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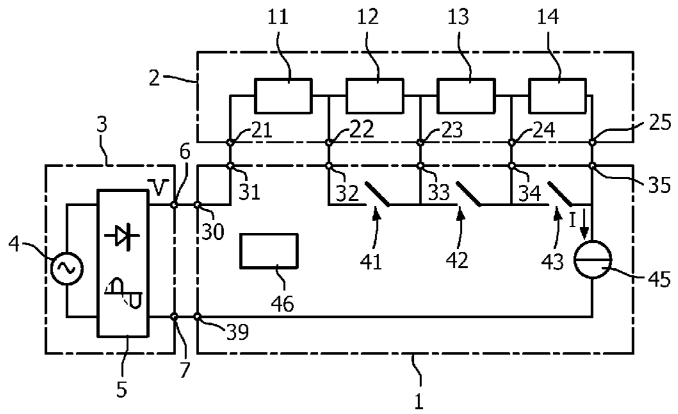

FIG. 1a

(57) Abstract: In a method of lighting at least part of a space, a light emitting diode (LED) string is used. The LED string comprises a first LED segment and at least one further LED segment,which are connected in series, each LED segment comprising at least one LED. The LED string is powered by a rectified AC voltage. The first LED segment is powered when the rectified AC voltage is above a first voltage level, and the first LED segment and the further LED segment are powered when the rectified AC voltage is above a second voltage level higher than the first voltage level. The first LED segment is arranged to radiate light to a first volume of the space, and the further LED segment is arranged to radiate light to a second volume of the space, the first volume being at least partly different from the second volume. The first volume may at least partly overlap the second volume.

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METHOD AND DEVICE FOR LIGHTING A SPACE USING AN LED STRING

FIELD OF THE INVENTION

The present invention relates to the field of LED (Light Emitting Diode) lighting. More in particular, the present invention relates to a method and a device for lighting a space, using an LED string of LED segments connected in series.

BACKGROUND OF THE INVENTION

US Patent No. 7,081,722 discloses a method and a circuit for driving LEDs in multiphase. A string of LEDs divided into groups connected to each other in series is provided. Each group is coupled to ground through separate conductive paths. A phase switch is provided in each conductive path. By increasing the input voltage, the string of LEDs are caused to turn on, group by group, in a sequence downstream the string.

In the field of LED lighting, a need exists to further enhance lighting functionality and to create specific spatially distributed lighting.

SUMMARY OF THE INVENTION

It would be desirable to provide a method and a device for lighting a space with spatially distributed lighting. It would also be desirable to provide spatially distributed lighting in a simple way and at reduced costs.

To better address this concern, in a first aspect according to the invention a method of lighting at least part of a space is provided, using a light emitting diode (LED) string comprising a first LED segment and at least one further LED segment, which are connected in series, each LED segment comprising at least one LED, the LED string being powered by a rectified AC voltage. The first LED segment is powered when the rectified AC voltage is above a first voltage level, and the first LED segment and the further LED segment are powered when the rectified AC voltage is above a second voltage level higher than the first voltage level. The first LED segment is arranged to radiate light to a first volume of the space, and the further LED segment is arranged to radiate light to a second volume of the space, the first volume being at least partly different from the second volume. The first LED segment emits light having first light properties, and the further LED segment emits light having second light properties being equal to, or different from, the light properties of the first LED segment. The light properties may comprise light intensity and light color.

The LED string, hereinafter also referred to as LED module, comprises a plurality of LED segments connected in series. Each LED segment may comprise one or more LEDs mutually connected as desired. The voltage of each LED segment may be the same as, or different from, other segments. The number of LED segments in a LED string may be chosen differently, and is at least two.

The LED string may comprise LED segments all radiating light of the same color.

In other embodiments, one or more first LED segments may emit light having a first color temperature, and one or more further LED segments may emit light having a second color temperature. The first color temperature of light emitted by one first LED segment may differ from a first color temperature of light emitted by another first LED segment, and the second color temperature of light emitted by one further LED segment may differ from a second color temperature of light emitted by another further LED segment. The first LED segment may emit red, orange, yellow or amber light, including any combination thereof, and including saturated or less saturated colors.

When the AC voltage is not dimmed, both the first LED segment(s) and the further LED segment(s) are powered during a half cycle of the mains voltage, where the mains voltage will exceed both the first voltage level and the second voltage level.

When driving a string of LED segments as described above with an undimmed rectified AC voltage, the LED segments will operate according to the voltage level applied. In a half cycle of the mains voltage, when the momentary voltage rises, initially the first LED segment will be powered above the first voltage level to radiate light, and then additionally, when the momentary voltage rises further, (a) further LED segment(s) may be powered above the second voltage level to radiate light, while the further LED segment(s) and the first LED segment subsequently cease to radiate light when the momentary voltage falls below the second voltage level and the first voltage level, respectively. When the first LED segment and the further LED segment(s) are arranged to light first and second volumes, respectively, which are at least partly different from one another, a proportion of the light generated by the string of LED segments lights the first volume, and another proportion lights the second volume(s).

When the AC voltage is dimmed, both the duration of powering the first LED segment(s) and the duration of powering the further LED segment(s) during a half cycle of the mains voltage are reduced. When the AC voltage is dimmed such that the first voltage level is exceeded but the second voltage level is not exceeded during a half cycle of the mains voltage, only the first LED segment(s) will be powered during the half cycle. Consequently, the higher the dimming, the more the first LED segment(s) will dominate the intensity and/or color temperature of the light emitted by the LED string as a whole.

When the string of LED segments is dimmed, such as by phase-angle cutting of the AC voltage, or by decreasing the voltage amplitude, or by a combination thereof, the ratio of the proportions of the light generated by the string of LED segments lighting the first and second volume(s), respectively, will change automatically, that is to say, according to the inherent properties (e.g. forward operating voltage) of the LED segments and the respective driver circuit operation. This insight has led to the present invention, where the changing ratio is used to design a particular spatial light distribution while dimming, which is suitable for a specific purpose. In this design, a light intensity and light color generated by LED segments may be taken into account.

An LED module is dimmed when it operates at a lower mean voltage than the nominal voltage for which it is designed. As the voltage is decreased, the LED module power and the light output decrease accordingly. A variable voltage for dimming an LED module is produced by a dimming device coupled between an AC voltage and the LED module. The dimmer may be a device for varying the voltage amplitude, however, usually it is a solid-state switching device, switching the AC voltage on and off at the mains voltage frequency, thereby supplying power pulses to the LED module.

The dimmer may operate by phase-cut dimming, either by switching the voltage off during a first portion of a half cycle of the voltage, and switching the voltage on during a last portion of a half cycle of the voltage (also referred to as forward phase-cut dimming), or by switching the voltage on during a first portion of a half cycle of the voltage, and switching the voltage off during a last portion of a half cycle of the voltage (also referred to as reverse phase-cut dimming). Forward phase-cut dimming is cheap, and uses robust electronics. Reverse phase-cut dimming is more expensive and requires more complex electronics, but some loads, such as electronic transformers, operate better and generate less audible noise when this type of dimming is used.

When a user sets a level of dimming on the dimmer (input), a light level results (output). In most dimmers, the output of the dimmer is not directly proportional to the input. Different dimmers produce different dimmer curves defining the relationship between level of dimming and light level.

In an embodiment of the method of the present invention, the first volume at least partly overlaps the second volume. In the overlapping part, the light intensity, when both the first LED segment and the further LED segment are in operation to emit light, is highest, while outside the overlapping part light intensities are lower. This may provide a gradually decreasing light intensity away from the overlapping part. Additionally, or alternatively, in the overlapping part, the light color, when both the first LED segment and the further LED segment are in operation to emit light, may be different from the light color outside the overlapping part, when the color of the light radiated by the first LED segment is different from the color of the light radiated by the further LED segment.

In a second aspect of the invention, an LED module for lighting at least part of a space is provided, the LED module comprising a string which comprises a first LED segment and at least one further LED segment connected in series, wherein each LED segment comprises at least one LED. The first LED segment is adapted to be powered when the rectified AC voltage is above a first voltage level, and the first LED segment and the further LED segment are adapted to be powered when the rectified AC voltage is above a second voltage level higher than the first voltage level. The first LED segment is arranged to radiate light to a first volume of the space, and the further LED segment is arranged to radiate light to a second volume of the space, the first volume being at least partly different from the second volume.

In an embodiment of the LED module, the first LED segment is adapted to radiate light in a beam having a first direction, and the further LED segment is adapted to radiate light in a beam having a second direction different from the first direction. Here, a direction of a beam of light may be taken to be represented by a vector starting in the center of the associated LED segment, pointing away from said center, and being located centrally in the beam of light.

In an embodiment, the first direction is opposite to the second direction. The first direction may be downwards, and the second direction may be upwards in a specific application of the LED module. Such an arrangement may be used in a table lamp, where dimming of the LED module will result in decreasing the proportion of the light radiated upward by the LED module relative to the proportion of the light radiated downward by the LED module, thereby creating an increasingly intimate lighting atmosphere while increasing dimming.

In an embodiment of the LED module, the first LED segment and the further LED segment radiate light in beams having the same radiating direction. In such an embodiment, each beam may light a different volume, while all beams overlap.

In a further aspect of the invention, an LED lighting module is provided, the LED lighting module comprising the LED module of the invention. The LED lighting module further comprises an LED driver circuit comprising: LED driver input terminals adapted to be connected to a rectified AC voltage; a switching device connected in parallel to each further LED segment; a current control device connected between the LED driver input terminals; and control circuitry for controlling an open state or a closed state of each switching device. The control circuitry is adapted to control each switching device so as to be in a closed state when the rectified AC voltage is below a predetermined voltage level, and to control the switching device connected to a further LED segment to be in an open state when the rectified AC voltage is above the predetermined voltage level.

In a further aspect of the invention, an LED lighting module is provided, the LED lighting module comprising the LED module of the invention. The LED lighting module further comprises an LED driver circuit comprising: LED driver input terminals adapted to be connected to a rectified AC voltage; a switching device connected in parallel to the first LED segment, and a switching device connected in parallel to each further LED segment; a current control device connected between the LED driver input terminals; and control circuitry for controlling an open state or a closed state of each switching device. The control circuitry is adapted to control the switching device connected in parallel to the first LED segment so as to be in an open state and the switching device connected in parallel to a further LED segment so as to be in a closed state when the rectified AC voltage is above a first voltage level and below a second voltage level higher than the first voltage level, respectively, and to control the switching device connected to a further LED segment so as to be in an open state when the rectified AC voltage is above the second voltage level.

In a further aspect of the invention, an LED lighting module is provided, the LED lighting module comprising the LED module of the invention. The LED lighting module further comprises an LED driver circuit comprising: LED driver input terminals adapted to be connected to a rectified AC voltage; for each LED segment, a current control device connected between one terminal of the LED segment and an LED driver input terminal; and control circuitry for controlling a current in each current control device. The control circuitry is adapted to control the current control device of the first LED segment so as to allow a current to flow when the rectified AC voltage is above a first voltage level, and so as to disallow a current to flow when the rectified AC voltage is above a second voltage level higher than the first voltage level.

In an embodiment of one of the LED lighting modules, at least one of the current control devices is adapted to pulse-width modulate the current flowing through it to provide an additional LED segment light output control.

In a further aspect of the invention, a dimmable LED lighting module is provided, the dimmable LED lighting module comprising the LED lighting module of the invention, a rectifier and a dimming device.

These and other aspects of the invention will be more readily appreciated as the same becomes better understood by reference to the following detailed description and considered in connection with the accompanying drawings in which like reference symbols designate like parts.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1a depicts a diagram of a first embodiment of an LED lighting circuit in which different modules are indicated by dash-dotted lines.

Fig. 1b depicts a diagram of a second embodiment of an LED lighting circuit in which different modules are indicate by dash-dotted lines.

Figure 2 depicts currents in different LED segments, as a function of the phase angle in a half cycle of the (rectified) AC voltage in the LED lighting circuit according to Fig. 1a.

Fig. 3 depicts simulation results of ratios of the light output of the different LED segments compared with the total light output of all LED segments, and average current, at a variation of a phase-cutting angle α of the (rectified) AC voltage in the LED lighting circuit according to Fig. 1a at the currents depicted in Fig. 2.

Fig. 4 depicts a detail of Fig. 3.

Fig. 5 depicts currents in different LED segments, as a function of the phase angle in a half cycle of the (rectified) AC voltage in the LED lighting circuit according to Fig. 1b.

Fig. 6 depicts simulation results of ratios of the light output of the different LED segments compared with the total light output of all LED segments, and average current, at a variation of a phase-cutting angle α of the (rectified) AC voltage in the LED lighting circuit according to Fig. 1b at the currents depicted in Fig. 5.

Figure 7 depicts currents in different LED segments, as a function of the phase angle in a half cycle of the (rectified) AC voltage in the LED lighting circuit according to Fig. 1a.

Fig. 8 depicts simulation results of ratios of the light output of the different LED segments compared with the total light output of all LED segments, and average current, at a variation of a phase-cutting angle α of the (rectified) AC voltage in the LED lighting circuit according to Fig. 1a at the currents depicted in Fig. 7.

Fig. 9 depicts measured graphs of color temperature versus light intensity for an embodiment of an LED string, and for a GLS (incandescent lamp).

Fig. 10 schematically depicts (part of) a lighting module comprising four LED segments of an LED string.

Fig. 11 depicts curves illustrating a relationship between a phase-cutting angle of the AC voltage in an LED lighting module, and a ratio between radiation from LED segments radiating in one direction, and radiation from LED segments radiating in another direction.

Fig. 12 schematically depicts a lighting device, in particular a side view of a table lamp comprising a lighting module similar to the one of Fig. 10.

Fig. 13 schematically illustrates beams of radiation emitted from different LED segments of a LED lighting module of the present invention.

Fig. 14 illustrates different areas illuminated by different LED segments of the lighting module of Fig. 13.

Figs. 15a, 15b, 15c and 15d illustrate different composite areas illuminated by different LED segments of different LED lighting modules of Fig. 13 arranged in a row.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1a depicts an embodiment of an LED driver circuit 1 for driving a LED module 2. The LED driver circuit 1 is adapted to be coupled to a power supply 3 which may comprise an AC voltage supply 4 coupled to a rectifier and dimming device 5.

The power supply 3 has output terminals 6, 7 for supplying a rectified AC voltage according to the voltage amplitude and frequency used locally. The voltage supplied by the power supply 3 may be a forward phase-cut voltage or a reverse phase-cut voltage to provide a dimming function by varying the average voltage at the output terminals, depending on the cutting angle set automatically or by a user in the rectifier and dimming device 5.

The LED module 2 comprises a plurality of LED segments 11, 12, 13, 14 connected in series. Each LED segment 11, 12, 13, 14 may comprise one or more LEDs mutually connected as desired. The voltage of each LED segment 11, 12, 13, 14 may be the same as, or different from, other segments, for example about 30 V, about 36 V, or about 70 V. The number of LED segments in a LED module may be chosen to be different, and is at least two. The LED module 2 has terminals 21, 22, 23, 24, and 25, whereby each LED segment is accessible by two terminals. LED segment 11 has terminals 21 and 22, LED segment 12 has terminals 22 and 23, LED segment 13 has terminals 23 and 24, and LED segment 14 has terminals 24 and 25. Each of the terminals 21, 22, 23, 24 and 25 is available for coupling to a LED driver circuit 1.

The LED driver circuit 1 comprises a plurality of terminals 30, 31, 32, 33, 34, 35 and 39. Terminals 30 and 39 are adapted to be coupled to output terminals 6, 7 of the power supply 3. Terminals 31, 32, 33, 34 and 35 are adapted to be coupled to the terminals 21, 22, 23, 24 and 25, respectively, of the LED module 2. The LED driver circuit 1 comprises switching devices 41, 42 and 43 connected between terminals 32 and 33, 33 and 34, and 34 and 35, respectively. Examples of switching devices suitable for use in the LED driver circuit 1 are switchable transistors, such as field effect transistors or bipolar transistors. A current control device 45 is connected between terminals 35 and 39 of the LED driver circuit 1. The LED driver circuit 1 further comprises control circuitry 46 operatively connected to the switching devices 41, 42 and 43 for, in use, bringing the switching devices 41, 42 and 43 into an open state (non-conducting) or a closed state (conducting) at a desired timing. An example of such timed operation is given below. The control circuitry 46 may further optionally be operatively connected to the current control device 45 to, in use, control the current flowing through the current control device 45 at a desired timing, which may also be pulse-width modulation.

It is noted that in an alternative embodiment, the rectifier and dimmer device 5 may be part of the LED driver circuit 1.

The combination of the LED driver circuit 1 and the LED module 2 will be referred to as LED lighting module.

Fig. 1b depicts an embodiment of an LED driver circuit 8 for driving the LED module 2 from the power supply 3. The configuration of the LED module 2 and the power supply 3 may be similar or identical to the configurations as explained with reference to Fig. 1a, and the same reference numerals have been used to identify components thereof.

The LED driver circuit 8 comprises a plurality of terminals 50, 51, 52, 53, 54, 55 and 59. Terminals 50 and 59 are adapted to be coupled to output terminals 6, 7 of the power supply 3. Terminals 51, 52, 53, 54 and 55 are adapted to be coupled to the terminals 21, 22, 23, 24 and 25, respectively, of the LED module 2. The LED driver circuit 8 comprises a plurality of current control devices 61, 62, 63 and 64 connected between terminals 52 and 59, 53 and 59, 54 and 59, and 55 and 59, respectively. The LED driver circuit 8 may further optionally comprise control circuitry 66 operatively connected to the current control devices 61, 62, 63 and 64 to, in use, control the current flowing through each of the current control devices 61, 62, 63, 64. An example of such operation is given below.

An LED segment 11, 12, 13, 14 emits a distinct color of light, when in use. The following colors of light are distinguished:

- cold white (CW) light having a high color temperature, e.g. of about 5,000 K;
- neutral white or normal white (NW) light having a color temperature lower than cold white, e.g. of about 4,000 K;
- warm white (WW) light, such as yellow or orange light, having a color temperture lower than NW;
- amber (AM) light having a color temperature lower than WW;
- red (RD) light having a color temperature lower than AM.

In the LED module 2, all LED segments may emit the same color of light. In other embodiments, at least one of the LED segments may emit NW light, WW light, AM light and/or RD light, and at least another one of the other LED segments may emit CW light, NW light (when the at least one of the LED segments does not emit NW light) and/or WW light (when the at least one of the LED segments does not emit NW or WW light). Thus, the following combinations of light emitted by different LED segments 11, 12, 13 and 14 may be present according to Table I below, where X indicates a combination of the light in the same column and row:

	NW	WW	AM	RD
CW	X	X	X	X
NW		X	X	X
WW			X	X

Table 1: color combinations in LED module

Fig. 2 illustrates an operation of an embodiment of the circuit of Fig. 1a, wherein LED segment 11 may emit WW or RD or AM or RD/AM light, and at least one of the other LED segments 12, 13 and 14 may emit light having a higher color temperature than LED segment 11. In other embodiments, the color temperature of the light emitted by the LED segments 11, 12, 13 and 14 may be the same. The mode of operation is constant current delivered by the power supply 3. In this mode of operation, the current through the LED segments is not adjusted as a function of the number of LED segments turned on.

In Fig. 2, curve V represents the rectified mains voltage V. As shown by curve V, in a half cycle (phase angle running from 0 – 180 degrees) of the rectified mains voltage, the amplitude of the voltage V increases from zero value at 0 degrees to a top value at 90 degrees, and recedes back to zero value at 180 degrees.

It is assumed that all LED segments 11, 12, 13, 14 have about the same on-voltage. It is further assumed that at 0 degrees all switching devices 41, 42 and 43 are in a closed state, or that at least one of the switching devices 41, 42 and 43 is in an open state.

When the voltage V increases from 0 degrees onwards, at about 11 degrees the voltage V is at a first level sufficient for a current I, amplitude-controlled by the current control device 45, to run in the LED segment 11. All switching devices 41, 42 and 43 should then be in a closed state, or be brought into a closed state, and the current I will flow through the LED segment 11, the closed switches 41, 42 and 43, and the current control device 45. The value of the current I flowing through the LED segment 11 is indicated by I11.

At about 23 degrees, the voltage V is at a second level sufficient for the LED segments 11 and 12 to be conducting, and for the current I, still controlled in amplitude by the current control device 45, to run in the series-connected LED segments 11 and 12. The switching device 41 should then be brought into an open state, while the switching devices 42 and 43 remain in a closed state, to allow the current I, already flowing through LED segment 11, to run also in LED segment 12. The current flowing through LED segment 12 is indicated by I12.

At about 36 degrees, the voltage V is at a third level sufficient for the LED segments 11, 12 and 13 to be conducting, and for the current I, still controlled in amplitude by the current control device 45, to run in the series-connected LED segments 11, 12 and 13. The switching device 41 should then remain in an open state, while the switching device 42 should be brought into an open state, and the swithching device 43 should remain in a closed state, to allow the current I, already flowing through LED segments 11 and 12, to run also in LED segment 13. The current flowing through LED segment 13 is indicated by I13.

At about 52 degrees, the voltage V is at a fourth level sufficient for the LED segments 11, 12, 13 and 14 to be conducting, and for the current I, still controlled in amplitude by the current control device 45, to run in the series-connected LED segments 11, 12, 13 and 14. The switching devices 41 and 42 should then remain in an open state, and the switching device 43 should be brought into an open state, to allow the current I, already flowing through LED segments 11, 12 and 13, to run also in LED segment 14. The current flowing through LED segment 14 is indicated by I14.

Between about 52 and about 128 degrees, the voltage V remains above the fourth level sufficient for the LED segments 11, 12, 13 and 14 to be conducting, and for the current I, still controlled in amplitude by the current control device 45, to run in the series-connected LED segments 11, 12, 13 and 14. All switching devices 41, 42 and 43 remain open.

At about 128 degrees, the voltage V decreases to below the fourth level, and becomes insufficient for the LED segment 14 to be conducting, but is still sufficient for the LED segments 11, 12 and 13 to be conducting, and for the current I, still controlled in amplitude by the current control device 45, to run in the series-connected LED segments 11, 12 and 13. The switching device 43 should then be brought into a closed state, while the switching devices 41 and 42 remain in an open state, to allow the current I to continue to run in the LED segments 11, 12 and 13. Current I14 becomes zero.

At about 144 degrees, the voltage V decreases to below the third level, and becomes insufficient for the LED segment 13 to be conducting, but is still sufficient for the LED segments 11 and 12 to be conducting, and for the current I, still controlled in amplitude by the current control device 45, to run in the series-connected LED segments 11 and 12. The switching device 42 should then be brought into a closed state, while the switching device 41 remains in an open state and the switching device 43 remains in a closed state, to allow the current I to continue to run in the LED segments 11 and 12. Current I13 becomes zero.

At about 157 degrees, the voltage V decreases to below the second level, and becomes insufficient for the LED segment 12 to be conducting, but is still sufficient for the LED segment 11 to be conducting, and for the current I, still controlled in amplitude by the current control device 45, to run in LED segment 11. The switching device 41 should then be brought into a closed state, while the switching devices 42 and 43 remain in a closed state, to allow the current I to continue to run in the LED segment 11. Current I12 becomes zero.

At about 169 degrees, the voltage V decreases to below the first level, and becomes insufficient for the LED segment 11 to be conducting. Current I11 becomes zero.

After about 169 degrees, each of the switching devices may be in an open or closed state. The voltage V is insufficient to have a current I flowing in any of the LED segments 11, 12, 13 or 14.

Fig. 3 illustrates the ratios R of the light output of the LED segments 11 (ratio R11), 12 (ratio R12), 13 (ratio R13) and 14 (ratio R14) compared with the total light output of the LED module 2 (vertical axis) at a variation of a phase-cutting angle α of the AC voltage (horizontal axis) in the rectifier and dimming device 5, for each LED segment 11, 12, 13, 14. At every phase-cutting angle α, the following equation holds true: R11 + R12 + R13 + R14 = 100%.

If the phase-cutting angle α is 0 degrees (no phase cutting), then the ratio R11 of the light output of LED segment 11 to the total light output of the LED module 2 as seen over a half cycle of the AC voltage, is about 33%. For LED segments 12, 13 and 14, the ratios R12, R13 and R14 are about 28%, 23% and 16%, respectively.

As can be understood from Fig. 2, and can be seen in Fig. 3, the ratios R11, R12, R13 and R14 remain the same when the phase-cutting angle α is between 0 degrees and 11 degrees, since it does not affect the conduction times of any of the LED segments. As can further be understood from Fig. 2, and can be seen in Fig. 3, the ratio R14 becomes zero when the phase-curring angle α is greater than 128 degrees, since LED segment 14 cannot conduct at such phase-cutting angles α. When the phase-cutting angle α is greater than 144 degrees, the ratio R13 becomes zero, since LED segment 13 cannot conduct at such phase-cutting angles α. When the phase-cutting angle α is greater than 157 degrees, the ratio R12 becomes zero, since LED segment 12 cannot conduct at such phase-cutting angles α. When the phase-cutting angle α is between 157 and 169 degrees, the ratio R11 becomes 100%, since LED segment 11 is the only one which would come into a conducting state during a half cycle of the voltage V. When the phase-cutting angle α is greater than 169 degrees, the ratio R11 becomes zero, since LED segment 11 cannot conduct at such phase-cutting angles α. In fact, none of the LED segments 11, 12, 13 or 14 can conduct when the phase-cutting angle α is greater than 169 degrees.

In Fig. 3, curve Iav shows the average current through the LED segments 11, 12, 13, 14 at different phase-cutting angles α.

Fig. 4 shows a detail of Fig. 3, i.e. curve R11 for phase-cutting angles between 30 degrees and 150 degrees, which is a typical operating range for a rectifier and dimming device 5. As illustrated by Fig. 3, for LED segments 12, 13 and 14, the respective ratios R12, R13 and R14 remain substantially the same, or decrease, when the phase-cutting angle α increases within the operating range of Fig. 4. However, the ratio R11 increases significantly when the phase-cutting angle α increases within the operating range of Fig. 4.

If the color temperature of the light emitted by the LED segment 11 is lower than the color temperature of at least one of the other LED segments 12, 13, 14, then the effect of dimming the LED string of the LED module 2 is that the color temperature of the light emitted by the LED segment 11 and at least LED segment 12 of the LED module 2 may decrease when the phase-cutting angle α increases, due to the LED segment 11 becoming dominant over one or more of the other LED segments 12, 13, 14, or in other words: the ratio R11 increases more than any of the ratios R12, R13, R14. As a result, when dimming the LED module 2, the (overall) color temperature of the light emitted by LED segment 11 and one or more of the LED segments 12, 13 and 14 may exhibit a decrease similar to that of an incandescent lamp. The user of the LED module may perceive a color behavior which resembles a BBL (black body line) behavior.

As an example, at least the LED segment 11 may emit RD light, or RD/AM light, whereas at least one of the other LED segments 12, 13 and 14 may emit WW, NW and/or CW light.

In alternative embodiments, all LED segments may emit light having the same color temperature.

Fig. 5 illustrates an operation of an embodiment of the circuit of Fig. 1b, wherein the LED segment 11 may emit WW or RD or AM or RD/AM light, and at least one of the LED segments 12, 13 and 14 may emit light having a higher color temperature than the LED segment 11. In other embodiments, the color temperature of the light emitted by the LED segments 11, 12, 13 and 14 may be the same. The mode of operation is constant power delivered by the power supply 3. In this mode of operation, the current through the LED segments is adjusted as a function of the number of LED segments turned on.

In Fig. 5, curve V represents a half cycle (phase angle running from 0 – 180 degrees) of the rectified mains voltage V.

It is assumed that all LED segments 11, 12, 13, 14 have about the same on-voltage.

When the voltage V increases from 0 degrees onwards, at about 11 degrees the voltage V is at a first level sufficient for a current I having a value I1, amplitude-controlled by current control device 61, to run in LED segment 11. No current flows in the other LED segments 12, 13, 14.

At about 23 degrees, the voltage V is at a second level sufficient for the LED segments 11 and 12 to be conducting. The current I is adjusted to have a value I2, amplitude-controlled by current control device 62, to run in series-connected LED segments 11 and 12. Current control device 61 is controlled by control circuitry 66 not to conduct current. No current flows in the other LED segments 13 and 14.

At about 36 degrees, the voltage V is at a third level sufficient for the LED segments 11, 12 and 13 to be conducting. The current I is adjusted to have a value I3, amplitude-controlled by current control device 63, to run in series-connected LED segments 11, 12 and 13. Current control devices 61 and 62 are controlled by control circuitry 66 not to conduct current. No current flows in the LED segment 14.

At about 52 degrees, the voltage V is at a fourth level sufficient for the LED segment 11, 12, 13 and 14 to be conducting. The current is adjusted to have a value I4, amplitude-controlled by current control device 64, to run in series-connected LED segments 11, 12, 13 and 14. Current control devices 61, 62 and 63 are controlled by control circuitry 66 not to conduct current.

Between about 52 and about 128 degrees, the voltage V remains above the fourth level sufficient for the LED segments 11, 12, 13 and 14 to be conducting, and for the current I, still controlled in amplitude by the current control device 64, to run in the series-connected LED segments 11, 12, 13 and 14. All current control devices 61, 62 and 63 are in an open state, i.e. do not conduct current.

At about 128 degrees, the voltage V decreases below the fourth level, and becomes insufficient for the LED segment 14 to be conducting, but is still sufficient for the LED segments 11, 12 and 13 to be conducting, and for the current I to run in the series-connected LED segments 11, 12 and 13.The current control device 63 then adjusts the amplitude of the current I to have a value I3. Current control devices 61 and 62 are controlled by control circuitry 66 not to conduct current.

At about 144 degrees, the voltage V decreases below the third level, and becomes insufficient for the LED segments 13 and 14 to be conducting, but is still sufficient for the LED segments 11 and 12 to be conducting, and for the current I to run in the series-connected LED segments 11 and 12. The current control device 62 then adjusts the amplitude of the current I to a value I2. Current control device 61 is controlled by control circuitry 66 not to conduct current.

At about 157 degrees, the voltage V decreases below the second level, and becomes insufficient for the LED segments 12, 13 and 14 to be conducting, but is still sufficient for the LED segment 11 to be conducting, and for the current I to run in LED segment 11. The current control device 61 then adjusts the amplitude of the current I to a value I1.

At about 169 degrees, the voltage V decreases below the first level, and becomes insufficient for LED segment 11 to be conducting. Current I becomes zero.

Beyond about 169 degrees, the voltage V is insufficient to have a current I flow in any of the LED segments 11, 12, 13 or 14.

Fig. 6 illustrates the ratios R of the light output of the LED segments 11 (ratio R11), 12 (ratio R12), 13 (ratio R13) and 14 (ratio R14) compared with the total light output of the LED module 2 (vertical axis) at a variation of a phase-cutting angle α of the AC voltage (horizontal axis) in the rectifier and dimming device 5, for each LED segment 11, 12, 13, 14. At every phase-cutting angle α, the following equation holds true: R11 + R12 + R13 + R14 = 100%.

If the phase-cutting angle α is 0 degrees (no phase cutting), then the ratio R11 of the light output of LED segment 11 to the total light output of the LED module 2 as seen over a half cycle of the AC voltage, is about 42%. For LED segments 12, 13 and 14, the ratios R12, R13 and R14 are about 27%, 19% and 12%, respectively.

As can be understood from Fig. 5, and can be seen in Fig. 6, the ratios R11, R12, R13 and R14 remain the same when the phase-cutting angle α is between 0 degrees and 11 degrees, since at these values it does not affect the conduction times of any of the LED segments. As can further be understood from Fig. 5, and can be seen in Fig. 6, the ratio R14 becomes zero when the phase-curring angle α is greater than 128 degrees, since LED segment 14 cannot conduct at such phase-cutting angles α. When the phase-cutting angle α is greater than 144 degrees, the ratio R13 becomes zero, since LED segment 13 cannot conduct at such phase-cutting angles α. When the phase-cutting angle α is greater than 157 degrees, the ratio R12 becomes zero, since LED segment 12 cannot conduct at such phase-cutting angles α. When the phase-cutting angle α is between 157 and 169 degrees, the ratio R11 becomes 100%, since LED segment 11 is the only one which would come into a conducting state during a half cycle of the voltage V. When the phase-cutting angle α is greater than 169 degrees, the ratio R11 becomes zero, since LED segment 11 cannot conduct at such phase-cutting angles α. In fact, none of the LED segments 11, 12, 13 or 14 can conduct when the phase-cutting angle α is greater than 169 degrees.

In Fig. 6, curve Iav shows the average current through the LED segments 11, 12, 13, 14 at different phase-cutting angles α.

It follows from Fig. 6 that the effect of dimming the LED string of the LED module 2 is that the color temperature of the light emitted by the LED module 2 may decrease when the phase-cutting angle α increases, due to the LED segment 11 becoming dominant over the other LED segments 12, 13, 14, or in other words: the ratio R11 increases more than any of the ratios R12, R13, R14. As a result, when dimming the LED module 2, the (overall) color temperature of the light emitted by LED segment 11 and one or more of the LED segments 12, 13 and 14 may decrease in a way similar to an incandescent lamp.

Fig. 7 illustrates an operation of an embodiment of the circuit of Fig. 1a, wherein the LED segment 11 may emit WW or RD or AM or RD/AM light, and at least one of the LED segments 12, 13 and 14 may emit light having a higher color temperature than the LED segment 11. In other embodiments, the color temperature of the light emitted by the LED segments 11, 12, 13 and 14 may be the same. The mode of operation delivers 50% modulated LED segment current by the power supply 3. In this mode of operation, the current through the LED segments varies over a half cycle of the voltage V.

In Fig. 7, curve V represents a half cycle (0 – 180 degrees) of the rectified mains voltage V.

It is assumed that all LED segments 11, 12, 13, 14 have about the same on-voltage.

For a description of the circuit of Fig. 1a in the mode of operation illustrated in Fig. 7, reference is made to the description of Fig. 3 above, where the only difference is that once a current I flows through an LED segment, it is 50% pulse width modulated.

Fig. 8 illustrates the ratios R of the light output of the LED segments 11 (ratio R11), 12 (ratio R12), 13 (ratio R13) and 14 (ratio R14) compared with the total light output of the LED module 2 (vertical axis) at a variation of a phase-cutting angle α of the AC voltage (horizontal axis) in the rectifier and dimming device 5, for each LED segment 11, 12, 13, 14. At every phase-cutting angle α, the following equation holds true: R11 + R12 + R13 + R14 = 100%.

When the phase-cutting angle α is 0 degrees (no phase cutting), the ratio R11 of the light output of LED segment 11 in the total light output of the LED module 2 as seen over a half cycle of the AC voltage, is about 33%. For LED segments 12, 13 and 14, the ratios R12, R13 and R14 are about 28%, 23% and 16%, respectively.

As can be understood from Fig. 7, and can be seen in Fig. 8, the ratios R11, R12, R13 and R14 remain the same when the phase-cutting angle α is between 0 degrees and 11 degrees, since at these values it does not affect the conduction times of any of the LED segments. As can further be understood from Fig. 7, and can be seen in Fig. 8, the ratio R14 becomes zero when the phase-cutting angle α is greater than 128 degrees, since LED segment 14 cannot conduct at such phase-cutting angles α. When the phase-cutting angle α is greater than 144 degrees, the ratio R13 becomes zero, since LED segment 13 cannot conduct at such phase-cutting angles α. When the phase-cutting angle α is greater than 157 degrees, the ratio R12 becomes zero, since LED segment 12 cannot conduct at such phase-cutting angles α. When the phase-cutting angle α is between 157 and 169 degrees, the ratio R11 becomes 100%, since LED segment 11 is the only one which would come into a conducting state during a half cycle of the voltage V. When the phase-cutting angle α is greater than 169 degrees, the ratio R11 becomes zero, since LED segment 11 cannot conduct at such phase-cutting angles α. In fact, none of the LED segments 11, 12, 13 or 14 can conduct when the phase-cutting angle α is greater than 169 degrees.

In Fig. 8, curve Iav shows the average current through the LED segments 11, 12, 13, 14 at different phase-cutting angles α.

It follows from Fig. 8 that the effect of dimming the LED string of the LED module 2 is that the color temperature of the light emitted by the LED module 2 may decrease when the phase-cutting angle α increases, due to the LED segment 11 becoming dominant over the other LED segments 12, 13, 14, or in other words: the ratio R11 increases more than any of the ratios R12, R13, R14. As a result, when dimming the LED module 2, the (overall) color temperature of the light emitted by the LED segment 11 and one or more of the LED segments 12, 13 and 14 may decrease in a way similar to an incandescent lamp.

When comparing Figs. 3 (in conjuction with 4), 6 and 8, it appears that in all three scenarios, for LED segments 12, 13 and 14, the respective ratios R12, R13 and R14 remain substantially the same, or decrease, in a repesentative operating range of the phase-cutting angle α, such as the operating range illustrated in Fig. 4. However, the ratio R11 increases significantly when the phase-cutting angle α increases within the operating range. The ratio R11 may additionally be adjusted by adjusting the current flowing through LED segment 11 by a predetermined control of the current control devices 45 (Figs. 1a, 2, 3, 4, 7 and 8) or 61 (Figs. 1b, 5 and 6), respectively, possibly supplemented by a predetermined control of the current control devices 62, 63 and/or 64 (Figs. 1b, 5 and 6).

It is noted that the LED driver circuit 1 in Fig. 1a has switching devices 41, 42 and 43 which are adapted so as to be connected in parallel with respective LED segments 12, 13 and 14. For LED segment 11, there is no respective switching device. However, in an alternative embodiment of the LED driver circuit 1, a switching device may be connected in parallel with LED segment 11, and operatively connected to control circuitry 46 for opening and closing the switching device in a controlled manner. In such circumstances, when the voltage V is at a first level, any of the LED segments 11, 12, 13, 14 may be selected to conduct current I, by bringing its respective switching device into an open state. This means that the LED segment 11, in that case, does not need to be the first LED segment to be conducting, and does not need to emit light having a color temperature which is lower than the color temperature of at least one of the other LED segments. The first LED segment to be conducting and to emit light having a color temperature lower than the color temperature of at least one of the other LED segments may be selected to be any of the LED segments 11, 12, 13 or 14, when the LED driver circuit has a switching device adapted to be connected in parallel to each one of the LED segments. In other embodiments, the color temperature of all LED segments may be the same.

In the above description of operations of the LED driver circuits 1 and 8, as shown in Figs. 1a and 1b, respectively, it has been assumed that all LED segments have about the same on-voltage, i.e. the voltage at which the LED segment starts to conduct current. However, different LED segments may have different on-voltages, which will influence the phase angles at which the LED segment concerned may start or stop to conduct and emit light.

Fig. 9 shows a first graph, marked EMB, of measurements of the color temperature T (K) of an embodiment of a LED module comprising six LED segments of 50 V each, where the first LED segment emits amber light, and the other five LED segments emit white light, plotted against the light intensity LI (%) of the LED module over a dimming range. For comparison, the color temperature of a common GLS (incandescent lamp) is plotted against its light intensity in the same diagram. As can be seen, both for the LED module and the GLS, the color temperature of the emitted light as a whole decreases in a similar way, demonstrating that the LED module as a whole shows a similar behaviour of the color temperature of its emitted light as a GLS.

Fig. 10 shows an LED module having a support 70 on which four (4) LED segments 11, 12, 13 and 14 are mounted. The LED segments 11, 12, 13 and 14 may be part of an LED module 2 as depicted in Fig. 1a or 1b. The LED segments 11, 12, 13 and 14 are connected in series, and may each comprise one or more LEDs mutually connected as desired (series, parallel, or series-parallel). The operating voltage of each LED segment 11, 12, 13, 14 may be the same as, or different from, other segments, for example about 30 V, about 36 V, or about 70 V. The number of LED segments in a LED module may be chosen differently, and is at least two. In the arrangement of Fig. 10, the color and/or the intensity of the light emitted by each of the LED segments 11, 12, 13 and 14 at a normal operating voltage may be the same as one or more of the other LED segments, or different therefrom, as explained above.

For the following explanation, it is assumed that LED segments 11 and 12 on the support 70 of the LED module of Fig. 10 radiate light downwards, while LED segments 13 and 14 of the LED module of Fig. 10 radiate light upwards.

When the LED segments 11, 12, 13 and 14 are included in an LED lighting circuit as shown in Fig. 1a or 1b, and operated by a phase-cut voltage in a dimming operation, e.g. as explained by reference to Fig. 3 or Fig. 6, respectively, a ratio Rdu of the intensity of light radiated downwards (by the LED segments 13, 14) to the intensity of light radiated upwards (by the LED segments 11, 12) may be measured as a function of a conduction angle β (where $\beta = 180^o - \alpha$, with α being a phase-cut angle in forward (leading edge) phase-cut dimming or in reverse (trailing edge) phase-cut dimming). A result of such measurements is shown in the graphs of Fig. 11, where the curve marked FD has been obtained for forward phase-cut dimming, and the curve marked RD has been obtained for reverse phase-cut dimming. Both curves show that at a relatively small amount of dimming, i.e. large (e.g. more than 70°) conduction angles β (corresponding to phase-cut angles e.g. smaller than 110°), the proportion of light radiated downwards compared to the proportion of light radiated upwards may be relatively constant. However, with decreasing conduction angles β (corresponding to increasing phase-cut angles α), the ratio of light radiated downwards to light radiated upwards increases such that most light is radiated downwards.

As illustrated in Fig. 12, when the LED module of Fig. 10 is operated as illustrated in Fig. 11, a table lamp 71 having a lampshade 75 comprising a support 70 carrying the LED segments 11, 12, 13, 14, may radiate a beam of light 72 downwards and a beam of light 73 upwards. At large conduction angles β, light is radiated both downwards in beam 72 and upwards in beam 73. As the conduction angle β decreases, the light radiated upwards in beam 73 decreases, while the light radiated downwards in beam 72 may also decrease, however, to a lesser extent. As the conduction angle β decreases further, the point will be reached where no light is radiated upwards anymore, while light is still radiated downwards. Accordingly, by operating a string of LED segments 11, 12, 13 and 14, in the manner explained above, enhanced control of the lighting atmosphere is obtained as compared to conventional dimming, where both light radiated upwards and light radiated downwards from the table lamp 71 would be affected by dimming of the LED module in the lamp. If the different LED segments 11, 12, 13 and 14 radiate light of the same color, then the ratio of intensities of the light radiated in beam 72 to the light radiated in beam 73 is affected by dimming the LED module in the lamp. If the different LED segments 11, 12, 13 and 14 radiate light of different colors, then the ratio of intensities of the light radiated in beam 72 to the light radiated in beam 73, as well as the color of the light in each of the beams 72, 73, may be affected by dimming the LED module of the lamp.

Fig. 13 illustrates another configuration of LED segments 11, 12, 13 and 14 on a support 80 of a LED module. All LED segments 11, 12, 13 and 14 radiate light in the same direction. As an example, LED segment 11 radiates light in a beam B11, LED segment 12 radiates light in a beam B12 which is wider than beam B11, LED segment 13 radiates light in a beam B13 which is wider than beams B11 and B12, and LED segment 14 radiates light in a beam B14 which is wider than beams B11, B12 and B13. All beams B11, B12, B13 and B14 demonstrate an overlap.

Fig. 14 illustrates exemplary areas A11, A12, A13 and A14 illuminated by the beams B11, B12, B13 and B14, respectively. Thus, an area A11, A12, A13 and A14 can be seen as a cross-section of the beam B11, B12, B13 and B14, respectively, where the beams each at least partly define a volume. It can be seen that in one direction, the areas A11, A12, A13 and A14 have the same dimension, whereas in a direction at right angles to said one direction, area A14 is wider than area A13, area A13 is wider than area A12, and area A12 is wider than area A11.

When the string of LED segments 11, 12, 13 and 14 is not dimmed, an area A14 will be illuminated such that the light intensity and/or the light color within area A11 may be different from the light intensity and/or the light color within area A12 outside area A11, since all LED segments 11, 12, 13 and 14 provide light (having the same or different intensities and/or colors). The same applies to area A13 outside area A12, and to area A14 outside area A13. When dimming the string of LED segments 11, 12, 13 and 14, such as by phase-cut dimming and/or voltage-amplitude dimming, gradually less light will be provided to area A14 outside area A13, area A13 outside area A12, and area A12 outside area A11, until the point is reached where only light is provided to area A11. Accordingly, the illuminated area narrows when dimming increases.

When a chain of LED modules, each comprising LED segments 11, 12, 13 and 14, is arranged in a spaced configuration along a line to illuminate, for example, a corridor having a length and a width, with said line extending at the upper part of the corridor in the length direction thereof, and the light is directed to the floor of the corridor, the corridor can be illuminated as illustrated in Figs. 15a, 15b, 15c and 15d. If all (in the non-limiting, illustrated example: four) LED modules are dimmed in the same way, then, in a non-dimming state, a string of areas A14-1, A14-2, A14-3 and A14-4 will be illuminated, as a result of which the light intensity and/or the light color within areas A11-1, A11-2, A11-3 and A11-4 may be different from the light intensity and/or the light color within areas A12-1, A12-2, A12-3 and A12-4 outside areas A11-1, A11-2, A11-3 and A11-4, since all LED segments 11, 12, 13 and 14 of all LED modules provide light (having the same or different intensities and/or colors). The same applies to areas A13-1, A13-2, A13-3 and A13-4 outside areas A12-1, A12-2, A12-3 and A12-4, and to areas A14-1, A14-2, A14-3 and A14-4 outside areas A13-1, A13-2, A13-3 and A13-4. This is illustrated in Fig. 15d. When dimming the string of LED segments 11, 12, 13 and 14 of the LED modules, such as by phase-cut dimming and/or voltage amplitude dimming, gradually less light will be provided to areas A14-1, A14-2, A14-3 and A14-4 outside areas A13-1, A13-2, A13-3 and A13-4, until areas A14-1, A14-2, A14-3 and A14-4 outside areas A13-1, A13-2, A13-3 and A13-4 are not illuminated anymore (as illustrated in Fig. 15c), gradually less light will be provided to areas A13-1, A13-2, A13-3 and A13-4 outside areas A12-1, A12-2, A12-3 and A12-4, until areas A13-1, A13-2, A13-3 and A13-4 outside areas A12-1, A12-2, A12-3 and A12-4 are not illuminated anymore (as illustrated in Fig. 15b), and gradually less light will be provided to areas A12-1, A12-2, A12-3 and A12-4 outside areas A11-1, A11-2, A11-3 and A11-4, until the point is reached where only light is provided to areas A11-1, A11-2, A11-3 and A11-4 (as illustrated in Fig. 15a). Accordingly, the illuminated elongated area narrows when dimming increases. Such dimming of LEDs lighting a corridor is useful to adapt the width of the lighting to a use condition of the corridor, e.g. no dimming and consequently full width in periods of normal use, and adapted dimming in periods of reduced use, while maximum dimming may be adapted to maintain a safe lighting level in a central region of a corridor, while reducing the power consumption of the LED modules.

The invention as illustrated and described above is generally applicable at different mains voltages and mains frequencies, such as 230 V, 50 Hz in Europe or 110 V, 60 Hz in the USA. At 50 Hz, a half cycle (0 – 180 degrees) of the mains voltage takes 10 ms. At 60 Hz, a half cycle of the mains voltage takes 0.83 ms.

As explained above, in a method of lighting at least part of a space, a light emitting diode (LED) string is used. The LED string comprises a first LED segment and at least one further LED segment connected in series, each LED segment comprising at least one LED. The LED string is powered by a rectified AC voltage. The first LED segment is powered when the rectified AC voltage is above a first voltage level, and the first LED segment and the further LED segment are powered when the rectified AC voltage is above a second voltage level higher than the first voltage level. The first LED segment is arranged to radiate light to a first volume of the space, and the further LED segment is arranged to radiate light to a second volume of the space, the first volume being at least partly different from the second volume. The first volume may at least partly overlap the second volume.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope thereof.

CLAIMS:

1. A method of lighting at least part of a space, using a light emitting diode (LED) string comprising a first LED segment (11) and at least one further LED segment (12, 13, 14), which are connected in series, each LED segment comprising at least one LED, the LED string being powered by a rectified AC voltage,

wherein the first LED segment is powered when the rectified AC voltage is above a first voltage level, and the first LED segment and the further LED segment are powered when the rectified AC voltage is above a second voltage level higher than the first voltage level, and

wherein the first LED segment is arranged to radiate light to a first volume of the space, and the further LED segment is arranged to radiate light to a second volume of the space, the first volume being at least partly different from the second volume.

2. The method of claim 1, wherein the first volume at least partly overlaps the second volume.

3. An LED module (2) for lighting at least part of a space, the LED module comprising a LED string comprising a first LED segment (11) and at least one further LED segment (12, 13, 14) connected in series, wherein each LED segment comprises at least one LED;

wherein the LED string is adapted to be powered by a rectified AC voltage;

wherein the first LED segment is adapted to be powered when the rectified AC voltage is above a first voltage level, and the first LED segment and the further LED segment are adapted to be powered when the rectified AC voltage is above a second voltage level higher than the first voltage level, and

wherein the first LED segment is arranged to radiate light to a first volume of the space, and the further LED segment is arranged to radiate light to a second volume of the space, the first volume being at least partly different from the second volume.

4. The LED module of claim 3, wherein the first LED segment is adapted to radiate light in a beam having a first direction, and the further LED segment is adapted to radiate light in a beam having a second direction different from the first direction.

5. The LED module of claim 4, wherein the first direction is opposite to the second direction.

6. The LED module of claim 3, wherein the first LED segment and the further LED segment radiate light in beams (B11, B12, B13, B14) having the same radiating direction.

7. The LED module of claim 3, wherein the color temperature of the light radiated by the first LED segment is different from the color temperature of the light radiated by the further LED segment.

8. An LED lighting module comprising:
the LED module (2) of claim 3; and
an LED driver circuit (1) comprising:
- LED driver input terminals (50, 59) adapted to be connected to a rectified AC voltage;
- a switching device (41, 42, 43) connected in parallel to each further LED segment;
- a current control device (45) connected between the LED driver input terminals; and
- control circuitry (46) for controlling an open state or a closed state of each switching device, the control circuitry being adapted to control each switching device so as to be in a closed state when the rectified AC voltage is below a predetermined voltage level, and to control the switching device connected to a further LED segment so as to be in an open state when the rectified AC voltage is above the predetermined voltage level.

9. An LED lighting module comprising:
the LED module (2) of claim 3; and
an LED driver circuit (1) comprising:

- LED driver input terminals (50, 59) adapted to be connected to a rectified AC voltage;
- a switching device connected in parallel to the first LED segment, and a switching device connected in parallel to each further LED segment;
- a current control device (45) connected between the LED driver input terminals; and
- control circuitry (46) for controlling an open state or a closed state of each switching device, the control circuitry being adapted to control the switching device connected in parallel to the first LED segment so as to be in an open state and the switching device connected in parallel to a further LED segment to be in a closed state when the rectified AC voltage is above a first voltage level and below a second voltage level higher than the first voltage level, and to control the switching device connected to a further LED segment so as to be in an open state when the rectified AC voltage is above the second voltage level.

10. An LED lighting module comprising:
the LED module (2) of claim 3; and
an LED driver circuit (1) comprising:
- LED driver input terminals (50, 59) adapted to be connected to a rectified AC voltage;
- for each LED segment, a current control device (61, 62, 63, 64) connected between one terminal of the LED segment and an LED driver input terminal (59); and
- control circuitry (66) for controlling a current in each current control device, the control circuitry being adapted to control the current control device of the first LED segment so as to allow a current to flow when the rectified AC voltage is above a first voltage level, and disallow a current to flow when the rectified AC voltage is above a second voltage level higher than the first voltage level.

11. The LED lighting module of any of claims 8 to 11, wherein at least one of the current control devices is adapted to pulse-width modulate the current flowing through it.

12. A dimmable LED lighting module, comprising the LED lighting module according to any of claims 8 to 11, and a rectifier and a dimming device.

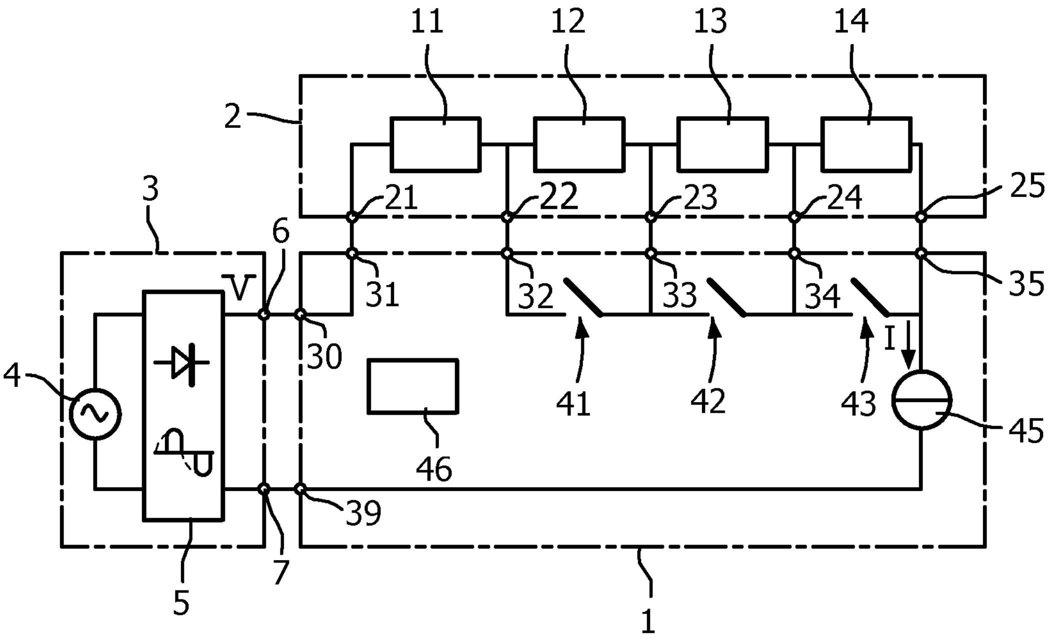
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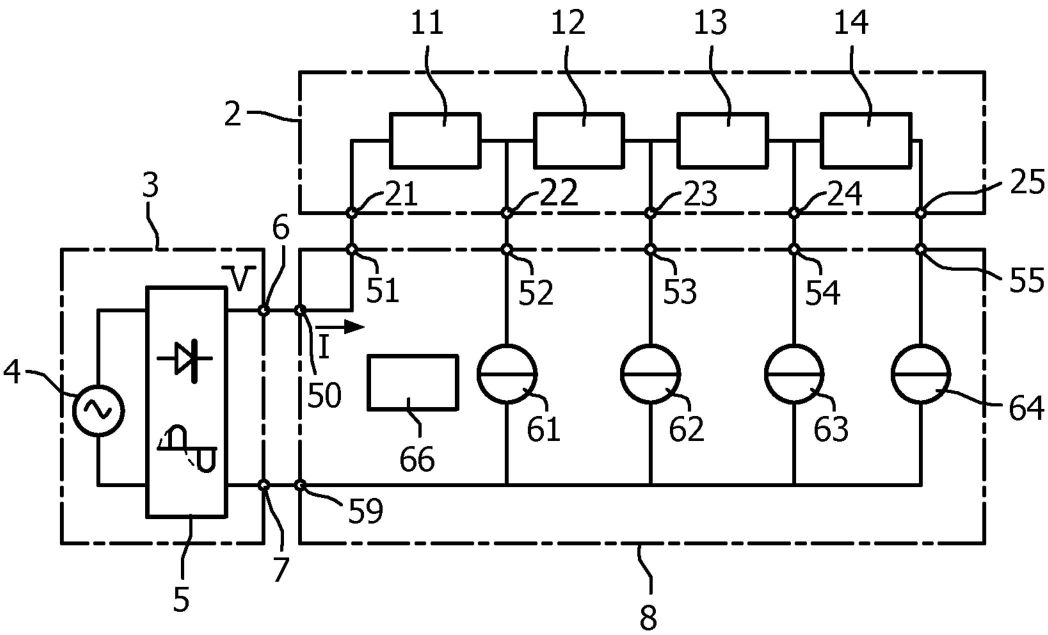
FIG. 1a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V
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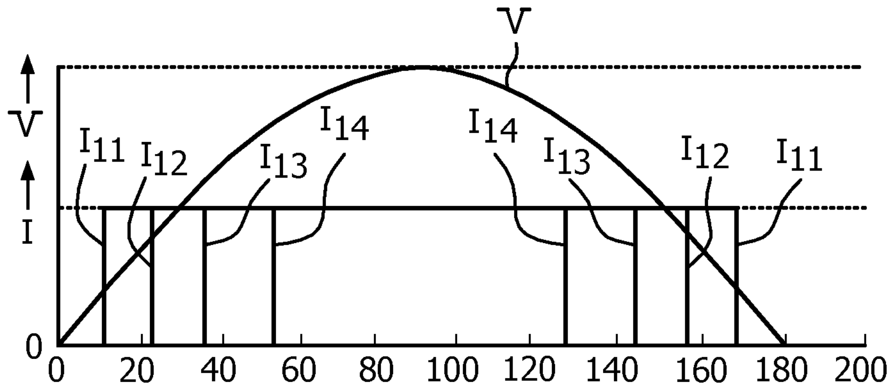
FIG. 1b


V
V
I
I11
I12
I13
I14
I14
I13
I12
I11
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100
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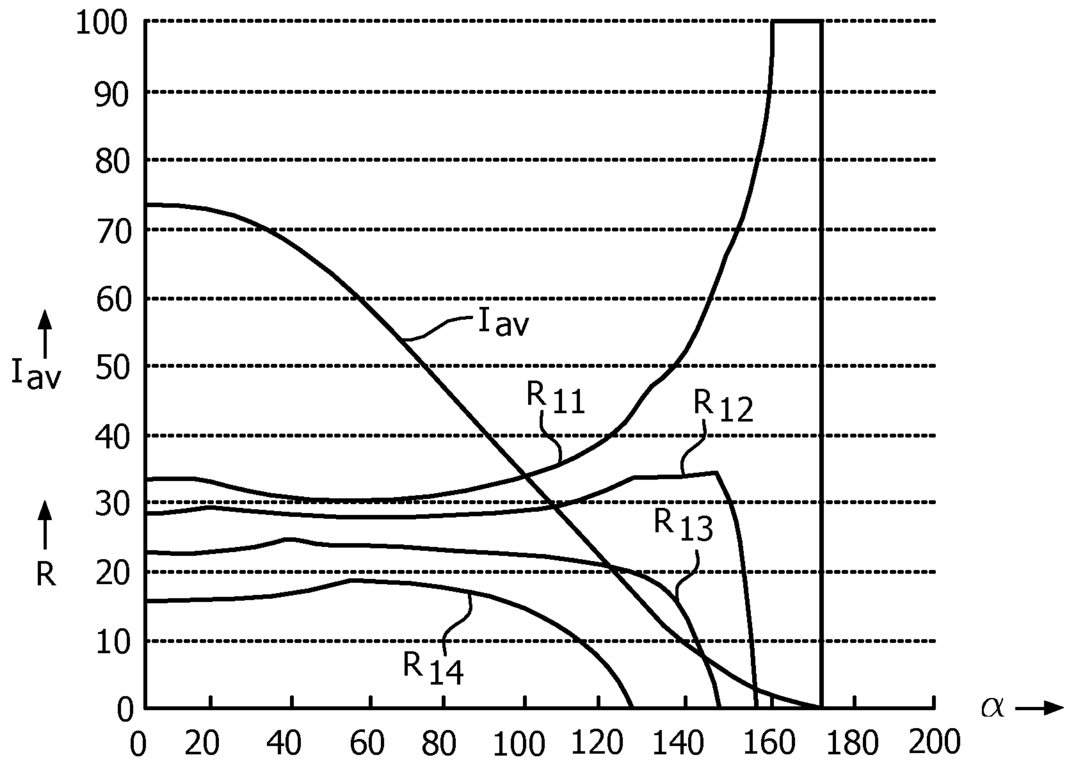
140
160
180
200

FIG. 2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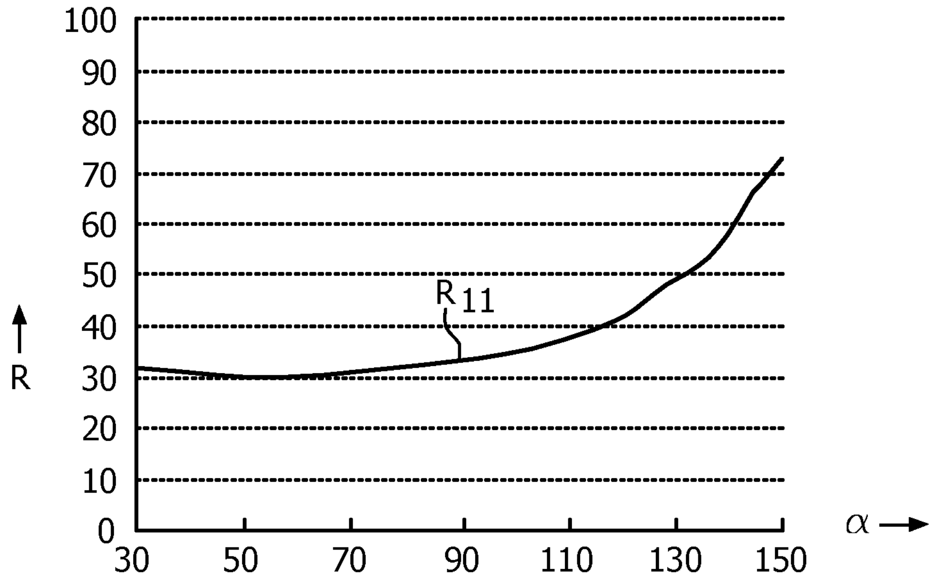
α

FIG. 3



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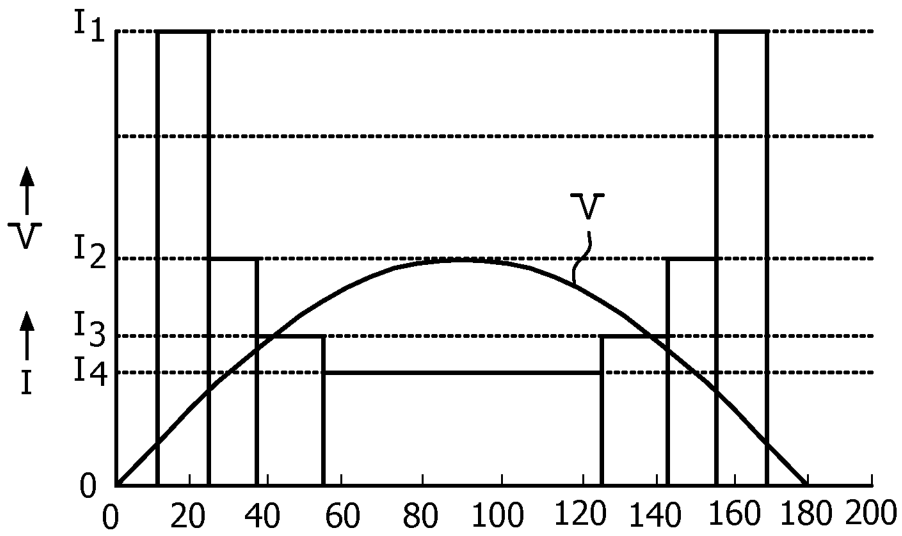
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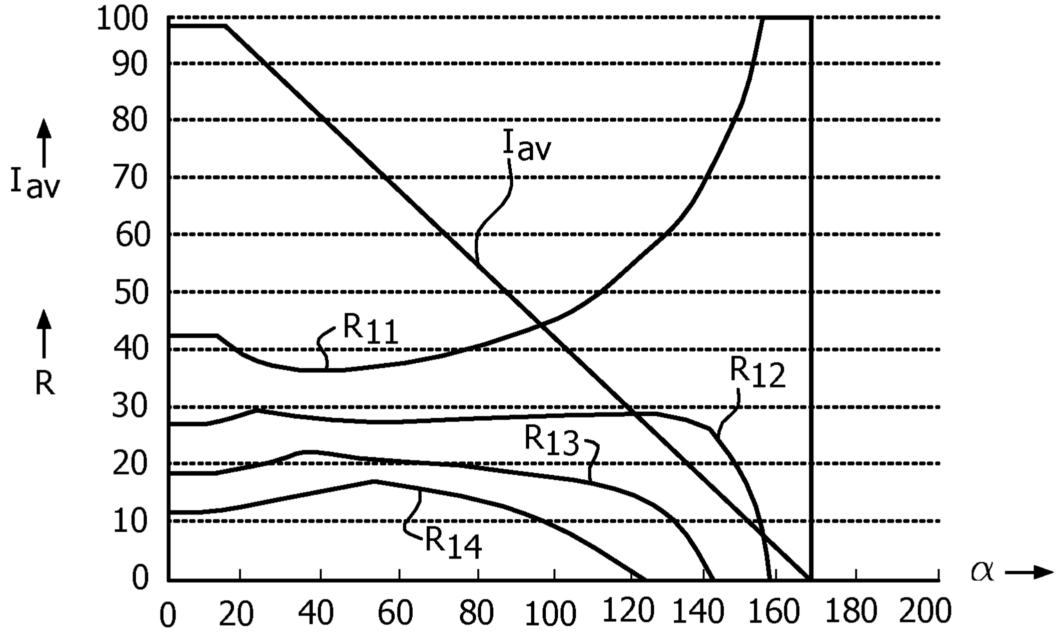
FIG. 5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200
α

FIG. 6

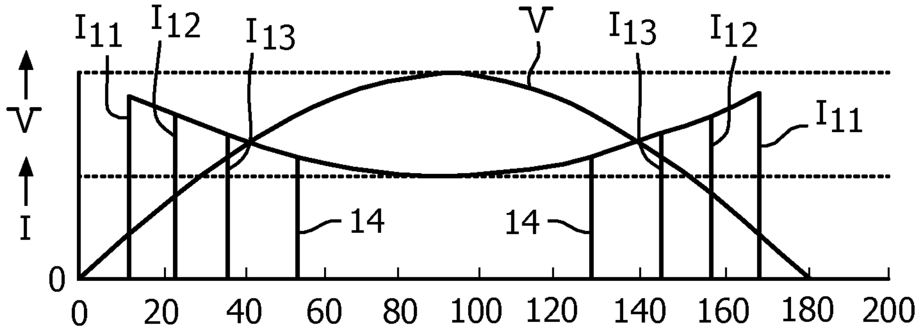
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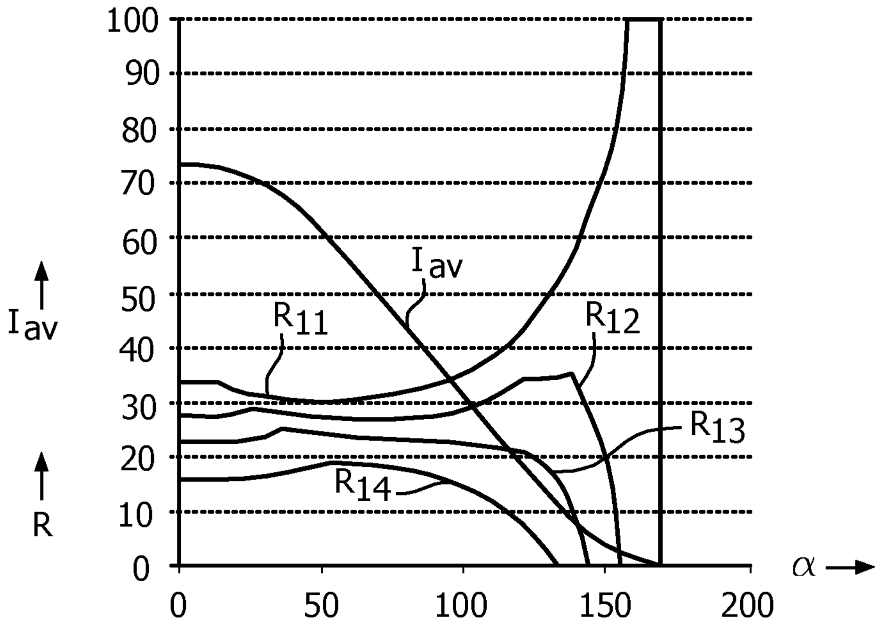
FIG. 7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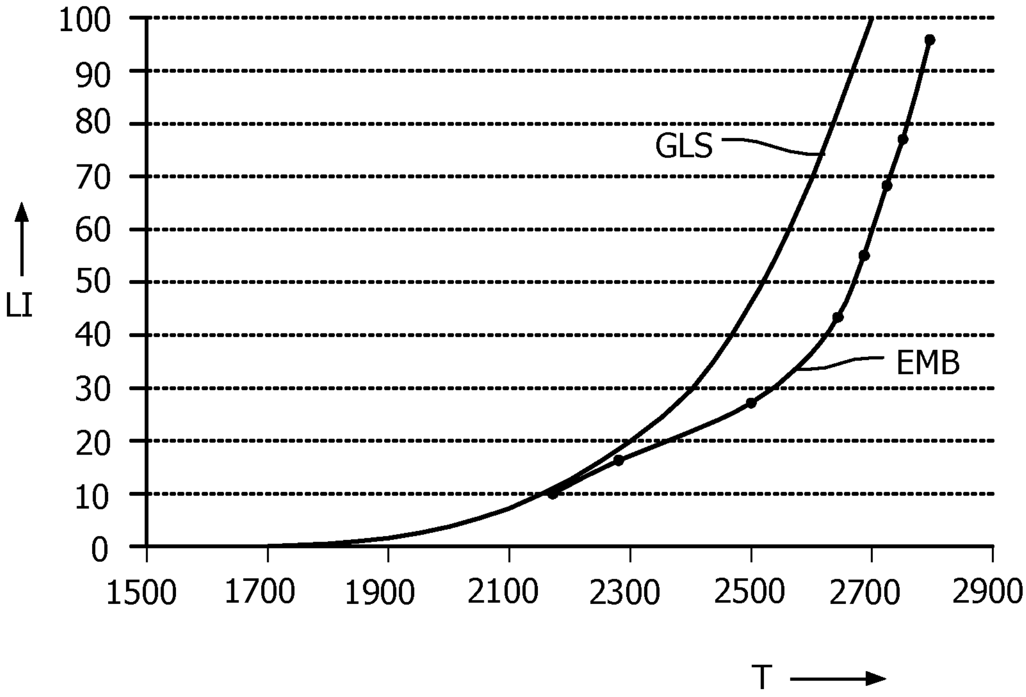
α

FIG. 8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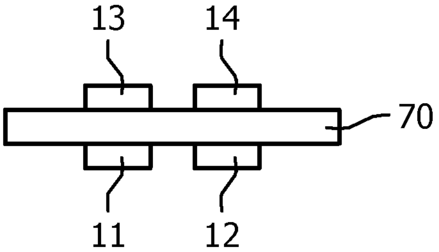
2100
2300
2500
2700
2900
T

FIG. 9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12

FIG. 10

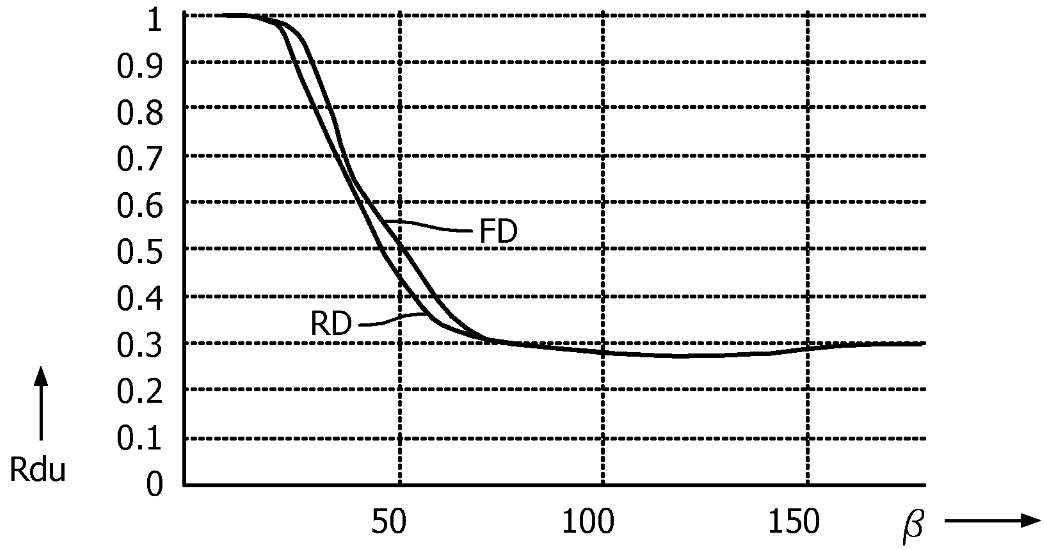

FIG. 11

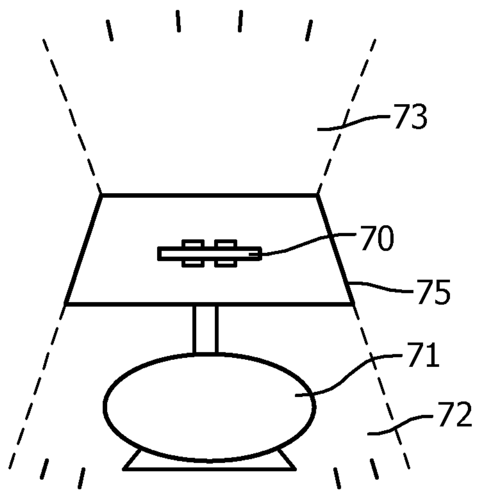

FIG. 12

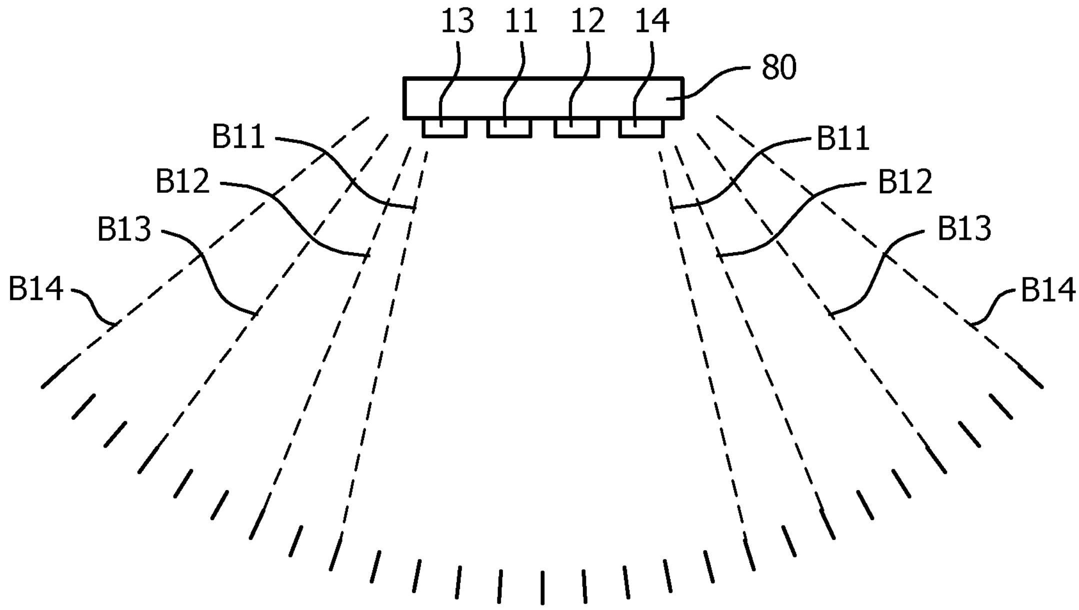

FIG. 13

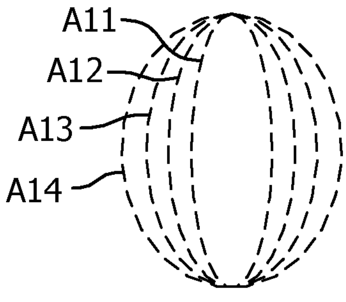

FIG. 14

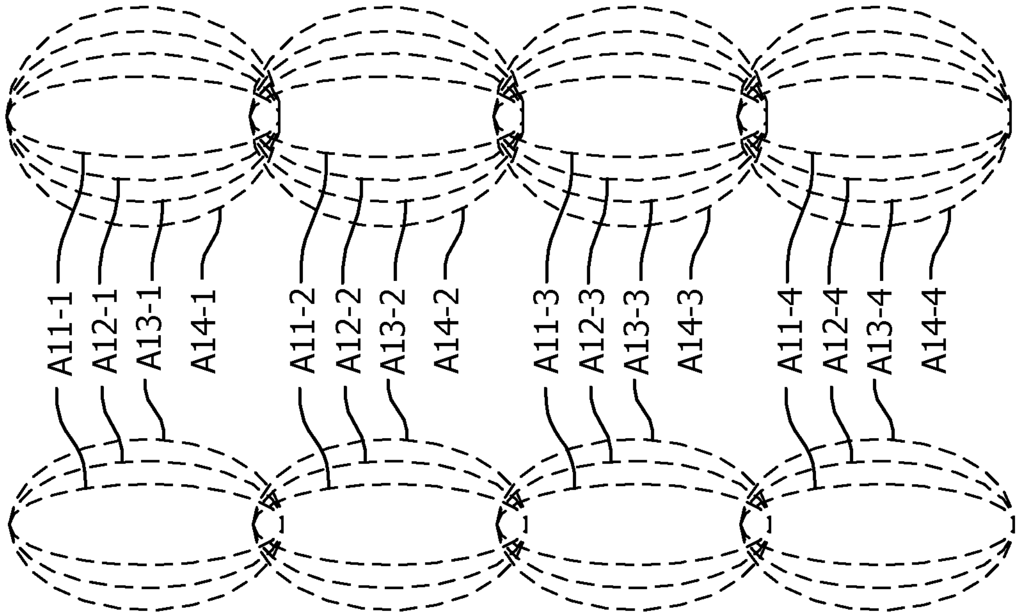

FIG. 15d

FIG. 15c

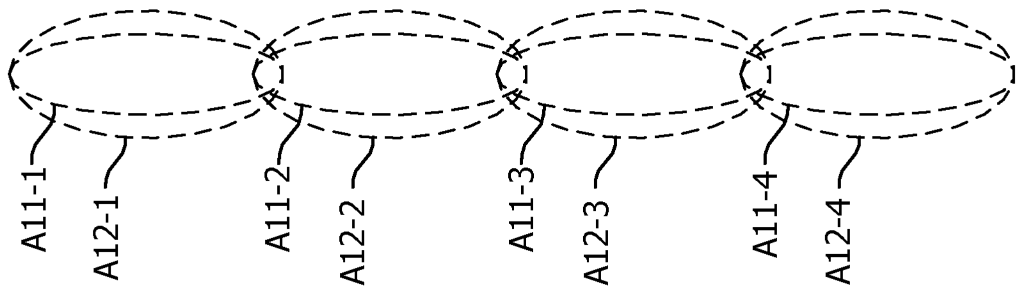

FIG. 15b

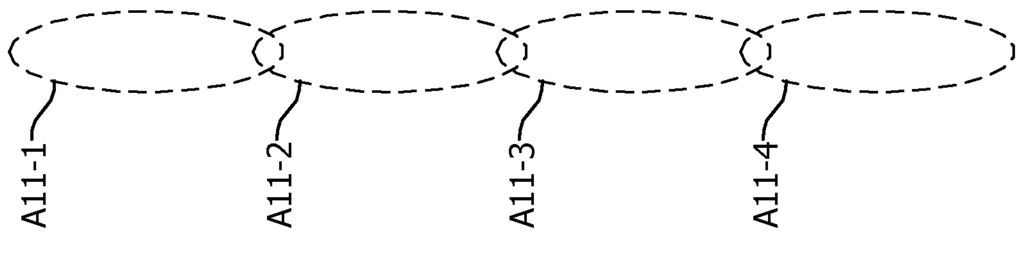

FIG. 15a

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/051147

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B33/08
ADD.

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 practicable, 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	US 2004/233145 A1 (CHIANG JOHNSON [TW]) 25 November 2004 (2004-11-25)	1-11
A	the whole document	12
X	US 2010/194298 A1 (KUWABARA KESANOBU [JP]) 5 August 2010 (2010-08-05)	1-11
A	the whole document	12
A	FR 2 901 956 A1 (LYRACOM SARL [FR]) 7 December 2007 (2007-12-07) the whole document	1-12
A,P	EP 2 299 783 A2 (STARCHIPS TECHNOLOGY INC [TW]) 23 March 2011 (2011-03-23) the whole document	1-12

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 June 2012	05/07/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Hunckler, José

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/051147

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	EP 2 254 392 A2 (ADVANCED CONNECTEK INC [TW]) 24 November 2010 (2010-11-24) the whole document -----	1-12
A	US 5 833 355 A (YOU CHENHUA [US] ET AL) 10 November 1998 (1998-11-10) the whole document -----	1-12
A,P	US 2011/273103 A1 (HONG SOON WON [KR]) 10 November 2011 (2011-11-10) the whole document -----	1-12

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2012/051147

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			JP 2011238605	A	24-11-2011
			KR 100997050	B1	29-11-2010
			US 2011273103	A1	10-11-2011