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(54) **Method and system of electrical supply for a LED illumination**

(57) The present invention relates to a method for supplying electric power to a plurality of loads (12A, 12B, 12C), in particular three loads, each of said loads essentially consisting of one or more LEDs, starting from an electric current (I10); said electric current (I10) is distributed cyclically among said loads (12A, 12B, 12C) in a manner such that substantially only one load is powered at a time, and that the electric charge quantities supplied at every cycle to said loads (12A, 12B, 12C) are regulated. The present invention also relates to a power supply system comprising analog and/or digital circuit means adapted to implement said method.

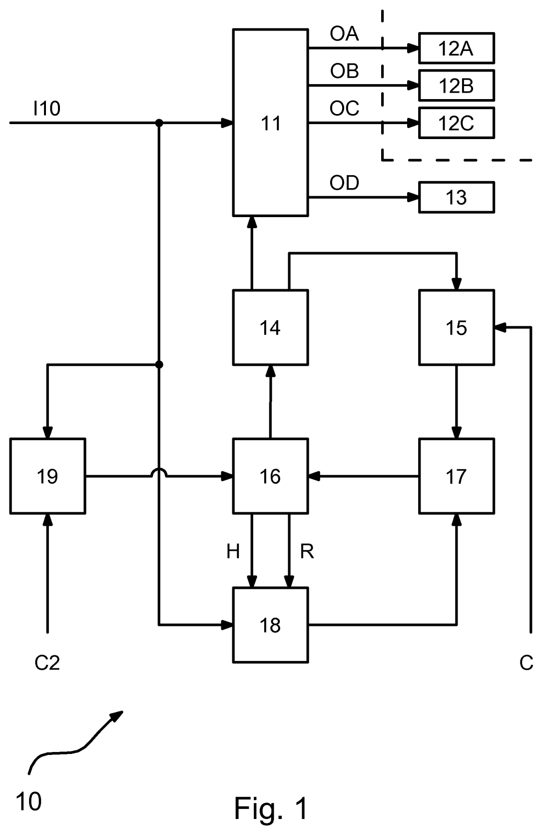

Fig. 1

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Description

[0001] The present invention relates to a power supply method and system for LED lighting applications.

[0002] The use of LEDs [Light Emitting Diodes] as electric lighting devices is rapidly increasing because of their high efficiency in transforming electric energy into luminous energy.

[0003] LEDs are diodes having an I V characteristic similar to that of a (low) voltage generator (e.g. with an output of just a few Volts) with a small resistor arranged in series (in the region where luminous energy is to be generated); therefore, they require a current source.

[0004] Commonly available electric power sources (batteries, public electric mains) have I V characteristics which resemble those of a (low or high) voltage generator.

[0005] It follows that LED lighting systems in general require a suitable electric power supply system.

[0006] In order to attain high illumination efficiency, it is of primary importance that the power supply system is efficient.

[0007] A light source having predetermined chromatic characteristics may be obtained, for example, through simultaneous use of red, green and blue LEDs; in fact, it is known that by properly combining the colours of the RGB [Red Green Blue] triplet it is possible to obtain any colour; in order to obtain the desired colour, currents having appropriate intensity must flow through the LEDs. The desired luminous intensity can be obtained by connecting in series LEDs having the same colour, so as to create LED arrays; thus, there will be one array for the red component, another one for the green component, and yet another one for the blue component; in general, the number of LEDs of each array may be different, since the LEDs' efficiency (ratio between luminous flux expressed in lumen and absorbed power expressed in Watt) varies depending on their colour. A solution based on this principle is known, for example, from patent application EP1791400.

[0008] When using LED arrays having different colours, high efficiency can be attained by following essentially two methods.

[0009] According to the first one of these methods, each LED array is powered by a switching current generator; this solution is very flexible, but requires a number of generators matching the number of arrays. Low luminous intensity can be obtained by partializing the current flowing in each array through the use of PWM [Pulse Width Modulation] techniques.

[0010] According to the second method, the LED arrays are powered by a single switching voltage generator, and the current flowing through each array is set by a corresponding current regulator (connected in series to the array); said regulator may either operate continuously or modulate the current by means of PAM [Pulse Amplitude Modulation] techniques.

[0011] In order to obtain an increased efficiency without having to employ a plurality of switching current generators, a number of solutions have been proposed which essentially aim at minimizing the voltage across the LEDs.

[0012] Patent application W02004/021744 discloses a high-efficiency LED driver circuit; such circuit has a plurality of outputs connected in parallel to one another, each for a respective LED, and includes a linear voltage regulator with a charge pump arranged in series; this solution permits to optimize the efficiency of the power supply section. The output of the charge pump is connected to the LEDs and to a driver circuit; the driver circuit comprises a linear current regulator for each output and a detector consisting of diodes arranged in a "wired-OR" connection connected to the LEDs' cathodes, which forms an undervoltage detector. The minimum voltage, which must be sufficient to allow the current regulators to operate in the linear zone, is used within a feedback circuit in order to set the optimum value of the charge pump output voltage. In practice, the charge pump output voltage is kept at the minimum value required for the operation of the current regulators. Since the various LEDs have different voltage drops, there will only be one current generator operating at the minimum voltage; the other current generators will operate at higher levels, thus causing power dissipation and making this solution not very efficient as a whole.

[0013] Patent application W02007/064694 disclosed a high-efficiency power supply for LED lighting applications; this solution employs a voltage regulator the output of which is connected to multiple loads consisting of LED arrays (such LED arrays generally include different numbers of LEDs); this solution also comprises one current regulator per LED array; these regulators are also adapted to generate a corresponding error signal when the current regulator is about to enter the nonlinear zone; such error signals drive the voltage regulator in a manner such that the voltage regulator output voltage is kept at the minimum value required for ensuring current regulation in the LED arrays.

[0014] The Applicant has realized that the existing solutions for supplying power to LED lighting systems are not yet fully satisfactory.

[0015] The solution disclosed by patent application W02004/021744 attains a certain level of efficiency; however, since it supplies the same voltage and the same current to a plurality of LEDs which are not identical to one another, it implies power dissipation; in fact, the voltage is maintained at the lowest usable value compatible with all of the different LEDs, but that value is optimum for one load only; also, this solution requires one current regulator per output and a detector having a number of inputs matching the number of outputs.

[0016] The solution disclosed by patent application W02007/064694 attains a certain level of efficiency but, since it supplies the same voltage to a plurality of LED arrays (in particular two in the example of Fig.1), which are generally different from one another, it wastes energy whenever the arrays are characterized by different voltage drops (e.g. because they are formed by a different number of LEDs); in fact, the voltage is maintained at the minimum usable value compatible with all of the different LED arrays, but that value is optimum for one load only; also, this solution requires one current regulator and one detector per output.

[0017] The Applicant realized that a fully satisfactory power supply system for LED lighting applications must be capable of regulating both brightness and chromatic efficiency (i.e., in simpler but less accurate words, "colour"), possibly in an independent manner (in particular, once a chromatic efficiency level has been selected, it must remain substantially the same as brightness changes), and must also maintain its efficiency as the brightness and/or chromatic efficiency levels change.

[0018] The Applicant then decided to find a solution for a power supply system for LED lighting applications which could overcome the drawbacks of the prior art while fulfilling the above-mentioned requirements.

[0019] Furthermore, the Applicant sought a flexible solution which could be easily adapted to various application contexts.

[0020] This object has been achieved through the method and the system having the features set out in the appended claims.

[0021] The present invention originates from the principle that very quick brightness variations are not perceived by the observer, the latter being essentially only sensitive to average brightness. This applies to both human beings and video cameras: for human beings, perceivable variations are of the order of ten milliseconds; for a photo or video camera, the minimum perceivable variations depend on the shutter opening time; since the minimum opening times range from 1/1000th of a second (1 mS) to 1/4000th of a second (250 uS), it can be stated that the minimum perceivable variations are of the order of hundreds of microseconds.

[0022] The present invention is based on the idea of distributing the power supply current cyclically among the various loads (by using an adequately small period as a function of the perceivable variations, as will be described in detail below) in a manner such that substantially only one load is powered at a time and the quantities of electric charge supplied per cycle to the loads are regulated.

[0023] Electric current distribution may be implemented in a very simple and effective way by using a distribution circuitry comprising substantially leakage-free electronic switches; thus, a very efficient generation of electric current to be supplied to the distribution circuitry, e.g. attained by means of a switching power supply, will result in the entire lighting system being very efficient as well.

[0024] In addition, since regulation occurs according to charge, the control of the electric energy supplied to the loads will be accurate and the electric energy supplied to the loads will be independent of the trend of the supply current inputted to the distribution circuitry; this will result in a very accurate control of brightness and "colour", as well as a very flexible solution.

[0025] The advantages of this solution over the prior art will be appreciated in terms of both circuitry and functionality.

[0026] In general, the method according to the present invention is used for supplying power to a plurality of loads, in particular three loads, each of said loads consisting essentially of one or more LEDs (connected in series to form a "LED array") by starting from an electric current; said electric current is distributed cyclically among said loads in a manner such that substantially only one load is powered at a time and the quantities of electric charge supplied per cycle to said loads are regulated.

[0027] The quantities of electric charge supplied to said loads may be regulated to predetermined values or else be set manually; predetermination may occur, for example, in the course of the production process, whereas manual setting may be done, for example, directly by an installer or indirectly by a user through a control unit, e.g. a logic control unit.

[0028] Said electric current may be distributed among said loads according to a cycle having a fixed or variable duration shorter than 40 mS, preferably shorter than 10 mS and/or preferably longer than 1 mS; this choice is particularly suitable for household lighting applications.

[0029] Said electric current may be distributed among said loads according to a cycle having a fixed or variable duration shorter than 1 mS, preferably longer than 10 uS, typically of the order of 100 uS; this choice is particularly suitable for photographic or cinematographic lighting applications.

[0030] According to the present invention, ratios can be defined among the quantities of electric charge supplied to said loads, and said ratios can be kept constant as said electric current changes. Said ratios may be predetermined or set manually; predetermination may occur, for example, in the course of the production process, whereas manual setting may be done, for example, directly by an installer or indirectly by a user through a control unit, e.g. a logic control unit.

[0031] Said electric current to be distributed may be short-circuited and thus sent to none of said loads when it is smaller than a predetermined value and/or when it is greater than a predetermined value; this possibility allows to prevent the LEDs from being supplied inappropriately.

[0032] Said electric current to be distributed may be obtained from a switching power supply, in particular featuring current control, more in particular featuring current control and a rippled or pulsed output current.

[0033] The average value of said electric current to be distributed may be regulated to a predetermined value or else be set manually; predetermination may occur, for example, in the course of the production process, whereas manual setting may be done, for example, directly by an installer or indirectly by a user through a control unit, e.g. a logic control unit.

[0034] Said electric current to be distributed may be supplied to multiple loads of said plurality for short periods of time only, typically having a duration in the range of 100 nS to 1 uS. This overlap is useful, in particular, to avoid the risk of overvoltage when switching the current from one load to the next for the time required by this transition, which time is substantially equal to the time required for switching (on or off) a solid-state switch (e.g. a MOSFET); if the switching time is 150 nS, it is advisable that the overlap time is, for example, 300 nS; this overlap time is preferably significantly shorter than the period of the current distribution cycle, so as to avoid any significant errors in the regulation of the charge to be supplied to the loads.

[0035] In general, the power supply system for LED lighting applications according to the present invention has a plurality of outputs, in particular three outputs, used for supplying power to a corresponding plurality of loads; it comprises analog and/or digital circuit means adapted to implement the method according to the present invention.

[0036] The system may comprise a control unit totally implemented by wired logic (e.g. through an FPGA [Field-Programmable Gate Array]) or by programmed logic (e.g. through a microcontroller or microprocessor with internally stored program and data), or else implemented partly by wired logic and partly by programmed logic. Said control unit is adapted to control the electric current distribution among said outputs; when programmed logic is used, current distribution will take place in accordance with said program and said data.

[0037] Independently of the type of logic employed, the system may advantageously be manufactured by integrating all of its electric components into a SOC [System On Chip].

[0038] The most appropriate embodiment of the system and control unit will depend on the type of application and on the number of pieces to be produced.

[0039] The system may comprise circuit means adapted to selectively make an internal short-circuit as an alternative to supplying power to said loads; this possibility may be used for preventing the LEDs from being supplied inappropriately or for obtaining special electric and/or luminous effects.

[0040] The system may further comprise a switching power supply, in particular featuring current control, more in particular featuring current control and a rippled or pulsed output current; this means that current control is based on the average, not the instantaneous, current value. Advantageously, said power supply has no capacitors connected in parallel to its output, so that the output voltage can change rapidly and adapt to the load without significant effects on the output current (which flows through the load).

[0041] From a structural point of view, the power supply system for LED lighting applications according to the present invention has one input for receiving an electric current and a plurality of outputs for supplying power to a corresponding plurality of loads, and comprises:

- a switching circuit having one input coupled to said system input and a plurality of outputs respectively connected to said plurality of system outputs (for the loads), adapted to alternately connect its input to one of its outputs,
- an electric charge meter circuit connected in a manner such as to measure the charge supplied to said system outputs, and
- a logic circuit connected in a manner such as to receive the readings of said meter circuit and output switching control signals to said switching circuit in accordance with the received readings, so as to regulate the electric charges supplied to said outputs at every cycle.

[0042] Said switching circuit may consist essentially of a plurality of MOSFET transistors matching the plurality of system outputs.

[0043] Said switching circuit may comprise an additional output connected to an electric short-circuit path; in this case, said switching circuit is adapted to connect its input to said additional output as an alternative or in addition to the connection to one of said plurality of outputs; said additional output as well as the short-circuit path are internal to the power supply system. Said switching circuit typically comprises an additional MOSFET transistor for said additional output.

[0044] Said electric charge meter circuit may comprise a resistor (connected to a voltage reference, in particular to ground) and an integrator circuit, preferably only one resistor and only one integrator circuit, both of which are connected to the input of said switching circuit; in this case, said resistor is connected in a manner such as to convert into voltage the current inputted to said switching circuit (which is flowing through one of the loads), and said integrator circuit is connected in a manner such as to integrate the voltage dropping across said resistor and then calculate the electric charge received by said switching circuit and supplied to one of the loads.

[0045] Said charge meter circuit may comprise a comparator circuit having a first input and a second input; in this case, said first input is connected to the output of said integrator circuit and said second input receives a reference signal.

[0046] Said integrator circuit may be fitted with a reset input which may, for example, be activated at every new reading.

[0047] Said integrator circuit may be fitted with a hold input which stops integration when active; it may be used, for example, in order to temporarily suspend a measurement in progress.

[0048] Said logic circuit may be coupled on its input side to the output of an integrator circuit, preferably through a comparator circuit; in this manner, the logic circuit can detect the integrations executed by said integrator circuit (in other words, the electric charge readings).

[0049] The output of said logic circuit may be connected to control inputs of said switching circuit; in this case, the number of control inputs of said switching circuit matches the number of outputs of said switching circuit; in this manner, said logic circuit can control, among other things, the switching of the input electric current among the various outputs (and hence among the various loads).

[0050] Said logic circuit may be coupled on its output side to an input of a comparator circuit, preferably through a digital-to-analog converter circuit; such a connection allows the logic circuit to generate reference signals. Said reference signals may be used, for example, for regulating the average value of the current supplied to the system outputs (and hence to the various loads) and/or the electric charge to be supplied at every cycle to each system output (and hence to the various loads); in the former case, such reference signals permit to control the LED lighting brightness through the logic circuit; in the latter case, such reference signals permit to control the LED lighting colour through the logic circuit.

[0051] Said logic circuit may be connected on its output side to a reset input of an integrator circuit; thus, said logic circuit can determine, for example, the beginning and the end of electric charge measurements taken by means of said integrator circuit.

[0052] Said logic circuit may consist essentially of a microprocessor or a microcontroller, which optionally may also be integrated together with other components into a SOC [System On Chip]; as an alternative, the same functionalities may be implemented by wired logic, e.g. through an FPGA [Field-Programmable Gate Array].

[0053] The system may additionally comprise a current meter circuit connected in a manner such as to measure the current supplied to said system outputs (and hence to the various loads).

[0054] Said current meter circuit may comprise a resistor (connected to a voltage reference, in particular to ground) and a comparator circuit, preferably only one resistor and only one comparator circuit, both of which are connected to the input of said switching circuit; in this case, said resistor is connected in a manner such as to convert into voltage the current inputted to said switching circuit (which is flowing through one of the loads), and said comparator circuit is connected in a manner such as to compare the voltage dropping across said resistor with a threshold voltage and check whether said (upper or lower) voltage threshold is crossed, which actually corresponds to an (upper or lower) current threshold being crossed.

[0055] The output of said current meter circuit may be connected to a control input of said switching circuit; in this case, said current meter circuit is adapted to output a switching control signal as a function of the readings obtained; it is thus possible, for example, to switch the input current to a particular output of said switching circuit if the (upper or lower) threshold is crossed; this particular output is typically connected to an electric short-circuit path.

[0056] The output of said current meter circuit may be connected to an integrator circuit; in this case, said current meter circuit is adapted to output a hold signal to said integrator circuit as a function of the readings obtained; it is thus possible, for example, to stop the integration if the (upper or lower) threshold is crossed.

[0057] The system may further comprise a power supply having a supply output connected to the input of said switching circuit; in this case, for ensuring high efficiency said power supply must be of the switching type and feature current control.

[0058] Said power supply may be of the type providing a rippled or pulsed output current; this means that current control is based on the average, not the instantaneous, current value. Advantageously, said power supply has no capacitors connected in parallel to its output, so that the output voltage can change rapidly and adapt to the load without significant effects on the output current (which flows through the load).

[0059] Said current control may include a current meter circuit connected in a manner such as to measure the current available at the output of said power supply.

[0060] Said current meter circuit may comprise a resistor (connected to a voltage reference, in particular to ground) and an error amplifier circuit.

[0061] Said current control may also comprise, for example, a PWM [Pulse Width Modulation] modulator.

[0062] In this case, said resistor is connected in a manner such as to convert into voltage the output current of said power supply (e.g. at the input of said switching circuit), and said error amplifier circuit is connected in a manner such as to compare the voltage dropping across said resistor with a reference voltage proportional to the desired average value of the output current.

[0063] The output of said error amplifier circuit drives, for example, said PWM modulator so as to obtain an output current having the desired average value.

[0064] The system may comprise a low-pass filter or network connected to said error amplifier so as to filter the voltage dropping across said resistor.

[0065] The system may comprise a control unit having an output for a reference voltage; in this case, said output is connected to said error amplifier circuit preferably through a digital-to-analog converter circuit; it is thus possible to set the average value of the output current of said power supply (and hence the LED lighting brightness) through the control unit.

[0066] The system may comprise a single resistor for taking readings of two or more different functions of the system.

[0067] The system may comprise a control unit, preferably a logic control unit, in particular a microprocessor or microcontroller-based control unit, adapted to generate internal control signals in order to determine the chromatic efficiency and/or brightness of the LED lighting.

[0068] The system may comprise user interface means connected to said control unit for light adjustment purposes.

[0069] The system may comprise at least one sensor, in particular a temperature or brightness or colour sensor, connected to said control unit for light adjustment purposes.

[0070] The system may comprise wired or wireless communication means connected to said control unit and allowing for direct or indirect light adjustment.

[0071] The present invention will become more apparent from the following description and from the annexed drawings, wherein:

Fig.1 is a conceptual block diagram of a first power supply system according to the present invention,
Fig.2 is a block diagram of a switching power supply which may be used with or within a power supply system according to the present invention,
Fig.3 is a very general block diagram of a second power supply system according to the present invention,
Fig.4 shows the possible current patterns over time at four points of the diagram of Fig.1,
Fig.5 shows the current/luminous flux characteristics of a red LED and a blue LED, and
Fig.6 is a simplified circuit diagram of a power supply system according to the present invention.

[0072] Said description and said drawings are only to be considered as non-limiting explanatory examples; also, they are both schematic and simplified.

[0073] It is worth mentioning beforehand that the present invention typically applies to lighting systems that include LEDs of three different colours (red, green and blue), but is also applicable without difficulty and without requiring any changes to a smaller or greater number of colours (e.g. red, green, blue and white).

[0074] The instantaneous luminous power emitted by a LED is proportional to the electric current that is flowing through it according to a coefficient that takes conversion efficiency into account, as per the following formula:

$$\text{(F1)} \qquad Popt = k * I$$

[0075] The luminous flux of a light source is defined as the integral (in the source emission band) of the product of the luminous power by the (human) visibility coefficient.

[0076] Fig.5 is a graph that shows the relation between luminous flux (in lumen) and electric current (in mA) for a red LED (RC graph) and a blue LED (BC graph); the graph of a green LED will be intermediate between the red LED and the blue LED. As a first approximation, luminous flux is linearly proportional to current (for both the red LED and the blue LED) between 100mA and 1000mA; below 100mA, the behaviour of these LEDs typically cannot be foreseen and is not repeatable. As a first approximation, the ratio between the luminous flux of the red LED and the luminous flux of the blue LED is substantially constant and independent of electric current.

[0077] The luminous energy emitted within a certain time interval [t,t+T] is therefore proportional to the charge flowing through the LED within the same time, as per the following formula:

$$\text{(F2)} \qquad Eopt([t,t+T]) = k * Q([t,t+T])$$

[0078] The operation of any device capable of sensing or recording luminous signals (eye, photo camera, video camera, ...) is based on the luminous energy received within a certain time interval, the duration of which will hereafter be generally designated as "'τ"; said duration is of the order of a tenth of a second for humans and a hundredth or thousandth of a second (depending on exposure time) for photo and video cameras; if we consider the time interval [t, t+τ], the luminous sensation S which can be associated with said interval will be proportional, to a certain extent, to the luminous energy received during said interval, as per the following formula:

$$\text{(F3)} \qquad S(t+\tau) \propto Eopt([t,t+\tau])$$

[0079] Any variations in the luminous energy occurring during intervals significantly shorter than "τ" are not perceived as "variations", in that the sensing or recording means carry out an integration process.

[0080] As aforementioned, variations perceivable by human beings are of the order of ten milliseconds; for a photo or video camera, the minimum perceivable variations depend on the shutter opening time; since the minimum opening times range from 1/1000th of a second (1 mS) to 1/4000th of a second (250 uS), it can be stated that the minimum perceivable variations are of the order of hundreds of microseconds.

[0081] Therefore, if a LED power supply system and method operate in such a way as to vary the LEDs' instantaneous luminous power over time along a time scale "T" significantly smaller than "τ", the luminous sensation will not depend on instantaneous luminous power, but solely on the average value of the instantaneous luminous power calculated over the interval "τ". This is one of the main considerations from which the present invention originates.

[0082] According to the present invention, an input electric current is available and power must be supplied to a plurality of loads, each essentially consisting of one or more LEDs connected in series (called "LED arrays").

[0083] With reference to Fig.1, the electric current taken into consideration is the current available at an input I10, hereafter referred to as i(I10), whereas the loads are designated 12A, 12B, 12C and are connected to respective outputs OA, OB, OC; Fig.1 shows three loads because this is the most typical embodiment of the present invention; in particular, the load 12A essentially consists of a series connection of a certain number (e.g. seven) of red LEDs, the load 12B essentially consists of a series connection of a certain number (e.g. six) of green LEDs, and the load 12C essentially consists of a series connection of a certain number (e.g. five) of blue LEDs.

[0084] With reference to Fig.1, according to the present invention the current i(I10) is distributed cyclically (at a suitable rhythm) among the different loads 12A, 12B, 12C in a manner such that substantially only one load is powered at a time; this distribution is carried out by block 11, which is a switching circuit appropriately driven by the remaining circuitry; Fig. 4 shows the time pattern of the input current i(I10) (Fig.4A), of the current at the output OA flowing through the load 12A (Fig.4B), of the current at the output OB flowing through the load 12B (Fig.4C), and of the current at the output OC flowing through the load 12C (Fig.4D); the current i(I10) is supplied for a time t1 to the load OA, then for a time t2 to the load OB, then for a time t3 to the load OC, then for a time t4 to the load OA, then for a time t5 to the load OB, then for a time t6 to the load OC, then for a time t7 to the load OA, then for a time t8 to the load OB, then for a time t9 to the load OC, and so on.

[0085] In general, $t1 \neq t2 \neq t3 \neq t4 \neq t5 \neq t6 \neq t7 \neq t8 \neq t9 \neq \ldots$, and if any of the times "t1+t2+t3", "t2+t3+t4", "t3+t4+t5", "t4+t5+t6", "t5+t6+t7", "t6+t7+t8", "t7+t8+t9" (which correspond to the duration of one cycle, whatever the latter is considered to be), ... is appreciably shorter than "τ" , then the luminous sensation deriving from the LEDs of the three loads will be linearly proportional to the average value of the instantaneous luminous power emitted by the LEDs calculated over the interval "τ"; total brightness will depend on the sum of the average luminous power outputs of the three loads, whereas chromatic efficiency will depend on the ratios of the average luminous power outputs of the three loads.

[0086] If the lighting system is only intended for household illumination (and therefore the reference device is the human eye), then the cycle duration must be shorter than 40 mS and preferably between 10 mS and 1 mS; if the lighting system is intended for use with photo or video cameras, then it will be appropriate to select a cycle duration shorter than 1 mS, preferably longer than 10 uS, typically of the order of 100 uS, in order to make it suitable for the typical exposure times of these apparatuses (which may be as short as 1/4000th of a second).

[0087] If the input current is constant, the observations made so far will suffice for designing the power supply system for the LED lighting system. In such a case, it is conceivable that t1=t4=t7 , t2=t5=t8 , t3=t6=t9, ..., the values of "t1", "t2", "t3" being selected in a manner such that "t1+t2+t3" is less than one "τ" (suitable for the type of illumination concerned) and that the ratios "t1/t2", "t1/t3", "t2/t3" are such as to provide the desired chromatic efficiency, the value of the (constant) input current being selected in a manner such as to ensure the desired brightness level. Current supply and distribution ensure high efficiency, because no energy is wasted due to loads receiving inappropriate voltage; of course, it will be necessary to employ a source of substantially constant and inherently efficient direct electric current.

[0088] The assumption that input current is constant is generally not true; as a matter of facts, LED lighting systems often make use of switching power supplies (which are very efficient) as sources of electric energy; if left unfiltered, the output current of the latter (which is inputted to the distribution circuitry) is rippled and may show, for example, the pattern illustrated in Fig.4A. It is not uncommon that current ripples are such as to reach zero or values close to zero (e.g. when the power supply is operating in "discontinuous mode"); in this case, the current will have a pulsed pattern, and the pulses may have, for example, a triangular or trapezoidal shape. The present invention is applicable to both cases.

[0089] Therefore, according to the present invention, the current is distributed cyclically among the various loads in a manner such that the quantities of electric charge supplied per cycle to the loads are regulated; in other words, the electric variable used for determining said distribution is the charge supplied to the loads. The cycle starts by supplying power (i.e. delivering input current) to a first load; then, the charge received by said load is measured until it reaches a reference level (Q1) associated with the first load; next, power to the first load is cut out and the second load starts being supplied (the input current is switched from the first load to the second load) until the charge received by the second load reaches a reference level (Q2) associated with the second load; finally, power to the second load is cut out and the third load starts being supplied (the input current is switched from the second load to the third load) until the charge received by the third load reaches a reference level (Q3) associated with the third load; then this distribution cycle is repeated.

[0090] The distribution mechanism will be described below with the help of mathematical formulae.

[0091] Given that Q1, Q2 and Q3 are the electric charges transferred to the loads during the intervals t1, t2 and t3. Given that io(t) is the output current supplied by the electric power source (in particular by the switching power supply), which current generally consists of a direct component Io and a series of components having various frequencies.

[0092] Said electric charges are given by the following formulae:

$$Q1 = \int^{t1} io(t)\,dt$$

$$Q2 = \int^{t2} io(t)\,dt$$

$$Q3 = \int^{t3} io(t)\,dt$$

[0093] Q1, Q2 and Q3 are an integral of a current; hence they have the dimension of an electric charge.

[0094] Let us consider the currents i1(t), i2(t) and i3(t) respectively flowing through the three loads.

[0095] Taking into account one distribution cycle, current i1 is different from zero within interval t1, and is substantially equal to zero outside said interval; the same considerations also apply to currents i2 and i3.

[0096] In the light of the construction of the distribution mechanism, it can be assumed that said currents have a period Tr=t1+t2+t3.

[0097] The average value i1av of current i1(t), calculated in the period Tr, is:

$$i1av(Tr) = 1/Tr * \int^{Tr} io(t)\,dt = 1/Tr * \int^{t1} io(t)\,dt = Q1/Tr$$

[0098] Likewise, the average values i2av and i3av of currents i2 and i3 will be:

$$i2av(Tr) = Q2/Tr$$

$$i3av(Tr) = Q3/Tr$$

[0099] The system ensures that, regardless of the progress of current io(t) within the interval Tr, the ratio between the average values of i1, i2 and i3 is only dependent on Q1, Q2 and Q3, which are values set in the system.

[0100] In particular, the ratios between the average values of currents i1, i2 and i3 in Tr and the average value of current io in Tr are, respectively:

$$Q1/(Q1+Q2+Q3) \qquad Q2/(Q1+Q2+Q3) \qquad Q3/(Q1+Q2+Q3)$$

[0101] It follows that, if the reference values of the distribution system are set to the values Q1, Q2 and Q3 and the current supplied by the electric power source (in particular by the switching power supply) is set to the average value

Io, the following average values of currents I1, 12 and 13 will be obtained:

$$I1=Io*Q1/Q \qquad I2=Io*Q2/Q \qquad I3=Io*Q3/Q$$

where Q=Q1+Q2+Q3.

[0102] In general, it can be assumed that, in addition to the average current component, there may also be undesired components present on the mains voltage or generated by the distribution mechanism. Such a situation can be analyzed as follows. In stationary state, in the presence of a noise signal which width-modulates the rippled or pulsed current outputted by the source, the value of each current flowing through the loads can be expressed as explained below.

[0103] Let us assume that the switching frequency Fc=1/Tc of the power supply used as a current source is much greater than the frequency Fr=1/Tr of the distribution cycle, and that the frequency f=ω/2π of the modulating signal (having a width k) is much less than Fr.

[0104] Let us consider, without losing generality, the average values of the currents for each period Tr. Being the variation of the average current in the interval Tr negligible in the light of the above assumptions, it can be asserted that:

$$io(n*Tr) = Io*(1+k\cos(\omega*n*Tr))$$

[0105] It follows that:

$$Q=Q1+Q2+Q3=\int_{Tr} io(n*Tr)*dt = Io*(1+k\cos(\omega*n*Tr))*Tr$$

and hence that:

$$i1(n*Tr)=Q1/Tr=Q1/Q*Io*(1+k\cos(\omega*n*Tr))$$

[0106] Similar expressions will be obtained for the other currents i2 and i3.

[0107] The above formula expresses the concept previously mentioned, i.e. that, thanks to the distribution mechanism, the currents supplied to the LEDs have an average value equal to the desired value (for current i1, equal to the value Q1/Q*Io) and show an undesired overlapped signal (which is however insignificant if the pulse frequency ω is high enough with respect to the integration time "τ" of the sensing or recording devices) multiplied by Q1/Q.

[0108] The following will analyze the effects of the distribution mechanism.

[0109] In the presence of current transients caused by the mechanism used for distributing (and switching) the current to different loads, the resulting behaviour can be schematized as follows.

[0110] For simplicity, it will be assumed herein that the distribution mechanism operates between two LED arrays only, designated "array1 and "array2", that the voltage drop across array1, through which current i1 flows, is V1 (e.g. 60 V), and that the voltage drop across array2, through which current i2 flows, is V2 (e.g. 80 V).

[0111] When the current is switched from array 1 to array2 a negative current transient is generated, whereas when the current is switched from array2 to array1 a positive current transient is generated; the shape and duration of these transients depend on the characteristics of the current source.

[0112] In the presence of transients caused by a distribution mechanism operating at a frequency Fr, given that transients have a period Tr, the current io(t) can be expressed as (this also applies to currents i1, i2 and i3):

$$io(t) = Io + \sum_{n} In * \cos(n * \omega r + \varphi n)$$

wherein the transients' contribution is developed in series.

[0113] Since the integral in Tr of the components other than Io is null, it will be obtained that:

$$Q = Q1 + Q2 + Q3 = \int_{Tr} io(t) * dt = \int_{Tr} Iodt$$

[0114] The same considerations also apply to currents i1, i2 and i3.

[0115] This demonstrates that transients bring about undesired (but possibly negligible) components at a frequency Fr (or higher), without however causing any error as far as the direct components are concerned.

[0116] The operating frequency of the distributor must be selected to be sufficiently high, and it must be taken into account that said frequency may change with the current produced by the current source (unless the thresholds Q1, Q2, Q3 are changed).

[0117] It should nonetheless be pointed out that, even in the presence of undesired ripples, the system exactly provides the set chromatic characteristics.

[0118] In the embodiment of Fig.1, which is a power supply system designated as a whole by reference numeral 10, the charges supplied to the various loads are measured through a single circuitry connected to the input I10; said circuitry comprises an integrator circuit 18 which integrates the current flowing through the input I10 and outputs the value of the measured charge; the reference levels are represented by block 15, which outputs one of the reference levels; block 17 is a comparator circuit that compares the value of the measured charge with the reference value and outputs a logic value corresponding to the result of said comparison; said result may be either "negative", if the value of the measured charge is smaller than the reference level, or "positive", if the value of the measured charge is equal to or greater than the reference level; block 16 is a logic circuitry which receives, among other things, the result of said comparison and outputs, among other things, a load switching command and a reset command (R); as soon as the comparison result becomes "positive", the logic circuitry 16 sends the load switching command to a block 14 and the reset command (R) to the integrator circuit 18; when the integrator circuit 18 receives a reset command, it starts a new measurement; block 14 is a selector circuit which, upon receiving a load switching command, outputs a switching command for the switching circuit 11 and a selection command for block 15; the switching circuit 11 connects the input I10 electrically to one of its outputs OA, OB, OC (the function of the internal output OD will be explained later on) according to the switching command received; block 15 outputs a reference level corresponding to the selection command received.

[0119] The following mathematical discussion will confirm the full applicability of the method according to the present invention even to the case wherein the input current has constant polarity but not a constant value.

[0120] Hereafter, "i" will designate the "load" index, "j" will designate the distribution "cycle" index, "G(i)" will designate the gain of the integrator circuit when it is acting upon the current flowing through the load "i" (in the case of the diagram of Fig.1, the gain of the integrator circuit 18 is constant and independent of load), "L(i)" will designate the reference level associated with the load "i", d(i,j) will designate the time elapsing between the reset of the integrator circuit and the achievement of the reference level L(i) when current is flowing through the load "i" - this time may be called "integration interval duration" or "integration time"; since the input current shows significant variations, it is preferable to consider it to be different from cycle to cycle; with reference to Fig.4, d(1,1)=t1 , d(2,1)=t2 , d(3,1)=t3 , d(1,2)=t4 , d(2,2)=t5 , d(3,2) =t6 , d(1,3)=t7 , d(2,3)=t8 , d(3,3)=t9 .

[0121] Formula F2 will give the following:

$$\text{(F4)} \qquad \text{Eopt}(i,[t,t+d(i,j)]) = k(i) * Q(i,[t,t+d(i,j)])$$

where [t,t+d(i,j)] indicates the time interval of load "i" of cycle "j"; it will also be obtained that:

$$\text{(F5)} \qquad Q(i,[t,t+d(i,j)]) = L(i) / G(i)$$

[0122] According to the most typical implementations of the present invention, formula F5 can be simplified by assuming that only one of the two parameters L and G varies from one load to another; in the implementation of Fig.1, only L, i.e. the reference level, varies from one load to another, while G remains constant.
[0123] Therefore, the ratio L(i)/G(i) can be written as (L/G)(i), thus obtaining that:

$$\text{(F6)} \qquad Q(i,[t,t+d(i,j)]) = (L/G)(i)$$

and, finally, that:

$$\text{(F7)} \qquad Eopt(i,[t,t+d(i,j)]) = k(i) * (L/G)(i)$$

[0124] It should be noted that, although d(i,j) generally depends on the cycle index "j", Eopt(i,[t,t+d(i,j)]) is not dependent on the cycle index "j", but solely on the load index "i", due to the fact that luminous energy derives from an operation of integration over time of the instantaneous luminous power.
[0125] Hence the following will be obtained:

$$\text{(F8)} \qquad Eopt(i,[t,t+d(i,j)]) = Eopt(i) = k(i) * (L/G)(i)$$

[0126] It will thus be necessary to ensure that T(1,j)+T(2,j)+ ... T(n,j)<<τ for any value of "j" .
[0127] Indicating with "n" the number of loads to be supplied and with "m" the number of complete cycles occurring within the time "τ", it will be obtained that:

$$\begin{aligned} \text{(F9)} \qquad \tau = \quad & T(1,j)+T(2,j) + \ldots T(n,j) + \\ & T(1,j+1) + T(2,j+1) + \ldots + T(n,j+1) + \\ & \ldots \\ & T(1,j+m) + T(2,j+m) + \ldots + T(n,j+m) + \delta \end{aligned}$$

where "δ" designates the duration of the non-completed cycle portion comprised within the time "τ".
[0128] Because the duration of the non-completed cycle portion is shorter than the duration of a full cycle, it will be obtained that $\delta << \tau$.
[0129] Since, according to the hypotheses taken into account above, load "i" emits the same luminous energy Eopt (i) for each interval [t,t+d(i,j)], the following formula will give the energy emitted by the load "i" within the interval [t,t+τ]:

$$\text{(F10)} \qquad m * Eopt(i) <= Eopt(i,[t,t+\tau]) <= (m+1) * Eopt(i)$$

and the average power within said interval will be given by the following formula:

$$\text{(F11)} \qquad 1/\tau * m * Eopt(i) <= Popt(i) <= 1/\tau * (m+1) * Eopt(i)$$

or by the following formula:

$$\text{(F12)} \qquad 1/\tau * m * k(i)*(L/G(i)) <= Popt(i) <= 1/\tau * (m+1) * k(i)*(L/G(i))$$

[0130] Popt(i) is thus determined by the factor m*k(i)*(L/G(i)) with, at the very most, a maximum relative error equal to l/m; and because, in the light of the above hypotheses, m>>1, said error can be made very small and hence neglected.
[0131] In general, considering the sequence of "p" consecutive time intervals having duration "τ", [t+p*τ,t+p*τ+τ], it will be obtained that "m" depends on "p" (i.e. the number of cycles completed within the time "τ" is variable); this is because both the instantaneous value and the average value of the input current may vary over time.
[0132] However, if we assume that the average value of the input current is constant or varies very slowly (time scale TT>>τ), then the average value of the input current (calculated within the time τ) can be considered to be constant for a relatively long sequence of consecutive time intervals having duration "τ", and therefore also that the charge Q[t+p*τ, t+p*τ+τ] transferred within said time intervals can be considered to be constant, i.e. independent of "p", and can be designated Q(τ).
[0133] In general, the charge transferred to load "i" during the cycle "j" should be indicated with Q(i,j) ; however, according to the above hypotheses, said charge does not depend on "j", but solely on "i", and therefore it cannot be designated Q(i).
[0134] It will thus be obtained that:

$$\text{(F13)} \qquad Q(\tau) = m * (Q(1) + Q(2) + \dots Q(n)) + q$$

where "q" indicates the charge transferred in a non-completed cycle portion.
[0135] Based on the above assumptions, it will be obtained that q<<Q(1)+Q(2)+ ... +Q(n))<Q(τ).
[0136] As Q(τ) varies, m will vary as well, and so will Popt(i) in a linearly proportional way.
[0137] The invariance of chromatic efficiency corresponds to the invariance of all power ratios Popt(i1)/Popt(i2).
[0138] At most, each of said power ratios may vary from the rated value by the following factors:

$$\text{(F14)} \qquad F(-) = 1\text{-}1/(m+1)$$

$$\text{(F15)} \qquad F(+) = 1+1/m$$

[0139] Since m is always >> 1 , chromatic efficiency is well under control and can be kept substantially constant as total brightness (as well as the average value of the input current) varies.
[0140] Although this control is discontinuous by nature, it is perceived as a continuous process when discontinuities are spread over a time scale much smaller than that which is typical of the devices used for sensing or recording luminous signals (eye, photo camera, video camera, ...); this is achieved by properly sizing the system parameters.
[0141] It is apparent from the above description that the method according to the present invention can be implemented independently of the trend of the input current.
[0142] The chromatic efficiency of the LEDs connected to the lighting system, i.e. the loads, depends on how the electric current is distributed among the various loads (as well as on the characteristics of the loads themselves, i.e. number, colour and power rating of the various LEDs), more precisely on how the charge is distributed among the various loads.
[0143] In the case of the circuit of Fig.1, chromatic efficiency essentially depends on the reference levels provided by block 15; if such reference levels remain constant, then chromatic efficiency will remain substantially constant even when the average current at the input I10 varies (there may be small variations due to the fact that the LEDs' characteristics are not perfectly linear and linearly proportional to one another, as shown in Fig.5); on the contrary, if said levels are

changed, then chromatic efficiency will change too; this allows the chromatic efficiency of the lighting system to be changed; arrow C1 directed to block 15 in Fig.1 indicates the possibility of modifying the reference levels while the circuit is operating. When choosing the reference levels and sizing the integrator circuit, it is necessary to take into account the previously explained time constraints.

[0144] Depending on the application of the present invention, chromatic efficiency is predetermined during the production stage or set by the installer or final user, e.g. through user interface means; in the case of the circuit of Fig.1, for example, the charge quantities supplied to the various loads at every cycle are predetermined or set.

[0145] The brightness of the LED lighting can be adjusted separately from chromatic efficiency, preferably upstream of the chromatic efficiency adjustment circuitry. To this end, one may, for example, connect a switching power supply like the one shown very diagrammatically in Fig.2 and designated as a whole by reference numeral 20, upstream of the circuit 10 of Fig.1; the assembly formed by these two circuits provides a (more complex and enhanced) power supply system according to the present invention, as shown in Fig.3; the circuit of Fig.3 also comprises a control unit 30, in particular a logic control unit, which will be described later on.

[0146] The power supply 20 has one input 120 and one output 020, and comprises a power converter circuit 21 having a main input connected to the input 120, a control input and a main output connected to the output 020, a regulator circuit 22 having a main input connected to the output 020, a control input and a main output connected to the control input of the power converter circuit 21, and a block 23 that outputs a reference level to the regulator circuit 22. The output current of the circuit 20 has a regulated value which depends on the reference level provided by block 23 to the circuit 22; because this is a switching power supply with internal current control, and because there are no filters upstream of its output 020, the output current will be rippled or pulsed, periodic, and regulated only in terms of average value. Depending on the application of the present invention, brightness is predetermined during the production stage or set by the installer or the final user, e.g. through user interface means. Arrow C3 directed to block 23 in Fig.2 indicates the possibility of modifying the reference level while the circuit is operating.

[0147] According to the present invention, as aforementioned, in principle only one load is supplied at a time through the input current. However, electric circuits are not capable of making instantaneous switchings. In order to avoid the risk that for short periods of time no input current is supplied to any load, resulting is high voltages being generated (internal to the power supply system according to the present invention), it is preferable that for short periods of time the input current is supplied to at least two loads (such periods of time may be in the range of 100 nS to 1 uS): for example, if the input current is to be supplied to a first load in a first time interval and to a second load in a second time interval, for a short period of time intermediate between the two time intervals the input current will be supplied to both the first and second loads, thus being subdivided between the two loads based on the dynamic on/off characteristics of the switches (MOSFET).

[0148] Depending on the electric power source employed, the value of its output current (inputted to the distribution circuitry) may be reduced considerably for certain periods of time and sometimes even become zero (this is the case of switching power supplies operating in "discontinuous mode"). Also, the flux-current characteristic of a LED can be considered to be linear only if the current flowing through it is greater than a minimum value; below said minimum value, the behaviour of the LED cannot be foreseen and is not repeatable. In Fig.4, said minimum value is designated "ith"; in this specific example, the input current i(I10) is rippled, but its ripples never fall below the minimum value "ith".

[0149] In order to overcome this problem, this solution proposes that the input current be short-circuited if its value is lower than a certain value, in particular for all the time that said current is lower than such value.

[0150] This teaching ensures that no energy, or at least no significant quantity thereof, is wasted. In fact, the input current is typically obtained from a switching power supply, and the latter will suffer reduced losses when its output is short-circuited, on condition that, of course, sizing is done appropriately and a suitable topology is used.

[0151] As for the circuitry, this teaching may be implemented through a current meter circuit connected in a manner such as to measure the current supplied to the outputs of the power supply system and circuit means adapted to selectively establish an internal short-circuit of the input current as an alternative to supplying power to the loads; the current meter circuit is adapted to detect when said current is lower than a certain current threshold, and is connected to said circuit means in a manner such that the internal short-circuit is established when said current is lower than said current threshold. In the example of Fig.1, the current meter circuit (which comprises a comparator) corresponds to block 19; arrow C2 directed to block 19 indicates the possibility of modifying the current threshold while the circuit is operating; the output of block 19 is connected to an input of the logic circuitry 16 which, in response to the current readings received from block 19 (e.g. "current under threshold"), can generate a particular load switching command for the selector circuit 14; when the selector circuit 14 receives the particular load switching command, it outputs a particular switching command for the switching circuit 11; when the switching circuit 11 receives the particular load switching command, it connects the input I10 electrically to an "internal" output OD, which is connected to an internal electric short-circuit path 13. Advantageously, the logic circuitry 16, in response to the current readings received from block 19 (e.g. "current under threshold"), may generate a hold command (H) for the integrator circuit 18; when the integrator circuit 18 receives a hold command (H), it (temporarily) stops the reading process; in fact, when the input current is small and is not being supplied to any load, it does not contribute to generating luminous energy and therefore should not be taken into account for chromatic efficiency adjustment purposes.

[0152] If the current flowing through a LED exceeds a maximum value, the LED may be damaged.

[0153] In order to overcome this problem, the present invention proposes that the input current be short-circuited if its value is greater than a certain value, in particular for all the time that said current is greater than said value; such a solution may also be used in addition to any circuitry dedicated to limiting the internal current of the electric power source of the lighting system.

[0154] This teaching ensures that no energy, or at least no significant quantity thereof, is wasted. In fact, the input current is typically obtained from a switching power supply, and the latter will suffer reduced losses when its output is short-circuited, on condition that, of course, sizing is done appropriately and a suitable topology is used. In this situation, it should also be mentioned that a certain energy portion must necessarily be dissipated in order to bring again the input current below the maximum value which can be tolerated by the various LEDs, and that it is essential to employ a fast current limiter, typically connected to the primary winding.

[0155] As for the circuitry, this teaching may be implemented through a current meter circuit connected in a manner such as to measure the current supplied to the outputs of the power supply system and circuit means adapted to selectively establish an internal short-circuit of the input current as an alternative to supplying power to the loads; the current meter circuit is adapted to detect when said current is greater than a certain current threshold, and is connected to said circuit means in a manner such that the internal short-circuit is established when said current is higher than said current threshold.

[0156] It can therefore be understood that it may be appropriate to establish the internal short-circuit both when the current is below a lower current threshold and when the current is above an upper current threshold; this functionality can advantageously be integrated into the same circuitry. In the example of Fig.1, this result can be obtained by having the current meter circuit 19 notify the logic circuitry 16 both cases of lower and upper threshold crossing; in such a case, arrow C2 may indicate the possibility of modifying both current thresholds.

[0157] The system of Fig. 3 comprises an electronic control unit; in particular, it is a microprocessor or microcontroller-based control unit.

[0158] The unit 30 is equipped with a program and data (both of which are stored internally) and is adapted to control the circuitry 10 (for current distribution) and the circuitry 20 (for current regulation) according to said program and said data; in particular, it sends the reference levels for chromatic efficiency adjustment to the circuitry 10 (arrow C1) and the reference level for brightness adjustment to the circuitry 20 (arrow C3); in addition, it may also send to the circuitry 10 (dashed arrow C2) the lower current threshold level and/or the upper current threshold level for the activation of the short-circuit path.

[0159] The system of Fig.3 may further comprise user interface means connected to the unit 30 and allowing a user to adjust the lighting, in particular the brightness and/or chromatic efficiency thereof; said means may be, for example, one or more (mechanical or touch-type) buttons and/or one or more knobs.

[0160] The system of Fig.3 may further comprise at least one sensor, in particular a temperature, brightness or colour sensor, connected to the unit 30 for light adjustment purposes, in particular for brightness and/or chromatic efficiency adjustment. Since the behaviour of power LEDs is strongly dependent on the temperature of the junction thereof, it may be advantageous to provide a temperature sensor arranged near the LEDs in order to acquire the temperature value and change the reference level for brightness adjustment and/or one or more reference levels for chromatic efficiency adjustment accordingly; this will ensure compensation of temperature-induced errors. Wherever high brightness and/or chromatic efficiency accuracy is required (e.g. as in photographic applications), it may be advantageous to provide a brightness sensor and/or a chromatic efficiency sensor in order to acquire the reading(s) thereof and change the reference level for brightness adjustment and/or one or more reference levels for chromatic efficiency adjustment accordingly.

[0161] The system of Fig.3 may further comprise communication means connected to the unit 30 for direct or indirect light adjustment; this feature may be useful, in particular, in complex lighting systems or in a "home automation" or "building automation" system. Such resources may comprise, for example, wired or wireless interfaces and possibly computer programs; by way of example, said interfaces may be, among others, serial interfaces (RS-232, USB, ...), Ethernet interfaces, WiFi interfaces, Bluetooth or ZigBee interfaces, or telephone interfaces (line modem or GSM and/or GPRS modem). Based on this teaching, the power supply system (and hence the lighting) can be controlled from a short distance (e.g. through an interface point) and/or from a medium distance (e.g. through a LAN [Local Area Network]) and/or from a long distance (e.g. through a telephone connection or via the Internet). It should be noted that the communication means may be used not only for receiving brightness and/or chromatic efficiency adjustment commands, but also for transmitting light monitoring information.

[0162] It can be understood from the above description that it is possible, through a switching circuit, to switch an input current among a plurality of loads (each essentially consisting of a series connection of a certain number of LEDs) and a short-circuit path. According to the above description, the short-circuit path is to be connected to the current input as an alternative to the loads when the input current is too low or too high. However, the technical teaching relating to the use of a short-circuit path goes beyond this specific goal; in fact, thanks to said path it is possible to obtain particular lighting effects such as, for example, sudden light switch-off and/or switch-on or light brightness adjustment. Any of the above-mentioned effects can be obtained by using the switching circuit of Fig. 1 (which corresponds to a plurality of transistors in Fig.6), provided that it receives appropriate switching commands.

[0163] The circuit of Fig.6, designated as a whole 600, is a power supply system according to the present invention and can be considered to be a circuit embodiment of the block diagram of Fig.3. Actually, according to this embodiment blocks 10 and 20 of Fig.3 are partially integrated together, and block 30 of Fig.3 largely (though not totally) corresponds to block 630 of Fig.6. Fig.6 highlights the circuit points corresponding to the inputs I10 and 120 and to the outputs 020, OA, OB, OC of the block diagram of Fig.3.

[0164] The circuit 600 of Fig.6 comprises: a diode bridge 601, a "power factor" correction circuit 602, an input voltage levelling capacitor 603, a transformer 604, a polarity reversal protection diode 605, a resistor 606, four MOSFET power transistors 607, 608, 609, 610, a comparator 611, a threshold voltage generator 612, an OR logic port 613, a controlled switch 614, a resistor 615, a comparator 616, a capacitor 617, a controlled switch 618, a comparator 619, a monostable circuit 620, a MOSFET power transistor 621, a resistor 622, a PWM [Pulse-Width Modulation] modulator 623, also acting as a current limiter, a low-pass filter 624, a comparator 625, a compensation network 626, two digital-to-analog converters 627 and 628, in particular of the 4-bit "R-2R network" type, a logic control unit 630.

[0165] The circuit 600 of Fig.6 comprises:

- a switching circuit essentially consisting of the components 607, 608, 609, 610,
- a charge meter circuit essentially consisting of the components 606, 615, 616, 617, 618, 619,
- a logic circuit essentially consisting of the component 630.

[0166] The switching circuit has an input I10 coupled to the system input 120 and a plurality of outputs OA, OB, OC respectively connected to a plurality of system outputs, and is adapted to alternately connect its input I10 to its outputs OA, OB, OC;

[0167] The charge meter circuit is connected in a manner such as to measure the charge supplied to said outputs OA, OB, OC.

[0168] The logic circuit is connected in a manner such as to receive the readings of the charge meter circuit and to output switching commands to the switching circuit according to the received readings.

[0169] The switching circuit comprises an additional output OD connected to an electric short-circuit path, and is adapted to connect its input I10 to said output OD as an alternative or in addition to the connection to one of its outputs OA, OB, OC; there is also an additional MOSFET transistor 610 for connecting the output OD.

[0170] The charge meter circuit comprises a resistor 606 (connected to a voltage reference, in particular to ground) and an integrator circuit (essentially consisting of the components 615, 616, 617); in the case of Fig.6, there is only one resistor and only one integrator circuit, both of which are connected to the input I10 of the switching circuit. The integrator circuit is connected in a manner such as to integrate the voltage dropping across the resistor 606.

[0171] The charge meter circuit further comprises a comparator circuit 619 having a first input and a second input; the first input is connected to the output of the integrator circuit 616, whereas the second input receives a reference signal (from the logic control unit 630 via the converter 628).

[0172] The integrator circuit is equipped with a reset input corresponding to the control input of the switch 618.

[0173] The integrator circuit is also equipped with a hold input corresponding to the control input of the switch 614.

[0174] The logic circuit 630 is coupled on its input side to the output of the integrator circuit 616, preferably via a comparator circuit 619.

[0175] The logic circuit 630 is connected on its output side to control inputs of the switching circuit (port terminals of transistors 607, 608, 609, 610); the number of said control inputs matches the number of outputs OA, OB, OC, OD of the switching circuit.

[0176] The logic circuit 630 is coupled on its output side to an input of a comparator circuit, preferably via a digital-to-analog converter circuit; this feature applies to both the comparator 619, through the converter 628, and the comparator 625, through the converter 627.

[0177] The logic circuit 630 is indirectly connected to the reset input of an integrator circuit (through the components 619 and 620); as an alternative, this may be a direct connection.

[0178] The logic circuit 630 essentially consists of a microprocessor or a microcontroller; of course, memories for programs and data are provided as well.

[0179] The circuit 600 further comprises a current meter circuit essentially consisting of the components 606, 611, 612; it is so connected as to measure the current supplied to the outputs OA, OC, OC. The current meter circuit comprises a resistor 606 (connected to a voltage reference, in particular to ground) and a comparator circuit 611, preferably only one resistor and only one comparator circuit, both of which are connected to the input I10 of the switching circuit; the comparator circuit is connected in a manner such as to compare the voltage dropping across the resistor 606 with a threshold voltage supplied by the generator 612.

[0180] The output of the current meter circuit is (indirectly) connected to an input of the switching circuit (the port terminal of the transistor 610); the current meter circuit is adapted to output a switching command signal in accordance with the readings obtained. Furthermore, the output of the current meter circuit is (indirectly) connected to the integrator circuit (the control input for the switch 614) and is adapted to output a hold signal to the integrator circuit in accordance with the readings obtained. The OR port 613, which is connected to an output of the logic circuit 630, allows the logic circuit 630 to control the transistor 610.

[0181] The circuit 600 further comprises a switching power supply connected upstream of the input I10 of the switching circuit; said power supply features current control and has an unfiltered output (020) - in fact, no capacitor is connected thereto; in particular, it is an AC-DC converter of the "flyback" type with constant average output current (alternative solutions may employ a different type of converter); it essentially consists of the components 601, 603, 604, 605, 606, 621, 622, 623, 625.

[0182] The power supply current control uses a current meter circuit connected in a manner such as to measure the current supplied to the output 020 of the power supply itself; it comprises a resistor 606 (connected to a voltage reference, in particular to ground) and an error amplifier circuit 625, and is connected in a manner such as to compare the voltage dropping across the resistor 606 with a reference voltage (coming from the logic control unit 630 via the converter 627 and being proportional to the desired average value of the power supply output current). There is also a low-pass filter 624 connected in a manner such as to filter the voltage dropping across the resistor 606 before it is supplied to the error amplifier circuit 625.

[0183] In the circuit 600, advantageously, a single resistor, i.e. the resistor 606, allows to take readings for two or more different system functions; in this example, it is used to take charge readings for the switch as well as current readings for both the switch and the power supply.

[0184] The "power factor" correction circuit 602, connected immediately downstream of the diode bridge 601 and immediately upstream of the power converter circuit, is not strictly necessary, but may be required by electric regulations and ensures higher efficiency in terms of electric energy exploitation; the same applies to a filter (not shown in Fig.6) against the noise generated by the power supply system.

[0185] The structure and operation of the power converters will not be described any further, since they are well known in the art; it is just worth mentioning here that the resistor 622 is used for detecting current on the primary winding of the transformer 604 and hence, among other things, to provide overcurrent protection by means of the modulator 623; the compensation network 626 is used for appropriately adjusting the feedback loop, and the function of the low-pass filter 624 is to ensure that the adjustment is made on the basis of the average, not the instantaneous, output current.

[0186] Since the converters 627 and 628 are 4-bit converters, it is possible to adjust the brightness to 16 different levels and the chromatic efficiency to 4096 different levels (16 levels for each of the three colours); this is certainly more than enough for any household application, and is attained by means of simple, fast (and inexpensive) converters.

[0187] The loads can be chosen freely; according to one of the many possible embodiments, a first load connected to the output OA may consist of six green LEDs having a characteristic similar to that shown in Fig.5 (luminous flux of 40 lumen at 350 mA), a second load connected to the output OB may consist of seven red LEDs having a characteristic similar to that shown in Fig.5 (luminous flux of 80 lumen at 350 mA), a third load connected to the output OC may consist of five blue LEDs having a characteristic similar to that shown in Fig.5 (luminous flux of 20 lumen at 350 mA).

[0188] Whatever the load being supplied, the efficiency of the power supply system will be substantially equal to that of the input power supply, which for a switching power supply is 80-90%. To be precise, it is necessary to take into account a small loss due to the internal switching operations of the system, in particular the switching operations of the transistors of the switching circuit; for this reason, it is advisable not to increase too much the current switching rhythm (unless strictly required by a specific lighting application), even though the circuit according to the present invention may operate at very fast paces. Additionally, the method according to the present invention allows to use a current distribution period shorter than, equal to or even longer than the switching period of the switching power supply while still ensuring good accuracy; according to a typical embodiment, the distribution frequency (which must not be necessarily constant) is about one tenth of the switching frequency (which is constant and equal to, for example, 50-100 KHz).

[0189] This 80-90% efficiency is much higher than that attainable by optimizing the power supply for just one load of a plurality of loads, which may easily drop below 70%.

Claims

1. Method for supplying electric power to a plurality of loads (12A, 12B, 12C), in particular three loads, each of said loads essentially consisting of one or more LEDs, starting from an electric current (i(I10)), **characterized in that** said electric current (i(I10)) is distributed cyclically among said loads (12A, 12B, 12C) in a manner such that substantially only one load is powered at a time, and that the electric charge quantities supplied at every cycle to said loads (12A, 12B, 12C) are regulated.

2. Method according to claim 1, wherein the electric charge quantities supplied to said loads (12A, 12B, 12C) are regulated to predetermined or set values (C1).

3. Method according to claim 1 or 2, wherein said electric current (i(I10)) is distributed among said loads (12A, 12B, 12C) according to a cycle having a fixed or variable duration (t1+t2+t3 ; t4+t5+t6 ; t7+t8+t9) shorter than 40 mS, preferably shorter than 10 mS and/or preferably longer than 1 mS.

4. Method according to claim 1 or 2, wherein said electric current is distributed among said loads according to a cycle having a fixed or variable duration (t1+t2+t3 ; t4+t5+t6 ; t7+t8+t9) shorter than 1 mS, preferably longer than 10 uS, typically around 100 uS.

5. Method according to any of the preceding claims, wherein ratios are defined among the electric charge quantities supplied to said loads (12A, 12B, 12C), and wherein said ratios are kept constant as said electric current (i(I10)) changes.

6. Method according to claim 5, wherein said ratios are predetermined or set (C1).

7. Method according to any of the preceding claims, wherein said electric current (i(I10)) is short-circuited (13) and is not supplied to any of said loads (12A, 12B, 12C) when it is smaller than a predetermined value (ith) and/or when it is greater than a predetermined value.

8. Method according to any of the preceding claims, wherein said electric current (i(I10)) is obtained from a switching power supply (20), in particular featuring current control, more in particular featuring current control and a rippled or pulsed output current.

9. Method according to any of the preceding claims, wherein the average value of said electric current (i(I10)) is regulated to a predetermined or set value (C3).

10. Power supply system for LED lighting applications, having a plurality of outputs (OA, OB, OC), in particular three outputs, for supplying electric power to a corresponding plurality of loads (12A, 12B, 12C), **characterized by** comprising analog and/or digital circuit means adapted to implement the method according to any of the preceding claims.

11. System according to claim 10, **characterized by** comprising circuit means (11, 13) adapted to selectively provide an internal short-circuit as an alternative to supplying power to said loads (12A, 12B, 12C).

12. System according to claim 10 or 11, **characterized by** further comprising a switching power supply (20), in particular featuring current control, more in particular featuring current control and a rippled or pulsed output current.

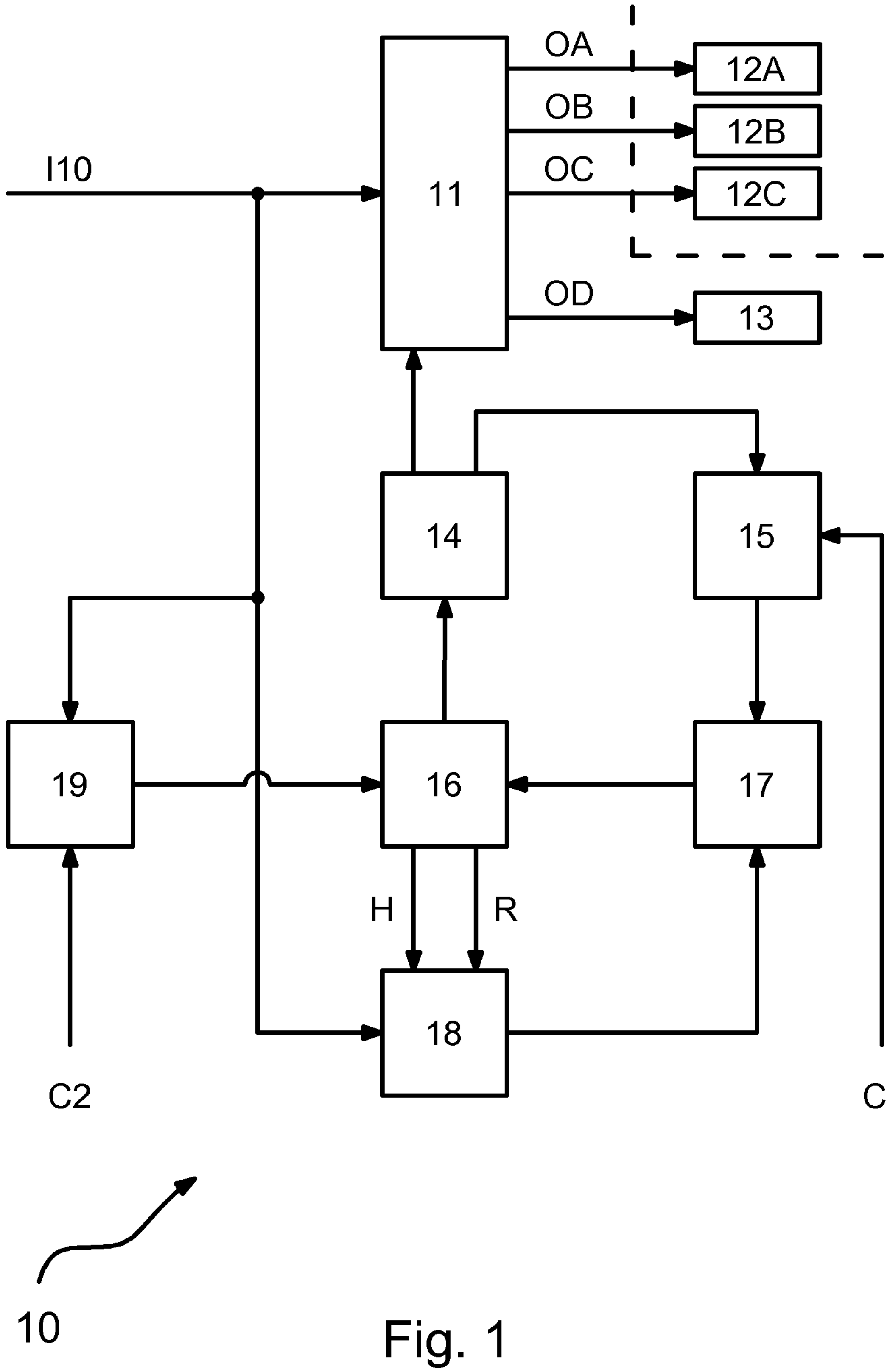

Fig. 1

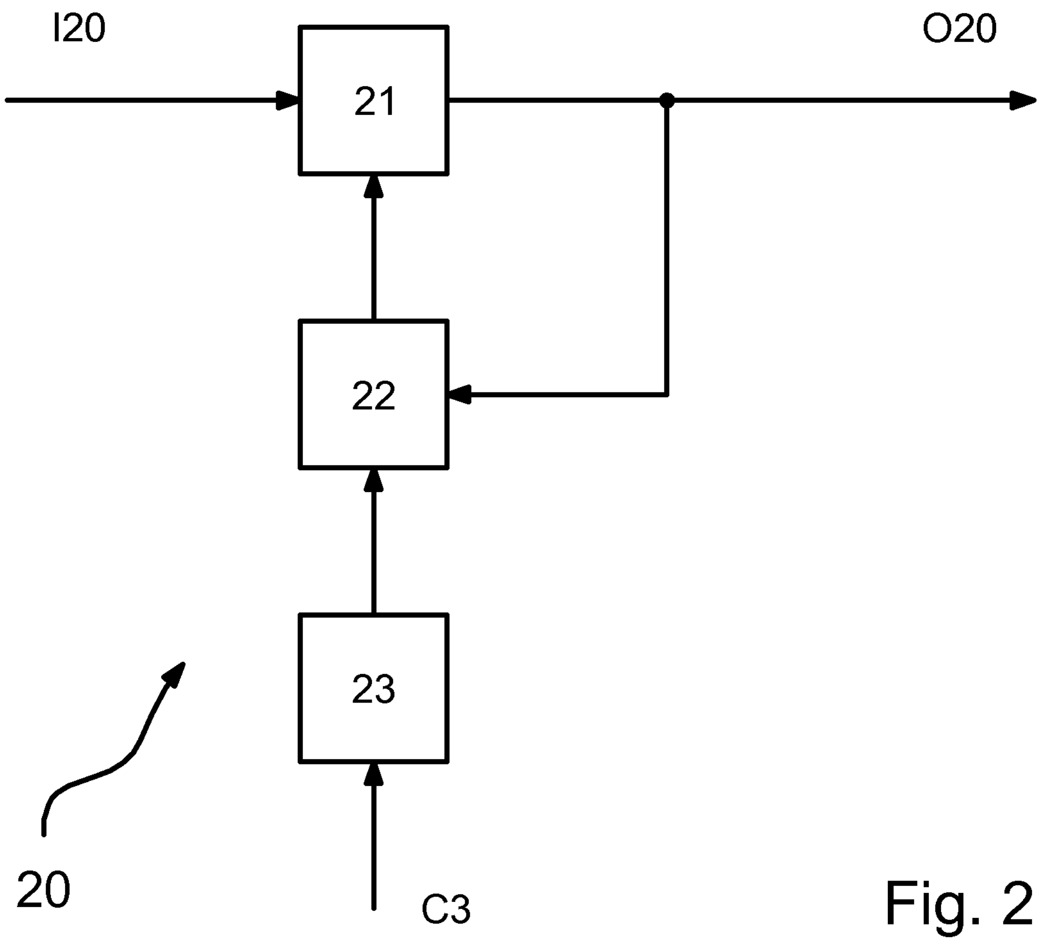

Fig. 2

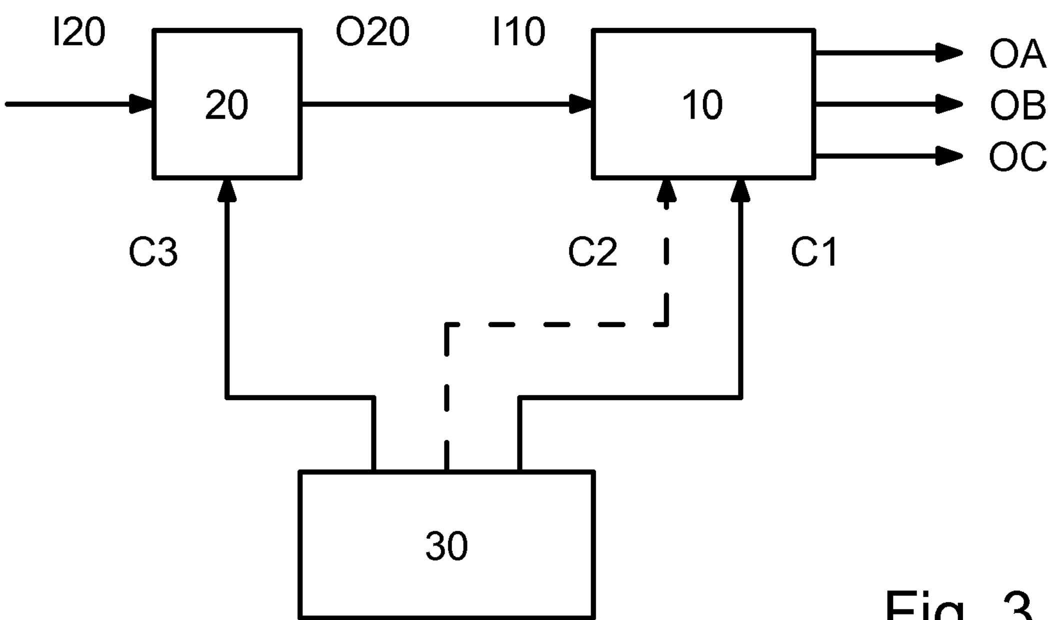

Fig. 3

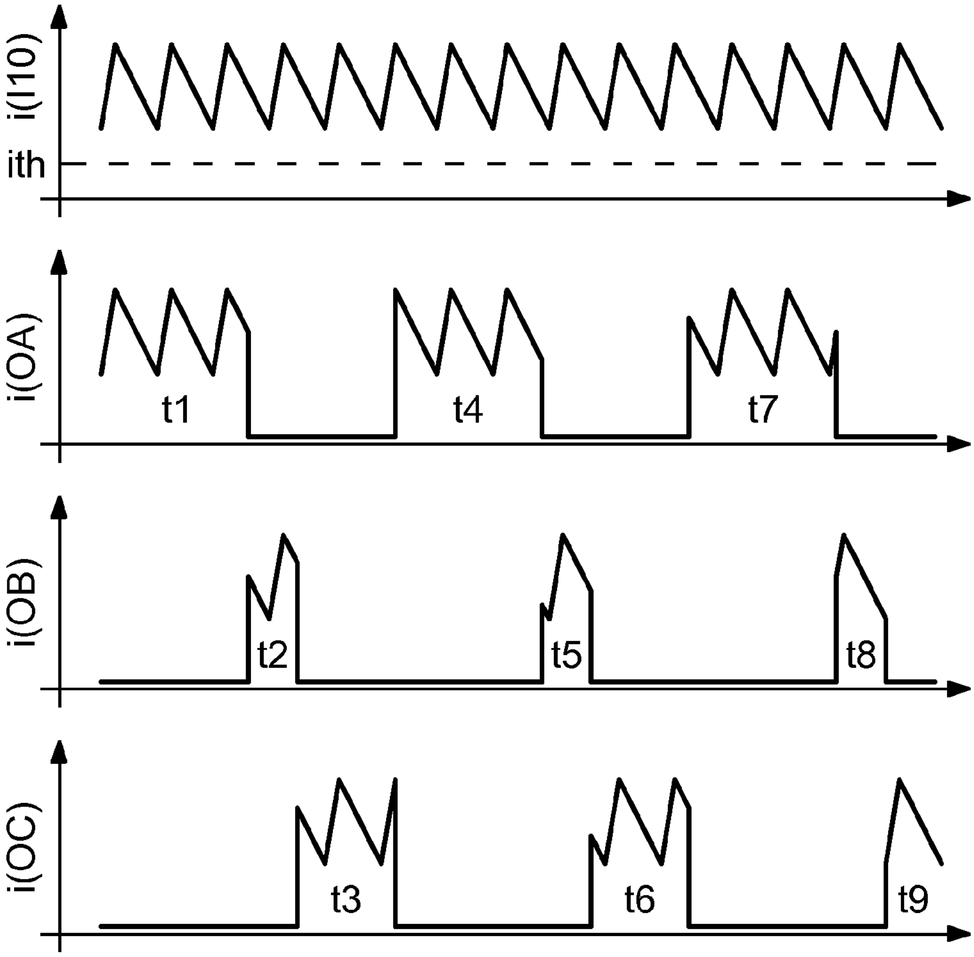

Fig. 4A

Fig. 4B

Fig. 4C

Fig. 4D

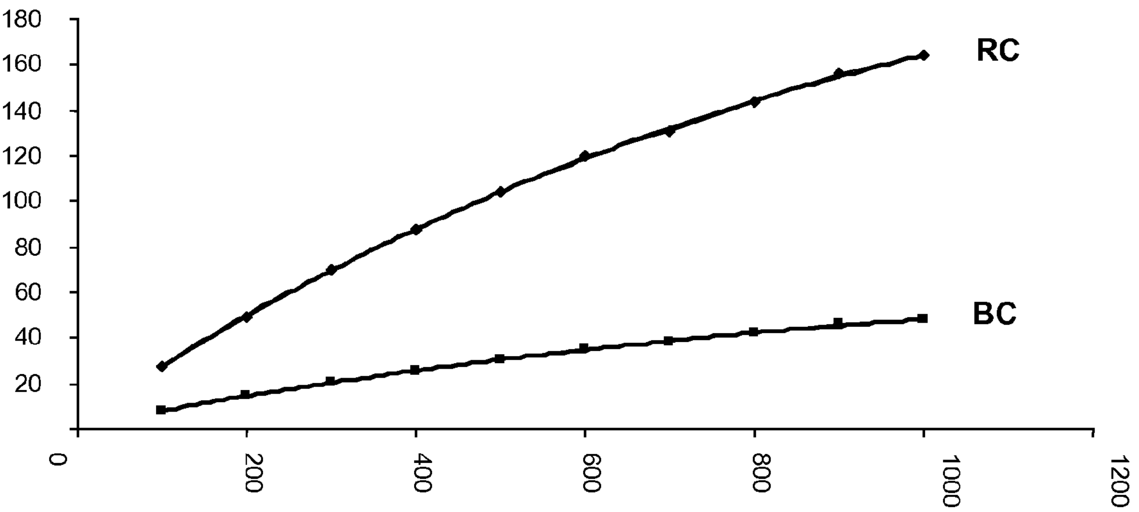

Fig. 5

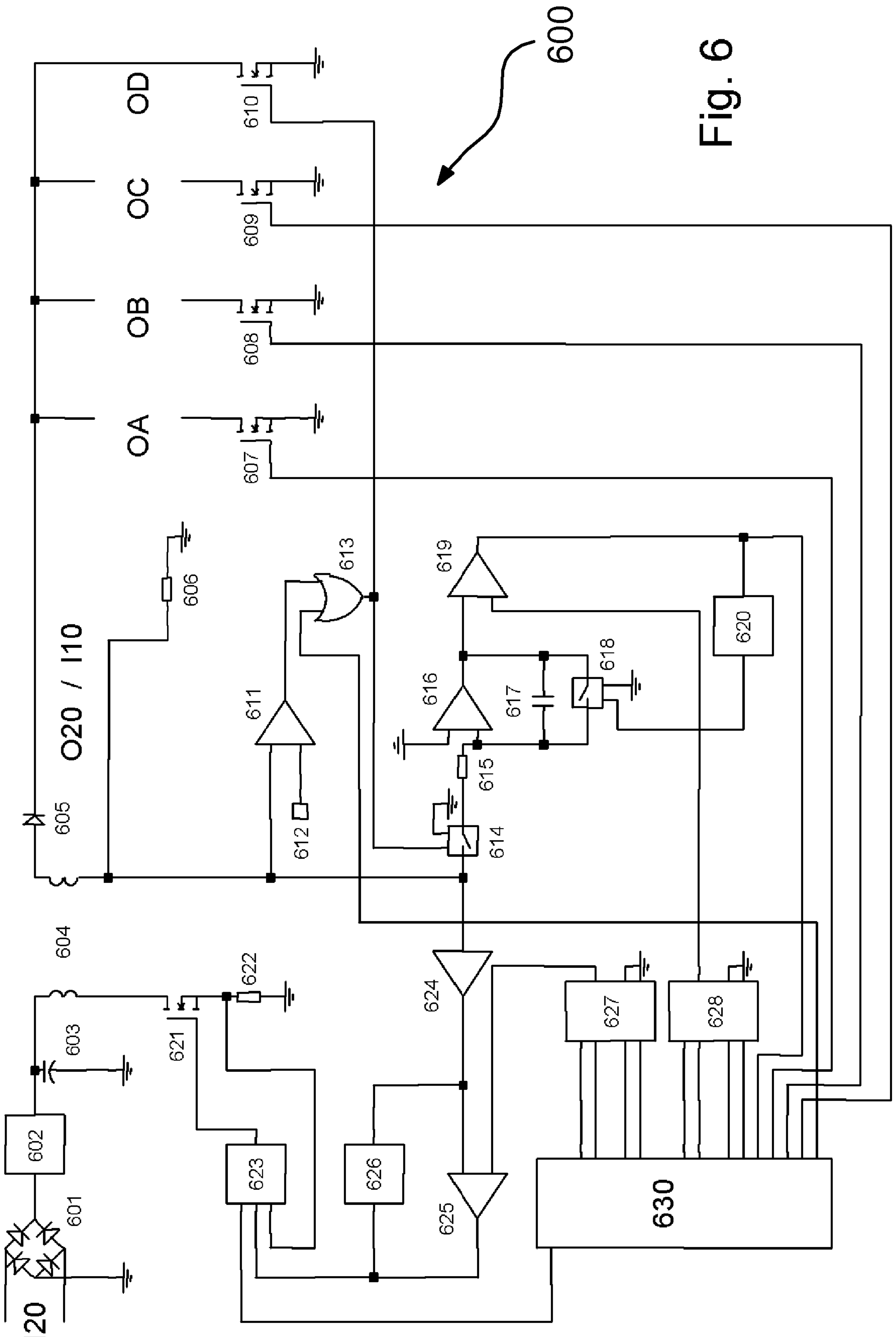
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Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 10 15 0469

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	23 April 2010	João Carlos Silva

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CATEGORY OF CITED DOCUMENTS

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23-04-2010

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