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(54) **Dimmable control for an LED lamp**

(57) A control circuit for an electric lamp. The circuit is operable to: measure the amplitude of an input signal; and generate a control signal for the lamp. The value of the control signal is changed only in response to a change in the amplitude of the input signal which exceeds a non-zero threshold.

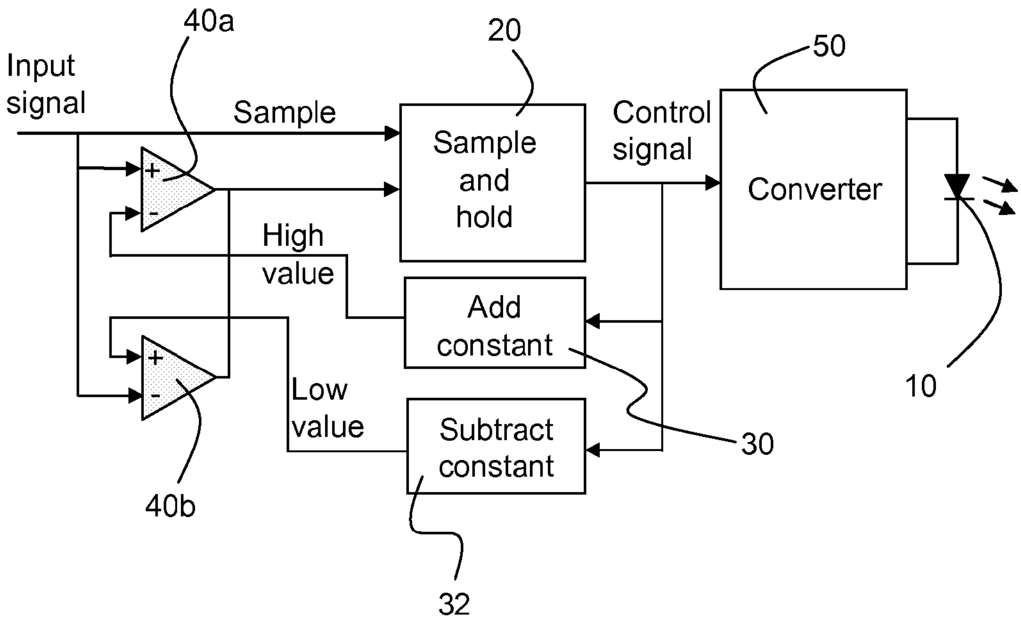


FIG 2

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## Description

**[0001]** This invention relates to a control circuit and method for an electric lamp. In particular, it relates to dimmable control of solid state lighting (SSL).

**[0002]** With the recent attention on power consumption, carbon-footprint and climate change, energy efficient lighting is becoming increasingly important. Indeed, in some countries, legislation prohibiting the sale of incandescent bulbs has already been enacted, as part of the drive for greater energy efficiency. SSL offers great savings in energy consumption compared with incandescent light-bulbs. Light Emitting Diode (LED) lighting solutions have now been developed which reach the minimum requirements for retrofit lamps. Here, a "retrofit lamp" refers to a light generating device which can be used as a direct like-for-like replacement for an incandescent light-bulb (or other conventional lamp) in an existing light fitting. Such lamps are starting to be produced in large quantities throughout the world.

**[0003]** The dimmer switch is commonly used in existing household and other electrical infrastructure to control the light level. They are typically wall mounted and operate by chopping the mains voltage (varying the duty-cycle) to vary the amount of power passed on to the light source. These devices are also called phase-cut dimmers. Due to the nature of the various lamp types (incandescent, low-voltage halogen and compact fluorescent), there are different types of wall mounted dimmers:

- Type R dimmers are leading-edge phase-cut dimmers that are only intended for use with standard incandescent bulbs and mains voltage halogen lamps (exhibiting a resistive load, R).
- Type R, L dimmers are leading-edge phase-cut dimmers that are intended for use with standard incandescent bulbs; mains voltage halogen lamps (exhibiting a resistive load, R); and normal transformers/ motors (exhibiting an inductive load, L).
- Type R, C dimmers are trailing-edge phase-cut dimmers that are intended for use with standard incandescent bulbs; mains voltage halogen lamps (resistive load, R); and electronic halogen transformers (capacitive load, C).

**[0004]** In dimmers of all these types, the variation in opening angle of the Alternating Current (AC) voltage phase results in a certain time interval (duty-cycle) in each AC period in which energy dissipation occurs within the filament of an incandescent bulb or a halogen lamp. The temperature of the filament will determine the amount of radiation that occurs, and the spectrum of this radiation. It can be shown that, as a result, the emitted light-intensity depends exponentially on the opening phase angle. The variation of temperature will also cause the electrical resistance of the filament to change, and this has a stabilizing effect on light output.

**[0005]** Dimmable mains LED driver circuits are also known. LED lamps differ from conventional light bulbs, in that they need to have a circuit that converts the mains voltage into a controlled current used to drive the LEDs. Typically, a converter using electronics switching technology, such as a Switched Mode Power Supply (SMPS), is used for this purpose. Dimmable LED drivers have additional functionality in order to be compatible with mains phase-cut dimmers. They are built into several known LED lamps, and are compatible with most wall-mounted dimmers. For example, US 2009/160358 discloses a controller for controlling an intensity of an LED using a conventional AC dimmer.

**[0006]** According to a first aspect of the present invention, there is provided a control circuit for an electric lamp, operable to:

> measure the amplitude of an input signal; and
> generate a control signal for controlling the brightness of the lamp,
> wherein the value of the control signal is changed only in response to a change in the amplitude of the input signal exceeding a non-zero threshold.

**[0007]** The input signal to the control circuit may be the output of a dimmer switch, preferably a phase-cut dimmer switch. The input signal may be rectified and/or processed or converted to Direct Current (DC) before it is provided to the control circuit. The input signal may be a voltage signal and the control signal may also be a voltage signal.

**[0008]** The present inventor has recognised that LED-lamps in combination with phase-cut dimmers exhibit a slow variation in light output, called shimmer. This is caused by mains voltage variation and pollution - for example by Electro-Magnetic Interference (EMI) - in combination with the susceptibility of LEDs and their associated driver electronics to the resulting phase shifts. According to embodiments of the invention, susceptibility to this slow variation can be removed without reducing the responsiveness of the lamps to user control.

**[0009]** This is achieved by ignoring small amplitude variations in the input signal, on the assumption that these are due to shimmer. That is, the control signal output by the circuit is only modified when the input signal from the dimmer changes by more than a given amount. The threshold is chosen to distinguish between user control of the dimmer switch (above the threshold) and unwanted variations in the AC signal (below the threshold).

**[0010]** The threshold may have a constant value.

**[0011]** In this way, the differential threshold for detecting user interaction with the dimmer switch is the same, regardless of the initial amplitude of the input signal or the control signal. A suitable constant-valued differential threshold may be chosen from the range 1% to 5% of the nominal Root Mean Squared (RMS) AC voltage, more preferably around 1.5% to 2% of the nominal voltage. Standards may specify maximum voltage variation between successive peaks of the same polarity. In this case, a threshold chosen slightly above this target may be advantageous. For mains electricity supplies in Europe, experiments have shown that a threshold of about 4v is a suitable starting point. This equates to approximately 1.75% of the nominal RMS voltage, 230v. The mains voltage variation to be rejected may however be different in different environments, depending on line voltage, network quality and the types of electrical equipment connected to the same mains circuit.

**[0012]** The circuit may comprise: a first comparator, for comparing a measured amplitude of the input signal with a first reference amplitude, wherein the value of the control signal is increased if the measured amplitude is greater than the first reference amplitude.

**[0013]** The circuit preferably also comprises: a second comparator, for comparing a measured amplitude of the input signal with a second reference amplitude, wherein the value of the control signal is decreased if the measured amplitude is less than the second reference amplitude.

**[0014]** The circuit may further comprise a sample and hold circuit, for storing a measured amplitude of the input signal, wherein the sample and hold circuit is controlled by the first and second comparators such that the measured amplitude is stored when it rises above the first reference amplitude or drops below the second reference amplitude.

**[0015]** This provides one simple way of measuring differential changes in the input signal and implementing appropriate control of the lamp.

**[0016]** Each of the first and second reference amplitudes may be derived from the stored amplitude of the input signal.

**[0017]** To implement a differential-threshold test, the reference amplitudes can be derived from a previously measured value of the input signal amplitude.

**[0018]** At least one of the first or second reference voltages is preferably obtained by respectively adding or subtracting a constant value to or from the stored amplitude.

**[0019]** This provides a constant differential threshold, independently of the present or previous value of the input signal or control signal.

**[0020]** The stored amplitude is preferably output as the control signal for the lamp.

**[0021]** This provides a simple control circuit.

**[0022]** The control circuit may further comprise a converter adapted to drive the lamp with a current that is in exponential proportion to the control signal.

**[0023]** If the lamp has a linear response to current, this allows the lamp to mimic the response of a conventional incandescent bulb, for example.

**[0024]** The control circuit may further comprise a low-pass filter for smoothing the input signal.

**[0025]** Smoothing the input using a low-pass filter will remove brief, small variations. This may enable the threshold to be reduced, since the amplitude of variation due to noise or distortion of the AC mains signal is reduced. This can lead to a control circuit that is more sensitive to user interaction with the dimmer switch.

**[0026]** Also provided is a dimmable LED lamp comprising: at least one LED; and a control circuit as summarised above.

**[0027]** According to another aspect of the invention, there is provided a method of controlling an electric lamp, comprising:

measuring the amplitude of an input signal; and
generating a control signal for the lamp,
wherein the value of the control signal is changed only in response to a change in the amplitude of the input signal exceeding a non-zero threshold.

**[0028]** This method can be implemented by a bespoke electrical control circuit (that is, in hardware), or may be implemented by a programmable microcontroller or microprocessor following suitable software instructions.

**[0029]** Measuring the amplitude of the input signal may comprise: sampling and storing a first, reference amplitude value of the input signal; and sampling a second amplitude value of the input signal, and generating the control signal for the lamp may comprise: comparing the second amplitude value with the reference amplitude value; and, if the difference is greater than a non-zero threshold, setting the control signal according to the second amplitude value.

**[0030]** Also provided is a computer program comprising computer program code means adapted to perform all the steps of a method as summarised above, when said program is run on a computer; and such a computer program embodied on a computer readable medium.

**[0031]** The invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 illustrates a typical response curve for an LED driver circuit under the control of a phase-cut dimmer;
Fig. 2 is a block diagram of a control circuit according to an embodiment of the invention;
Fig. 3 is a graph showing an example of the signals in the circuit of Fig. 2, when in use;
Fig. 4 is a flowchart illustrating a method according to an embodiment of the invention;
Fig. 5 illustrates an analogue implementation of average voltage detection;
Fig. 6 illustrates an analogue implementation of phase detection; and
Fig. 7 illustrates a digital implementation of phase detection.

**[0032]** Embodiments of the invention reduce or eliminate variation in light output due to instability of the dimmer and driver that is caused by typical mains-voltage variation. Although conventional incandescent bulbs and halogen lamps also suffer from the same instability caused by the gain of the phase-cut dimmer, the slow thermal response of the filament combined with the current stabilizing effect of the filament means that the actual variation in light output is not perceptible in most cases. However, with LED lamps, these damping and stabilizing effects do not occur. LEDs have a light output that is approximately proportional to the current flowing through the LED, and the response time with current variations is much faster. As a result, LED drivers are much more prone to shimmer and flicker. Within the driver for the LEDs, information about the position of the dimmer must be measured from the input voltage and translated into an LED current which regulates the light output.

**[0033]** Whereas incandescent bulbs and halogen lamps by the nature of their exponential curve have a broad range of dimming, and the existing dimmers are designed to match such a load, this is not the case for LED lamps. The load of a LED lamp is much smaller. Furthermore, a compromise must be made, to achieve compatibility with the widest possible selection of existing dimmers: in order to obtain a full dimming-range with an arbitrarily chosen dimmer switch, only a partial part of the phase angle is used to measure dimming position. Consequently, for any given dimmer switch, there will usually be two zones (called dead-bands) at either end of the dimmer switch range, in which the LED lamp will not respond to variations in the dimmer switch position.

**[0034]** This is illustrated in Fig. 1. The lower graph shows one half-cycle of the AC signal. A dimmer acts either by delaying the rise of the leading edge, or by forcing the trailing edge to zero early. The portion of the AC signal "cut" by this is shown by the hatched triangles. In an ideal dimmer switch, when the dimmer is turned up to its maximum value, there should be no cutting - that is, the full AC cycle is passed to the light-fitting unchanged. Likewise, when the dimmer is turned down fully, the whole cycle should be cut. However, most real dimmers will provide control only over a portion of the 180 degree phase. To account for this variation among real dimmer devices, the control circuit response curve (shown in the upper plot of Fig. 1) only provides variation over the central range of phases. This means that full control of the light output will be possible with almost any real dimmer device. Unfortunately, it requires the creation of dead bands 1 and 2, in which varying the phase angle has no effect on light output. It also means that the maximum gain of the control curve is increasesd (that is, the slope of the curve is made steeper). As indicated in the drawing, a small amount of phase jitter/wobble in the mains AC signal then results in a relatively larger shimmer in the light output. In other words, the remaining dimming curve will be steeper and this increased gain will increase the susceptibility to unintended light variations, when the supply voltage varies.

**[0035]** A control circuit according to an embodiment uses a trip-level detector to adjust the light output only when a threshold is exceeded. This will remove the problem of shimmer of LED lamps in combination with dimmers. This solution not only applies to phase-cut dimmers but can also be applied to all other control methods of SSL lamps and lighting where slow variation of light output due to variation of input control signal occurs. The trip level detection can be implemented in several ways, either in hardware or by software program.

**[0036]** Fig. 2 shows a control circuit according to an embodiment of the invention. An LED 10 is powered by a converter 50. The function of the converter is, to convert an input voltage into a driving current suitable for the attached LED load. Conventional circuits for doing this are well known to those skilled in the art. One simple discrete solution is to use a resistor, but this may lack controllability. Alternatively, the converter may be a discrete linear regulator, or it may have advanced electronics using semiconductor and magnetic components (for example, in an SMPS) to realize the converter functionality. The converter is controlled by a control signal that is generated by the control circuit in response to an input signal. This input signal is based on the AC voltage received from the phase-cut dimmer and it includes variations due to impurities in the mains AC signal. The processing applied to the output signal of the phase-cut dimmer, in order to produce an input signal that is suitable for the circuit of Fig. 2, will be described in greater detail below, with reference to Figs. 5-7. The control circuit of Fig. 2 aims to reduce or eliminate the effect of the input variations on the control signal and hence the light output of the LED 10.

**[0037]** The control circuit comprises a sample and hold circuit 20; an adder circuit 30; subtraction circuit 32; and two comparators 40a, 40b. The sample and hold circuit samples and stores the amplitude of the input voltage. Triggering of the sample and hold operation is controlled by the comparators 40a, 40b as will be described further below. The stored amplitude of the input signal, at the output of the sample and hold circuit 20 is the control signal for the converter 50 and is also provided at the input of the adder 30 and subtraction circuit 32. Adder 30 adds a constant value to the amplitude, to provide a high reference value. Subtractor 32 subtracts a constant value from the stored amplitude, to produce a low reference value. The constants added and subtracted are the same, in this embodiment: plus and minus 4v, respectively, assuming a nominal RMS AC voltage of 230v.

**[0038]** The comparators 40a, 40b are connected such that the high and low values are treated as a differential band, within which the control signal will not be updated (changed). Only when the high value is exceeded or the input drops below the low value will the control signal vary. To achieve this, the first comparator 40a receives the high reference value at its inverting (-) input and the input signal at its non-inverting (+) input. Consequently, the first comparator will output a logic-high ("1") when the input is greater than the high reference value. Conversely, the second comparator 40b receives the low reference value at its non-inverting (+) input and the input signal at its inverting (-) input. Therefore, the second comparator will output logic-high ("1") when the input signal is less than the low reference value output by the subtractor 32. The outputs of both comparators are connected to the sample and hold circuit, so that the sample and hold is triggered if either comparator outputs a logic 1.

**[0039]** When the input is stable (unchanging) the control signal and the input are (approximately) identical and so neither comparator triggers the sample and hold circuit. When the input changes by an amount greater than the constant differential value (here, 1v), the sample and hold is triggered, which updates the control signal and resets the reference voltages supplied to the comparators 40a, 40b.

**[0040]** Fig. 3 shows a graph illustrating the operation of the circuit over time. V[vinput] corresponds to the input signal; V[vcontrol] to the control signal; and I[led] the resulting LED current that is close to proportional with light output of the lamp. There is a logarithmic relation between control signal and led current, to compensate for the logarithmic eye sensitivity. This is relationship is produced by the converter 50. In this way, the LED lamp will match the dimming curve of a conventional incandescent lamp. Note, however, that this relationship is not essential. For example, it may be desired instead to have a linear relationship if control of power consumption, rather than perceived light output is the dominant consideration.

**[0041]** In the time period between 0 and 1.5 sec, there is user interaction: The dimmer knob is rotated to set lower light output from time=0 until 1 sec, and to increase light output between 1 and 1.5 seconds. The light adjusts accordingly in discrete steps. The number of steps is determined by selection of the constant differential threshold values. The number of steps should be sufficient to offer enough resolution in selectable light level, for the user; but, at the same time, the thresholds should allow a big enough variation to offer shimmer rejection. Between 1.5 and 3.5 seconds, there is a slow but limited variation in input signal, but the control signal does not follow because the amplitude is less than the differential threshold. As a result, the light level remains unchanged.

**[0042]** It should be mentioned that this embodiment does not achieve shimmer rejection by simply converting the incoming input signal into discrete steps, as is common with analog digital converters, for example. A single conversion into discrete steps would offer filtering within the margin of its lowest resolution, but would aggravate shimmer when the input signal level is close to, or at the transition level between two states. Instead, in the present embodiment, upon crossing the threshold the crossed threshold is adopted as new next value. Note that there will always be a timing delay in the control electronics. Here, though, the dynamics of the comparators and sample and hold are assumed to be much faster than the human interaction time with the dimmer switch - for example, 100-300mS for the human turning the dimmer knob, compared with a few nanoseconds or microseconds for the control electronics.

**[0043]** It is of course possible to create a digital implementation of the analogue circuit shown in Fig. 2, in which the voltage at the input is quantized; the comparison with the differential threshold is evaluated digitally and the control signal generated converted back to analogue form at an output. In this case, naturally, the quantization step-size at the input should be smaller than the differential threshold, for the circuit to successfully reject shimmer.

**[0044]** If a digital implementation is preferred, an analogue to digital converter can be included between the output of the phase-cut dimmer and the input to the control circuit. Correspondingly, the digital to analogue conversion can be performed by the converter itself (where the converter has digital logic) or between the control signal output and the converter (where the converter has analogue input).

**[0045]** Fig. 4 shows a flowchart for a method according to an embodiment of the invention. This can be used to create a digital implementation of the circuit of Fig. 2, with a corresponding input signal and control signal.

**[0046]** The method starts 100 by sampling 110 the input signal and storing 120 the sampled valued in a variable A. Next, the value A is compared with a previously stored value B. (In the first iteration, B is initialized so that it is equal to A).In step 130, it is determined if A is less than B-1. This implements the comparison with the low reference value. The low reference value is B-1. Here, the value "1" refers to the differential threshold, which in this case is set equal to the minimum quantization step resolution. The actual threshold in volts may therefore be set arbitrarily and suitable voltage values have already been discussed above. If A is below this threshold, B is updated 140 with the value A and the control signal is updated to take the value B. If, in step 130, the value of A was greater than or equal to the low reference threshold, the next test 160 is instead performed. Here, A is compared 160 with B+1. If A is greater than this high reference value, the method proceeds to step 140, where B is updated with the value of A, and the control signal is set 150 to the same value. If not, the method returns to step 110, to re-sample the input signal.

**[0047]** Comparing the method of Fig. 4 with the circuit of Fig. 2, it can be seen that the value A is the current value of the input signal, whereas the variable B corresponds to the value previously stored by the sample and hold circuit 20. The method of Fig. 4 can be implemented as a software program for a microcontroller or microprocessor. The microprocessor can then control the converter circuit 50 in the same manner as the circuit of Fig. 2.

**[0048]** As mentioned previously above, the input to the control circuit of Fig. 2 should preferably be a processed version of the waveform generated by the phase-cut dimmer. In general, an integration operation should be applied, to provide a temporally-averaged measure of the waveform over the complete AC cycle. Two methods of integration will be considered here: voltage integration and phase integration. Voltage integration aims to sum (integrate) the magnitude of the voltage signal, while phase integration aims to measure the on-time of the phase-cut dimmer switch. With phase detection, there is a linear dependency between dimmer opening angle and the Input Signal of fig. 2. With average voltage detection, the result is a cosine curve.

**[0049]** Fig. 5 shows an example of an average voltage detector, implemented in the analogue domain. A phase-cut dimmer 501 is connected in series with the live mains terminal L, in the conventional manner. The output of the dimmer 501 and the neutral mains wire N are connected to the input of a Full-Wave Rectifier (FWR) 502. The input signal to the FWR is a phase-cut version of the mains AC signal - consisting of a partial positive half-cycle and partial negative half-cycle. The output of the rectifier is a corresponding series of (positive) pulses at twice the mains frequency. The output of the rectifier 502 is connected to an integrator circuit comprising two series-connected resistors R1 and R2; and a capacitor C1, connected in parallel with the second resistor R2. The RC circuit smoothes (or integrates) the voltage pulses produced by the rectifier, to provide a signal that represents the average of the full-wave rectified, phase-cut mains signal. This output average rectified voltage signal can be measured across the capacitor C1 and forms the input to the control circuit.

**[0050]** The values of R1 and R2, which together form a resistive divider, are preferably high-ohmic because only a voltage measurement is required. For example, for R1, resistive values between 500KOhm to 10 Mega Ohm are common. As will be apparent to the skilled addressee, the precise values will also depend on the input impedance of the succeeding electronics. Taking the example of R1=1Mega Ohm and Vmains = 230V AC, the resistive power dissipation is P=V^2/R=230^2/1000000 = 53mW. This loss is negligible, since the power saving from using an SSL lamp in comparison with an incandescent bulb is typically in the range of 10-50 Watts. Furthermore, the losses present in the phase cut dimmer, which are in the range of 2-3 Watts, will dominate.

**[0051]** Fig. 6 shows an example of an analogue circuit for producing an input signal for the control circuit by phase detection. As in the circuit of Fig. 5, the phase-cut dimmer 501 is connected to a full-wave rectifier 502; and the output of the FWR 502 is connected to a resistive divider, consisting of R1 and R2. The mains input voltage is modified by the dimmer. The opening angle $\varphi$ corresponds to the dimmer position. In Fig. 6, instead of using a capacitor to integrate or smooth the voltage, a comparator circuit 605 is used to detect the opening angle. One input of the comparator 605 is connected to the output of the resistive divider (between R1 and R2). The other input of the comparator 605 is connected to a reference voltage $V_{ref}$, which is just above 0v, to ensure that the output of the comparator always resets to zero in each half cycle, even if the opening angle is at its maximum of 180 degrees. A retriggerable monostable element 601 (also called a "one shot" or monostable multivibrator), connected to the output of the comparator 605, is used to control an analogue switch 602 that copies the voltage on capacitor C1 to capacitor C2. The one shot 601 is triggered by a falling edge of the comparator output. In other words, it generates a pulse when the rectified, phase-cut mains signal falls to zero (at the end of the on-time). Capacitor C1 is reset to zero each cycle using another switch 603 and is charged, during a time corresponding to $\varphi$, by current source $I_{ch}$. An OR-function 604, which controls the (inverting) input of the switch 603, ensures that the voltage over C1 is not discharged before copying into C2, and lets C1 charge again when the dimmer start to conduct. The OR-function has one input from the output of the comparator and another input from the output of the one-shot. Therefore, during the on-time, $\varphi$, and the brief pulse of the one-shot immediately afterwards, the OR gate outputs logic-one, which keeps the switch 603 open. After the one-shot pulse (but before the start of the next "on" period $\varphi$), the OR gate outputs logic-zero, which closes the switch 603, to discharge the integrating capacitor C1. The voltage which accumulates on the capacitor C1 during the on-time represents the opening angle $\varphi$.

**[0052]** A third alternative is shown in Fig. 7. This illustrates a digital implementation of phase detection. The mains input voltage is modified by the dimmer. The opening angle $\varphi$ corresponds to the dimmer position. Using a resistive divider R1, R2 and comparator 605, this time is converted to a control signal. A retriggerable monostable element 601 (one shot) is used to control a counter and register logic element 702. This element starts to count up when the enable input is activated (high). On the rising edge of the output of the one-shot 601 the value of the internal counter is relayed and stored in the output buffer. At the lowering edge, the counter is reset. The oscillator 703 provides a signal controlling the counter speed.

**[0053]** In each of these three examples, the bandwidth of the integrator/detector circuit is chosen to be less than 300mS (corresponding to the typical human interaction time) but greater than a single period of the signal. For a 50Hz mains AC signal, for example, this minimum time is 20ms - or 10ms if the signal is full wave rectified (doubling its frequency and halving the period). The invention is applicable to general lighting retrofit applications, preferably those based on LEDs. It is also relevant for other non-retrofit lighting applications that have means of controlling the light output in a continuously variable or multi-level quantised fashion. It is primarily directed to mains phase-cut dimmable methods, but may also find utility with other means of control where the (noise) variation of the input signal is slower than the normal speed of human interaction time.

**[0054]** 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.

**[0055]** For example, it is possible to operate the invention in embodiments in which the sizes of the positive and negative differential thresholds are different, or in which the differential threshold is variable. The disturbance to the mains voltage may be asymmetric - for example, larger negative spikes could be caused by switching on and net loading of heavy machinery, or equipment with high inrush-current like refrigerators, but smaller positive spikes. In this case, it would be desirable for the negative threshold to be larger than the positive threshold. Of course, this will affect the user experience also: the user will have to turn the dimmer knob further to dim the light than to brighten it.

**[0056]** It may also be beneficial to use a change-threshold that varies with the amplitude of the input signal. The size of the change needed to trigger a change in the control signal (and therefore LED light output) sets an effective minimum step size in the brightness of the LED. It may be desirable to choose the threshold according to the existing brightness, since the human eye perceives changes in brightness in a logarithmic relation to the actual light intensity. Thus, varying the step size may give a better impression of perceptually equal steps in brightness. By way of example, the threshold could be determined in linear proportion to the stored amplitude of the input signal. That is, the step size may be relatively larger at higher values of the input signal. The threshold step-size is executed before the exponential relationship is created by the converter (to match the driving current to the human perception of brightness). There could however be a non-linear relation between control of the light output and the input signal to the control circuit, output from the dimmer. Phase-cut dimmers have such a non-linear transfer for average rectified output voltage (which is the integral of a sine-wave, dependent on the opening angle of phase).

**[0057]** Alternatively, or in addition, it may be beneficial to vary the threshold in accordance with a predicted level of noise/variation in the mains AC signal. For example, the distortion may be greater at certain times of the day or night, or may be correlated with demand in the supply network.

**[0058]** The effectiveness of embodiments can be enhanced by combining the circuit of Fig. 2 with a low-pass filter that blocks input signal distortion due to other phenomena, like line noise; thermal noise; line pollution due to other equipment; RF interference with the input signal; crosstalk, and so on.

**[0059]** Note that filtering alone (without threshold-based testing of the input signal) is unlikely to solve the problem of shimmer by itself. In order to reject shimmer, the bandwidth of the filter would need to be lower than the slowest variation of mains AC voltage. As a result, the lamp response to user interaction (changing the dimmer switch position) will be sluggish, resulting in non-intuitive control that does not match the control speed when using a conventional incandescent bulb. The acceptable response time for the user interaction is in the region of 300ms or less. In contrast to a pure filter-based approach embodiments of the invention are active over the complete frequency band and can be combined with normal filtering, for additional benefit.

**[0060]** The input signal can be obtained by measuring voltage; current; relaying a digital signal imposed on the mains line (Power line control); a separate cable interconnected with the lamp (for example, three wire control or Digital Addressable Lighting Interface - DALI); or other interfacing methods like RF control (for example, Zigbee or Z-Wave), infrared control or mechanical control where slow variation of control information can occur.

**[0061]** Note that the flowchart of Fig. 4 could be used either to implement computer code, embedded code, or a state machine. There are various platforms suitable for implementing methods according to embodiments of the invention in the digital domain. Computer code can be executed in a simple microcontroller, like the Intel 8051-compatible microcontroller. Embedded code can be VHDL that is transferred to an FPGA, for example to prototype a desired circuit. A state machine can also be devised in silicon, so that it becomes a dedicated design of an Integrated Circuit (IC) or part of an IC.

**[0062]** 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 fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measured cannot be used to advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

## Claims

1. A control circuit for an electric lamp, operable to:

   measure the amplitude of an input signal; and
   generate a control signal for the lamp,
   wherein the value of the control signal is changed only in response to a change in the amplitude of the input signal exceeding a non-zero threshold.

2. A control circuit according to claim 1, wherein the threshold has a constant value.

3. A control circuit according to claim 1, wherein the circuit comprises:

a first comparator, for comparing a measured amplitude of the input signal with a first reference amplitude,
wherein the value of the control signal is increased if the measured amplitude is greater than the first reference amplitude.

**4.** A control circuit according to claim 3, wherein the circuit comprises:

a second comparator, for comparing a measured amplitude of the input signal with a second reference amplitude,
wherein the value of the control signal is decreased if the measured amplitude is less than the second reference amplitude.

**5.** A control circuit according to claim 4, further comprising
a sample and hold circuit, for storing a measured amplitude of the input signal,
wherein the sample and hold circuit is controlled by the first and second comparators such that the measured amplitude is stored when it rises above the first reference amplitude or drops below the second reference amplitude.

**6.** A control circuit according to claim 4 or claim 5, wherein each of the first and second reference amplitudes is derived from the stored amplitude of the input signal.

**7.** A control circuit according to claim 6, wherein at least one of the first or second reference amplitudes is obtained by respectively adding or subtracting a constant value to or from the stored amplitude.

**8.** A control circuit according to any of claims 5 to 7, wherein the stored amplitude is output as the control signal for the lamp.

**9.** A control circuit according to any preceding claim, further comprising a converter adapted to drive the lamp with a current that is exponentially related to the control signal.

**10.** A control circuit according to any preceding claim, further comprising a low-pass filter for smoothing the input signal.

**11.** A dimmable LED lamp comprising:

at least one LED; and
a control circuit according to any preceding claim.

**12.** A method of controlling an electric lamp, comprising:

measuring the amplitude of an input signal; and
generating a control signal for the lamp,
wherein the value of the control signal is changed only in response to a change in the amplitude of the input signal exceeding a non-zero threshold.

**13.** A method according to claim 12, wherein:

measuring the amplitude of the input signal comprises:

sampling and storing a first, reference amplitude value of the input signal; and
sampling a second amplitude value of the input signal,

and wherein

generating the control signal for the lamp comprises:

comparing the second amplitude value with the reference amplitude value; and,
if the difference is greater than a non-zero threshold, setting the control signal according to the second amplitude value.

**14.** A computer program comprising computer program code means adapted to perform all the steps of any of claims 12 to 13 when said program is run on a computer.

**15.** A computer program as claimed in claim 14 embodied on a computer readable medium.

**Amended claims in accordance with Rule 137(2) EPC.**

**1.** A control circuit for an electric lamp, adapted to:

measure the amplitude of an input voltage signal comprising amplitude variations due to variation in mains AC voltage; and
generate a control signal for the lamp,
wherein the value of the control signal is changed only in response to a change in the amplitude of the input signal exceeding a non-zero threshold.

**2.** A control circuit according to claim 1, wherein the threshold has a constant value.

**3.** A control circuit according to claim 1, wherein the circuit comprises:

a first comparator, for comparing a measured

amplitude of the input signal with a first reference amplitude, the first reference amplitude being derived from a previously measured value of the input signal amplitude,
wherein the value of the control signal is increased if the measured amplitude is greater than the first reference amplitude.

**4.** A control circuit according to claim 3, wherein the circuit comprises:

a second comparator, for comparing a measured amplitude of the input signal with a second reference amplitude, the second reference amplitude being derived from a previously measured value of the input signal amplitude,
wherein the value of the control signal is decreased if the measured amplitude is less than the second reference amplitude.

**5.** A control circuit according to claim 4, further comprising
a sample and hold circuit, for storing a measured amplitude of the input signal,
wherein the sample and hold circuit is controlled by the first and second comparators such that the measured amplitude is stored when it rises above the first reference amplitude or drops below the second reference amplitude.

**6.** A control circuit according to claim 5, wherein at least one of the first or second reference amplitudes is obtained by respectively adding or subtracting a constant value to or from the stored amplitude.

**7.** A control circuit according to claim 5 or claim 6, wherein the stored amplitude is output as the control signal for the lamp.

**8.** A control circuit according to any preceding claim, further comprising a converter adapted to drive the lamp with a current that is exponentially related to the control signal.

**9.** A control circuit according to any preceding claim, further comprising a low-pass filter for smoothing the input signal.

**10.** A dimmable LED lamp comprising:

at least one LED; and
a control circuit according to any preceding claim.

**11.** A method of controlling an electric lamp, comprising:

measuring the amplitude of an input voltage signal comprising amplitude variations due to variation in mains AC voltage; and
generating a control signal for the lamp,
wherein the value of the control signal is changed only in response to a change in the amplitude of the input signal exceeding a non-zero threshold.

**12.** A method according to claim 11, wherein:

measuring the amplitude of the input signal comprises:

sampling and storing a first, reference amplitude value of the input signal; and
sampling a second amplitude value of the input signal, and wherein

generating the control signal for the lamp comprises:

comparing the second amplitude value with the reference amplitude value; and,
if the difference is greater than a non-zero threshold, setting the control signal according to the second amplitude value.

**14.** A computer program comprising computer program code means adapted to perform all the steps of any of claims 12 to 13 when said program is run on a computer.

**15.** A computer program as claimed in claim 14 embodied on a computer readable medium.

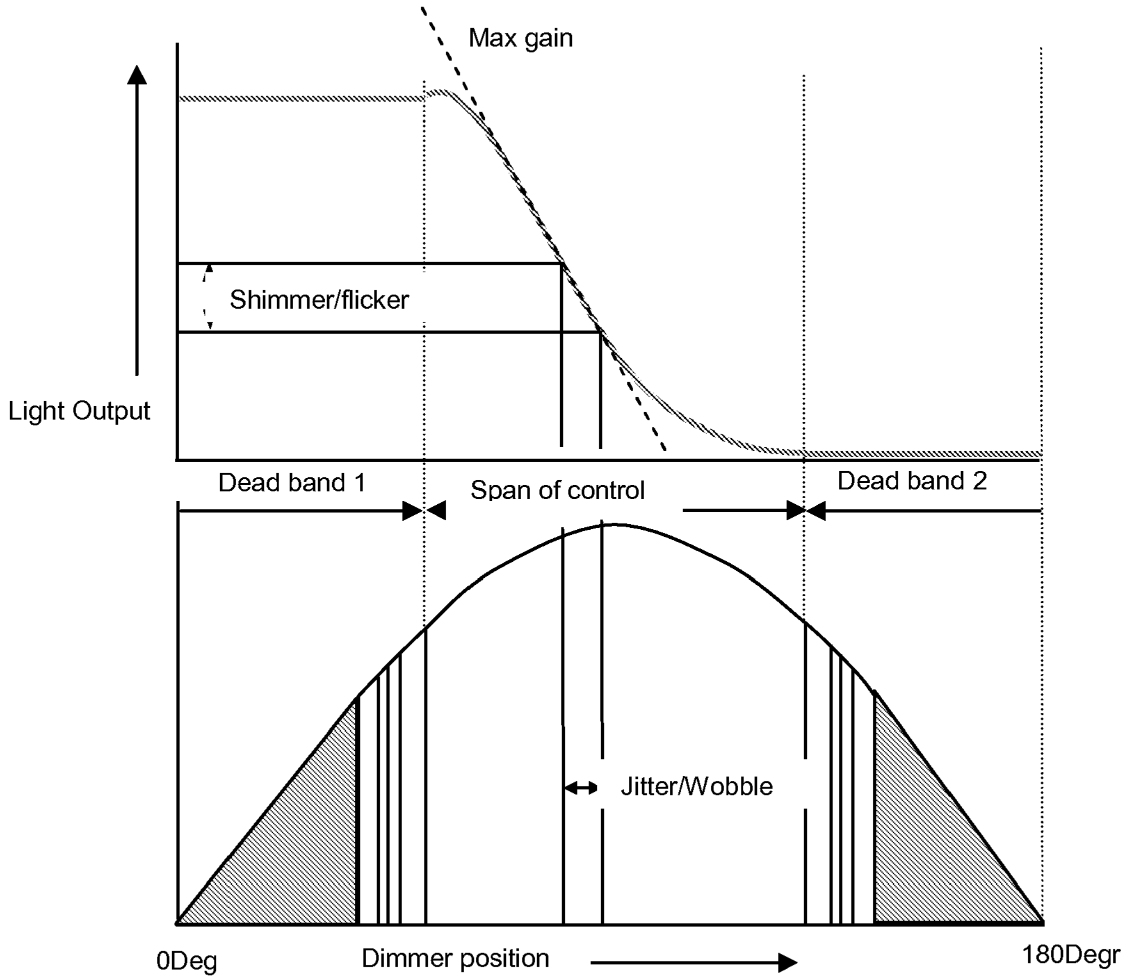
Max gain
Shimmer/flicker
Light Output
Dead band 1
Span of control
Dead band 2
Jitter/Wobble
0Deg
Dimmer position
180Degr

FIG 1

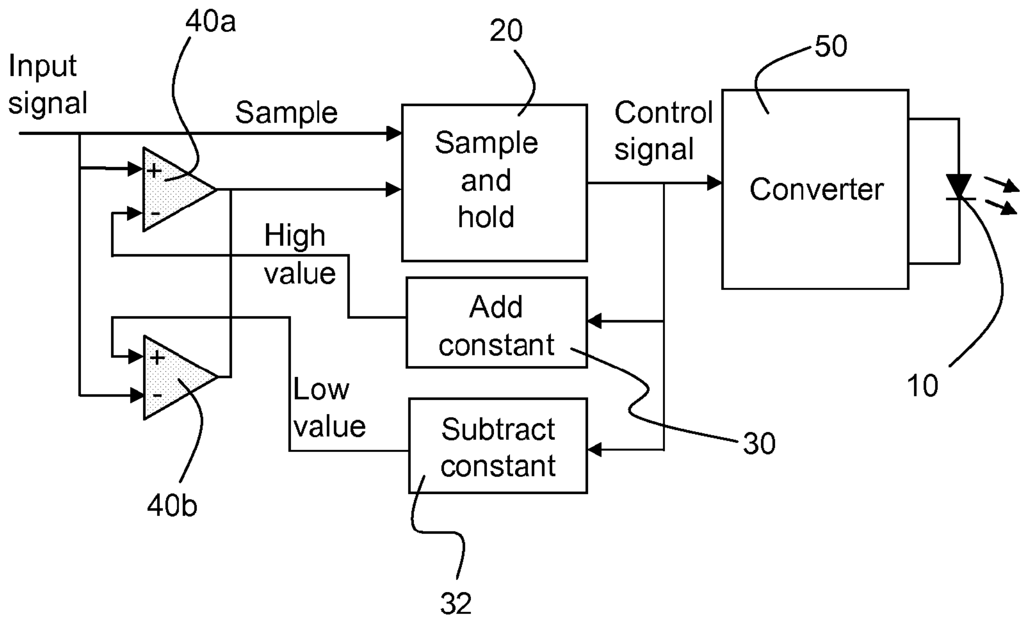
40a
20
50
Input signal
Sample
Control signal
Sample and hold
Converter
High value
Add constant
10
Low value
Subtract constant
30
40b
32

FIG 2

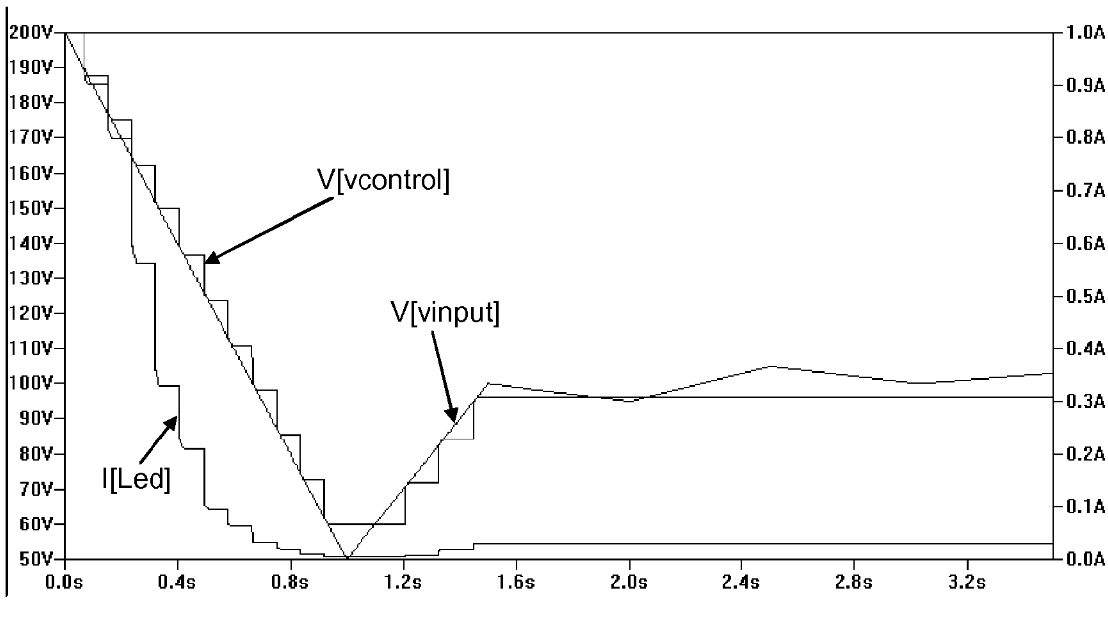
200V
190V
180V
170V
160V
150V
140V
130V
120V
110V
100V
90V
80V
70V
60V
50V
1.0A
0.9A
0.8A
0.7A
0.6A
0.5A
0.4A
0.3A
0.2A
0.1A
0.0A
0.0s
0.4s
0.8s
1.2s
1.6s
2.0s
2.4s
2.8s
3.2s
V[vcontrol]
V[vinput]
I[Led]

FIG 3

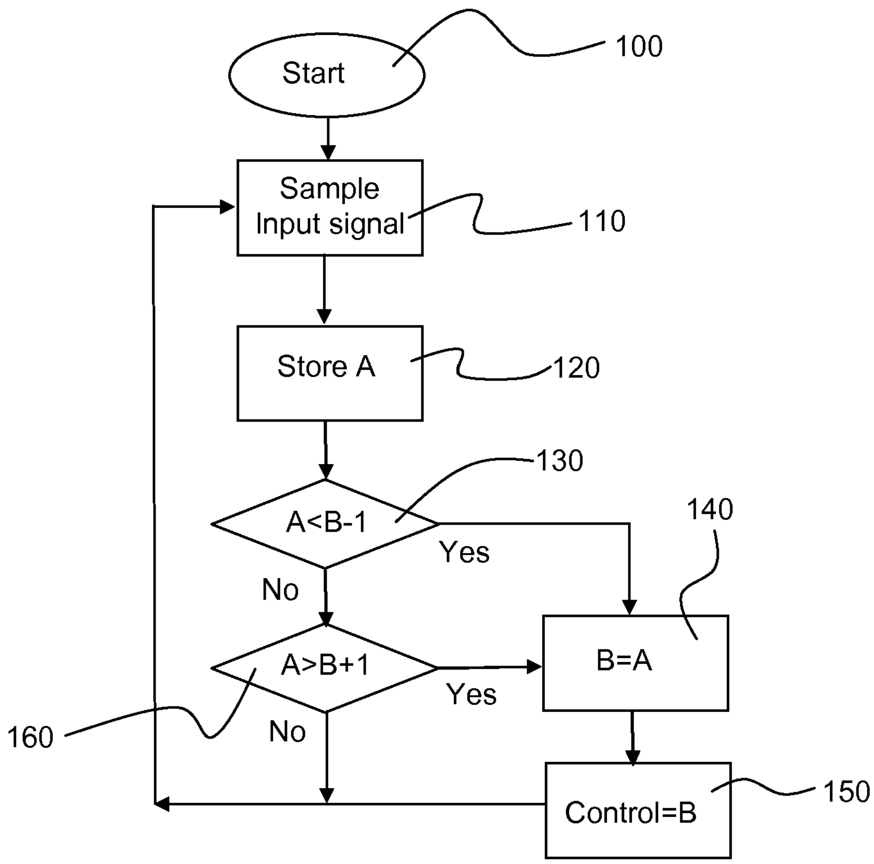
Start
100
Sample
Input signal
110
Store A
120
130
A<B-1
Yes
No
140
B=A
A>B+1
Yes
No
160
Control=B
150

FIG 4

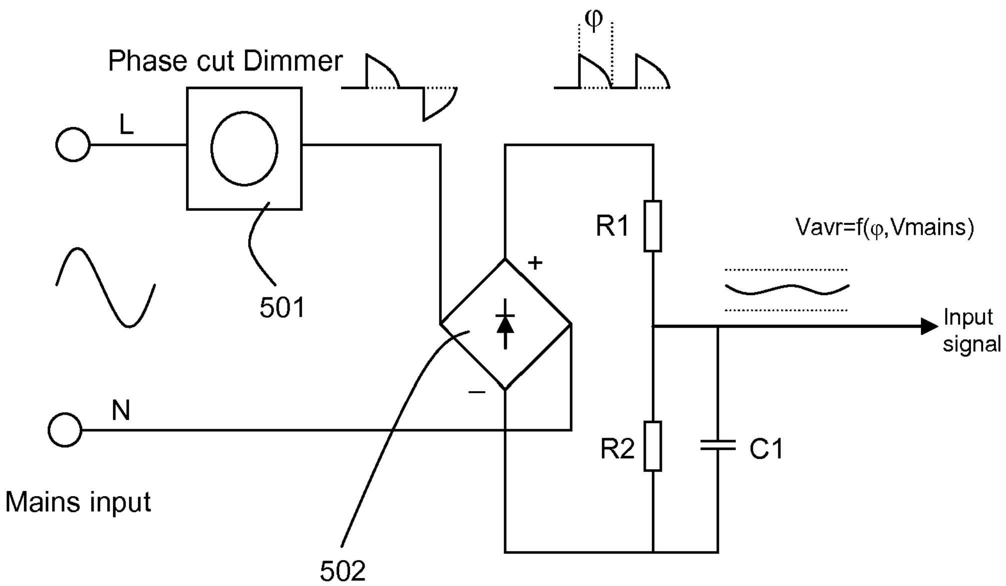
φ
Phase cut Dimmer
L
501
R1
Vavr=f(φ,Vmains)
+
Input
signal
–
N
R2
C1
Mains input
502

FIG 5

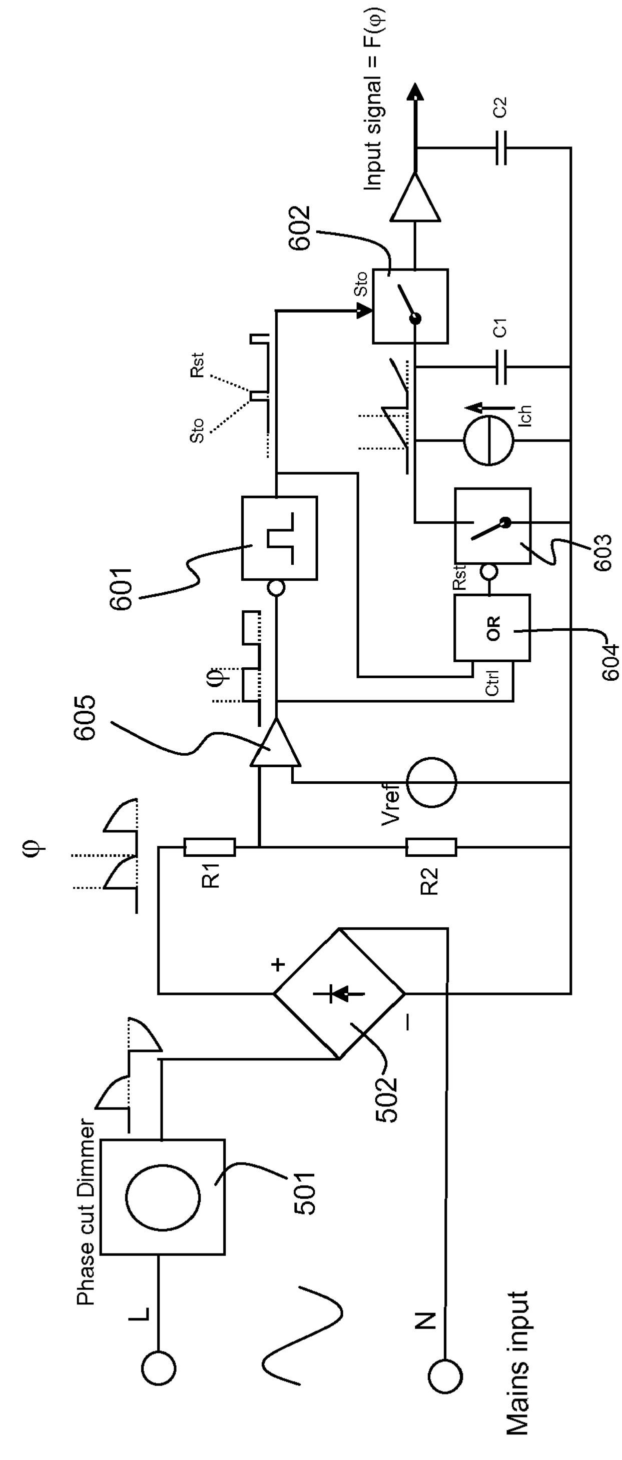
Input signal = F(φ)
C2
602
Sto
C1
Rst
Sto
Ich
601
603
604
OR
Rst
Ctrl
φ
605
Vref
φ
R1
R2
+
−
502
Phase cut Dimmer
501
L
N
Mains input

FIG 6

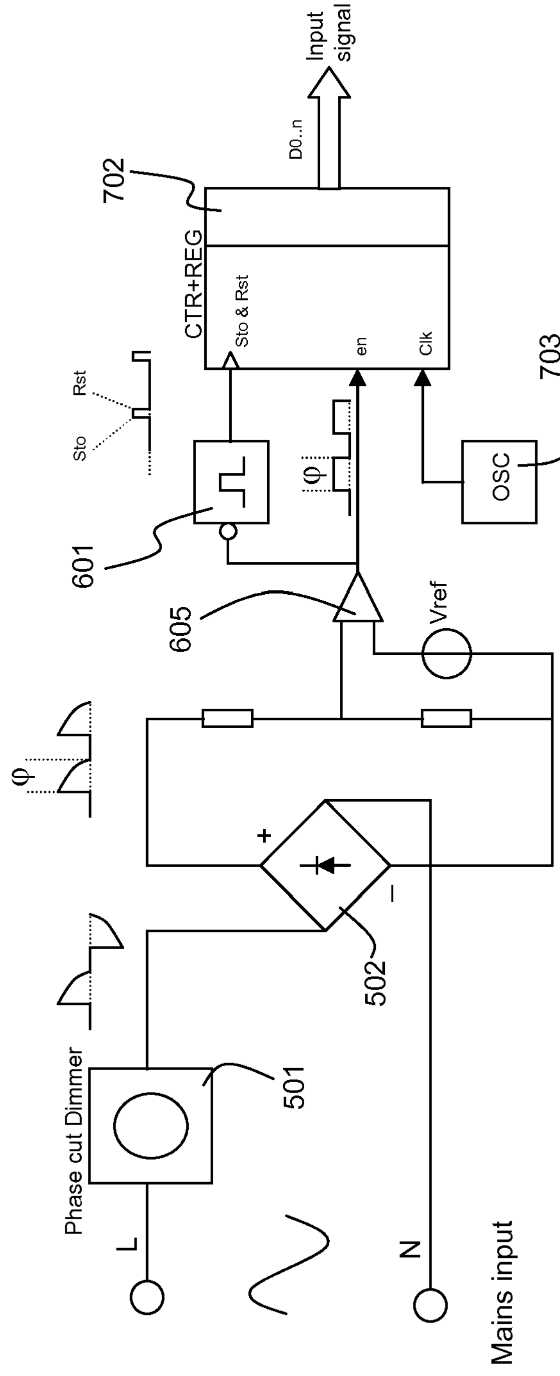
Input signal
D0..n
702
CTR+REG
Sto & Rst
en
Clk
Sto
Rst
703
OSC
601
φ
605
Vref
φ
+
–
502
501
Phase cut Dimmer
L
N
Mains input

FIG 7

Europäisches Patentamt
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# EUROPEAN SEARCH REPORT

Application Number
EP 10 17 1479

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
|---|---|---|---|
| Y | WO 2008/112735 A2 (CIRRUS LOGIC INC [US]) 18 September 2008 (2008-09-18)<br>* page 8, paragraph 38 - page 9, paragraph 39; figure 4A *<br>* page 9, paragraph 40 - page 10, paragraph 42; figures 4B,4C,4D *<br>----- | 6-11 | INV.<br>H05B33/08 |
| Y | US 3 387 222 A (HELLWARTH GEORGE A ET AL) 4 June 1968 (1968-06-04)<br>* column 1, line 50 - line 54 *<br>----- | 6-11 | |
| A | US 2009/212826 A1 (MIZUNAGA SUNAO [JP]) 27 August 2009 (2009-08-27)<br>* page 2 - page 3; figures 4,6 *<br>----- | 6-11 | |
| X | GB 2 309 516 A (CONCEPT IND SDN BDH [MY]) 30 July 1997 (1997-07-30)<br>* figure 2 *<br>----- | 1-5,<br>12-15 | |
| X | WO 2009/136331 A2 (PHILIPS INTELLECTUAL PROPERTY [DE]; KONINKL PHILIPS ELECTRONICS NV [NL]) 12 November 2009 (2009-11-12)<br>* page 7 - page 8; figure 1 *<br>* page 10, line 18 - line 20 *<br>----- | 1-5,<br>12-15 | TECHNICAL FIELDS SEARCHED (IPC)<br>H05B<br>G01R<br>H03K |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| The Hague | 29 November 2010 | Benedetti, Gabriele |

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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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& : member of the same patent family, corresponding document

## ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 10 17 1479

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29-11-2010

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EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

## REFERENCES CITED IN THE DESCRIPTION

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