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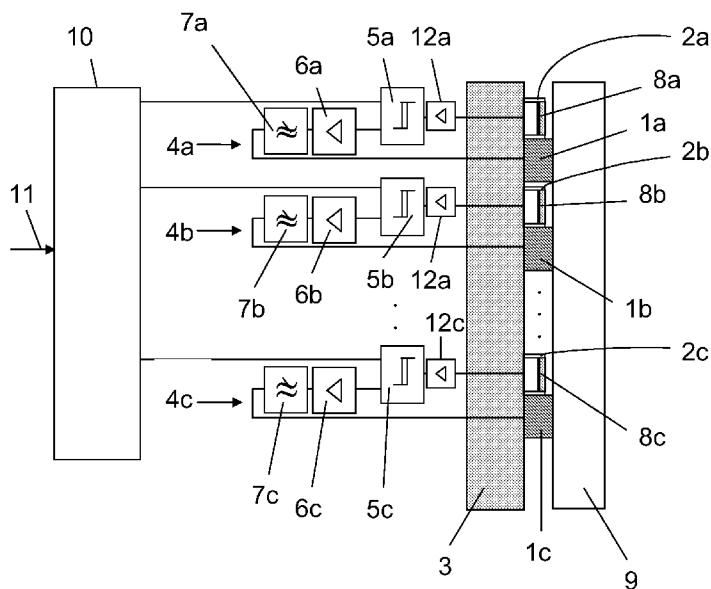
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(54) Title: A COLOR LIGHTING DEVICE



(57) Abstract: The invention relates to a color lighting device comprising at least one light-emitting source (1a, 1b, 1c) fixed on a common substrate (3), each light-emitting source (1a, 1b, 1c) comprising at least one light-emitting diode (LED) (1a, 1b, 1c), each light-emitting source (1a, 1b, 1c) comprising one photosensor (2a, 2b, 2c) that detects the light output only of the associated light source (1a, 1b, 1c), and each light-emitting source (1a, 1b, 1c) being connected to an analog control circuit (4a, 4b, 4c) that controls the drive of each light-emitting source (1a, 1b, 1c) separately on the basis of a light output detected by the associated photosensor (2a, 2b, 2c), while each control circuit (4a, 4b, 4c) comprises a comparator (5a, 5b, 5c) connected to the associated photosensor (2a, 2b, 2c).

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A color lighting device

5 The invention relates to a color lighting device comprising a plurality of light-emitting sources fixed on a common substrate, wherein each light-emitting source comprises at least one light-emitting diode (LED).

10 It is known that LEDs of different colors are used for constructing a lighting device that generates a wide range of colors. These LEDs define an area in the CIE xy-color-space which shows the color that can be realized by the weighted linear combination of these LEDs (e.g. red(R), green(G) and blue(B)). In future high-power LEDs, the dissipated power will lead to a temperature increase of the dies close to 200°C. At this temperature the emission spectrum of the LEDs shifts in an unacceptable way. One of the disadvantages is that the shift is noticed by the human eyes.

15 Red and green LEDs are known which are made of blue LEDs with a phosphor-ceramic layer on the top of the dies. Nevertheless, the intensity is still a function of the temperature, the current, and the lifetime. It is known that RGB-sensors can be used to control the color point. A considerable disadvantage of this approach is that these RGB-sensors are currently expensive and will suffer from their temperature dependency. Thus, one of the basic problems of known color lighting devices with color point control systems is that the sensor for color sensing has to fit the CIE color-matching functions. There are several commercial RGB-sensors available that claim to be close to the CIE color-matching functions, but none of these is sufficiently close to the CIE color-matching functions for the color control task. Furthermore, most of these 20 RGB-sensors degrade at elevated temperatures. Another disadvantage of color lighting devices with color point control systems is that the spectral insensitivity has to be independent of the temperature, which is not the case for normal photodiodes. Anyhow, these sensors are specified for temperature ranges, e.g. up to 85°C, which is at some 25 distance to the above-mentioned temperature.

30 Furthermore, it is known that color lighting devices comprise a control

circuit with pulse width modulation (PWM), which controls the light output or the color of each single diode of the color lighting device. One of the disadvantages is that said color point control systems with pulse width modulation require very precise, complex and expensive components. Disadvantageously, PWM controlled multi-color lighting

5 devices drive the LED in a very inefficient point if less than 100 % of the maximum brightness is used (which is typically the case). In some cases it is possible that electromagnetic interaction with the environment occurs due to the high-frequency current components (required for accurate PWM).

10

US 2002/0130326 A1 describes a lighting device comprising a plurality of LEDs that are arranged in an at least two-dimensionally dispersed manner, a transparent resin layer that covers the plurality of LEDs in an integrated form, a photodetection unit using a photodetector that detects a light emission intensity from the plurality of LEDs,

15 a power supply circuit unit that controls driving of the plurality of the LEDs based on a detection output from the photo-detection unit, wherein a number of the photodetectors is smaller than the number of LEDs, and the photodetector detects an intensity of light emitted from the LEDs and propagated through the transparent resin layer. The LEDs for different colors are turned on with mutually different timings. The photodetector can

20 thus only detect the light intensity sequentially for each color.

The invention has for its object to eliminate the above disadvantages. In particular, it is an object of the invention to provide a lighting device with an

25 inexpensive and simple setup with means for color point stabilization such that, even though each LED has different light-emission characteristics, a predetermined light-output state can be obtained.

This object is achieved by a color lighting device as taught by claim 1 of the present invention. The preferred embodiments of the invention are defined in the

30 dependent claims.

Accordingly, a color lighting device is provided comprising at least one light-emitting source fixed on a common substrate, each light-emitting source comprising at least one light-emitting diode (LED), each light-emitting source comprising one photosensor that detects the light output only of the associated source,

5 and each light-emitting source being connected to an analog control circuit that controls the drive of each light-emitting source separately on the basis of a light output detected by the associated photosensor, while each control circuit comprises a comparator connected to the associated photosensor. One of the essential advantages of this invention is that the control circuit controlling the color of the multi-color lighting

10 device comprises a pure analog setup. Preferably, the color lighting device consists of light-emitting sources which emit blue light, the peak wavelength being in the range from 420 to 470 nm, red light with the peak wavelength being in the range from 590 to 630 nm, and green light with a peak wavelength being in the range from 510 to 550 nm. Alternatively, the light-emitting source emits invisible light, which may be ultraviolet

15 light. The light source may comprise only a single diode producing light of a defined color. Alternatively, the light source may comprise a plurality of LEDs together producing light of a certain color which issues from the lighting device. Certainly, each LED may emit light with an individual peak wavelength. This means that each light source may comprise a bundle of LEDs, each LED emitting light of a different color.

20 During the illumination process the color of the light output leaving the light source is a mixture of all single light contributions from the LEDs. According to a preferred embodiment of the present invention, the device consists of a plurality of n light sources that emit light, wherein each light-emitting source is separately driven by a single driver line. For example, the light-emitting source may consist of a mixture of small, e.g. GaN

25 LEDs or broad-band emitters, e.g. phosphor-converted LEDs. During the illumination procedure the analog control circuit controls all light-emitting sources simultaneously in order to keep the optical output from the lighting device constant for a long time.

Each light-emitting source comprises an individual photosensor that detects the light output of said source. Every single photosensor is arranged in the color

30 lighting device in such a manner that only the emitted light of the source is measured by the associated photosensor. Thus, high-quality information on the actual light output of

each single light source can be obtained. According to the invention, the control circuit comprises an analog two-point control system. Each photosensor detects a photo signal containing the information on the actual light output of the associated light source.

Preferably, this signal is amplified and translated into an input for an analog

5 comparator, where it is compared with a reference signal. If the photosignal is less than the reference signal, the control circuit provides a high output-signal and if the photosignal is greater than the reference signal, the control circuit provides a low output-signal. If the two values of said signals are nearly equal, a low output-signal can also be provided. Preferably, the high output signal and the low output signal are fixed
10 values stored in the color lighting device, which either increase or decrease the driving signal for the light-emitting source. The described two-point control has an easy setup and is even more efficient than a color control based on pulse width modulation.
Moreover, the control procedure does not generate any flickering of the light output, because in the present invention the current through the light source is changed with
15 very low speed for color adjustment purposes. The present invention is suitable for simultaneous use of e.g. phosphor-converted LEDs and narrow-band LEDs (GaN, AlGaAs, etc). Compared with the pulse width modulation used for light output control, the present multi-color lighting device requires a short current rise time.

In a preferred embodiment, the comparator is an analog Schmitt trigger.

20 Preferably, the Schmitt trigger changes its output state when its input voltage level rises above a certain reference voltage. However, the output does not switch back automatically when the input voltage level sinks again unless a second, lower reference voltage threshold is crossed. This difference in threshold voltages results in a hysteresis. Advantageously, the hysteresis guards against noise that would otherwise cause a rapid
25 switching back and forth between the two output states when the inputs are closed to the threshold voltage. Furthermore, the hysteresis is adjusted with respect to the low-pass filter that ensures that frequencies below 400 Hz are impossible.

In another preferred embodiment, the control circuit comprises a driver connected to the comparator, wherein the output of the driver is guided to a low-pass-
30 filter connected to each light source. Depending on whether the output-signal of the comparator is high or low, the driving signal is changed in that a current flowing

through the corresponding light source is changed, thereby preventing a change in the light output. The optical output from the device can thus be kept constant for a long time. According to a preferred embodiment of the invention, the driver is an amplifier or a switch. Preferably, the Schmitt trigger jumps between the high and the low output 5 signal, the driver output signal being filtered by the low-pass filter that smoothes the driving signal to each light source.

Alternatively, the photosensor is arranged on the substrate next or adjacent to the light source. Also, it is possible that the photosensor is positioned between the light source and the substrate. In this case the light source is arranged on the 10 photosensor. In another preferred embodiment, the substrate is arranged between the photosensor and the light source. That means that the photosensor is fixed at the opposite side of the substrate, where the light source is not positioned. A wave guide may be formed in the substrate between the light source and the photosensor in order to interconnect these two components. In a possible embodiment of the invention, the 15 photosensor and/or the light source may be embedded in the substrate. Furthermore, the core of the substrate may be made of metal so as to diffuse and dissipate heat generated by each LED effectively. Alternatively, the substrate may be made of epoxy resin or may be a composite substrate made of epoxy resin mixed with alumina.

In a preferred embodiment of the present invention, the photosensor 20 comprises a filter that is sensitive to the color of the associated light source. Said filter may be an optical filter. In order to prevent a wrong correction of the light output of the light source, the photosensor detects only the light output of the corresponding light source and is insensitive to other colors. Thus, overlapping areas are not generated. Preferably, each photosensor with a filter has a constant sensitivity over the wavelength 25 range of interest for the applied colors. For narrow-band emitters, the filter response may be constant over a small wavelength regime. A filter response may have a very narrow band for phosphor-converted LEDs with a smooth response in the wavelength range of the peak sensitivity of the filtered-photosensor. Preferably, the filters allow light in the wavelength ranges corresponding to those emitted by the respective light 30 sources to pass through, so that the photosensor that deals with the respective luminescent colors is provided with a specific sensitivity to a certain light source.

According to the invention, the filters are constructed such that their spectral transmissivities are adjusted to light that conforms with the peak wavelengths of the corresponding colors of light of the respective associated light sources.

In a preferred embodiment of the color lighting device, the filter comprises

- 5 at least one layer that is e.g. placed on the photosensor. The photosensor may be a silicon photodiode with dielectric layers on top in order to achieve the required spectral sensitivity of the filtered photodiode. In another preferred embodiment, the filter comprises a plurality of conductive layers. Alternatively, a constant response can be achieved by using a narrow-band filter with different responses on top of each
- 10 photosensor, e.g. a Fabry-Perot filter.

The present invention also relates to a method of controlling the light output of a color lighting device with at least one light-emitting source fixed on a common substrate, each light-emitting source comprising at least one light-emitting diode, each light-emitting source comprising one photosensor that detects the light output only of

- 15 the associated light-emitting source, and each light-emitting source being connected to an analog control circuit that controls the drive of each light-emitting source separately on the basis of a light output detected by the associated photosensor, while each control circuit comprises a comparator connected to the associated photosensor, said method comprising the following steps for color control: First, a photosignal is detected, which
- 20 comprises the information on the actual light output of the single light source. After that, the photosignal is guided to the control circuit, where the comparator compares the photosignal with a reference signal, the control circuit providing a high output-signal that increases the driving signal for the light-emitting source if the photosignal is less than the reference signal. If the photosignal is greater than the reference signal, the
- 25 control circuit provides a low output-signal that decreases the driving signal for the light-emitting source.

Preferably, the control circuit comprises a driver connected to the comparator, wherein the output of the driver is guided to a low-pass-filter connected to the light source, the value of the low output signal being zero. If the photosignal is

- 30 greater than the reference signal, the value of the low output signal is zero. Consequently, the driver does not guide a signal, and as a result the driving signal for

the light source decreases. Advantageously, the low-pass filter has a cut-off frequency of at least 10kHz, making for a slow control circuit. The frequency determines the maximum rise time of the light source. If the user requires a higher rise time, the cut-off frequency can simply be increased. Preferably, the combination of low-pass filter and 5 comparator does not allow frequencies below 400 Hz.

The described steps of the control procedure may be performed continuously and/or simultaneously for each light source. Certainly, said steps can be conducted periodically during operation of the lighting device. Advantageously, the measured photosignals are stored in a memory of a color controller which comprises a CPU for 10 running an algorithm to calculate, for example, the brightness of each light source.

Preferably, the photosignal and the reference signal are voltage signals or current signals. For example the Schmitt trigger compares the output voltage signal of the photosensor with the reference voltage signal. If the photovoltage signal is less than the reference voltage signal, the output voltage of the Schmitt trigger is switched to a high 15 output voltage signal. If the photovoltage signal is greater than the reference voltage signal, the output voltage signal of the Schmitt trigger is switched to a low output voltage.

The color lighting device as well as the method mentioned above can be used in a variety of systems, among them automotive systems, home lighting systems, backlighting systems for displays, ambient lighting systems, flashes for cameras (with 20 adjustable color), or shop lighting systems.

The aforementioned components, as well as the claimed components and the components to be used in accordance with the invention in the described embodiments, are not subject to any special exceptions with respect to the size, shape, material selection, and technical concept, such that the selection criteria known in the pertinent 25 field can be applied without limitations.

Additional details, characteristics, and advantages of the invention are disclosed in the dependent claims and the following description of the respective Figure, which is given by way of example only and shows a preferred embodiment of the lighting device according to the invention.

30 Figure 1 is a highly schematic view of a color lighting device according to one embodiment of the present invention. The color lighting device comprises a

plurality of light-emitting sources 1a, 1b, 1c having a certain distance to each other. In the embodiment shown, each light source 1a, 1b, 1c consists of a single LED 1a, 1b, 1c, i.e. the LED 1a, 1b, 1c is the light source 1a, 1b, 1c itself.

Alternatively, each light source 1a, 1b, 1c may comprise a bundle of LEDs, 5 which is not illustrated explicitly. Each LED 1a, 1b, 1c is mounted on a substrate 3 that constitutes a heat sink. Each LED 1a, 1b, 1c comprises an adjacent photosensor 2a, 2b, 2c which is also fixed on said substrate 3. Each light-emitting diode 1a, 1b, 1c is connected to a single analog control circuit 4a, 4b, 4c comprising a comparator 5a, 5b, 5c, a driver 6a, 6b, 6c, and a low-pass filter 7a, 7b, 7c. In the embodiment shown, the 10 comparator 5a, 5b, 5c is an analog Schmitt trigger connected to the associated photosensor 2a, 2b, 2c via a related amplifier 12a, 12b, 12c. The reference signals are connected to a color controller interface 10 which translates the user input 11 into the reference signals. The control circuits 4a, 4b, 4c are connected in parallel for controlling the drive of each light-emitting diode 1a, 1b, 1c separately on the basis of a light output 15 detected by the associated photosensor 2a, 2b, 2c. Each photosensor 2a, 2b, 2c comprises a matched filter 8a, 8b, 8c. In the embodiment shown, the LED 1a emits red light, the LED 1b emits green light, and the LED 1c emits blue light. Certainly, the color lighting device may contain more than the colors mentioned here, which are separately controlled via the analog control circuit 4a, 4b, 4c. All circuits 4a, 4b, 4c are 20 electrically identical, and therefore the red circuit line 4a only will be described in the following.

During the illumination process of the color lighting device, the photosensor 2a detects the light output of the associated red light source 1a. In order to get the correct information about the light output of the diode 1a, the photosensor 2a comprises 25 said filter 8a, which transmits only the wavelength of the emitted light of the LED 1a. This means that the filtered photosensor 2a is insensitive to other colors. The measured photosignal is a voltage signal of the photosensor 2a, which is guided via amplifier 12a to the comparator 5a. In the embodiment described, the comparator 5a is a Schmitt trigger 5a which compares the voltage signal of the photosensor 2a with a reference 30 voltage signal. If the photovoltage signal is less than the reference voltage signal, the control circuit 4a provides a high output signal which increases the driving signal of the

light-emitting diode 1a. If the photovoltage signal is substantially equal to or greater than the reference voltage signal, the control circuit 4a provides a low output-signal which decreases the driving signal for the light-emitting diode 1a. The output of the Schmitt trigger 5a thus jumps between two voltage values.

5 The output of the Schmitt trigger 5a is connected to an amplifier 6a. The output of the amplifier 6a is applied to the low-pass filter 7a that is directly connected to the LED 1a. In the embodiment shown, the low-pass filter 7a has a cut-off frequency of 10 kHz. The described lighting device with the arranged control circuit 4a, 4b, 4c for each LED 1a, 1b, 1c allows an independent and parallel light output sensing of each
10 color of said lighting device. The use of an analog circuit 4a, 4b, 4c for each LED 1a, 1b, 1c, wherein the photosignal of the photosensor 2a, 2b, 2c is used as a feedback-signal, provides an inexpensive and easy setup. Complex components like analog digital converters and digital signal processors with software are not necessary for the described analog color point stabilization of the multi-lighting device.

15 According to the embodiment, the high output voltage signal is approximately 5 V. This causes an increase in the driving current for the light-emitting diode 1a. If the photovoltage signal is greater than the reference voltage signal, the control circuit 4a provides a low, i.e. zero output voltage signal, which decreases the driving current for the light-emitting diode 1a. That means that the amplifier does not
20 pass a current to the low-pass-filter 7a.

The LEDs 1a, 1b, 1c and the photosensors 2a, 2b, 2c are covered by an optical element 9 which is made of a transparent material.

LIST OF REFERENCE NUMERALS

- 1a light source, light-emitting diode, LED
- 1b light source, light-emitting diode, LED
- 1c light source, light-emitting diode, LED
- 5 2a photosensor
- 2b photosensor
- 2c photosensor
- 3 substrate
- 4a analog control circuit
- 10 4b analog control circuit
- 4c analog control circuit
- 5a comparator, Schmitt trigger
- 5b comparator, Schmitt trigger
- 5c comparator, Schmitt trigger
- 15 6a driver, amplifier
- 6b driver, amplifier
- 6c driver, amplifier
- 7a low-pass filter
- 7b low-pass filter
- 20 7c low-pass filter
- 8a optical filter
- 8b optical filter
- 8c optical filter
- 9 optic
- 25 10 color management unit
- 11 user input
- 12a amplifier
- 12b amplifier
- 12c amplifier

CLAIMS

5

1. A color lighting device comprising
 - at least one light-emitting source (1a,1b,1c) fixed on a common substrate (3),
 - each light-emitting source (1a,1b,1c) comprising at least one light-emitting diode (LED) (1a, 1b, 1c),
 - 10 - each light-emitting source (1a, 1b, 1c) comprising one photosensor (2a, 2b, 2c) that detects the light output of the associated source (1a,1b,1c) only, and
 - each light-emitting source (1a, 1b, 1c) being connected to an analog control circuit (4a, 4b, 4c) that controls the drive of each light source (1a, 1b, 1c) separately on the basis of a light output detected by the associated photosensor (2a, 2b, 2c),
 - 15 - each control circuit (4a,4b,4c) comprising a comparator (5a, 5b, 5c) connected to the associated photosensor (2a,2b,2c).

2. The color lighting device as claimed in claim 1, characterized in that the comparator (5a, 5b, 5c) is an analog Schmitt trigger (5a, 5b, 5c).

20

3. The color lighting device as claimed in claim 1 or 2, characterized in that the control circuit (4a, 4b, 4c) comprises a driver (6a, 6b, 6c) which is connected to the comparator (5a, 5b, 5c), the output of the driver (6a, 6b, 6c) being guided to a low-pass filter (7a, 7b, 7c) which is connected to the light source (1a, 1b, 1c).

25

4. The color lighting device according to any of the preceding claims, characterized in that the driver (6a, 6b, 6c) is an amplifier or a switch.

- 30 5. The color lighting device according to any of the preceding claims, characterized in that the photosensor (2a, 2b, 2c) is arranged on the substrate (3) next to the light source (1a,1b,1c), or the photosensor (2a, 2b, 2c) is positioned between the

light source (1a, 1b, 1c) and the substrate (3), or the substrate (3) is arranged between the photosensor (2a, 2b, 2c) and the light source (1a, 1b, 1c).

6. The color lighting device according to any of the preceding claims,
5 characterized in that the photosensor (2a, 2b, 2c) comprises an optical filter (8a, 8b, 8c).

7. The color lighting device according to any of the preceding claims,
characterized in that the optical filter (8a, 8b, 8c) comprises at least one layer that is
arranged on the photosensor (2a, 2b, 2c).

10 8. The color lighting device according to any of the preceding claims,
characterized in that the optical filter (8a, 8b, 8c) comprises a plurality of layers, which
are dielectric layers and/or conductive layers.

15 9. The color lighting device according to any of the preceding claims,
characterized in that the filter (8a, 8b, 8c) is sensitive only to the color of the light
produced by the associated light source (1a, 1b, 1c).

10. A method of controlling the light output of a color lighting device with
20 at least one light-emitting source (1a, 1b, 1c) fixed on a common substrate (3),
each light-emitting source (1a, 1b, 1c) comprising at least one light-emitting diode (1a, 1b,
1c),
each light-emitting source (1a, 1b, 1c) comprising one photosensor (2a, 2b, 2c) that
detects the light output only of the associated light source (1a, 1b, 1c), and
25 each light-emitting source (1a, 1b, 1c) being connected to an analog control circuit (4a,
4b, 4c) that controls the drive of each light-emitting source (1a, 1b, 1c) separately on
the basis of a light output detected by the associated photosensor (2a, 2b, 2c),
each control circuit (4a, 4b, 4c) comprising a comparator (5a, 5b, 5c) connected to the
associated photosensor (2a, 2b, 2c),
30 which method comprises the following steps:

detecting a photosignal that contains information on the actual light output of
the single light source (1a, 1b, 1c),

guiding the photosignal to the control circuit (4a, 4b, 4c), in which the comparator (5a, 5b, 5c) compares the photosignal with a reference signal, whereupon

if the photosignal < reference signal

5 the control circuit (4a, 4b, 4c) provides a high output signal that increases the driving signal for the light-emitting source (1a, 1b, 1c),

if the photosignal > reference signal

the control circuit (4a, 4b, 4c) provides a low outputsignal that decreases the driving signal for the light-emitting source (1a,1b,1c).

10

11. The method as claimed in claim 10, characterized in that the control circuit (4a, 4b, 4c) comprises a driver (6a, 6b, 6c) connected to the comparator (5a, 5b, 5c), the output of the driver (6a, 6b, 6c) being guided to a low-pass filter (7a, 7b, 7c) which is connected to the light source (1a, 1b, 1c), and the value of the low output signal being zero.

12. The method as claimed in claim 10 or 11, characterized in that the combination of low-pass- filter (7a, 7b, 7c) and comparator (5a, 5b, 5c) does not allow frequencies below 400 Hz.

20

13. The method according to any of the preceding claims 10 to 12, characterized in that the steps of claim 10 are performed continuously.

14. The method according to any of the preceding claims 10 to 13, 25 characterized in that the photosignal and the reference signal are voltage signals or current signals.

15. The method according to any of the preceding claims 10 to 14, 30 characterized in that the steps of claim 10 are performed simultaneously for all light-emitting sources (1a, 1b, 1c).

16. The method as in the claims 10 to 15 in combination with a color lighting device according to the claims 1 to 9.

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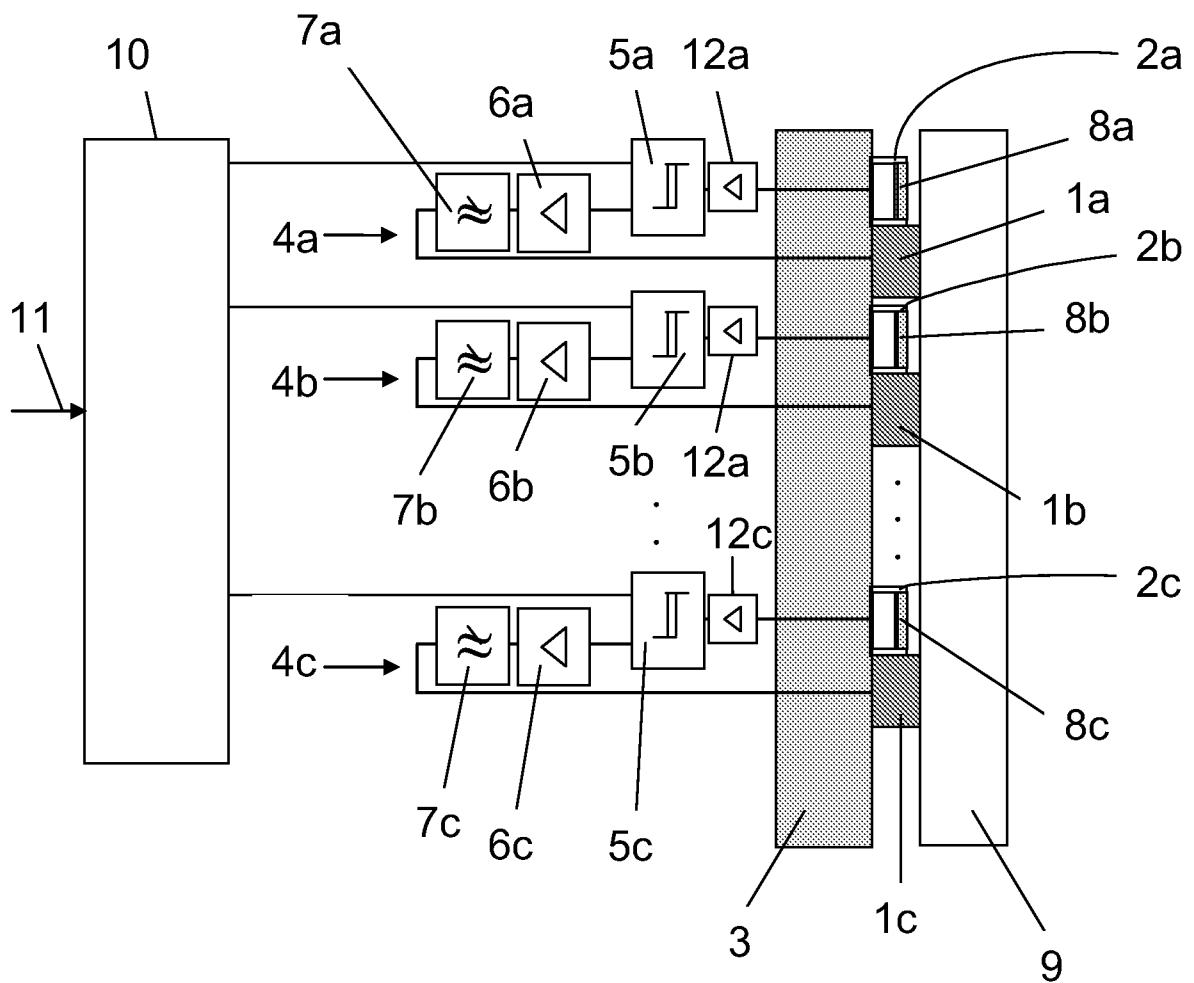


FIG. 1

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2006/053689

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B33/08

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|---|-----------------------|
| X | EP 1 152 642 A2 (AGILENT TECHNOLOGIES INC [US]) 7 November 2001 (2001-11-07) columns 2-5; figures 1,2 ----- | 1-16 |
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| A | WO 02/080625 A (KONINKL PHILIPS ELECTRONICS NV [NL]) 10 October 2002 (2002-10-10) the whole document ----- | 1-16 |
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