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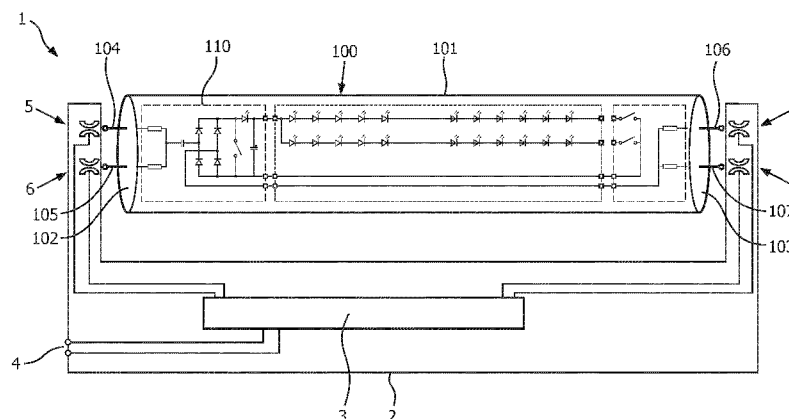
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(54) **Title:** LED LAMP DEVICE HAVING TWO OR MORE LIGHT STRINGS**FIG. 1A**

(57) **Abstract:** An LED lamp device (100) comprises: a supply section (110) having input terminals (104, 105, 106, 107) for connecting to output terminals of a TL ballast (3) and having output terminals (108, 109); at least two lighting strings (121, 122), each lighting string being coupled in series with a dedicated controllable switch (S1, S2), wherein the series arrangements of lighting strings and switches are connected in parallel to said output terminals (108, 109); a control circuit (150) for controlling the controllable switches (S1, S2); wherein the control circuit is adapted to control the switches to be successively ON and OFF so as to make each string sequentially output light, wherein a next switch in succession is switched ON before the corresponding previous switch is switched OFF such as to assure an overlap between successive ON periods of different switches.

LED LAMP DEVICE HAVING TWO OR MORE LIGHT STRINGS

FIELD OF THE INVENTION

The present invention relates in general to the field of lighting, particularly to the field of LED lighting.

5 BACKGROUND OF THE INVENTION

A TL lamp is a conventional and well-known type of lamp. It generally comprises a gas-filled tube and two spaced-apart electrodes, which receive electrical power. In order to be able to power such lamp from AC mains, typically 230V @ 50 Hz in Europe, a TL lighting system comprises a ballast, and for starting the lamp
10 the system conventionally includes a starter switch. While a conventional ballast is a cupper ballast, more advanced ballasts are electronic ballasts.

In the past years, LED lighting technology has been rapidly developed, and LEDs have been more and more used for the purpose of illumination as an alternative to incandescent or TL lamps. LED lighting technology includes the
15 development of new driver systems, specifically adapted to the characteristics of LEDs. However, there is also a desire for retrofit, i.e. it is desirable to provide an LED lamp device that has the shape of a standard TL lamp and that can be used to replace such standard TL lamp.

US20100090530A1 discloses driving the different LED loads in a sequential
20 way and there is overlap between the ON durations of different LED loads. But US20100090530A1 does not use a TL ballast to drive the LEDs.

SUMMARY OF THE INVENTION

LED lamp devices suitable for retrofitting a TL lamp have already been
25 developed. However, there is a lack of TL-compatible LED lamp devices which allow dimming and colour mixing control.

It is therefore an objective of this invention to provide an LED lamp device that can be quickly and easily mounted in a TL luminaire of the type having an electronic ballast, to instantly replace an old TL tube without the need to re-wire the luminaire,
30 and that is capable of dimming and/or colour/colour temperature mixing control.

In a first aspect, an LED lamp device according to the present invention has two or more LED strings with mutually different output characteristics, which strings can be switched on or off individually, and a control device for controlling this switching. The control device is adapted to time the switching moments such that a
35 next string is switched on before the previous string is switched off. Specifically, according to this first aspect, the present invention provides an LED lamp device comprising a supply section having input terminals for connecting to output terminals

of a TL ballast and having output terminals; at least two lighting strings, each lighting string being coupled in series with a dedicated controllable switch, wherein the series arrangements of lighting strings and switches are connected in parallel to said output terminals; a control circuit for controlling the controllable switches; wherein the
5 control circuit is adapted to control the switches to be successively ON and OFF so as to make each string sequentially output light, wherein a next switch in succession is switched ON before the corresponding previous switch is switched OFF such as to assure an overlap between successive ON periods of different switches.

As a result, any temporal gap between successive current periods is avoided,
10 and therefore the occurrence of current spikes is avoided.

In a preferred embodiment, a short circuit switch is closed before the next string is switched on and opened after the previous string is switched off. This avoids any complications relating to division of current between lamp strings.

In a second aspect, an LED lamp device according to the present invention
15 has one or more LED strings with mutually different output characteristics, which strings can be switched on or off individually, and a control device for controlling this switching. The control device is adapted to time the switching moments such that a next string is switched on after the previous string is switched off. A short circuit switch is closed before the previous string is switched off and opened after the next
20 string is switched on. As a result, any temporal gap between successive current periods is avoided, and therefore the occurrence of current spikes is avoided.

Further advantageous elaborations are mentioned in the dependent claims.

In a further embodiment, the controllable circuit switch is connected in series
25 with a dummy load without light output to selectively connect the dummy load to the output terminals, or wherein the further controllable circuit switch is a shunt switch directly connected between the output terminals to short circuit the output terminals. This embodiment gives more specific way of implementing the controllable circuit switch.

30 In a further embodiment, different lighting strings have different output characteristics. And preferably, said output characteristics are one or more of colour and colour temperature. This embodiment enables the LED lamp device provide flexible output characteristic.

In a further embodiment, the LED lamp comprises a remote control transmitter
35 unit for sending command signals to the control circuit, and wherein the control circuit is adapted to set timing and duty cycle of control signals for the lighting strings on the basis of the received command signals. This embodiment gives a more specific implementation in the control of the flexible output characteristic.

In a further embodiment, different lighting strings have different output characteristics. The command signals from the transmitter unit contain information defining a desired overall output characteristic of the LED lamp device including a desired dimming level, and the control circuit is adapted to calculate a duty cycle for each control signal on the basis of the desired overall output characteristic, the desired dimming level, the individual output characteristics of the different lighting strings, and a desired time length of the overlap between successive ON periods of different switches. This embodiment gives a more specific implementation on how to control different lighting string to output the desired overall output characteristic.

In a still further embodiment, the control circuit is adapted to calculate an effective light duty cycle for the respective lighting strings and for the no-light portion in each repetition period, and to calculate a duty cycle for each control signal on the basis of the calculated effective light duty cycle while correcting for the fact that light output is suppressed if an ON signal for a lighting string overlaps with an ON signal for the further controllable circuit switch and for the fact how light output in two lighting strings is divided in each string if ON signals for these lighting strings overlap while not overlapping with an ON signal for the further controllable circuit switch. This embodiment adjusts the duty cycles of different strings by considering the output influence of the overlapping between lighting strings or overlapping between lighting string and circuit switch.

In an aspect of integration, there is provided a luminaire, comprising a TL ballast for providing ballast current and an LED lamp device according to any of the above embodiments powered by said TL ballast.

In an aspect of method, there is provided a method for driving different LED strings in a system receiving power from a TL ballast, the method including the steps of connecting the strings in parallel to an output of a supply unit, and successively switching different strings ON and OFF in sequence, and switching the next string ON before switching the previous string OFF such that there is always overlap between successive ON periods of different strings wherein such overlap is for enabling a continuity of the TL ballast current and avoid a case where there is no conductive path for the TL ballast current.

In a more specific aspect, there is provided a method for driving at least one LED string in a system receiving power from a TL ballast, the method including the steps of connecting the string in parallel to an output of a supply unit, providing a shunt switch, connecting the shunt switch in parallel to the output of the supply unit, and successively switching the string and the shunt switch ON and OFF in sequence, such that the beginning and the end of an ON period of a string is always overlapping

with the end or beginning, respectively, of an ON period of another string or of the shunt switch wherein such overlap is for enabling a continuity of the TL ballast current and avoid a case where there is no conductive path for the TL ballast current.

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BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects, features and advantages of the present invention will be further explained by or be apparent from the following description of one or more preferred embodiments with reference to the drawings, in which same

10 reference numerals indicate same or similar parts, and in which:

figure 1A schematically shows an LED lamp device;

figure 1B is a circuit diagram of the LED lamp device;

figure 2 is a graph illustrating the working point of an LED lamp device;

figure 3 is a graph showing control signals in the LED lamp device;

15 figure 4 is a graph showing control signals in the LED lamp device;

figure 5A is a graph showing control signals in the LED lamp device;

figure 5B is a graph showing control signals in the LED lamp device;

figure 5C is a graph showing control signals in the LED lamp device.

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DETAILED DESCRIPTION OF THE INVENTION

Figure 1A schematically shows a luminaire 1, having a housing 2 that accommodates an electronic ballast 3, an input 4 for receiving AC mains, and connectors 5, 6, 7, 8 for receiving connector pins of a TL tube (not shown). The housing 2 further accommodates wires that connect the input 4 and the connectors 5, 6, 7, 8 to the electronic ballast 3. Such luminaire 1 is commonly known.

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Figure 1A further schematically shows a LED lamp device 100 according to the present invention, having a generally tube-shaped housing 101 with end caps 102, 103 and connector pins 104, 105, 106, 107 protruding from these end caps 102, 103, respectively. To replace a standard TL tube, the LED lamp device 100 is mounted in the luminaire 1, with its connector pins 104, 105, 106, 107 connecting to the connectors 5, 6, 7, 8, respectively.

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The electronic ballast 3 is designed for supplying an HF current into a standard TL tube. The LED lamp device 100 comprises a supply section 110 that is designed to convert this HF ballast output current, which is input current for the LED lamp supply section 110, to a substantially constant DC current. Figure 1B is a circuit diagram of the LED lamp device 100. Figures 1A and 1B illustrate that the supply section 110 may comprise a diode rectifier bridge 111 having 4 diodes D1, D2, D3, D4 in a usual layout. Input terminals of the diode rectifier bridge 111 are connected to

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the connector pins 104, 105, 106, 107 via protection resistors R1, R2, R3, R4, respectively, and a filter capacitor C2. Output terminals of the diode rectifier bridge 111 are connected to a series arrangement of a diode D5 and a buffer capacitor C1 for smoothing out the ripple current. The supply section 110 has output terminals 108, 109 coupled to the terminals of the buffer capacitor C1.

The LED lamp device 100 further comprises an LED section 120. The LED section 120 comprises two or more LED strings 121, 122. In figure 1A, the strings are shown as strings, while in figure 1B the strings are depicted as single LEDs. Each LED string comprises a plurality of LEDs, connected in series and/or in parallel. All LEDs within one string may have mutually the same characteristics, but this is not essential. The LEDs in two different strings have mutually different output characteristics. In an example, the output characteristic is color temperature, the first string 121 is a string of warm white LEDs and the second string 122 is a string of cold white LEDs. Each LED string 121, 122 has an associated controllable switch S1, S2 connected in series. The series arrangements of LED string 121, 122 and associated controllable switch S1, S2 are connected in parallel to the output terminals 108, 109 of the supply section 110. It should be noted that the output characteristic is not limited to color temperature. For example, the output characteristic may include color, and the strings can include respective red, green, blue LEDs strings.

In a practical design, as illustrated in figure 1A, the circuit is arranged on three separate PCBs. A first PCB carries the supply section 110 with two of the protection resistors R1, R2 and is arranged near one end cap 102 for connecting to the connector pins 104, 105. A second PCB carries the controllable switches S1, S2 and the other protection resistors R3, R4 and is arranged near the opposite end cap 103 for connecting to the other connector pins 106, 107. A third PCB carries the LED strings 121, 122 and connection lines for connecting the common node of the other protection resistors R3, R4 to the diode bridge 111 on the first PCB and for connecting the common node of the controllable switches S1, S2 to an output terminal of the supply section 110 on the first PCB.

Figure 2 is a graph showing the typical output power characteristics of a typical ballast (curve 21) and the typical load characteristic of an LED string (curve 22). The graph shows current (horizontal axis) versus voltage (vertical axis) in arbitrary units. It can be seen that a higher output voltage results in higher LED current, while on the other hand a higher output current results in a lower output voltage. The intersection of these two curves defines a working point 23. It should be clear that the precise position of the LED curve depends on the number of LEDs in the string in question, and on the individual characteristics of the individual LEDs.

If the number of LEDs in a string is chosen such that the forward voltage of the string is close to the steady state operating voltage of the TL lamp, the LED lamp 100 as a whole will receive similar power and current as compared to the TL lamp.

5 In each LED string 121, 122, the number of LEDs in series is chosen such that the different strings have mutually substantially the same forward voltage. Noting that the individual forward voltages of individual LEDs in different strings may differ, the number of LEDs per string may differ correspondingly.

10 Figure 1B illustrates, that the supply section 110 further comprises a series arrangement of a dummy load 112 and a controllable circuit switch S3, in the following also indicated as third switch S3 or controllable dummy load switch S3, connected in parallel to the output terminals 108, 109 of the supply section 110. The dummy load 112 may be a resistor, as shown, but may also be another type of current consuming component. For instance, the dummy load may be implemented
15 as a string of non-light-emitting diodes. The dummy load with its associated switch may be physically located on the first PCB with the components of the supply section 110, as shown in figure 1B, or on the third PCB connected in parallel to the LED strings 121, 122. In figure 1B, the series arrangement of the dummy load with its associated switch is shown connected in parallel to the output of the rectifier 111, i.e.
20 on the lefthand side of diode D5. Alternatively, this series arrangement might also be connected in parallel to the buffer capacitor C1, i.e. on the righthand side of diode D5.

For controlling the switches S1, S2, S3, the LED lamp device 100 further comprises a control device 150, for instance a suitably programmed controller or
25 microprocessor. A low voltage power supply 153 receives power from the supply section 110 for powering the control device 150. The control device 150 has control output terminals coupled to respective control terminals of the controllable switches S1, S2, S3, as shown in interrupted lines. The control device 150 can be remotely controlled by a user. For that purpose, the control device 150 is associated with a
30 receiver 151 for receiving a wireless user control signal transmitted by a transmitter unit 152 that is handled by the user or by a higher control system. In principle, any suitable wireless communication technology can be used here, for instance infrared, Bluetooth, ZigBee, wifi.

35 With the transmitter unit 152, the user can issue command signals that indicate a certain desired setting of colour and intensity. The control device 150 generates suitable control signals CS1, CS2 and CS3 respectively for the controllable switches S1, S2, S3 to implement the user command, as will be explained hereinafter.

Figure 3 is a graph that shows possible control signals for the controllable switches S1, S2, S3 as a function of time (horizontal axis). The control signals are indicated as CS1, CS2, CS3 for the controllable switches S1, S2, S3, respectively. The signals are illustratively shown as digital voltage signals that are either high (H) or low (L), with H indicating that the controlled switch is conductive (ON) while L indicates that the controlled switch is non-conductive (OFF). The voltage levels corresponding to H and L may depend on the type of components used.

In one possible mode, the control device 150 turns the first controllable switch S1 ON continuously, with the other switches S2 and S3 OFF (not shown in the figure). This would result in output light of the LED lamp device 100 as a whole that is fully determined by the characteristics of the first string LEDs 121 (in the example: warm white light). However, this would mean that the LEDs receive the same current as normally consumed by a TL-lamp, hereinafter indicated as nominal TL current, which is too high for LEDs. The LEDs would become too hot, the colour of the emitted light might shift, and the LEDs might even fail. To avoid this problem, the control device 150 turns the first controllable switch S1 alternatively ON and OFF, at a certain repetition frequency f_R that is sufficiently high to avoid perceptible flickering. The duty cycle $\Delta 1$ of the first control signal CS1, shown in figure 3 at [A], determines the average LED current and the average light output intensity. The maximum allowable duty cycle is indicated as $\Delta 1_M$. Here, duty cycle Δ is defined as the ratio between ON-time T_H and repetition period $T_R = 1/f_R$.

Nevertheless, the LED lamp device 100 as a whole should consume constant current because the electronic ballast 3 provides constant current (more precisely: HF current with constant magnitude). To achieve this, the control device 150 turns the third controllable switch S3 alternatively ON and OFF, in counter phase with the first controllable switch S1, so that the third controllable switch S3 is ON when the first controllable switch S1 is OFF, and vice versa, as shown in figure 3 at [A]. It should be clear that $\Delta 1 + \Delta 3 = 1$ and $\Delta 1 < \Delta 1_M$.

A similar type of operation can be done with the second controllable switch S2 to obtain cold white light output. In fact, if there are three or more LED strings with individual switches, the above would apply to each individual string.

Dimming, while maintaining the output light colour, is done by reducing the duty cycle of the control signal for the LED strings.

For obtaining output light having an intermediate colour in between warm white and cold white, the control device 150 turns both the first controllable switch S1 and the second controllable switch S2 ON and OFF consecutively, as shown in figure 3 at [B]. In the illustrative example of figure 3, the second control signal CS2 is made high when the first control signal CS1 is made low, and the third control signal CS3

for the dummy load 112 is made high when the second control signal CS2 is made low. It should be clear that $\Delta 1 + \Delta 2 + \Delta 3 = 1$ and $\Delta 1 < \Delta 1_M$ and $\Delta 2 < \Delta 2_M$.

Dimming, while maintaining the output light colour, is done by reducing the duty cycles $\Delta 1$ and $\Delta 2$ of the first and second control signals CS1 and CS2 for the LED strings with the same factor, and setting the duty cycle $\Delta 3$ of the third control signal CS3 to make up the balance: $\Delta 3 = 1 - (\Delta 1 + \Delta 2)$. Varying the output light colour between the two extreme colours is done by varying the ratio between the duty cycles $\Delta 1$ and $\Delta 2$ of the first and second control signals CS1 and CS2.

The signals shown in figure 3 are idealized theoretical signals, having ideal timing and ideal block shape. In practice, however, there is some inevitable tolerance on the timing of the signals, and on the rise time and fall time of the signals, while further there is some response delay in the controlled switches. As a consequence, it may happen that, at the moment when a switch makes a transition from the ON state to the OFF state, the next switch is not yet making the transition from the OFF state to the ON state yet. Then, there would be a brief moment when there is no conductive path for the ballast current, which results in a current spike within the ballast. This is undesirable.

To overcome this problem, the control device 150 is adapted to cause an overlap between two successive ON periods of different switches. This is illustrated in figure 4, which is a graph comparable to figure 3. The figure shows a repetition period from t_0 to t_R , coinciding with the successive transitions from H to L of the third control signal CS3. The repetition period has a duration $T_R = t_R - t_0$.

The first control signal CS1 makes a transition from L to H at a first rise time t_{11} before t_0 , and makes a transition from H to L at a first fall time t_{12} .

The second control signal CS2 makes a transition from L to H at a second rise time t_{21} before t_{12} , and makes a transition from H to L at a second fall time t_{22} .

The third control signal CS3 makes a transition from L to H at a third rise time t_{31} before t_{22} , and makes a transition from H to L at a third fall time $t_{32} = t_R$.

The first control signal CS1 has a duty cycle $\Delta 1 = (t_{12} - t_{11})/T_R$.

The second control signal CS2 has a duty cycle $\Delta 2 = (t_{22} - t_{21})/T_R$.

The third control signal CS3 has a duty cycle $\Delta 3 = (t_{32} - t_{31})/T_R$.

It should be clear that $\Delta 1 + \Delta 2 + \Delta 3 > 1$

The overlap $\Delta 12 = t_{12} - t_{21}$ between the first control signal CS1 and the second control signal CS2, the overlap $\Delta 23 = t_{22} - t_{31}$ between the second control signal CS2 and the third control signal CS3, and the overlap $\Delta 31 = t_{32} - t_{11}$ between the third control signal CS3 and the first control signal CS1 may be mutually equal but this is not essential. In any case, these overlaps are selected sufficiently large such that, with a view to possible tolerances in practice, it is guaranteed that the LED lamp

device 100 provides a current conducting path at all times. The precise length of these overlaps is not essential: as long as the overlap is larger than zero, the advantageous effect according to embodiments of the present invention is provided. However, it is preferred that the overlap is as small as possible, taking into account possible tolerances such as to avoid the risk of the overlap becoming less than zero in practice. Selecting the overlap to be larger would reduce the dimming range. In a preferred embodiment, the overlap is shorter than 10% of the repetition period T_R , more preferably shorter than 5% of the repetition period T_R . In a preferred embodiment, the overlap is in the range of 1-3 % of the repetition period T_R , more preferably about 2% of the repetition period T_R .

The overlapping of the control signals assures an overlapping of current conduction of the loads in series with the respective switches, and thus assures continuity of current flow in the device, i.e. a continuity of output current for the ballast 3 without current spikes. This effect is achieved irrespective of the nature of the loads. This means that it is not essential to use the dummy load.

For instance, in the example of figure 4, assume that the light output level is increased. It will be seen that $\Delta 1$ and/or $\Delta 2$ increase, so that $\Delta 3$ can be decreased. When t_{22} overlaps with t_{11} , so that $\Delta 1 + \Delta 2 > 1$, $\Delta 3$ may be set at zero. Further, in a lamp having three or more LED strings, the control signals CS1, CS2, CS3 in figure 4 could be illustrative of the control signals for the switches associated with the LED strings, with the switch for the dummy load staying continuously non-conductive.

Based on the input command signal received via receiver 151, the control device 150 is adapted to calculate duty cycles $\Delta 1$, $\Delta 2$ for the respective light strings 121, 122, in such a manner that the desired light output level and light output colour will result. The control device 150 further calculates a continuity factor CF defined as $CF = \Sigma \Delta - 1$, wherein $\Sigma \Delta$ indicates a summation of all LED duty cycles. In the illustrated example with two LED strings, $\Sigma \Delta = \Delta 1 + \Delta 2$. Let Δ_{ij} denote the overlap between successive switch ON periods; it follows that the total overlap per repetition period T_R can be denoted as $N \cdot \Delta_{ij}$, with N indicating the number of LED strings. If $CF > 0$, it is in principle possible for the control device 150 to set the timing for the respective control signals CS1, CS2 such that there is always overlap between successive switch ON periods, with $\Delta_{ij} = CF/N$. If $CF < 0$, this is not possible, and the control device 150 is adapted to actuate the third switch S3 associated with the dummy load 112, setting the duty cycle $\Delta 3$ for the third switch S3 equal to $\Sigma \Delta$, and setting $\Delta_{ij} = CF/(N+1)$.

Figure 4 also shows the resulting light output L1 and L2 from the light strings 121 and 122, based on the assumption that the light output is proportional to LED current. During the overlap $\Delta 12$ between the first control signal CS1 and the second

control signal CS2, the two strings 121 and 122 are connected in parallel and therefore the ballast current is divided between these two LED strings. For sake of convenience, it is assumed that each LED string receives 50% of the ballast current. A similar remark applies to the overlap $\Delta 23$ between the second control signal CS2 and the third control signal CS3 and the overlap $\Delta 31$ between the third control signal CS3 and the first control signal CS1, although in those cases the division of current depends on the resistor value of the dummy load resistor 112. For sake of convenience of discussion, it is again assumed that each LED string receives 50% of the ballast current, and that the dummy load resistor 112 consequently also receives 50% of the ballast current during the respective overlap periods $\Delta 23$ and $\Delta 31$.

Assuming $\Delta 12 = \Delta 23 = \Delta 31 = \Delta X$, it can now easily be seen that, as far as the light output is concerned, the two LED strings 121 and 122 have effective duty cycles $\Delta 1_{\text{eff}} = \Delta 1 - 0.5 \cdot \Delta X$ and $\Delta 2_{\text{eff}} = \Delta 2 - 0.5 \cdot \Delta X$, respectively. The control device 150 is adapted to take this effect into account. Assume that for a certain desired light output the duty cycle of the first LED string 121 should have a first desired value D1 and that the duty cycle of the second LED string 122 should have a second desired value D2. Normally, the control device 150 would set $\Delta 1 = D1$ and $\Delta 2 = D2$. In the overlap situation of the embodiment of the present invention, the control device 150 is adapted to set:

$\Delta 1 = D1 + 0.5 \cdot \Delta X$ and $\Delta 2 = D2 + 0.5 \cdot \Delta X$.

This is based on the following calculation:

$$\Delta 1_{\text{eff}} = D1 = \Delta 1 - 0.5 \cdot \Delta X$$

$$\Delta 2_{\text{eff}} = D2 = \Delta 2 - 0.5 \cdot \Delta X$$

$$D1 + 0.5 \cdot \Delta X = \Delta 1$$

$$D2 + 0.5 \cdot \Delta X = \Delta 2$$

In the above discussion, it is assumed that the dummy load has a certain resistance so that current flow results in a certain voltage drop. In practice, cost-efficient resistances have a rather high tolerance, so the influence of the dummy load in the above has tolerances. Further, the current flowing in a resistive dummy load represents a power consumption, which is a loss of power. In a preferred embodiment, these disadvantages can be eliminated by omitting the dummy load, i.e. to have the third switch S3 be a short circuit switch. This can also be expressed by saying that the dummy load has a very small resistance value, or zero. In such case, during the time periods when the third control signal CS3 is H, the voltage drop over the LED strings is zero, or in any case very low, so that no current is flowing in the LED strings, irrespective whether the corresponding switches are conductive or not. Evidently, during those time periods there is no contribution to the light output. Thus, for each of the LED strings 121, 122, the effective duty cycle or light duty cycle $\Delta 1_{\text{eff}}$ or $\Delta 2_{\text{eff}}$, respectively, is equal to the signal duty cycle $\Delta 1$ or $\Delta 2$, respectively, of the corresponding control signal minus the respective overlap with the control signal for

the short-circuiting third switch S3 and also minus half of the overlap with another LED string.

This is illustrated in figures 5A and 5B, which are graphs comparable to figure 4. These figures show the transition from S1 ON to S2 ON, and only show the first control signal CS1 making its transition from H to L at the first fall time t_{12} , the second control signal CS2 making its transition from L to H at the second rise time t_{21} , and the third control signal CS3 making transitions from L to H at the third rise time t_{31} and from H to L at the third fall time t_{32} .

Figure 5A illustrates a situation where t_{21} is later than t_{12} , t_{31} is earlier than t_{12} and t_{32} is later than t_{21} . It should be clear that a current conductive path is guaranteed at all times, notwithstanding the large time delay between t_{12} and t_{21} . It should further be clear that during the overlap from t_{31} to t_{12} , no current is flowing in the first LED string 121, so that this portion of the duty cycle $\Delta 1$ of the first control signal CS1 does not contribute to the effective duty cycle $\Delta 1_{eff}$. Likewise, it should further be clear that during the overlap from t_{21} to t_{32} , no current is flowing in the second LED string 122, so that this portion of the duty cycle $\Delta 2$ of the second control signal CS2 does not contribute to the effective duty cycle $\Delta 2_{eff}$.

A similar effect may take place in the transition from S2 ON to S1 ON.

Figure 5B illustrates a situation where t_{21} is earlier than t_{12} , t_{31} is earlier than t_{21} and t_{32} is later than t_{12} . It should be clear that a current conductive path is guaranteed at all times. It should further be clear that during the overlap from t_{31} to t_{12} , no current is flowing in the first LED string 121, so that this portion of the duty cycle $\Delta 1$ of the first control signal CS1 does not contribute to the effective duty cycle $\Delta 1_{eff}$. Likewise, it should further be clear that during the overlap from t_{21} to t_{32} , no current is flowing in the second LED string 122, so that this portion of the duty cycle $\Delta 2$ of the second control signal CS2 does not contribute to the effective duty cycle $\Delta 2_{eff}$. Finally, it should further be clear that, since no current is flowing in any of the LED strings during the overlap from t_{21} to t_{12} , no effects of current division between LED strings play any role.

A similar effect may take place in the transition from S2 ON to S1 ON.

It is noted that the embodiment of figures 5A and 5B may involve a short circuiting of the third switch S3 for each transition between LED strings, thus the third switch S3 would be switched N times during the switching cycle, wherein N indicates the number of LED strings.

It is further noted that any calculation of timing of the switching moments, on the basis of desired light output and hence desired effective duty cycles, can advantageously be performed by software in the control device 150.

It is possible to combine the above-described features. Figure 5C illustrates an embodiment where at the transition from S1 ON to S2 ON the LED control signals

overlap to achieve the effect discussed with reference to figure 4, while at the transition from S2 ON to S1 ON the LED control signals leave a gap that is bridged by the third control signal CS3 for the short circuit switch S3 to achieve the effect discussed with reference to figure 5A.

In an example, it is desired to have a light output having a ratio warm white light to cold white light of 2 to 1, and having a light output level of 75% (or dim level of 25%). This is achieved with light consisting of 50% warm white light, 25% cold white light, and 25% no light, i.e. $\Delta 1=50\%$, $\Delta 2=25\%$, $\Delta 3=25\%$. In an example, it is desired to have $\Delta 12 = \Delta 23 = \Delta 31 = \Delta X = 5\%$. It will be seen that now for the control signals

CS1, CS2, CS2 the respective duty cycles can be calculated as:

$\Delta 1_{\text{eff}} = 50\% = \Delta 1 - \Delta 31 - 0.5 \cdot \Delta 12 = \Delta 1 - 7.5\%$, therefore $\Delta 1_{\text{eff}} = 57.5\%$.

$\Delta 2_{\text{eff}} = 25\% = \Delta 2 - 0.5 \cdot \Delta 12 - \Delta 23 = \Delta 2 - 7.5\%$, therefore $\Delta 2_{\text{eff}} = 32.5\%$.

$\Delta 3_{\text{eff}} = 25\% = \Delta 3 + \Delta 23 = \Delta 3 + 5\%$, therefore $\Delta 3_{\text{eff}} = 30\%$.

Summarizing, the present invention provides an LED lamp device that comprises:

a supply section having input terminals for connecting to output terminals of a TL ballast and having output terminals;

at least two lighting strings, each lighting string being coupled in series with a

dedicated controllable switch, wherein the series arrangements of lighting strings and switches are connected in parallel to said output terminals;

a control circuit for controlling the controllable switches;

wherein the control circuit is adapted to control the switches to be successively ON and OFF so as to make each string sequentially output light, wherein a next switch in succession is switched ON before the corresponding previous switch is switched OFF such as to assure an overlap between successive ON periods of different switches.

The present invention also provides an LED lamp device comprising:

a supply section having input terminals for connecting to output terminals of a TL ballast and having output terminals;

at least two loads, each load being coupled in series with a dedicated controllable switch, wherein each series arrangement of load and switch is connected in parallel to said output terminals;

wherein at least two of said loads comprise a lighting string;

a control circuit for controlling the controllable switches;

wherein the control circuit is adapted to control the switches to be successively ON and OFF so as to direct power to each string sequentially during a repetition period, wherein a next switch in succession is switched ON before the corresponding previous switch is switched OFF such as to assure an overlap between successive

ON periods of different switches. In a preferred embodiment, at least one of said loads is a non-light-emitting dummy load. The dummy load preferably has a low resistance, or even zero resistance.

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While the invention has been illustrated and described in detail in the drawings and foregoing description, it should be clear to a person skilled in the art that such illustration and description are to be considered illustrative or exemplary and not restrictive. The invention is not limited to the disclosed embodiments; rather, several variations and modifications are possible within the protective scope of the invention as defined in the appending claims. For instance, although the invention has been explained for the case of LEDs, the gist of the invention can also be applied in the case of light sources of different type.

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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. A single processor or other unit may fulfil the functions of several items recited in the claims. Even if certain features are recited in different dependent claims, the present invention also relates to an embodiment comprising these features in common. Any reference signs in the claims should not be construed as limiting the scope.

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In the above, the present invention has been explained with reference to block diagrams, which illustrate functional blocks of the device according to the present invention. It is to be understood that one or more of these functional blocks may be implemented in hardware, where the function of such functional block is performed by individual hardware components, but it is also possible that one or more of these functional blocks are implemented in software, so that the function of such functional block is performed by one or more program lines of a computer program or a programmable device such as a microprocessor, microcontroller, digital signal processor, etc.

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WHAT IS CLAIMED IS:

1. LED lamp device (100) comprising:

a supply section (110) having input terminals (104, 105, 106, 107) for connecting to output terminals of a TL ballast (3) and having output terminals (108, 109);

at least two lighting strings (121, 122), each lighting string being coupled in series with a dedicated controllable switch (S1, S2), wherein the series arrangements of lighting strings and switches are connected in parallel to said output terminals (108, 109);

a control circuit (150) for controlling the controllable switches (S1, S2);

wherein the control circuit is adapted to control the switches to be successively ON

and OFF so as to make each string sequentially output light, wherein a next switch in succession is switched ON before the corresponding previous switch is switched OFF such as to assure an overlap between successive ON periods of different switches, wherein such overlap is for enabling a continuity of the TL ballast (3) current and avoid a case where there is no conductive path for the TL ballast (3) current.

2. LED lamp device (100) comprising:

a supply section (110) having input terminals (104, 105, 106, 107) for connecting to output terminals of a TL ballast (3) and having output terminals (108, 109);

at least one lighting strings (121, 122), each lighting string being coupled in series with a dedicated controllable switch (S1, S2), wherein the series arrangements of lighting strings and switches are connected in parallel to said output terminals (108, 109);

a further controllable circuit switch (S3) connected in parallel to the output terminals (108, 109);

a control circuit (150) for controlling the controllable switches (S1, S2, S3);

wherein the control circuit is adapted to control the switches to be successively ON

and OFF so as to make each string sequentially output light during a repetition period (TR) and to suppress light output at least once during the repetition period, wherein a next switch in succession is switched ON before the corresponding previous switch is switched OFF wherein such overlap is for enabling a continuity of the TL ballast (3) current and avoid a case where there is no conductive path for the TL ballast (3) current.

3. LED lamp device according to claim 2,

wherein the control circuit is adapted:

- to control the controllable switch (S1) of a first lighting string (121) in succession to make a transition from ON to OFF at a first time (t_{12});
 - to control the controllable switch (S2) of the next lighting string (122) in succession to make a transition from OFF to ON at a second time (t_{21}) later than the first time (t_{12});
 - and to control the further controllable circuit switch (S3) to make a transition from OFF to ON at a third time (t_{31}) earlier than the first time (t_{12}) and to make a transition from ON to OFF at a fourth time (t_{32}) later than the second time (t_{21}), while maintaining the further controllable circuit switch (S3) in the ON state continuously from the third time (t_{31}) to the fourth time (t_{32}).
4. LED lamp device according to claim 2, comprising at least two lighting strings (121, 122), wherein the control circuit is adapted:
- to control the controllable switch (S1) of a first lighting string (121) in succession to make a transition from ON to OFF at a first time (t_{12});
 - to control the controllable switch (S2) of the next lighting string (122) in succession to make a transition from OFF to ON at a second time (t_{21}) earlier than the first time (t_{12});
 - and to control the further controllable circuit switch (S3) to make a transition from OFF to ON at a third time (t_{31}) earlier than the second time (t_{21}) and to make a transition from ON to OFF at a fourth time (t_{32}) later than the first time (t_{12}), while maintaining the further controllable circuit switch (S3) in the ON state continuously from the third time (t_{31}) to the fourth time (t_{32}).
5. LED lamp device according to claim 2, wherein the further controllable circuit switch (S3) is connected in series with a dummy load (112) without light output to selectively connect the dummy load (112) to the output terminals (108, 109), or wherein the further controllable circuit switch (S3) is a shunt switch directly connected between the output terminals (108, 109) to short circuit the output terminals.
6. LED lamp device according to claim 1 or 2, wherein different lighting strings have different output characteristics.
7. LED lamp device according to claim 6, wherein said output characteristics are one or more of colour and colour temperature.
8. LED lamp device according to claim 1 or 2, further comprising a remote control transmitter unit (152) for sending command signals to the control circuit (150), and

wherein the control circuit (150) is adapted to set timing and duty cycle of control signals (CS1, CS2) for the lighting strings on the basis of the received command signals.

- 5 9. LED lamp device according to claim 8, wherein different lighting strings have different output characteristics, wherein the command signals from the transmitter unit (152) contain information defining a desired overall output characteristic of the LED lamp device including a desired dimming level, and wherein the control circuit (150) is adapted to calculate a duty cycle ($\Delta 1$, $\Delta 2$, $\Delta 3$) for each control signal (CS1, CS2; CS3) on the basis of the desired overall output characteristic, the desired dimming level, the individual output characteristics of the different lighting strings, and a desired time length (ΔX) of the overlap between successive ON periods of different switches.
- 10 10. LED lamp device according to claim 9, wherein the control circuit (150) is adapted to calculate an effective light duty cycle ($\Delta 1_{eff}$, $\Delta 2_{eff}$, $\Delta 3_{eff}$) for the respective lighting strings and for the no-light portion in each repetition period, and to calculate a duty cycle ($\Delta 1$, $\Delta 2$, $\Delta 3$) for each control signal (CS1, CS2; CS3) on the basis of the calculated effective light duty cycle ($\Delta 1_{eff}$, $\Delta 2_{eff}$, $\Delta 3_{eff}$) while correcting for the fact how light output is suppressed in case that an ON signal for a lighting string overlaps with an ON signal for the further controllable circuit switch (S3) and for the fact how light output in two lighting strings is divided in each string in case that ON signals for these lighting strings overlap while not overlapping with an ON signal for the further controllable circuit switch (S3).
- 25 11. Luminaire (1), comprising a TL ballast (3) for providing ballast current and an LED lamp device according to any of claims 1-10 powered by said TL ballast (3).
- 30 12. Method for driving different LED strings in a system receiving power from a TL ballast (3), the method including the steps of connecting the strings in parallel to an output of a supply unit (110), and successively switching different strings ON and OFF in sequence, and switching the next string ON before switching the previous string OFF such that there is always overlap between successive ON periods of different strings wherein such overlap is for enabling a continuity of the TL ballast (3) current and avoid a case where there is no conductive path for the TL ballast (3) current.
- 35 13. Method for driving at least one LED string in a system receiving power from a TL ballast (3), the method including the steps of connecting the string in parallel to an

- output of a supply unit (110), providing a shunt switch (S3), connecting the shunt switch (S3) in parallel to the output of the supply unit (110), and successively switching the string and the shunt switch (S3) ON and OFF in sequence, such that the beginning and the end of an ON period of a string is always overlapping with the
- 5 end or beginning, respectively, of an ON period of another string or of the shunt switch wherein such overlap is for enabling a continuity of the TL ballast (3) current and avoid a case where there is no conductive path for the TL ballast (3) current.

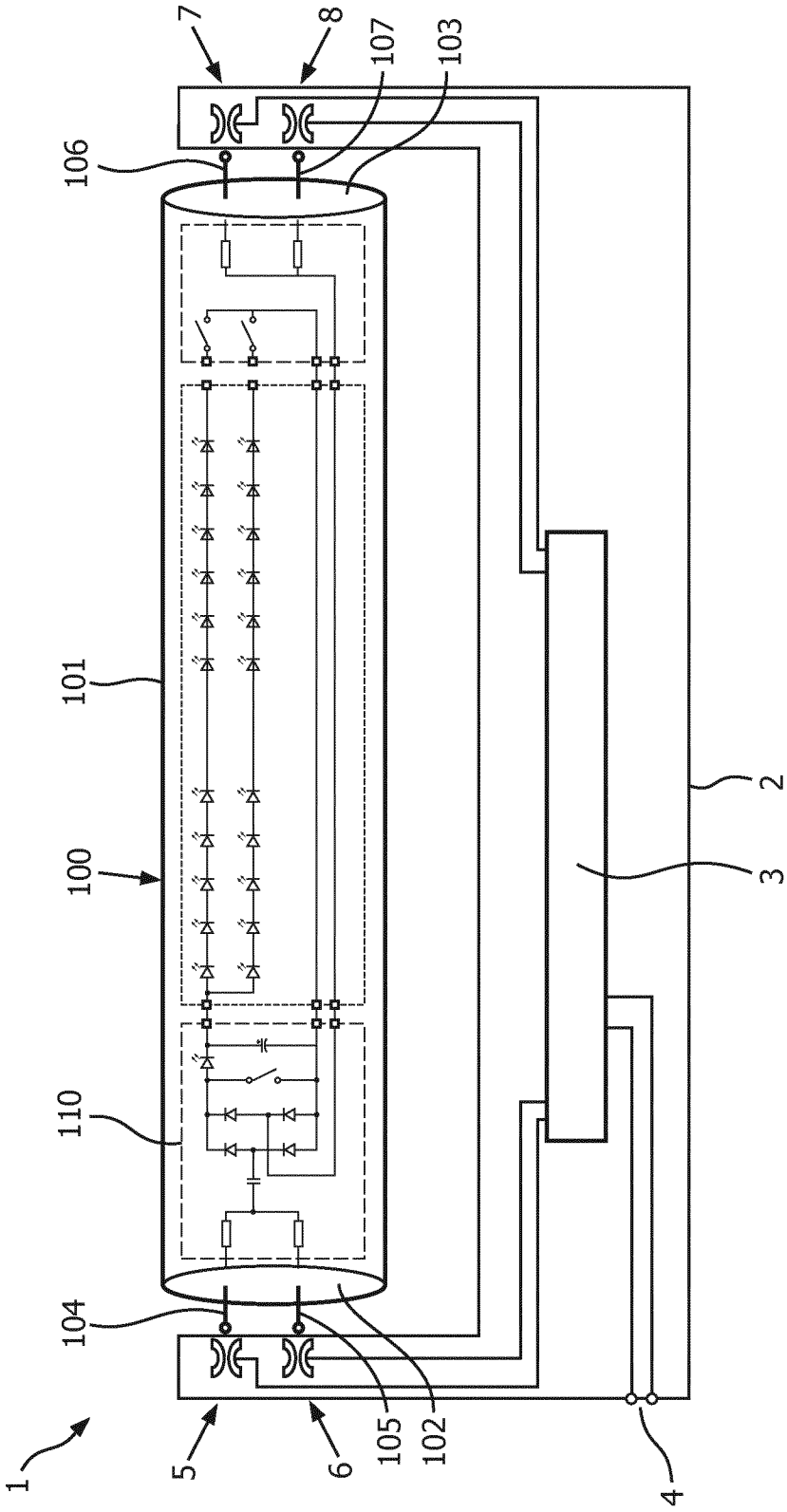


FIG. 1A

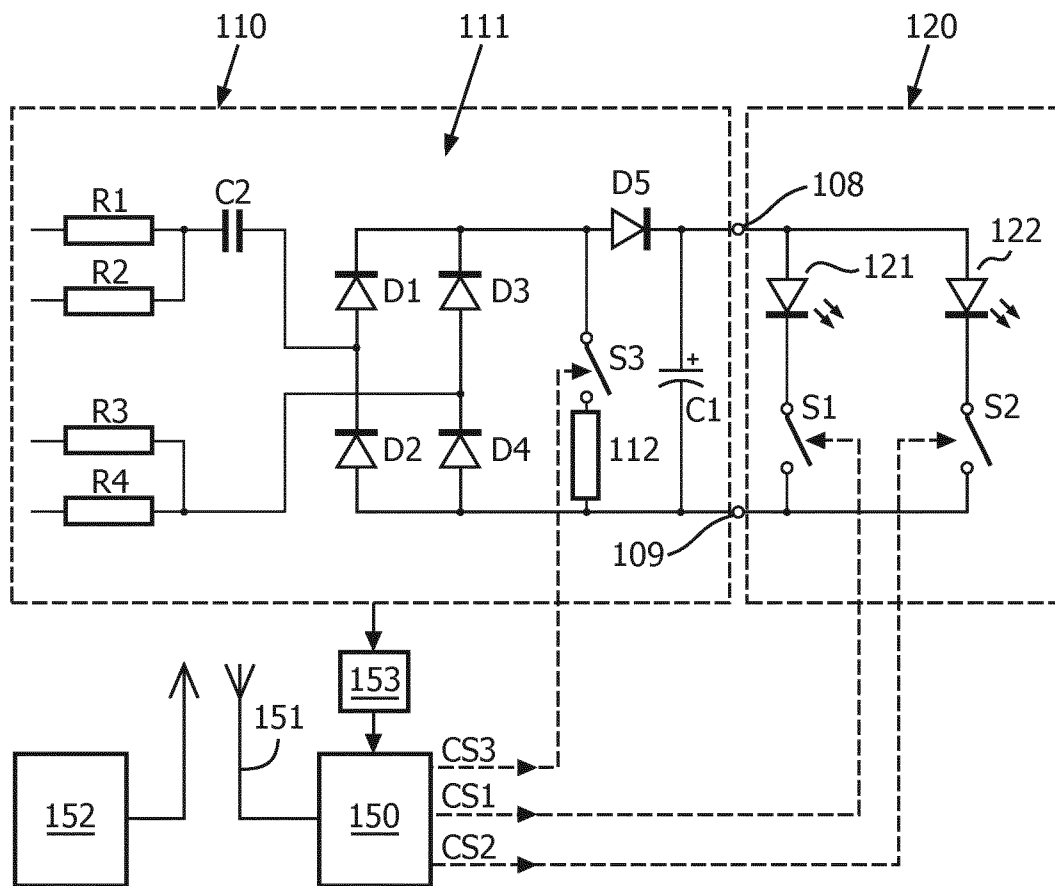


FIG. 1B

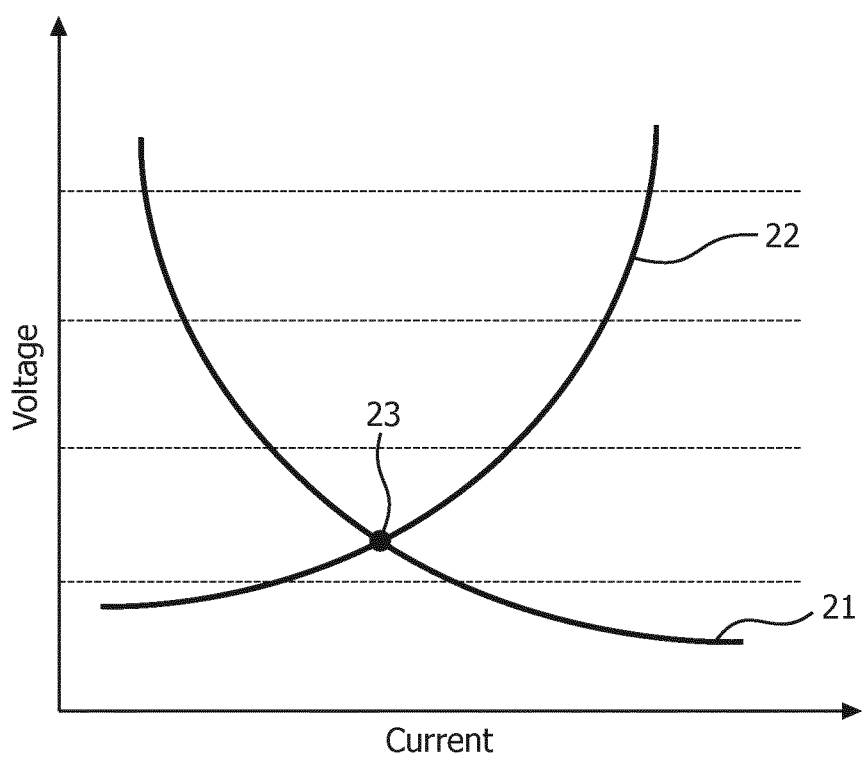


FIG. 2

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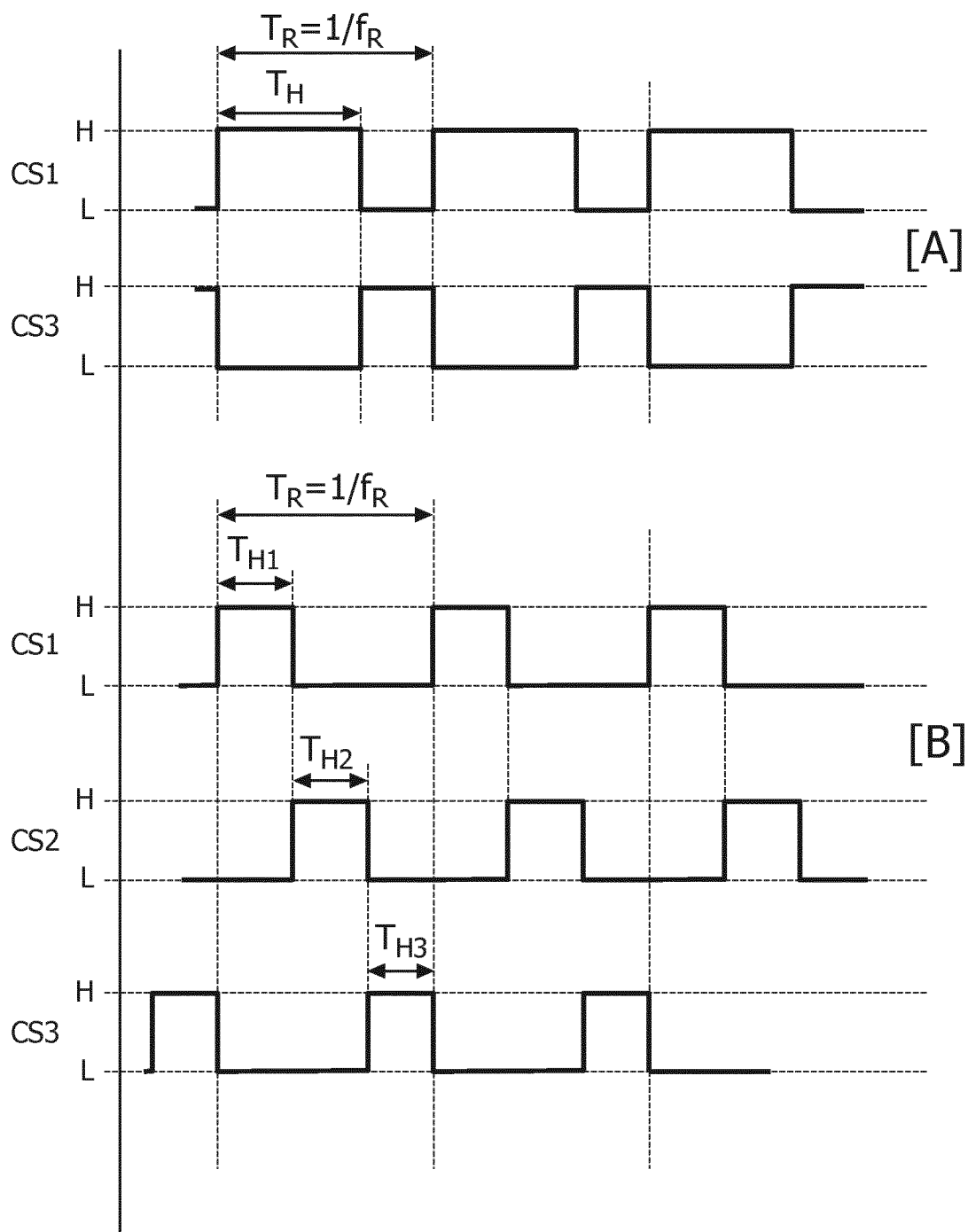


FIG. 3

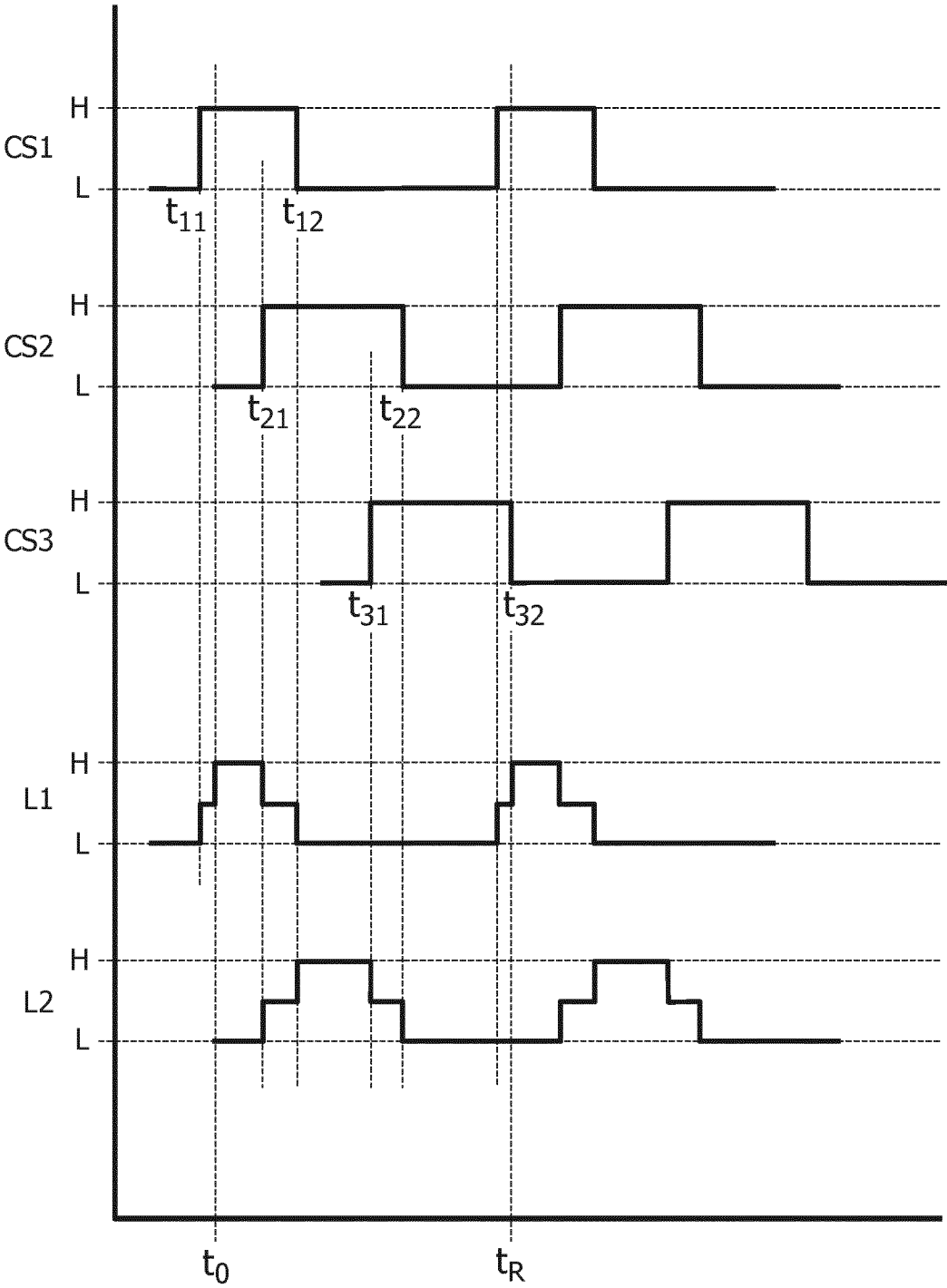


FIG. 4

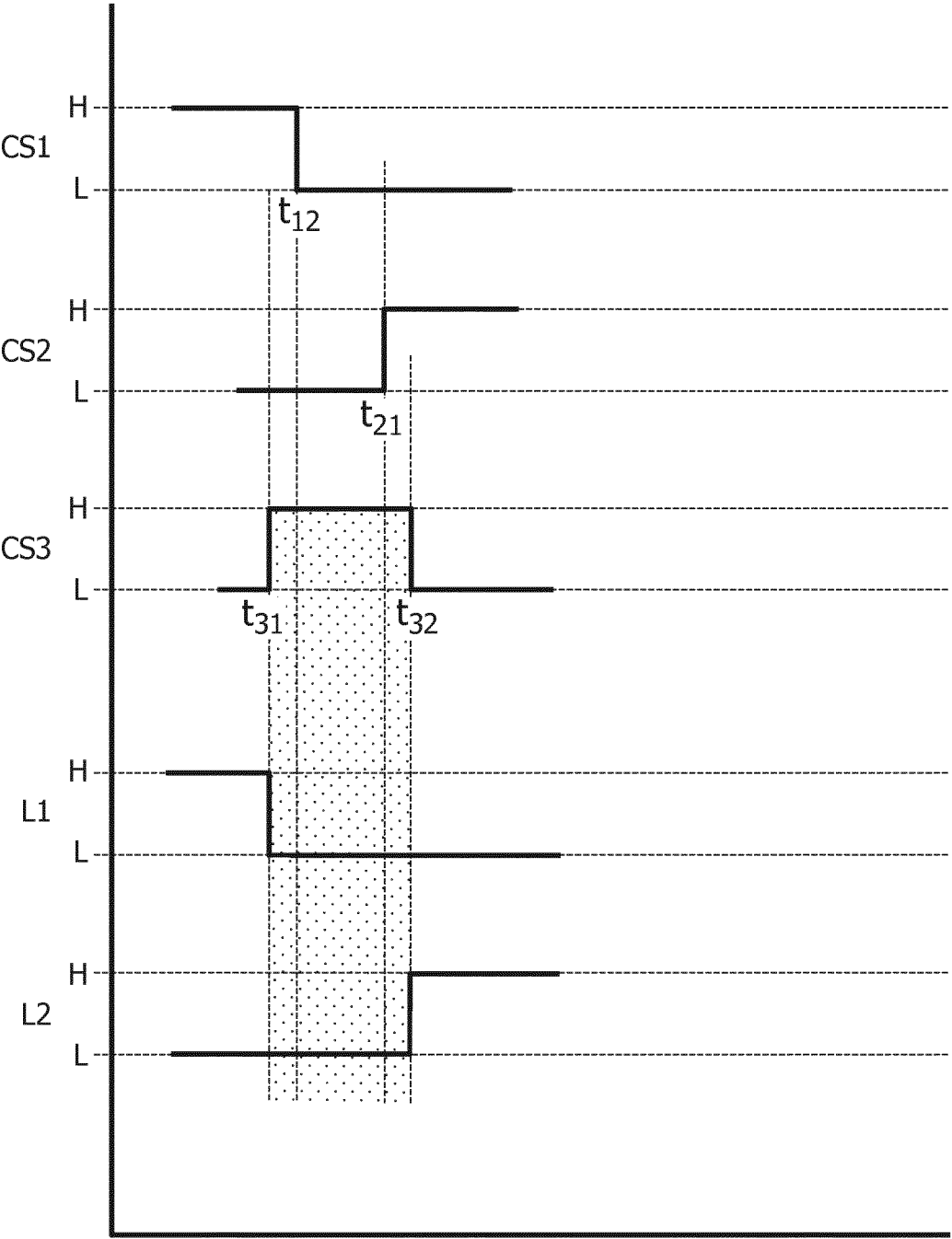


FIG. 5A

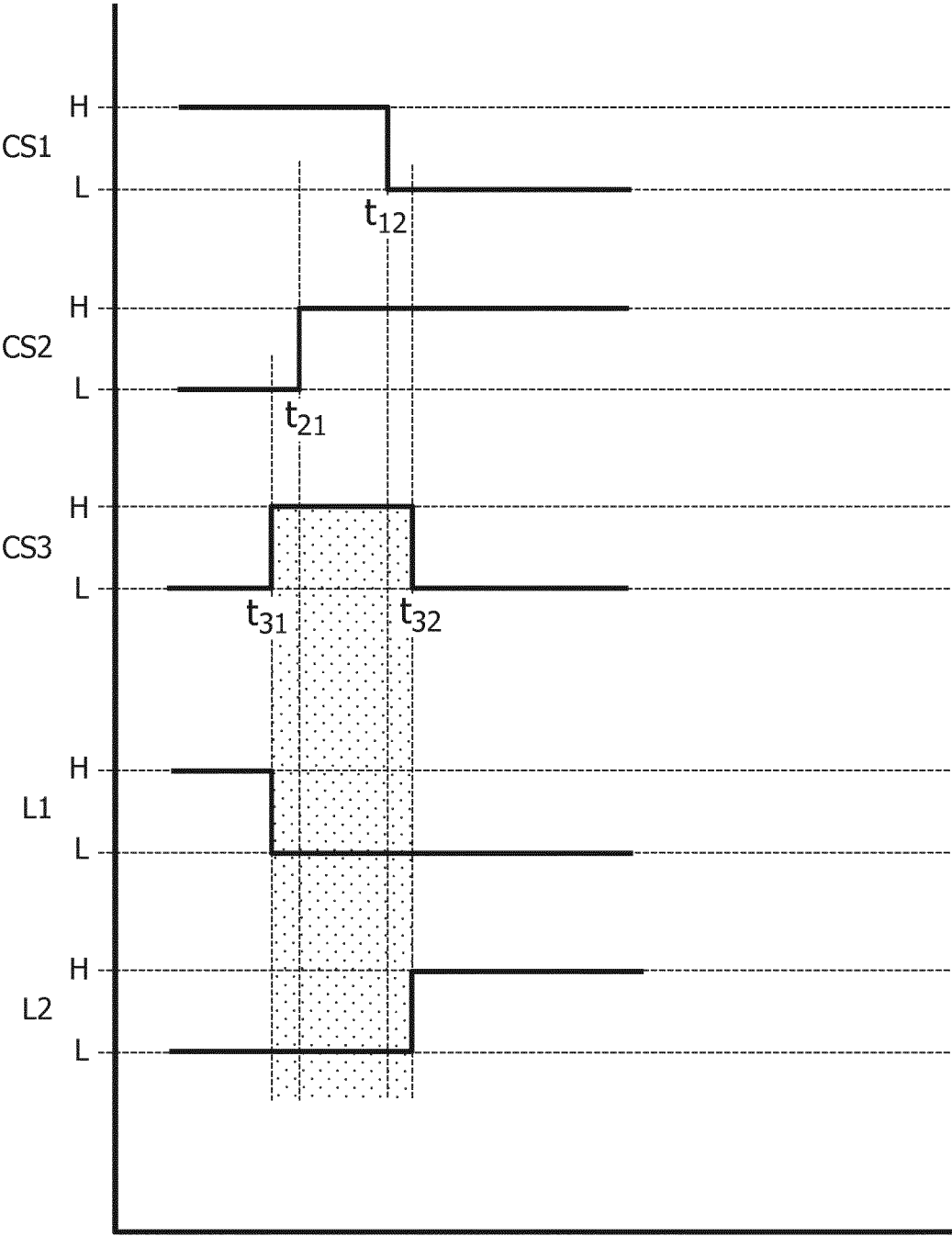


FIG. 5B

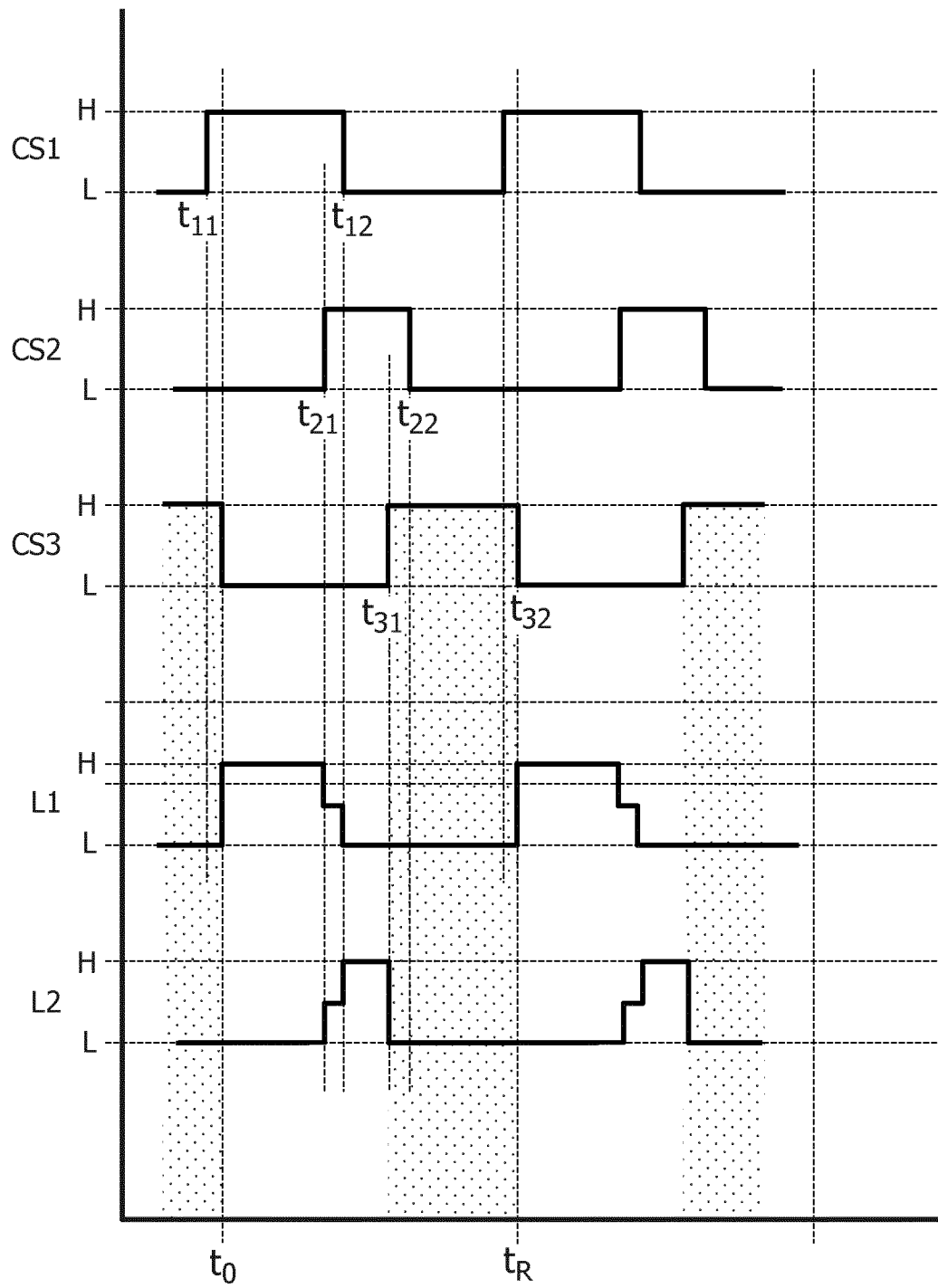


FIG. 5C

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/061745

A. CLASSIFICATION OF SUBJECT MATTER

INV. H05B33/08 F21K99/00
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 F21K F21S F21V H01L H02J H02M H03K

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, WPI Data, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2010/090530 A1 (WATANABE CHIRO [JP]) 15 April 2010 (2010-04-15) abstract; figures 1-3, 5, 6 page 1, paragraph 2 page 3, paragraph 37 - page 4, paragraph 59 page 4, paragraph 75 - page 7, paragraph 116	1-8, 11-13 9,10
Y	----- WO 2013/024389 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; TAO HAIMIN [NL]) 21 February 2013 (2013-02-21) abstract; figure 1 page 3, paragraph 13 - page 6, paragraph 25 page 12, paragraph 57 - page 13, paragraph 58 ----- -/-	1-4, 11-13



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

20 August 2015

Date of mailing of the international search report

31/08/2015

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/061745

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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Y	----- CN 101 932 172 A (LANDRY GRAY RICHARD) 29 December 2010 (2010-12-29) the whole document -----	6-8

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Information on patent family members

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