatus according to the present invention the time base signal generator comprises at least one capacitor connected at a node via a resistor and/or a current source to a predetermined supply voltage of said signal transformation unit.

[0011] In a possible embodiment of the apparatus according to the present invention the voltage at the node of said time base signal generator is applied to a positive input of a voltage comparator having a negative input connected to a predetermined reference voltage close to the supply voltage.

[0012] In a possible embodiment of the apparatus according to the present invention an output of the voltage comparator activates means to precharge the capacitor of the time base signal generator to a start voltage causing the time base signal generator to act as an oscillator which generates a saw tooth signal with an exponential shape having a minimum voltage value equal to the start voltage and a maximum voltage level equal to the predetermined reference voltage.

[0013] In a possible embodiment of the apparatus according to the present invention the node of the time base signal generator is connected to a first input of the signal comparator which compares a voltage level of said node with a voltage level of the varying input amplitude dimmer control signal applied to a second input of the signal comparator to provide the pulse width modulated (PWM)-signal at an output of the signal comparator.

[0014] In a possible embodiment of the apparatus according to the present invention the signal comparator is supplied with a voltage difference having as a high level the upper supply voltage forming a maximum level of the transformation curve and having as a low level the lower supply voltage forming a minimum level of the transformation curve.

[0015] In a possible embodiment of the apparatus according to the present invention a ratio between a signal level of

the varying input amplitude dimmer control signal and the predetermined supply voltage of the signal transformation unit corresponds to a light level provided by the light source.

[0016] In a possible embodiment of the apparatus according to the present invention the varying input amplitude dimmer control signal is a voltage dimmer control signal comprising a voltage level corresponding to a phase cut of a TRIAC transistor wall dimmer providing the voltage dimmer control signal.

[0017] In a possible embodiment of the apparatus according to the present invention the varying input amplitude dimmer control signal is a linear signal provided by an adjustable resistor divider that is connected to the supply voltage to generate an adjustable output voltage as the linear varying input amplitude dimmer control signal.

[0018] In a possible embodiment of the apparatus according to the present invention the low pass filter is a low pass filter of first or higher order comprising a predetermined corner frequency.

[0019] In a possible embodiment the low pass filter is a passive low pass filter.

[0020] In an alternative embodiment the low pass filter is an active low pass filter.

[0021] In a possible embodiment of the apparatus according to the present invention the corner frequency of the low pass filter is adapted to be low enough so that a spread of a switching frequency of the pulse width modulated (PWM)-signal and a spread of the corner frequency does not have an impact on the transformation curve.

[0022] The invention further provides a light emitting device comprising an apparatus for dimming a light source of said light emitting device wherein said apparatus transforms with a transformation curve adapted to compensate a predetermined eye-sensitivity-curve a linear varying input amplitude dimmer control signal provided by a dimmer into an output amplitude dimmer control signal applied to the light source of said light emitting device.

[0023] In a possible embodiment of the light emitting device according to the present invention the light source of the light emitting device is formed by a linear light source comprising at least one light emitting diode LED or a compact fluorescent lamp CFL or any other linear light source.

[0024] In a possible embodiment of the light emitting device according to the present invention the light emitting device further comprises a mains-low-pass-filter which transforms a phase cut dimmer control signal provided by the dimmer into the linear varying input amplitude dimmer control signal.

[0025] The invention further provides a method for dimming a light source comprising the features of claim 17.

[0026] The invention provides a method for dimming a light source wherein a varying input amplitude dimmer control signal provided by a dimmer is transformed with a transformation curve adapted to compensate a predetermined eye-sensitivity-curve into an output amplitude dimmer control signal applied to the light source.

[0027] The method according to the present invention can be used for dimming a linear light source comprising light emitting diodes or compact fluorescent lamps.

[0028] In the following embodiments of the apparatus and method for dimming a light source are described with reference to the enclosed figures in more detail.

Fig. 1 shows a block diagram of a possible embodiment of an apparatus for dimming a light source according to the present invention;

Fig. 2 shows a circuit diagram for illustrating a possible embodiment of a signal transformation unit as employed by the apparatus for dimming a light source as shown in Fig. 1;

Fig. 3A, 3B show signal diagrams for illustrating a possible embodiment for a signal transformation unit as employed by an apparatus for dimming a light source according to a possible embodiment;

Fig. 4 shows a diagram for illustrating the functionality of an apparatus for dimming a light source according to the present invention;

Fig. 5 shows a further diagram for illustrating the functionality of an apparatus for dimming a light source according to possible embodiments of the present invention;

Fig. 6 shows a block diagram of a possible embodiment of a light emitting device according to the present invention;

Fig. 7 shows a signal diagram for illustrating a functionality of a light emitting device according to a possible embodiment.

Fig. 8 shows a diagram of a circuit generating a current as employed by a time base signal generator used by the apparatus according to the present invention.

[0029] As can be seen in Fig. 1 an apparatus 1 according to a possible embodiment of the present invention is provided for dimming a light source 2, in particular a linear light source such as a light emitting diode LED for a compact fluorescent lamp CFL. The apparatus 1 transforms a varying input amplitude dimmer control signal IADCS provided by a dimmer 3 into an output amplitude dimmer control signal OADCS applied to the light source 2. The apparatus 1 provides a transformation curve to compensate a predetermined eye-sensitivity-curve of a human eye of a user. By means of this transformation curve the varying input amplitude dimmer control signal IADCS provided by the dimmer 3 is transformed by the apparatus 1 into the output amplitude dimmer control signal OADCS applied by the apparatus 1 to the light source 2. In the shown embodiment of Fig. 1 the apparatus 1 forms a separate device connected between the dimmer 3 and the light source 2. In an alternative embodiment the apparatus 1 can be integrated in the dimmer 3. In a still further embodiment the apparatus 1 can be integrated in a light emitting device or lamp comprising the light source 2.

[0030] As can be seen in Fig. 1 the apparatus 1 comprises a signal transformation unit 4 and a low pass filter 5. The signal transformation unit 4 comprises a time base signal generator 4A generating a time base signal TBS to a signal comparator 4B comparing the time base signal TBS with the varying input amplitude dimmer control signal IADCS provided by the dimmer 3. The output of the signal comparator 4 is formed by a pulse width modulated PWM-signal supplied to the low pass filter 5. The signal transformation unit 4 transforms the varying input amplitude dimmer control signal IADCS into the pulse width modulated PWM-signal applied to the low pass filter 5 which transforms the received pulse width modulated PWM-signal into the output amplitude dimmer control signal OADCS applied by the apparatus 1 to the light source 2.

[0031] Fig. 2 shows a possible embodiment of the signal transformation unit 4 within the apparatus 1. In the shown implementation of Fig. 2 the time base signal generator 4A comprises at least one capacitor C connected at a node N via a resistor R to a predetermined supply voltage V_{DD} . The time base signal generator further comprises in a possible embodiment a current source supplying the node N with an adjustable supply current I_s . The voltage at the node N of the time base signal generator 4A as shown in Fig. 2 is applied to a positive input of a voltage comparator which can be formed by an operation amplifier opAmp. The voltage comparator comprises a negative input which is connected to a predetermined reference voltage V_{stop} ($V_{stop} > V_{start}$) which can be close to the supply voltage V_{DD} of the signal transformation unit 4. The output of the voltage comparator controls means for precharging the capacitor C of the time base signal generator 4A to a start voltage V_{Start} . The means for precharging the capacitor C is formed in the shown embodiment by a switch SW being controlled by the output of the operational amplifier opAmp. The time base signal generator 4A as shown in Fig. 2 acts an oscillator which generates a saw tooth signal with an exponential shape as a time base signal TBS having a minimum voltage value equal to the start voltage V_{Start} and a maximum voltage V_{stop} being equal or close to the predetermined reference voltage.

[0032] Fig. 3A shows a signal diagram for illustrating the time base signal TBS generated by a time base signal generator 4A as shown in Fig. 2. In the shown embodiment the generated time base signal TBS is a periodically signal and in particular a saw tooth signal with an exponential shape similar to a shark fin as shown in Fig. 3A. The exponential time base signal is generated by the time base signal generator 4A through charging the capacitor C by applying a voltage by means of the resistor R shown in Fig. 2.

[0033] The generated time base signal TBS is supplied to the signal comparator 4B which can be formed in the embodiment shown in Fig. 2 also by an operational amplifier opAmp. The signal comparator 4B compares the generated time base signal TBS with the varying input amplitude dimmer control IADCS to provide the pulse width modulated signal PWM supplied to the low pass filter 5. In the shown embodiment of Fig. 2 the node N of the time base signal generator 4A is connected to a first input of the signal comparator 4B which compares the voltage level at the node N with a voltage level of the varying input amplitude dimmer control signal IADCS applied to a second (negative) input of the signal comparator 4B to provide the pulse width modulated signal PWM at an output of the signal comparator 4B. As can be seen in Fig. 2 the signal comparator 4B is supplied with a voltage difference having as a high level the upper supply voltage forming a maximum of the transformation curve and having as a low level the lower supply voltage forming a minimum level of the transformation curve.

[0034] Fig. 3B shows a pulse width modulated PWM signal generated by the signal comparator 4B within the signal transformation unit 4. With the apparatus 1 according to the present invention the transformation curve TC is generated for transforming the input signal to the pulse width modulated PWM signal using a time base reference signal TBS having the exponential shape as shown in Fig. 3A. Consequently a linear varying input amplitude dimmer control signal IADCS is changed to a pulse width modulated PWM signal with an exponential varying duty cycle.

[0035] The time reference signal is transferred back to an amplitude signal through the low pass filter 5 thus providing an exponential transfer function or transformation curve TC for transforming the input signal to the output signal.

[0036] The low pass filter 5 of the compensation apparatus 1 integrates the pulse width modulated (PWM) signal:

$$V_{out} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} V_{PWM} \cdot dt \quad \begin{cases} KT < t < ton + KT & V_{PWM} = V_{max} \\ ton + KT < t < KT + T & V_{PWM} = V_{min} \end{cases} \quad (1)$$

[0037] The resulting transfer function or compensation curve provided by the apparatus 1 has an exponential shape to compensate a logarithmic eye-sensitivity-curve of a human eye. Accordingly, the transformation curve TC provided by the apparatus 1 is an inverse logarithmic curve having a small output voltage variation at a low input voltage and having a higher output voltage variation for larger input voltage.

[0038] In the embodiment of Fig. 2 the capacitor C of the time base signal generator 4A is charged with a current depending on the voltage $V_{DD} + I_S \times R$ and the resistance value of the resistor R thus creating an exponential capacitor voltage as an exponential time reference signal:

$$V_c(t) = (V_{DD} + I_S \cdot R) \cdot \left[1 - \left(1 - \frac{V_{start}}{V_{DD} + I_S \cdot R} \right) e^{\frac{-t}{RC}} \right] \quad (2)$$

[0039] The capacitor C of the time base signal generator 4A is charged to a predetermined end voltage level V_{Stop} . When the capacitor C reaches this end voltage level V_{Stop} the capacitor C is discharged to the starting voltage V_{Start} and the cycle starts again as shown in Fig. 3A. The stop voltage V_{Stop} determines the period T of the pulse width modulated PWM signal wherein the period T is the time in which the capacitor C is charged from the starting voltage V_{Start} to the stop voltage V_{Stop} . The stop voltage level V_{Stop} also determines the start point of the dimming curve, i.e. when no dimming is performed. The output signal of the signal comparator 4B is the pulse width modulated PWM signal which is a square wave signal having an amplitude comprising a low voltage level V_{min} and a high voltage level V_{max} and having a period of T as well as a duty cycle of ton/T . For the on-time ton the output voltage is V_{max} and for the off-time or remaining time the output voltage is V_{min} .

[0040] The average output voltage of the pulse width modulated PWM signal is the exponential reference voltage:

$$V_{OUT} = \frac{1}{T} \int_0^T V_{PWM} dt = \frac{ton}{T} (V_{max} - V_{min}) + V_{min} \quad (3)$$

with:

(4)

$$\frac{ton}{T} = \frac{\ln(V_{DD} + I_S R - V_{DIM}) - \ln(V_{DD} + I_S R - V_{start})}{\ln(V_{DD} + I_S R - V_{stop}) - \ln(V_{DD} + I_S R - V_{start})} = \frac{\ln(V_{DD} + I_S R - V_{DIM})}{c2 - c1} - \frac{c1}{c2 - c1}$$

and with $ton/T=0$ when the dimming level V_{DIM} level ($= I_{ADCS}$) $\leq V_{Start}$ and $ton/T=1$ when $V_{DIM} \geq V_{Stop}$, wherein C1 and C2 are constants.

[0041] The current I_S can be generated with a VI converter as shown in Fig. 8 with a reference voltage, V_{ref} , and a converting resistor, R_{VI} , matched to the resistor R in the Time Base Signal Generator 4A. This results in that $I_S \cdot R$ in the

Time Base block 4A is mainly dependent on the V_{ref} voltage of the VI converter, $I_S \cdot R = V_{ref} \cdot \frac{R}{R_{VI}}$, and therefore insensitive to temperature changes and process spread of the resistors.

[0042] If $\ln(V_{DD} + I_s R - V_{DIM}) > C1$ the transfer function TC is more exponentially curved and when

[0043] $\ln(V_{DD} + I_s R - V_{DIM}) < C1$ the transfer function TC is a more linear function as can be seen in the diagram of Fig. 5.

[0044] Fig. 5 shows an exemplary duty cycle with $V_{Start}=1V$, $V_{Stop}=3V$, $V_{DD}+I_s R=3,2V$ or $4V$, wherein V_{DIM} is $1V$ to $3V$. According to the linearity of the shown transformation curve TC is defined by circuit design having a maximum light level of 100% and a minimum light level of about 5%.

[0045] Fig. 4 shows a diagram for illustrating the functionality of the apparatus and method for dimming a light source according to the present invention.

[0046] Within the first quarter I of the shown diagram the logarithmic eye-sensitivity-curve ESC of a human eye is compensated by a transformation curve TC having an exponential shape adapted to compensate the logarithmic eye-sensitivity curve ESC of the human eye. This transformation curve TC having an exponential shape is shown in the second quarter II of the diagram. The apparatus 1 according to the present invention is designed to provide the transformation curve TC in quarter II which has an exponential shape adapted to compensate the logarithmic eye-sensitivity-curve ESC shown in the first quarter I. As can be seen from the diagram in Fig. 4 a linear variation of an actuator such as a turning knob of a dimmer leads to a linear change of the eye perception of the human eye and allows an easy control of the light setting for a user. A linear variation of the dimmer leads as shown in Fig. 4 to a linear varying input amplitude dimmer control signal IADCS applied to the compensation apparatus 1 according to the present invention as shown in Fig. 1. To linearize the control of the light perception the transformation of the linear varying input amplitude control signal IADCS to the output amplitude dimmer control signal OADCS is done by means of an exponential transformation curve TC as shown in the second quarter II of Fig. 4. For instance, if a human user changes the degree of a turning knob of dimmer from e.g. 45° to 135° this causes in the shown exemplary embodiment a variation of the output amplitude dimmer control signal OADCS from 25% of the supply voltage to 75% of the supply voltage. In the exemplary embodiment as shown in Fig. 4 the transfer from the turning knob (actuator degree ϕ) to the dimming voltage or input amplitude dimmer control signal IADCS is set to a linear curve. In alternative embodiments this curve can also be non-linear. For example when using a TRIAC dimmer the transfer from the turning knob degree to the phase cut of the sine wave can be non-linear, i.e. the dimming voltage has a linear relationship with the phase cut.

[0047] In a preferred embodiment of the apparatus 1 according to the present invention the slope of the exponential transformation curve TC shown in the second quarter II of the diagram shown in Fig. 4 is adaptable. The form of the transformation curve TC shown in the second quarter II has an exponential shape which can be adapted to compensate the logarithmic eye-sensitivity-curve ESC of the human eye.

[0048] Fig. 5 shows a duty cycle of the pulse width modulated PWM signal depending on the dimming voltage provided by the dimmer, i.e. the varying input amplitude dimmer control signal IADCS. The slope and linearity of the curve shown in Fig. 4 depends on the circuit design of the compensation apparatus 1 and in particular of the signal transformation unit 4 shown in Fig. 1. By changing the value of the resistor R and the currents S as provided by the integrated current source of the time base signal generator as well as by changing the supply voltage V_{DD} the slope and form of the curve can be adapted.

[0049] In a possible embodiment the circuit element of the time base signal generator 4A and the signal comparator S4B within the signal transformation unit 4, i.e. the resistor R, the capacitor C, the current source as well as the operation amplifiers OpAmp are integrated into an integrated circuit IC. In a possible embodiment at least some circuit elements such as the resistor R and the capacitor C of the time base signal generator 4A can be formed by discrete circuit elements connected to an integrated circuit. In a still further embodiment some circuit parameters such as the resistance value of the resistor R and/or the capacitance of the capacitor C and the current amplitude of the current generated by the current source are adaptable, i.e. they can be set by a user to change the transformation curve TC shown in Fig. 5. In the shown exemplary embodiment of Fig. 5 the supply voltage V_{DD} for the signal transformation unit 4 has $4V$ and the dimming voltage can be varied between $1V$ and $3V$ corresponding to 25% and 75% of the supply voltage V_{DD} . In the shown exemplary embodiment the maximum light level (100%) corresponds to a voltage setting of $3V$ and the minimum light level (5%) has a set voltage of $1V$. Depending on the circuit design in particular depending on the resistance value of the resistor R and the current amplitude of the current source the shape of the transformation curve TC can be more linear or more bent depending on the logarithmic eye-sensitivity-curve ESC of the human eye of different users.

[0050] Using a pulse width modulated PWM signal to generate the transformation curve TC with an exponential shape has the advantages that the dimming curve mainly depends on the accuracy of the applied supply voltage V_{DD} . The start and end value voltage of the dimming curve can easily set with the amplitudes, V_{min} to V_{max} , of the pulse width modulated PWM signal and are independent of the transfer function.

[0051] The transfer from a high dimming setting to a low dimming setting is a transfer function TC with an exponential shape whereby the transfer function only depends on the accuracy to detect the voltage references (speed comparators) and on the accuracy of the voltage references.

[0052] A further advantage is that a temperature dependency and process dependency and a component spread of circuit components such as a resistor R and capacitor C within the time base signal generator 4A do only affect the period time T, however, do not affect the duty cycle of the pulse width modulated PWM signal.

[0053] With the apparatus 1 according to the present invention a ratio between a signal level of the varying input amplitude dimmer control signal IADCS and the predetermined supply voltage V_{DD} of said signal transformation unit 4 corresponds to a light level provided by the light source 2.

[0054] The signal transformation unit 4 as shown in Fig. 1 applies a pulse width modulated PWM signal to the low pass filter 5. The low pass filter 5 is formed in a possible embodiment by an active low pass filter. In an alternative embodiment the low pass filter 5 can also be formed by a passive low pass filter. In a possible embodiment the low pass filter 5 can be also integrated along with the signal transformation unit 4 in an integrated circuit IC. In a possible embodiment the low pass filter 5 is a low pass filter of first order comprising a predetermined corner frequency. In a still further possible embodiment the low pass filter 5 is a filter of second or higher order comprising a predetermined corner frequency. The corner frequency of the low pass filter 5 is adapted to be low enough so that a spread of a switching frequency of the pulse width modulated signal PWM supplied to the low pass filter 5 by the signal transformation unit 4 and a spread of the corner frequency does not have an impact of the transformation curve TC which compensates the logarithmic eye-sensitivity-curve ESC of the human eye.

[0055] Fig. 6 shows a block diagram of a possible embodiment of a light-emitting device 6 comprising a compensation apparatus 1 for dimming a light source 2 integrated in the light emitting device 6. The light emitting device 6 as shown in Fig. 6 is a light lamp or an illuminating device comprising one or several light sources 2 wherein each light source 2 can receive a control signal from a corresponding compensation apparatus 1. Accordingly, the light emitting device 6 can comprise more than one compensation apparatus 1 and more than one light source 2. The light source 2 can be formed by a linear light source comprising for example a light emitting diode LED or a compact fluorescent lamp CFL. The compensation apparatus 1 as shown in Fig. 6 can control one light source 2 or at the same time several light sources 2 connected in parallel to the low pass filter 5. In the shown embodiment of Fig. 6 the light emitting device 6 further comprises a mains-low-pass-filter 7 which transforms a phase cut dimmer control signal provided by the dimmer 3 to provide as a linear input amplitude dimmer control signal IADCS applied to the signal transformation unit 4. The cut off of the mains-low-pass-filter 7 can in a possible embodiment be less than 100 Hz.

[0056] Fig. 7 shows a signal diagram for a phase cut signal PCS applied by a dimmer 3 such as a TRIAC dimmer. As can be seen in the signal diagram of Fig. 7 the signal is a phase cut rectified sign wave supply voltage having in the shown example an amplitude of 340 V and a period of $t=10$ ms. The dim level voltage can be in a range from 0 to the supply voltage V_{DD} :

$$VDIMLVL = \frac{\varphi}{180^\circ} \cdot VDD \quad (5)$$

[0057] For a phase lower than 45° the output voltage represents a minimum dim level. Accordingly, the minimum voltage V_{min} of the pulse width modulated PWM signal is the minimum dim level and the start voltage V_{Start} is $1/4 V_{DD}$. In a possible embodiment for a phase higher than 135° the output voltage is maximal so that the maximum voltage V_{max} of the pulse width modulated signal is the maximal voltage and the stop voltage V_{Stop} is $3/4 V_{DD}$. The minimum dim level is 5% of the maximal output level.

(6)

$$\frac{t_{on}}{T} = \frac{\ln(VDD + IsR - VDIM) - \ln(VDD + IsR - \frac{1}{4}VDD)}{\ln(VDD + IsR - \frac{3}{4}VDD) - \ln(VDD + IsR - \frac{1}{4}VDD)} = \frac{\ln(VDD + IsR - VDIM) - c1}{c2}$$

or with $\alpha \cdot VDD = Is \cdot R$

$$\frac{t_{on}}{T} = \frac{\ln(1 + \alpha - \frac{VDIM}{VDD}) - c3}{c4}, \quad 1/4VDD < VDIM < 3/4VDD$$

[0058] The accuracy of the curves mainly depends on the accuracy of the reference supply voltage V_{DD} . Is generated with a VI converter with R_{VI} matched to R of time generator block 4A. The VDD voltage is constructed with the same reference voltage which is used in the VI converter.

[0059] In a possible embodiment the reference supply voltage V_{DD} is 4 V, resulting in a start voltage $V_{Start} = 1V$ and a stop voltage $V_{Stop} = 3 V$ for the time base signal generator 4A. In a possible embodiment the maximum output voltage VPWMmax is set to 2 V resulting in 100 mV (5% of VPWMmax) for VPWMmin.

$$VDIMLVL \leq V_{start}, \quad VLOG = 0.1V$$

$$V_{start} \leq VDIMLVL \leq V_{stop}, \quad VLOG = 0.1 + \frac{t_{on}}{T} \cdot (2 - 0.1) (7)$$

$$VDIMLVL \geq V_{stop}, \quad VLOG = 2V$$

[0060] The apparatus 1 for dimming the light source 2 according to the present invention as shown in the embodiment of Fig. 1 can be implemented in a possible embodiment by an analogue circuitry as shown in Fig. 2. In a possible embodiment the apparatus 1 for dimming a light source 2 by a compensation transformation curve TC can be implemented in the digital domain. The compensation apparatus 1 as shown in Fig. 1 can be implemented by an integrated circuit or a discrete circuitry. The compensation apparatus 1 according to the present invention can also be integrated in a light emitting device 6 having one or several linear light sources 2. In a possible embodiment the dimmer 3 is located in a wall of a building. In a still further embodiment the dimmer 3 can also be integrated in the light emitting device 6 having a compensation apparatus 1 according to the present invention. Further, it is possible that the compensation apparatus 1 as well as the mains-low-pass-filter 7 as shown in Fig. 6 are integrated in a dimmer 3 for dimming a light source 2.

[0061] The invention provides also a method for dimming a light source 2 wherein a varying input dimmer control signal IADCS provided by a dimmer 3 is transformed with a transformation curve adapted to compensate a predetermined eye-sensitivity-curve ESC into an output amplitude dimmer control signal OADCS applied to the light source 2.

[0062] In a possible embodiment the eye-sensitivity-curve ESC of a human eye is measured and stored in a data base or data memory. In a possible embodiment the measured eye-sensitivity-curve ESC of a human eye is read-out of the data memory and a corresponding matching transformation curve TC is calculated. This transformation curve TC has an exponential shape adapted to compensate the logarithmic eye-sensitivity-curve ESC of the human eye read from the data memory. In a possible embodiment the design parameters of the signal transformation unit 4 in particular the values of the resistance of the resistor R and the generate current by the current source as well as the supply reference voltage V_{DD} are selected or programmed such that the transformation curve TC is adapted to compensate the measured logarithmic eye-sensitivity-curve ESC of the human eye which can be an individual ESC curve of a specific user. In a possible embodiment the resistance value of the resistor R, the current amplitude generated by the DC current source of the time base signal generator 4A as well as the reference supply voltage V_{DD} are adaptable and are set in such a way that the resulting transformation curve TC is adapted to compensate the measured eye-sensitivity-curve ESC of the human eye of a user.

Claims

1. An apparatus (1) for dimming a light source (2) which transforms with a transformation curve (TC) adapted to compensate a predetermined eye-sensitivity-curve (ESC), a varying input amplitude-dimmer-control signal (IADCS) provided by a dimmer (3) into an output amplitude dimmer control signal (OADCS) applied to said light source (2).
2. The apparatus according to claim 1, wherein said transformation curve (TC) is formed by a transformation curve having an exponential shape adapted

to compensate a logarithmic eye-sensitivity-curve (ESC) of a human eye.

3. The apparatus according to claims 1 or 2,
 wherein said apparatus (1) comprises
 5 a signal transformation unit (4) which transforms said varying input amplitude dimmer control signal (IADCS) into a pulse width modulated (PWM)-signal and
 a low pass filter (5) which transforms the pulse width modulated (PWM)-signal into said output amplitude dimmer control signal (OADCS) applied to said light source (2).
- 10 4. The apparatus according to claims 1 to 3,
 wherein said signal transformation unit (4) comprises a time base signal generator (4A) for generating a time base signal (TBS) and
 a signal comparator (4B) which compares the generated time base signal (TBS) with the varying input amplitude dimmer control signal (IADCS) to provide said pulse width modulated (PWM)-signal supplied to said low pass filter (5) .
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5. The apparatus according to claim 4,
 wherein said time base signal generator (4A) comprises at least one capacitor (C) connected at a node (N) via a resistor (R) and/or a current source to a predetermined supply voltage (V_{DD}) of said signal transformation unit (4) .
- 20 6. The apparatus according to claim 5,
 wherein the voltage at said node (N) of said time base signal generator (4A) is applied to a positive input of a voltage comparator having a negative input connected to a predetermined reference voltage close to the supply voltage (V_{DD}),
 wherein an output of said voltage comparator activates means (SW) to precharge said capacitor (C) of said time
 25 base signal generator (4A) to a start voltage (V_{start}) causing said timebase signal generator (4A) to act as an oscillator which generates a sawtooth signal with an exponential shape having a minimum voltage value equal to the start voltage (V_{start}) and a maximum voltage level (V_{stop}) equal to the predetermined reference voltage.
7. The apparatus according to claim 5,
 wherein said node (N) of said time base signal generator (4A) is connected to a first input of the signal comparator
 30 (4B) which compares a voltage level at said node (N) with a voltage level of said varying input amplitude dimmer control signal (IADCS) applied to a second input of said signal comparator (4B) to provide said pulse width modulated (PWM) -signal at an output of said signal comparator (4B).
8. The apparatus according to claim 7,
 35 wherein said signal comparator (4B) is supplied with a voltage difference having as a high level the upper supply voltage forming a maximum level of said transformation curve (TC) and having as a low level the lower supply voltage forming a minimum level of said transformation curve (TC).
9. The apparatus according to claims 1 to 8,
 40 wherein a ratio between a signal level of said varying input amplitude dimmer control signal (IADCS) and said predetermined supply voltage (V_{DD}) of said signal transformation unit (4) corresponds to a light level provided by said light source (2).
10. The apparatus according to claims 1 to 9,
 45 wherein said varying input amplitude dimmer control signal (IADCS) is a voltage dimmer control signal comprising a voltage level corresponding to a phase cut of a TRIAC transistor wall dimmer providing said voltage dimmer control signal.
11. The apparatus according claim 1 to 8,
 50 wherein said varying input amplitude dimmer control signal (IADCS) is a linear signal provided by an adjustable resistor divider that is connected to the supply voltage (V_{DD}) to generate an adjustable output voltage as the linear varying input amplitude dimmer control signal (IADCS).
12. The apparatus according to claims 3 to 11,
 55 wherein said low pass filter (5) is a low pass filter of first or second order comprising a predetermined corner frequency.
13. The apparatus according to claim 12,
 wherein the corner frequency of said low pass filter (5) is adapted to be low enough so that a spread of a switching

frequency of said pulse width modulated (PWM) -signal and a spread of said corner frequency does not have an impact on said transformation curve (TC).

5 **14.** A light emitting device (6) comprising an apparatus (1) according to one of the preceding claims 1 to 13.

15. The light emitting device (6) according to claim 14,
wherein said light source (2) is formed by a linear light source comprising at least one light emitting diode (LED) or a compact fluorescent lamp (CFL) or any other linear light source.

10 **16.** The light emitting device (6) according to claims 14 or 15,
wherein said light emitting device (6) further comprises a mains-low-pass-filter (7) which transforms a phase cut dimmer control signal provided by said dimmer (3) into said linear varying input amplitude dimmer control signal (IADCS) .

15 **17.** A method for dimming a light source (2) wherein a varying input amplitude dimmer control signal (IADCS) provided by a dimmer (3) is transformed with a transformation curve (TC) adapted to compensate a predetermined eye-sensitivity-curve (ESC) into an output amplitude dimmer control signal (OADCS) applied to said light source (2).

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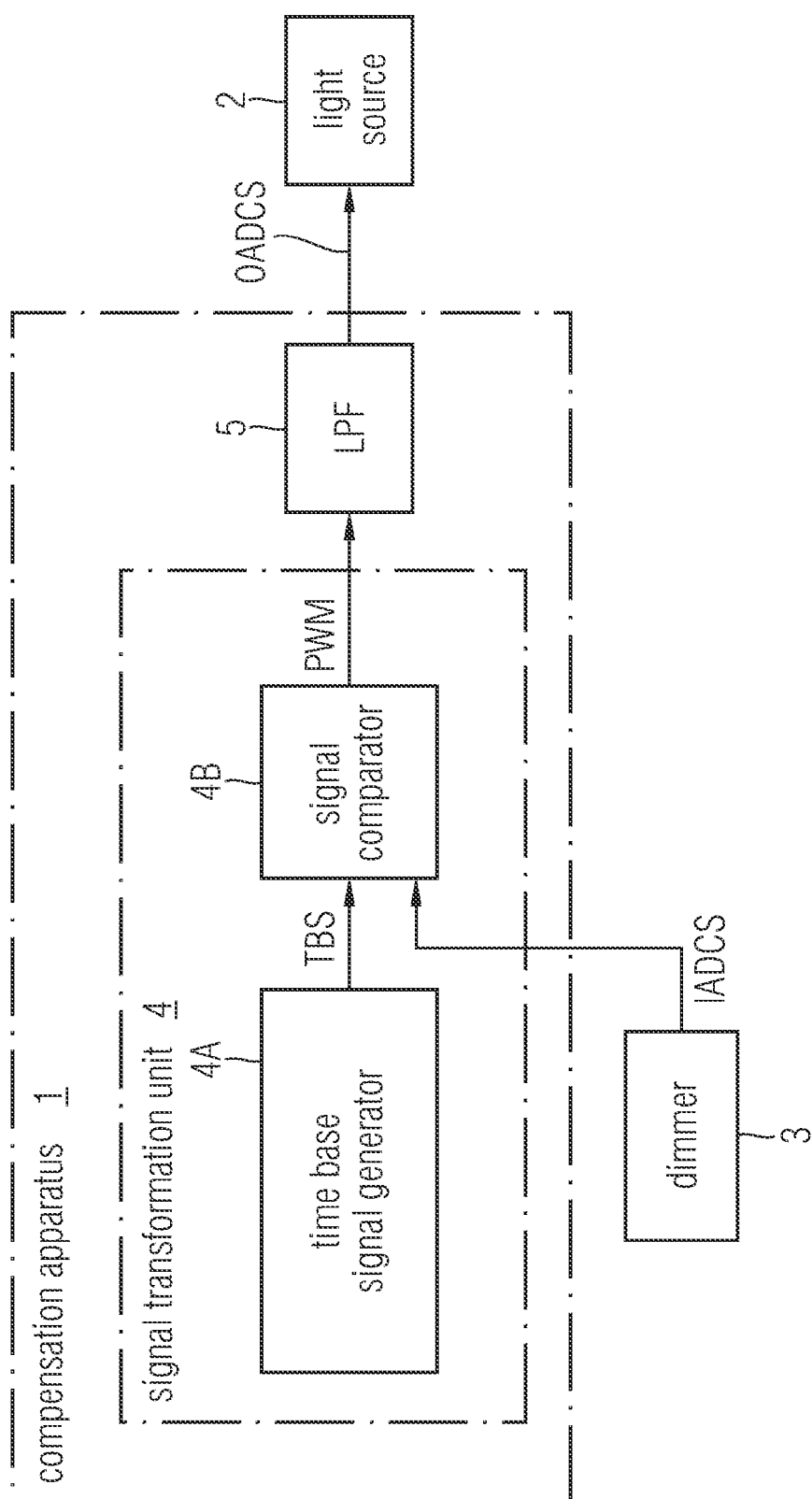


Fig. 1

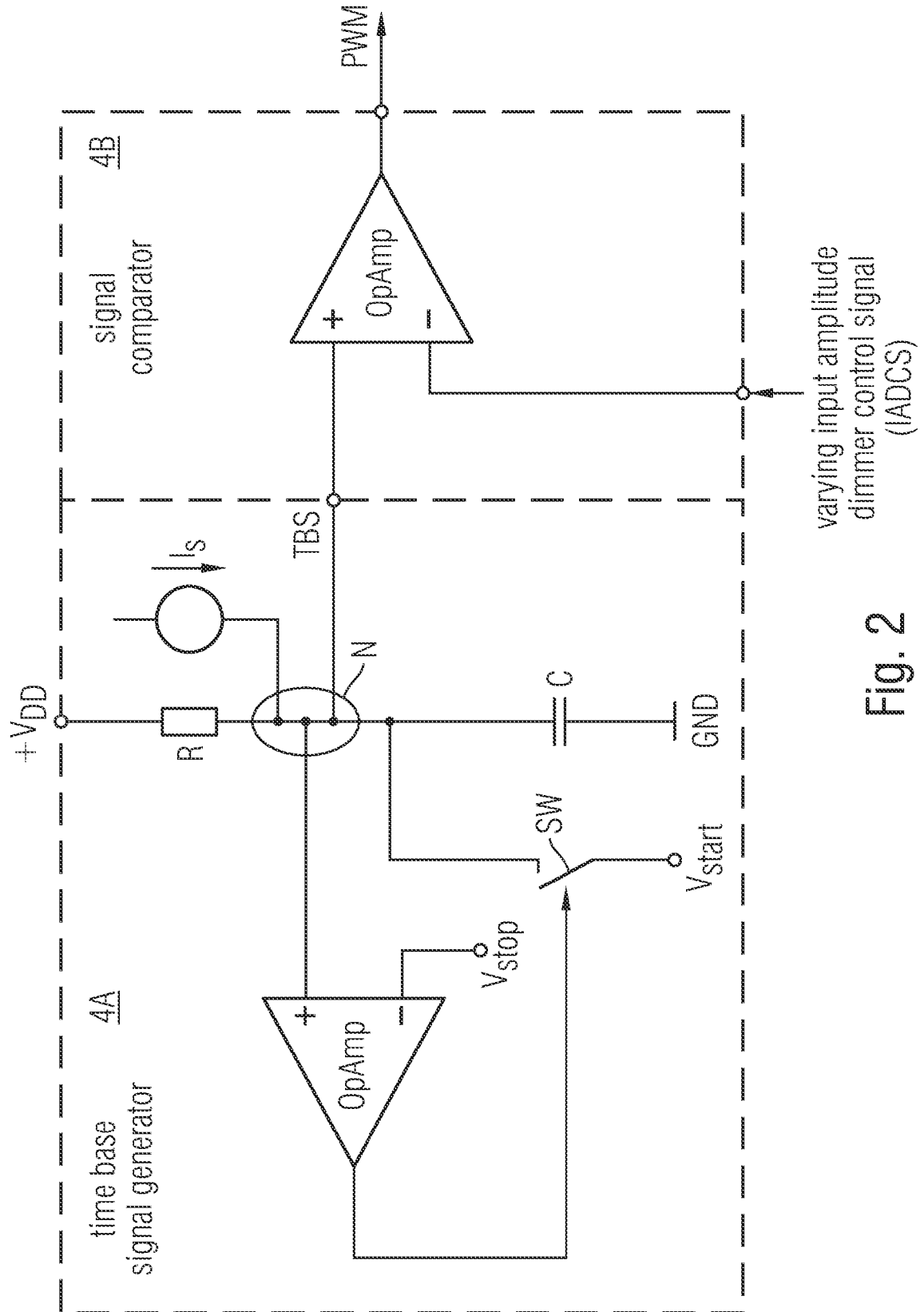


Fig. 2

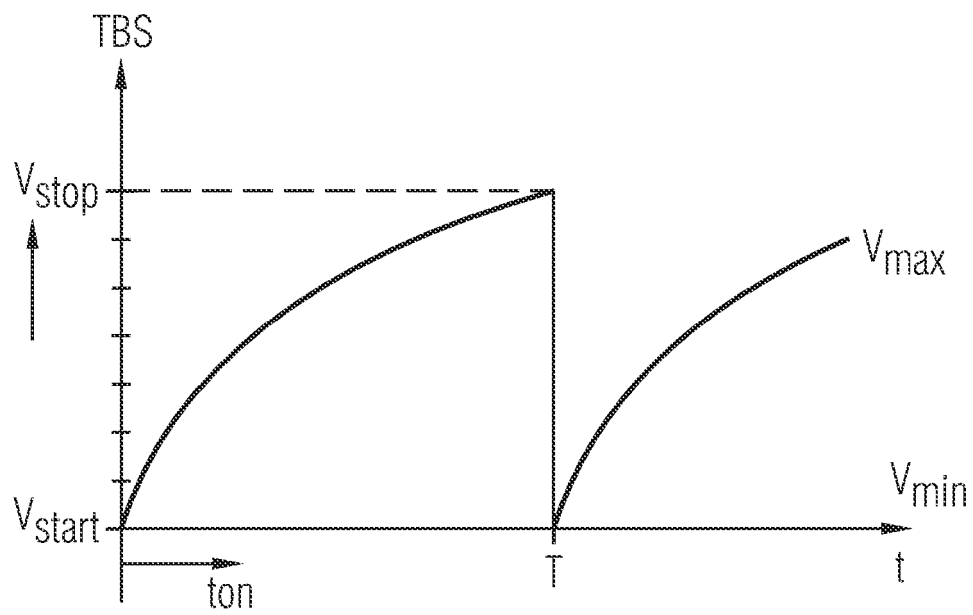


Fig. 3A

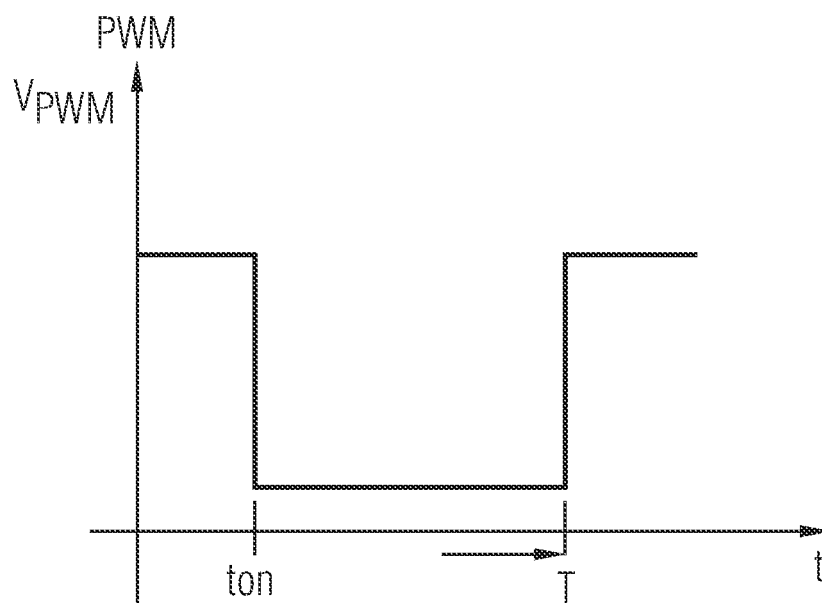


Fig. 3B

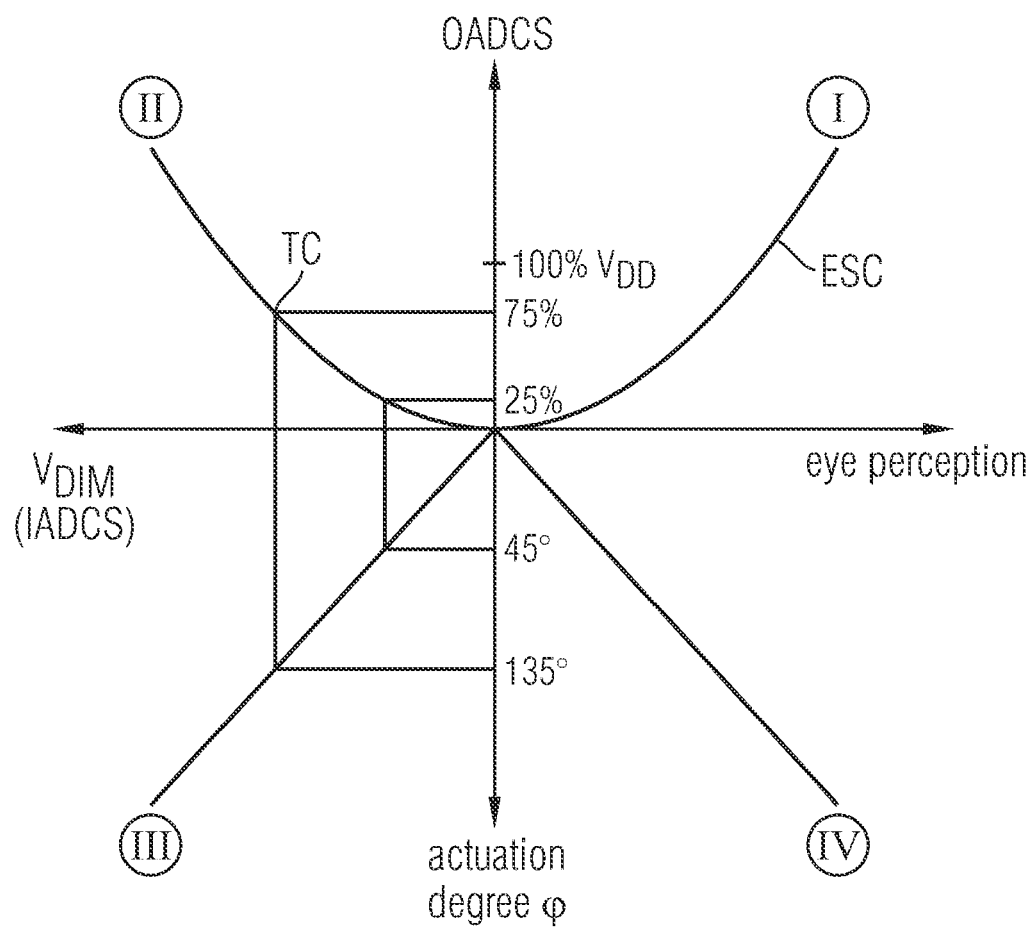


Fig. 4

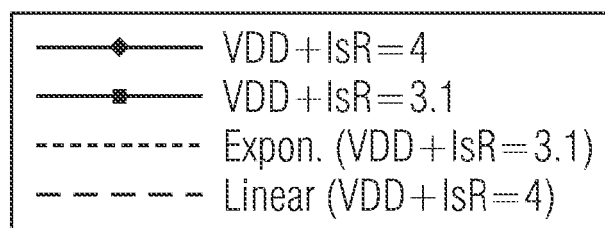
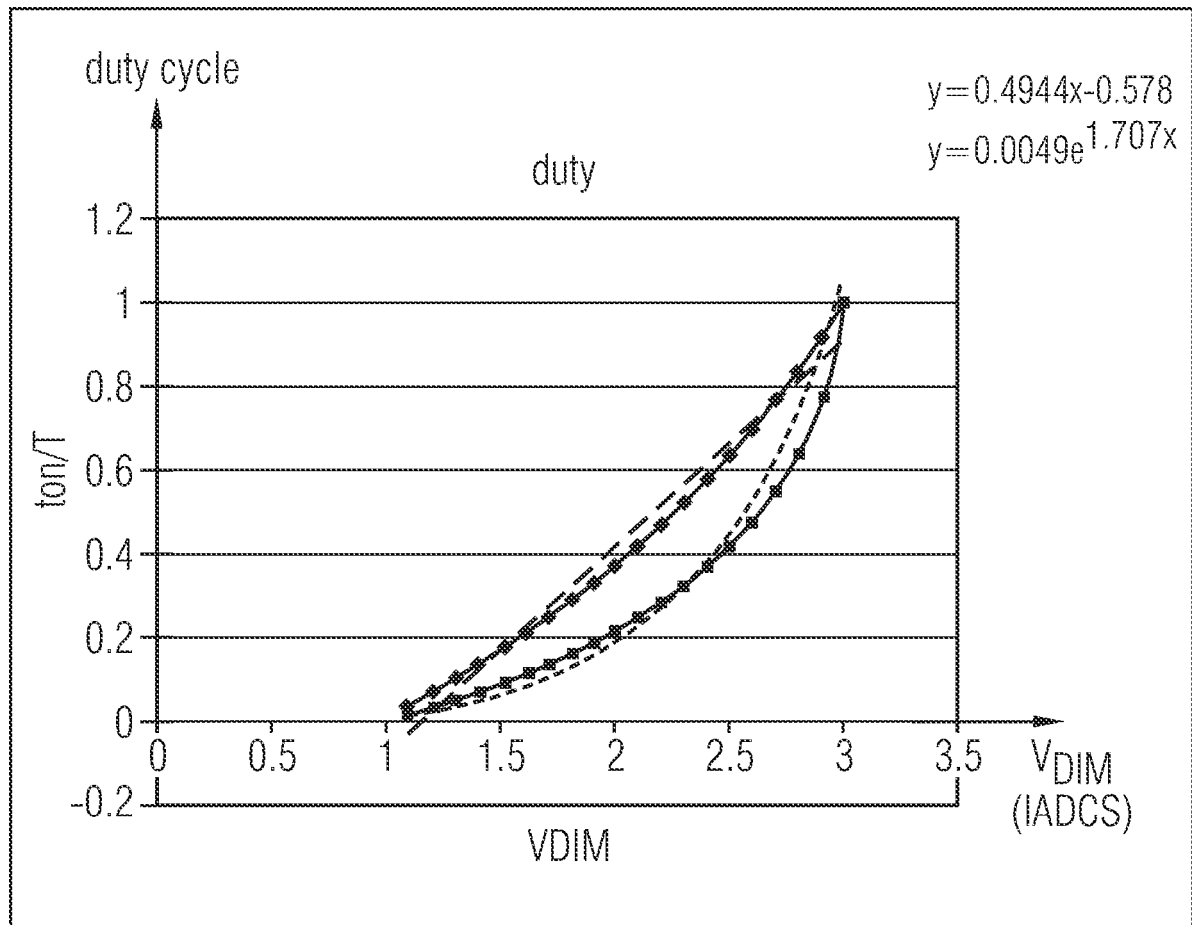


Fig. 5

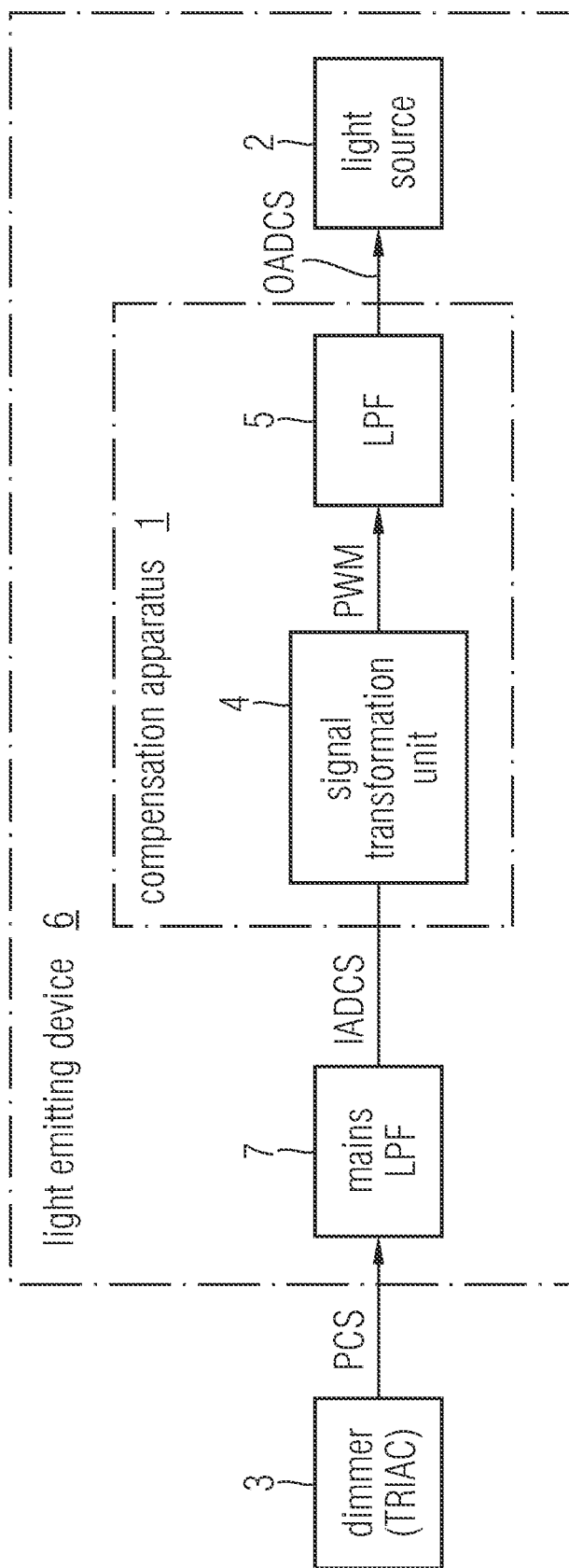


Fig. 6

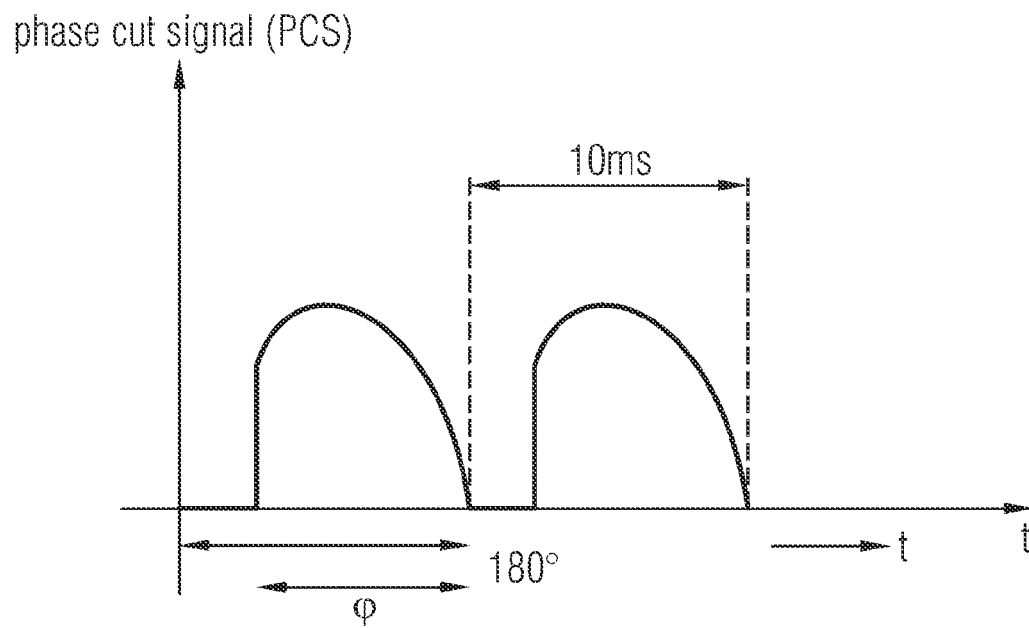


Fig. 7

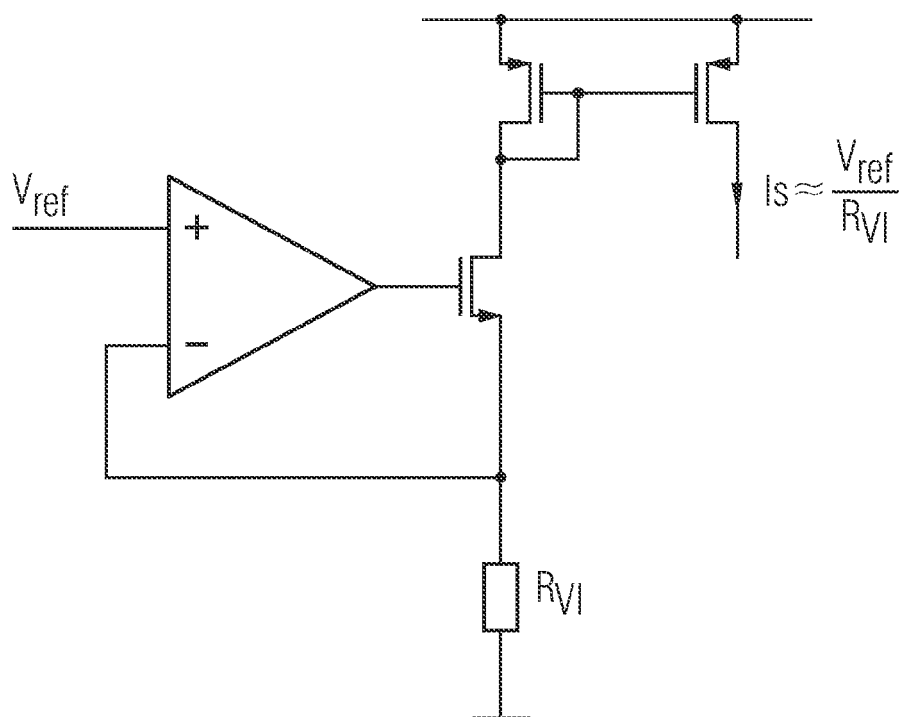


Fig. 8



EUROPEAN SEARCH REPORT

Application Number
EP 10 19 7221

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 10 2009 013897 A1 (TRIDONICATCO GMBH & CO KG [AT]) 23 September 2010 (2010-09-23) * paragraphs [0001], [0026], [0027], [0029] - [0034]; figures 2-5 *	1,2,14, 15,17	INV. H05B37/02
X	US 2010/090618 A1 (VELTMAN ANDRE [NL]) 15 April 2010 (2010-04-15) * paragraphs [0003], [0007] - [0011], [0017], [0073] - [0085]; figures 2,3,6,8-10 *	1,2,10, 14-17	
X	FR 2 931 616 A1 (ECE [FR]) 27 November 2009 (2009-11-27) * page 5, line 8 - page 6, line 22; figures 1,2 *	1,9,11, 14,17	
X	WO 2009/136328 A1 (NXP BV [NL]; KOOLEN GERT-JAN [NL]) 12 November 2009 (2009-11-12) * page 1, line 29 - page 2, line 31; figures 1-3 *	1,2,10, 14-17	
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			H05B
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 7 June 2011	Examiner Albertsson, Gustav
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EP 10 19 7221

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07-06-2011

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