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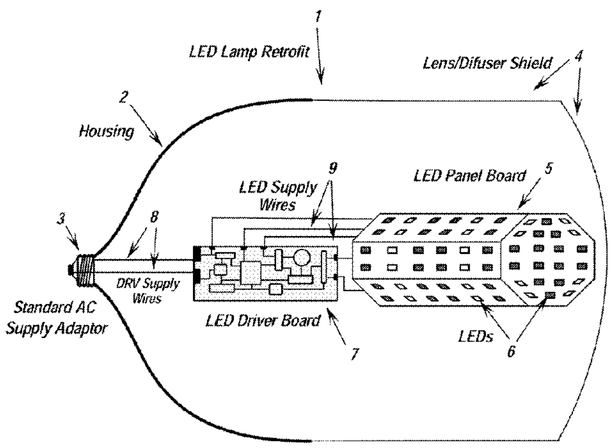
(54) Title: NEAR UNITY POWER FACTOR LONG LIFE LOW COST LED LAMP RETROFIT SYSTEM AND METHOD

Fig. 1: Dimmable LED Lamp Retrofit For Classic Incandescent Lamps



(57) Abstract: Disclosed are various embodiments of low cost high quality LED (Light Emitting Diode) retrofit lamp devices capable of operating in a wide range of power and to supersede conventional lighting devices such as incandescent, halogen, sodium or fluorescent lamps. The disclosed embodiments include various LED lamp retrofit apparatuses that maximize the electro-mechanical-optical compatibility of seven interactive systems, such as: LEDs, LED Panel, Supply Adaptor, Housing, Lens/diffuser Shield, In/Out Electrical Wiring an LED driver. LED lamp retrofit apparatuses include incandescent, halogen, fluorescent, and sodium lamps. Drivers for such LED retrofit lamps include alone or in combination is double stage boost - isolated flyback, single stage boost, no opto-coupler isolated flyback, single stage single ground flyback, single stage constant off time buck-boost, single stage single ground self-supply buck-boost, pseudo double stage boost-isolated flyback, pseudo double stage boost - non isolated flyback, pseudo double stage boost - COT buck- boost, pseudo double stage boost - SG buck-boost, series circuit monolithic, parallel circuit monolithic, single cell anode loaded voltage controlled limited current switch (VCLCsw), single cell cathode loaded voltage controlled limited current switch (VCLCsw), overall feedback series monolithic circuit, overall feedback parallel monolithic circuit, monolithic multi stripes, high reliability series monolithic circuit, minimum parts series monolithic

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circuit, minimum parts parallel monolithic circuit, 120Vac series monolithic circuit, simplified series monolithic circuit, simplified parallel monolithic circuit, monolithic diodes source feedback parallel circuit, operational amplifier (OPAM) monolithic parallel circuit, diodes gate feedback monolithic parallel circuit, resistor gate feedback monolithic parallel circuit, according to one embodiment, totem pole feedback monolithic parallel circuit, monolithic 8 Pin DC chip, and monolithic 8 Pin AC chip

NEAR UNITY POWER FACTOR LONG LIFE LOW COST LED LAMP RETROFIT SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of US Provisional Patent Application No. 61/576,604 filed 12/16/2011, entitled "NEAR UNITY POWER FACTOR LONG LIFE LOW COST LED LAMP RETROFIT SYSTEM AND METHOD"; and US Provisional Patent Application No. 61/710,286 filed 10/5/2012, entitled "NEAR UNITY POWER FACTOR LONG LIFE LOW COST LED LAMP RETROFIT SYSTEM AND METHOD", each of which is incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

The various embodiments disclosed herein relate to low cost high quality LED (Light Emitting Diode) retrofit lamp devices capable to operate in a wide range of power and to supersede conventional lighting devices such as incandescent, halogen, sodium or fluorescent lamps.

More particularly, the disclosed embodiments relate to a LED lamp retrofit apparatus that maximizes the electro-mechanical-optical compatibility of seven interactive systems, such as: LEDs, LED Panel, Supply Adaptor, Housing, Lens/diffuser Shield, In/Out Electrical Wiring an LED driver.

2. Introduction

2.1 Lighting Needs versus Electrical Energy Resources

According to the data provided by the Energy Information Association *(2003, Commercial Buildings Energy consumption Survey, Table E3, Fig. 4),* with respect to the commercial buildings in the USA, the ratio of the total electrical energy used for Lighting is 38%, respectively about 3 times larger than the electrical energy used, in the same sector, for the next three large consumers, such as Cooling (13%), Ventilation (13%) and Refrigeration (12%).

Several hundred million dollars and tons of combustive resources are exhausted, yearly, for producing this energy, while experts in ecology warn of global warming and the need for green energy, green products, and energy consumption reduction.

By reducing 4 to 10 times the amount and cost of the energy spent for lighting, the lighting industry may become a minor consumer, even at the country level, and the saved electrical energy could be used more efficiently or more economically, for fulfilling the urgent needs solicited by many other branches of the industry.

The solution to achieve this goal already exist: the immediate replacement of all the existing conventional lamps with LED Lamp Retrofits, since the latest developed LED devices have already proved to be 5 to 10 times more efficient than the incandescent and halogen bulbs, and more reliable, compact and less polluting light sources than the fluorescent and sodium lamps.

However, the right and complete implementation of these new LED devices will take some time, because of several issues that will be presented below, especially, the issues associated to a potentially possible "Low Cost High Quality LED Lamp Retrofit" ideal device.

The main purpose of all novel solutions disclosed herein is to show that, by maximizing the attributes of each component included in a LED lamp retrofit, while optimizing their each-other compatibility, a cost reduction of 30-50% per unit could be obtained for a high quality device, featuring top specs, such as: Efficiency Eff > 90%, Power Factor PF > 0.99, Harmonic Distortions A.THD < 10%, less parts count, low size and weight, high reliability and minimum five years lifespan.

2.2 Conventional Lamps

The main light sources existing in the worldwide market are the incandescent, halogen, sodium, fluorescent and LED lamps, each of them having advantages and disadvantages with respect to each other.

2.3 Incandescent Lamps

An incandescent light bulb, incandescent lamp or incandescent light globe (or conventional Edison bulb) is an electrical device which produces light via a filament heated to a sufficiently high temperature by an electric current passing through it until it glows.

The incandescent lamp comprises four main components: a glass "lens-diffuser-shield" housing (or "glass bulb"), a lighting filament, a filament's supply wiring system and a supply adaptor for connecting the filament with an electrical AC or DC power source.

The filament is typically a tungsten wire heated with electrical current up to its incandescence limit (near melting point), for allowing emission of photons, via a standard socket called "Edison screw" which provides mechanical support to the glass bulb and electrical connection to the AC electrical grid.

The hot filament is protected from oxidation with the glass bulb from which the air is evacuated (vacuum), extending its typical lifespan to about 1,000 hours.

The glass housing may have any size or shape, from a quarter of inch diameter transparent sphere to a ten inch semi-transparent (translucent or milky coated) egg-shaped balloon.

The filament's supply wiring system consists of two or more feed-through terminals or wires embedded in glass. Particular devices such as the "three-way light bulbs" have two filaments and three conducting contacts in their bases. The filaments share a common ground, and can be lit separately or together. Common powers include 30-70-1 OOw, 50-1 00-1 50w, and 100-200-300w, with the first two numbers referring to the individual filaments, and the third giving the combined wattage.

The incandescent lamp main advantages are: low manufacturing cost, allowance for many different physical shapes, size and AC or DC supply voltage range (1.5v - 300v), ideal power factor (PF = 1), less harmonic distortion (A.THD < 5%), natural (similar to the sun's) light emitted Omni-directionally (360°), negligible ultraviolet light exposure, compatibility with triac dimmer control devices and no risk of contaminating the environment with hazardous waste materials such as lead, mercury, or cadmium.

These advantages kept this "Edison bulb" as the # 1 source of electrical light, worldwide for over 100 years.

The incandescent lamp's main disadvantages are: low efficiency (1.9 - 2.6%, typically), low efficacy (12-17 lumens per watt, typically), fragile when mechanical shocks or vibrations occur and very hot (over 100°C at 10Ow), with respect to other lighting devices.

Because of these limitations and/or inconveniences, the incandescent lamps have been replaced in many applications by other types of electric lights, such as halogen, sodium, fluorescent lamps, compact fluorescent lamps (CFL), and light-emitting diodes (LEDs).

"Some jurisdictions, such as the European Union, are in the process of phasing out the use of incandescent light bulbs by banning them with laws to force them being replaced with more energy-efficient lighting." (Source: Wikipedia – "Incandescent light bulb".)

2.4 Halogen Lamps

A halogen lamp, also known as a tungsten halogen lamp or quartz iodine lamp is also an incandescent lamp which does not use vacuum for delaying the filament oxidation, but a small amount of a halogen such as iodine or bromine added which, combined with the tungsten filament produces a halogen cycle chemical reaction that re-deposits evaporated tungsten back on the filament, prolonging its lifespan and keeping the envelope clear.

This process allows the halogen lamp to operate at a higher temperature than a standard gas-filled lamp of similar power and lifespan, generating more light in the visible spectrum.

The halogen lamp comprises the same four main components as the incandescent lamp plus the halogen gas inserted in the glass housing.

The flood halogen lamp has the housing covered, internally, with a silvery coating (mirror), focusing the light in only one direction, in an angle of about 120 degrees, via a transparent or milky frontal lens/diffuser.

The advantages of the halogen lamps are similar to those of the incandescent lamp, featuring a higher efficiency (2.6-3.5%) and efficacy (18-24 lumens/watt) than the incandescent lamp and additionally, their smaller size at higher power range, permits their use in more compact optical systems for high brightness projectors and illumination, which make them to be a preferred lighting sources at hotels, theaters, casinos, aircraft, watercrafts, and automobiles.

The main disadvantages of the halogen lamp are also similar to those of the incandescent lamp and, in addition, the halogen lamps generate more heat and ultraviolet radiation, requiring some specialized coating of the glass housing for decreasing the level of this radiation down to a non-dangerous level, for the end user.

"Halogen lamps were used on the Times Square Ball from 1999 to 2006. However, from 2007 onwards, the halogen lamps were replaced with LED lights. The year numerals that light up when the ball reaches the bottom used halogen lighting for the last time for the 2009 ball drop. It was announced on the Times Square website that the year numerals for the 2010 ball drop would use LED lights." (Source: Wikipedia - Halogen lamp.)

2.5 Sodium-vapor Lamps

A sodium-vapor lamp is a gas-discharge lamp that uses low pressure sodium (LPS) or high pleasure sodium (HPS) techniques to generate light.

LPS are the most efficient light sources so far, having an outer glass vacuum envelope around the inner discharge tube for thermal insulation, but their specific yellow light appearance limits their application to outdoor lighting such as street lamps and parking lots.

HPS have a larger light spectrum but lower efficiency and poorer depiction than other lamps.

The main advantages of the sodium-vapor lamps are: very high efficiency (22-30%) and efficacy (150-200 lumens/watt), as well as the ability to work at very high power range (400W - 1kW).

The main disadvantages of the sodium-vapor lamps are: the yellow light limiting their use only to outdoor applications, long warm-up/start-up time (several minutes), need of a ballast device (some bulb types), large size, large heat dissipation, fragility versus mechanical shocks or vibrations, and higher manufacturing cost.

The sodium lamps "yellow light" change, noticeably, the original color of objects around (i.e. a red car appears orange, under this light), however, for cities having astronomical observatories around (such as San Jose, California), this light is the ideal one, because it could be easily blocked by selected filters matched with the halogen lamps yellowish light spectrum, with the purpose of getting a darker sky and, implicitly, a brighter stars view.

Nevertheless, now the ultra bright LEDs can do the same job, if necessary, featuring a more accurate control of their light emission spectrum (or color temperature) for increasing the astronomical observatories filters' efficiency, and not necessarily just in the yellow light spectrum but in a different one, offering a more natural light.

At this time the LPS are still the most efficient sources of light existing in the market, since the LEDs typical efficacy is about 100 lumens per watt.

However, besides the fact that the research for ultra bright LEDs just started a few years ago, and new improvements are announced, worldwide, almost on monthly basis (at the "experimental level there are already LEDs exciding 220 lumens per watt), all the other features of the LEDs, such as: longer lifetime, lower manufacturing cost, more compact and robustness versus vibrations, lower size and heat dissipation, no need of ballast, instant start-up, accurate control of the light spectrum, and possibility to reach 2-3kW power without increasing the device temperature, are sufficient advantages of the LED lamps retrofit for making the sodium ones obsolete. (Source: Wikipedia - Sodium-vapor lamp.)

2.6 Fluorescent Lamps

A fluorescent lamp or fluorescent tube is a gas-discharge lamp that uses electricity to excite mercury vapors in the presence of an inert gas, for producing ultraviolet light which causes the fluorescence of a phosphor coating placed internally, and implicitly, light in the visible spectrum.

The fluorescent lamp is comprised of the same components as halogen lamps, with one difference being the glass lens-diffuser-shield housing is typically a long glass tube coated with a milky phosphorous substance and filled not with halogen but neon. The lighting filament is actually split in two separate filaments positioned at each end of the tube housing. The two filaments' supply wiring system consists of two wires per filament and the supply adaptor for connecting the filament with an electrical AC or DC power source consists of two plastic caps, having two terminals each, positioned at each end of the glass tube.

Additionally, the fluorescent lamp uses, externally, a more sophisticated AC supply fixture, including two extra devices; the "ballast" which is typically a large impedance coil for limiting the lamp operating current, and the "starter", which is basically a voltage controlled switch, which automatically turns "ON" when the voltage across its terminals is higher and "OFF" when the voltage across its terminals is lower than pre-established threshold amounts.

The fluorescent ballast is supplied with AC electrical voltage via two separate circuits: a) the first circuit including one terminal of the first filament, the ballast, and one terminal of the second filament, coupled in series, and b) the second circuit including the starter, coupled in series with the two remained terminals of the filaments.

Simply presented, when a high AC voltage (100-240Vac) source is applied to the fluorescent lamp four terminals, the starter switch is turned "ON" for a short time, closing the two filaments AC circuit, the filaments get warm providing the necessary means to trigger the "ignition", for the gas inside the lamp to become conductive and to absorb from the AC voltage source as much current as the ballast, coupled in series with the other two terminals of the filaments, would allow. For example, if the AC voltage is 120V and the fluorescent lamp power is 60W, the ballast impedance must be calculated to limit the current at I = P/V = 60/120 = 0.5 A.

Immediately after the lamp's ignition is established, the voltage across the starter decreases, and the starter switch turns "OFF", disconnecting the filaments circuit from the AC voltage source. However, the filaments are kept warm now by the lamp current, so there is no more need for the starter's switch to be "ON".

In other words, for producing the ignition, the starter switches ON-OFF for several times, closing and interrupting the ballast AC circuit, via the two filaments, the ballast (inductor) will generate very high voltage spikes (over 1kV, with no "load") at each time when the starter's switches "OFF" (current interruptions) and the lamp does not absorb any current from the AC source. Eventually, after several ON-OFF cycles, the lamp reaches its ignition, and a 0.5A current is crossing the lamp, with no more interruptions, so the ballast does not generates any more high voltage spikes (the lamp becomes a 60W "load"), and the starter remains in its OFF state until the next time when the lamp is, first disconnected, then re-connected to the AC voltage source.

Since over 30 years, many companies around the world, starting with Philips, General Electric, and Osram-Sylvania have been supplying fluorescent lamps and adequate lamp fixtures having standard sizes, AC supply adaptors sockets, and wiring circuits for allowing easy interchangeability of lamps, ballasts, and starters, for several standard power ranges. In one embodiment, for example, as described in more detail hereinbelow, the present specification provides a "fast, easy and safe implementation of a fluorescent LED lamp retrofit in a standard AC supply fixture", by eliminating the need to rework the wiring circuit, as all the others solutions recommend.

A particular florescent lamp is the CFL (Compact Fluorescent Lamp) which uses a smaller diameter glass tube housing, following a spiral shaped (known as the "curly bulb") which, being designed to replace conventional incandescent lamps, is connected to the power line via a standard Edison screw AC supply adaptor.

The fluorescent lamps main advantages over the incandescent and halogen lamps are: higher efficiency (9-1 1%), higher efficacy (50-100 lumens/watt) and implicitly, less heat dissipation.

These advantages were sufficient to have made the fluorescent lamps the most used source of light for indoor applications such as commercial buildings, business offices and industrial workplaces.

The fluorescent lamp has many disadvantages, such as: higher cost for the entire lighting system (including the lamp, ballast, starter, and the AC supply fixture), low power factor (0.5 - 0.7) which requires power factor correction circuits, high level of harmonic distortions (A.THD 60-120%), causing unpleasant radio interference, shorter lifespan if there are switched ON-OFF frequently, longer start-up time (1-3 seconds), ultraviolet emission, lower efficiency or malfunction if the ambient temperature is too high (35 - 60°C) or too low (below 0*C) with respect to the standard room temperature (24°C), relatively large size or complex shape, flickering (stroboscopic effect), incompatibility with triac dimmers and disposal/recycling problems, due to the toxic substances, such as phosphor and mercury, used in their ignition and light emission process.

Because of these inconveniences, the fluorescent lamps are gradually being replaced with more reliable, efficient, compact and less polluting devices, such as LED Lamps. (Source: Wikipedia - "Fluorescent Lamp", "Compact Fluorescent Lamp".)

2.7 LED Lamps

An LED lamp (or LED light bulb) is a solid-state (semiconductor) lamp that uses light-emitting diodes (LEDs) as light sources.

The LEDs are small, compact and very efficient lighting devices which, connected in series or parallel circuits (stripes or columns), can provide visible light in a wide range of power, from 50mW to over 1kW.

The LED lamps are complex devices capable of reaching higher performances than all the conventional lamps if each of their main components, especially the LED driver circuit, is properly chosen and specifically designed to solve the main inconveniences of only one specific conventional lamp, existing currently in the market.

The most crucial parameters such as: lifespan, efficiency, power factor, harmonic distortions, dimming factor, utilization factor and flickering depend, almost exclusively, on the LED driver circuit's configuration and electrical performances. In various embodiments, the present specification provides "LED Drivers" in an "LED Lamp Retrofit", for example.

Because, the LED lamp retrofits and implicitly, their LED driver circuit represent the main subjects of this specification, and a fair comparative presentation of a specific LED lamp advantages, versus conventional lamps and/or other LED lamps, requires a very complex market analysis study, a detailed description of several conventional "LED lamp retrofits" and "LED Lamp Drivers" will be presented hereinbelow.

3. LED Lamp Retrofits

By definition, a "lamp retrofit" should have the physical aspect, light distribution, brightness, size and supply adaptor connections pretty similar to each specific conventional lamp subject of replacement.

Since in the worldwide market, there are hundred kinds of different incandescent, halogen, sodium and fluorescent lamps operating in a 1W-1kW power range and having different size and shape, from a few feet long tube fluorescent lamp down to a quarter of an inch diameter spherical flash lighter's bulb, obviously it cannot be only "one LED lamp retrofit" replacing, alone, all the existing conventional lamps.

Over the last five years, the LED lamp retrofits are successfully replacing almost all the conventional lighting devices and governments of developed countries are encouraging and supporting this action.

The main issue associated to these LED lamp retrofits immediate replacement of the conventional lamps is the higher cost per unit, an inconvenience which could be compensated if the retrofits' lifetime can be sufficiently extended (5-10 years) for end users to be able to recover the extra cost from the monthly savings in the electrical utility bill.

Unfortunately, because the LED lamp retrofits comprise LED driver circuits, which include unreliable and bulky parts such as high voltage electrolytic capacitors and oscillating coils, the lifetime of these retrofits could be estimated, conservatively, up to about two years, a fact which forces the manufacturers to guarantee 5 years lifetime of their product only if the product is not used more than 4-8 hours a day.

Therefore now, most of the worldwide power management companies are doing their best efforts to solve these issues, either by decreasing the retrofits cost per unit down to the same cost as the conventional lamp replaced, which could be considered "the economical marketing strategy", or by prolonging, sufficiently, the lifespan of the LED lamp retrofits, for justifying their extra cost, which cold be considered "the high tech marketing strategy".

3.1 Implementation

A good quality LED lamp retrofit should replace, easily and operatively, each conventional lamp, matching, as closed as possible the physical dimensions, electrical supply adaptor, light intensity and light quality of the conventional lamp it is designed to replace.

Additionally, the recently introduced "smart control systems" require, or will require, more complex lighting systems having the capability to allow control via computers, in a "remote feedback" manner, in which each Lamp retrofit provides data (obtained via sensors) about its momentarily status in its particularly environment, for parameters such as temperature, humidity, outdoor light, motion in vicinity, current consumption versus light intensity, than the computer controls each node or lamp, accordingly, in an "ON-OFF Mode", for a better distribution of light and for avoiding "overheating" in some areas, or in a "Dimming Mode" for adjusting, properly, the light intensity and/or color, in other areas.

Such a smart control system implementation is possible and not to difficult to be achieved now, more than ever before, since all LED lamp retrofits include electronic driver boards, for controlling the LED current despite large variations of the supply voltage and ambient temperature, and since the cost of the digital parts used in I/O data communications have decreased dramatically, over the last ten years, the upgraded lamp retrofits cost per unit will not increase, significantly, if a "remote feedback" circuit will be included in a "smart LED driver" board and an "I/O data wiring connectors system", or "wireless communication system" would be added to a "smart LED lamp retrofit" device, for "remote feedback" purposes. In various embodiments, for example, the present specification provides remote control and feedback in an LED lamp retrofit as described in connection with Fig. 20, which includes a micro-controller and temperature sensor.

Since the low cost per unit is a mandatory demand of the large volume markets and an important subject of this specification as well, the following description of each LED Lamp retrofit will include references related to the cost associated to the manufacture and/or operations process of each particularly lamp retrofit.

In this light, features such High Efficiency, High Efficacy and High Power Factor represent not just "state of the art" attributes, but also economic advantages associated to each particularly LED lamp retrofit, since a *"Near Unity Power Factor Long Life Low Cost LED Lamp Retrofit"* could save an amount of money equivalent to more than times its total cost, by considering the 50-90% of electrical energy saved over ten years (or over 100,000 hours non-stop operation), versus the $0.15 cost per kilowatt, saved for each hour of operation.

In other words, over at least five years time period, an end user will get full return and additional cash profit for each LED lamp retrofit purchased, even the retrofit's costs is now 3-5 times more expensive than the conventional lamps, operating in the same power range.

With respect to the electrical energy utility bill, everybody know that a highly efficient lamp saves money, because as long as the electricity meter (counter) shows less amount of kWh (kilo-watt-hours), for the same light quality and period of time, obviously the utility (PG&E) bill will be less expensive. However, not too many end users know that, since a few years ago when PG&E has introduced its "smart meters", the electrical utility bill has been substantially increased (up to 40% for consumers having PF=0.6) for "Low Power Factor Electrical Devices" so from now on, only the "Near Unity Power Factor" devices will have the benefit of "no extra charge", in the monthly electrical utility bill.

This new way of billing the consumers of electricity in California has been already confirmed by the Pacific Gas & Electric (PG&E) in an internet educational publication:

"Power factor adjustment is calculated for larger customers, over 400kW, to appropriately charge for the larger percentage of reactive power used. At PG&E we average the power factor over the entire monthly billing period. " (http://www.pge.com/includes/docs/pdfs/mvbusiness/customerservice/energystatus/powerqualitv/understanding.pdf)

This apparent "overcharge" is totally fair, since for each electrical device absorbing 60W power, under a power factor coefficient of 0.6 , the utility (PG&E) has to deliver 100VA "reactive power", even the difference of 40VA is not used by the end user, but is converted in "overheat" by the utility provider's high power transformers, relays and wiring systems.

The best solution to solve these issues is to include a PFC sub-circuit in each LED lamp retrofit's driver circuit, in such a manner for the size and cost of the upgraded driver to not increase considerably.

Accordingly, all the LED driver novel solutions presented in this patent application allow for near unity (0.95 - 0.99) power factor LED lamp retrofits, in which the PFC sub-circuit's cost is less than 5% of the entire lamp's cost, featuring less parts count and size, as well.

3.2 Incandescent Lamp Retrofit

An incandescent lamp retrofit, as discussed hereinbelow in connection with the embodiment shown in Fig. 1, for example, should provide its light omni-directionally (360 degrees angle) in a range of power from 2W (5-1 0W conventional luminaries replacement) to 10 watts (40-1 OOW conventional Edison bulb replacement), it is supposed to have the same supply socket or the same size "Edison Screw" AC supply adaptor and the same physical shape a for being able to replace, easily and operatively, any conventional incandescent bulb.

The US Department Of Energy (DOE) recommended a minimum power factor of 0.7 for the lamp retrofits used in residential areas and a minimum 0.9 power factor for the business and industrial lighting section.

However since, on one hand, the low power LED lamp retrofits' parts total cost is more expensive than the cost of a "tungsten filament" and, on the other hand the internal space available in this low size bulb is too small for allowing the use of high quality LED driver circuits, most of the large volume manufacturers, such as Phillips, GE, Lights of America and others have already introduced in the market thousands of LED lamp retrofits having a very poor power factor (0.5 - 0.75).

Good reputation semiconductor companies, such as Tl, Philips, Power Integrations, Linear Technology, iWatt, ONSEMI, Fairchild are advertising new LED driver circuit solutions featuring a power factor over 0.9 on monthly basis, since over three years ago, however, either because this solution is still too expensive at this time and/or because the size of the driver circuits is too large to fit in the limited available space inside of the lamp, none of these solutions are used currently, by the large volume LED lamp retrofit manufacturers.

3.3 Halogen (Flood) Lamp Retrofit

A halogen flood lamp retrofit, as discussed hereinbelow in connection with the embodiment shown in Fig. 2, for example, should be larger in size for operating in a 10-14 Watts power range, having the same "Edison Screw" AC supply adaptor and it is supposed to focus its light in only one direction (flood), under an angle of about 120 degrees.

The LED lamp retrofits for larger power halogen bulbs have sufficient internal available space for adding a PFC board, however, by considering the low cost of the existing halogen bulbs, it is almost impossible for the large volume manufacturers to build high quality lamp retrofits, at a competitive cost per unit, unless the LEDs and/or the LED driver boards cost decreases, considerably.

3.4 Fluorescent Lamp Retrofit

A fluorescent lamp retrofit, as discussed hereinbelow in connection with the embodiment shown in Fig. 3, for example, should follow a tube shape having, precisely, the size as and the same conventional two connectors AC supply adaptor coupled, symmetrically, at both ends of the lamp, in order to match with the Phillips, GE and Sylvania standard supply fixture and to operate in a 16 - 24 watts power range for reaching at least the same light intensity as a 60-80 watts fluorescent lamps.

For this particular retrofit, the LED lamp has significant advantages, consisting in the fact that the fluorescent lamp light angle is 360°, however, these lamps' fixtures are mounted against the wall, so almost 50% of its lighting capacity is wasted, unless good quality mirrors (reflectors) are included in the fixture, for guiding the light back, in the right direction. The LEDs 120 degrees light angle allows this kind of retrofit to reach the same light intensity and better quality (sun light), guided on the right direction, and with just 15W power consumption to replace a 60W conventional fluorescent lamp, without using large and expensive bright white fixtures or reflectors, as discussed hereinbelow in connection with the LED lamp retrofit embodiment associated with an LED panel for a T8 retrofit.

An additional advantage of this particular retrofit consists in the fact that the size and cost of the replaced lamp (including its large and expensive fixture, ballast and starter) allow for a "higher performance higher cost" LED lamp, but unfortunately, still most of the new T8 fluorescent LED lamp retrofits, existing in the market, have the power factor less than 0.9 (some of them even less than 0.7), because of the extra cost and extra size of the driver board, required by a PFC circuit comprising 15-30 parts, typically.

3.5 Other Lamps Retrofits

Other LED lamp retrofits, as discussed hereinbelow in connection with the embodiment shown in Fig. 4, for example, could be designated to replace very small bulbs, large street lighting sodium lamps or huge lighting panels, accordingly in such applications it is recommendable for the LED lamp retrofit to be designed as a "compact light engine" unit, respectively, to have a spherical or cubical monolithic configuration which allows for many units to be connected next to each other, in series and/or parallel circuits, similar to the conventional lighting panels using hundreds of incandescent bulbs.

Ideally, a "compact light engine" should include only two parts, respectively an LED Array module and a silicon microchip, coupled directly to the LEDs.

Some "pioneers" in the worldwide industry, such as Exclara, Supertex, Seoul Semiconductor and a few others have introduced a new technology that eliminates the need for capacitors and coils used in the "conventional LED drivers" and allows for "Monolithic LED Driver" (fully integrated) solutions, near unity power factor and over 90% efficiency.

This new technology could be the key to "the right solution" for a very low cost, but also very high quality, LED lamp retrofit.

Accordingly, the present specification provides several novel solutions for upgrading incandescent, halogen, sodium and fluorescent LED lamp retrofits, comprising conventional LED drivers, as well as monolithic LED drivers.

4. LED Lamps Retrofits Main Components

For a fair and easier quality versus cost comparison between all lighting devices presented in the present specification it would be considered that, similar to the embodiments presented herein, all LED lamp retrofits existing in the market comprise the same seven main components, such as: LEDs, LED Panel, Supply Adaptor System, Housing, Lens/diffuser Shield, LED Driver, and LED driver's In/Out Electrical Wiring System, regardless of the fact that some of the lamps may appear to have fewer components, because two or more parts are integrated into one component capable of performing, simultaneously, 2-3 functions required by a particular LED lamp retrofit's lighting operations.

The LED lamp retrofits performances quality and operation lifetime depend on the physical configuration, electrical characteristics, reliability and lifespan of each of its components, as well as on the capability of these components to match each other, for optimizing the quality versus cost feature of each particularly lamp retrofit.

4.1 LEDs And LED Arrays

The LEDs are basically mono-chromatic Light Emitting Diodes or nonlinear semiconductor devices introduced in the industry since over thirty years ago as "tiny monochromatic lighting sources" capable of generating just a few colors, such as Red (or Infrared), Green, Yellow and Orange used, mostly, in display panels for electronic equipment, stereos, toys, infrared remote control and other low power lighting applications.

Because of their small power consumption (20-1 OOmW) and low cost, there was no need for a "high efficiency high power factor LED drivers", at that time, since even a low power/low cost operational amplifier could supply an LED in a "constant voltage constant current" manner, securing the circuit lifespan for a period of 10-20 years.

During the last decade, shortly after the blue LED was finally created, the applications field of these devices has increased dramatically, because by combining, in whatever ratio, the Red, Green and Blue ("RGB") colors, any other "specific color" of the visible spectrum (from Infrared to Ultraviolet, including "White") could be easily obtained, offering the necessary means for the high efficiency "color video display" used now in small and ultra large TV/Monitors/Advertising video screens, as discussed hereinbelow in connection with the embodiments for RGB type LED lamp retrofits, for example.

Over the last five years, the "Ultra Bright White LED" technology, developed from the blue LED technology, has been rapidly developed by high volume manufacturers such as CREE, Lumileds, Nichia, and many others, offering a large diversity of LED devices operating in a range of power from 50mW to over 5W per unit, which can be easily connected in series and/or parallel circuits (similar to the conventional diodes matrix circuits) and used in low power (1-50W), as well as in high power (100W-1kW) LED lamp retrofits, absorbing 5-10 less electrical energy than incandescent or halogen lamps, from the AC power grid, for similar lighting power.

At this range of power and especially, for such serious applications such as aircrafts, watercrafts, street and commercial lighting systems, obviously a low power and cost operational amplifier cannot secure the job, so there is an urgent need for more complex "high reliability, high performance, long lifetime LED lamp" driver circuits, capable to operate in a range of power from 1W to 1kW.

The 50mW LEDs require a constant current of maximum 20mA and their cost per unit is very low now, after the apparition of the higher current (100mA to 5A) LEDs which offer the advantage of using less number of LEDs for any given power of a LED lamp retrofit. In the same range of power, the cost of 100 LEDs of 50mW power each is now lower than 5 LEDs of 1W power each, but because five LEDs could be connected in only one stripe having its current secured by only one constant current sink device, while the 100 small power LEDs may need 20 constant current sink devices (in the same configuration of 5 LEDs per stripe), most of designers prefer to use the more expensive higher power five LEDs. South Asian manufacturers prefer the low cost low power LEDs, using hundreds of them in only one T8 fluorescent retrofit lamp, connected in 20-30 stripes and using low cost ballast resistors, per each stripe, instead of constant current sink devices. This solution is good only for reducing the retrofit cost per unit, however, the chances for these kind of lamps to last more than two years are very low, as discussed hereinbelow in connection with the embodiment shown in Fig. 24, for example.

Many LEDs manufacturers now offer the so called "LED Array", "6V LED", "20V LED" or "50V LED" which are, actually, two, six, fifteen or more LEDs mounted, very close to each other on a thin aluminum board, then connected to each other in series and/or parallel circuits using a very productive and cost effective technology that allows printed circuits deposited on an "aluminum oxide" substrate which solved, simultaneously, the heat transfer and the electrical isolation issues associated to the manufacturing process of LED lamp retrofits using more than one

LED, as discussed, for example, hereinbelow in connection with the embodiments shown in Figs. 4 and 20.

The LEDs main advantages over the conventional lamps are: more compact, smaller size and weight, higher efficiency, higher efficacy, less heat dissipation, highly resistant to mechanical shocks and vibrations, longer lifespan, precisely controlled light spectrum, no ultraviolet or x-Ray radiations and no disposal/recycling problems.

The main inconvenience associated to the LED's behavior is the nonlinearity aspect, associated to the fact that typically, an LED absorbs almost no current when the voltage across its terminals increases from 0V up to about 2.8V, than it starts absorbing rapidly, more and more current when the voltage increases between 2.8V and 3.3V supply and finally, the LED may me be exposed to irreversible damages (or simply it may "blow up") if the LED's current increases above its recommended limit, even by increasing the voltage (and not limiting, somehow, the LED's current) with just 0.1-0.2 volts.

Additional inconveniences consists of the fact that the LEDs require rectified AC current which calls for a relatively sophisticated and expensive power factor correction circuit, the LEDs current amount changes, considerably, with ambient temperature variations, when coupled in parallel stripes the LEDs need a ballast resistor or a constant current sink for balancing the current per each stripe, they lose completely the light at any time when the voltage across a LED stripe is only a few fractions of a volt lower than the typical multiple of 2.8V-3.3V threshold, creating an irritating "flickering" effect, especially when dimmers are used.

In conclusion, the LEDs have a strong potential to be the future ideal lighting source which will replace, eventually, all the conventional lamps existing around, however, because of several inconveniences, these amazingly compact and efficient devices cannot perform as well as expected from an efficient and reliable lamp retrofit without having "full match" with each and all the other six components, discussed hereinbelow, in various example combinations and permutationsf.

4.2 LED Panels

The LED panels are, basically, the mechanical support for one or more LEDs connected in any series or parallel circuit combination offering the optimum implementation or maximum brightness with respect to the lamp's physical configuration, available internal space, light direction, dimming capability and uniform light distribution of each specific LED panel included in a specific LED lamp retrofit.

The LED panel configuration and the electrical connection between the LEDs have to be designed in such a manner for providing maximum brightness by using or not using a reflecting mirror and, also, the light has to be symmetrically distributed on the entire LED panel surface, even a dimmer reduces the maxim supply voltage, switching "off", one after the other, all the LEDs stripes, as the maximum supply voltage decreases.

Four main LED panel configurations are currently used, or could be used, such as:

a) a three dimensional LED panels for incandescent LED lamp retrofits, which has to secure an Omni-directional light and a symmetrically distributed light in case the amplitude of the supply peak decreases, as discussed hereinbelow in connection with the embodiments shown in Figs. 5 and 6, for example,

b) a flat disk LED panels for halogen (flood) LED Lamp retrofits, as discussed hereinbelow in connection with the embodiment shown in Fig. 2, for example, which provides a spot light and a symmetrically distributed light in case the amplitude of the peak input voltage decreases, as discussed hereinbelow in connection with the embodiment shown in Fig. 6, for example,

c) a flat rectangular LED panels for fluorescent LED Lamp retrofits, as discussed hereinbelow in connection with the embodiment shown in Fig. 3, for example, which provides uniform light over a several feet long transparent tube and where the light has to remain symmetrically distributed in case the amplitude of the supply peak voltage decreases, as discussed hereinbelow in connection with the embodiment shown in Fig. 5, for example, and

d) a flat miniature LED Array for monolithic light engine LED lamp retrofits, as discussed hereinbelow in connection with the embodiment shown in Fig. 4, for example, which provides a uniform and symmetrically distributed light in case the amplitude of the supply voltage decreases, as discussed hereinbelow in connection with the embodiment shown in Fig. 7, for example.

4.3 Supply Adaptors

For any lamp retrofit, the supply adaptor is a component, which allows the end user to replace, shortly and operatively, the obsolete conventional lamp used until the day of replacement, without any need to employ an authorized electrician and/or to take the risk of doing "improvisation" in order to connect the new lamp to the dangerous high voltage electrical power grid's standard terminal.

Therefore, most of the LED lamp retrofits are equipped with exactly the same supply adaptor, described above, for each standard power and size incandescent, halogen, sodium, and fluorescent lamp, subject of the replacement.

4.4 Housings

The LED lamps retrofits' housings have significant economical advantages, with respect to the conventional lamps' housing, because since the LEDs do not need vacuum or rare gases for producing light, there is also no need for the housing to be made from glass, which is heavier, more fragile and more expensive than plastic or aluminum.

The housing provides mechanical support and environmental protection (against raining, humidity or dust) for all the other components of the retrofit lamp, and it could appear as a transparent plastic globe which replace also the lens/diffuser shield, or it could be made from aluminum and used also as LED panel and as heat sink for cooling down the LEDs operation temperature and keeping them highly efficient.

In case the housing is made from aluminum, or any other metal, serious precautions have to be taken, making sure there is a 2kV-4kV isolator material between the housing and any electrical component (LEDs, LED panel, LED driver, supply adaptor, wiring supply circuit) coupled, directly, to the AC power grid, for protecting the end users against electrical shock hazard, as discussed hereinbelow in connection with the embodiments of non-isolated drivers, such as a monolithic driver, for example.

4.5 Lens/Diffuser Shields

The lens/diffuser shields of the existing LED lamp retrofits have different size, shape and transparence grade (transparent, translucent, milky, color filter, magnifying glass stripes, etc.) following, as close as possible, the exact appearance of the conventional lamp subject of replacement, in order to provide at least the same intensity, quality and spectrum of light to many end users which, for different reasons, may have strong preference for a specific lamp type.

Some of the LEDs, existing in the market, come with a small magnifying lens incorporated into their plastic package, which increase their brightness but decrease their light cone's angle, down to about 90°.

For outdoor applications, the lens/diffuser shield device has to be hermetically (water proof) coupled to the housing of a LED lamp retrofit, for securing the lamp's high reliability versus rain, dust or any other adverse factor able to damage the LED lamp retrofit's circuit.

4.6 In/Out Electrical Wiring System.

The LED driver's in/out electrical wiring system comprise three main circuits, such as:

a) a driver supply circuit, which consists of two or more wires coupled with a DC source such as a car battery, a high voltage AC source such as the 120V-240V power grid, or to a 50-60Hz power transformer.

b) Ta LED supply circuit, which may also include two or more wires, in accordance with the configuration of the LED driver and the LED panel circuits.

c) a remote feedback wiring circuit, comprising two or more wires coupled between the LED driver circuit, which should include sensors and a microcontroller system capable of exchanging in/out data, and an "in/out data connector" which connects the LED lamp retrofit with an external computer system or directly to the internet.

Currently, there are already available "smart remote control circuits" via which end users can switch on/off or even dim all lights in their apartment, via internet, even during a trip out of the country.

4.7 LED Drivers

Currently, there are hundreds of different LED driver circuit configurations available on the worldwide market, each of them following different circuit topologies and offering different advantages, such as: lower cost, smaller size, less parts count, higher efficiency, higher power factor, less harmonics (noise), off line

(90-240Vac supply range) capabilities, wide range dimming capabilities, however, each of them having some limitations or inconveniences, as well.

Very generically, these devices could be separated in two main groups such as: a) ballast LED drivers, b) Switching Mode Power Supply (SMPS) LED drivers, and c) Monolithic LED Drivers, all of them being capable to operate as DC/DC or AC/DC LED diver circuits, if a bridge rectifier is performing the AC/DC conversion.

The ballast LED drivers are the most simple and cost effective ones, consisting of just a resistor or a simple constant current sink (CCS) circuit coupled in series with one or more LEDs.

The SMPS LED drivers are now the most used devices in the LED lighting industry, following the conventional (over 30 years old) Pulse Width Modulation (PWM) converter control method, based on the coils and capacitors capability of storing electrical energy, being currently promoted in the worldwide market by all major power management companies, such as Tl, Phillips, Maxim, ST Micro, Toshiba, Fairchild, ONSEMI, Power Integrations, Semtech, Linear Technology, and many others.

The Monolithic LED drivers provide a unique controlling method which eliminates the need for coils and capacitor and allows for a very compact and cost effective fully integrated driver circuit solution, being introduced in the market recently, by several "pioneers" in the industry, such as Exclara, Seul Semiconductor, Samsung, Supertex and a few other companies.

Since each of the three controlling methods mentioned above allows for many different circuit topology applications having advantages, but also inconveniences with respect to each-other and the SMPS LED drivers, as well as the Monolithic LED drivers are, both, important subjects of the present specification, detailed description of several LED driver circuit solutions, promoted in the market by very good reputation power management companies, will be presented hereinbelow.

5. Simple Ballast LED Driver Circuits

5.1 Resistor Ballast LED Driver

In low power range and regulated (constant) voltage DC/DC applications, a LED Driver circuit working at room temperature (23° - 25°C) could be extremely simple and cost effective, consisting of just "one resistor" (costing less than

$0.01) coupled in series with a LED, or a LEDs stripe, as a "ballast circuit", for limiting the LED's current down to a safe amount, representing typically, no more than 80% of the LED's maximum ratings specs, for securing "safe margins" versus the LEDs current/voltage specs variation, from unit to unit (LED's specs tolerance), and versus small variations of the ambient temperature and/or supply voltage ripples.

As a simple example, in an applications where the supply voltage is obtained from a 12V DC car battery, the voltage per each LED is required to be 3.2V and the maximum average current, Imax, is 20mA (16mA as 80% of Imax), the most "simple driver" is a resistor coupled in series with a "stripe" (column of devices coupled in series) of three LEDs requiring 3.2V x 3 = 9.6V where the resistor's value is 12V - 9.6V = 2.4V/0.016A = 150 Ohms, and the system efficiency is Eff = 9.6/12 = 80%.

For getting "more light", many stripes of three LEDs having a ballast resistor of about 150 Ohms could be connected in parallel and, in ideal and stable environmental conditions, if the substantially low efficiency of this particular system is ignored, a resistor could be the most simple and low cost driver included in a LED lamp retrofit, designated to replace the conventional incandescent or halogen bulbs used in the automotive industry.

However, in real world situations, the simple solution described above has many disadvantages since it does not protect the LEDs against large variations of the supply voltage (a car battery voltage may vary from 9V to 15V) or ambient temperature (summer vs. winter seasons) and additionally, a significant percent of the supply electrical energy is lost in heat, on the ballast resistors, decreasing the entire LED Lamp retrofit efficiency down to 80%, or less.

Therefore, in order to overcome these shortcomings, there is a need for more complex LED driver circuits capable of maintaining the LED current and voltage within precise pre-established limits, despite large variations of supply voltage and/or ambient temperature, in such a manner for the conversion of the electrical energy in light to reach maximum efficiency.

5.2 Constant Current Sink LED Drivers

The constant Current Sink ("CCS") drivers, are capable of securing a safe current trough the LED stripe, despite large variation of ambient temperature, however, when the supply voltage increase to an amount significantly higher than the LED stripe's threshold voltage, the difference in the voltage will increase the heat dissipation of the CCS device and implicitly will decrease the driver's efficiency. On the other hand, when the system supply voltage goes lower than the LED stripe's threshold voltage, even for a short period of time (ripples), the entire LED stripe will shut off its light, for that period of time, creating an irritating flickering (stroboscopic) effect.

In conclusion, the CCS devices are useful and strongly recommended only in DC circuits where the supply voltage is reasonably constant (small ripples) and close to the LED stripe's threshold voltage.

Nevertheless, there are already on the market very low cost CCS LED drivers used even in AC circuits (via a bridge rectifier), but their poor efficiency, power factor and A.THD parameters represent a strong barrier for this kind of driver to become the ideal "low cost high performances" LED drivers, on the worldwide market.

6. Switching Mode Power Supply iSMPS) LED Driver

The SMPS LED driver circuits follow conventional Pulse Width Modulation (PWM) boost, buck, buck-boost or flyback transformer converter circuit topologies which include reactive components, capable of storing and converting the electrical energy, such as inductors and capacitors as well as integrated circuits, transistors, diodes and resistors.

The main inconvenience of the SMPS drivers consists of their dependence on bulky and unreliable reactive components, such as oscillating coils and electrolytic capacitors in order to convert and store the electrical energy, as well as filtering coils and high voltage capacitors for their EMI (low pass) filters, which stop the high frequency noise, generated by the SMPS converters, to penetrate the electrical power grid.

At relatively high temperatures, which are expected inside of LED lamp retrofits, the electrolytic capacitors lifespan is relatively short (about 2 years) and also, the high frequency coils or transformers (flyback) isolation and/or magnetic core characteristics could change, dramatically, with the ambient temperature and humidity factors, limiting the lifetime of the entire LED lamp retrofit device down to 2-3 years.

6.1 DC/DC SMPS LED drivers

The DC/DC SMPS LED drivers are capable of overcoming the shortfalls in all the ballast LED drivers, in a conventional manner, by using a PWM converter comprising a controlling circuit (semiconductors), an oscillating inductor (coil) capable to, periodically store and deliver electrical energy, in high frequency constant output voltage pulses, to a load (LEDs), across which there is a capacitor that storage the electrical energy, for keeping the LEDs lighting, without flickering. The modern PWM controller integrated circuits (ICs) can control their output voltage, in such a manner, that even if the system supply voltage goes lower, or ten times higher than the LEDs stripe's threshold voltage, the voltage across the LEDs stripe remains constant, and just a little higher than the LEDs stripe's threshold voltage, for avoiding flicker and maximizing the system's efficiency.

6.2 Constant Voltage Constant Current LED Drivers

The constant Voltage Constant Current ("CVCC") LED Drivers use both, a PWM converter and a CCS device for securing, at the highest degree, the stability of the LEDs voltage and current parameters and prolonging the LED lamp retrofit's lifespan to the maximum period of time allowed by each component, especially by the unreliable high voltage electrolytic capacitors, included in most of the SMPD LED drivers.

For achieving ultra-reliable CVCC LED driver solutions, a conventional CCS circuit including a MOSFET buffer transistor in feedback with an operational amplifier (OPAM) is recommended to be inserted in series with each LED stripe for securing long term lifespan to the LED lamp retrofit. As good examples both, the MAX16834 LED driver chip provided by Maxim and the LT3756 LED driver chip provided by Linear Technology are capable of offering this state of the art CVCC circuit implementation, by using an additional external MOSFET buffer as CCS, controlled by an internal OPAM, however, this protection is used for only one LED stripe. For more than three stripes, this very reliable OPAM-MOSFET-CCS circuit becomes too expensive and therefore designers prefer to use only one stripe of higher power and more expensive LEDs, rather than cheaper LEDs coupled in more stripes. Accordingly, in various embodiments, the present specification provides a CVCC LED driver as described hereinbelow in connection with Figs. 8 and9, for example.

The maximum efficiency of a DC/DC SMPS LED Lamp retrofit depends of the number of LEDs per stripe and the PWM circuit topology used for the LED driver. As more LEDs are connected in series on one stripe, the higher the voltage threshold and, implicitly, the lower the entire circuit's current will be, for the same power range. Lower current means lower heat, which means lower dissipation and higher efficiency. However, the four conventional PWM circuit topologies mentioned above have their own particular advantages and shortcomings, such as:

6.3 Boost Topology

The boost circuit topology allows for the simplest (less parts count), most efficient (Eff = 90-95%, typically) and low cost PFC or PWM LED driver implementations, with two main shortcomings:

a) it does not offer isolation between the input and output circuits and

b) its output voltage is always higher than its maximum input voltage.

In relation to the LED driver's case designated for automotive battery LED lamp retrofits supplied with 10-15V as mentioned above, a safe constant output of minimum 17Vdc of a boost circuit will supply a stripe of 5 LEDs (assuming a 3.2V/LED, 16V/5 LEDs) coupled in series, with only 1V remaining across the driver's buffer. Since the LED current is equal with the CCS buffer current, the "output circuit efficiency" (LEDs - CCS) is, briefly: Eff = 16/17 = 0.94. In case a higher output voltage is chosen, it has to be increased in increments of 3.2V, for adding one, two more LEDs, and keeping the "extra voltage" not higher than 1V with respect to the LED stripe maxim voltage, for maintaining a good efficiency of the system. In high power/high efficiency boost driver systems, that "extra voltage" has to be dropped down to 0.1 V (using low value sense resistors techniques), for the entire boost system's efficiency to be around 0.94, since about 5% of the supply energy is dissipated in heat by the boost inductor (coil), the MOSFET switch, the controller IC and the other 15-20 components included in the circuit.

6.4 Buck Topology

The buck circuit topology, which also allows for circuits with fewer component counts, is reasonably efficient (Eff = 85-90%, typically) and cost effective, having two main shortcomings:

a) it does not offer isolation between the input and output circuits, but even more, there is a direct current from the high voltage DC source trough the LED stripe to ground which could damage the LEDs if the converter's buffer fails in a "short circuit" fashion and,

b) its output voltage is always lower than its minimum input voltage.

In relation to the LED driver's case designated for automotive battery LED lamp retrofits supplied with 10-15V mentioned above, a safe constant output of maximum 9Vdc of a buck circuit is too low to supply a 3 LEDs stripe (3 x 3.2V = 9.6V so no LED will light), so in case that a stripe of only 2 LEDs (3.2V x 2 = 6.4 V) is used, the voltage difference will be 9V - 6.4V = 2.6 V which means a "LED Stripe - CCS output circuit" with an efficiency of just 71%, which is unacceptable.

Therefore in any design, the buck output voltage has to be set as closed as possible to the two LEDs stripe threshold voltage (6.4 V) and, for the same total numbers of LEDs and lighting power of a LED Lamp retrofit, more LED stripes have to be added, fact which will increase the circuit total current and implicitly, the entire system efficiency will decrease.

6.5 Buck-boost Topology

The buck-boost circuit topology overcomes some of the above mentioned shortcomings by allowing higher, equal or lower output voltage with respect to its input supply voltage amount, operating with good efficiency (85-90, typically) and less parts count.

The SEPIC (Single-Ended Primary-Inductor) converter is a particular buck-boost circuit having non-inverted output coupling energy from the input to the output via a series capacitor to a second SEPIC inductor, fact which increase the complexity of the circuit but allows for a "single ground" configuration which eliminate the need for differential or opto-coupler sensing of the current or voltage across the load.

The three main shortcomings of the buck-boost topology are:

a) it does not offer isolation between the input and output circuits,

b) it requires sophisticated differential voltage sensing method of the output V/I parameters (not for SEPIC) because its output circuit has a different zero volts reference with respect to the input circuit,

c) it requires a special "constant Off time" controller IC when it is working in CCM (Continuous Conduction Mode) and an additional power factor correction circuit in AC applications.

6.6 Flyback Topology

The flyback circuit topology is the only circuit which, via its two coils flyback transformer, provides complete isolation between its input and output circuits and allows for higher, equal or lower output voltage with respect to its supply voltage amount.

The flyback circuit shortcomings are: more expensive, more parts count, larger size, lower efficiency (75-85%, typically, 90% using expensive parts), two separate grounds which require a sophisticated differential current/voltage sensing circuit and an additional opto-coupler circuit, in order to control the momentary value of the LED's current and voltage parameters with respect to isolated ground, and to secure the circuit's long term lifespan.

In conclusion, the flyback circuit main advantage is the "full isolation between the input (AC power grid) and the output (LEDs) circuit, fact which make this circuit the most preferred one in situations when a LED lamp retrofit has a "metallic housing" and a risk of electrical shock hazard may exist for the end users.

Nevertheless, most of the worldwide providers of LED lamp retrofits solved this problem by using plastic or glass housing and/or by using a 2kV-4kV isolated material inserted between the LEDs (output) and the LED panel (or the aluminum heat sink), solution which allows the use of more efficient and cost effectively LED drivers, following boost or buck-boost topologies.

6.7 AC/DC SMPS LED drivers

The AC/DC SMPS LED drivers follow the same three main circuit topologies described above, but they are more expensive and sophisticated than the DC/DC ones because, in the AC-to-DC conversion systems, an additional PFC (Power Factor Correction) sub-circuit is required, which increases by 30-50% the number of components and implicitly, the size and cost of the AC/DC LED driver, function of the block schematic topology chosen, respectively, "double stage" or "single stage".

6.8 Double Stage LED Drivers

The Double Stage SMPS LED driver systems are the "state of the art topologies" in which a first stage AC/DC PFC sub-circuit (boost, typically) converts, under near unity power factor, the inputted unregulated AC Voltage into a pre-regulated outputted DC voltage, and a following second stage DC/DC PWM sub-circuit (buck, buck-boost or flyback) converts the inputted pre-regulated DC voltage into an outputted Regulated DC Voltage, while controlling, precisely, the LED stripes current amount, as well. The double stage system uses two integrated circuits (one PFC and one PWM) controllers, two MOSFET buffers and two oscillating inductors, besides 40-60 other lower cost parts, fact which increase, substantially its cost and size, with respect to the single stage solution.

6.9 Single Stage SMPS LED Drivers

The Single Stage SMPS LED driver systems are the "cost effective topologies" in which only one sub-circuit performs both, the PFC and the PWM functions, using only one integrated circuit, one MOSFET buffer transistor and one oscillating inductor, saving 20-50% of the circuit parts count, size and cost, with respect to the Double Stage topology, under lower performance.

More details related to the SMPS LED Drivers advantages and shortcomings will be presented hereinbelow.

7. Monolithic LED Driver Circuits

It will be appreciated that the monolithic LED drivers could be considered "the ideal LED drivers of the future", because they are capable of reducing a 30-100 components SMPS LED driver circuit, down to only "one solid state component", respectively down to just one microchip capable of driving LED stripes in a very safe and reliable CVCC manner, featuring top performance in AC circuits, as well, such as Eff > 95%, PF > 0.99 and A.THD < 5%.

Additional grounds for designers to do their best to develop and promote, shortly, this very new technology into the worldwide market, consist in their amazingly small size (miniature surface mount chip which can fit in any small lamp or even inside of a LED or LED Array's package) and their "virtually unlimited life time" which will solve, at last, the main issue the SMPS drivers are facing right now.

The main shortcomings of conventional monolithic LED drivers are lower utilization factor, higher flickering coefficient and dependence on a specific number of LEDs per stripe, for any given supply voltage amount.

Nevertheless by considering on one hand, the very short time that has passed since this new technology has left the pioneer designers R&D bench and on the other hand, the endless potential advantage offered by these devices, chances are for the monolithic LED driver to become "the monolithic LED lamp retrofit" of the future, reaching top performances and a manufacturing cost lower than the manufacture cost of our conventional Edison bulb, today.

Therefore, the present specification provides only ten SMPS LED driver embodiments and twenty Monolithic LED embodiments.

More details related to the Monolithic LED Drivers advantages and shortcomings will be presented hereinbelow.

8. LED Drivers Comparison Criteria

For a fair evaluation with respect to the quality versus cost feature of each particular LED driver, versus other drivers provided by hundreds of power management product manufacturers, worldwide, first it is recommended to separate them in "similar drivers groups" and after that to set up suitable criteria of comparison.

Besides the very conventional boost, buck, buck-boost and isolated non isolated (single ground) flyback topologies mentioned above, there are many other options available for designers, for improving or optimizing a driver's performance, size and cost, by choosing the Continuous Mode, the Discontinuous Mode or the Critical Conduction Mode of operations, executed in a Fixed Frequency, Constant ON Time Variable Frequency, or Constant Off Time Variable Frequency manner, and therefore, it is not easy to make a direct comparison in such a hot market where, "revolutionary innovations" are advertised, worldwide, almost on a monthly basis.

The complexity of choices a circuit designer faces is endless and by considering the fact that the high power LED drivers industry has only about five years of competitive history, the common sense conclusions are:

a) there is no proven "ideal LED lamp retrofit" in the existing market, at this time.

b) there could be many other ways to design a LED driver circuit and sufficient room for improvements.

c) the only way to evaluate, fairly, the quality of a new LED driver circuit, is to compare it with several existing solutions operating in the same range of power and following the same (or similar) topology provided by the top experts of the power management industry.

An evenhanded comparison is supposed to be based on at least 14 key data arranged in a "Parts and Performance Chart" approach, providing sufficient information about the size, quality and cost features of each LED driver, such as:

1) Parts Count section, including the expensive parts amount (in parenthesis) shows the system complexity and provides indications of the circuit's size and cost.

2) Integrated Circuits section, including expensive opto-couplers (in parenthesis), shows the number of controller chips required by a particularly design.

3) Transistors section, including expensive FET transistors (in parenthesis), shows the number of transistors required by a particularly design.

4) Diodes section, including the more expensive bridge, Schottky and fast recovery (in parenthesis) shows the number of diodes required by a particularly design.

5) Capacitors section, including unreliable, bulky and expensive electrolytic capacitors (in parenthesis) shows the number of capacitors required by a particularly design.

6) Inductors section, including unreliable, bulky and expensive transformers (in parenthesis) shows the number of coils required by a particularly design.

7) Resistors section, including more expensive larger size high power current sense resistors (in parenthesis) shows the number of resistors required by a particularly design.

8) Efficiency section shows the driver's quality to put money back in its end user's pocket, offering more light but lower monthly electricity bill, than other drivers.

9) Power Factor showing the amount of overheat eliminated from the national power grid and environment.

10) A.THD showing the degree of pollution saved from the national

power grid and environment (radio noise).

11) LED Stripes CCS section shows how many LED stripes a particularly LED driver can control in a very safe CVCC (constant voltage constant current) mode of operations.

12) Board Size section shows if the driver can fit or not in small or flat bulb retrofits, and could be Extra Large (EL), Large (L), Medium (M), Small (S) and Very Small (VS).

13) Total Cost section indicate the relative cost of the driver's parts and labor, estimated as Very High (VH), High (H), Medium (M), Low (L) and Very Low (VL).

12) Lifetime section shows the pre-estimated lifetime of a driver, function of the lifespan of its components, measures in years (yrs) of operations at 24 hours a day use, showing also the degree of hope the end user may have to recover partially, or in full, the much higher cost price he had to pay for this amazingly efficient but still fragile LED lamp retrofit (i.e., important feature and sales point).

Accordingly, the present specification provides a detailed description of the related art, created over the years by leading LED Driver designers.

Since the LED driver is a vital component of all LED lamp retrofits and therefore, in various embodiments, the present specification provides novel LED driver systems featuring low component count, smaller size, lower cost, longer lifetime and higher electrical performances than most of the high quality LED drivers, existing in the worldwide market.

In order to achieve this goal for each kind of LED lamp retrofit required by the existing market, the LED driver embodiments described herein provides one specific topology, such as boost, buck-boost of flyback, applied in a double stage or single stage manner and of course, using fixed or variable frequency techniques approach, for optimizing all the parameters involved in a high quality/low cost LED driver's design.

In the same light, several novel circuit embodiments are provided targeting high quality low cost monolithic LED drivers, have been included in this specification.

For a fair appreciation of the value, importance and/or immediate need of each improvement or novel system presented herein, each embodiment will be fully described and presented, comparatively, in accordance with the same 14 key factors mentioned above, with a very similar high quality LED driver solution, published in Datasheets, Application Notes or technical Magazines by companies having very good reputation in the worldwide power management industry, such as: Texas Instruments, Fairchiid, Power Integrations, Maxim, Seoul Semiconductor, Linear Technology, Intersil, Exciara, Supertex, and others.

9. Related Art - SMPS LED Drivers

9.1 Double Stage Off-line Boost-Flyback Isolated SMPS - TI

A double stage off-line boost-flyback circuit example, suitable to the context of the present specification, is revealed in the Texas Instruments *(TI)* publication *"SLUU341B"* entitled *"PR883: A300-W, Universal Input, Isolated PFC Power Supply for LCD TV Applications",* published in December 2008, capable of providing a constant output voltage of 24 V for loads up to 12 A at high performance complying with the power quality meeting the Energy Star requirements and the IEC standards. It achieves state of the art double stage circuit control methods including, as a first stage, a boost pre-regulator securing a near unity power factor in an off-line (85-265Vrms) range of input voltage and, as second stage, an LLC resonant DC-DC isolated flyback converter. The control system design requires five integrated circuits, such as the *UCC28061* for the first stage, the *UCC25600* as well as two opto-couplers *H11AV1A-M* using the *TL431AIDBV* voltage reference for the second stage, and the *UCC2813D-4* for an extra flyback converter, providing bias supplies to the entire system.

The most significant data of the SMPS circuit described above, collected from Table 1 (page 2) and Table 4 (pages 19, 20, 31) of the above-referenced TI publication are provided in the parts and performance chart shown below.

The SMPS circuit's performances specifications collected from Table 1 (page 2) and the components amount of each category, collected from Table 4 (pages 19, 20, 31) of the above-referenced TI publication, are summarized in Table 1, below.

Table 1: Double Stage Off Line Isolated Boost-Flyback Driver – Texas Instruments						
1	Parts Count (expensive)	136	*(32)*	8.	Efficiency (typ.)	87%
2	Integrated Circuits - (*opto-couplers)*	5	*(2)*	9	Power Factor (typ.)	0.95
3	Transistors - (*FETs)*	8	*(5)*	10	A.THD (typ.)	<10%
4	Diodes – (bridge & *fast*	14	*(9)*	11	LED Stripes CCS	1

	recovery)					
5	Capacitors - (electrolytic)	50	*(11)*	12	Board Size	VL
6	Inductors - *(Transformers)*	3	*(3)*	13	Cost (total)	VH
7	Resistors - *(high power)*	56	*(2)*	14	Lifetime *(years)*	3

The main advantage of this double stage SMPS circuit consist in the fact that provides I/O circuits isolation and the first stage (boost) converts the unregulated AC input voltage into a regulated (390V) DC voltage, so the second stage (flyback) will always have sufficiently high supply voltage amount for delivering to its load a precisely regulated DC voltage having very small ripples.

The main shortcomings of this circuit are:

a. Too many parts count.

b. Too many and expensive integrate circuits.

c. Too many expensive UIF diodes.

d. Too many bulky and unreliable electrolytic capacitors.

e. Too many bulky, unreliable and expensive inductors.

f. Very Large size of the driver board which does not allow its use in small size devices.

g. Very high cost solution, incompatible to the excepted cost of LED lamp retrofits operating in small and medium power range.

In contrast, the various embodiments disclosed provide several solutions to solve all the above mentioned inconveniences, including a novel double stage system embodiment and four "pseudo double stage" system embodiments capable to reach similar performances
(Eff > 87%, PF > 0.99%, A.THD < 10%) while reducing the parts count, size and cost in a ratio of 40-60% with respect to this particularly LED driver solution.

9.2 Double Stage SEPIC/Buck LED Driver - Suoertex

A double stage SEPIC/buck LED Driver circuit example, suitable to the context of the disclosed embodiments, is shown in the Supertex, Inc. *"HV9931DB2v1"* chip presentation folder regarding a *"LED Driver Demo Board Input 230VAC // Output 350mA, 40V"* capable of providing a constant output voltage up to 40V to a 14W load at very good performance. It achieves decent quality double stage circuit control methods including, as a first stage, a buck-boost (SEPIC) pre-regulator securing a near unity power factor in a range of 200-265Vrms input voltage and, as second stage, a non isolated pack current limited Constant Off Time (COT) buck converter operating in a continuous conduction mode (CCM). The control system design requires only one MOSFET transistor and controller IC, the *HV9931LG* for both, first and second stages, having up 30% inductor current ripple.

The most significant data of the LED driver circuit described above, collected from the *HV9931LG* chip presentation folders are provided in the parts and performance chart shown below in Table 2.

Table 2: Double Stage Non-Isolated Off Line SEPIC/Buck LED Driver – Supertex						
1	Parts Count	63	*(9)*	8	*Efficiency (typ.)*	87%
2	Integrated Circuits - (*opto-couplers)*	1	*(0)*	9	Power Factor (typ.)	0.95
3	Transistors - (*FETs)*	5	*(1)*	10	A.THD (typ.)	<10%
4	Diodes – (bridge & *fast recovery)*	13	*(6)*	11	LED Stripes CCS	1
5	Capacitors – (electrolytic)	15	*(0)*	12	Board Size	M
6	Inductors - *(Transformers)*	4	*(0)*	13	Cost (total)	M
7	Resistors - *(high power)*	25	*(2)*	14	Lifetime *(years)*	3

The main advantages of this particular converter circuit is that it uses only one MOSFET transistor and one integrated circuit to control both stages, does not use electrolytic capacitors and eliminates the need for opto-couplers or differential sensing voltage amplifiers by using the SEPIC buck-boost configuration which allows the controller IC to sense the LEDs current with respect to a common ground.

The main shortcomings of this circuit are:

a) No Isolation between the input and the output circuits.

b) Too many parts count.

c) Too many and bulky coils

d) Too many and expensive UIF diodes.

e) High current ripples of the inductor.

f) Medium size of driver board which does not allow its use in very small size LED lamp retrofits.

g) Relatively high cost for small range power retrofits.

h) The SEPIC capacitor (E31) is bulky, expensive and it may lead to instability, in time, at high frequency AC current, shortening the retrofit's lifespan.

The present specification provides several embodiments to overcome

the above mentioned shortcomings, including a novel double stage system embodiment and four "pseudo double stage" system embodiments capable to reach similar performances
(Eff > 87%, PF > 0.99%, A.THD < 10%) while reducing the parts count, size and cost in a ratio of 25-30% with respect to this particularly LED driver solution.

9.3 Boost Single Stage Off Line LED Driver - Intersil

A boost single stage LED Driver circuit example, suitable to the context of the present specification, is illustrated and described in the Intersil application note *AN1387.0* entitled *"White LED Driver Circuits for Off-Line Applications using Standard PWM Controllers",* published on February 12, 2009 for the use of its proprietary *ISL6445IAZ-TK* integrated circuit (IC), which is a capable of operating in three different topologies, such as Single Stage Boost, Single Stage (SEPIC) Buck-boost and Single Stage Flyback LED driver circuits. This single stage boost LED driver application illustrated in Fig. 12 of the above-reference Intefrsil publication. *Detailed Boost Converter Schematic* (page 11), of the publication, is a very conventional one, using the *ISL6445IAZ-TK* chip as a PWM/PFC controller and a second dual operational amplifier *LM358* (Texas Instruments) chip for controlling, differentially, the voltage and current across the LEDs, with respect to a high precision micro-power shunt voltage reference chip *LM4041* (Texas Instruments). The circuit is capable of reaching near unity power factor, operating in critical conduction mode (CrCM) and delivering an output voltage of 250Vdc, when is supplied at 90-120Vac (Japan and USA), being designed for high power LED panels using over 50 LEDs per one stripe, and it requires an additional operational amplifier for securing the constant current of each additional LED stripe.

The most significant data of the LED driver circuit described above collected from the ISL6445IAZ-TK chip presentation folders are summarized in Table 3 below.

Table 3: Boost Single Stage Off Line LED Driver – Intersil

1	Parts Count (expensive)	42	*(11)*	8	Efficiency (typ.)	90%
2	Integrated Circuits - (*opto-couplers)*	3	*(0)*	9	Power Factor (typ.)	>0.9
3	Transistors - (*FETs)*	2	*(1)*	10	A.THD (typ.)	<20%
4	Diodes – (bridge & *fast recovery)*	13	*(6)*	11	LED Stripes CCS	1

5	Capacitors - (electrolytic)	11	*(3)*	12	Board Size	M
6	Inductors - *(Transformers)*	2	*(0)*	13	Cost (total)	L
7	Resistors - *(high power)*	19	*(1)*	14	Lifetime *(years)*	3

The main advantage of this particular single stage boost converter circuit is the higher efficiency it provides over all the other topologies, very important feature in high power application.

The main shortcomings of this circuit are:

a) No I/O circuits isolation.

b) Too many parts for a single stage boost converter.

b) Three integrated circuits instead of one.

c) The ISL6445IAZ-TK chip supply circuit is too large and expensive, consisting in a high voltage series regulator, including a high voltage (350V) transistor, a zener diode, and four resistors.

d) Requires unreliable electrolytic capacitors.

e) CCS for only one LED stripe.

f) Minimum 50 LEDs per stripe, at 120Vac supply.

Various embodiments according to the present specification provide several solutions to solve all the above mentioned inconveniences, including a novel boost single stage system embodiment capable to reach better performances (Eff > 93%, PF > 0.99%, A.THD < 10%) while reducing the parts count, size and cost in a ratio of 15-20% with respect to this particularly LED driver solution.

9.4 Buck-boost S. Stage LED Driver - Supertex vs. UTC

A Buck-boost single stage low cost LED Driver circuit example, suitable to the context of the present specification, is shown in the Supertex, Inc. *"HV9921"* chip presentation folder regarding its minimum parts *"3-Pin Switch-Mode LED Driver IC"* capable of providing a constant output current of 20mA to LED stripe despite an extremely large (85-264Vrms) variation of the AC supply voltage. This was the most simple and low cost DC/DC LED driver, however, because it uses the COT (constant off time variable frequency) mode of operation, in AC/DC applications it has serious problems with the PF and A.THD parameters. For solving the PF and A.THD issues in the AC applications of the *HV9921* chip, Supertex has recommended the use of a low cost passive PFC solution, consisting in a precisely calculated LC filter (one coil two capacitors) and eventually, Supertex has introduced its upgraded chip *HV9931LG,* described above, which was able to provide near unity power factor (PF=0.98) in a double stage topology.

The Chinese designers have followed up, shortly, this very low cost solution, advertising similar solution using the capabilities of a new generation of affordable eight pin COT driver chips, including the *QX9910,* provided by QXMD and the *UCT4390,* provided by UCT.

The variable frequency-constant of time single stage buck-boost LED driver circuit advertised by UCT in the *UCT4390* chip's datasheets features reasonable performance in AC applications by using a conventional "valley fill filter" passive PFC circuit, consisting of two capacitors coupled in series across the output of the supply rectifier bridge, having a first rectifier diode coupled between them and two extra rectifier diodes, coupled from the anode and the cathode of the first rectifier diode to the positive and the negative outputs of the bridge rectifier, in such a manner for the capacitors to have a series charging circuit and a parallel discharging circuit. Since the equivalent capacitance of two equal valued capacitors coupled in series is half of each capacitor and in parallel circuit is double of each capacitor, the power factor is significantly improved (typically 0.85-0.9), especially if additional low pass (or EMI) filters, consisting of one double coil and two capacitors, are included into the AC supply circuit.

The most significant data of the LED driver circuit described above, collected from the *UTC4390* chip presentation folders are summarized in Table 4 below.

Table 4: Buck-boost Single Stage Off-line Low Cost LED Driver – UTC						
1	Parts Count	32	*10*	8.	Efficiency (typ.)	80%
2	Integrated Circuits - (*opto-couplers)*	1	*(0)*	9	Power Factor (typ.)	0.85
3	Transistors - (*FETs)*	2	*(2)*	10	A.THD (typ.)	<30%
4	Diodes – (bridge & *fast recovery)*	11	*(1)*	11	LED Stripes CCS	1
5	Capacitors – (electrolytic)	10	*(5)*	12	Board Size	M
6	Inductors - *(Transformers)*	2	*(1)*	13	Cost (total)	L
7	Resistors - *(high power)*	6	*(2)*	14	Lifetime *(years)*	2

The main advantages of this particular constant off time LED driver circuit are: low component count, medium size board and low total manufacturing cost, fact which made China the # 1 provider of fluorescent LED lamps retrofits in the entire

South Asia's market and a major competitor in the worldwide market.

The main shortcomings of this circuit are:

a) Short lifetime because of the electrolytic capacitors.
b) No Isolation between the input and the output circuits.
c) Too many bulky and unreliable electrolytic capacitors.
d) The need for 2-3 EMI filters for reaching PF=0.9.
e) No voltage control over the LED stripe.
f) Supplies the IC controller via a second FET transistor.
g) Bulky coils and capacitors increase the board size.
h) Relatively low performance versus other solutions.

The present specification provides several embodiments to overcome the above mentioned shortcomings, including novel and lower cost COT LED driver circuit embodiments used with valley fill filters and/or used as second stage DC/DC converters in low cost high power factor (PF=0.99) double stage LED lamp retrofit driver circuit embodiments.

9.6 Buck-boost Single Stage LED Driver - PI

A buck-boost single stage LED driver circuit example, suitable to the context of the present specification, is shown in the Power Integrations *(PI) "Constant Current <2% Regulation) Non-Isolated Buck-Boost, Power Factor Corrected 18 W LED Driver Using LinkSwitch -PH LNK419EG"* design example report of Dec. 8, 201 1.

This driver circuit is capable to provide a 200V voltage and 90mA current +/- 30% ripple DC output in an AC supply range of 90-265V.

The LNK419EG controller chip includes the MOSFET buffer and is capable of limiting converter output current maintaining a near unity power factor and does not use opto-couplers and operational amplifiers for sensing the output current, but a 11 parts feedback circuit including a voltage shunt regulator chip *LMV431AIMF* a high voltage transistor *FMMT560,* 2 diodes, 5 resistors and 2 capacitors

The most significant data of the LED driver circuit described above, collected from the LNK419EG chip presentation folders are summarized in Table 5 below.

Table 5: Buck-boost Single Stage Off-line LED Driver - Power Integrations

1	Parts Count (expensive)	37	*(7)*	8.	Efficiency (typ.)	89%
2	Integrated Circuits - (*opto-couplers)*	1	*(0)*	9	Power Factor (typ.)	>0.92
3	Transistors - (*FETs)*	1	*(0)*	10	A.THD (typ.)	<30%
4	Diodes – (bridge & *fast recovery)*	7	*(4)*	11	LED Stripes CCS	1
5	Capacitors – (electrolytic)	10	*(2)*	12	Board Size	S
6	Inductors - *(Transformers)*	3	*(0)*	13	Cost (total)	L
7	Resistors - *(high power)*	15	*(1)*	14	Lifetime *(years)*	3

The main advantages of this particular buck-boost converter circuit are: the controller chip *LNK419EG* includes the large and expensive MOSFET buffer, is capable to control the output current while keeping the power factor near unity and does not use expensive opto-couplers and operational amplifiers for current feedback but lower cost passive parts and a bipolar transistor.

The main shortcomings of this circuit are:

a) No Isolation between the input and the output circuits.

b) The current feedback requires too many parts (11).

c) Transistors are instable with variation of temperature.

d) High current ripples of the output current (30%).

e) Too many and expensive UIF diodes.

f) Relatively high cost for small range power retrofits.

The present specification provides several embodiments to overcome the above mentioned shortcomings, including a single stage single ground buck-boost system embodiment capable of reaching better performances (Eff > 88%, PF > 0.99%, A.THD < 10%) while reducing the parts count, size and cost in a ratio of 20-35% with respect to this particularly LED driver solution.

9.3 Flyback S. Stage Non-Isolated Led Driver - Intersil

A flyback single stage LED Driver circuit example, suitable to the context of the present specification, is illustrated and described in the Intersil application note *AN1387.0* entitled *"White LED Driver Circuits for Off-Line Applications using Standard PWM Controllers",* published on February 12, 2009 for the use of its proprietary *ISL6445IAZ- TK* integrated circuit (IC), which is a capable to operate in three different topologies, such as Single Stage Boost, Single Stage (SEPIC) Buck-boost and Single Stage Flyback LED driver circuits. This single stage non-isolated flyback LED driver application illustrated in Fig. 14 of the above-referenced Intersil paublication. *"Detailed Flyback Converter Schematic"* (page 13) is a very conventional one, using the same components as the Intersil boost converter described above, respectively the *ISL6445IAZ-TK* chip as a PWM/PFC controller and a dual operational amplifier *LM358* chip for controlling, differentially, the voltage and current across the LEDs, with respect to a high precision micro-power shunt voltage reference chip *LM4041.* The main differences with respect to the boost circuit consists of the fact that the flyback inductor is a two coils transformer and therefore, a three parts conventional snubber circuit, consisting of one diode, one resistor and one capacitor, has been added in the drain circuit of the MOSFET buffer (Q1), for high voltage limitation.

The circuit is capable of reaching near unity power factor, operating in critical conduction mode (CrCM) and delivering an output voltage, usually, lower than the input AC voltage (90-260Vac) having the capably to supply one stripe of one or more LEDs connected in series and requiring an additional operational amplifier for securing the constant current of each additional LED stripe.

The most significant data of the flyback LED driver circuit described above, collected from the *ISL6445IAZ-TK* chip presentation folders is summarized in Table 6 below.

Table 6: Flyback Single Stage Off-line Non-Isolated LED Driver – Intersil						
1	Parts Count (expensive)	53	*(13)*	8.	Efficiency (typ.)	80%
2	Integrated Circuits - (*opto-couplers)*	3	*(0)*	9	Power Factor (typ.)	>0.9
3	Transistors - (*FETs)*	2	*(1)*	10	A.THD (typ.)	<20%
4	Diodes – (bridge & *fast recovery)*	14	*(7)*	11	LED Stripes CCS	1
5	Capacitors – (electrolytic)	12	*(3)*	12	Board Size	M
6	Inductors - *(Transformers)*	2	*(1)*	13	Cost (total)	M
7	Resistors - *(high power)*	20	*(1)*	14	Lifetime *(years)*	3

The main advantage of this particular single stage non-isolated flyback converter circuit consists of its very safe and accurate control of the LED current and voltage, via the two operational amplifiers included in the *LM358* and the precise reference provided by the *LM4041* voltage shunt regulator, despite large variations of the ambient temperature.

The main shortcomings of this circuit are:

a) No I/O circuits isolation.

b) Too many parts for a single stage boost converter.

b) Three integrated circuits instead of one.

c) Too many parts (6) used for the controller chip supply.

d) Requires bulky and unreliable electrolytic capacitors.

e) CCS for only one LED stripe.

f) Higher cost than other similar topology solutions.

The present specification provides several embodiments to overcome the above mentioned shortcomings, including a novel non-isolated and isolated single stage LED driver system embodiment, capable of reaching better performances (Eff > 88%, PF > 0.99%, A.THD < 10%) while reducing component count, size and cost in a ratio of 30-50% with respect to this particularly *LM4041* LED driver solution.

9.7 Flyback Single Stage Isolated LED Driver - Fairchild

A flyback single stage isolated LED driver circuit example, suitable to the context of the present specification, is shown in the Fairchild application note AN-9737 entitled *"Design Guide for Single-Stage Flyback AC-DC Converter Using FL6961 for LED Lighting"* presenting a 16.8W power factor corrected LED driver, delivering an output of 24V/0.7A and featuring soft-starting and CVCC feedback for a very accurate (cycle-by-cycle) and reliable control of the LED stripe's V/I parameters.

The *FL6961* controller chip operates in constant on-time (variable off time) and CrCM (critical conduction mode, at the boundary between the discontinuous and continuous mode of operation) for securing a good power factor while controlling also the LEDs maximum voltage and current. The *FL6961* chip supply voltage is obtained via an additional winding added to the flyback transformer and the output voltage/current feedback is conventional, using the *KA358* dual error amplifier, the *KA431* voltage shunt regulator as reference and the *FOD81 7* opto-coupler, for securing the input/output circuits isolation.

The most significant data of the LED driver circuit described above, collected from the *LNK419EG* chip presentation folders is summarized in Table 7 below.

Table 7: Flyback Single Stage Off-line Isolated LED Driver - Fairchild						
1	Parts Count (expensive)	47	*(17)*	8.	Efficiency (typ.)	82%

2	Integrated Circuits - (*opto-couplers)*	4	*(1)*	9	Power Factor (typ.)	>0.9
3	Transistors - (*FETs)*	1	*(1)*	10	A.THD (typ.)	<20%
4	Diodes – (bridge & *fast recovery)*	9	*(4)*	11	LED Stripes CCS	1
5	Capacitors – (electrolytic)	13	*(3)*	12	Board Size	S
6	Inductors - *(Transformers)*	4	*(1)*	13	Cost (total)	M
7	Resistors - *(high power)*	16	*(7)*	14	Lifetime *(years)*	3

The main advantages of this particular flyback converter circuit are: uses only one chip to control the output current and voltage while keeping the power factor near unity, uses precise and reliable voltage shunt regulator and operational amplifiers for voltage and current feedback and uses opto-coupler for securing the input/output circuits isolation.

The main shortcomings of this circuit are:

a) Many parts count.

b) Expensive V/I feedback circuit.

c) Higher cost than other isolated flyback solutions.

d) CCS for only one LED stripe.

e) Larger Vout ripples than double stage solutions.

The present specification provides several embodiments to solve the above mentioned shortcomings including single stage isolated flyback and double stage multi-columns LED driver system embodiments capable of reaching better performance (Eff > 85%, PF > 0.99%, A.THD < 10%) while reducing component count, size and cost in a ratio of 20-35% with respect to this particularly LED driver solution.

9.8 Flyback Single Stage Isolated LED Driver - PI

A flyback single stage isolated LED driver circuit example, suitable to the context of the present specification, is shown in the Power Integrations *(PI)* RDR-193 application entitled *"Reference Design Reports for s High Efficiency (>81%), High Power Factor (>0.9) TRIAC Dimmable 7W LED Driver Using LinkSwitch -PH LNK403EG"* presenting a 7W power factor corrected LED driver, delivering an output of 21V/0.33A in a supply range of 90-265VAC.

The *LNK403EG* controller chip operates in CCM (continuous conduction mode of operations) and the output current regulation is sensed entirely from the primary side of the flyback transformer eliminating the need of the expensive opto-coupler, operational amplifier and voltage shunt regulator connected, usually, in the flyback secondary side.

The most significant data of the LED driver circuit described above collected from the LNK403EG chip presentation folders is summarized in Table 8 below.

Table 8: Flyback Single Stage Off-line Isolated LED Driver - Power Integrations						
1	Parts Count (expensive)	50	*(13)*	8.	Efficiency (typ.)	81%
2	Integrated Circuits - (*opto-couplers)*	1	*(0)*	9	Power Factor (typ.)	>0.9
3	Transistors - (*FETs)*	3	*(1)*	10	A.THD (typ.)	<20%
4	Diodes – (bridge & *fast recovery)*	12	*(5)*	11	LED Stripes CCS	1
5	Capacitors – (electrolytic)	12	*(5)*	12	Board Size	S
6	Inductors - *(Transformers)*	3	*(1)*	13	Cost (total)	M
7	Resistors - *(high power)*	19	*(1)*	14	Lifetime *(years)*	3

The main advantages of this particular flyback converter circuit are: uses only one chip to control the output current and voltage while keeping the power factor near unity, the MOSFET buffer is included in the controller chip and senses the LEDs current from the primary section of the flyback transformer for securing the input/output circuits isolation and eliminating the need for the expensive conventional current feedback circuit.

The main shortcomings of this circuit are:

a) Many parts count.

b) Too many (5) electrolytic capacitors.

c) Requires an ultra fast diode in the buffer circuit.

d) Higher cost than other isolated flyback solutions.

e) Relatively low Eff and PF for high cost.

f) CCS for only one LED stripe.

g) Larger Vout ripples than double stage solutions.

The present specification provides several embodiments to solve the above mentioned shortcomings, including a single stage isolated flyback and a double stage multi-columns LED driver system embodiments capable to reach better performances (Eff > 88%, PF > 0.99%, A.THD < 10%) while reducing the parts count, size and cost in a ratio of 20-25% with respect to this particularly LED driver solution.

9.9 Flyback Single Stage Isolated LED Driver - LT

A flyback single stage isolated LED driver circuit example, suitable to the context of the present specification, is shown in the Linear Technology *(LT)* demo manual *DC1744A* entitled *"LT3799 Offline Isolate Flyback LED Driver with PFC"* presenting a power factor corrected LED driver capable to deliver 4-1 00W to an LED display in a supply range of 90-265VAC.

The *LT3799* controller chip operates in critical conduction mode (CrCM, at the boundary between the discontinuous and continuous mode of operation, similar to the Fairchild's *FL6961,* presented above) for securing a good power factor while controlling also the output current regulation (similar to the Pi's *LNK403EG)* entirely from the primary side of the flyback transformer eliminating the need of the expensive opto-coupler, operational amplifier and voltage shunt regulator connected, usually, in the flyback secondary side.

The most significant data of the LED driver circuit described above, collected from the *LT3799* chip presentation folders is summarized in Table 9 below.

Table 9: Flyback Single Stage Off-line Isolated LED Driver - Linear Technology						
1	Parts Count (expensive)	41	*(9)*	8.	Efficiency (typ.)	>80%
2	Integrated Circuits - (*opto-couplers)*	1	*(0)*	9	Power Factor (typ.)	>0.9
3	Transistors - (*FETs)*	1	*(1)*	10	A.THD (typ.)	<20%
4	Diodes – (bridge & *fast recovery)*	6	*(5)*	11	LED Stripes CCS	1
5	Capacitors – (electrolytic)	11	*(1)*	12	Board Size	S
6	Inductors - *(Transformers)*	4	*(1)*	13	Cost (total)	VH
7	Resistors - *(high power)*	18	*(1)*	14	Lifetime *(years)*	3

The main advantages of this particular flyback converter circuit are: uses only one chip to control the output current and voltage while keeping the power factor near unity and senses the LEDs current from the primary section of the flyback transformer, eliminating the need for the expensive conventional error amplifier feedback circuit and opto-coupler for securing the I/O circuits isolation, using only one electrolytic capacitor.

The main shortcomings of this circuit are:

a) LT's driver solutions and parts are very expensive.

b) Relatively low Eff and PF for very high cost.

c) CCS for only one LED stripe.

d) Larger Vout ripples than double stage solutions.

The present specification provides several embodiments to solve the above mentioned shortcomings, including a single stage isolated flyback and a double stage multi-columns LED driver system embodiments capable to reach better performances (Eff > 88%, PF > 0.99%, A.THD < 10%) while reducing component count, size and cost in a ratio of 20-25% with respect to this particularly LED driver solution.

10. Related Art - Monolithic LED Drivers

10.1 Low Dissipation Controllable Electron Valve

A patent entitled *"Low Dissipation Electron Valve For Controlling Energy Delivered To A Load And Method Therefore"* was issued on *Jan. 28, 1997,* as *US Pat. No. 5,598,093,* where the inventor, Beniamin Acatrinei (author of the present specification) has revealed a new and original way of controlling the transfer of the electrical energy from an AC generator to a load by using the capabilities of a novel and extremely versatile "electron valve" called the "Benistor", name coming from its "Blockade of Electrical Network" capability leading to an original "SSCVCC" (self-switching constant voltage constant current) mode of operation.

Unlike the previously invented solid state electron valves, such as the "transistor" and "thyristor" (SCR - Silicon Control Rectifier), the Benistor is able to control a high power rectified AC sine wave and deliver a suitable electrical supply to any kind of loads (including LEDs) in linear, switching and/or SSCVCC operations manner, without requiring an external driver circuit (similar to the transistor) and also, without dissipating significant energy internally (similar to the thyristor).

By using this original SSCVCC mode of operation, the Benistor eliminates the needs for coils and capacitors used in most conventional AC/DC or DC/DC converters and, in circuits where it is coupled, directly, between a bridge rectifier ("BR") and a load, the Benistor delivers to its load a continuous (by switching ON) or interrupted (by switching OFF) DC supply, in such a manner as to always keep the voltage across the load within pre-established limits, despite large variations of its input supply (BR's output) voltage.

The Benistor can operate in a linear manner, as well, for keeping the load current within pre-established limits, although this mode of operation is not as efficient as the self-switching one.

For being able to perform this complex SSCVCC mode of operations, the "conventional" Benistor relies on seven in/out terminals, such as:

a) a "Vin" (voltage input) input power terminal coupled to the BR's positive output,

b) a "CE" (common electrode) terminal coupled to the BR's negative output (or ground, "GND"),

c) a "Vout" (voltage output) output power terminal coupled across the load, jointly with the CE terminal,

d) an "ON-OFF" voltage control input terminal which turns ON an internal switch between Vin and Vout when Vin<Von-off and turns OFF the internal switch between Vin and Vout when Vin>Von-off

e) an "OFF-ON" voltage control input terminal which does the same self-switching job but in opposite phase with respect to the ON-OFF input terminal.

f) a "CC+" voltage control input terminal operating "in positive phase" with the output, respectively the current delivered by Vout increases when the amount of the voltage applied a the CC+ terminal increases, and

g) a "CC-" terminal which operates opposite than CC+.

This extremely versatile device has its own electrical symbol, similar to a vacuum tube and multi-terminal transistor devices, and does not require external components but only fixed or variable DC voltage applied to its terminals, for operating like a transistor, thyristor, operational amplifier, window comparator, CCS (constant current sink), VCS (voltage controlled switch), and of course, similar to the conventional complex transistors circuits, "Benistors complex circuits" could be achieved, where two or more Benistors could be connected in very many configurations, such as: series, parallel, mirror, totem pole, push-pull, etc.

Despite the fact that the Benistor's internal block schematic circuit appears sophisticated, especially because of its seven terminals, minimum parts Benistors may have as few as three terminals (like a transistor) and internally, only a two transistors circuit, looking similar to the conventional thyristor's equivalent circuit (i.e., NPN and PNP transistors coupled mutually, base-collector) with one difference being the base of the NPN transistor is "in air" (not connected) for allowing many other ways to connect the two transistors with the external circuit and of course, to make available many additional applications.

Because of its amazing simplicity and versatility, on July 6, 1998 the Benistor achieved the "Cover Feature Story" award of Electronic Design Magazine, a very good reputation technical publication, where the Benistor was called "The Fourth Element", which appeared in the worldwide electronic industry after the only three other "electron valves" created over the last one hundred years, such as the vacuum tube, the transistor, and the thyristor.

Unfortunately, at that time there were no "Ultra Bright White LED" and no "LED Lamp Retrofits" applications where the Benistor could confirm its special capabilities.

Therefore, in accordance with the present specification, several embodiments are provided that employ the Benistor's concept for achieving low cost, small size, no coils or capacitors and, eventually, no external parts monolithic LED driver, the "chip" which could be the main component of future "ideal" LED lamp retrofit devices.

<u>10.2 System For Providing AC Line Power To Lighting Devices - Exclara</u>

A patent application entitled *"Apparatus, Method And System For Providing AC Line Power To Lighting Devices"* has been published on *Dec. 9, 2010,* as the *US Patent Application Publication No. 2010/0308739 A1* (Inventors: Shteynberg et.al., Assignee: *Exclara, Inc.)* revealing several LED driver converter circuits comprising no reactive components, but only solid state components such as transistors and resistors, parts which can be integrated into a "driver chip", eventually.

Exclara, Inc. is one of the active "pioneers" in the LED lighting industry which devoted a significant part of its product development course for eliminating completely the unreliable, bulky and expensive reactive components, such as coils and capacitors, targeting a "monolithic LED driver" device which could be executed fast and cost effectively in a silicon foundry, for reducing the size and cost of the LED lamp retrofits and, more importantly, to increase the maximum lifetime of these efficient devices, since the solid state devices feature a "virtually unlimited lifetime", while the electrolytic capacitors "get dry", and compromise the lifespan of the entire LED lamp in just about 2 years of use, at 24 hours per day.

The embodiments presented in the above mentioned patent application publication, show a solid state "Controller" circuit features a relatively complex block schematic diagram, comprising a "Digital Logic Circuit" which activates or deactivates several "Switch Driver" devices which, external to the main Controller circuit, connect or disconnect several LED stripes included in a rectified AC supply circuit, in specific sequences determined by several other sub-circuits, such as: A/D Converters, Sync Signal Generator, Vcc Generator, Over Voltage Detector, Under voltage detector, Power On Reset, Memory and a Clock sub-circuit which establish the sequences timing, respectively the precise time when each Switch Driver connects or disconnects its designated LED stripe.

Each Switch Driver is equipped with a power MOSFET transistor, controlled in the gate by a fast driver including a comparator followed by a push-pull buffer, in order to increase the commutation speed and, implicitly, to decrease the On-Off transit time dissipation of each Switch Driver's power MOSFET transistor.

Eventually, by means of several voltage and current sensors input compared with internal voltage references and/or the logic data existing in the Memory sub-circuit, following a set of instructions shown in Fig. 22 of the above mentioned patent application publication, the Controller circuit connects, progressively, the LED stripes in such a manner, that when the amount of the voltage delivered by the bridge rectifies reaches its peak value (i.e., 170V for 120Vrms line used in USA), all LED stripes are to be connected in series, when the AC supply voltage reaches its half value, only half of the LED stripes are to be connected and, finally, when the AC supply voltage decays down to 20-30V, then only one LED stripe is to be connected to the power line.

In this way, the controller is able to limit the LED current in 4 or more steps, so the current shape of the LED lamp retrofit device will appear like a "pyramid", of 4 or more "square waves" positioned one on top of the other, based on how many Switch Drivers have a specific controller chip, and because the LEDs current increases proportionally with the AC supply voltage amount, the driver can reach a power factor parameter of over 0.9, in accordance to the Department of Energy and Energy Star's latest directives.

The first LED driver chip, *"EXC100"* introduced in the market by Exclara is presented by a LED lamp retrofit manufacturer, Everlight (www.everliqht.com) under the title "Everlight HV LEDs Driving Note" which provides the schematic diagram, electrical specs and the device's current versus voltage shape, showing that only three LED stripes are used, for retrofits operating in the 4-10W power range.

The most significant data collected from Everlight's web site regarding Exclara's monolithic LED driver chip, the EXC100, is summarized in Table 10 below.

Table 10: System For Providing AC Line Power To Lighting Devices - Exclara						
1	Parts Count (expensive)	10	*(0)*	8.	Efficiency (typ.)	85%
2	Integrated Circuits - (*opto-couplers)*	1	*(0)*	9	Power Factor (typ.)	0.95
3	Transistors - (*FETs)*	0	*(0)*	10	A.THD (typ.)	<20%
4	Diodes – (bridge & *fast recovery)*	0	*(0)*	11	LED Stripes CCS	4
5	Capacitors – (electrolytic)	0	*(0)*	12	Board Size	VS
6	Inductors - *(Transformers)*	0	*(0)*	13	Cost (total)	VL
7	Resistors - *(high power)*	9	*(0)*	14	Lifetime *(years)*	5+

The main advantages of this particular monolithic LED driver circuit are: high performance, less parts count (10), very low size, very low cost and over 5 years lifetime.

As a brief comparison with the conventional SMPS driver solutions, the EXC100 chip's cost is $1.39/unit and the LT3799 cost is $2.70/unit, a chip which requires 40 additional parts and labor for its driver board and eventually, the LED lamp retrofit using the EXC100 has good chances to operate 2-3 years longer than the other.

The main shortcomings of this circuit are:

a) Very sophisticated internal architecture of the chip.

b) Up to 40 pin package, because of many A/D grounds.

c) Nine external resistors.

d) Square wave instead of sine wave current shape.

e) Very sophisticated design implementation calculations.

f) Visible flicker at low power and when dimmer are used.

The present specification provides several embodiments to solve the above mentioned shortcomings, including several monolithic LED driver system embodiments capable to reach higher performances (Eff = 93%, PF = 0.996%, A.THD = 6%) while reducing the parts count down to only "one part", respectively a lower size chip featuring only 8 pin package, extremely simple internal architecture and lower manufacturing cost in comparison to this particularly monolithic LED driver solution.

10.2 Linear LED Driver For Fluorescent Lighting Retrofits

A News Release presentation document entitled *"New Sequential, Linear LED Drivers From Supertex Ideal For Fluorescent Tube Lighting Retrofits"* has been published on *April 3, 2012* by Supertex, Inc., which is a recognized leader in high voltage analog and mixed integrated circuits (ICs), for introducing CL8800 and CL8801, sequential, linear LED drivers designed to drive long strings of low cost, low current LEDs in solid-state replacements for fluorescent tubes, incandescent bulbs and CFL bulbs. Both ICs minimize driver circuit component counts, requiring just four or six resistors and a diode bridge in addition to the IC.

The CL8800 has been designed for 230VAC input and the CL8801 for 120VAC input, and none of them requires coils or capacitors in the external circuit and, except for four additional components for transient protection, there is no need even for the typically used EMI filter since the two ICs do not use high frequency switching current techniques but only multi-stage linear regulators.

Several schematic diagrams exposed in the CL800 datasheets folder show that the Supertex new monolithic LED driver chip's pin-out configuration, functionality and LED stripe design calculations are almost identical to the Exclara's EXC100 controller chip, described above.

The most significant data collected from the Supertex *CL8800* chip's datasheets is summarized in Table 11 below:

Table 11: Linear LED Driver For Fluorescent Lighting Retrofits – Supertex						
1	Parts Count (expensive)	7	*(0)*	8.	Efficiency (typ.)	90%
2	Integrated Circuits - (*opto-couplers)*	1	*(0)*	9	Power Factor (typ.)	>0.9
3	Transistors - (*FETs)*	0	*(0)*	10	A.THD (typ.)	<10%
4	Diodes – (bridge & *fast recovery)*	0	*(0)*	11	LED Stripes CCS	6
5	Capacitors – (electrolytic)	0	*(0)*	12	Board Size	VS
6	Inductors - *(Transformers)*	0	*(0)*	13	Cost (total)	VL
7	Resistors - *(high power)*	6	*(0)*	14	Lifetime *(years)*	5+

The performance shown in Table 11 looks a bit better than Exclara's shown in Table 10, and the cost/unit is higher ($2.38). However, since no patent application of Supertex Inc. has been published yet, and externally, the CL8800 circuit looks almost identical to the EXC100 circuit, the advantages and shortcomings related to this new monolithic LED driver solution are, more likely, very similar to ones presented above, for the Exclara EXC100 controller chip.

11. Conclusions

At this time, there are already hundreds of different LED Lamp retrofits available on the worldwide market for replacing all conventional incandescent, halogen, fluorescent, and sodium lamps. However, it will take some time until a few retrofit solutions will replace, rapidly the conventional lamps because of the cost versus quality and lifetime issues associated with these new devices.

Power management industry experts overwhelmingly agree that the LEDs are the "ideal light sources" of the future. However, similar to a "sodium lamp" which cannot provide "bright and efficient light" without "sodium", a LED lamp retrofit cannot provide "good quality light" without a LED driver, and, with respect to this device's quality versus cost matters, there are hundreds of different concepts, opinions, and solutions, provided by the worldwide power management industry experts.

On one hand, we have the US and European experts providing "high quality, high reliability, but high cost LED drivers" and, on the other hand, we have the South Asian experts providing "reasonable quality, less reliability, but very low cost LED drivers" and, therefore, the market does not have yet "the ideal device", which logically cannot be anything else but a "low cost, high performance, long lifetime LED lamp retrofit" apparatus which is, actually, the main subject of the present specification.

As presented above, the SMPS LED drivers and the Monolithic LED drivers have advantages but also many shortcomings, and, because of that, several embodiments referred to novel LED driver systems, whether or not they employ coils and capacitors, have been included in the present specification.

Therefore, an urgent need exists for low cost high quality LED lamp retrofits having fewer, smaller, or even no electrolytic capacitors, fewer, smaller, or even no coils, higher efficiency, higher power factor, low harmonic distortions, and lower total manufacturing cost, for replacing safely, shortly, and easily, all the existing obsolete conventional lamps, in such a manner for the end users to benefit of more light paying lower electricity bill, getting longer utilization time and lower total cost associated to each LED lamp retrofit, purchased.

SUMMARY

In one embodiment, a new LED Lamp Retrofit apparatus is provided, which via novel internal constant voltage constant current control and/or light display systems is capable of significantly increasing its operation time, featuring near unity power factor, low harmonic distortions, high efficiency, less parts, low size weigh and cost.

In another embodiment, a new LED Lamp Retrofit apparatus is provided, which is capable of replacing any conventional Incandescent Lamp, without any modifications to its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters.

In another embodiment, a new LED Lamp Retrofit apparatus is provided, which is capable of replacing any conventional Halogen Lamp, without any modifications to its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters.

In another embodiment, a new LED Lamp Retrofit apparatus is provided, which is capable of replacing any conventional Fluorescent Lamp, without any modifications of its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters.

In another embodiment, a new LED Lamp Retrofit apparatus is provided, which is capable of replacing any conventional Sodium Lamp, without any modifications to its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters.

In another embodiment, a new LED Lamp Retrofit apparatus is provided, which is capable of replacing any_conventional electrical lamp, without any modifications to its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters by using a novel Double Stage LED Driver circuit system, in order to reach the best performances in the medium and high power range.

In another embodiment, a new LED Lamp Retrofit apparatus is provide, which is capable of replacing any_conventional electrical lamp, without any modifications to its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters by using a novel Double Stage Boost-Flyback LED Driver circuit system, in order to reach the best performances in the medium and high power range, as well as the "Isolation" required by some end users.

In another embodiment, a new LED Lamp Retrofit device is provided, which is capable of replacing any conventional electrical lamp, without any modifications to its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters by using a novel Single Stage Boost LED Driver circuit system, in order to reach the best performances in the medium and high power range and reduce the parts count, size and cost/unit by not providing the "Isolation", if it is not required by some end users.

In another embodiment, a new LED Lamp Retrofit apparatus is provided, which is capable of replacing any_conventional electrical lamp, without any modifications to its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters by using a novel No Opto-Coupler Isolated Flyback LED Driver circuit system, in order to reduce the parts count, size and cost/unit and also to provide the "Isolation" required by some end users.

In another embodiment, a new LED Lamp Retrofit apparatus is provide, which is capable of replacing any_conventional electrical lamp, without any modifications ot its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters by using a novel Single Stage Single Ground Flyback LED Driver circuit system, in order to reduce the LEDs supply voltage, the parts count, size and cost/unit by not providing the "Isolation" if it is nor required by some end users.

In another embodiment, a new LED Lamp Retrofit apparatus is provide, which is capable of replacing any conventional electrical lamp, without any modifications of its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters by using a novel Single Stage Non Isolated Buck-Boost LED Driver circuit system, in order to reduce the LEDs supply voltage, the parts count, size and cost/unit.

In another embodiment, a new LED Lamp Retrofit apparatus is provided, which is capable of replacing any conventional electrical lamp, without any modifications of its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters by using a novel Pseudo Double Stage LED Driver circuit system, in order to reduce the LEDs supply voltage, the parts count, size and cost/unit.

In another embodiment, a new LED Lamp Retrofit apparatus is provided, which is capable of replacing any conventional electrical lamp, without any modifications to its standard electro-mechanical fixture, while providing longer operation lifetime and better light quality with respect to the Efficiency, Power Factor and Total Harmonic Distortions parameters by using a novel Monolithic LED Driver circuit system, in order to reduce, down to minimum the parts count(just one chip), the size and cost/unit, by eliminating the need for reactive components such as coils and capacitors, while the lamp's Power Factor and the Efficiency parameters are maintained at the "state of the art" level.

In accordance with the disclosed embodiments broadly described herein, a Near Unity Power Factor Long Life Low Cost LED Lamp Retrofit System And Method are provided, which generically include LED lamp retrofit components plus several other novel controlling systems that confer to the novel device the necessary capabilities to perform at the "state of the art" level, while featuring low component count, lower weight, size and cost.

In addition to the foregoing, various other method and/or system and/or program product aspects are set forth and described in the teachings such as text (e.g., claims and/or detailed description) and/or drawings of the present disclosure.

The foregoing is a summary and thus may contain simplifications, generalizations, inclusions, and/or omissions of detail; consequently, those skilled in the art will appreciate that the summary is illustrative only and is NOT intended to be in any way limiting. Other aspects, features, and advantages of the devices and/or processes and/or other subject matter described herein will become apparent in the teachings set forth herein.

In one or more various aspects, related systems include but are not limited to circuitry and/or programming for effecting herein-referenced method aspects; the circuitry and/or programming can be virtually any combination of hardware, software, and/or firmware configured to affect the herein-referenced method aspects depending upon the design choices of the system designer. In addition to the foregoing, various other method and/or system aspects are set forth and described in the teachings such as text (e.g., claims and/or detailed description) and/or drawings of the present disclosure.

The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

The disclosed embodiments provide the novel parts, constructions, arrangements, combinations and improvements herein shown and described. Novel features of the disclosed embodiments will become apparent from the following description when taken in combination with the accompanying drawings. It will be understood, however, that the drawings are for purposes of illustration and are not to be construed as defining the scope or limits of the claimed subject matter appended hereto.

Additional features of the disclosed embodiments will be set forth in the description that follows, and in part will be apparent from the description, or may be learned by practice or computer simulations of the circuits presented herein.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the claimed subject matter.

The accompanying drawings are included to provide a further understanding of the various embodiments of near unity power factor long life low cost led lamp retrofit system and method and are incorporated in and constitute a part of this specification. In addition, the accompanying drawings and illustrative embodiments together with the description, serve to explain the principles of the claimed subject matter.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 is a dimmable LED lamp retrofit for conventional incandescent lamps, according to one embodiment.

Fig. 2 is a dimmable LED lamp retrofit for conventional flood/halogen lamps, according to one embodiment.

Fig. 3 is a dimmable LED lamp retrofit for conventional fluorescent lamps, according to one embodiment.

Fig. 4 is a dimmable monolithic LED lamp retrofit, according to one embodiment.

Fig. 5 is a dimmable LED circuit system for rectangular LED panel showing six different LED connection configurations, according to various embodiments.

Fig. 6 is a dimmable LED circuit system for round (disc) LED panel showing twelve different LED connection configurations, according to various embodiments.

Fig. 7 is a dimmable LED array display showing nine different LED connection configurations, according to various embodiments.

Fig. 8 is a double stage boost - isolated flyback multi-columns LED driver, according to one embodiment.

Fig. 9 is a single stage boost multi-columns LED driver, according to one embodiment.

Fig. 10 is a no opto-coupler isolated flyback LED driver, according to one embodiment.

Fig. 11 is a single stage single ground flyback LED driver, according to one embodiment.

Fig. 12 is a single stage constant off time buck-boost LED driver, according to one embodiment.

Fig. 13 is a single stage single ground self-supply buck-boost LED driver, according to one embodiment.

Fig. 14 is a pseudo double stage boost-isolated flyback LED driver, according to one embodiment.

Fig. 15 is a pseudo double stage boost - non isolated flyback LED driver, according to one embodiment.

Fig. 16 is a pseudo double stage boost - COT buck-boost LED driver, according to one embodiment.

Fig. 17 is a pseudo double stage boost - SG buck-boost LED driver, according to one embodiment.

Fig. 18a is a monolithic LED driver - the series circuit method, according to one embodiment.

FIG. 18b is a series of current/voltage graphs obtained from the series circuit monolithic LED driver shown in Fig. 18a.

Fig. 19a is a monolithic LED driver - the parallel circuit method, according to one embodiment.

Fig. 19b shows a series of current/voltage graphs obtained from the Benistor monolithic LED driver shown in Fig. 19a.

Fig. 20 is a single cell anode loaded voltage controlled limited current switch (VCLCsw) LED driver circuit, according to one embodiment.

Fig. 21 is a single cell cathode loaded voltage controlled limited current switch (VCLCsw) LED driver circuit, according to one embodiment.

Fig. 22a is a simplified schematic of a monolithic LED driver - overall feedback series circuit method, according to one embodiment.

Fig. 22b shows a series of current/voltage graphs obtained from the Benistor monolithic LED driver shown in Fig. 22a.

Fig. 23a is a simplified schematic of a monolithic LED driver - overall feedback parallel circuit method, according to one embodiment.

Fig. 23b shows a series of current/voltage graphs obtained from the monolithic LED driver shown in Fig. 23a.

Fig. 24 is a monolithic multi stripes LED driver - series circuit, according to one embodiment.

Fig. 25 is a monolithic LED driver - high reliability series circuit, according to one embodiment.

Fig. 26a is a simplified schematic of a monolithic LED driver - minimum parts series circuit, according to one embodiment.

Fig. 26b shows a series of current/voltage graphs obtained from the monolithic LED driver shown in Fig. 26a.

Fig. 27a is a simplified schematic of a monolithic LED driver - minimum parts parallel circuit, according to one embodiment.

Fig. 27b shows a series of current/voltage graphs obtained from the monolithic LED driver shown in Fig. 27a.

Fig. 28 is a 120Vac series circuit monolithic LED driver, according to one embodiment.

Fig. 29 is a LED array and driver chip embodied system - simplified series circuit, according to one embodiment.

Fig. 30 is a LED array and driver chip embodied system - simplified parallel circuit, according to one embodiment.

Fig. 31 shows a monolithic LED driver - diodes source feedback parallel circuit, according to one embodiment.

Fig. 32 shows a monolithic LED driver - operational amplifier (OPAM) current feedback parallel circuit, according to one embodiment.

Fig. 33 shows a monolithic LED driver - diodes gate feedback parallel circuit, according to one embodiment.

Fig. 34 shows a monolithic LED driver - resistor gate feedback parallel circuit, according to one embodiment.

Fig. 35 shows a monolithic LED driver - totem pole feedback parallel circuit, according to one embodiment.

Fig. 36 shows a monolithic LED driver in an 8 Pin DC chip, according to one embodiment.

Fig. 37 shows a monolithic LED driver in an 8 Pin AC chip, according to one embodiment.

Fig. 38 is a block schematic diagram of a Classic Benistor embodiment.

Fig. 39A is an electronic symbol design for the positive OFF/ON Benistor embodiment.

Fig. 39B is an electronic symbol design for the negative ON/OFF Benistor embodiment.

Fig. 39C is an electronic symbol design for the universal Linear Benistor embodiment.

Fig. 39D is an electronic symbol design for the Classic Benistor embodiment.

Fig. 39E is an electronic symbol design for the Double OFF/ON Benistor embodiment.

Fig. 39F is an electronic symbol design for the Three-Terminal Benistor embodiment.

Fig. 40A is a graphical illustration of the Linear Benistor's voltage versus time.

Fig. 40B is a graphical illustration of the OFF/ON Benistor's voltage versus time.

Fig. 40C is a graphical illustration of the ON/OFF Benistor's voltage versus time.

Fig. 40D is a graphical illustration of the OFF/ON/OFF combination Benistor's voltage versus time.

Fig. 40E is a graphical illustration of the ON/OFF/ON combination Benistor's voltage versus time.

Fig. 40F is a graphical illustration of the OFF/ON/LINEAR combination Benistor's voltage versus time.

Fig. 40G is a graphical illustration of the ON/OFF/LINEAR combination Benistor's voltage versus time.

Fig. 40H is a graphical illustration of the OFF/ON/OFF/LINEAR combination Benistor's voltage versus time.

Fig. 401 is a graphical illustration of the ON/OFF/ON/LINEAR combination Benistor's voltage versus time.

Fig. 40J is a graphical illustration of the Switching Benistor's voltage versus time.

DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here.

In a general sense, those skilled in the art will also recognize that the various aspects described herein which can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, and/or any combination thereof can be viewed as being composed of various types of "electrical circuitry". Consequently, as used herein "electrical circuitry" includes, but is not limited to, electrical circuitry having at least one discrete electrical circuit, electrical circuitry having at least one integrated circuit, electrical circuitry having at least one application specific integrated circuit. Those having skill in the art will recognize that the subject matter described herein may be implemented in an analog or digital fashion or some combination thereof.

12. Description of the LED Lamp Retrofit Apparatus Embodiments

Dimmable LED Lamp Retrofit For Conventional Incandescent Lamps

EMBODIMENT 1

Fig. 1 shows an embodiment of a dimmable LED lamp retrofit apparatus for incandescent lamps.

As embodied herein, a LED lamp retrofit (1) comprises a housing (2), a standard Edison screw AC supply adaptor (3), a lens/diffuser shield (4), a LED panel board (5), one or more LEDs (6), a LED driver board (7), a driver supply wires circuitry (8) and a LED supply wires circuitry (9).

As further embodied herein, the housing (2) of the LED lamp retrofit (1) is mechanically attached to the AC supply adaptor (3) having two electrical terminals connected to the LED driver board (7) via the AC supply wires (8). The LED Driver Board (7) is electrically connected, via two or more LED supply wires (9), to the LEDs (6), which are mechanically attached to the LED panel board (5).

The incandescent LED lamp retrofit (1) may comprise other electrical wires for remote control or intelligent feedback control applications and therefore, for the reminder of this wiring circuitries the LED driver supply wires circuitry (8), together with the LED supply wire circuitry (9) and together with any other electrical control wires circuitry may be called, collectively, the In/Out ("I/O") electrical wiring system.

As still embodied herein, the LED lamp retrofit (1) comprises also a lens/diffuser shield (4), which can be built in "one piece" with the housing (i.e. a glass or plastic balloon) or it could be built as a separate piece mechanically attached to the lamp retrofit (1) housing (2).

Because this particular embodiment, illustrated in Fig. 1, is designated to replace conventional incandescent lamps, the LED panel board (5) has a three dimensional configuration following an octagonal, hexagonal, cylindrical or triangular base shape, in order to allow the LEDs (6) to provide light, nearly uniform, in all directions around (360 degrees, or omni-directional), despite the fact that the LEDs existing in market have only 120 degrees light angle, typically.

Alternatively, the LEDs (6) 360° light angle could be obtained even if the LED panel board is flat (a two dimensions disc, rectangular or square LED array, already available in the market) if the lens/diffuser shield (4) is tridimensional, respectively a transparent or milky optical prism capable of splitting, omni-directional, the light generated by the LEDs (6), in a 120° angle.

The mechanical support for the AC supply adaptor (3), lens/diffuser shield (4) and all the internal parts of the lamp retrofit (1) is the housing (2) which is typically made from glass, plastic or aluminum. If the material used for the housing (2) is metallic, then it can be used also as a heat sink for the LEDs (6) and the large power parts included in the driver board (7), under the precaution for a high voltage isolator material to be used in between, for eliminating potential electrical shock for the end users. If the material used for the housing (2) is glass or plastic, then the lens/diffuser shield (4) component could be eliminated, in some specific mechanical designs.

The LED panel (5) provides mechanical support, isolation for the electrical connections and heat absorption (sink) and for the LEDs (6).

The AC supply adaptor (3) is, typically, a conventional "Edison Screw" connector, which allows for full compatibility and easy replacement of the conventional incandescent (Edison) bulbs. From case to case, as a function of the size or specific mechanical design of the lamp retrofit (1), the supply adaptor (3) may have more than two connections and/or different configurations for easy replacement of any bulb.

The lens/diffuser shield (4) is the protection screen which allows the LEDs (6) light to get out but does not allow water or other objects to get in and, eventually, to damage the lamp retrofit (1) internal circuit. As a function of the lamp retrofit (1) configuration and/or electrical performances, the lens/diffuser shield (4) could be made from a transparent or translucent glass or plastic material. In some special case, the lens/diffuser shield (4) could be made from a transparent material coated with a substrate containing phosphor or other substances used in conventional fluorescent lamps or kinescope tubes' coating, in order to "store the light" for a short period of time and thus reducing the flickering phenomenon which may occur in situations when the LED driver board (7) is designed to supply the LEDs (6) with unfiltered (pulse) or high ripples DC voltage.

The LED driver board (7) is an AC/DC converter and power supply adaptor, providing constant voltage and/or constant current to the LEDs (6). The LED driver board (7) schematic diagram topology, complexity and size could be very different, from case to case, as a function of the targeted performances, size and cost per unit of each specific lamp retrofit unit.

Several LED driver circuits having different topologies and mode of operation will be fully described below, in other sections of this specification.

EMBODIMENT 2

Dimmable LED Lamp Retrofit For Conventional Halogen Lamps

Fig. 2 shows an embodiment of a dimmable LED lamp retrofit apparatus for conventional flood/halogen lamps.

As embodied herein, a LED lamp retrofit (11) comprises a housing (12), a standard AC supply adaptor (13), a lens/diffuser shield (14), a LED panel board (15), one or more LEDs (16), a LED driver board (17), a driver supply wires circuitry (18) and a LED supply wires circuitry (19).

As further embodied herein, the housing (12) of the LED lamp retrofit (11) is mechanically attached to the AC supply adaptor (13) having two electrical terminals connected to the LED driver board (17) via the AC supply wires (18). The LED Driver Board (17) is electrically connected, via two or more LED supply wires (19), to the LEDs (16), which are mechanically attached to the LED panel board (15).

As still embodied herein, the LED lamp retrofit (11) comprises also a lens/diffuser shield (14), which is mechanically attached to the lamp retrofit (11) housing (12).

Because this particular embodiment, illustrated in Fig. 2, is designated to replace conventional flood/halogen lamps which via an internal mirror focus their light in a single direction, in a 120 degrees angle, similar to most of the LEDs existing in market, the LED panel board (15) of the flood/halogen LED lamp retrofit (11) has a two dimensional configuration, following a disc, octagon, hexagon, rectangle, or triangle shape.

Except the two dimensional shape of the LED driver board (17), versus the three-dimensional shape of the LED panel board (15), the description of all the other components included in the flood/halogen LED lamp retrofit (11) shown in Fig. 2, such as housing (12), AC supply adaptor (13), lens/diffuser shield (14), LED driver board (17), driver supply wires (18) and LED supply wires (19), is similar to the description made above, for the incandescent LED lamp retrofit (1) shown in Fig. 1.

EMBODIMENT 3

Dimmable LED Lamp Retrofit For Conventional Fluorescent Lamps

Fig. 3 shows an embodiment of a dimmable LED lamp retrofit apparatus for conventional fluorescent lamps.

As embodied herein, a fluorescent LED lamp retrofit (21) comprises a housing (22), a first standard AC supply adaptor (23) including a not connected terminal (31) and a connected terminal (32), a lens/diffuser shield (24), a LED panel board (25), several LEDs (26), a LED driver board (27), a driver supply wires circuitry (28), a LED supply wires circuitry (29) and a second standard AC supply adaptor (30) including a not connected terminal (33) and a connected terminal (34).

As further embodied herein, in this specific embodiment, the housing (22) and the lens/diffuser shield (24) could appear, together, as a single glass or plastic tube, following as closed as possible, the shape and dimensions of a conventional fluorescent lamp tube for allowing easy replacement in standard fixtures. In some situations, the housing (22) could be a separate piece of metal used as mechanical support for the fluorescent lamp retrofit (21) and, simultaneously, as heat sink attached to the back side of the LEDs (26), replacing also the LED panel board (25), while the lens/diffuser shield (24) could be a separate piece of transparent or translucent plastic positioned in the front (lighting) side of the LEDs (26), being mechanically attached to the housing (22).

As still embodied herein, the housing (22), or the housing (22) and the lens diffuser shield (24), tube assembly of the fluorescent LED lamp retrofit (21) is mechanically attached, at one end to the first AC supply adaptor (23) and second AC supply adaptor (30).

As yet embodied herein, only one of the two terminals attached to the two standard AC adaptors are connected to the LED driver board (27) via the AC supply wires (28), respectively the terminal (32) on one end of the housing and the terminal (34) attached to the other end of the tube housing (22). For a faster and easier replacement of the fluorescent bulbs in their conventional (Philips) fixtures, without necessarily disconnecting and reworking the existing ballast and starter wiring sub-circuit (i.e., it takes significant time and money for authorized electricians to do this job, for millions of fluorescent bulbs replacement, at the country scale), the connected terminals must be either the two terminals (32, 34) mentioned above, located (both) on the lower side of the LED panel board (25), or the other two terminals (31 , 33) located (both) on the higher side of the LED panel board (25). In this way, by "flipping" the LED lamp retrofit (21) in such a manner for the two connected terminals to be included in the ballast's circuit, the starter is automatically eliminated from the lamp's circuit (i.e., LED lamps have no filaments) and the ballast could remain in the circuit (as a wire or filter), since it could not damage the LED driver without receiving the periodically ON-OFF pulses generated by the "starter" device. If the lamp retrofit (21) is flipped the opposite way, the two connected terminals are coupled in the starter's circuit and the ballast remains "in air" (not connected) so, again, no damage can happen to the LED lamp retrofit (21) or its related circuit. The not connected terminals (31 and 33) are attached to the standard AC adaptor (23) only for guaranteeing a full mechanical compatibility with the standard fluorescent lamps' fixtures. The LED Driver Board (27) is connected, via two or more LED supply wires (29), to the LEDs (26), which are mechanically attached (or bonded) to the LED panel board (25) in such a manner to allow for a good thermal contact and high voltage electrical isolation.

Because this particular embodiment, illustrated in Fig. 3, is designated to replace conventional fluorescent lamps, the LED panel board (25) has a long rectangular configuration in order to provide equally distributed light in the entire space of the lamp retrofit (21), similar to the conventional fluorescent lamp.

A very important aspect regarding each of the LEDs (26) specific position and electrical connections with the driver board (27) via the LED supply wires (29), concerning dimmers control versus the light equal distribution inside of the fluorescent LED lamp retrofit (21) is presented below, in a separate section of this specification.

Except the long tube housing (22)and lens diffuser shield (24)assembly shape, the long rectangular shape of the LED panel board (25) and the standard AC adaptor (23) mechanical/electrical fixture compatibility issues mentioned above, the description of all the other parts included in the fluorescent LED lamp retrofit (21) shown in Fig. 3 is similar to the description made above, for the incandescent LED lamp retrofit (1).

The LED driver board (27) and its related LED supply wires (29) may appear in many and very different configurations, as presented below, in separate sections of this patent application.

EMBODIMENT 4

Dimmable Monolithic LED Lamp Retrofit

Fig. 4 shows an embodiment of a dimmable monolithic LED lamp retrofit apparatus for conventional lamps and/or a dimmable "light engine" in which a monolithic LED driver chip is embodied in a monolithic LED array system.

As embodied herein, the monolithic dimmable LED lamp retrofit (41) comprises a housing (42), a LED panel board including a lens/diffuser shield (43), an assembly of LEDs (44), a LED driver chip (45), and an AC or DC supply adaptor (46).

As farther embodied herein, in this specific embodiment, the housing (42) is a monolithic unit or a "molded brick" made from a specific alloy, used in the semiconductor chips packaging manufacturing process, which provides electrical isolation and allows for heat dissipation internally and externally, in such a manner that all the hot components located inside of the brick can be cooled down by an external heat sink, bonded or mechanically attached to any part of the external surface of the brick.

As still embodied herein, inside of the molded brick housing (42) the LED driver chip (45) is embodied in (or pin by pin connected to) an array of LEDs (44) and externally, the LED driver chip (45) is coupled to the AC or DC supply adaptor (46).

As yet embodied herein, the external AC or DC supply adaptor (46) may appear in many different physical configurations in order to facilitate the replacement of any existing conventional bulb and the LED panel board lens diffuser shield (43) may also have many different physical configurations and it could be a piece of wafer (LEDs Array), together with the LEDs (44).

The LED driver chip (45) internal circuit configuration is presented below, in separate sections of this specification.

The main purpose of this specific embodiment is to provide an efficient, small size, low cost and compact (one piece) lighting device which, similar to the conventional incandescent bulbs, allows for parallel or series connections to the AC grid and because its fully integrated driver chip (45) improvement, the LED lamp retrofit (41) allows for a fully automatic manufacturing process, offering all the necessary means for a fast, very large volume and low cost production.

Therefore, the LED lamp retrofit (41) presented in Fig. 4 may be addressed as "The Ultimate Lighting Device" ("ULD"), or "The Ultimate Light Engine" ("ULE"), in further sections of this specification.

<u>13. Description of the LED Panel Embodiments</u>

EMBODIMENT 5

Dimmable LED Circuit System For Rectangular LED Panel

Fig. 5 shows an embodiment of a dimmable LED circuit system for a rectangular LED panel, targeting applications in lighting displays of the fluorescent lamp retrofits.

As embodied herein, the rectangular LED display circuit subject of this particular embodiment comprises 48 LEDs symbolized by 48 small squares. The color filled squares symbolize "the lighting LEDs" and the blank squares symbolize "the not lighting LEDs".

As further embodied herein, the 48 LEDs panel has been divided in six panel displays, starting with panel "I" and finishing with panel "VI", in which the lighting LEDs number increases with an increment of 8 LEDs per panel.

As still embodied herein, the 6 different panel display configurations show that no matter if 8, 16, 24, 32, 40 or all 48 LEDs are lighting at one time, there is always a "Symmetrical LEDs Connections Arrangement" ("SLCA") in which the light is equally distributed on the entire space of the display panel.

This SLCA is imperative necessarily in situations when a dimmer introduced in the LEDs circuit reduces not only the LEDs current, but also the LEDs AC or DC supply voltage down to a level lower than the minimum threshold voltage required by two or more LEDs connected in series, per one stripe.

Several configurations of LED drivers capable to manage SLCA are presented below, in separate sections of this patent application.

EMBODIMENT 6

Dimmable LED Circuit System For Round LED Panel

Fig. 6 shows an embodiment of a dimmable LED circuit system for round (disc) LED panel, targeting applications in lighting displays of the flood halogen lamp retrofits.

As embodied herein, the round (disk) LED display circuit subject of this particular embodiment comprises 48 LEDs symbolized by 48 small circles. The color filled circles symbolize "the lighting LEDs" and the blank circles symbolize "the not lighting LEDs".

As further embodied herein, the 48 LEDs panel has been divided into twelve panel displays, starting with panel "a)" and finishing with panel "l)", in which the lighting LEDs number increases with an increment of 4 LEDs per panel.

As still embodied herein, the 12 different panel display configurations show that no matter if 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44 or all 48 LEDs are lighting at one time, there is always a "Symmetrical LEDs Connections Arrangement" ("SLCA") in which the light is equally distributed on the entire space of the display panel.

The details about the SLCA and its compatible LED driver have been presented above, at the description of the rectangular LED panel display shown in Fig. 5.

EMBODIMENT 7

Dimmable LED Array Display System

Fig. 7 shows an embodiment of a dimmable LED array display system for a square LED panel, targeting applications in lighting displays for street or parking lot lamp retrofits, comprising one or more LED Array devices.

As embodied herein, the square LED display circuit subject of this particular embodiment comprises 36 LEDs symbolized by 36 small squares. The color filled squares symbolize "the lighting LEDs" and the blank squares symbolize "the not lighting LEDs".

As further embodied herein, the 36 LEDs panel has been divided in nine panel displays, starting with panel "a)" and finishing with panel "i)", in which the lighting LEDs number increases with an increment of 4 LEDs per panel.

As still embodied herein, the nine different panel display configurations shows that no matter if 4,8, 12, 16, 20, 24, 28, 32, or all 36 LEDs are lighting at one time, there is always a "Symmetrical LEDs Connections Arrangement" ("SLCA") in which the light is equally distributed on the entire space of the display panel.

The details about the SLCA and its compatible LED driver have been presented above, at the description of the rectangular LED panel display shown in

Fig. 5.

14. Description of the SMPS Driver Embodiments

Introduction

This embodiments description section, of the present specification, comprises ten (10) SMPS converter circuit solution embodiments. These embodiments are capable of superseding all the other similar topology SMPS LED driver solutions depicted above, at the related art section. Such may be accomplished by the means of several novel control methods and/or novel sub-circuit systems used in each of these particular LED driver embodiments, for securing the high quality electrical parameter as well as the long life operations of suitable LED lamp retrofit apparatuses by matching. Accordingly, each particular LED driver system with its suitable additional components and or mechanical-optical-electrical systems included in a particular LED lamp retrofit, such as: housing, supply adaptor, LEDs, LED panel, lens/diffuser shield and I/O electrical wiring system.

Since the "low total manufacturing cost" (including the components cost) is also a very important subject of this specification and, as it was presented above, the most expensive component included in SMPS LED driver circuits are the coils, electrolytic capacitors, MOSFET or high power transistors, fast recovery diodes and the IC controller chips. Each of the SMPS circuit embodiments presented herein comprises a minimum parts set allowed by the specific topology adopted, and for providing "high performance low parts count" LED driver solution, several novel methods, techniques and/or original sub-circuit systems, such as "Self-supply buck-boost" or "Pseudo double stage" design approaches have been used.

Additionally, since the most important part in a SMPS converter is its main PWM/PFC Controller IC which costs $0.55 to $2,60 per unit typically, the design of all and each SMPS circuit embodiments presented in this specification has been done, in such a manner to can use efficiently and safely, the most popular, reliable and cost effective PWM controller chip used in the worldwide SMPS industry, such as the UC3842, introduced by Unitrode, Inc. (now Texas Instruments) over twenty years ago and sold now in over half a billion units a year, by all power management semiconductor companies, at a reasonable cost between $0.12 (South Asia) and $0.17 (ON Semiconductor, USA) per unit. This affordable price allows for millions of dollars yearly savings for each large volume, worldwide, LED lamp retrofits manufacture's budget and, implicitly, a lower cost per retrofit unit paid by the end users.

EMBODIMENT 8

Double Stage Isolated Boost-Flyback Multi-Columns LED Driver

Fig. 8 shows an embodiment of a double stage isolated boost-flyback multi-column LED driver circuit.

Description Of The Components Connections

As embodied herein, a double stage boost-isolated flyback multi-columns LED driver circuit comprises an AC-to-DC converter sub-circuit including an alternative current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output coupled to an input ground (55) terminal and its positive output coupled to ground (55) via a first filtering capacitor Cf1 (54) and coupled directly to a pulse voltage input VPin (101) which is the first terminal of a five terminals boost power factor correction sub-circuit PFC-b (100).

The PFC-b (100) sub-circuit has a pre regulated DC voltage output VDCpr (102) second terminal, followed by a boost feedback input FBb (103) third terminal coupled to VDCpr (102), followed by a zero voltage fourth terminal coupled to (55) followed by an integrated circuit voltage supply fifth terminal Vic (117).

A two coils boost inductor Lb (110) has its first coil coupled at one end to VPin (101) and the other end to the anode of an output boost diode Dob (111). The second coil of Lb (110) having one end coupled to ground (55) and the other end to the anode of a supply diode Dvcc (115). The Dob (111) has its anode coupled also to the drain of a boost MOSFET transistor Mb (112) and its cathode to the VDCpr (102) output terminal. The Mb (112) has its source coupled to (55) and its gate coupled to a driving output terminal "DRV", of a four terminals power factor corrector integrated circuit PFCic (113).

The PFCic (113) other three terminals are "GND" coupled to (55), followed by "FB" coupled to the FBb (103) terminal and "Vcc" coupled to the cathode of Dvcc (115). The other terminal of Rst (114) is also coupled to the cathode of Dvcc (115) and to (55) via a voltage supply capacitor Cvcc (116). The VDCpr (102) output terminal is coupled to the input ground (55) via a second filtering capacitor Cf2 (190) and directly to a DC voltage input VDCin (201) which is the first terminal of a six terminals flyback pulse width modulation sub-circuit PWM-f (200). The PWM-f (200) sub-circuit has a DC voltage output VDCo (202) second terminal, followed by a feedback input FBf (203) third terminal, followed by a zero-voltage fourth terminal coupled to the input ground (55), followed by a fifth terminal coupled to an output ground (65), which is isolated to the input ground (55), and followed by a voltage supply Vic (117) sixth terminal.

The PWM-f (200) sub-circuit comprises a two coils flyback transformer TRf (210) having its first coil coupled at one end to the VDCin (201) and the other end coupled to the drain of a flyback MOSFET transistor Mf (212). The TRf (210) second coil having one end coupled to (65) and the other end to the anode of a flyback output diode Dof (211). The Mf (212) has its source coupled to (55) and its gate coupled to a second driving output terminal "DRV", of a second four terminals pulse width modulator integrated circuit PWMic (213). The PWMic (213) second terminal is "GND" coupled to (55), followed by a third terminal "FB" coupled to the FBf (203) and followed by a forth terminal "Vcc" coupled to the cathode of Dvcc (115) via the Vic (117). The cathode of Dof (211) is coupled to (65) via a third filtering capacitor Cf3 (290) and directly, via VDCo (202) to a voltage supply input Vsi (301), which is the first terminal of a five terminal LED Panel (300) sub-circuit.

The LED Panel (300) sub-circuit has also a Vd+ (302) second terminal, followed by a Vd- (303) third terminal, followed by a LED current Iled (304) fourth terminal and followed by a reference voltage (406) fifth terminal. The LED Panel (300) sub-circuit comprises three identical LED column sub-circuits, such as: a first LED column LEDc1 (310) including several LEDs coupled in a series circuit where the anode of the first LED is coupled to the Vsi (301) terminal and the cathode of the last LED is coupled to the anode of a first diode DI1+ (321) having its cathode coupled to Vd+ (302), and to the cathode of a second diode DI1- (322) having its anode coupled to Vd- (303) and to the Iled (304) terminal via a constant current sink device CCS1 (331) having a third control terminal coupled to Vref (406). A second LED column LEDc2 (311) including several LEDs coupled in a series circuit where the anode of the first LED is coupled to the Vsi (301) terminal and the cathode of the last LED is coupled to the anode of a first diode DI2+ (323) having its cathode coupled to Vd+

(302), and to the cathode of a second diode Dl2- (324) having its anode coupled to Vd- (303) and to the Iled (304) terminal via a constant current sink device CCS2 (332) having a third control terminal coupled to Vref (406). A third or last ("z") LED column LEDcz (312) including several LEDs coupled in a series circuit where the anode of the first LED is coupled to the Vsi (301) terminal and the cathode of the last LED is coupled to the anode of a first diode Dlz+ (325) having its cathode coupled to Vd+ (302), and to the cathode of a second diode Dlz- (326) having its anode coupled to Vd- (303) and to the Iled (304) terminal via a constant current sink device CCSz (333) having a third control terminal coupled to Vref (406). The first terminal Vsi (301) of the LED Panel (300) is also coupled to a first terminal Vmax (401) of a seven terminals constant voltage constant current control sub-circuit CVCC (400).

The CVCC (400) sub-circuit has also a second terminal Vdif+ (402) coupled to Vd+ (302). A third terminal Vdif- (403) is coupled to Vd- (303). A fourth terminal Imax (404) is coupled directly to Iled (304) and via a LED current sense resistor Rsled (360) to the output ground (65). A fifth terminal Ctrl (405) followed by a sixth terminal Vref (406) are coupled to Vref (406) terminal of the LED Panel (300) sub-circuit. A seventh terminal is coupled to the output ground (65). The CVCC (400) sub-circuit comprises a first open collector operational amplifier A1 (410) having one input coupled to Vmax (401). A threshold reference voltage Vrefl is coupled at the other input and its output coupled to Ctrl (405). A second open collector operational amplifier A2 (411) has one input coupled to Vdif+ (402) and the other input coupled to Vdif- (403). Its output is coupled to Ctrl (405). A third open collector operational amplifier A3 (412) has one input coupled to Imax (404), a threshold reference voltage Vref2 coupled at the other input and its output coupled to Ctrl (405). The Vmax (401) terminal is also coupled to the cathode of a voltage reference (Zener) diode VR (421), via a current limitation resistor Rvref (422). One terminal of a first voltage reference resistor Rr1 (423) is coupled, to the cathode of VR (422) and the other one is coupled to Vref (406) and to one terminal of a second voltage reference resistor Rr2 (424). The other terminal of Rr2 (424) and the anode of VR (422) are coupled together to the output ground (65).

Externally to the CVCC (400) sub-circuit, a four terminals opto-coupler OC (450) device comprising a two terminals LED having an anode and a cathode and a two terminals NPN transistor having an emitter and a collector. The anode of the LED is coupled to Vref (406) and the cathode is coupled to Ctrl (405). The emitter is coupled to the input ground (55) and the collector coupled to FBf (203).

Description Of The Block Schematic

As still embodied herein, a double stage isolated boost-flyback multi-column LED driver system embodiment comprises, besides a conventional AC-to-DC converter circuit including the AC generator Vac (51), the low-pass filter EMI (52), the bridge rectifier BR (53)and the capacitor CF1 (54), a power factor correction boost PFC-b (100) first sub-circuit representing the first stage of the entire driver system, followed by a pulse width modulation flyback PWM-f (200) second sub-circuit, a LED Panel (300) third sub-circuit and constant voltage constant current CVCC (400) fourth sub-circuit, representing, together, the second stage of the entire driver system.

Description Of The "Conventional" Input AC-DC Converter

As yet embodied herein, the conventional AC-to-DC converter circuit provides an unregulated DC voltage across the capacitor CF1 (54) via the bridge rectifier BR (53) which has its negative output terminal coupled to the input ground (55) and its positive output terminal coupled to the VPin (101) input terminal of the PFC-b (100) sub-circuit. The EMI (52) filter is configured to allow (low impedance for) the low frequency (typically, 50Hz-60Hz) currents to easily pass from the Vac generator to the PFC-b (100) sub-circuit and to stop (high impedance for) the high frequency (typically, 20kHz-200kHz) currents, generated inside of the LED driver circuit, to come back to the Vac (51) generator (i.e. the AC Electrical Grid). The first filtering capacitor Cf1 (54) has a relatively low value (10nF - 200nF) for filtering high frequency currents but, on the other hand, to not create significant distortions of the low frequency current and, implicitly, to decrease the entire system's power factor coefficient.

Description of the 1st Stage - PFC Boost Converter

As further embodied herein, the PFC-b (100) sub-circuit representing "the first stage" of the entire LED driver embodiment is the initial functional block designated to deliver a pre-regulated DC supply voltage to the other sub-circuits, in a near unity power factor manner. This allows for an optimal transfer of electrical energy between the alternating current generator Vac (51) and the LED Panel (300), which is the "load" of the entire driver circuit. Since the LEDs require DC voltage stored, usually, in large value (bulk) capacitors (10uF to 1000uF), the main function performed by the PFC-b (100) sub-circuit is to deliver a pre-regulated voltage across a relatively large value capacitor for the entire LED driver circuit current's shape to follow, as close as possible, the phase and shape of the AC generator (51), respectively a rectified sine-wave shape, regardless of each of the other sub-circuits' current shape. For this purpose, the PFC-b (100) is a boost converter sub-circuit having a rectified sine-wave pulse voltage inputted at its VPin (101), and delivering a DC pre-regulated voltage via its VDCpr (102) output terminal, which is higher in amount than the peak input voltage, with respect to a zero volts input ground (55) terminal.

The boost inductor Lb (110) is coupled from VPin (101) to the input ground (55) via a MOSFET switch Mb (112). The boost inductor Lb (110) generates a higher output voltage across a second filtering capacitor Cf2 (190) via a fast recovery diode Dob (111). This is a result of high frequency ON-OFF switching pulses enforced by the Mb (112) buffer and generated by the power factor correction integrated circuit PFCic (113), which generates driving square wave pulses to the gate of Mb (112) via its DRV terminal.

The output voltage amount is sensed by the PFCic (113) controller via its FB terminal, which is coupled to VDCpr (102) via the FBb (103) terminal. The maximum voltage at VDCpr is limited by PFCic (113) by decreasing, accordingly, the ON time of its driving pulses, implicitly, by lowering the average current of the boost inductor Lb (110). The PFCic (113) start-up supply is secured by a large value starting resistor Rst (114) which delivers a fraction VPin (101) voltage to its supply terminal Vcc, with respect to its zero voltage terminal GND, coupled to the input ground (55). A larger current supply is delivered by the secondary coil of Lb (110) via Dvcc (115) and Cvcc (116), as soon as the Mb (112) switch forces Lb (110) to oscillate.

The PFC-b (100) sub-circuit's simplicity allows for very low cost controller circuits, which could be conventional power factor correction circuits or even very low cost pulse with modulation integrated circuits, such as the controllers included in the most commonly used UC384x series.

Description Of The 2nd Stage - The Flyback (200)

As yet embodied herein, the PWM-f (200) sub-circuit represents "the second stage" of the LED driver circuit subject of this specification. The PWM-f (200) is the second functional block designated to deliver DC supply to the LED Panel (300) sub-circuit in a constant voltage constant current ("CVCC) manner, which offers maximum safety and lifetime to the LED devices. The LED Panel (300) represents the main load of the entire system. For this purpose, the PWM-f (200) is a flyback converter sub-circuit having a pre-regulated DC voltage inputted at its VDCin (201). The PWM-f (200) delivers a regulated DC voltage via its VDCo (202) output terminal, which is, typically, much lower in amount than the input voltage with respect to a zero volts output ground (65) terminal.

The flyback transformer TRf (210) has its primary coil coupled from VDCin (201) to the input ground (55) via a MOSFET switch Mf (212). The flyback transformer TRf (210) generates the lower amount regulated DC voltage across a third filtering capacitor Cf3 (290) via a secondary coil and a fast recovery diode Dof (21 1). This is a result of high frequency ON-OFF switching pulses enforced by the Mf (212) buffer and generated by the pulse width modulation integrated circuit PWMic (213), which generates driving square wave pulses to the gate of Mf (212), via its DRV terminal.

The output voltage amount is sensed by the PWMic (213) controller via its FB terminal, which is coupled to the hot output terminal of the opto-coupler device OC (450) via the FBb (103) terminal of PWM-f (200) sub-circuit. The output voltage at VDCo (202) is limited and/or regulated by PFCic (113) by decreasing or increasing, accordingly, the ON time of its driving pulses, and implicitly, by controlling, cycle by cycle the average current of the flyback transformer Lf (210) primary coil. The PWMic (21 3) supply at its Vcc terminal is taken, via the Vic (117) terminal, from the previous controller PFCic (113) Vcc supply terminal, with respect to its zero voltage terminal GND, coupled also to the input ground (55). The PFC-b (100) sub-circuit's simplicity allows for very low cost controller circuits, such as the controllers included in the most commonly used UC384x series.

Description Of The LED Panel (300) & CVCC (400) Blocks

As further embodied herein, the LED Panel (300) sub-circuit comprises three LED columns and protection circuitry, which provide fast correction feedback to the PWMic (213) controller via the CVCC (400) sub-circuit. The CVCC

(400) sub-circuit comprises three operational amplifiers having their output coupled together to the input of an opto-coupler (450) device which has its output coupled to the feedback input FBf (203) of the PWM-f (200) flyback sub-circuit.

Accordingly, the supply voltage delivered by the PWM-f (200) flyback sub-circuit via its VDCo (202) is inputted, simultaneously at the Vsl (301) terminal of the LED Panel (300) and at the Vmax (401) input of the CVCC (400) controlling sub-circuit, then regulated in feedback, via the operational amplifier A 1 (410) which has a stable reference voltage Vrefl for comparison.

The current of LED Panel (300) is corrected by the A3 (412) operational amplifier feedback, by sensing the voltage collected across the sense resistor Rsled (360)via the Imax (404) terminal and comparing it to a second reference voltage Vref2. The operational amplifier A2 (41 1) performs a special feedback function, strongly related to the LED Panel (300) internal protection circuit.

As still embodied herein, internally the LED Panel (300) sub-circuit comprises three LED columns and a protection circuit comprising three constant current sinks and six diodes which secure the constant current for each LED column. Additionally, it offers a very simple and cost effective protection for "un-balanced LED columns". The protection circuit provides a special protection for cases when one or more LEDs are damaged or not consistent in voltage versus current specifications, with the others. Since the protection circuit is identical for all columns, to simplify the description of this sub-circuit, only the first two columns LEDc1 (310) and LED (31 1) protection circuit will be fully described. Considering that the same control method could be applied to many ("z") LED columns.

The LEDc1 column includes several LEDs coupled in series. The anode of the first LED is coupled to the positive supply terminal Vsl (301). The cathode of the last LED is coupled to the Iled (304) terminal via a constant current sink device CCS1 (331). The constant current sink device CCS1 (331) is biased with a constant voltage received from the CVCC (400) sub-circuit. The constant voltage is created from VDCo (202) via Rvref (422) and VR (421 and delivered via Rr1 (423), Rr2 (424) and the Vref (406) terminal.

The Iled (304) terminal delivers the entire LED Panel (300) current to the output ground (65) terminal via the Rsled (360) sense resistor. Connected to the cathode of LEDc1 (310) last LED, there is a first diode D1+ (321) coupled with its cathode to the Vd+ (302) terminal. A second diode D1- (322) is coupled to the Vd- (303) terminal. Similarly for the LEDc2 (31 1) column, the anode of the first LED also is coupled to the positive supply terminal Vsl (301) and the cathode of the last LED also is coupled to the Iled (304) terminal, via a constant current sink device CCS1 (331) biased with a constant voltage received via the Vref (406) terminal. Connected to the cathode of LEDc2 (31 1) last LED, there is a first diode D1+ (321) coupled with its cathode to the Vd+ (302) terminal. A second diode D1- (322) is coupled to the Vd- (303) terminal. The Vd+ (302) and Vd- (303) terminals are coupled to the two inputs of A2 (41 1). This symbolizes a differential error amplifier that is able to shut down the driving pulse delivered by PWMic (213) to the gate of Mf (212) buffer, via the opto-coupler OC (450) and the feedback terminal FBf (203), at any time when the difference of the voltage between Vd+ (302) and Vd- (303) is larger than a pre-established limit.

Under normal operating conditions, if all LEDs in the LEDc1 (310) column and also all LEDs in the LEDc2 (31 1) column have identical voltage versus current specifications, and/or none of them are damaged, the voltage between Vd+ (302) and Vd- (303) terminals should be zero. However, as soon as something is wrong with only one LED in any of the two columns, a difference of voltage will appear at the input of the differential input error amplifier A2 (41 1). This error voltage will cause the PWMic (213) output driving pulse to be shut down to prevent malfunctions or further damages in the LED lamp circuit.

Alternatively, the error amplifier A2 (41 1) feedback could be used not to shut down the entire PWM-f (200) flyback sub-circuit, but only the damaged LED column. This may be accomplished by shutting down the bias supply of the CCS circuit which connects that column to the Iled (304) terminal. In this way, the damaged LED column cannot create further damages since it is practically completely disconnected from the LED panel (300) circuit.

This damage or inconsistency sensing technique offers the advantage of achieving a very accurate control of as many LED columns as needed. This is particularly advantageous in a large lighting system because the sensing technique does not employ expensive operational amplifiers. Rather, the sensing technique employs only two very low cost silicon diodes, per each LED column, inserted on the LED panel circuit and a four-wire buss feedback circuit connected with the LED driver CVCC section, for securing the LEDs protection and long lifetime.

Additionally, two extra wires could be included in series with one of the LED driver AC supply to allow remotely control via external relays or switches.

This double stage isolated boost-flyback multi-columns LED driver system embodiment provides a superior double stage LED driver solution, with respect to the related art, providing higher quality, lower parts count and implicitly board size and much lower cost, as summarized in Table 12 below:

Table 12: Double Stage Off-line LED Driver Comparison Chart

#	Parts & Performance	Texas Instruments		Supertex		Embodiment	
1	Parts Count (expensive)	**136**	*(32)*	**63**	*9*	**>50**	*9*
2	ICs (opto couplers)	**5**	*(2)*	**1**	*(0)*	**5**	*(2)*
3	Transistors - *(FETs)*	**8**	*(5)*	**5**	*(1)*	**2**	*(2)*
4	Diodes– (bridge & *fast rec.)*	**14**	*(9)*	**13**	*(10)*	**3**	*(3)*
5	Capacitors – (electrolytic)	**50**	*(11)*	**15**	*(0)*	**5**	*(2)*
6	Inductors - *(Transformers)*	**3**	*(3)*	**4**	*(0)*	**3**	*(2)*
7	Resistors - *(high power)*	**56**	*(2)*	**25**	*(2)*	**18**	*(2)*
8	Efficiency (typ.)	**87%**		**87%**		**87%**	
9	Power Factor (typ.)	**0.95**		**0.95**		**0.99**	
10	A.THD (typ.)	**<10%**		**<10%**		**<10%**	
11	LED Stripes CCS	**1**		**1**		**3**	
12	Board Size	**VL**		**ML**		**M**	
13	Cost (total)	**VH**		**M**		**L**	
14	Lifetime *(years)*	**3**		**3**		**5**	

The main advantages of the double stage SMPS embodiment circuit system consist in the fact that provides I/O circuits isolation and the first stage (boost) converts the unregulated AC input voltage into a regulated (390V) DC voltage. Therefore, the second stage (flyback) will always have sufficiently high supply voltage amount for delivering to its load a precisely regulated DC voltage having much smaller ripples, and less flicker, than can be obtained in a single stage converter.

Additionally, this double stage LED driver embodiment, subject of this specification, provides low component count, lower size, lower manufacturing cost, equal or higher electrical performance for a similar double stage driver solutions. Most importantly, this double stage LED driver embodiment provides a very safe and reliable CVCC control solution by including a CCS per each LED stripe. This increases significantly operation lifetime (up to 5 years) of the LED lamp retrofits by protecting the LEDs against any un-predicted and/or fast variations of the supply voltage and/or ambient temperature.

As an important note, the Supertex solution has significant lower parts count amount than the TI's solution because it does not provide I/O circuit isolation (for avoiding to use opto-coupler and error amplifiers), feature which is a mandatory requirement in some market segments.

EMBODIMENT 9

Single Stage Boost Multi-Columns LED Driver

Fig. 9 shows an embodiment of a single stage boost multi-column LED driver circuit.

Description of the Connections

As embodied herein, a single stage boost multi-columns LED driver circuit comprises an AC-to-DC converter sub-circuit including an alternating current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53) which has its negative output coupled to ground (55) and its positive output coupled to ground (55) via a first filtering capacitor Cf1 (54).

A two coils boost inductor Lb (110) has its primary coil coupled on one end to the positive output of bridge rectifier BR (53) and the other end coupled simultaneously to the anode of a boost output diode Dob (111) and to the drain of a MOSFET transistor Mb (112). The Lb (110) secondary coil having one end coupled to ground (55) and the other end to the anode of a supply diode Dvcc (115). The supply diode Dvcc (115) has its cathode coupled to the positive output of BR (53) via a starting resistor Rst (114) and to ground (55) via a supply capacitor Cvcc (116).

An eight terminal pulse width modulation integrated circuit PWMic (120) has a first terminal "Vcc" coupled to the cathode of Dvcc (115). A second terminal "DRV" is coupled via a gate resistor Rg (121) to the gate of Mb (112) which gas its source electrode coupled to ground (55). A third terminal "Is" is coupled to the emitter of a voltage ramp NPN transistor Qvr (125) via a first voltage ramp resistor Vr1 (126). A fourth terminal "GND" is coupled to ground (55). A fifth terminal "Osc" is coupled directly to the base of Qvr (125) and to ground (55) via a timing capacitor Ct (124). A sixth terminal "Vref" (406) is coupled simultaneously via a capacitor Cr (122) to ground (55), via a timing resistor Rt (123) to the Osc terminal, and directly to the collector of Qvr (125). A seventh terminal "Comp" is coupled to one terminal of a compensating capacitor Cc (130). An eighth terminal "FB" is coupled to the other terminal of Cc (130).

A soft start over voltage control sub-circuit (SSOVC) (140) comprises a first soft start diode Dss1 (142) having its anode coupled to the Comp terminal of PWMic (120) together with the cathode of a second soft start diode Dss2 (143). The cathode of Dss1 (142) together with the anode of Dss2 (143) are coupled to the FB terminal of PWMic (120) via a soft start capacitor Css (141). The FB terminal of PWMic (120) is also coupled via a first feedback resistor Rfb1 (128) to the cathode of the boost output diode Dob (111) and to ground (55) via a second feedback resistor Rfb2 (129). The cathode of Dob (111) is also coupled via a second filtering capacitor Cf2 (190) to ground (55) and directly to a voltage supply input Vsi (301).

A first terminal of a five terminal LED Panel (300) sub-circuit also is coupled to the cathode of Dob (111). The LED Panel (300) sub-circuit has also a second terminal Vd+ (302) coupled to the cathode of a controlling Zener diode Dzctrl (434) and to the emitter of a PNP controlling transistor Qctrl (431) which has its collector together with the anode of Dzctrl (434) coupled to the Is terminal of PWMic (120) via a resistor (433). A third terminal Vd- (303) is coupled to the base of Qctrl (431) via a resistor (432). A fourth terminal (304) coupled to ground via a current sense resistor Rsled (360) and to the Is terminal of the PWMic (120) via a resistor Rvr2 (127). A fifth terminal (406) coupled to the Vref terminal of the PWMic (120).

The LED Panel (300) sub-circuit comprises three identical LED column sub-circuits. This includes a first LED column LEDc1 (310) including several LEDs coupled in a series circuit where the anode of the first LED is coupled to the Vsi (301) terminal and the cathode of the last LED is coupled to the anode of a first diode Dl1+ (321). The cathode of the first diode Dl1+ (321) is coupled to Vd+ (302) and to the cathode of a second diode DM- (322). The anode of diode DM- (322) is coupled to Vd- (303) and to the collector of a first NPN transistor (343). The first NPN transistor (343) has its emitter coupled to Iled (304) via a first resistor (344) and its base coupled directly to the collector of a second NPN transistor (342) and via a second resistor (341) to Vref (406). The second NPN transistor (242) has its emitter coupled to Iled (304) and its base coupled to the emitter of the first NPN transistor (343).

A second LED column LEDc2 (311) including several LEDs is coupled in a series circuit where the anode of the first LED is coupled to the Vsi (301) terminal and the cathode of the last LED is coupled to the anode of a first diode Dl2+ (323). The anode of the first diode D12+ (323) has its cathode coupled to Vd+ (302)

and to the cathode of a second diode DI2- (324). The second diode DI2- (324) has its anode coupled to Vd- (303) and to the collector of a first NPN transistor (347). The first NPN transistor (347) has its emitter coupled to Iled (304) via a first resistor (348) and its base coupled directly to the collector of a second NPN transistor (346) and via a second resistor (345) to Vref (406). The second NPN transistor (246) has its emitter coupled to Iled (304) and its base coupled to the emitter of the first NPN transistor (347).

A third or last ("z") LED column LEDcz (312) includes several LEDs coupled in a series circuit where the anode of the first LED is coupled to the Vsi (301) terminal and the cathode of the last LED is coupled to the anode of a first diode Dlz+ (325). The first diode Dlz+ (325) has its cathode coupled to Vd+ (302) and to the cathode of a second diode Dlz- (326). The second diode Dlz- (326) has its anode coupled to Vd- (303) and to the collector of a first NPN transistor (351). The first NPN transistor (351) has its emitter coupled to Iled (304) via a first resistor (352) and its base coupled directly to the collector of a second NPN transistor (350) and via a second resistor (349) to Vref (406). The second NPN transistor (250) has its emitter coupled to Iled (304) and its base coupled to the emitter of the first NPN transistor (351).

Description Of The Block Schematic

As further embodied herein, a single stage boost multi-column LED driver system comprises a conventional AC-to-DC converter sub-circuit, a power factor correction ("PFC") sub-circuit and a LED Panel (300) sub-circuit.

Description Of The PFC Boost

The conventional AC-to-DC converter circuit, including the AC generator Vac (51), the low-pass filter EMI (52), the bridge rectifier BR (53) and the capacitor CF1 (54) provides an unregulated DC voltage across the capacitor CF1 (54) via the bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output terminal coupled to ground (55) and its positive output terminal coupled to one terminal of the boost inductor Lb (110) primary coil of the PFC sub-circuit. The EMI (52) filter is configured to allow (low impedance for) the low frequency (typically, 50Hz-60Hz) currents to easily pass from the Vac generator to the PFC-b (100) sub-circuit and to stop (high impedance for) the high frequency (typically, 20kHz-200kHz) currents, generated inside of the LED driver circuit, to come back to the Vac (51) generator (i.e., the AC Electrical Grid). The first filtering capacitor Cf1 (54) has a relatively sufficiently low value (10nF - 200nF) for filtering high frequency currents but, on the other hand, to do not create significant distortions of the low fervency current and, implicitly, to decrease the entire system's power factor coefficient.

As still embodied herein, the PFC sub-circuit is configured to deliver a regulated DC supply voltage to the LED Panel (300) sub-circuit, in a manner which allows for an optimal transfer of electrical energy between the alternative current generator Vac (51) and the LED Panel (300). The LED Panel (300) is the "load" of the entire system. Since the LEDs require DC voltage stored, usually, in large value (bulk) capacitors (10uF to 1000uF), the main function performed by the PFC sub-circuit is to deliver a regulated voltage across a relatively large value capacitor, in such a manner for the entire LED driver circuit current's shape to follow, as closed as possible, the phase and shape of the AC generator (51), respectively a rectified sine-wave shape, regardless of each of the other sub-circuits' current shape.

For this purpose, the PFC sub-circuit is a boost converter having a rectified sine-wave pulse voltage as input supply voltage and delivering a regulated DC voltage to the LED Panel (300) supply input Vsl (301) terminal and an output voltage which is higher in amount than the peak input voltage, with respect to a zero volts input ground (55) terminal. The primary coil of the boost inductor Lb (1 10) is coupled from the positive output of BR (53) to ground (55) via a MOSFET switch Mb (1 12). The boost inductor Lb (1 10) generates the higher output voltage across a second filtering capacitor Cf2 (1 90) via a fast recovery diode Dob (1 11), as a result of high frequency ON-OFF switching pulses enforced by the Mb (1 12) buffer, and generated by the pulse width modulation integrated circuit PWMic (120). The PWMic (120) generates driving square wave pulses to the gate of Mb (1 12), via its DRV terminal and the gate resistor Rg (12 1). The output voltage amount is sensed by the PWMic (120) controller's FB terminal, which is coupled to the PFC sub-circuit output FBb (103) via Rfb1 (128) and to ground (55) via Rfb2 (129).

Description Of The SSOVC Sub-Circuit

The PWMic (120) feedback voltage compensation is done by the compensation capacitor Cc (130) coupled between the FB and Comp terminals, which has coupled in parallel the soft start over voltage control SSOVC (140) sub-circuit comprising the two diodes Dss1 (142) and Dss2 (143) and the capacitor Css (141). This simple circuit offers a much faster and stable compensation by allowing the use of a higher value capacitor without decreasing the sensitivity of the FB input, because of the voltage threshold and current nonlinearity of the diodes. The maximum voltage at VBb (103) output is limited by PFCic (113) by decreasing, accordingly, the ON time of its driving pulses, and implicitly, by lowering the average current of the boost inductor Lb (110).

Description of conventional operations of the UC3842

The PWMic (120) start-up supply is secured by a large value starting resistor Rst (114) which delivers a fraction VPin (101) voltage to its supply terminal Vcc, with respect to its zero voltage terminal GND, coupled to ground (55). A larger current supply is delivered by the secondary coil of Lb (110) via Dvcc (115) and Cvcc (116), as soon as the Mb (112) switch forces Lb (110) to oscillate. The Rt (123) resistor and the Ct (124) capacitor are establish the PWMic (120) operating frequency and the capacitor Cr (122) improves the Vref terminal stability. The transistor Qvr (125) together with the resistors divider Rvr1 (126) and Rvr2 (127) create a voltage ramp signal at the Is terminal of the PWMic (120) for limiting the output signal duty cycle down to a pre-established limit and allowing the controller to operate in voltage mode.

The PFC sub-circuit's simplicity allows for very low cost controller circuits, such as the controllers included in the most commonly used UC384x series.

Description Of The LED Panel (300)

As yet embodied herein, the LED Panel (300) sub-circuit comprises three LED columns and a protection circuitry which provide fast correction feedback to the PWMic (120) controller. The supply voltage inputted at Vsl (301) terminal is controlled by the FB terminal of PWMic (120) in a ratio determined by the Rfb1 (128), Rfb2 (129) divider. The current of LED Panel (300) is corrected by the PWMic (120) by receiving in its current sense Is terminal a fraction of the the voltage collected across the sense resistor Rsled (360) via the Rvr2 (127). Vref2. The sub-circuit including Qctrl (431), Dzctrl (434) and the two resistors (432) and (433) performs a special feedback function, strongly related to the LED Panel (300) internal protection circuit.

As still embodied herein, internally the LED Panel (300) sub-circuit comprises three LED columns and a protection circuit comprising three constant current sinks and six diodes which secures the constant current for each LED column. Additionally, it offers a very simple and cost effective protection for "un-balanced LED columns", respectively a special protection for cases when one or more LEDs are damaged or not consistent in voltage versus current specs, with the others. Since the protection circuit is identical for all columns, for simplifying the description of this sub-circuit, only the first two columns LEDc1 (31 0) and LED (31 1) protection circuit will be fully described, considering that the same control method could be apply to many ("z") LED columns.

The LEDc1 column includes several LEDs coupled in series, having the anode of the first LED coupled to the positive supply terminal Vsl (301) and the cathode of the last LED coupled to the Iled (304) terminal, via a constant current sink device CCS1 (331) biased with a constant voltage received from the Vref terminal of the PWMic (120) controller chip. The Iled (304) terminal delivers the entire LED Panel (300) current to ground (55) terminal via the Rsled (360) sense resistor. Connected to the cathode of LEDc1 (310) last LED, there is a first diode D1+ (321) coupled with its cathode to the Vd+ (302) terminal and a second diode D1- (322) coupled to the Vd- (303) terminal.

Similarly for the LEDc2 (31 1) column, the anode of the first LED coupled also to the positive supply terminal Vsl (301) and the cathode of the last LED coupled also to the Iled (304) terminal, via a constant current sink device CCS1 (331) biased with a constant voltage received from the Vref (406) terminal. Connected to the cathode of LEDc2 (31 1) last LED, there is a first diode D1+ (321) coupled with its cathode to the Vd+ (302) terminal and a second diode D1- (322) coupled to the Vd- (303) terminal. The Vd+ (302) is coupled to the current sense Is terminal of the PWMic (120) via the Dzctrl (434)and the resistor (433) for decreasing the controller's driving signal duty cycle, and the output voltage at FBb (103), at any time when the Vd+ voltage amount exceeds the Dzctrl (434) zener diode nominal voltage.

The transistor Qctrl (431) acts as a differential error amplifier by having its emitter coupled to Vd+ (302), its base coupled to Vd- (303) via the resistor (432) and its collector coupled to the current sense Is terminal of the PWMic (120). Under normal operating conditions, if all LEDs included in the LEDd (310) column and also, all LEDs included in the LEDc2 (311) column have identical voltage versus current specifications and/or none of them is damaged, the voltage between Vd+ (302) and Vd- (303) terminals is supposed to be zero. However, as soon as something is wrong with only one LED included in any of the two columns, a difference of voltage will appear between the base and emitter of the Qctrl (432) and, if that voltage is higher than a pre-established amount, then the Qctrl (431) transistor's collector terminal will increase the voltage at the Is terminal of the PWMic (120) and eventually, the controller chip's driving signal will be shut down for preventing malfunctions or further damages in the LED lamp circuit.

Alternatively, the Qctrl (431) transistor's feedback could be used not to shut down the PWMic (120) controller chip, but only the damaged LED column, by shutting down the bias supply of the CCS circuit which connects that column to the Iled (304) terminal and in this way the damaged LED column cannot create further damages since it is practically completely disconnected from the LED panel (300) circuit.

This damages or inconsistency sensing method offers the advantage of achieving a very accurate control of as many LED columns as needed, in a large lighting system, without using expensive operational amplifiers, but only two very low cost silicon diodes, per each LED column, inserted on the LED panel circuit and, a four wire buss feedback circuit connected with the LED driver CVCC section, for securing the LEDs protection and long lifetime.

Additionally, two extra wires could be included in series with one of the LED driver AC supply to allow remotely control via external relays or switches.

This embodiment provides a superior double stage LED driver solution with respect to the related art, providing higher quality, lower parts count, lower board size longer lifetime and much lower cost, as summarized in Table 13 below:

Table 13. Single Stage Off-Line Boost LED Driver Comparison Chart

#	Parts & Performance	Intersil		Embodiment	
1	Parts Count (expensive)	**42**	*(11)*	**36**	*(6)*
2	ICs (opto couplers)	**3**	*(0)*	**1**	*(0)*
3	Transistors - *(FETs)*	**2**	*(1)*	**1**	*(1)*
4	Diodes- (bridge & *fast rec.)*	**13**	*(6)*	**12**	*(1)*
5	Capacitors - (electrolytic)	**11**	*(3)*	**5**	*(2)*
6	Inductors - *(Transformers)*	**2**	*(0)*	**2**	*(1)*
7	Resistors - *(high power)*	**19**	*(1)*	**15**	*(1)*
8	Efficiency (typ.)	**90%**		**93%**	
9	Power Factor (typ.)	**>0.9**		**0.995**	

Table 13. Single Stage Off-Line Boost LED Driver Comparison Chart					
10	A.THD (typ.)	**<20%**		**8%**	
11	LED Stripes CCS	**1**		**3**	
12	Board Size	**M**		**S**	
13	Cost (total)	**L**		**VL**	
14	Lifetime ***(years)***	**3**		**5**	

The main advantages versus the related art of this single stage off-line boost converter circuit embodiment consists in lower parts count and size, higher performance and lower cost. Additionally, the three LED stripes CCS allows for more output power and longer lifetime of the LED lamp retrofit which uses this more reliable LED driver circuit system solution.

EMBODIMENT 10

No Opto-Coupler Isolated Flyback LED Driver

Fig. 10 shows an embodiment of a no opto-coupler isolated flyback LED driver circuit.

Description of the connections

As embodied herein, a no opto-coupler isolated flyback LED driver circuit (200) comprises a direct current voltage source VDCin (201), which supplies the drain of a MOSFET transistor Mf (212) via a primary coil of a three coils flyback transformer Trf (210). The transformer Trf (210) has, besides one primary coil, one low current secondary coil and one large current secondary coil.

A snubber circuit SnC (220) including a Zener diode Dzsn (221) coupled in series with a rectifier diode Dsn (222), in such a manner that the cathode of Dzsn (221) is coupled to VDCin (201) and the anode of Dsn (222) is coupled to the drain of Mf (212). The drain of Mf (212) is attached across the Trf (210) primary coil. The low current coil of Trf (210) having one end coupled to an input ground terminal (55) and the other end coupled to the anode of a feedback diode Dvfb (251) which has its cathode coupled to (55) via a feedback capacitor Cvfb (252). The large current secondary coil of Trf (210) having one end coupled to an output ground terminal (65) and the other end coupled to the anode of a flyback diode Df (211), which has its cathode coupled to the output ground (65) via a filtering capacitor Cf3 (290) and in parallel, via a column of several LEDs coupled in series LEDc1 (310).

The Mf (212) has its source coupled to the input ground (55) via a sense resistor (232) and its gate coupled to a driving terminal of an eight terminal pulse width modulation integrated circuit PWMic (120) via a gate resistor (231). The PWMic (120) has a second terminal Vcc coupled to a DC supply terminal Vic (117). A third terminal Is is coupled to the Mf (212) drain via a resistor Isf (241) and to the input ground (55) via a capacitor (242). A fourth terminal GND is coupled to the input ground (55). A fifth terminal Osc is coupled to (55) via a capacitor Ct (124). A sixth terminal Vref is coupled to Osc via a resistor Rt (123) and to (55) via a capacitor Cr (122). A seventh terminal Comp is coupled to one terminal of a compensation capacitor Cc (130). An eighth terminal FB is coupled to the other terminal of the Cc (130).

A two terminals soft start over voltage control sub-circuit SSOVC (140) is coupled across the FB and the Comp terminals. The FB terminal is also coupled to the cathode of the Dvfb (251) via a first feedback resistor Rfb1 (128) and to (55) via a second feedback resistor Rfb2 (129). A four terminal VFCFB sub-circuit (260) has a first terminal Vsin coupled to the cathode of Dvfb (251). A second terminal Ctrl is coupled to the Comp terminal of PWMic 120. A third terminal Vrin is coupled to the Vref terminal of PWMic 120. A fourth terminal is coupled to the input ground (55).

Description of Flyback Converter

As further embodied herein, the PWM-f (200) main circuit is a conventional low cost high performance isolated DC flyback converter using a UC3842 controller, which can operate as a "second stage" sub-circuit, after a PFC boost converter, in off-line AC circuits, as well.

Two novel sub-circuits included in this flyback converter system, such as the SSOVC (140) (soft start and over-voltage control) and the VFCFB (voltage follower current feedback) increase, substantially, the performances and control capabilities of the UC3842 (120) chip, while reducing the parts count, size and cost of the entire system.

As still embodied herein, the UC3842 controller chip operates in its very conventional CCM (continuous conduction mode) of operations by delivering a PWM driving signal to the MOSFET buffer transistor Mf (212), which via the flyback transformer TRf (210), creates two output supply voltages. The two output supply voltages are: a) a high current supply voltage rectified by the diode Df (211) and filtered by the capacitor Cf3 (200) for supplying the LED stripe (310), and b) a low current feedback supply voltage signal rectified by the diode Dffb (251) and integrated by the capacitor Cvfb (252), to the controller chip (120) FB input via the two resistors divider Rfb1 (128), Rfb2 (129) and the compensation capacitor Cc (130).

The converter operating frequency is set by the resistor Rt (123) and the capacitor Ct (124) at the Osc terminal of the controller IC (120). The capacitor Cr (122) filters the 5V precise reference delivered by the controller (120) via its Vref output and the spikes of the current feedback signal collected by the Is input of the controller (120), from the sense resistor (232) coupled between the Mf (212) source terminal and the input ground (55) are filtered by a simple current spikes filter sub-circuit IsF (240), consisting of a resistor (241) and a capacitor (242).

The sense resistor (232) is calculated, in such a manner, to limit the MOSFET buffer (212) and implicitly the TRf (210) primary coil peak current to an amount lower than a dangerous limit at wich the Trf (210) secondary maxim current may damage the LEDs.

The two diodes and one low value capacitor SSOVC (140) sub-circuit, which has been introduced at the boost converter section of the previous embodiment's description, performs the same soft-start and overvoltage control job, improving the PWM chip (120) feedback control capability.

The VFCFB (260) sub-circuit comprises a zener diode Dzvf (264) which has its cathode coupled to the hot (not grounded) terminal of the capacitor Cvfb (252) and its anode coupled, simultaneously, to the base of a PNP transistor (261), to the input ground (55) via a first resistor Rvf- (263) and to the Vref output of the controller chip (120) via a second resistor Rvf+ (262). The PNP transistor (261) has its collector coupled to the input circuit ground (55) and its emitter coupled to the Comp terminal of the controller chip (120).

This simple and very low cost VFCFB (260) circuit eliminates the need for the complex and expensive circuit used, typically, in the load current feedback of the isolated flyback converter circuits, such as opto-coupler, error amplifier, voltage shunt reference, resistors and capacitors.

The method of using this circuit is based on the following considerations:

a) the flyback output voltage, over the LED stripe, is sensed and kept constant via the voltage feedback signal collected via the low current secondary of the flyback transformer;

b) the maximum current of TRf (21 0) is limited by the sense resistor (232);

c) the voltage and current range variation, within the ambient temperature are anticipated in the converter design's calculations; and

d) in conclusion, the only un-predictable fact which could happened is one or more LEDs included in the load stripe to fail, in short-circuit (i.e., near zero resistance and near voltage across), a fact which will cause a drop of the output voltage, followed by a proportional drop in the voltage feedback sense circuit, a fact which will force the controller IC (120) to increase the pulse duty cycle in order to "compensate" and to increase the output voltage, fact which will lead, finally, to irreversible damages of the remained working LEDs (310), the flyback transformer (210) and the MOSFET buffer (212).

Only in this unpredictable situation, the VFCFB sub-circuit operates as follows:

a) the zener diode (264) threshold voltage and the voltage in concert with the voltage created by the Rvf+ (262) and the Rvf- (263) resistors divider is calculate, in such a manner, for during the time the feedback voltage is in a pre-established range, the amount of voltage in the Qvf (261) base to be higher than the amount of voltage in the Comp terminal of the controller chip (120), so the Qvf (261) transistor to be blocked, having near zero emitter-collector current; and

b) when the voltage reference amount drops, significantly, confirming the failure of one or more LEDs in the load stripe, than the voltage at the base of Qvf (262) will drop accordingly, its emitter-collector current will increase and the controller chip's (120) Comp terminal voltage amount will decrease, keeping the controller (120) output driving signal at a low duty-cycle and, implicitly, limiting the output current al a lower level for protecting all the parts included in the high current section of the circuit.

This VFCFB (260) circuit is basically a "primary side current sensing circuit" following a different sensing method than all the other used in the related art.

This embodiment is not compared with the related art solutions because it represents only a low cost DC isolated flyback driver which requires a "first stage PFC boost", in order to operate in the off-line AC LED drivers' section.

EMBODIMENT 11

Single Stage Single Ground Flyback LED Driver

Fig. 11 shows an embodiment of a single stage single ground flyback LED driver circuit. This driver circuit includes many elements similar to the other embodiments presented above. Therefore, the description of this embodiment will be shorter, focused only to the new elements provided by this system embodiment.

Description Of Connections

As embodied herein, a single stage single ground flyback LED driver circuit comprises an AC-to-DC converter sub-circuit including an alternating current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53). The negative output of the bridge rectifier BR (53) is coupled to ground (55) and its positive output is coupled to a first filtering capacitor Cf1 (54).

From the output of the bridge rectifier BR (53) is supplied the drain of a MOSFET transistor Mf (212) via a primary coil of a three coils flyback transformer Trf (210) having, besides one primary coil, one low current secondary coil and one large current secondary coil.

A snubber circuit SnC (140) is coupled in parallel to the flyback transformer (210) primary coil.

The low current coil of Trf (210) having one end coupled to ground (55) and the other end coupled to the anode of a supply diode (115) which has its cathode coupled to (55) via a filtering capacitor (116).

The large current secondary coil of Trf (210) having one end coupled to ground (55) and the other end coupled to the anode of a flyback output diode Df (211) which has its cathode coupled to ground (55) via a filtering capacitor Cf3 (290) and in parallel, it supplies a column (stripe) of several LEDs, LEDc1 (310) coupled in series, via a current sense resistor Rsled (360), to ground (55).

The Mf (212) has its source coupled to ground (55) and its gate coupled to a driving terminal of an eight terminal pulse width modulation integrated circuit PWMic (120) via a gate resistor (231).

The PWMic (120) has a second terminal Vcc coupled to the cathode of the supply diode (115). A third terminal Is is coupled to ground (55) via a resistor Rvr2 (127) and to the emitter of a voltage ramp NPN transistor Qvr (55) via another resistor

Rvr1 (126). A fourth terminal GND is coupled to the system ground (55). A fifth terminal Osc is coupled to ground (55) via a capacitor Ct (124). A sixth terminal Vref is coupled to Osc via a resistor Rt (123) and to (55) via a capacitor Cr (122). A seventh terminal Comp is coupled to one terminal of a compensation capacitor Cc (130). An eighth terminal FB is coupled to the other terminal of the capacitor Cc (130).

A two terminal soft start over voltage control sub-circuit SSOVC (140) is coupled across the FB and the Comp terminals.

The FB terminal is also coupled to the cathode of the Dvfb (251) via a first feedback resistor Rfb1 (128) and to (55) via a second feedback resistor Rfb2 (129).

The voltage ramp NPN transistor Qvr has its collector coupled to the Vref terminal and its base is coupled to the OSC terminal of the PWMic (120).

An operational amplifier A3 (412) has one input coupled to ground (55) via the Rsled (360), the other input coupled via a first divider resistor (142) to ground (55) and via a second divider resistor to the Vref terminal of the PWMic (120) and the output of A3 (412) is coupled to the Comp terminal of the PWMic (120).

Description Of The Conventional Passive AC/DC Converter

The conventional AC-to-DC converter circuit, including the AC generator Vac (51), the low-pass filter EMI (52), the bridge rectifier BR (53) and the capacitor CF1 (54) provides an unregulated DC voltage across the capacitor CF1 (54) via the bridge rectifier BR (53) which has its negative output terminal coupled to ground (55) and its positive output terminal coupled to ground (55) via the first filtering capacitor Cf1 (54).

The EMI (52) filter is designed in such a manner to allow (low impedance for) the low frequency (typically, 50Hz-60Hz) currents to easily pass from the Vac generator to the PFC-b (100) sub-circuit and to stop (high impedance for) the high frequency (typically, 20kHz-200kHz) currents, generated inside of the LED driver circuit, to come back to the Vac (51) generator (i.e. back into the AC Electrical Power Grid).

The first filtering capacitor Cf1 (54) has a relatively low value (10nF - 200nF) for filtering high frequency currents but, on the other hand, to do not create significant distortions of the low fervency current and, implicitly, to decrease the entire system's power factor coefficient.

Description Of Flyback Converter

As further embodied herein, the PWM-f (200) main circuit is a conventional low cost high performance non-isolated flyback converter using at maximum the low cost UC3842 IC's capabilities to work, simultaneously, as a PFC controller, as well as a PWM controller, allowing the system to operate as a single stage single ground off-line AC LED driver.

The SnC (140) conventional snubber circuit functionality and importance have been also described above.

The NPN transistor Qvr operates in a conventional mode, providing a fraction of the voltage ramp signal collected from the Osc terminal to the Is terminal of the PWMic (120) via the Rv1 (126) and Rv2 (127) resistors, for limiting the controller's driving signal's duty cycle down to a pre-established limit.

The output voltage control is executed also in a conventional manner, in which the voltage provided by the low current secondary coil of the flyback transformer TRf (210) is used, simultaneously, as a supply voltage for the PWMic (120) and as voltage feedback signal, collected by the FB terminal of the PWMic (120), via the very precise voltage divider resistors Rfb1 (128) and RFb2 (129).

Two novel soft start and over-voltage control compensation sub-circuit SSOVC (140), which has been described above, secures a very fast and reliable compensation function, in such a manner that a very low cost PWM chip, such as UC3842 can work also as a very good quality PFC controller, if all the other sub-circuits of the system, as well as the mode of operation selected (CrCM) by the designer, concur for this accomplishment.

The operational amplifier A3 (412) is also performing a conventional function, by sensing the LEDc1 (310) stripe current with one of its inputs via Rsled, comparing it with a precise and constant, over temperature, reference voltage provided by the Vref terminal of PWMic (120). When the LEDc1 (310) current is higher than a pre-established limit, the A3 (412) output lowers the amount of voltage at the Comp terminal of PWMic (120), which decreases the duty-cycle of its driving pulses, accordingly, until the LED current decreases within the pre-established limits.

For lower cost and size applications, the operational amplifier A3 (412) could be replaced with a low cost NPN transistor or by coupling Rvr2 to ground (55) via Rsled (232), in such a manner for that the Is input of the PWMic (120) can control the output current. However, the accuracy of control will not reach the same quality.

As still embodied herein, in this off-line AC flyback configuration the UC3842 controller chip works in a constant frequency critical conduction mode (CrCM) mode of operation. This ideal topology allows the system to control very accurately, in a CVCC manner, the voltage and current across the LEDc1 (310) load, while the power factor of the converter remains over 0.99 for the time the controller chip (120) feedback and compensation sub-circuits provide a constant signal.

The UC3842 is one of the most used and reliable PWM controller IC. In this particular circuit, the UC3842 PWM controller IC has the benefit of receiving a very stable load voltage feedback, secured by the SSOVC (140) sub-circuit, and a very stable load current feedback, secured by a low cost good quality operational amplifier. Accordingly, this single stage single ground flyback LED driver circuit can compete in quality and reliability with any similar LED driver solution provided by reputable companies in the worldwide power management industry business.

This embodiment provides a superior single stage single ground off-line AC flyback LED driver solution with respect to the related art, providing higher quality, lower parts count, lower board size longer lifetime and much lower cost, as summarized in Table 14 below:

Table 14. Simple Stage Single Ground Flyback LED Driver Comparison Chart

#	Parts & Performance	Intersil		Embodiment	
1	Parts Count (expensive)	**53**	*(11)*	**27**	*(9)*
2	ICs (opto couplers)	**3**	*(0)*	**2**	*(0)*
3	Transistors - (*FETs*)	**2**	*(1)*	**2**	*(1)*
4	Diodes– (bridge & *fast rec.)*	**14**	*(6)*	**5**	*(3)*
5	Capacitors – (electrolytic)	**12**	*(3)*	**6**	*(3)*
6	Inductors - *(Transformers)*	**2**	*(0)*	**2**	*(1)*
7	Resistors - *(high power)*	**20**	*(1)*	**10**	*(1)*
8	Efficiency (typ.)	**>82%**		**>82%**	
9	Power Factor (typ.)	**>0.9**		**0.995**	
10	A.THD (typ.)	**<20%**		**8%**	
11	LED Stripes CCS	**1**		**1**	
12	Board Size	**M**		**S**	
13	Cost (total)	**M**		**V**	
14	Lifetime *(years)*	**3**		**3**	

The main advantage over the related art of this single stage off-line non-isolated converter circuit embodiment consists in lower parts count, size, higher performance and lower cost. Additionally, the controller chip used, the UC 3842 is the most cost effective good quality PWM chip, in the worldwide industry.

EMBODIMENT 12

Single Stage Constant Off Time Buck-boost LED Driver

Fig. 12 shows an embodiment of a single stage constant off time buck-boost LED driver circuit.

Description Of Connections

As embodied herein, a single stage constant off time buck-boost LED driver circuit comprises an AC-to-DC converter sub-circuit including an alternating current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output coupled to ground (55) and its positive output coupled to ground (55) via a first filtering capacitor Cf1 (54).

The output of the bridge rectifier BR (53) supplies the drain of a MOSFET transistor Mbb (512) via an LED column load LEDc1 (310) coupled in parallel to a primary coil of a two coils buck-boost transformer Lbb (510) having a primary high current coil and a low current secondary coil.

The low current secondary coil of Lbb (510) having one end coupled to ground (55) and the other end coupled to the anode of a supply diode (116) which has its cathode coupled to (55) via a filtering capacitor (115).

The Mbb (512) has its source coupled to ground (55) via a sense resistor (532) and its gate coupled to a driving terminal of an eight terminal pulse width modulation integrated circuit PWMic (120) via a gate resistor (531).

The PWMic (120) has a second terminal Vcc coupled to the cathode of the supply diode (116). A third terminal Is is coupled to ground (55) via a current spikes filter sub-circuit Isf (240) operatively coupled with the sense resistor (532). A fourth terminal GND is coupled to the system ground (55). A fifth terminal Osc is coupled to ground (55) via a capacitor Ct (124). A sixth terminal Vref is coupled to Osc via a resistor Rt (123) and to (55) via a capacitor Cr (122). A seventh terminal Comp is coupled to one terminal of a compensation capacitor Cc (130). An eighth terminal FB is coupled to the other terminal of the capacitor Cc (130).

A two terminal soft start over voltage control sub-circuit SSOVC (140) is coupled across the FB and the Comp terminals.

The FB terminal is also coupled to the collector of a voltage sense transistor Qvs (521) via a first feedback resistor Rfb1 (128) and to ground (55) via a second feedback resistor Rfb2 (129).

The voltage sense PNP transistor Qvs (521) together with a voltage sense resistor Rvs (523) coupled across its base-emitter junction and a zener diode coupled with the anode to the base of Qvs (521) and the cathode to the drain of Mbb (512) structure a differential voltage sense sub-circuit DVs (520).

A buck-boost diode Dbb (51 1) is coupled with the anode to the drain of Mbb (512) and with the cathode is coupled to the positive output of the bridge rectifier BR (53).

A buck-boost capacitor Cbb (514) is coupled across LEDc1 (310).

A starting resistor (Rst) is coupled from the positive output of BR (53) to the Vcc terminal of the PWMic controller (120).

A conventional two capacitors, three diodes and one resistor valley-fill filter sub-circuit VF-PCf (20) is couple operatively across the output terminals of BR (53).

A constant of time NPN transistor Qcot (541) has the emitter coupled to ground (55) the base coupled via a resistor Rcot (542) to the DRV terminal and the collector coupled to the Osc terminal of PWMic (120).

Description of the Conventional Passive AC/DC Converter

The conventional AC-to-DC converter circuit, including the AC generator Vac (51), the low-pass filter EMI (52), the bridge rectifier BR (53) and the capacitor CF1 (54) provides an unregulated DC voltage across the capacitor CF1 (54) via the bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output terminal coupled to ground (55) and its positive output terminal coupled to ground (55) via the first filtering capacitor Cf1 (54).

The EMI (52) filter is designed in such a manner to allow (low impedance for) the low frequency (typically, 50Hz-60Hz) currents to easily pass from the Vac generator to the PFC-b (100) sub-circuit and to stop (high impedance for) the high frequency (typically, 20kHz-200kHz) currents, generated inside of the LED driver circuit, to come back to the Vac (51) generator (i.e. back into the AC Electrical

Power Grid).

The first filtering capacitor Cf1 (54) has a relatively low value (10nF - 200nF) for filtering high frequency currents but, on the other hand, to do not create significant distortions of the low fervency current and, implicitly, to decrease the entire system's power factor coefficient.

Description Of The Constant Off Time (COT) Buck-boost Converter

As further embodied herein, this LED driver circuit operates as a high quality constant off time (COT) buck boost converter not by using an expensive conventional COT integrated circuit, but rather, by using a cost effective PWM chip such as the UC3842, which was not designed for such mode of operations, as a result of two significant improvements:

The first significant improvement consist in connecting a low cost NPN transistor, as a switch between ground (55) and the Osc terminal, controlled by the DRV output of PWMic (120) in such a manner, that at each time when the output of PWMic (120) is in its High state, the Qcot (541) transistor discharges the oscillator timing capacitor Ct (124), forcing the output driving pulse signal to have a constant OFF time, regardless of its momentarily ON time, controlled in a conventional PWM manner, in accordance to the voltage or current sensors signals.

The second significant improvement consists of the faster and more reliable SSOVC (140) compensation sub-circuit which allow the UC3842 chip to operate as well and reliable as an expensive chip designed for the COT mode of operations, only.

Other additional low cost sub-circuits, such as the valley fill filter (20), replacing a sophisticated and expensive PFC boost converter and the DVs (520) replacing another expensive voltage feedback circuit including an opto-coupler, an operational amplifier and a voltage shunt regulator make this solution ideal for the low cost market, especially for low power (1W-9W) LED lamp retrofits, where a cost effective valley fill filter can reach over 0.9 power factor and meet the Energy Star's requirements.

This embodiment provides a cost effective single stage constant off time buck-boost LED driver solution able to reach a lower cost even in competition with the South Asian LED driver providers, while offering superior performance and longer lifetime, as the summarized in Table 15 below:

Table 15: Single Stage COT Buck-boost LED Drivers Comparison Chart					
#	Parts & Performance	UTC (China)		Embodiment	
1	Parts Count (expensive)	**32**	*12*	**31**	*10*
2	ICs (opto couplers)	**1**	*(0)*	**1**	*(0)*
3	Transistors - *(FETs)*	**2**	*(2)*	**3**	*(1)*
4	Diodes- (bridge & *fast rec.)*	**11**	*(2)*	**9**	*(2)*
5	Capacitors - (electrolytic)	**10**	*(5)*	**8**	*(5)*
6	Inductors - *(Transformers)*	**2**	*(1)*	**2**	*(1)*
7	Resistors - *(high power)*	**6**	*(2)*	**8**	*(1)*
8	Efficiency (typ.)	**< 80%**		**< 83%**	
9	Power Factor (typ.)	**0.85**		**0.9**	
10	A.THD (typ.)	**<30%**		**< 20%**	
11	LED Stripes CCS	**1**		**1**	
12	Board Size	**M**		**M**	
13	Cost (total)	**L**		**L**	
14	Lifetime *(years)*	**2**		**3**	

The main advantage over the related art of this single stage COT buck-boost LED Driver circuit embodiment are: provides CVCC which increases the life time, higher efficiency by not supplying the chip directly from the high DC voltage and lower cost by using a cost effective controller IC and only one MOSFET transistor.

EMBODIMENT 13

Single Stage Single Ground Self Supply Buck-boost LED Driver

Fig. 13 shows an embodiment of a single stage single ground self supply buck-boost LED driver circuit.

Description Of Connections

As embodied herein, a single stage single ground self supply buck-boost LED driver circuit comprises an AC-to-DC converter sub-circuit including an alternating current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output coupled to ground (55) and its positive output coupled to ground (55) via a first filtering capacitor Cf1 (54).

The positive output of the bridge rectifier BR (53) supplies the drain of a

MOSFET transistor Mbb (512) via a buck-boost coil Lbb (510).

The Mbb (512) source is coupled to the negative output of the bridge rectifier BR (53).

A first buck-boost diode Dbb1 (51 1) has the anode coupled to Mbb (512) drain and the cathode coupled to the positive output of the bridge rectifier BR (53) via a first buck-boost capacitor Cbb1 (514) and to ground (55) via a second buck-boost capacitor Cbb2 (515).

A second buck-boost diode is coupled with its cathode to the bridge rectifier BR (53) positive output and with the anode to ground (55).

A start resistor Rst (1 14) is coupled from the negative terminal of the bridge rectifier BR (53) to ground (55).

The Mbb (512) receives driving signal across its gate source terminals via a secondary coil of ground separator transformer GS (520) which has the primary coil coupled with one terminal to GND (55) and the other terminal coupled to the driving terminal of an eight terminal controller chip PWMic (120) via a driving capacitor Cdrv (522).

The PWMic (120) has a second terminal Vcc coupled to the cathode of Dbb1 (51 1). A third terminal Is is coupled to ground (55) via a resistor Rvr2 (127) and to the emitter of a voltage ramp NPN transistor Qvr (125) via another resistor Rvr1 (126). A fourth terminal GND is coupled to the system ground (55). A fifth terminal Osc is coupled to ground (55) via a capacitor Ct (124). A sixth terminal Vref is coupled to Osc via a resistor Rt (123) and to (55) via a capacitor Cr (122). A seventh terminal Comp is coupled to one terminal of a compensation capacitor Cc (130). An eighth terminal FB is coupled to the other terminal of the capacitor Cc (130).

A two terminal soft start over voltage control sub-circuit SSOVC (140) is coupled across the FB and the Comp terminals.

The FB terminal is also coupled to the cathode of the Dbb1 (51 1) via a first feedback resistor Rfb1 (128) and to (55) via a second feedback resistor Rfb2 (129).

The voltage ramp NPN transistor Qvr has its collector coupled to the Vref terminal and its base is coupled to the OSC terminal of the PWMic (120).

A several LED column LEDc1 (310) is coupled directly to the cathode of Cbb1 and via a current sense resistor Rsled (360) to ground (360)

An operational amplifier A3 (412) has one input coupled to ground (55) via the Rsled (360), the other input coupled to a voltage reference Vref 2 and the output of A3 (412) is coupled to the Comp terminal of the PWMic (120).

Description Of The "Single Ground-Self Supply" Issues

As further embodied herein, historically the possibility to design a conventional buck-boost circuit which allows only one chip (i.e., a single stage topology) to convert from a higher voltage to a lower one and then to supply itself from that lower voltage, having access to the same zero voltage reference (or ground) with the load, did not look possible. Therefore, the worldwide designers came up with less efficient and/or more sophisticated topologies, such as Buck or SEPIC topologies, which allow the controller IC for direct (i.e., no opto-coupler) voltage feedback with respect to the load's momentary voltage or current amount.

The main issue for accomplishing such a single ground self supply in a conventional buck-boost topology consisted in the fact that such system would need an extra DC voltage, such as a battery, to provide start-up power supply to the controller chip, in parallel with a bulk capacitor and a high current resistive load, which would require a too large power, inefficient, "starting resistor", coupled to the main supply voltage.

As a simple example, for a 6W power buck-boost having a resistive load calculated for 1A at 6V, to create this voltage across the load and "start-up" a PWM chip capable of maintaining its own supply after "ignition", at a standard supply of 120V, the power dissipated by a start-up resistor would be 120V-6v x 1A = 114 W. In addition, a 200uF bulk capacitor across the load will require a minimum 20-50A of start-up current, a situation which further discourages this approach. This is true even if, eventually, after "ignition" the starting resistor is disconnected from the circuit via a high voltage programmable switch. This is because at that power range, the starting resistor would be larger in size than the entire converter circuit board.

Description Of The Start-Up Method And Procedure

Therefore, the approach used in this embodiment includes a "two steps start up" method, in which, besides the PWMic (120) controller and the buck-boost inductor (Lbb), six additional parts such as: the starting resistor Rst (114), the first buck-boost diode Dbb1 (51 1), the second buck-boost diode Dbb2 (516), the first buck-boost capacitor Cbb1 (514), the second buck-boost capacitor Cbb2 (514) and the load

LEDcl (310) are utilized for accomplishing the "single ground-self supply" goal, in a conventional buck-boost topology circuit.

As still embodied herein, when the single stage single ground self supply buck-boost LED driver circuit, subject of this specification, is connected to the AC line, a small power (0.25 W) starting resistor Rst (1 14) coupled between the negative terminal of the bridge rectifier BR (53) and ground (55) will close a current outputted by the positive terminal of the high voltage bridge rectifier (53) in a circuit including several parts, such as: the buck-boost inductor Lbb (510), the first buck-boost diode Dbb1 (51 1), the Vcc and GND supply terminals of PWMic (120) and ground (55).

Until a start up voltage of about 9V start-up required by the PWMic (120) arises across the low value (1uF-10uf) second buck-boost capacitor Cbb2 (515) and the PWMic (120) supply terminals, except the start-up current of less than 1mA, required by the chip, there is no other significant current in parallel, since the feedback resistor Rfb1 has a very large value (over 100k), the bulk capacitor Cbb1 (514) is not included in this circuit, the second buck-boost diode Dbb2 (516) is opposite polarized, the MOSFET buffer Mbb (512) is Off and the load, LEDc1 (310) is not a resistor, but a stripe of four or more LEDs which absorbs almost no current until the voltage across the stripe raises over twelve volts.

Description Of The Main Operation

As soon as the PWMic (120) receives its required nine volts supply and then starts oscillating, the MOSFET buffer Mbb receives a PWM signal at its gate via the ground separating transformer GS (520) and activates the buck-boost inductor Lbb (510) which supplies with a DC voltage, via the first buck-boost diode Dbb1, the bulk capacitor Cbb1 and via the second buck-boost diode Dbb2 (516) the second buck-boost capacitor Cbb2 (515) and the PWMic (120) controller chip.

Only after the voltage across the Cbb1 (514) rises above twelve volts, the LEDc1 (310) load start absorbing current and from this moment, the PWMic (120) maintains its supply and controls, directly its own supply voltage, and the LEDd (310) maxim voltage.

The operational amplifier A3 (412) provides a very accurate current feedback, however, it could be eliminated from the system, without losing much quality, in the manner described in the previous embodiment.

For a near unity power factor, the PWMic (120) circuit is set for a CrCM (critical conduction mode) of operation and the rest of the system operations are conventional and reliable.

Description Of The "Single Ground" Advantage

As still embodied herein, this LED driver circuit introduces a revolutionary step up with respect to the conventional buck-boost topology's main issue, respectively the ground of the system is no longer the negative terminal of the bridge rectifier BR (53). In contrast, the disclosed embodiment separates the MOSFET buffer transistor Mbb (512) and the BR (53) negative terminal via the GS (520) ground separator transformer. The ground of the system now becomes the same 0V reference of the LEDc1 (310) load and the GND terminal of the controller chip PWMic (120). This fact improves, dramatically, the control capability of the PWMic (120) chip over the LEDc1 (310) voltage and current parameters, by allowing direct and very reliable CVCC control and by eliminating the need for expensive, bulky and slower feedback opto-coupler, operational amplifier, voltage shunt regulator and several additional components, such as resistors, capacitors and diodes involved, typically, in feedback circuits having different grounds and/or zero voltage references.

Description Of The "Self Supply" Additional Advantages

Additional advantages of this "single ground, self supply" novel topology arise from the fact that the PWMic (120) chip is no longer supplied in the conventional way, by using a secondary coil added to the buck-boost inductor and a simple rectifying supply circuit, but directly from the LEDc1 (310) load's supply DC voltage, in parallel to the buck-boost inductor Lbb (510) and main buck-boost capacitor Cbb 2 (515). This fact offers, simultaneously, three other advantages:

a) eliminates the need for an additional supply circuit, comprising a secondary coil, a rectifier diode and an electrolytic capacitor;

b) receives robust and reliable supply directly from the output bulk capacitor; and

c) eliminates the risk of flicker which occurs, more often, when external dimmer control is used and the controller chip may stop and re-start its operations because of having insufficient supply voltage during a long OFF time of the dimmer, first, because the bulk capacitor has sufficient storing resources to remain charged for a longer period of time and, second, because the LEDc1 (310) stripe threshold (i.e. about 3V per LED) cannot discharge, completely, the output bulk capacitor, even when there is no AC supply voltage for a few minutes.

For this embodiment there is no need for a comparison chart with the related art, since the advantages of this solution are too obvious.

EMBODIMENT 14

Pseudo Double Stage Boost-Isolated Flyback LED Driver

Fig. 14 shows an embodiment of a pseudo double stage boost-isolated flyback LED Driver circuit.

Description Of The AC/DC Converter Connections

As embodied herein, a pseudo double stage boost-isolated flyback LED driver circuit comprises an AC to-DC converter sub-circuit including an alternative current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output coupled to ground (55) and its positive output coupled to ground (55) via a first filtering capacitor Cf1 (54).

Description Of Boost Converter Connections

A boost coil Lb (110) is coupled from the positive output of the bridge rectifier BR to the drain of a boost MOSFET transistor Mb (112) and to the anode of a boost diode Db (111) which has its cathode coupled to ground (55) via a second filtering capacitor Cf2 (190).

The boost MOSFET transistor Mb (112) source is coupled to ground (55) and its gate is coupled to a driving terminal (DRV) of an 8 terminals controller chip PWMic (120), via a gate resistor Rg (121).

Description Of The Flyback Converter Connections

As embodied herein, an isolated flyback LED driver circuit (200) comprises a direct current voltage source VDCin (201) which supplies the drain of a MOSFET transistor Mf (212) via a primary coil of a three coils flyback transformer Trf (210) having, besides one primary coil, one low current secondary coil and one large current secondary coil.

A snubber circuit (220) including a Zener diode Dzsn (221) coupled in series with a rectifier diode Dsn (222), in such a manner that the cathode of Dzsn (221) is coupled to VDCin (201) and the anode of Dsn (222) is coupled to the drain of Mf (212), which is attached across the Trf (210) primary coil.

The low current coil of Trf (210) having one end coupled to an input ground terminal (55) and the other end coupled to the anode of a feedback diode Dvfb (251) which has its cathode coupled to (55) via a feedback capacitor Cvfb (252).

The large current secondary coil of Trf (210) having one end coupled to an output ground terminal (65) and the other end coupled to the anode of a flyback diode Df (211) which has its cathode coupled to the output ground (65) via a filtering capacitor Cf3 (290) and in parallel, via a column of several LEDs coupled in series LEDc1 (310).

The Mf (212) has its source coupled to the input ground (55) via a sense resistor (232) and its gate coupled to a driving terminal of an eight terminal pulse width modulation integrated circuit PWMic (120) via a gate resistor (231). The PWMic (120) has a second terminal Vcc coupled to a DC supply terminal Vic (117). A third terminal Is is coupled to the Mf (212) drain via a resistor Isf (241) and to the input ground (55) via a capacitor (242). A fourth terminal GND is coupled to the input ground (55). A fifth terminal Osc is coupled to (55) via a capacitor Ct (124). A sixth terminal Vref is coupled to Osc via a resistor Rt (123) and to (55) via a capacitor Cr (122). A seventh terminal Comp is coupled to one terminal of a compensation capacitor Cc (130) and an eighth terminal FB coupled to the other terminal of the Cc (130).

A two terminal soft start over voltage control sub-circuit SSOVC (140) is coupled across the FB and the Comp terminals. The FB terminal is also coupled to the cathode of the Dvfb (251) via a first feedback resistor Rfb1 (128) and to (55) via a second feedback resistor Rfb2 (129).

A four terminal VFCFB sub-circuit (260) has a first terminal Vsin coupled to the cathode of Dvfb (251). A second terminal Ctrl is coupled to the Comp terminal of PWMic 120. A third terminal Vrin is coupled to the Vref terminal of PWMic

120. A fourth terminal is coupled to the input ground (55).

The Pseudo Double Stage Boost Flyback System Description

The boost coil Lb (110), boost diode Db (111), boost transistor Mb (112) and the second filtering capacitor Cf2 (190) perform the same function as the boost coil Lb (110), boost diode Db (111), boost transistor Mb (112) and the second filtering capacitor Cf2 (190) components previously described in connection with the embodiment section shown in Fig. 8 entitled "Double Stage Boost-Isolated Flyback Multi Columns LED Driver Embodiment", as fully described above.

Also the schematic diagram of the PWM-f (200) flyback converter circuit of this embodiment has been executed, in functionality, identical to the embodiment previously discussed in connection with Fig. 10 entitled "No Opto-Coupler Isolated Flyback LED Driver Embodiment". The embodiment of Fig. 10 is an illustration of the advantages provided by a revolutionary method of controlling double stage converter circuits using only one controller chip and two MOSFET buffer transistors.

As further embedded herein, a pseudo double stage boost-isolated flyback LED driver circuit, using one controller chip and two buffer switching transistors is capable of reaching similar performances regarding the power factor, efficiency, and low ripple output voltage as a conventional double stage converter circuit. Such advantages can be obtained when the boost inductor (or coil) and the flyback inductor are configured to boost outputted DC voltage across the second filtering capacitor Cf2 to be always higher than the peak voltage of the AC input, and also, sufficiently low so as not to exceed the maximum voltage of the high voltage switching transistor and diodes used in both converter circuits.

A "master-slave" control method is applied between the two stages in which the "master" is the flyback converter, compensating in feedback, at any time, the load momentary current amount requirements and the "slave" is the boost converter, compensating its output voltage, accordingly.

Since both converters are in phase regarding the output power, respectively when the LEDc1 (310) load requires higher current, for the same input power, the voltage across Cf2 (190) is supposed to decrease. However, the PWMic (120) controller chip increases immediately its driving pulse duty cycle to increase the flyback output current in the LEDc1 (310) load and, a larger duty cycle will increase, proportionally, the voltage across Cf2 (190), via Mb (112) and Lb (110). This procedure will provide an almost constant voltage across the second filtering capacitor Cf2.

By designing the coils for the CrCM (critical conduction mode) of operation, the system will feature near unity power factor, regardless of large variations of the load's current.

This revolutionary improvement reduces the component count, size, and cost of a LED driver by about 35-40%, without losing the main advantage of the bulky and expensive double stage topology, specifically a "low ripple output voltage" and implicitly, lower flickering of the LED lamp retrofit using such drivers.

For this embodiment there is no need for a comparison chart with the related art, since the advantages of this solution self evident.

EMBODIMENT 15

Pseudo Double Stage Boost Non-Isolated Flyback LED Driver

Fig. 15 shows an embodiment of a pseudo double stage boost non-isolated flyback LED Driver circuit.

Description Of The AC/DC Converter Connections

As embodied herein, the pseudo double stage boost non-isolated flyback LED driver circuit comprises an AC-to-DC converter sub-circuit including an alternative current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output coupled to ground (55) and its positive output coupled to ground (55) via a first filtering capacitor Cf1 (54).

Description Of Boost Converter Connections

A boost coil Lb (110) is coupled from the positive output of the bridge rectifier BR (54) to the anode of a first boost diode Db (111) which has its cathode coupled to ground (55) via a second filtering capacitor Cf2 (190) and to a second boost diode Db2 (601) which has its cathode coupled to the drain of a flyback MOSFET buffer transistor Mf (212) which drives a non isolated flyback converter.

Description Of The Flyback Converter Connections

The cathode of the first boost diode Db (111) supplies the drain of a MOSFET transistor Mf (212) via a primary coil of a three coils flyback transformer Trf (210) having, besides one primary coil, one low current secondary coil and one large current secondary coil.

A snubber circuit SnC (140) is coupled in parallel to the flyback transformer (210) primary coil.

The low current coil of Trf (210) having one end coupled to ground (55) and the other end coupled to the anode of a supply diode (115) which has its cathode coupled to (55) via a filtering capacitor (116).

The large current secondary coil of Trf (210) having one end coupled to ground (55) and the other end coupled to the anode of a flyback output diode Df (211) which has its cathode coupled to ground (55) via a filtering capacitor Cf3 (290) and in parallel, it supplies a column (stripe) of several LEDs , LEDc1 (310) coupled in series, via a current sense resistor Rsled (360), to ground (55).

The Mf (212) has its source coupled to ground (55) and its gate coupled to a driving terminal of an eight terminal pulse width modulation integrated circuit PWMic (120) via a gate resistor (231).

The PWMic (120) has a second terminal Vcc coupled to the cathode of the supply diode (115). A third terminal Is is coupled to ground (55) via a resistor Rvr2 (127) and to the emitter of a voltage ramp NPN transistor Qvr (55) via another resistor Rvr1 (126). A fourth terminal GND is coupled to the system ground (55). A fifth terminal Osc is coupled to ground (55) via a capacitor Ct (124). A sixth terminal Vref is coupled to Osc via a resistor Rt (123) and to ground (55) via a capacitor Cr (122). A seventh terminal Comp is coupled to one terminal of a compensation capacitor Cc (130). An eighth terminal FB is coupled to the other terminal of the capacitor Cc (130).

A two terminals soft start over voltage control sub-circuit SSOVC (140) is coupled across the FB and the Comp terminals.

The FB terminal is also coupled to the cathode of the Dvfb (251) via a first feedback resistor Rfb1 (128) and to (55) via a second feedback resistor Rfb2 (129).

The voltage ramp NPN transistor Qvr has its collector coupled to the Vref terminal and its base is coupled to the OSC terminal of the PWMic (120)

An operational amplifier A3 (412) has one input coupled to ground (55) via the Rsled (360), the other input coupled via a first divider resistor (142) to ground (55) and via a second divider resistor to the Vref terminal of the PWMic (120) and the output of A3 (412) is coupled to the Comp terminal of the PWMic (120).

The Pseudo Double Stage Boost Non Isolated Flyback System Description

The boost coil Lb (110), boost diode Db (111), and the second filtering capacitor Cf2 (190) perform the same function as the boost coil Lb (110), boost diode Db (111) and the second filtering capacitor Cf2 (190) parts previously described in connection with the embodiment shown in Fig. 8 entitled "Double Stage Boost-Isolated Flyback Multi Columns LED Driver Embodiment", as fully described above.

Also the schematic diagram of the non isolated flyback converter circuit of this embodiment has been executed, in functionality, identical to the embodiment previously discussed in connection with in Fig. 11 entitled "Single Stage Single Ground Flyback LED Driver Embodiment", which provides a better illustration of the advantages provided by a revolutionary method of controlling double stage converter circuits using only one controller chip and two MOSFET buffer transistors.

As further embedded herein, a pseudo double stage boost-isolated flyback LED driver circuit, using one controller chip and one buffer switching transistor, which via the second boost diode Db2 (601) is capable to reach similar performances regarding the power factor, efficiency, and low ripple output voltage as a conventional double stage converter circuit if the boost inductor (or coil) and the flyback inductor are designed in such a manner for the boost outputted DC voltage across the second filtering capacitor Cf2 to be always higher than the peak voltage of the AC input, but also, sufficiently low to not exceed the maximum voltage of the high voltage switching transistor and diodes used in both converter circuits.

The functionality of this pseudo double stage converter has been fully described at the previous embodiment section.

The only difference consists in the fact that the MOSFET buffer transistor has been replaced with a much less expensive, smaller size, and lower dissipation diode.

Similar to the previous embodiment, there is no need for a comparison chart with the related art here, since the advantages of this solution are obvious.

EMBODIMENT 16

Pseudo Double Stage Boost-COT Buck-boost LED Driver

Fig. 16 shows an embodiment of a pseudo double stage boost constant off time buck-boost LED Driver circuit.

Description Of The AC/DC Converter Connections

As embodied herein, a pseudo double stage boost constant off time buck-boost LED driver circuit comprises an AC to DC converter sub-circuit including an alternative current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output coupled to ground (55) and its positive output coupled to ground (55) via a first filtering capacitor Cf1 (54).

Description Of Connections

As further embodied herein, a pseudo double stage boost constant off time buck-boost LED driver circuit comprises an AC to DC converter sub-circuit including an alternative current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output coupled to ground (55) and its positive output coupled to (55) via a first filtering capacitor Cf1 (54).

The drain of a MOSFET boost buffer transistor Mb (112) is supplied from the positive output of the bridge rectifier BR (53) via a primary coil of a boost inductor Lb (110), which is also coupled with the anode of a boost diode Db (111) which has the cathode coupled to ground via second filtering capacitor Cf2 (190).

The Mb (112) source is coupled to ground (55) and the gate is coupled to the driving output of a controller chip PWMic (120) via a gate resistor (121).

The secondary coil of the boost inductor Lb (110) has one terminal coupled to ground (55) and the other terminal coupled to the anode of a supply diode Dvcc (115) which has the cathode coupled to ground via a supply capacitor Cvcc (116) and to the positive output of the bridge rectifier via a start resistor Vst (114) and to the Vcc terminal of the eight terminals controller chip PWMic (120).

The drain of a buck-boost MOSFET transistor Mbb (512) is supplied from the cathode of the boost diode Db (111) via a buck-boost coil Lbb (510) coupled in series with a LEDs column load LEDc1 (310).

The Mbb (512) has its source coupled to ground (55) via a sense resistor (532) and its gate coupled to a driving terminal of an eight terminal pulse width modulation integrated circuit PWMic (120) via a gate resistor (531).

The PWMic (120) has a second terminal Vcc coupled to the cathode of the supply diode (115). A third terminal Is is coupled to ground (55) via a one resistor one capacitor current spikes filter sub-circuit Isf (240) operatively coupled with the sense resistor (532). A fourth terminal GND is coupled to the system ground (55). A fifth terminal Osc is coupled to ground (55) via a capacitor Ct (124). A sixth terminal Vref is coupled to Osc via a resistor Rt (123) and to (55) via a capacitor Cr (122). A seventh terminal Comp is coupled to one terminal of a compensation capacitor Cc (130). An eighth terminal FB is coupled to the other terminal of the capacitor Cc (130).

A two terminal soft start over voltage control sub-circuit SSOVC (140) is coupled across the FB and the Comp terminals.

The FB terminal is also coupled to the collector of a voltage sense transistor Qvs (521) via a first feedback resistor Rfb1 (128) and to ground (55) via a second feedback resistor Rfb2 (129).

The voltage sense PNP transistor Qvs (521) together with a voltage sense resistor Rvs (523) coupled across its base-emitter junction and a zener diode coupled with the anode to the base of Qvs (521) and the cathode to the drain of Mbb (512) structure a differential voltage sense sub-circuit DVs (520).

A buck-boost diode Dbb (511) is coupled with the anode to Mbb (512) drain and with the cathode to the positive output of the cathode of the boost diode (111)

A buck-boost capacitor Cbb (514) is coupled across LEDc1 (310).

A constant off time NPN transistor Qcot (540) has the emitter coupled to ground (55) the base coupled via a resistor Rcot (542) to the DRV terminal and the collector coupled to the Osc terminal of PWMic (120).

The Pseudo Double Stage Boost Non Isolated Flyback System Description

The boost coil Lb (110), boost diode Db (111), boost transistor Mb (112) and the second filtering capacitor Cf2 (190) are performing the same function as the boost coil Lb (110), boost transistor (112), boost diode Db (111) and the second filtering capacitor Cf2 (190) parts previously described in connection with the embodiment shown in Fig. 8 entitled "Double Stage Boost-Isolated Flyback Multi Columns LED Driver Embodiment", as fully described above.

Also the schematic diagram of the COT buck-boost converter circuit of this embodiment has been executed, in purpose, identical to the one shown, previously, in Fig 12 entitled "Single Stage Single Constant Off Time Buck-boost LED Driver Embodiment", for a better illustration of the advantages provided by a revolutionary method of controlling double stage converter circuits using only one controller chip and two MOSFET buffer transistors.

The method and functionality of a pseudo double stage converter has been fully described at the previous embodiment section.

The only difference consists in replacing the passive valley-fill filter sub-circuit VF-PCf (20) with a higher performance active PFC circuit including the boost coil Lb (110), boost diode Db (111), boost transistor Mb (112) and the second filtering capacitor Cf2 (190) .

Similar to the previous embodiment, there is no need for a comparison chart with the related art here, since the advantages of this solution self evident.

EMBODIMENT 17

Pseudo Double Stage Boost Single Ground Self Supply Buck-boost LED Driver

Fig. 17 shows an embodiment of a pseudo double stage boost single ground self supply buck-boost LED Driver circuit.

Description Of Connections

As embodied herein, a pseudo double stage boost single ground self supply buck-boost LED Driver circuit comprises an AC-to-DC converter sub-circuit including an alternative current generator Vac (51), a low pass filter EMI (52) having its input coupled to Vac (51) and the output coupled to the AC input of a bridge rectifier BR (53). The bridge rectifier BR (53) has its negative output coupled to ground (55) and its positive output coupled to (55) via a first filtering capacitor Cf1 (54).

A boost coil Lb (110) is coupled with one terminal to the positive output of the bridge rectifier BR (53) and the other one to the anode of a first boost diode Db (111) and to the anode of a second boost diode Db2 (119).

The cathode of Db (111) is coupled with a first terminal of a buck-boost coil Lbb (510) and to the cathode of a second buck-boost diode Dbb2 (516) and to a first terminal of a first buck-boost capacitor Cbb1 (514).

The anode of Dbb2 is coupled to ground (55).

The other terminal of Cbb1 (514) is coupled to the cathode of a first buck-boost diode which has its anode coupled with the second terminal of Lbb (510) and to the drain of the Mbb (512) transistor.

A second buck-boost capacitor Cbb2 is coupled between the cathode of Dbb1 (511) and ground (55).

A second boost diode Db2 (119) is coupled with its cathode to the drain of Mbb (512) and with its anode to the anode of Db (111) and to the second terminal of Lb (110). A starting resistor is coupled between the negative terminal of BR (53) and ground (55).

The second terminal of Lbb (510) is coupled to the anode of a first buck-boost diode Dbb (511) and to the drain of a MOSFET transistor Mbb (512).

The MOSFET transistor Mbb (512) has its source coupled to the negative terminal of BR (53) and receives driving signal across its gate source terminals via a secondary coil of a ground separator transformer GS (520).

The primary coil of Gs (520) has one terminal coupled to ground (55) and the other terminal coupled, via a driving capacitor Cdrv (522) to a driving terminal of a eight terminals controller chip PWMic (120).

The PWMic (120) has a second terminal Vcc coupled to the cathode of Dbb1 (511). A third terminal Is is coupled to ground (55) via a resistor Rvr2 (127) and to the emitter of a voltage ramp NPN transistor Qvr (125) via another resistor Rvr1 (126). A fourth terminal GND coupled to the system ground (55). A fifth terminal Osc coupled to ground (55) via a capacitor Ct (124). A sixth terminal Vref coupled to Osc via a resistor Rt (123) and to (55) via a capacitor Cr (122). A seventh terminal Comp coupled to one terminal of a compensation capacitor Cc (130). An eighth terminal FB coupled to the other terminal of the capacitor Cc (130).

The FB terminal is also coupled to the cathode of the Dbb1 (511) via a first feedback resistor Rfb1 (128) and to ground (55) via a second feedback resistor Rfb2 (129).

The voltage ramp NPN transistor Qvr has its collector coupled to the Vref terminal and its base is coupled to the OSC terminal of the PWMic (120).

A several LEDs column LEDc1 (310) is coupled directly to the cathode of Cbb1 and via a current sense resistor Rsled (360) to ground (55).

Description Of The "Single Ground-Self Supply" Issues

As further embodied herein, historically the possibility to design a conventional buck-boost circuit which allows only one chip (i.e., a single stage topology) to do the conversion from a higher voltage to a lower one and than to supply itself from that lower voltage, having access to the same zero voltage reference (or ground) with the load, did not look possible. Therefore, the worldwide designers came with less efficient and/or more sophisticated topologies, such as Buck, or SEPIC, which allow the controller IC for direct (i.e., no opto-coupler) voltage feedback with respect to the load's momentary voltage or current amount.

The main issue for accomplishing such a single ground self supply in a conventional buck-boost topology consisted in the fact that such system would need an extra DC voltage, such as a battery, to provide start-up power supply to the controller chip, in parallel with a bulk capacitor and a high current resistive load, which would require a too large power, and inefficient, "starting resistor", coupled to the main supply voltage.

As a simple example, for a 6W power buck-boost having a resistive load calculated for 1A at 6V, to create this voltage across the load and "start-up" a PWM chip capable of maintaining its own supply after "ignition", at a standard supply of 120V, the power dissipated by a start-up resistor would be 120V-6v x 1A = 114 W. In addition, a 200uF bulk capacitor across the load will require a minimum 20-50A of start-up current, a situation which further discourages this approach. This is true even if, eventually, after "ignition" the starting resistor is disconnected from the circuit via a high voltage programmable switch. This is because at that power range, the starting resistor would be larger in size than the entire converter circuit board.

Description Of The Start-Up Method And Procedure

Therefore, the approach used in this embodiment includes a "two step start up" method, in which, besides the PWMic (120) controller and the buck-boost inductor (Lbb), six additional parts such as: the starting resistor Rst (114), the first buck-boost diode Dbb1 (511), the second buck-boost diode Dbb2 (516), the first buck-boost capacitor Cbb1 (514), the second buck-boost capacitor Cbb2 (514) and the load LEDc1 (310) are concurring for accomplishing the "single ground-self supply" goal, in a conventional buck-boost topology circuit.

As still embodied herein, when the single stage single ground self supply buck-boost LED driver circuit, subject of this invention, is connected to the AC line, a small power (0.25 W) starting resistor Rst (114) coupled between the negative terminal of the bridge rectifier BR (53) and ground (55) will close a current outputted by the positive terminal of the high voltage bridge rectifier (53) in a circuit including several parts, such as: the buck-boost inductor Lbb (510), the first buck-boost diode Dbb1 (511), the Vcc and GND supply terminals of PWMic (120) and ground (55).

The Pseudo Double Stage Boost Single Ground Buck-boost System Description

The boost converter mode of operations have been fully described in connection with the embodiment shown in Fig. 8 entitled "Double Stage Boost-Isolated Flyback Multi Columns LED Driver Embodiment", and in this embodiment circuit the Db2 (119) replace the MOSFET boost buffer transistor Mb (112).

Also the schematic diagram of the single ground buck-boost converter circuit of this embodiment has been executed, in purpose, identical to the embodiment previously shown in connection with Fig. 13 entitled "Single Stage Single Ground Self supply Buck-boost LED Driver Embodiment", for a better illustration of the advantages provided by a revolutionary method of controlling double stage converter circuits using only one controller chip and one MOSFET buffer transistor.

The method and functionality of a pseudo double stage converter and single ground self supply novel techniques have been fully described in the previous embodiments presentation.

For this embodiment there is also no need for a comparison chart with the related art, since the parts count, size, performance and cost advantages of these solutions self evident.

15. Description of the Monolithic LED Driver Embodiments

Introduction

This embodiments description section, of the present specification, comprises twenty (20) solid state ("monolithic") LED driver circuit solution embodiments capable to supersede all the other similar topology LED driver solutions depicted above, at the related art section, by the means of several novel control methods and/or novel sub-circuit systems used in each of these particular LED driver embodiments.

None of the worldwide top manufacturers in the power management semiconductor industry are yet, visibly, involved in this very new and promising LED drivers technology except Samsung, Seoul Semiconductor Exclara, Supertex, and a few other "pioneers", which advertise their products under different presentation names, such as AC LED Lamps, or Solid State LED Lamps, or Single Chip LED Lamps, or Sequential LED Drivers, all names which are not sufficiently clear (i.e., the SMPS LED lamps could be called AC LED Lamps, or Single Chip LED Lamps or Solid State LED Lamps) and/or do not depict, exhaustively, the purpose and final goal of this new device, respectively, a compact, tiny or one piece LED lamp.

Therefore, in accordance with the present specification, the term "monolithic" is used because it is more generic and representative for a device, which eventually, could become a very tiny and low cost lighting device, having only two supply terminals and a conventional screw AC adaptor, similar to the existing Edison bulbs today, about which nobody cares what kind of technology is used inside, as long as good quality light is achieved.

The LED devices cannot be connected, directly, to the 120-240Vac standard electrical power line, nor to a 12Vdc automobile battery, like all the conventional bulbs, because they are semiconductor (solid state) devices requiring a precise limited current which establishes a voltage of 2.8V - 3.5V, per each typical Galium Nitride (GaN) LED unit. Because of this issue, a LED lamps retrofit may comprise one or more LED units, connected in series or parallel circuits, in such a manner to be compatible with their supply source, and being also "diodes", they require a rectifier circuit for operating in AC systems.

By considering the LED devices requirement for precise current/voltage control, there is needed a "supply adaptor" for being connected, safely, to an unregulated DC or AC electrical supply line and, as presented in the introduction herein, these adaptors could be ballast, SMPS or monolithic driver devices, each of them having particular advantages and shortcomings.

With respect to the monolithic drivers objectives and design issues, which represent the main subject of this patent application's chapter, conventional devices such as the bulky coils and capacitors are obviously out of discussion, because, by definition, monolithic means "one piece", a term which is used currently for "full custom designed" chips, versus "hybrid" chips, which are not called monolithic, but "multi-chips modules" (MCM).

Coils and capacitors are the only known reactive components capable of storing and converting an unregulated voltage line in a constant voltage and/or constant current supply line. There are no monolithic devices, designed specifically for reducing a 120-240Vac supply line down to a 4-20Vdc supply, suitable for one or several LED devices coupled in series, other than either the thyristor (the SCR, silicon controlled rectifier), invented over 30 years ago, and the Benistor, introduced in 1997 - 1999 in two US patents and technical magazines (see related art).

Nevertheless, many other complex sequential switching systems using "capacitive pump charge" circuits and/or other sophisticated digital voltage controlled switching systems, can also perform this voltage conversion, efficiently, however in many situations, very complex systems are less reliable and more expensive.

Therefore, in this section of the specification, some of the embodiments presented herein will be based on the Benistor's concept of controlling, efficiently, the transfer of electrical energy from an AC or DC source to a load, and some of them will go beyond that, revealing novel methods and/or original systems for controlling, specifically, these very efficient but also very fragile and non-linear LED devices.

All the theoretical or practical embodiments presented below have one final goal: "the ultimate lighting device" built as a very low cost monolithic chip able to be embedded in a LED array wafer lamp retrofit, coupled directly, via two wires only, to the standards 50-60 Hz, 120V-240V AC line and featuring efficiency over 90%, power factor over 0.99 and A.THD lower than 10%.

EMBODIMENT 18

Monolithic LED Driver - The Series Circuit Method

Fig. 18a shows an embodiment of a four Benistor series monolithic

LED driver block schematic circuit. **Fig. 18b** shows a series of current/voltage graphs obtained from the Benistor monolithic LED driver shown in FIG. 18a.

Prior to describing the remaining embodiments comprising a Benistor component, the present specification now turns briefly to **Figs. 38-40,** hereinbelow, for a discussion of the internal structure and functionality of one embodiment of a Benistor device.

Description of the Components Connections

As embodied herein, this monolithic LED driver circuit comprises a minimum parts AC-to-DC converter sub-circuit including a bridge rectifier BR (53) operatively coupled to an AC voltage generator Vac (51) for providing an unfiltered DC pulse voltage at its positive output terminal Vin, with respect to its negative output terminal coupled to ground (53), and four a four Benistor LED driver sub-circuit comprising:

(a) A first eight terminal Benistor Sw1 (601) comprising:

- a first anode "A" terminal coupled to Vin;

- a second cathode "K" terminal coupled to the anode of a first LEDs column LEDc1 (721);

- a third voltage sense "Vs" terminal coupled to the anode A terminal of SW1 (601);

- a fourth voltage set terminal "Von" coupled to the positive terminal of a DC voltage source (613) having its negative terminal coupled to a "ZVR" terminal of Sw1 ;

- a fifth voltage set terminal "Voff" coupled to the positive terminal of a DC voltage source (614) having its negative terminal coupled to a "ZVR" terminal of Sw1 ;

- a sixth current set terminal "Cc" coupled to the cathode of LEDc1 (721) and a first terminal of a first current sense resistor Rc1 (722);

- a seventh feedback terminal "FB" coupled to a feedback terminal of a second eight terminal Benistor Sw2 (602); and

- an eighth zero voltage reference terminal "ZVR" coupled with the second terminal of Rc1 (722).

(b) A second eight terminal Benistor Sw2 (602) comprising:

- a first anode "A" terminal coupled to Vin;

- a second cathode "K" terminal coupled to the second terminal of Rc1 (722) and the anode of a second LEDs column LEDc2 (722);

- a third voltage sense "Vs" terminal coupled to the anode A terminal of SW2 (602);

- a fourth voltage set terminal "Von" coupled to the positive terminal of a DC voltage source (623) having its negative terminal coupled to a "ZVR" terminal of Sw2;

- a fifth voltage set terminal "Voff" coupled to the positive terminal of a DC voltage source (624) having its negative terminal coupled to a "ZVR" terminal of Sw2;

- a sixth current set terminal "Cc" coupled to the cathode of LEDc2 (731) and a first terminal of a second current sense resistor Rc2 (732);

- a seventh feedback terminal "FB" coupled to a feedback terminal of a third eight terminal Benistor Sw3 (603); and

- an eighth zero voltage reference terminal "ZVR" coupled with the second terminal of Rc2 (732),

(c) A third eight terminal Benistor Sw3 (603) comprising:

- a first anode "A" terminal coupled to Vin;

- a second cathode "K" terminal coupled to the anode of a third LEDs column LEDc3 (741);

- a third voltage sense "Vs" terminal coupled to the anode A terminal of SW3 (603);

- a fourth voltage set terminal "Von" coupled to the positive terminal of a DC voltage source (633) having its negative terminal coupled to a "ZVR" terminal of Sw3;

- a fifth voltage set terminal "Voff" coupled to the positive terminal of a DC voltage source (634) having its negative terminal coupled to a "ZVR" terminal of Sw3;

- a sixth current set terminal "Cc" coupled to the cathode of LEDc3 (741) and a first terminal of a first current sense resistor Rc3 (742);

- a seventh feedback terminal "FB" coupled to a feedback terminal of a fourth eight terminal Benistor Sw4 (604); and

- an eighth zero voltage reference terminal "ZVR" coupled with the second terminal of Rc3 (742).

(d) A fourth eight terminal Benistor Sw4 (604) comprising:

- a first anode "A" terminal coupled to Vin;

- a second cathode "K" terminal coupled to the anode of a fourth LEDs column LEDc4 (751);

- a third voltage sense "Vs" terminal coupled to the anode A terminal of SW4 (604);

- a fourth voltage set terminal "Von" coupled to the positive terminal of a DC voltage source (643) having its negative terminal coupled to a "ZVR" terminal of Sw4;

- a fifth voltage set terminal "Voff" coupled to the positive terminal of a DC voltage source (644) having its negative terminal coupled to a "ZVR" terminal of Sw4;

- a sixth current set terminal "Cc" coupled to the cathode of LEDc4 (751) and a first terminal of a fourth current sense resistor Rc4 (752);

- a seventh feedback terminal "FB" coupled to the feedback terminal of the third eight terminal Benistor Sw2 (603); and

- an eighth zero voltage reference terminal "ZVR" coupled with the fourth terminal of Rc4 (752) and system ground (55).

Description Of The Benistor Functionality

As still embodied herein, a Benistor is a multi-terminals controllable electron valve (an upgraded monolithic solid state version of old vacuum tubes such as pentodes or hexodes) which, in this particular configuration has eight terminals, such as:

1) An A (Anode or Vin) power input terminal which is, typically, connected to the supply source's output;

2) A K (Cathode or Vout) power output terminal, which is, typically, connected to the load;

3) A Vs terminal sensing the voltage of the Anode, Cathode or any other node of the system;

4) A Von low power input terminal which activates (switch ON) an internal switch between the Anode and Cathode only during the time when the Vs voltage amount is higher than the voltage amount applied at the Von terminal;

5) A Voff low power input terminal which des-activates (switch OFF) the internal switch between the Anode and Cathode during the time when the

Vs voltage amount is higher than the voltage amount applied at the Voff terminal;

6) A Cc low power input terminal which forces the Anode-Cathode ("AK") junction of the Benistor to operate linearly and decrease the external circuit current, in a ratio proportional to the increasing voltage applied at the Cc terminal, in such a manner that, gradually, when the voltage applied to Cc is 0V, the AK junction has no resistance (0 ohms) allowing the maximum current required by the load and when the voltage applied to Cc is 1V or higher, the AK junction has infinite resistance (10 Mohms) limiting the load's current near zero;

7) A FB low power feedback terminal which, typically, is connected to other Benistors feedback terminal with the purpose to "smoothly synchronize" the ON-OFF switching operations, in order to avoid gaps in the circuit main current and prevent an unnecessary increase of noise and, implicitly, of the A.THD parameter, fact that create a decrease of the entire system power factor parameter; and

8) A "ZVR" low current zero voltage reference terminal which is, typically, coupled to the ground of the system but, in some situation it can be used for forcing the Benistor to become a constant current sync ("CCS") by inserting a resistor in its circuit.

Description Of The LED Driver Functionality

As yet embodied herein, a four Benistors series LED driver circuit shown in Fig. 18a can control, in a CVCC (constant voltage constant current) manner, a 120-240Vac LED lamp retrofit lighting panel, comprising four stripes of LEDs, under very high efficiency and near unity power factor, in a self-switching mode of operations (i.e., Benistors do not require external components such as coils or capacitors to generate periodical ON-OFF oscillations), by forcing the LED lamp retrofit's main current to follow a sine wave graph shape, in phase with the supply voltage's graph shape (for achieving PF > 0.99), as it is illustrated in Fig. 18b, Current/Voltage Graphs, section E.

This performance is accomplished, on the one hand, by setting properly the voltage amount of each DC voltage source applied to the Von and Voff voltage control inputs of each Benistor (613 to 644), for delivering the right voltage to each of the four LED stripes and, on the other hand, by selecting the right value of the current sense resistors (Rc1 to Rc4) for the current control inputs of each

Benistor to limit each LED stripe current in accordance to pre-established limits.

As the graph presented at section D of Fig. 18b shows, during the time when the supply input AC voltage (120Vrms means 170Vpeak) increases, from zero to about 33V, only the fourth Benistor Sw4 (604) is switched ON, allowing an increasing current to cross the fourth LEDs column LEDc4 (651), comprising 11 LEDs having 3V/LED threshold, until the current reaches a pre-established limit, than the LEDc4 (651) stripe current is limited by the Cc terminal of the forth Benistor SW4 (604) until the supply voltage increases to about 66V, reaching the next 10 LEDs stripe, LEDc3 (741) threshold voltage, moment when the feedback FB terminals of Sw4 (604) and Sw3 (603) allows, smoothly, the transfer of control from the fourth Benistor to the third one, respectively the Sw4 (604) switches OFF and the Sw3 (603) switches ON and from this moment until the supply voltage reaches 99V, the Cc current control terminal limits the current of both LED stripes LEDc4 (651) and LEDc3 (741) to a higher amount established by the value of the third current sense resistor Rc3 (742).

In this manner, when the AC supply voltage reaches its 170V peak value, only the first Benistor Sw1 (601) is switched ON and its Cc terminal limits the current of all four stripes down to a pre-established amount calculated for 5W, 10W or 100W LED lamp retrofits.

When the voltage starts decreasing, back to zero, the process is reversed in such a manner that, with the exception of short transit time periods, when the Benistors transfer the control, smoothly, to each-other only one Benistor is ON and all the others are OFF.

When the calculation of the number of LEDs per stripe is done correctly, the efficiency of this system can exceed 96%, superseding absolutely all the SMPS LED driver topologies existing in the industry.

By considering the top performance, low component count down to "one chip driver", miniature size, virtually unlimited life, the possibility to be embedded in an LED array module and very low manufacturing cost of this kind of drivers, evidently these devices have good chances to become the future "Ultimate LED Lamp Retrofits".

EMBODIMENT 19

Monolithic LED Driver - The Parallel Circuit Method

Fig. 19a shows an embodiment of a four Benistor parallel monolithic LED driver block schematic circuit. **Fig. 19b** shows a series of current/voltage graphs obtained from the Benistor monolithic LED driver shown in FIG. 19a.

Description Of The Components Connections

As embodied herein, a monolithic LED driver circuit comprises a minimum parts AC-to-DC converter sub-circuit including a bridge rectifier BR (53) operatively coupled to an AC voltage generator Vac (51) for providing an unfiltered DC pulse voltage at its positive output terminal Vin, with respect to its negative output terminal coupled to ground (53), and a four Benistors LED driver sub-circuit.

The four Benistors LED drive sub-circuit comprises:

(a) A first eight terminal Benistor Sw1 (601) comprising:

- a first anode "A" terminal coupled to the cathode of a first LEDs column LEDc1 (721), which has the anode coupled to Vin;

- a second cathode "K" terminal coupled to a first current sense resistor Rc1 (722) which has the other terminal coupled to ground (55);

- a third voltage sense "Vs" terminal coupled to Vin;

- a fourth voltage set terminal "Von" coupled to the positive terminal of a DC voltage source (613) having its negative terminal coupled to ground (55);

- a fifth voltage set terminal "Voff" coupled to the positive terminal of a DC voltage source (614) having its negative terminal coupled to ground (55);

- a sixth current set terminal "Cc" coupled also to the first terminal of Rc1 (722);

- a seventh feedback terminal "FB" coupled to a feedback terminal of a second eight terminal Benistor Sw2 (602); and

- an eighth zero voltage reference terminal "ZVR" coupled to ground (55).

(b) A second eight terminal Benistor Sw2 (602) comprising:

- a first anode "A" terminal coupled to the cathode of a second LEDs column LEDc2 (731), which has the anode coupled to the cathode of LEDc1 (721);

- a second cathode "K" terminal coupled to a second current sense resistor Rc2 (722) which has the other terminal coupled to ground (55);

- a third voltage sense "Vs" terminal coupled to Vin;

- a fourth voltage set terminal "Von" coupled to the positive terminal of a DC voltage source (623) having its negative terminal coupled to ground (55);

- a fifth voltage set terminal "Voff" coupled to the positive terminal of a DC voltage source (624) having its negative terminal coupled to ground (55);

- a sixth current set terminal "Cc" coupled also to the first terminal of Rc2 (732);

- a seventh feedback terminal "FB" coupled to the FB terminal of Sw1 (601); and

- an eighth zero voltage reference terminal "ZVR" coupled to ground (55).

(c) A third eight terminal Benistor Sw3 (603) comprising:

- a first anode "A" terminal coupled to the cathode of a third LEDs column LEDc3 (741), which have the anode coupled to the cathode of LEDc2 (731);

- a second cathode "K" terminal coupled to a third current sense resistor Rc3 (742) which has the other terminal coupled to ground (55);

- a third voltage sense "Vs" terminal coupled to Vin;

- a fourth voltage set terminal "Von" coupled to the positive terminal of a DC voltage source (633) having its negative terminal coupled to ground (55);

- a fifth voltage set terminal "Voff" coupled to the positive terminal of a DC voltage source (634) having its negative terminal coupled to ground (55);

- a sixth current set terminal "Cc" coupled also to the first terminal of Rc3 (742);

- a seventh feedback terminal "FB" coupled to the FB terminal of Sw2 (602); and

- an eighth zero voltage reference terminal "ZVR" coupled to ground (55).

(d) A fourth eight terminal Benistor Sw4 (604) comprising:

- a first anode "A" terminal coupled to the cathode of a fourth LEDs column LEDc4 (751), which have the anode coupled to the cathode of LEDc3 (741);

- a second cathode "K" terminal coupled to a fourth current sense resistor Rc4 (752) which has the other terminal coupled to ground (55);

- a third voltage sense "Vs" terminal coupled to Vin;

- a fourth voltage set terminal "Von" coupled to the positive terminal of a DC voltage source (643) having its negative terminal coupled to ground (55);

- a fifth voltage set terminal "Voff" coupled to the positive terminal of a DC voltage source (644) having its negative terminal coupled to ground (55);

- a sixth current set terminal "Cc" coupled also to the first terminal of Rc4 (752);

- a seventh feedback terminal "FB" coupled to the FB terminal of Sw3 (603); and

- an eighth zero voltage reference terminal "ZVR" coupled to ground (55).

The functionality of the Benistor was described above in connection with Fig. 18a.

Description Of The LED Driver Functionality

As yet embodied herein, the four Benistors parallel LED driver circuit shown in Fig. 19a in accordance with the present specification is capable of controlling, in a CVCC (constant voltage constant current) manner, a 120-240Vac LED lamp retrofit lighting panel, comprising four stripes of LEDs, under very high efficiency and near unity power factor, in a self-switching mode of operations (i.e., Benistors do not require external components such as coils or capacitors to generate periodical ON-OFF oscillations), by forcing the LED lamp retrofit's main current to follow a sine wave graph shape, in phase with the supply voltage's graph shape (for achieving PF > 0.99), as illustrated in Fig. 18b, Current/Voltage Graphs, section E.

This performance is accomplished, on the one hand, by setting properly the voltage amount of each DC voltage source applied to the Von and Voff voltage control inputs of each Benistor (613 to 644), for delivering the right voltage to each of the four LED stripes and, on the other hand, by selecting the right value of the current sense resistors (Rc1 to Rc4) for the current control inputs of each Benistor to limit each LED stripe current in accordance to pre-established limits.

As the graph presented at section D of Fig. 19b shows, the parallel circuit works very similarly, but in opposite phase, with respect to the series circuit presented above in Fig. 18, respectively, as the supply voltage increases, the Sw1 (601) is the first one switching ON and the Sw4 (604) is the last one, controlling the voltage and current of all the four LED stripes.

EMBODIMENT 20

Single Cell Anode Loaded Voltage Controlled Limited Current Switch (VCLCsw) LED Driver

Fig. 20 shows an embodiment of a single cell anode loaded VCLC switch LED Driver circuit.

Description of the Components Connections

As embodied herein, this single cell anode loaded VCLC switch LED Driver circuit comprises a minimum component AC-to-DC converter sub-circuit including a bridge rectifier BR (53) operatively coupled to an AC voltage generator Vac (51) for providing an unfiltered DC pulse voltage at its positive output terminal Vin, with respect to its negative output terminal coupled to ground (53), and an eight terminal voltage controlled limited current switch VCLCsw (601) sub-circuit.

In one embodiment, the eight terminal voltage controlled limited current switch VCLCsw (601) sub-circuit comprises:

- a first anode "A" (651) terminal coupled, operatively, to Vin via a LED column LEDc 1 (721);

- a second cathode "K" (658) terminal coupled to a first terminal of a resistor Rc1 (722) having the other terminal coupled to ground (55);

- a third voltage sense "Vs" (562) terminal coupled directly to Vin;

- a fourth voltage set terminal "Von" coupled to the positive terminal of a DC voltage source (633) having its negative terminal coupled to ground (55);

- a fifth voltage set terminal "Voff" coupled to the positive terminal of a

DC voltage source (614) having its negative terminal coupled to ground (55);

- a sixth current set terminal "Cc" coupled also to the first terminal of Rc1 (722);

- a seventh feedback terminal "FB" unconnected; and

- an eighth zero voltage reference terminal "ZVR" coupled to ground (55).

Internally, the VCLCsw (601) comprises:

- a MOSFET buffer BUF (661) having its drain coupled to A (651) its source coupled to K (658) and its gate coupled to a micro-controller uC (666);

- a first comparator V1 (662) having one input coupled to Von (653), the other input coupled to Vs (652) and the output coupled to uC (666);

- a second comparator V2 (663) having one input coupled to Voff (654), the other input coupled to Vs (652) and the output coupled to uC (666);

- an operational amplifier C (665) having one input coupled to Cc (657), the other input coupled to uC (666) and the output coupled also to the uC (666);

- a voltage shunt voltage reference BGVR coupled with the anode to "ZVR" (655) and with it is cathode to the uC (666); and

- a temperature sensor Ts (667) coupled to uC (666).

Description of the Circuit's Functionality

As further embedded herein, this system embodiment represent a particular circuit topology, reveled down to components level, of the block schematic using Benistor symbol, presented in Fig. 19a Monolithic Led Driver - Parallel Circuit Method Embodiment, which is capable to control, precisely, the voltage and current of a LED stripe.

In this particular circuit, the VCLCsw (601) operations are controlled by the uC (666) micro-controller, which drives the MOSFET buffer BUF (661) in accordance to a suitable procedure determined, from time to time, by the complex signal received from its analog sensors, such as the momentary voltage amount at Vin, sensed by the V1 (662) and V2 (663), the LEDs momentary current, sensed by the operational amplifier C (665), the ambient temperature sensed by Ts (667).

The BGRVR (664) provides voltage references to the entire system for securing the operations precision and reliability.

The VCLCsw (601) represent only one cell, capable to control only one LED stripe.

Complex lighting systems may use 4, 8, 16 or 64 similar cells, controlling the LEDs not just at the stripe level but as "led by led" level as well, for increasing the efficiency up to over 97% (the more cell used the more efficient is the entire system) and the uC (666) to perform additional jobs, such as I/O digital data feedback, allowing remote control and fast adjustments of the light in large buildings, studios or theaters.

EMBODIMENT 21

Single Cell Cathode Loaded Voltage Controlled Limited Current Switch (VCLCsw) LED Driver

Fig. 21 shows an embodiment of a single cell cathode loaded VCLC switch LED Driver circuit.

Description of the Components Connections

As embodied herein, this single cell cathode loaded VCLC switch LED Driver circuit comprises a minimum parts AC-to-DC converter sub-circuit comrpising a bridge rectifier BR (53) operatively coupled to an AC voltage generator Vac (51) for providing an unfiltered DC pulse voltage at its positive output terminal Vin, with respect to its negative output terminal coupled to ground (53), and a six terminal voltage controlled limited current switch VCLCsw (601) sub-circuit.

The six terminal voltage controlled limited current switch VCLCsw (601) sub-circuit comprises:

- a first anode "A" (651) terminal coupled to Vin;
- a second cathode "K" (658) terminal coupled, via a LED column LEDc 1 (721) to a first terminal of a resistor Rc1 (722) having the other terminal coupled to ground (55);
- a third voltage set terminal "Von" (653) coupled to Vin;
- a fourth voltage set terminal "Voff (654) coupled to the anode of a zener diode Dv1 (686) having the cathode coupled to Vin via a resistor Rv1 (687);

- a fifth current set terminal "Cc" coupled also to the first terminal of Rc1 (722); and

- a sixth zero voltage reference terminal "ZVR" coupled to ground (55).

Internally, the VCLCsw (601) comprises:

- a MOSFET buffer BUF1 (681) having its drain coupled to A (651) its source coupled to K (658) and its gate coupled to the cathode a second zener diode Vlim1 (683) having the anode coupled to "ZVR" (655) terminal;

- a ON resistor Ron1 is coupled between the BUF (661) gate and Von (653) terminal;

- a voltage transistor Qv1 (685) having its base coupled to Voff (653) terminal, the collector coupled to BUF (681) gate and emitter coupled to "ZVR" (655); and

- a current transistor (684) having its base coupled to Cc (657) terminal, the collector coupled to BUF (681) gate and emitter coupled to "ZVR" (655) terminal.

Description Of The Circuit's Functionality

As further embedded herein, this system embodiment represent a particular circuit topology, reveled down to components level, of the block schematic using Benistor symbol, presented in Fig. 18a Monolithic Led Driver - Series Circuit Method Embodiment, which is capable to control, simultaneously, the voltage and current of a LED stripe.

In this particular circuit, Ron 1 (682) supplies the BUF1 (681) gate for keeping the buffer ON until Qv1 (685) switch it OFF as soon as Vin reaches a higher amount than the Dv1 (686) threshold.

Vlim (683) keeps the gate voltage of BUF1 (681) constant, despite large variations of the Vin voltage amount and Ron1 (682) current.

Qc1 (684) controls, linearly BUF1 (681) output current, by decreasing its gate voltage when the voltage across Rc1 (722) exceed 0.6V.

This different topology of the VCLCsw (601) controller represents another particular version of a very low cost Benistor cell.

Five or more cells, like this one, connected in series or parallel, are sufficient to drive LED lamp retrofits up to 20W.

EMBODIMENT 22

Monolithic LED Driver - Overall Feedback Series Circuit

Fig. 22a shows an embodiment of a monolithic LED driver-overall feedback series circuit. **Fig. 22b** shows a series of current/voltage graphs obtained from the monolithic LED driver shown in FIG. 22a.

Description of the Components Connections

As embodied herein, this low component count low cost monolithic LED driver circuit comprises a minimum parts AC-to-DC converter sub-circuit including a bridge rectifier BR (53) operatively coupled to an AC voltage generator Vac (51) for providing an unfiltered DC pulse voltage at its positive output terminal Vin, with respect to its negative output terminal coupled to ground (53), and a sub-circuit including four VCLCsw cells having current control only, wherein

(a) The first VCLCsw cell comprises:

- a first MOSFET buffer BUF1 (681) having its drain coupled to Vin, source coupled to the anode of a LED stripe LEDc1 (721) and gate coupled to the cathode of a zener diode Vlim1 (683);

- a NPN transistor Qc1 (684) having its base coupled to the cathode of LEDc1 (721) and a first terminal of a current resistor Rd (722), emitter coupled to the other terminal of Rd (722) and the anode of Vlim1 (683) and collector coupled to the gate of BUF1 (681); and

- a ON resistor Ron1 (682) coupled from Vin to the gate of BUF1 (681).

(b) The second VCLCsw cell comprises:

- a second MOSFET buffer BUF2 (691) having its drain coupled to Vin, source coupled to the anode of a second LED stripe LEDc2 (721) and the second terminal of Rd (722) and the gate coupled to the cathode of a second zener diode Vlim2 (693);

- a second NPN transistor Qc2 (694) having its base coupled to the cathode of LEDc2 (731) and a first terminal of a second current resistor Rc2 (732), emitter coupled to the other terminal of Rc2 (732) and the anode of Vlim2 (693) and the collector coupled to the gate of BUF2 (691); and

- a second ON resistor Ron2 (692) coupled from Vin to the gate of BUF2 (691).

(c) The third VCLCsw cell comprises:

- a third MOSFET buffer BUF3 (701) having its drain coupled to Vin, source to the anode of a third LED stripe LEDc3 (741) and the second terminal of Rc2 (732) and the gate coupled to the cathode of a third zener diode Vlim3 (703);

- a third NPN transistor Qc3 (701) having its base coupled to the cathode of LEDc3 (741) and a first terminal of a third current resistor Rc3 (742), emitter to the other terminal of Rc3 (742) and the anode of Vlim3 (703) and the collector coupled to the gate of BUF3 (701); and

- a third ON resistor Ron3 (702) coupled from Vin to the gate of BUF3 (701).

(d) The fourth VCLCsw cell comprises:

- a fourth MOSFET buffer BUF4 (71 1) having its drain coupled to Vin, source to the anode of a fourth LED stripe LEDc4 (751) and the second terminal of Rc3 (742) and the gate coupled to the cathode of a third zener diode Vlim4 (713);

- a fourth NPN transistor Qc4 (714) having its base coupled to the cathode of LEDc4 (751) and a first terminal of a fourth current resistor Rc4 (752), emitter to the other terminal of Rc4 (752) and the anode of Vlim4 (713) and the collector coupled to the gate of BUF4 (71 1); and

- a fourth ON resistor Ron4 (712) coupled from Vin to the gate of BUF4 (71 1).

Description Of The Circuit's Functionality

As further embedded herein, this system embodiment shows the circuit of a four stripes LED driver where have been used four identical VCLCsw cells similar to the circuit shown in Fig. 21 , in this circuit having only current control, so the Voff transistor Qv1 (685) and its attached zener diode Dv1 (686) have been removed.

These embodiments reveal the advantage of the feedback created by the fact that the VCLCsw cells are connected in a "totem pole" configuration, which allows each higher level buffer transistor to smoothly switch OFF the lower level one.

In this embodiment the voltage control is obtained automatically, from the current control transistor, which decreases the buffer's voltage in the gate when the current in LEDs increases.

A 12W LED lamp retrofit bench prototype has been executed, following exactly this particularly topology having six identical cells. The driver's main current shape is illustrated in Fig. 22b.

The bench test results have shown a good power factor over 0.96, even with this very low parts count and cost circuit.

EMBODIMENT 23

Monolithic LED Driver-Overall Feedback Parallel Circuit

Fig. 23a shows an embodiment of a monolithic LED driver-overall feedback parallel circuit comprising four VCLCsw cells using the same simple transistor-zener diode voltage control shown in Fig. 21 and removing the current control transistor, for using feedback current control, only. **Fig. 23b** shows a series of current/voltage graphs obtained from the Benistor monolithic LED driver shown in FIG. 23a.

As embodied herein, this less parts low cost monolithic LED driver circuit comprises a minimum parts AC-to-DC converter sub-circuit including a bridge rectifier BR (53) operatively coupled to an AC voltage generator Vac (51) for providing an un-filtrated DC pulse voltage at its positive output terminal Vin, with respect to its negative output terminal coupled to ground (53) and a sub-circuit including four VCLCsw cells connected in parallel, wherein

(a) The first VCLCsw cell comprises:

- a first MOSFET buffer BUF1 (681) having its drain coupled the cathode of a LED stripe LEDc1 (721) having its anode coupled to Vin, its source coupled to a first terminal of a current resistor Rc1 (722) and its gate coupled to the cathode of a zener diode Vlim1 (683) having its anode coupled to ground (55);

- a voltage control NPN transistor Qv1 (685) having its base coupled to the anode of a first zener diode Dv1 (686) which has its anode coupled to the cathode of LEDc1 (721) via a resistor Rv1 (687), its emitter is coupled to ground (55) and its collector is coupled to the gate of BUF1 (681); and

- a ON resistor Ron1 (682) coupled from the cathode of LEDc1

(721) to the gate of BUF1 (681).

(b) The second VCLCsw cell comprises:

- a second MOSFET buffer BUF2 (691) having its drain coupled the cathode of a LED stripe LEDc2 (731) having its anode coupled to the cathode of LEDc1 (721), its source coupled to the second terminal of Rc1 (722) and a first terminal of a second current resistor Rc2 (732) and the BUF2 (691) gate is coupled to the cathode of a second zener diode Vlim2 (693) having its anode coupled to ground (55);

- a second voltage control NPN transistor Qv2 (695) having its base coupled to the anode of a second zener diode Dv2 (696) which has its anode coupled to the cathode of LEDc2 (731) via a resistor Rv2 (697), its emitter is coupled to ground (55) and its collector is coupled to the gate of BUF2 (691); and

- a second ON resistor Ron2 (692) coupled from the cathode of LEDc2 (731) to the gate of BUF2 (691).

(c) The third VCLCsw cell comprises:

- a third MOSFET buffer BUF3 (701) having its drain coupled the cathode of a LED stripe LEDc3 (741) having its anode coupled to the cathode of LEDc2 (731), its source coupled to the second terminal of Rc2 (732) and a first terminal of a third current resistor Rc3 (742) and the BUF3 (701) gate is coupled to the cathode of a third zener diode Vlim3 (703) having its anode coupled to ground (55);

- a third voltage control NPN transistor Qv3 (705) having its base coupled to the anode of a third zener diode Dv3 (706) which has its anode coupled to the cathode of LEDc3 (741) via a resistor Rv3 (707), its emitter is coupled to ground (55) and its collector is coupled to the gate of BUF3 (701); and

- a third ON resistor Ron3 (6702) coupled from the cathode of LEDc3 (741)to the gate of BUF3 (701).

(d) The fourth VCLCsw cell comprises:

- a fourth MOSFET buffer BUF4 (71 1) having its drain coupled the cathode of a LED stripe LEDc4 (751) having its anode coupled to the cathode of LEDc3 (741), its source coupled to a first terminal of a third current resistor Rc3 (742) and its gate coupled to the cathode of a fourth zener diode Vlim4 (713) having its anode coupled to ground (55);

- a fourth voltage control NPN transistor Qv4 (715) having its base coupled to the anode of a fourth zener diode Dv4 (713) which has its anode coupled to the cathode of LEDc4 (751) via a resistor Rv4 (717), its emitter is coupled to ground (55) and its collector is coupled to the gate of BUF4 (71 1); and

- a fourth ON resistor Ron4 (712) coupled from the cathode of LEDc4 (751)to the gate of BUF4 (71 1).

Description of the Circuit's Functionality

As further embedded herein, this system embodiment shows the circuit of a four stripes LED driver using four identical VCLCsw cells similar to the circuit shown in Fig. 21. This circuit provides only voltage control, so the current control transistor Qc1 (684) has been removed. The current control function being done, directly, by the feedback resistors inserted in each of the four buffer MOSFET transistors source, in a series circuit starting from the cell driving the first LED stripe next to the bridge rectifier BR (53) and finishing with the cell driving the last LED stripe, near ground (55).

It will be appreciated that, as used throughout the present specification, the term "series" with respect to this embodiment circuit's schematic diagram topology, does not refer to the position of the buffer transistor with respect to each other, since in all circuits, regardless of the method used, the buffers appear "in parallel" to each other, and only the "anode loaded" versus "cathode loaded" versions appears to be the only difference between them.

Rather, the term "series" refers to the fact that in this group of embodiments the "Vlim(n)" zener diodes are connected in series, or "totem pole", for setting an incrementally increase of the voltage, at each buffer's gate, for securing the "constant voltage" in each gate, proportional to the increasing number of LED stripes each buffer has to drive, in a CVCC mode of operations.

This aspect will become more evident at the description of the Embodiment 26: "Monolithic LED Driver - Minimum Parts Series Circuit Embodiment", hereinbelow, where the voltage control zener diodes Vlim1 to Vlim4 appear in a clear "series connection" configuration, where BUF4 has only 30V in gate, while BUF1 has about 140V in the gate, with respect to ground, because it drives 4 LED stripes having a threshold of about 33V per stripe.

On the other hand, in the circuits following the "Parallel Method" all buffers have the same voltage in the gate, so all gates can be coupled in "parallel" and their voltage could be even secured with only one zener diode".

These embodiments reveal the advantage of the current feedback created by the anode loaded VCLCsw cells having a current feedback applied directly to the buffer MOSFET transistors source level. This eliminates, in a simple way, the need for an additional current control transistor and simplifying the classic Benistor topology configuration.

The "totem pole" configuration of the sense resistors, starting from the Benistor cell closer to the bridge rectifier and ending with the Benistor cell next to ground allow for a very good current feedback, directly at the buffers level, allowing the buffer transistors to, smoothly, switch OFF the lower level one, in such a manner, that power factor over 0.99 is achievable, is the number of LEDs per each stripe and the value of each sense resistor are properly calculated.

Since the LEDs are more sensitive to current than voltage, and the MOSFET transistors are stable with the variation of temperature, especially when a good feedback current is accomplished, for "indoor LED lamp retrofits" applications (i.e., a reasonable temperature range of 15 - 40° Celsius), the three voltage control components included in each cell circuit, such as Qv(n), Dv(n) and Rv(n) could be eliminated, for reducing component count, size and cost of the entire circuit (which may include 3 to 60 Benistor cells, in some applications) without exposing the driver system to a high risk of losing control over the LED stripes.

A 14W LED lamp retrofit bench prototype has been implemented, following this particular topology, having five identical cells from which the three voltage control/protection parts have been removed.

Function of the value of each sense/feedback resistor current versus voltage shape of this particular "anode loaded multi-cell buffer resistor source feedback five Benistor cells LED driver" the current versus voltage graphs may follow three different shapes, such as:

a) the "flat sine wave" as it is illustrated in Fig. 27b entitled: "Monolithic LED Driver - Minimum Parts Parallel Circuit Embodiment" which features a very low peak current, power factor 0.95 and A.THD 18%,

b) the "stairs sine wave" as illustrated in Fig. 23b of this embodiment which features power factor 0.97 and A.THD 10% and,

c) the "clean sine wave" as illustrated in Fig. 19b entitled: "Monolithic LED Driver - The Parallel Method Circuit Embodiment" which features, power factor 0.996 and A.THD 4.7%,

More details about efficiency and other parameters and features are provided below, in the description of other embodiments.

As an important note, from this point forward, in order to save space in this, already, very complex patent application, the description of the connection between the parts of an embodiment, will be executed only is absolutely necessarily, if not, the description will be resumed to simple references pointing out the presentation of similar embodiments already fully described above.

EMBODIMENT 24

Monolithic Multi Stripes LED Driver - Series Circuit

Fig. 24 shows an embodiment of a monolithic multi stripes LED Driver - series circuit embodiment. The illustrated embodiment comprises four Benistor cells using the same simple topology described in connection with Fig. 22: "Monolithic LED Driver - Overall Feedback Series Circuit Method Embodiment and removing the current control transistor, for using feedback current control, only.

As embodied herein, this circuit embodied in Fig. 24 follows the same topology shown in Fig. 22: "Monolithic LED Driver - Overall Feedback Series Circuit Method Embodiment" with one difference being instead of having just one current control NPN transistor, such as Qc1 (684), in this circuit there are 2, 3, or 4 NPN transistors, such as Q1A (684), Q1B (688), Q1C (689) and Q1D (690) all of them coupled emitter-collector across the zener diode Vlim1 (683) for decreasing the BUF1 (681) gate voltage when the LED current increases.

In one embodiment, more than one current controller transistor may be used is that all LED manufacturer strongly recommend to do not connect LED stripes, in parallel, without connecting at least a ballast resistor, per each stripe, for balancing the small voltage difference which always exits, from unit to unit.

However, since in high quality LED drivers, some providers (see Related Art) prefer to include very expensive parts, such as one voltage shunt regulator and an operational plus a MOSFET buffer used as "constant current sync" (CCS) per each LED stripe just to increase, indefinitely, "the potential lifetime" of a specific LED lamp retrofit, in this particularly embodiment it was revealed a "low cost solution" for doing a similar job by using several low cost NPN transistor (a "2N2222" classic NPN transistor cost less than 1c/unit, in large volume markets) having the output coupled in parallel and just each transistor base to be coupled, via a separate sense resistor, in series to as many LED columns as required by a specific application, offering "a longer potential lifetime" to the LED lamp retrofits by using this low cost "multi-current control inputs Benistor" system, rather than use a "complete Benistor cell" per each LED stripe.

EMBODIMENT 25

Monolithic LED Driver - High Reliability Series Circuit

Fig. 25 shows an embodiment of a monolithic LED driver - high reliability series circuit embodiment.

As embodied herein, this circuit embodied in Fig. 25 follows the same four Benistor cells, series method topology described in connection with Fig. 21: "Monolithic LED Driver - Overall Feedback Series Circuit Method Embodiment" with one difference being instead of having just one current control NPN transistor, such as Qc1 (684) a more sophisticated and expensive CVCC system, including two operational amplifiers per each Benistor cell been used, for increasing the feedback precision and reliability of "Outdoor LED lamp retrofits", which may need to face large variations of temperature that always happens, from the winter to the summer time seasons.

This more reliable but also more expensive CVCC system includes a classic current feedback operational amplifier (OPAM) circuit sensing the LED stripe current via a sense resistor and a classic voltage OPAM circuit sensing the voltage across the LED stripe having both, the output coupled to the buffer transistor's gate, per each of the four Benistor cells.

This particular embodiment represents a very reliable series method Benistor circuit version, in which the operational amplifiers do not need a separate power supply, being supply, together with the LED stripe, by the MOSFET buffer transistor which runs each cell.

EMBODIMENT 26

Monolithic LED Driver - Minimum Parts Series Circuit

Fig. 26 shows an embodiment of a monolithic LED driver-overall feedback parallel circuit. The illustrated embodiment comprises four Benistor cells.

Description Of The Components Connections

As embodied herein, a minimum parts LED driver circuit comprises: a minimum parts AC to DC converter sub-circuit including a bridge rectifier BR (53) operatively coupled to an AC voltage generator Vac (51) for providing an un-filtrated DC pulse voltage at its positive output terminal Vin, with respect to its negative output terminal coupled to ground (53), and a minimum component count monolithic converter sub-circuit including four Benistor cells, comprising:

(a) The first Benistor cell comprising:

- a first MOSFET buffer BUF1 (681) having its drain coupled to Vin, source to the anode of a LED stripe LEDc1 (721) and gate to the cathode of a zener diode Vlim1 (683); and

- a ON resistor Ron1 (682) is coupled from Vin to the gate of BUF1 (681).

(b) The second Benistor cell comprising:

- a second MOSFET buffer BUF2 (691) having its drain coupled to Vin, source to the cathode of Ledc1 (721) and the anode of a second LED stripe LEDc2 (721) and the gate coupled to the anode of Vlim1 (683) and the cathode of a second zener diode Vlim2 (693); and

- a second ON resistor Ron2 (692) is coupled from Vin to the gate of BUF2 (691).

(c) The third Benistor cell comprising:

- a third MOSFET buffer BUF3 (701) having its drain coupled to Vin, source to the cathode of Ledc2 (731) and the anode of a third LED stripe LEDc3 (741) and the gate coupled to the anode of Vlim2 (693) and the cathode of a third zener diode Vlim3 (703); and

- a third ON resistor Ron3 (702) is coupled from Vin to the gate of BUF3 (701).

(d) The fourth Benistor cell comprising:

- a fourth MOSFET buffer BUF4 (71 1) having its drain coupled to Vin, source to the cathode of Ledc3 (741) and the anode of a fourth LED stripe LEDc2 (721) which has its cathode coupled to ground via a sense resistor Rc4 (752) and the gate coupled to the anode of Vlim3 (703) and the cathode of a second zener diode Vlim4 (713)which has its anode coupled to ground (55) via a voltage control resistor Rvc (753); and

- a fourth ON resistor Ron4 (712) is coupled from Vin to the gate of BUF4 (71 1).

Description Of The Circuit's Functionality

As further embodied herein, this system embodiment shows a circuit of a four stripes LED driver where have been used four minimum parts Benistor cells.

The name of the "series method" comes from the fact that, in order to secure the constant voltage feature of the system, several zener diodes (or voltage shunt regulators) have to be connected, from the ground (55) up to each buffer transistor gate, in series, in such a manner for each MOSFET buffer to operate as a constant current sink (CCS) with respect to the LED columns control and the sense resistor Rc4 (752).

As the schematic shows, BUF4 operates as a CCS limiting the current of LEDc4 (751) in accordance to its gate voltage, limited by Vlim4 (713) and the current resistor Rc4 (752) in a classic negative feedback way, in which, when the current in the LEDc4 (751) increases, the voltage across Rc4 (752) is supposed to increase, however, when the voltage across Rc4 (752) increases too much, the buffer BUF4 (71 1) gate-source voltage will decrease, fact which will result in lowering its output current, fact will lower the voltage across Rc4 (762), so in conclusion the zener diode Vlim (713) secures both, the output voltage and the output current, across the LEDc4 (751) stripe.

Following the same procedure, BUF1 (681) acts as CVCC controller for all four LED stripes, since if the LEDs current increases, for any reasons, (changes of the ambient temperature and/or higher input supply voltage) the voltage across Rc4 will increase and the four zener diodes, connected in series, will not allow that.

Besides this simple and cost effective CVCC converter behavior, this totem pole configuration allows for an extra negative feedback between the Benistors cells, respectively, when Vin increases, sufficiently, for BUF3 (701) to start having an increasing output current, and the voltage in its gate is calculated for BUF3 (701) to allow a higher current than BUF4 (71 1) in order for the lamp current to increase progressively an follow a sine wave shape, for a maxim power factor, the BUF3 will create across Rc4 (752) a sufficiently higher voltage for switching OFF BUF4 (71 1) and because of that, in this particularly circuit, there is no more need for the Voff transistor or comparator. In other words, this apparently very simple schematic is actually a very complex and reliable "four Benistors series method LED driver" system.

EMBODIMENT 27

Monolithic LED Driver - Minimum Part Parallel Circuit

Fig. 27a shows an embodiment of a monolithic LED driver-overall feedback parallel circuit. **Fig. 27b** shows a series of current/voltage graphs obtained from the Benistor monolithic LED driver shown in Fig. 27a.

Description of the Components Connections

As embodied herein, a minimum component count LED driver circuit comprises a minimum component count AC-to-DC converter sub-circuit including a bridge rectifier BR (53) operatively coupled to an AC voltage generator Vac (51) for providing an un-filtrated DC pulse voltage at its positive output terminal Vin, with respect to its negative output terminal coupled to ground (53), and a minimum component count monolithic converter sub-circuit including four Benistor cells comprising:

(a) The first Benistor cell comprises:

- a first MOSFET buffer BUF1 (681) having its drain coupled to the cathode of a first LED stripe LEDc1 (721) which has the anode coupled to Vin, its source coupled to the first terminal of a first sense resistor Rc1 (722) and gate to the cathode of a zener diode Vlim4 (713) which has the anode coupled to ground (55); and

- a ON resistor Ron1 (682) is coupled from Vin to the gate of BUF1 (681) and the cathode of Vlim4 (713).

(b) The second Benistor cell comprises:

- a second MOSFET buffer BUF1 (681) having its drain coupled to the cathode of a second LED stripe LEDc2 (731) which has the anode coupled to the cathode of LEDc1 (721), its source coupled to the second terminal of

Rc1 (722) and to the first terminal of a first sense resistor Rc1 (722) and the gate of BUF1 (681) is coupled to the cathode of Vlim4 (71 3).

(c) The third Benistor cell comprises:

- a third MOSFET buffer BUF3 (701) having its drain coupled to the cathode of a third LED stripe LEDc3 (741) which has the anode coupled to the cathode of LEDc2 (731), its source coupled to the second terminal of the second sense resistor Rc2 (732) and to the first terminal of a third sense resistor (742) and the gate of BUF3 (701) is coupled to the cathode of Vlim4 (713).

(d) the fourth Benistor cell comprises

- a fourth MOSFET buffer BUF4 (71 1) having its drain coupled to the cathode of a fourth LED stripe LEDc4 (751) which has the anode coupled to the cathode of LEDc3 (741), its source coupled to the second terminal of the third sense resistor Rc3 (742) and to the first terminal of a fourth sense resistor Rc4 (752) having the other terminal coupled to ground (55% and the gate of BUF3 (701) is coupled to the cathode of Vlim4 (713).

Description of the Circuit's Functionality

As further embedded herein, this system embodiment shows the circuit of a four stripes LED driver where have been used the parallel method of four minimum parts benistor cells.

The name of the "parallel method" comes from the fact that the gates of all MOSFET buffers can be supply in parallel, from the voltage source, have about the same voltage amount with respect to the ground of the system and, in some applications, all gates can be connected together to the output of only one voltage source, secured by only one zener diode or voltage shunt regulator.

This particular circuit embodiment is very similar to the one presented in Fig. 23: "Monolithic LED Driver - Overall Feedback Parallel Circuit Method Embodiment" which has been reduced to the minimum parts version by removing, from each benistor cell, the three voltage control parts, such as Qv(n), Dv(n) and Rv(n) since, in this circuit, the Voff function is performed in the same manner done at the previously presented series circuit embodiment, by an "overall feedback" based on which each buffer automatically shuts down the previous operating buffer so, at any time, when one buffer is ON all the other buffers are OFF, except for a short transit time during which in purpose, it is managed for the transit time to be done, smoothly, for avoiding gaps in thee LED lamp retrofit's main current, fact which will increase the A.THD and decrease the power factor.

As the schematic shows, all buffers operate as constant current sinks, the sense resistors of all buffers are coupled in series and, since larger sense resistor means lower current, when the gates are supplied from the same voltage source, obviously BUF4 (71 1) having only one sense resistor to ground (55) will deliver the largest current, and BUF1 (681) four series sense resistors to ground (55) will deliver the lowest current to the LED stripes included in each of them circuits.

As Fig. 23: " Monolithic LED Driver - Overall Feedback Parallel Circuit Method Embodiment - b) Current/Voltage Graphs" illustrates, as Vin increases there are four steps until the LED lamp reaches its maxim illumination, such as:

1. BUF1 (681) is the first one starting to have a drain-source current, producing light in the first stripe LEDc1 (721) because it has less number of LEDs in drain and its current is the lowest one, because it has four resistor in its source.

2. BUF2 (691) is the second one having a drain-source current, as soon as Vin reach an amount equal with two LED stripe threshold, producing light in both, LEDc1 (721) and LEDc2 (731) stripes and, because it has three resistors in the drain, BUF2 (691) will have a higher drain-source current and, as its current and source voltage increases, as lower becomes BUF1 (681) gate-source voltage and current and by the time BUF2 reaches its maxim current BUF1 is completely switched OFF.

As a very important part of the procedure, as Fig. 23b shows, the angle **"v"** in which the current of BUF1 (681) decays has to match, perfectly, with the angle **"z"** in which the BUF2 (691) arises, in such a manner for the retrofit lamp's current "Ivac" to do not decrease at all, but to increase, smoothly, to the next level, following the shape of the voltage shape, for a near unity power factor performance.

3. BUF3 (701) is the third one arising and has higher current then the previous buffers for the same reasons presented above, shutting OFF both, BUF1 (681) and BUF2 (691) producing light in three LED stripes, increasing its current to a maxim value pre-establishes by the value of the two current resistors included in its source circuit,

4. BUF4 (71 1) is the last one lighting all four stripes and following the same procedure at the other buffers, increasing the LED stripes' current an brightness up to the maxim specs of the lamp retrofit.

In conclusion, this apparently very simple circuit is actually a very complex and reliable "four Benistors parallel method LED driver" system.

EMBODIMENT 28

120Vac Series Circuit Monolithic LED Driver

Fig. 28 shows an embodiment of a 120Vac series circuit monolithic LED driver circuit.

As embodied herein, this circuit follows the same topology described in connection with Fig. 22: "Monolithic LED Driver - Overall Feedback Series Circuit Method Embodiment" with the differences being that it comprises six Benistor cells. The illustrated embodiment shows that a six Benistor cell series circuit can be easily build, in a monolithic configuration, as a "eight parts LED driver", including a standard 14 Pin chip, a bridge rectifier and six low cost resistors.

EMBODIMENT 29

LED Array And Driver Chip Embedded System Simplified Series Circuit Embodiment

Fig. 29 shows an embodiment of an LED array and driver chip embedded system simplified series circuit.

As embodied herein, a two terminals Anode and Cathode monolithic lighting series circuit (900) having a positive supply terminal A (901) and a negative supply terminal K (902) comprises:

- A first LEDs (903) having its anode coupled to the positive supply terminal A (901) of the monolithic lighting series circuit (900) and its cathode coupled to the anode of a second LED (904) having its cathode coupled to the anode of a third LED (905) having its cathode coupled the anode of a fourth LED (906) having its cathode coupled to the negative terminal K (902) via a current sense resistor Rc1 (914);

- A four sources-one drain MOSFET buffer BUF1 (91 1) having its drain coupled to the positive terminal A (901), its first source coupled to the cathode of the first LED (903), its second source coupled to the cathode of the second LED (904), its third source coupled to the cathode of the third LED (905), its fourth source coupled to the cathode of the fourth LED (906) and its gate coupled to the positive terminal A (901) via an ON resistor Ron (912) and to the collector of a current control NPN transistor Qc1 (913); and

- Qc1 has its base coupled to the cathode of the forth LED (906) and its emitter coupled to the negative terminal K (902).

As embodied herein, this circuit follows the same topology described in connection with Fig. 22: "Monolithic LED Driver - Overall Feedback Series Circuit Method Embodiment" with one difference being that it uses a single MOSFET transistor having one drain and four sources rather than four MOSFET transistors.

The embodiment drawing shows that a four Benistor cell series circuit can be easily build, in a monolithic configuration, as a "Four LEDs Lighting Unit", included in a just two terminals packaging, exactly like one LED.

EMBODIMENT 30

LED Array And Driver Chip Embedded System Simplified Parallel Embodiment

Fig. 30 shows an embodiment of a LED array and driver chip embedded system simplified parallel circuit.

As embodied herein, a two terminals Anode and Cathode monolithic lighting series circuit (900) having a positive supply terminal A (901) and a negative supply terminal K (902) comprises:

- A first LEDs (903) having its anode coupled to the positive supply terminal A (901) of the monolithic lighting series circuit (900) and its cathode coupled to the anode of a second LED (904) having its cathode coupled to the anode of a third LED (905) having its cathode coupled the anode of a fourth LED (906) having its cathode coupled to a fourth drain of a four drains-one source MOSFET buffer (921); and

- The four drains-one source MOSFET buffer BUF1 (921) has its source coupled to the negative terminal K (902), its first drain coupled to the cathode of the first LED (903), its second drain coupled to the cathode of the second LED (904), its third drain coupled to the cathode of the third LED (905), its fourth drain coupled to the cathode of the fourth LED (906) and its gate coupled to the positive terminal A (901) via an ON resistor Ron (922) and to the cathode of a zener diode Vlim1 (923) which has its anode coupled to the negative terminal K (902);

As embodied herein, this circuit follows the same topology described in connection with Fig. 27: "Monolithic LED Driver -Minimum Parts Parallel Circuit Embodiment" with one difference being that it uses a single MOSFET transistor having one drain and four sources rather than four MOSFET transistors.

The embodiment drawing shows that a four Benistor cells series circuit can be easily build, in a monolithic configuration, as a "Four LEDs Lighting Unit", included in a just two terminals packaging, exactly like one LED.

EMBODIMENT 31

Monolithic LED Driver - Diodes Source Feedback Parallel Circuit Embodiment

Fig. 31 shows an embodiment of a monolithic LED driver - diodes source feedback parallel circuit.

As embodied herein, this circuit follows the same topology described in connection with Fig. 27: "Monolithic LED Driver - Minimum Parts Parallel circuit embodiment" with one difference being it uses only one current resistor coupled between the source of the fourth buffer and ground (55) and the three resistors coupled between the other buffers sources have been replaced wit rectifier diodes positioned with the anode to the first buffer and the cathode to the fourth buffer. The advantage of this system consists in a faster switching time between the buffers, fact which increase the system efficiency.

EMBODIMENT 32

Monolithic LED Driver - Operational Amplifier (OPAM) Current Feedback Parallel Circuit Embodiment

Fig. 32 shows an embodiment of a monolithic LED driver - operational amplifier (OPAM) current feedback parallel circuit. This illustrated embodiment of the circuit follows the same topology described in connection with Fig. 27: "Monolithic LED Driver - Minimum Parts Parallel circuit embodiment" with the differences that it uses classic OPAM feedback for current control and an extra MOSFET transistor as a constant current source for supplying the OPAM. The advantage of this system consists in a more accurate control of the buffers current.

EMBODIMENT 33

Monolithic LED Driver - Diodes Gate Feedback Parallel Circuit Embodiment

Fig. 33 shows an embodiment of a monolithic LED driver - diodes gate feedback parallel circuit. This illustrated embodiment of the circuit follows the same topology described in connection with Fig. 27: "Monolithic LED Driver - Minimum Parts Parallel circuit embodiment" with one difference being that the gates of the buffers are not coupled together but rather the gate of the fourth buffer is supplied from Vin via a resistor and the supply of the other gates is done via three diodes such that manner the voltage in at the gate of the fourth buffer is higher than the voltage at the gate of the first buffer.

EMBODIMENT 34

Monolithic LED Driver - Resistor Gate Feedback Parallel Circuit Embodiment

Fig. 34 shows an embodiment of a monolithic LED driver - resistor gate feedback parallel circuit. The illustrated embodiment of the circuit follows the same topology described in connection with Fig. 27: "Monolithic LED Driver - Minimum Parts Parallel circuit embodiment" with one difference being that the gates of the buffers are not coupled together but rather the gate of the fourth buffer is supplied from Vin via a resistor and the supply of the other gates is done via three resistors such that the voltage in at the gate of the fourth buffer is higher than the voltage at the gate of the first buffer.

EMBODIMENT 35

Monolithic LED Driver - Totem Pole Feedback Parallel Circuit Embodiment

Fig. 35 shows an embodiment of a monolithic LED driver - totem pole feedback parallel circuit. The illustrated embodiment of the circuit follows the same topology as described in connection with Fig. 27: "Monolithic LED Driver - Minimum Parts Parallel circuit embodiment" with one difference being that two MOSFET transistors, coupled in a totem pole configuration, are used instead of one, for increasing the buffers control power per each cell.

EMBODIMENT 36

Monolithic LED Driver - 8 Pin DC Chip Embodiment

Fig. 36 shows an embodiment of a monolithic LED driver in an 8 Pin DC chip. The illustrated embodiment of the circuit follows the same topology as described in connection with Fig. 27: "Monolithic LED Driver - Minimum Parts Parallel circuit embodiment" with one difference being that the gates of the buffers are not coupled together but rather the gate of the fourth buffer is supplied from Vin via a resistor and the supply of the other gates is done via three resistors such that the voltage in at the gate of the fourth buffer is higher than the voltage at the gate of the first buffer. The embodiment drawing shows that a five Benistor cells parallel circuit can be easily build, in a monolithic configuration, as a "three parts LED driver", including a standard 8 Pin chip, a bridge rectifier and one low cost resistors.

EMBODIMENT 37

Monolithic LED Driver - 8 Pin AC Chip Embodiment

Fig. 37 shows an embodiment of a monolithic LED driver in an 8 Pin AC chip. The illustrated embodiment of the circuit follows the same topology described in connection with Fig. 27: "Monolithic LED Driver - Minimum Parts Parallel circuit embodiment" with one difference being that the gates of the buffers are not coupled together but rather the gate of the fourth buffer is supplied from Vin via a resistor and the supply of the other gates is done via three resistors such that the voltage at the gate pf the fourth buffer is higher than the voltage at the gate of the first buffer.

Additionally, the current resistors between the buffers sources have been replaced with diodes, for increasing the commutation speed and efficiency.

The embodiment drawing shoes that a five benistors cells parallel circuit can be easily build, in a monolithic configuration, reaching the ultimate goal: the "ONE PART LED DRIVER" as a standard 8 Pin chip connected, on one side to the LED panel and on the other side, directly to the AC line.

16. Description of the Benister Device

Figs. 38-40 describe one embodiment of a Benistor device, which may be employed in the various embodiments of monolithic LED driver circuits described herein. For a full description of a Benistor device, reference is given to US Patent No. 5,598,093 to Beniamin Acatrinei, inventor of the subject application. The entire disclosure of US Patent No. 5,598,093 is herein incorporated by reference.

A Benistor is a controllable electron valve. More particularly, the Benistor is a multi-electrode electron valve that is able to control, separately or simultaneously, the amount of current, the maximum voltage and/or the effective value of a pulse wave voltage incoming from a power source and outputting to a load. This controllable electron valve combines the large number and impedance of the vacuum tube's command electrodes, the transistor's flexibility, and the thyristor's (SCR's) self-switching mode of operation.

Turning now to **Fig. 38,** which is a block schematic diagram of a Classic Benistor embodiment. The block schematic diagram of the Benistor is illustrated in Fig. 38 and is designated generally by reference numeral 1010. The Benistor 1010 comprises a Power Controller 101 1, a Current Separator 1012, a Current Controller 1013, and a Voltage Threshold Controller 1014.

As embodied herein, the Power Controller 101 1 is connected to the VIN electrode 1001 , which is in turn connected to a positive pole of a rectified bridge 1022. The negative pole of the rectified bridge 1022 is connected to ground 1029. The other two terminals of the rectified bridge 1022 are connected to an AC power source 1021 . The Power Controller 101 1 is also connected to the VOUT electrode 1002, which is connected to a resistive load 1023, and the load 1023 is connected to ground 1029. The Power Controller 101 1 is internally connected to the Current Separator 1012.

The Current Separator 1012 is externally connected to a switch 1024 via the switch selector (SS) electrode 1006. The other connection of the external switch 1024 is connected to ground 1029. The Current Separator 1012 is internally connected to the Current Controller 1013 and the Voltage Controller 1014.

The Current Controller 1013 is externally connected to the positive pole of a first voltage reference source 1025 via the non-inverting cc electrode 1005, to the positive pole of a second voltage reference source 1025 via the inverting cc electrode 1004, and to ground 1029 via the common electrode (CE) 1003. The negative pole of both voltage reference sources 1025 and 1026 are connected to ground 1029.

The Voltage Threshold Controller 1014 is internally connected to the VIN electrode 1001 and to the common electrode (CE) 1003, which is connected to ground 1029. The Voltage Threshold Controller 1014 is externally connected to the positive pole of a third voltage reference source 1027 via the effective voltage control OFF/ON electrode 1007 and to a fourth voltage reference source 1028 via the maximum voltage control ON/OFF electrode 1008. The negative pole of each voltage reference source 1027, 1028 is connected to ground 1029.

As further embodied herein, a power pulse wave inputted at VIN electrode 1001 creates two currents, "Ivtc " (voltage threshold controller), and"lpc " (power controller). The value of Ivtc is small, nearly constant over time, and acts to create an internal reference voltage. The Ipc in turn divides to become two currents: a larger current, ILOAD (or load current), and a smaller current UN (or internal current). ILOAD is the largest current inside the component and is externally limited by the load's resistive value (Ohm's Law) and internally limited by the Current Controller 1013. The amount of the internal current UN is dependent upon the internal structure of the Power Controller 101 1 and the Current Separator 1012. The UN is variable between a few micro amperes, if the Power Controller 101 1 employs FET technology, and several milli amperes, if the Power Controller employs bipolar technology.

As embodied herein, the Power Controller 101 1 acts as a buffer for the entire component and is comprised of one or more transistors (bipolar, Darlington, MOS, FET, or hybrids) or SCRs. The Power Controller 101 1 acts as a switch with zero resistance when in the "ON" condition and with infinite resistance when in the "OFF" condition. The Power Controller 101 1 also accepts, as a dynamic resistor, linear variations from zero to infinity. The speed of commutation, the thermal coefficient, and the maximum internal power dissipation of this block are also important parameters.

The Current Separator 1012 provides a means for the Voltage Controller 1014 and Current Controller 1013 to control, simultaneously or separately, the Power Controller 101 1 and prevents reverse current from entering the Power Controller 101 1, the Current Controller 10 13, and the Voltage Threshold Controller

1014. The Current Separator 1012 also controls the work time/cycle of the Power Controller 101 1 via the switch selector SS electrode 1006. These functions may be performed by electronic switches, bipolar, FET, or MOS transistors, commutation diodes, zener diodes, etc.

The Current Controller 1013 functions to provide to the Power Controller 101 1 a linear variation of current from zero to the limits accepted by the components of the Power Controller 101 1. The Current Controller 1013 acts as a voltage/current converter for the Power Controller 101 1. The voltage inputted at the inverting current control electrode 4 with respect to the common electrode 1003 as a zero voltage reference, is indirectly proportional to the current outputted to the load via VOUT electrode 1002. The voltage inputted at the non-inverting current control electrode 1005, with respect to the common electrode 1003 as a zero voltage reference, is directly proportional to the current outputted to the load via Vout electrode 1002.

The components comprising the Current Controller 1013 may be bipolar, FET, or hybrid transistors, constant current sources, operational amplifiers, commutation diodes, zener diodes, etc.; must keep the internal current constant for large variations of voltage; and must provide a linear threshold, before which the Power Controller 1011 will operate in a linear mode and after which it will maintain the output current at zero despite further increases of the voltage input at the current control electrode 1006. This linear threshold is dependent upon the comportment of the components used in the current controller 1013. It is desirable, however, to have this linear threshold less than one volt, and ideally this linear threshold will be as close to zero as possible, thereby increasing the precision of the output voltage when the current control electrode 6 is acting as a reference for another electrode. The Current Controller 1013 provides a means for the Power Controller 101 1 to function in a switching mode of operation once the aforementioned linear threshold is passed, and a square wave generator is the input source at the current control electrode 1006. In this situation, as the amplitude of the square wave increases in relation to the linear threshold; the slew rate of the output of the Power Controller 1011 will also increase.

As further embodied herein, the Voltage Threshold Controller 1014 functions as a window comparator, having as reference voltage inputs the OFF/ON electrode 1007 and the ON/OFF electrode 8, and having as a comparison voltage input the VIN electrode 1001 . The output load 1023 may be an electronic switch or a current separator circuit. The Voltage Threshold Controller 1014 may comprise either transistors, bipolar, MOS, FET, or hybrids, for a monoblock structure (component), or two or more comparators, operational amplifiers, etc., for a polyblock structure (apparatus). The comparison occurring between the OFF/ON electrode 1007 or the ON/OFF electrode 1008, and the VIN electrode 1001 provides a means (via the Current Separator 1012) for the Power Controller 1011 to be either switched "OFF" or switched "ON". When the Power Controller 101 1 is in a switched "OFF" condition, the output at the VOUT electrode 1002 is zero; when it is in a switched "ON" condition, the output current at the VOUT electrode 1002 will be limited by the resistive value of the load or by the Current Controller 101 1 via the Current Separator 1012. 1007, which inputs a DC reference voltage (with the common electrode 1003 as a zero reference), the Power Controller 101 1 is in a switch "OFF" condition when the momentary voltage value at the VIN electrode 1001 is less than the reference voltage at the OFF/ON electrode 1007. Conversely, the Power Controller 101 1 is in a switched "ON" condition when the momentary voltage value at the VIN electrode 1001 is greater than the reference voltage input at the OFF/ON electrode 1007. In other words, during one complete cycle of the power wave and with the value of the reference voltage input at the OFF/ON electrode 1007 as 0<V(off-on) <VIN (max), the Power Controller 101 1 will be first "OFF", then "ON", and then "OFF" again.

Based on this comparison, the Benistor acts as a self-switching controllable electron valve in an "OFF/ON" mode of operation. The output voltage waveform at the VOUT electrode 1002 to a resistive load is shown in **Fig. 40B** and reflects a variety of reference voltages, between zero and VIN (max), at the OFF/ON electrode 1007. When the electrode used for comparison with the VIN electrode is the ON/OFF electrode, which inputs a DC reference voltage (with the common electrode 3 as a zero reference), the Power Controller 101 1 is in a switched "ON" condition when the momentary voltage value at the VIN electrode 1001 is less than the reference voltage at the ON/OFF electrode 8. Conversely, the Power Controller is in a switched "OFF" condition when the momentary voltage value at the VIN electrode 1001 is greater than the reference voltage at the ON/OFF electrode 1008. In other words, during one complete cycle of the power wave and with the value of the reference voltage input at the ON/OFF electrode 8 as 0<V(on-off) <VIN (max), the Power Controller 101 1 will be first "ON", then "OFF", and then "ON" again. Based on this comparison, the Benistor acts as a self-switching, controllable electron valve in an "ON/OFF" mode of operation. The output voltage waveform at the VOUT

electrode 1002 to a resistive load is shown in **Fig. 40C** and reflects a variety of reference voltages, between zero and VIN (max), at the ON/OFF electrode 1008.

In order to explain the self-switching mode of operation of the Benistor when both voltage control electrodes are simultaneously inputting two different reference voltages, a review of the window comparator mode of operation is provided. A window comparator, also referred to as a "double ended comparator," is a circuit that detects whether or not an input voltage is between two specified voltage limits, called a window. This may be normally accomplished by logically combining the outputs from both an inverting and a non-inverting comparator. When the input level is greater than the upper reference voltage (VUL) the window, or less than the lower reference voltage (VLL) of the window, the output of the circuit is at VMAX. If the level of the input voltage is in the window between VLL and VUL, the output voltage is zero. In summary: Rule 1:VOUT =0, when VLL<VIN <VUL. Rule 2:VOUT =VMAX, when VIN <VLL or VIN >VUL.

Based on Rules 1 and 2 above, the state of the window comparator's output can be anticipated for any combination of the momentary voltage at VIN with respect to the reference voltages input as VUL and VLL, or for any combination of the reference sources VUL and VLL with respect to ground (zero voltage) or to the maximum voltage in the circuit (VMAX).

In a first particular condition (A), during which the VIN trip from a rectified bridge is a cyclic pulse, from zero to a maximum voltage and back to zero, and the parameters are defined as follows-0<VIN <VMAX, VLL<VUL<VMAX, and 0<VLL<VUL (the upper level voltage being less than VMAX but larger than the lower level voltage, and the lower level voltage being larger than zero)-five situations are possible:

Situation 1:0<VIN <VLL. In this situation, VIN is outside of the window. Therefore, based on Rule 2 above, the window comparator's output will be at VMAX, and the logic state will be "HI".

Situation 2: VLL<VIN <VUL. In this situation, VIN is inside of the window. Therefore, based on Rule 1 above, the window comparator's output will be zero voltage, and the logic state will be "LO".

Situation 3: VUL<VIN <VMAX. In this situation, IN V is outside of the window. Therefore, based on Rule 2 above, the window comparator's output will be at VMAX, and the logic state will be "HI".

Situation 4: VLL<VIN <VUL. In this situation, VIN is again inside of the

window. Therefore, based on Rule 1 above, the window comparator's output will be at zero, and the logic state will be "LO".

Situation 5:0<VIN <VLL. In this situation, VIN is outside of the window. Therefore, based on Rule 2 above, the window comparator's output will be at VMAX, and the logic state will be "HI".

In summary, VOUT has five alternating logic states for each cycle of the input wave. These logic states are: HI to LO to HI to LO to HI.

Besides condition (A) described above, four more particular conditions are possible: (B) VLL=0. In condition (B), when the lower level is zero (VLL electrode is grounded), situations 1 and 5 above are not possible. Therefore, VOUT has only three alternating logic states per cycle, namely, LO to HI to LO. (C) VUL=VMAX. In condition (C), when the upper level voltage equals the maximum voltage, situation 3 above cannot occur. Therefore, VOUT has three alternating logic states per cycle, namely, HI to LO to LO to HI, which equals HI to LO to HI. (D) VLL>VUL (including VLL=VMAX and VUL =0). In condition (D), when the lower level electrode voltage value is greater than the upper level electrode voltage value, no window is possible and situations 2 and 4 are not possible. Therefore, VOUT has only one output state for the entire logic cycle: namely, HI. (E) VLL=VUL(or VLL=0 and VUL=VMAX). In condition (E), when the lower level voltage is equal to the upper level voltage, the window encompasses zero to VMAX. Therefore, situations 1, 3, and 5 above are not possible, and VOUT has only one output state for the entire logic cycle: namely, LO.

Based on these principles of operation of a window comparator and outputting to the Current Separator 1012 (as an electronic switch or a current separator circuit), the two logic states, HI and LO, will be converted to a switched "ON" or switched "OFF" command to the Power Controller 1011. The structure of the Power Controller 1011 determines the way in which the Current Separator 1012 converts the logic state (HI or LO) from the Voltage Threshold Controller 1014, to a form of voltage and/or current required by the components of the Power Controller 1011 to act as an electronic switch. The condition of this switch may be ON when the logic state is HI, and OFF when the logic state is LO, or vice versa based on the switch's internal structure.

If the voltage threshold controller 1014 contains a window comparator, Condition a as stated above can be summarized as follows: VOUT will have five alternating logic states for each cycle of the input wave, these being LO to HI to LO to HI to LO. Also, all the other particularly situations will be in the opposite phase with respect to the parallel window comparators voltage against time output graphs.

As embodied herein, the Benistor, as a controllable electron valve, is able to control separately or simultaneously the output voltage (OFF/ON mode), the output maximum voltage (ON/OFF mode), and the output current (linear mode). Considering the OFF/ON electrode 1007, the upper level input, the ON/OFF electrode 8, and the lower level input of a window comparator, nine variations of these operational modes are possible:

1. LINEAR mode (see **Fig. 40A);**

2. OFF/ON mode (see **Fig. 40B);**

3. ON/OFF mode (see **Fig. 40C);**

4. OFF/ON and ON/OFF operating simultaneously, with OFF being predominate (see **Fig. 40D);**

5. ON/OFF and OFF/ON operating simultaneously, with ON being predominate (see **Fig. 40E);**

6. OFF/ON and Linear (see **Fig. 40F);**

7. ON/OFF and Linear (see **Fig. 40G);**

8. OFF/ON and ON/OFF and Linear, with OFF being predominate (see **Fig. 40H);**

9. ON/OFF and OFF/ON and Linear, with ON being predominate (see **Fig. 40I).**

Using two or more window comparators connected in parallel or in series, it is possible to cut a power pulse wave into the same number of distinct parts as the number of the window comparators used. The number of distinct parts created inside of a power pulse wave can also be increased by using variable, rather than fixed reference voltages, input at the control electrodes of the Benistor 1010.

Based on the four functional blocks 101 1, 1012, 1013, 1014 of the schematic diagram of Fig. 38 and combining the basic eight electrodes, infinite embodiments of the Benistor exist. Sometimes, two of the four functional blocks may be overlapped, by including in the schematic diagram of a particular embodiment a part that is able to provide the function of more than one block. While an exhaustive view of the controllable electron valve of the present invention is not possible, for a better view of the controllable electron valve described above, a number of embodiments will be described below in order to illustrate, only generically, the possibilities of the Benistor 10 of the present invention.

Figs. 39A to **39F** illustrate electronic symbols for six variations of the

Benistor. Fig. 39A shows the "Classic" Benistor having eight electrodes: a voltage input "VI N " electrode 1001 , a voltage output "VOUT " electrode 1002, a common "CE" electrode 1003, an inverting current control, "cc" 1004, a non-inverting current control electrode, "cc" 1005, a switch selector control electrode "SS" 1006, an effective voltage self-switching control electrode "OFF/ON" 1007, and a maximum voltage self-switching control electrode "ON/OFF" 1008. The figures suggest that the Benistor controls simultaneously and/or separately the output current or voltage, and the position of the various electrodes denominate the function of each of them. In other words, in a schematic diagram, the Benistor's symbol and the position of the electrodes will illustrate, alone, the particular function of each electrode.

Fig. 39B illustrates an "Inverting Classic" Benistor, which does not have the non-inverting current control input electrode, "cc" 1005.

Fig. 39C shows a "Double OFF/ON" Benistor's symbol, having one more "OFF/ON" (1009) electrode that replaces the "SS" electrode 1006.

Fig. 39D illustrates a "Positive OFF/ON" Benistor. This embodiment may comprise only the "OFF/ON" electrode 1007 for voltage control. An arrow placed on the "VIN" electrode 1001 symbolizes that only a positive current is accepted as a power input.

Fig. 39E illustrates a "Negative ON/OFF" Benistor. This embodiment comprises only the "ON/OFF" electrode 1008 for voltage control. An arrow placed on the "VIN" electrode 1001 symbolizes that only a negative current is accepted as a power input.

Fig. 39F illustrates an "Inverting Universal" Benistor. This embodiment comprises only the "cc" electrode 1001 . The fact that no arrow is placed on the "VIN" electrode 1001 symbolizes that any current, positive or negative, is accepted as a power input. The voltage-in electrode 1001 , "VIN ", inputs the entire power (voltage and current) from a variable (pulse) power source. Also the voltage and current input at VIN electrode 1001 provides momentary values used for internal comparisons and/or switching operations. This electrode is exposed to the largest variation of voltage and current, up to the limits of the component, and must be internally protected from a reverse current.

The voltage out electrode 1002, "VOUT ", delivers to a load a percent or the entire power input at the VIN electrode 1001 . The output current of VOUT 1002 is indirectly proportional to the voltage value input at the current control "cc" electrode 1006; the output effective voltage value of VOUT 1002 is indirectly proportional to the voltage value input at the "OFF/ON" electrode 1007; and the maximum voltage value of VOUT 1002 is the same as the voltage value input at the "ON/OFF" electrode 1008. The VOUT electrode 1002 is exposed to almost the same variations of voltage and current as the "VIN" electrode 1001 and must be protected from a reverse current.

The common electrode 1003, "CE", delivers to ground the cumulative value of all small internal control currents and represents the "zero reference" for the voltage value of the reference sources inputting to the three control electrodes. When CE 1003 is not connected to ground it can become a control electrode itself, used as a non-zero reference. In that situation CE 1003 is exposed to large variations of voltage and must be externally protected from a reverse current.

The effective voltage control electrode 1007, "OFF/ON", by inputting a fixed or variable voltage, controls the effective voltage value output at the VOUT electrode 1002 without affecting the maximum voltage value of the power wave input at the VIN electrode 1001 . The impedance of the voltage control electrode 1007 must be large enough to create a negligible input current; it must admit internally at least the same variations of voltage admitted by the VIN 1001 electrode; and it must be internally protected from a reverse current. When the momentary voltage value at the VIN electrode 1001 is less than the reference voltage at the OFF/ON electrode 1007, there will be no voltage output at the VOUT electrode 1002, and when the momentary voltage value at the VIN electrode 1001 is greater than the reference voltage at the OFF/ON electrode 1007, a predetermined effective voltage will be output at the VOUT electrode 1002.

The "ON/OFF" electrode 1008, by inputting a voltage value, limits the maximum voltage value at the VOUT electrode 1002 to the same reference voltage input at the ON/OFF electrode 1008. The impedance of the ON/OFF electrode 1008 must be large enough to provide for negligible input current; it must admit internally at least the same variations of voltage admitted by the VIN electrode 1001; and it must be internally protected from a reverse current. When the momentary voltage at the VIN electrode 1001 is less than the reference voltage at the ON/OFF electrode 1008, a predetermined voltage will be output at the VOUT electrode 1002, and when the momentary voltage value at the VIN electrode 1001 is greater than the reference voltage at the ON/OFF electrode 1005, there will be no voltage output at the VOUT electrode 1002.

The inverting current control electrode 1004, "cc", by inputting a fixed or variable voltage, controls the output (load) current. Inputting a linearly increasing voltage at the cc electrode 1004 between zero and a pre-established voltage (less than 1 volt) will linearly decrease the output current from a pre-established maximum value to zero, and the output current will remain at zero, despite further increases of voltage at the cc electrode 1004. The cc electrode 1004 has a large impedance and internally admits at least the same variations as the VIN electrode 1001 . (The current is negligible.) The cc electrode 1004 must be internally protected from a reverse current.

The non-inverting current control electrode 1005, "cc", by inputting a fixed or variable voltage, controls the output (load) current. Inputting a linearly increasing voltage at the cc electrode 1005 between zero and a pre-established voltage (less than 1 volt) will linearly increase the output current from zero to a pre-established maximum value, and the output current will remain at maximum value despite further increases of voltage at the cc electrode 1005. The cc electrode 1005 has a large impedance and internally admits at least the same variation of voltage as the VIN electrode 1001 . (The current is negligible.) The cc electrode 1005 must also be protected from a reverse current.

The switch selector electrode 1006, "SS", determines the work time/cycle of the Benistor-respectively, the number of "ON" times against the number of "OFF" times when the Benistor is acting in the self-switching mode of operation-during a power pulse cycle. The SS electrode 1006 has only two positions: (1) "in air" (not connected to ground) or (2) grounded (connected to ground). Depending on which position is chosen, the work time/cycle will be predominantly "ON" or predominantly "OFF."

As previously discussed, additional details regarding the Benistor device may be obtained from US Patent No. 5,598,093, which is herein incorporated by reference. The description now reverts to the discussion of Embodiments 18-37 above.

All of the above-mentioned U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in any Application Data Sheet, are incorporated herein by reference, to the extent not inconsistent herewith.

One skilled in the art will recognize that the herein described components (e.g., operations), devices, objects, and the discussion accompanying them are used as examples for the sake of conceptual clarity and that various configuration modifications are contemplated. Consequently, as used herein, the specific exemplars set forth and the accompanying discussion are intended to be representative of their more general classes. In general, use of any specific exemplar is intended to be representative of its class, and the non-inclusion of specific components (e.g., operations), devices, and objects should not be taken limiting.

With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations are not expressly set forth herein for sake of clarity.

The herein described subject matter sometimes illustrates different components contained within, or connected with, different other components. It is to be understood that such depicted architectures are merely exemplary, and that in fact many other architectures may be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being "operably connected", or "operably coupled," to each other to achieve the desired functionality, and any two components capable of being so associated can also be viewed as being "operably couplable," to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components, and/or wirelessly interactable, and/or wirelessly interacting components, and/or logically interacting, and/or logically interactable components.

In some instances, one or more components may be referred to herein as "configured to," "configurable to," "operable/operative to," "adapted/adaptable," "able to," "conformable/conformed to," etc. Those skilled in the art will recognize that "configured to" can generally encompass active-state components and/or inactive-state components and/or standby-state components, unless context requires otherwise.

While particular aspects of the present subject matter described herein have been shown and described, it will be apparent to those skilled in the art that, based upon the teachings herein, changes and modifications may be made without departing from the subject matter described herein and its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as are within the true spirit and scope of the subject matter described herein. It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to claims containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.)- It will be further understood by those within the art that typically a disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms unless context dictates otherwise. For example, the phrase "A or B" will be typically understood to include the possibilities of "A" or "B" or "A and B."

With respect to the appended claims, those skilled in the art will appreciate that recited operations therein may generally be performed in any order. Also, although various operational flows are presented in a sequence(s), it should be understood that the various operations may be performed in other orders than those which are illustrated, or may be performed concurrently. Examples of such alternate orderings may include overlapping, interleaved, interrupted, reordered, incremental, preparatory, supplemental, simultaneous, reverse, or other variant orderings, unless context dictates otherwise. Furthermore, terms like "responsive to," "related to," or other past-tense adjectives are generally not intended to exclude such variants, unless context dictates otherwise.

Those skilled in the art will recognize that it is common within the art to implement devices and/or processes and/or systems, and thereafter use engineering and/or other practices to integrate such implemented devices and/or processes and/or systems into more comprehensive devices and/or processes and/or systems. That is, at least a portion of the devices and/or processes and/or systems described herein can be integrated into other devices and/or processes and/or systems via a reasonable amount of experimentation.

CLAIMS

1. A double stage boost-isolated flyback light emitting diode (LED) driver circuit, comprising:

an AC/DC converter sub-circuit comprising a bridge rectifier configured to couple to an alternating current (AC) power source via a filter, the AC/DC converter sub-circuit to convert AC voltage received at an input to an unregulated direct current (DC) voltage across a first filtering capacitor, wherein the first filtering capacitor has a value selected to not significantly affect a power factor of the driver circuit;

a boost converter sub-circuit comprising an input operatively coupled to an output of the AC/DC converter sub-circuit to receive the unregulated DC voltage, convert the unregulated DC voltage, and provide a pre-regulated DC voltage across a second filtering capacitor, wherein the second filtering capacitor has a value selected to maintain a low ripple DC voltage at the output;

an isolated flyback converter comprising a power input sub-circuit operatively coupled to an output of the boost converter sub-circuit to receive the pre-regulated DC voltage across the second filtering capacitor, a low power feedback input operatively coupled with the output of an isolating opto-coupler device, the isolated flyback converter to convert the pre-regulated DC voltage to a constant voltage constant current DC voltage at its output;

an LED panel sub-circuit comprising an input operatively coupled to the isolated flyback converter sub-circuit output, the LED panel sub-circuit to supply at least one LED via at least one constant current sink device having a voltage reference input and a voltage/current sensing and protection sub-circuit coupled to the at least one LED, the LED panel sub-circuit having a voltage/current error sensing output; and

a constant voltage constant current control sub-circuit operatively coupled to the LED panel sub-circuit and comprising a voltage reference which supplies the reference input of the at least one constant current sink device and at least one error amplifier, the constant voltage constant current control sub-circuit operatively coupled with voltage and current outputs of the isolated flyback sub-circuit, the voltage/current sensing and protection sub-circuit outputs, an output of the constant voltage constant current control sub-circuit coupled to an input of the isolating opto-coupler device, to close a feedback loop with the flyback sub-circuit and to secure an isolated constant voltage constant current DC supply to the at least one LED.

2. The LED driver circuit of claim 1, comprising an electrical wiring system for the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

3. The LED driver circuit of claim 1 or 2, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

4. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a double stage boost-isolated flyback LED driver circuit according to claim 1;

an electrical wiring system for the LED driver circuit according to claim 2;

an LED panel according to claim 3;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

5. The LED lamp retrofit apparatus of claim 4, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

6. The LED lamp retrofit apparatus of claim 5, wherein the plurality of LEDs are

dimmable.

7. A single stage boost light emitting diode (LED) driver circuit, comprising:

an AC/DC converter sub-circuit comprising a bridge rectifier configured to couple to an alternating current (AC) power source via a filter, the AC/DC converter sub-circuit to convert AC voltage received at an input to a direct current (DC) unregulated across a first filtering capacitor, wherein the first filtering capacitor has a value selected to not significantly affect a power factor of the driver circuit;

a boost converter sub-circuit comprising an input operatively coupled to an output of the AC/DC converter sub-circuit to receive the unregulated DC voltage, convert the unregulated DC voltage, and provide a pre-regulated DC voltage across a second filtering capacitor, wherein the second filtering capacitor has a value selected to maintain a low ripple DC voltage at the output;

a pulse width modulation sub-circuit comprising an input operatively coupled to the boost converter sub-circuit, the pulse width modulation sub-circuit coupled to a voltage ramp signal to limit the output signal duty cycle down to a pre-established limit;

a soft start over voltage control sub-circuit operatively coupled to the pulse width modulation sub-circuit via a compensation capacitor to compensate a feedback voltage; and

an LED panel sub-circuit comprising an input operatively coupled to the pulse width modulation sub-circuit output, the LED panel sub-circuit to supply at least one LED via at least one constant current sink device having a voltage reference input and a voltage/current sensing and protection sub-circuit coupled to the at least one LED, the LED panel sub-circuit having a voltage/current error sensing output; and

a constant voltage constant current control sub-circuit operatively coupled to the LED panel sub-circuit and operatively coupled with the pulse width modulation sub-circuit, wherein the voltage/current sensing and protection sub-circuit outputs a differential error voltage to at least one transistor configured as a differential error amplifier coupled to the pulse width modulation sub-circuit and a constant current coupled to the pulse width modulation sub-circuit to close a feedback loop with the pulse width modulation sub-circuit and to secure a constant voltage constant current DC supply to the at least one LED.

8. The LED driver circuit of claim 7, comprising an electrical wiring system for

the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

9. The LED driver circuit of claim 7 or 8, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

10. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a single stage boost LED driver circuit according to claim 7;

an electrical wiring system for the LED driver circuit according to claim 8;

an LED panel according to claim 9;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

11. The LED lamp retrofit apparatus of claim 10, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

12. The LED lamp retrofit apparatus of claim 11, wherein the plurality of LEDs are dimmable.

13. A no opto-coupler isolated flyback light emitting diode (LED) driver circuit, comprising:

a three-coil flyback transformer comprising a primary coil, a low current secondary coil, and a high current secondary coil, the primary coil to receive a direct current (DC) input voltage from a DC voltage source and to couple the DC input voltage to a drain of a transistor, the high current secondary coil having one end coupled to ground and the other end coupled to the anode of a flyback diode, wherein the cathode of the flyback diode is coupled to at least one LED;

a snubber circuit operatively coupled to the primary coil of the transformer and the drain of the transistor, the snubber circuit coupled to the DC input voltage;

a pulse width modulation sub-circuit having an output coupled to a gate of the transistor and an input coupled to a sense resistor coupled in series with the source of the transistor, wherein the pulse width modulation sub-circuit delivers a pulse width modulated driving signal to the gate of the transistor, which via the flyback transformer creates two output supply voltages, a high current supply voltage rectified by the flyback diode and filtered by a filtering capacitor for supplying the at least one LED, and a low current feedback supply voltage signal rectified by the feedback diode and integrated by the integrating capacitor to a feedback input of the pulse width modulation sub-circuit via a resistor divider network and the compensation capacitor;

a soft start over voltage control sub-circuit operatively coupled to the pulse width modulation sub-circuit via a compensation capacitor to compensate a feedback voltage; and

a voltage follower current feedback sub-circuit coupled to the pulse width modulation sub-circuit, wherein a control input of the voltage follower current feedback sub-circuit is coupled to a compensation output of the pulse width modulation sub-circuit and to the soft start over voltage control sub-circuit, an input of the voltage follower current feedback sub-circuit is coupled to the cathode of a feedback diode and an integrating capacitor, wherein the anode of the feedback diode is coupled to one end of the low current secondary coil.

14. The LED driver circuit of claim 13, comprising an electrical wiring system for the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

15. The LED driver circuit of claim 13 or 14, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

16. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a no opto-coupler isolated flyback LED driver circuit according to claim 13;

an electrical wiring system for the LED driver circuit according to claim 14;

an LED panel according to claim 15;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

17. The LED lamp retrofit apparatus of claim 16, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

19. The LED lamp retrofit apparatus of claim 17, wherein the plurality of LEDs are dimmable.

20. A single stage single ground flyback light emitting diode (LED) driver circuit,

comprising:

an AC/DC converter sub-circuit comprising a bridge rectifier configured to couple to an alternating (AC) power source via a filter, the AC/DC converter sub-circuit to convert AC voltage received at an input to an unregulated direct current (DC) voltage across a first filtering capacitor, wherein the first filtering capacitor has a value selected to not significantly affect a power factor of the driver circuit;

a three-coil flyback transformer comprising a primary coil, a low current secondary coil, and a high current secondary coil, the primary coil to receive the unregulated DC voltage from the first filtering capacitor to a drain of a transistor, the high current secondary coil having one end coupled to ground and the other end coupled to a second filtering capacitor through a flyback diode, wherein the cathode of the flyback diode is coupled to at least one LED;

a snubber circuit operatively coupled to the primary coil of the transformer and the drain of the transistor, the snubber circuit coupled to the DC input voltage;

a pulse width modulation sub-circuit having an input coupled to the first filtering capacitor through a current limiting resistor and an output coupled to a gate of the transistor and an input coupled to a sense resistor coupled in series with the source of the transistor, wherein the pulse width modulation sub-circuit delivers a pulse width modulated driving signal to the gate of the transistor, which via the flyback transformer creates two output supply voltages, a high current supply voltage rectified by the flyback diode and filtered by the second filtering capacitor for supplying the at least one LED, and a low current feedback supply voltage signal rectified by the feedback diode and integrated by the integrating capacitor to a feedback input of the pulse width modulation sub-circuit via a resistor divider network and the compensation capacitor;

a soft start over voltage control sub-circuit operatively coupled to the pulse width modulation sub-circuit via a compensation capacitor to compensate a feedback voltage; and

an operational amplifier for sensing a current through the at least one LED such that when the current through the at least one LED is higher than a pre-established limit, the operational amplifier output lowers the amount of voltage at a compensation input of the pulse width modulation sub-circuit to decrease the duty-cycle of the pulse width modulated driving signal pulses until the current through the at least one LED decreases within the pre-established limits.

21. The LED driver circuit of claim 20, comprising an electrical wiring system for the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

22. The LED driver circuit of claim 20 or 21, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

23. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a single stage single ground flyback LED driver circuit according to claim 20;

an electrical wiring system for the LED driver circuit according to claim 21;

an LED panel according to claim 22;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

24. The LED lamp retrofit apparatus of claim 23, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

25. The LED lamp retrofit apparatus of claim 24, wherein the plurality of LEDs are

dimmable.

26. A single stage constant off time buck-boost light emitting diode (LED) driver circuit, comprising:

an AC/DC converter sub-circuit comprising a bridge rectifier configured to couple to an alternating (AC) power source via a filter, the AC/DC converter sub-circuit to convert AC voltage received at an input to an unregulated direct current (DC) voltage across a filtering capacitor, wherein the filtering capacitor has a value selected to not significantly affect a power factor of the driver circuit;

a buck-boost converter comprising a two-coil buck-boost transformer comprising a first coil and a second coil, the first coil having one end coupled to the first filtering capacitor to receive the unregulated DC voltage from the filtering capacitor and another end coupled to at least one LED and also coupled to the drain of the transistor through a buck-boost capacitor, the second coil having one end coupled to ground and another end coupled to an anode of a supply diode;

a pulse width modulation sub-circuit having an input coupled to the first filtering capacitor through a current limiting resistor and an output coupled to a gate of the transistor and another input coupled to a sense resistor coupled in series with the source of the transistor, wherein the pulse width modulation sub-circuit delivers a pulse width modulated driving signal to the gate of the transistor, which via the first coil of the buck-boost transformer creates an output supply voltage for supplying the at least one LED;

a soft start over voltage control sub-circuit operatively coupled to the pulse width modulation sub-circuit via a compensation capacitor to compensate a feedback voltage; and

a transistor connected as a switch between ground and an oscillator terminal of the pulse width modulation sub-circuit in parallel with an oscillator timing capacitor, wherein the transistor is controlled by the controlled by the pulse width modulated driving signal such that when the pulse width modulated driving signal is in a high state, the transistor discharges the oscillator timing capacitor forcing the pulse width modulated driving signal to have a constant off time, regardless of its momentarily on time.

27. The LED driver circuit of claim 26, comprising a valley fill filter coupled between the filtering capacitor and ground.

28. The LED driver circuit of claims 26 or 27, comprising an electrical wiring system for the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

29. The LED driver circuit of claims 26, 27, or 28, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

30. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a single stage constant off time buck-boost LED driver circuit according to claim 26 or 27;

an electrical wiring system for the LED driver circuit according to claim 29;

an LED panel according to claim 30;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

31. The LED lamp retrofit apparatus of claim 30, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

32. The LED lamp retrofit apparatus of claim 31, wherein the plurality of LEDs are dimmable.

33. A single stage single ground self supply buck-boost light emitting diode (LED) driver circuit, comprising:

an AC/DC converter sub-circuit comprising a bridge rectifier configured to couple to an alternating (AC) power source via a filter, the AC/DC converter sub-circuit to convert AC voltage received at an input to an unregulated direct current (DC) voltage across a filtering capacitor, wherein the filtering capacitor has a value selected to not significantly affect a power factor of the driver circuit;

a buck-boost converter comprising a single buck-boost inductor comprising a coil having one end coupled to the filtering capacitor to receive the unregulated DC voltage from the filtering capacitor and another end coupled to a drain of a transistor and a first buck-boost capacitor through a first buck-boost diode, wherein the first the buck-boost capacitor is coupled to at least one LED and to a second buck-boost capacitor, and a second buck-boost diode having an anode coupled to the filtering capacitor and the one end of the coil and a cathode coupled to the first buck-boost capacitor;

a pulse width modulation sub-circuit having an input coupled to the first filtering capacitor;

a ground separating transformer having a primary coil coupled to a pulse width modulation output of the pulse width modulation sub-circuit and a secondary coil coupled to a gate of the transistor, wherein the secondary coil applies a pulse width modulated driving signal to the gate of the transistor; and

a soft start over voltage control sub-circuit operatively coupled to the pulse width modulation sub-circuit via a compensation capacitor to compensate a feedback voltage;

wherein when the pulse width modulation sub-circuit receives its required power supply voltage and starts oscillating, the gate of the transistor receives the pulse width modulated signal from the secondary coil of the ground separating transformer and activates the buck-boost inductor which supplies with a DC voltage to the buck-boost capacitor via the buck-boost diode.

34. The LED driver of claim 34, comprising an operational amplifier for sensing a

current through the at least one LED such that when the current through the at least one LED is higher than a pre-established limit, the operational amplifier output lowers the amount of voltage at a compensation input of the pulse width modulation sub-circuit to decrease the duty-cycle of the pulse width modulated driving signal pulses until the current through the at least one LED decreases within the pre-established limits.

35. The LED driver circuit of claims 33 or 34, comprising an electrical wiring system for the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

36. The LED driver circuit of claims 33, 34, or 35, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

37. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a single stage single ground self supply buck-boost LED driver circuit according to claim 33 or 34;

an electrical wiring system for the LED driver circuit according to claim 35;

an LED panel according to claim 36;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and a lens for transmitting the light generated by the plurality of LEDs.

38. The LED lamp retrofit apparatus of claim 37, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

39. The LED lamp retrofit apparatus of claim 38, wherein the plurality of LEDs are dimmable.

40. A pseudo double stage boost isolated flyback light emitting diode (LED) driver circuit, comprising:

an AC/DC converter sub-circuit comprising a bridge rectifier configured to couple to an alternating (AC) power source via a filter, the AC/DC converter sub-circuit to convert AC voltage received at an input to an unregulated direct current (DC) voltage across a first filtering capacitor, wherein the first filtering capacitor has a value selected to not significantly affect a power factor of the driver circuit;

a boost converter comprising a coil having one end coupled to the first filtering capacitor to receive the unregulated DC voltage from the first filtering capacitor and another end coupled to a drain of a first transistor and a second filtering capacitor through a boost diode;

a three-coil flyback transformer comprising a primary coil, a low current secondary coil, and a high current secondary coil, the primary coil to receive a direct current (DC) input voltage from the second filtering capacitor and to couple the DC input voltage to a drain of a second transistor, the high current secondary coil having one end coupled to ground and the other end coupled to a third filtering capacitor through a flyback diode, wherein the cathode of the flyback diode is coupled to at least one LED;

a snubber circuit operatively coupled to the primary coil of the transformer and the drain of the second transistor, the snubber circuit coupled to the DC input voltage;

a pulse width modulation sub-circuit having an output coupled to gates of the first and second transistors and an input coupled to a sense resistor coupled in series with the source of the second transistor, wherein the pulse width modulation sub-circuit delivers a pulse width modulated driving signal to the gates of the first and second transistors, wherein the second transistor via the flyback transformer creates two output supply voltages, a high current supply voltage rectified by the flyback diode and filtered by a third filtering capacitor for supplying at least one LED, and a low current feedback supply voltage signal rectified by the feedback diode and integrated by an integrating capacitor to a feedback input of the pulse width modulation sub-circuit via a resistor divider network and the compensation capacitor;

a soft start over voltage control sub-circuit operatively coupled to the pulse width modulation sub-circuit via a compensation capacitor to compensate a feedback voltage; and

a voltage follower current feedback sub-circuit coupled to the pulse width modulation sub-circuit, wherein a control input of the voltage follower current feedback sub-circuit is coupled to a compensation output of the pulse width modulation sub-circuit and to the soft start over voltage control sub-circuit, an input of the voltage follower current feedback sub-circuit is coupled to the cathode of a feedback diode and an integrating capacitor, wherein the anode of the feedback diode is coupled to one end of the low current secondary coil.

41. The LED driver circuit of claim 40, comprising an electrical wiring system for the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

42. The LED driver circuit of claim 40 or 41, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

43. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a pseudo double stage boost isolated flyback LED driver circuit according to claim 40;

an electrical wiring system for the LED driver circuit according to claim 41;

an LED panel according to claim 42;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

44. The LED lamp retrofit apparatus of claim 43, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

45. The LED lamp retrofit apparatus of claim 44, wherein the plurality of LEDs are dimmable.

46. A pseudo double stage boost non isolated flyback light emitting diode (LED) driver circuit, comprising:

an AC/DC converter sub-circuit comprising a bridge rectifier configured to couple to an alternating (AC) power source via a filter, the AC/DC converter sub-circuit to convert AC voltage received at an input to an unregulated direct current (DC) voltage across a first filtering capacitor, wherein the first filtering capacitor has a value selected to not significantly affect a power factor of the driver circuit;

a boost converter comprising a coil having one end coupled to the first filtering capacitor to receive the unregulated DC voltage from the first filtering capacitor and another end coupled to a second filtering capacitor through a first boost diode and coupled to a drain of a transistor through a second boost diode;

a three-coil flyback transformer comprising a primary coil, a low current secondary coil, and a high current secondary coil, the primary coil to receive a direct current (DC) input voltage from the second filtering capacitor and to couple the DC input voltage to the drain of the transistor, the high current secondary coil having one end coupled to ground and the other end coupled to a third filtering capacitor through a flyback diode, wherein the cathode of the flyback diode is coupled to at least one LED;

a snubber circuit operatively coupled to the primary coil of the transformer and the drain of the second transistor, the snubber circuit coupled to the DC input voltage;

a pulse width modulation sub-circuit having an output coupled to gate of the transistor and an input coupled to a sense resistor coupled in series with the source of the transistor, wherein the pulse width modulation sub-circuit delivers a pulse width modulated driving signal to the gate of the transistor, wherein the transistor via the flyback transformer creates two output supply voltages, a high current supply voltage rectified by the flyback diode and filtered by the third filtering capacitor for supplying the at least one LED, and a low current feedback supply voltage signal rectified by the feedback diode and integrated by an integrating capacitor to a feedback input of the pulse width modulation sub-circuit via a resistor divider network and the compensation capacitor;

a soft start over voltage control sub-circuit operatively coupled to the pulse width modulation sub-circuit via a compensation capacitor to compensate a feedback voltage; and

an operational amplifier for sensing a current through the at least one LED such that when the current through the at least one LED is higher than a pre-established limit, the operational amplifier output lowers the amount of voltage at a compensation input of the pulse width modulation sub-circuit to decrease the duty-cycle of the pulse width modulated driving signal pulses until the current through the at least one LED decreases within the pre-established limits.

47. The LED driver circuit of claim 46, comprising an electrical wiring system for the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

48. The LED driver circuit of claim 46 or 48, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

49. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a pseudo double stage boost non isolated flyback LED driver circuit according to claim 46;

an electrical wiring system for the LED driver circuit according to claim 47;

an LED panel according to claim 48;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

50. The LED lamp retrofit apparatus of claim 46, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

51. The LED lamp retrofit apparatus of claim 50, wherein the plurality of LEDs are dimmable.

52. A pseudo double stage boost constant off time buck-boost light emitting diode (LED) driver circuit, comprising:

an AC/DC converter sub-circuit comprising a bridge rectifier configured to couple to an alternating (AC) power source via a filter, the AC/DC converter sub-circuit to convert AC voltage received at an input to an unregulated direct current (DC) voltage across a first filtering capacitor, wherein the first filtering capacitor has a value selected to not significantly affect a power factor of the driver circuit;

a buck-boost converter comprising a first coil and a second coil, the first coil having one end coupled to the first filtering capacitor to receive the unregulated DC voltage from the first filtering capacitor, the first coil having another end coupled to a drain of a first transistor and to a second filtering capacitor through a boost diode, wherein the cathode of the boost diode is coupled to at least one LED through a buck-boost coil and is coupled to a drain of a second transistor through a buck boost capacitor, the second coil having one end coupled to ground and another end coupled to the anode of a supply diode;

a pulse width modulation sub-circuit having an input coupled to the cathode of the supply diode and an output coupled to gates of the first and second transistors and another input coupled to a sense resistor coupled in series with the source of the second transistor, wherein the pulse width modulation sub-circuit delivers a pulse width modulated driving signal to the gates of the first and second transistors, which via the first coil of the buck-boost transformer creates an output supply voltage for supplying the at least one LED;

a soft start over voltage control sub-circuit operatively coupled to the pulse width modulation sub-circuit via a compensation capacitor to compensate a feedback voltage; and

a transistor connected as a switch between ground and an oscillator terminal of the pulse width modulation sub-circuit in parallel with an oscillator timing capacitor, wherein the transistor is controlled by the controlled by the pulse width modulated driving signal such that when the pulse width modulated driving signal is in a high state, the transistor discharges the oscillator timing capacitor forcing the pulse width modulated driving signal to have a constant off time, regardless of its momentarily on time.

53. The LED driver circuit of claim 5, comprising an electrical wiring system for the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

54. The LED driver circuit of claims 52 or 53, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

55. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a pseudo double stage boost constant off time buck-boost LED driver circuit according to claim 52;

an electrical wiring system for the LED driver circuit according to claim 53;

an LED panel according to claim 54;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

56. The LED lamp retrofit apparatus of claim 55, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

57. The LED lamp retrofit apparatus of claim 56, wherein the plurality of LEDs are dimmable.

58. A pseudo double stage boost single ground buck-boost light emitting diode (LED) driver circuit, comprising:

an AC/DC converter sub-circuit comprising a bridge rectifier configured to couple to an alternating (AC) power source via a filter, the AC/DC converter sub-circuit to convert AC voltage received at an input to an unregulated direct current

(DC) voltage across a filtering capacitor, wherein the filtering capacitor has a value selected to not significantly affect a power factor of the driver circuit;

a boost converter sub-circuit comprising a first boost coil having one end coupled to the filtering capacitor to receive the unregulated DC voltage from the filtering capacitor and another end coupled to a first buck-boost coil through a first boost diode and coupled to a drain of a transistor through a second boost diode, one end of the first buck-boost coil coupled to a first buck-boost capacitor through a first buck-boost diode and also coupled to the drain of the transistor, and the other end of the first buck-boost coil coupled to the cathode of a second buck-boost diode, the anode of the second buck-boost diode coupled to ground, wherein the first the buck-boost capacitor is coupled to a second buck-boost capacitor and at least one LED;

a pulse width modulation sub-circuit having an input coupled to the first and second buck-boost capacitors; and

a ground separating transformer having a primary coil coupled to a pulse width modulation output of the pulse width modulation sub-circuit and a secondary coil coupled to a gate of the transistor, wherein the secondary coil applies a pulse width modulated driving signal to the gate of the transistor;

wherein when the pulse width modulation sub-circuit receives its required power supply voltage and starts oscillating, the gate of the transistor receives the pulse width modulated signal from the secondary coil of the ground separating transformer and activates the buck-boost inductor which supplies with a DC voltage to the buck-boost capacitor via the buck-boost diode.

59. The LED driver of claim 58, comprising an operational amplifier for sensing a current through the at least one LED such that when the current through the at least one LED is higher than a pre-established limit, the operational amplifier output lowers the amount of voltage at a compensation input of the pulse width modulation sub-circuit to decrease the duty-cycle of the pulse width modulated driving signal pulses until the current through the at least one LED decreases within the pre-established limits.

60. The LED driver circuit of claims 58 or 59, comprising an electrical wiring system for the LED driver circuit, the electrical wiring system comprising:

a two wire circuit to couple the LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED; and

a two wire circuit, coupled in series with at least one of the LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

61. The LED driver circuit of claims 58, 59, or 60, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

62. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a pseudo double stage boost single ground buck-boost LED driver circuit according to claim 58;

an electrical wiring system for the LED driver circuit according to claim 59;

an LED panel according to claim 60;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

63. The LED lamp retrofit apparatus of claim 62, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

64. The LED lamp retrofit apparatus of claim 63, wherein the plurality of LEDs are dimmable.

65. A series monolithic light emitting diode (LED) driver circuit, comprising:

an AC-to-DC converter sub-circuit comprising a bridge rectifier operatively coupled to an AC voltage power source for providing an unfiltered direct current (DC) pulse voltage Vin at its positive output terminal with respect to its negative output terminal coupled to ground; and

at least one Benistor cell sub-circuit comprising:

an anode A terminal coupled to Vin;

a cathode K terminal coupled to the anode of a first LED column;

a voltage sense Vs terminal coupled to the anode A terminal;

a zero voltage reference terminal ZVR coupled with the second terminal of the first current sense resistor;

a voltage set terminal Von coupled to the positive terminal of a DC voltage source having its negative terminal coupled to the ZVR terminal;

a voltage set terminal Voff coupled to the positive terminal of a DC voltage source having its negative terminal coupled to the ZVR terminal;

a current set terminal Cc coupled to the cathode of the LED column and a first terminal of a first current sense resistor;

a feedback terminal FB configured to couple to a feedback terminal of a second eight terminal switch Benistor.

66. The series monolithic LED driver circuit of claim 65, comprising:

three additional Benistor cell sub-circuits, wherein the feedback terminals FB of each Benistor cell sub-circuits are connected; and

a second, third, and fourth LED column connected as follows:

the second LED column is connected in series with the first LED column and between a cathode terminal K and current set terminal Cc of the second Benistor cell;

the third LED column is connected in series with the second LED column and between a cathode terminal K and current set terminal Cc of the third Benistor cell; and

the fourth LED column is connected in series with the third LED column and between a cathode terminal K and current set terminal Cc of the fourth Benistor cell.

67. The series monolithic LED driver circuit of claims 65 or 66, comprising an electrical wiring system comprising:

a two wire circuit to couple the series monolithic LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED column;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED column; and

a two wire circuit, coupled in series with at least one of the series monolithic LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

68. The series monolithic LED driver circuit of claims 65, 66, or 67, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

69. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a series monolithic LED driver circuit according to claims 65 or 66;

an electrical wiring system for the LED driver circuit according to claim 67;

an LED panel according to claim 68;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

70. The LED lamp retrofit apparatus of claim 69, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

71. The LED lamp retrofit apparatus of claim 70, wherein the plurality of LEDs are dimmable.

72. A parallel monolithic light emitting diode (LED) driver circuit, comprising:

an AC-to-DC converter sub-circuit comprising a bridge rectifier operatively coupled to an AC voltage power source for providing an unfiltered direct current (DC) pulse voltage Vin at its positive output terminal with respect to its negative output terminal coupled to ground; and

at least one Benistor cell sub-circuit comprising:

an anode A terminal coupled to a cathode of a first LED column, which has the anode coupled to Vin;

a cathode K terminal coupled to a first current sense resistor which has the other terminal coupled to ground;

a voltage sense Vs terminal coupled to Vin;

a voltage set terminal Von coupled to the positive terminal of a DC voltage source having its negative terminal coupled to ground;

a voltage set terminal Voff coupled to the positive terminal of a DC voltage source having its negative terminal coupled to ground;

a current set terminal Cc coupled also to the first terminal of the current sense resistor;

a feedback terminal FB configured to couple to a feedback terminal of a second Benistor cell; and

a zero voltage reference terminal ZVR coupled to ground.

73. The parallel monolithic LED driver circuit of claim 72, comprising:

three additional Benistor cell sub-circuits, wherein the feedback terminals FB of each Benistor cell sub-circuits are connected; and

a second, third, and fourth LED column connected as follows:

an anode A terminal of the second Benistor cell is coupled to a cathode of the second LED column, which has the anode coupled to Vin;

an anode A terminal of the third Benistor cell is coupled to a cathode of the third LED column, which has the anode coupled to Vin;

an anode A terminal of the fourth Benistor cell is coupled to a cathode of the fourth LED column, which has the anode coupled to Vin;

74. The parallel monolithic LED driver circuit of claims 72 or 73, comprising an electrical wiring system comprising:

a two wire circuit to couple the parallel monolithic LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED column;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED column; and

a two wire circuit, coupled in series with at least one of the parallel monolithic LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

75. The parallel monolithic LED driver circuit of claims 72, 73, or 74, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

76. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a parallel monolithic LED driver circuit according to claims 72 or 73;

an electrical wiring system for the LED driver circuit according to claim 74;

an LED panel according to claim 75;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

77. The LED lamp retrofit apparatus of claim 76, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

78. The LED lamp retrofit apparatus of claim 77, wherein the plurality of LEDs are dimmable.

79. A single cell anode loaded voltage controlled limited current switch (VCLCsw) light emitting diode (LED) driver circuit, comprising:

an AC-to-DC converter sub-circuit comprising a bridge rectifier operatively coupled to an AC voltage power source for providing an unfiltered direct current (DC) pulse voltage Vin at its positive output terminal with respect to its negative output terminal coupled to ground; and

a single cell sub-circuit comprising:

an anode A terminal operatively coupled to Vin via a LED column;

a cathode K terminal coupled to a first terminal of a resistor having the other terminal coupled to ground;

a voltage sense Vs terminal coupled directly to Vin;

a voltage set terminal Von coupled to the positive terminal of a DC voltage source having its negative terminal coupled to ground;

a voltage set terminal Voff coupled to the positive terminal of a DC voltage source having its negative terminal coupled to ground;

a current set terminal Cc coupled also to the first terminal of the resistor;

a feedback terminal FB unconnected; and

a zero voltage reference terminal ZVR coupled to ground.

80. The single cell anode loaded VCLCsw LED driver circuit of claim 79, wherein the single cell sub-circuit comprises:

a MOSFET buffer BUF having its drain coupled to A, its source coupled to K, and its gate coupled to a micro-controller uC;

a first comparator V1 having one input coupled to Von, another input coupled to Vs, and an output coupled to the uC;

a second comparator V2 having one input coupled to Voff, another input coupled to Vs, and an output coupled to the uC;

an operational amplifier C having one input coupled to Cc, another input coupled to the uC, and an output coupled also to the uC;

a voltage shunt voltage reference BGVR coupled with the anode to ZVR and with its cathode to the uC; and

a temperature sensor Ts coupled to the uC.

81. The single cell anode loaded VCLCsw LED driver circuit of claim 79 or 80,

comprising an electrical wiring system comprising:

a two wire circuit to couple the single cell anode loaded VCLCsw LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED column;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED column; and

a two wire circuit, coupled in series with at least one of the parallel monolithic LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

82. The single cell anode loaded VCLCsw LED driver circuit of claims 79, 80, or 81, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

83. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a single cell anode loaded VCLCsw LED driver circuit according to claims 79 or 80;

an electrical wiring system for the LED driver circuit according to claim 81;

an LED panel according to claim 82;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

84. The LED lamp retrofit apparatus of claim 83, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

85. The LED lamp retrofit apparatus of claim 84, wherein the plurality of LEDs are dimmable.

86. A single cell cathode loaded voltage controlled limited current switch (VCLCsw) light emitting diode (LED) driver circuit, comprising:

an AC-to-DC converter sub-circuit comprising a bridge rectifier operatively coupled to an AC voltage power source for providing an unfiltered direct current (DC) pulse voltage Vin at its positive output terminal with respect to its negative output terminal coupled to ground; and

a single cell sub-circuit comprising:

an anode A terminal coupled to Vin;

a cathode K terminal coupled, via an LED column to a first terminal of a first resistor having the other terminal coupled to ground;

a voltage set terminal Von coupled to Vin;

a voltage set terminal Voff coupled to the anode of a zener diode having the cathode coupled to Vin via a second resistor;

a current set terminal Cc coupled also to the first terminal of the first resistor; and

a zero voltage reference terminal ZVR coupled to ground.

87. The single cell cathode loaded VCLCsw LED driver circuit of claim 86, wherein the single cell sub-circuit comprises:

a MOSFET buffer BUF1 having its drain coupled to A, its source coupled to K, and its gate coupled to the cathode a second zener diode Vlim1 having the anode coupled to ZVR terminal;

a ON resistor coupled between the BUF gate and the Von terminal;

a voltage transistor Qv1 having its base coupled to the Voff terminal, the collector coupled to BUF gate and emitter coupled to the ZVR terminal; and

a current transistor having its base coupled to the Cc terminal, the collector coupled to the BUF gate and emitter coupled to the ZVR terminal.

88. The single cell cathode loaded VCLCsw LED driver circuit of claim 86 or 87, comprising an electrical wiring system comprising:

a two wire circuit to couple the single cell anode loaded VCLCsw LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED column;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED column; and

a two wire circuit, coupled in series with at least one of the parallel monolithic LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

89. The single cell cathode loaded VCLCsw LED driver circuit of claims 86, 87, or 88, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

90. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a single cell cathode loaded VCLCsw LED driver circuit according to claims 86 or 87;

an electrical wiring system for the LED driver circuit according to claim 88;

an LED panel according to claim 89;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

91. The LED lamp retrofit apparatus of claim 90, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

92. The LED lamp retrofit apparatus of claim 91, wherein the plurality of LEDs are dimmable.

93. A series connected voltage controlled limited current switch (VCLCsw) light emitting diode (LED) driver circuit, comprising:

an AC-to-DC converter sub-circuit comprising a bridge rectifier operatively coupled to an AC voltage power source for providing an unfiltered direct current (DC) pulse voltage Vin at its positive output terminal with respect to its negative output terminal coupled to ground; and

at least two series connected cell sub-circuits, wherein the first cell sub-circuit comprises:

a first MOSFET buffer BUF1 having its drain coupled to Vin, source coupled to the anode of a first LED stripe LEDc1 and gate coupled to the cathode of a first zener diode Vlim1 ;

a NPN transistor Qc1 having its base coupled to the cathode of the first LED stripe LEDc1 and a first terminal of a current resistor Rc1, emitter coupled to the other terminal of the current resistor Rc1 and the anode of Vlim1 and collector coupled to the gate of the MOSFET buffer BUF1 ; and

a ON resistor Ron1 coupled from Vin to the gate of the MOSFET buffer BUF1; and

wherein the second cell sub-circuit comprises:

a second MOSFET buffer BUF2 having its drain coupled to Vin, source coupled to the anode of a second LED stripe LEDc2 and the second terminal of Rc1 and the gate coupled to the cathode of a second zener diode Vlim2;

a second NPN transistor Qc2 having its base coupled to the cathode of the second LED stripe LEDc2 and a first terminal of a second current resistor Rc2, emitter coupled to the other terminal of the second current resistor Rc2 and the anode of Vlim2 and the collector coupled to the gate of the second MOSFET buffer BUF2; and

a second ON resistor Ron2 coupled from Vin to the gate of the second MOSFET buffer BUF2.

94. The series connected VCLCsw LED driver circuit of claim 93, comprising an electrical wiring system comprising:

a two wire circuit to couple the series connected VCLCsw LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED column;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED column; and

a two wire circuit, coupled in series with at least one of the parallel monolithic LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

95. The series connected VCLCsw LED driver circuit of claims 93 or 94, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

96. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a series connected VCLCsw LED driver circuit according to claim 93;

an electrical wiring system for the LED driver circuit according to claim 94;

an LED panel according to claim 95;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

97. The LED lamp retrofit apparatus of claim 96, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

98. The LED lamp retrofit apparatus of claim 97, wherein the plurality of LEDs are dimmable.

99. A parallel connected voltage controlled limited current switch (VCLCsw) light emitting diode (LED) driver circuit, comprising:

an AC-to-DC converter sub-circuit comprising a bridge rectifier operatively coupled to an AC voltage power source for providing an unfiltered direct current (DC) pulse voltage Vin at its positive output terminal with respect to its negative output terminal coupled to ground; and

at least two parallel connected cell sub-circuits, wherein the first cell sub-circuit comprises:

a first MOSFET buffer BUF1 having its drain coupled the cathode of a first LED stripe LEDc1 having its anode coupled to Vin, its source coupled to a first terminal of a first current resistor Rc1 and its gate coupled to the cathode of a first zener diode Vlim1 having its anode coupled to ground;

a voltage control NPN transistor Qv1 having its base coupled to the anode of a second zener diode Dv1 which has its anode coupled to the cathode of first LED stripe LEDc1 via a first resistor Rv1, its emitter coupled to ground and its collector coupled to the gate of the first MOSFET buffer BUF1 ; and

a ON resistor Ron1 coupled from the cathode of the first LED stripe LEDc1 to the gate of the first MOSFET buffer BUF1; and

wherein the second cell sub-circuit comprises:

a second MOSFET buffer BUF2 having its drain coupled the cathode of a second LED stripe LEDc2 having its anode coupled to the cathode of the first LED stripe LEDd , its source coupled to the second terminal of the first current sense resistor Rd and a first terminal of a second current resistor Rc2 and the second MOSFET buffer BUF2 gate coupled to the cathode of a third zener diode Vlim2 having its anode coupled to ground;

a second voltage control NPN transistor Qv2 having its base coupled to the anode of a fourth zener diode Dv2 which has its anode coupled to the cathode of the second LED stripe LEDc2 via a resistor Rv2 , its emitter coupled to ground and its collector coupled to the gate of the second MOSFET buffer BUF2; and

a second ON resistor Ron2 coupled from the cathode of the second LED stripe LEDc2 to the gate of the second MOSFET buffer BUF2.

100. The parallel connected VCLCsw LED driver circuit of claim 99, comprising an electrical wiring system comprising:

a two wire circuit to couple the parallel connected VCLCsw LED driver circuit to an AC power source;

a two wire circuit for supplying the at least one LED column;

a four wire circuit for securing, in feedback, the constant voltage constant current DC supply to the at least one LED column; and

a two wire circuit, coupled in series with at least one of the parallel monolithic LED driver supply wires to remotely start/stop operation via external components selected from any one of a relay and a switch.

101. The parallel connected VCLCsw LED driver circuit of claims 99 or 100, comprising an LED panel, the LED panel comprising:

an LED board to receive a plurality of LEDs thereon and to enable light from LEDs to be generated omni-directionally;

wherein the board is made from a heat conducting metal to transfer heat from the LEDS; and

wherein the board is coated with an isolating oxide layer to receive circuit components.

102. A light emitting diode (LED) lamp retrofit apparatus, for conventional lamps, the apparatus comprising:

a parallel connected VCLCsw LED driver circuit according to claim 99;

an electrical wiring system for the LED driver circuit according to claim 100;

an LED panel according to claim 101;

a plurality of LEDs for converting to light energy the electrical energy absorbed from the AC power source;

an AC power source adapter to couple to an AC power source; and

a lens for transmitting the light generated by the plurality of LEDs.

103. The LED lamp retrofit apparatus of claim 102, wherein the LED lamp is configured to retrofit a conventional lamp selected from the group consisting of an incandescent lamp, a halogen lamp, a fluorescent lamp, and a sodium lamp, and combinations thereof.

104. The LED lamp retrofit apparatus of claim 103, wherein the plurality of LEDs are dimmable.

105. The series connected VCLCsw LED driver circuit of claim 93, comprising 2, 3, or 4 NPN transistors all of them coupled emitter-collector across the first zener diode Vlim1 for decreasing the first MOSFET buffer BUF1 gate voltage when the LED

current increases.

106. The single cell cathode loaded VCLCsw LED driver circuit of claim 86, wherein the single cell sub-circuit comprises a constant voltage constant current (CVCC) system, the CVCC system comprising:

at least a second sub-circuit cell connected in series with the first sub-circuit cell; and

two operational amplifiers per each cell sub-circuit to provide a feedback loop.

107. A monolithic light emitting diode (LED) driver overall feedback parallel circuit, comprising:

an AC-to-DC converter sub-circuit comprising a bridge rectifier operatively coupled to an AC voltage power source for providing an unfiltered direct current (DC) pulse voltage Vin at its positive output terminal with respect to its negative output terminal coupled to ground; and

at least one Benister cell sub-circuit, comprising:

a first MOSFET buffer BUF1 having its drain coupled to the cathode of a first LED stripe LEDc1 which has the anode coupled to Vin, its source coupled to the first terminal of a first sense resistor Rc1 and gate coupled to the cathode of a zener diode Vlim4 which has the anode coupled to ground; and

a ON resistor Ron1 is coupled from Vin to the gate of the first MOSFET buffer BUF1 and the cathode of the zener diode Vlim4.

Fig. 1: Dimmable LED Lamp Retrofit For Classic Incandescent Lamps

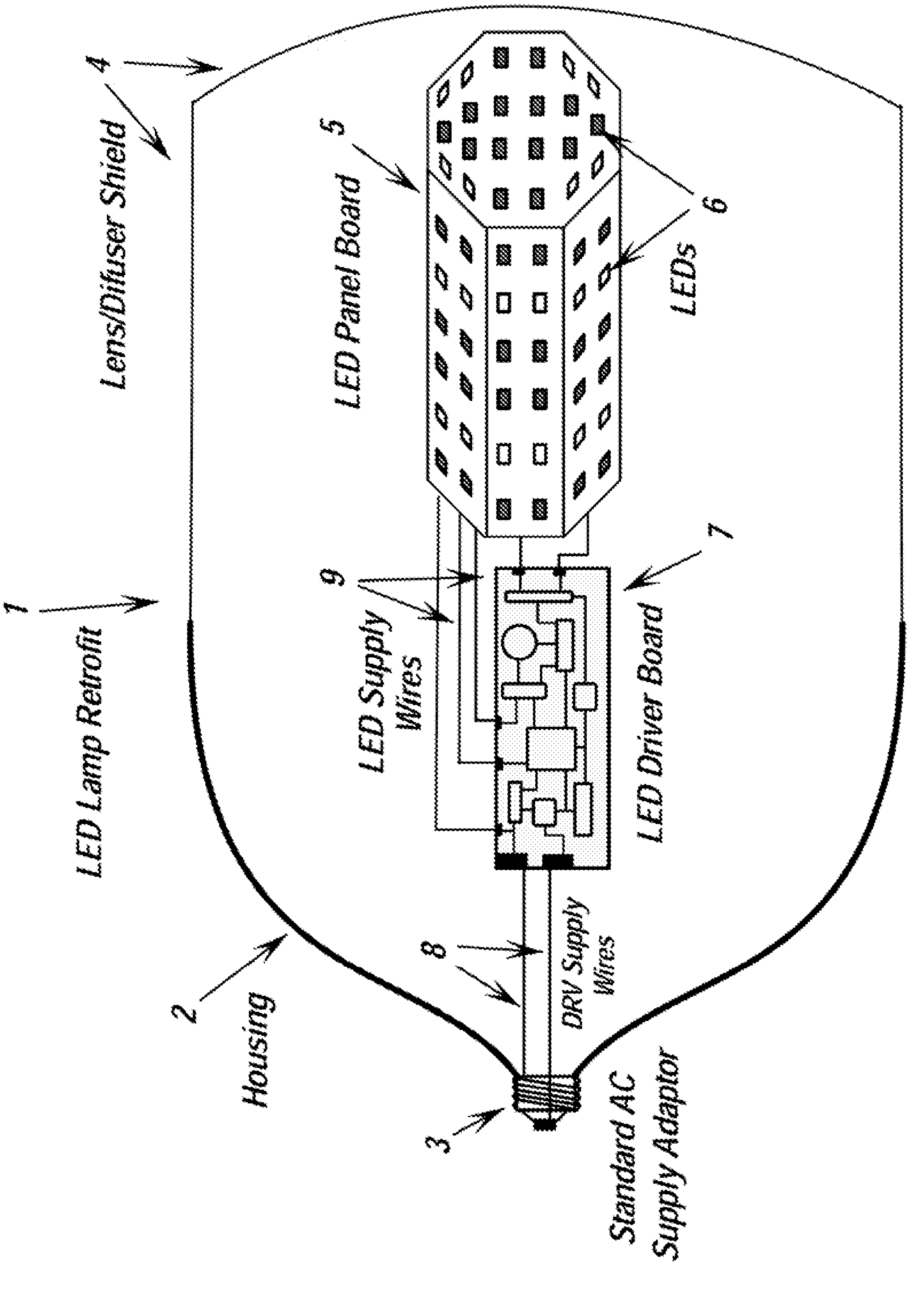


Fig. 2: Dimmable LED Lamp Retrofit For Classic Flood/Halogen Lamps

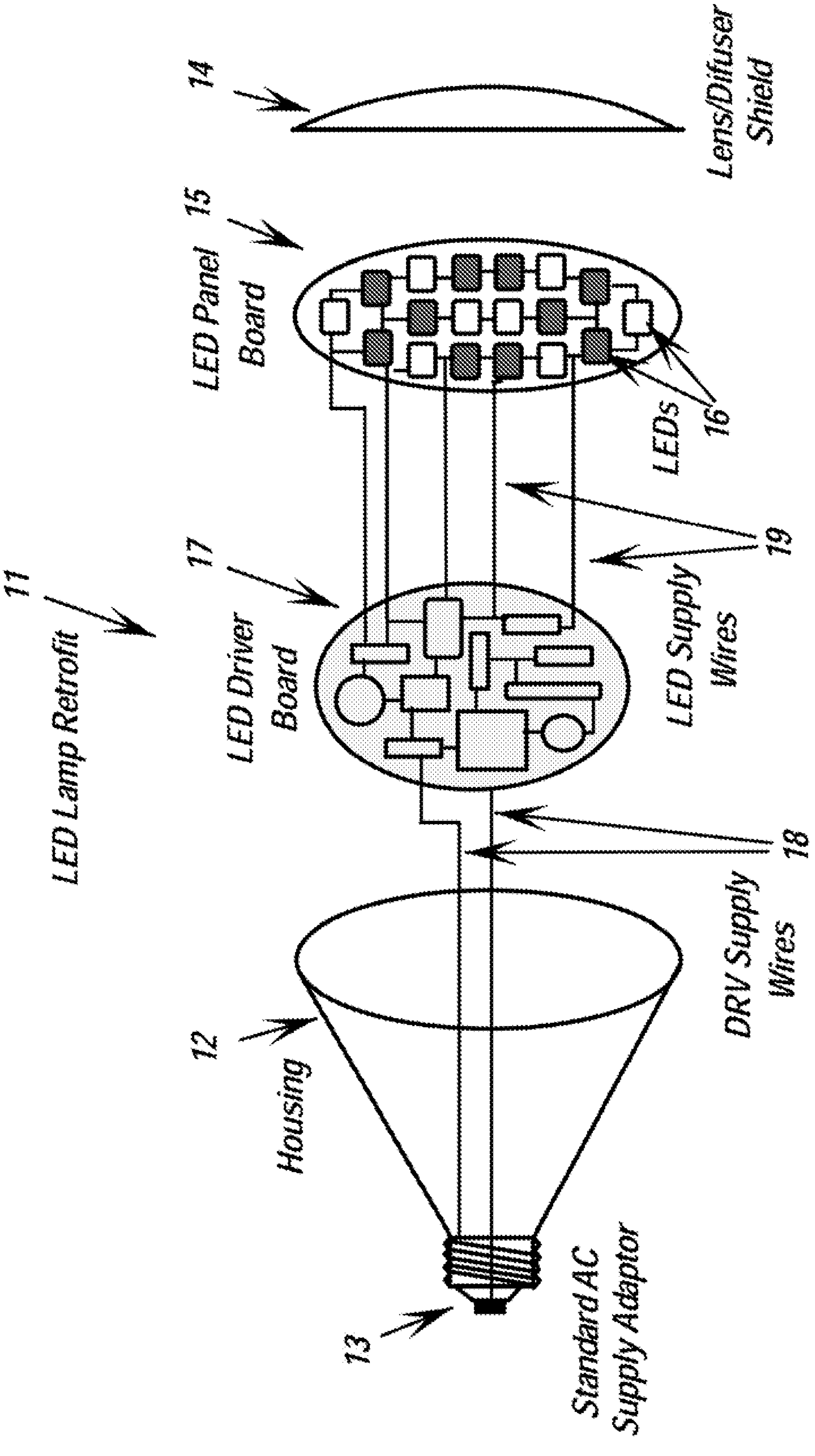


Fig. 3: Dimmable LED Lamp Retrofit For Classic Fluorescent Lamps

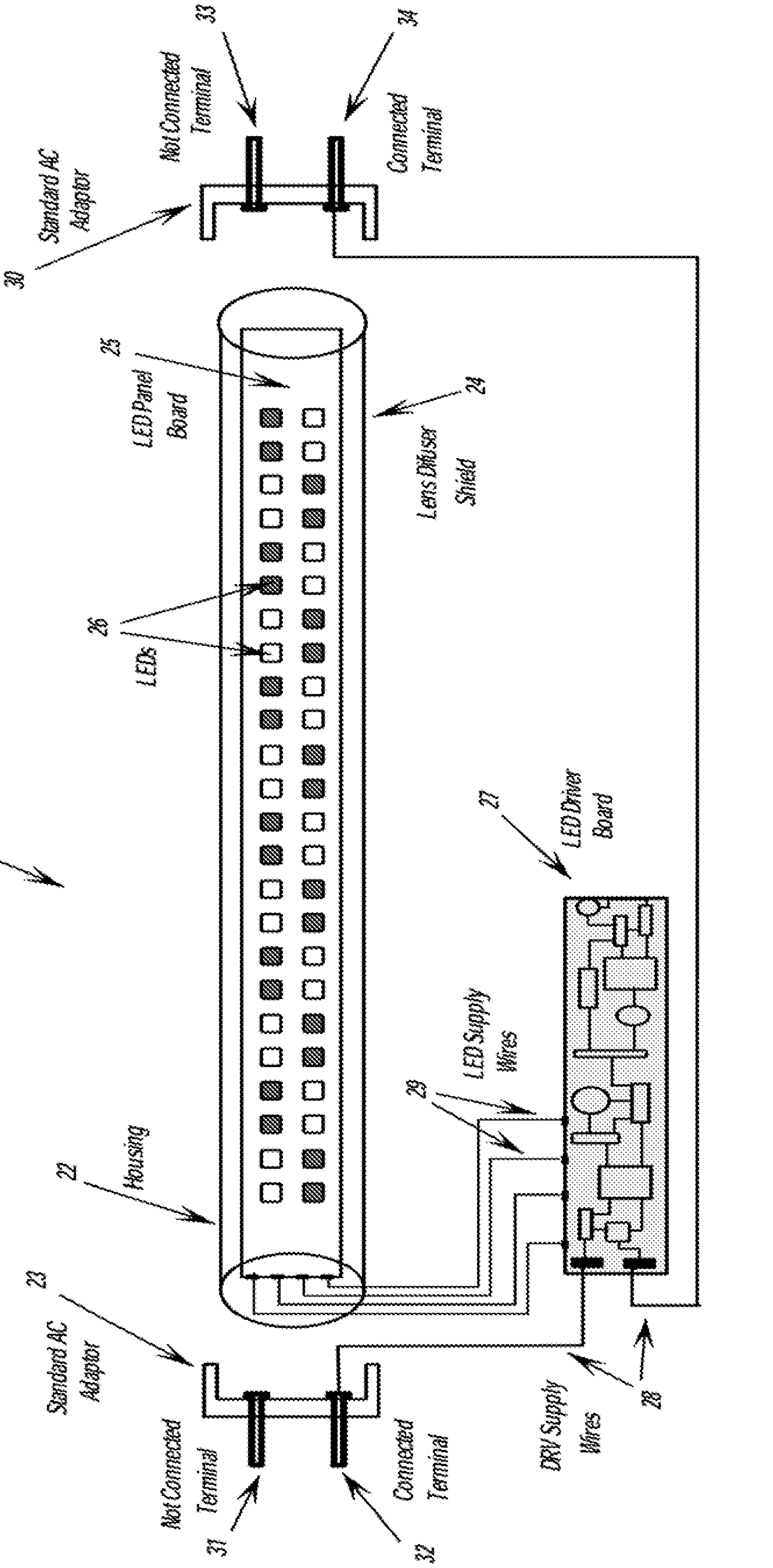


Fig. 4: Dimmable Monolithic LED Lamp Retrofit

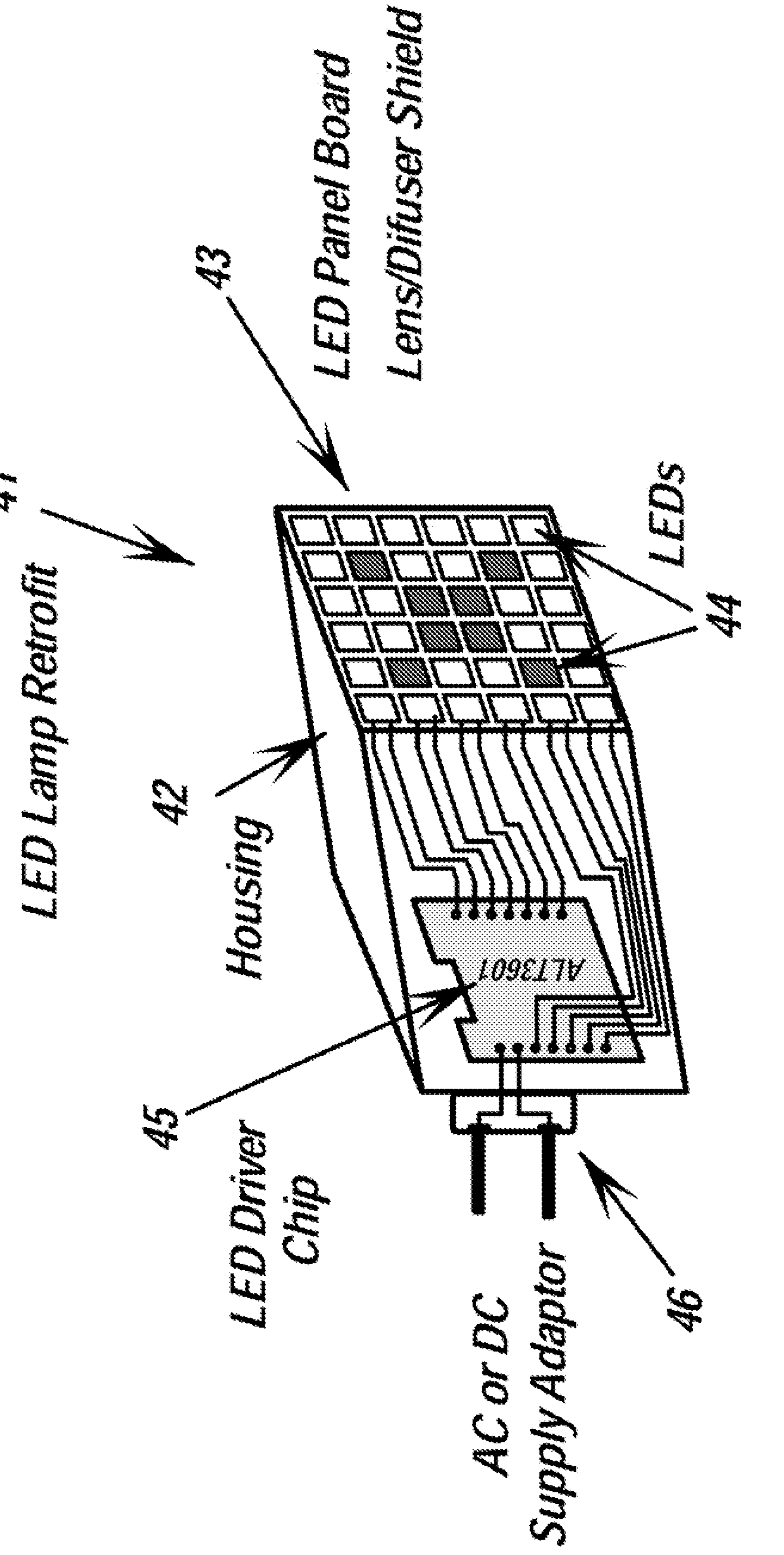


Fig. 5: Dimmable LED Circuit System For Rectangular LED Panel

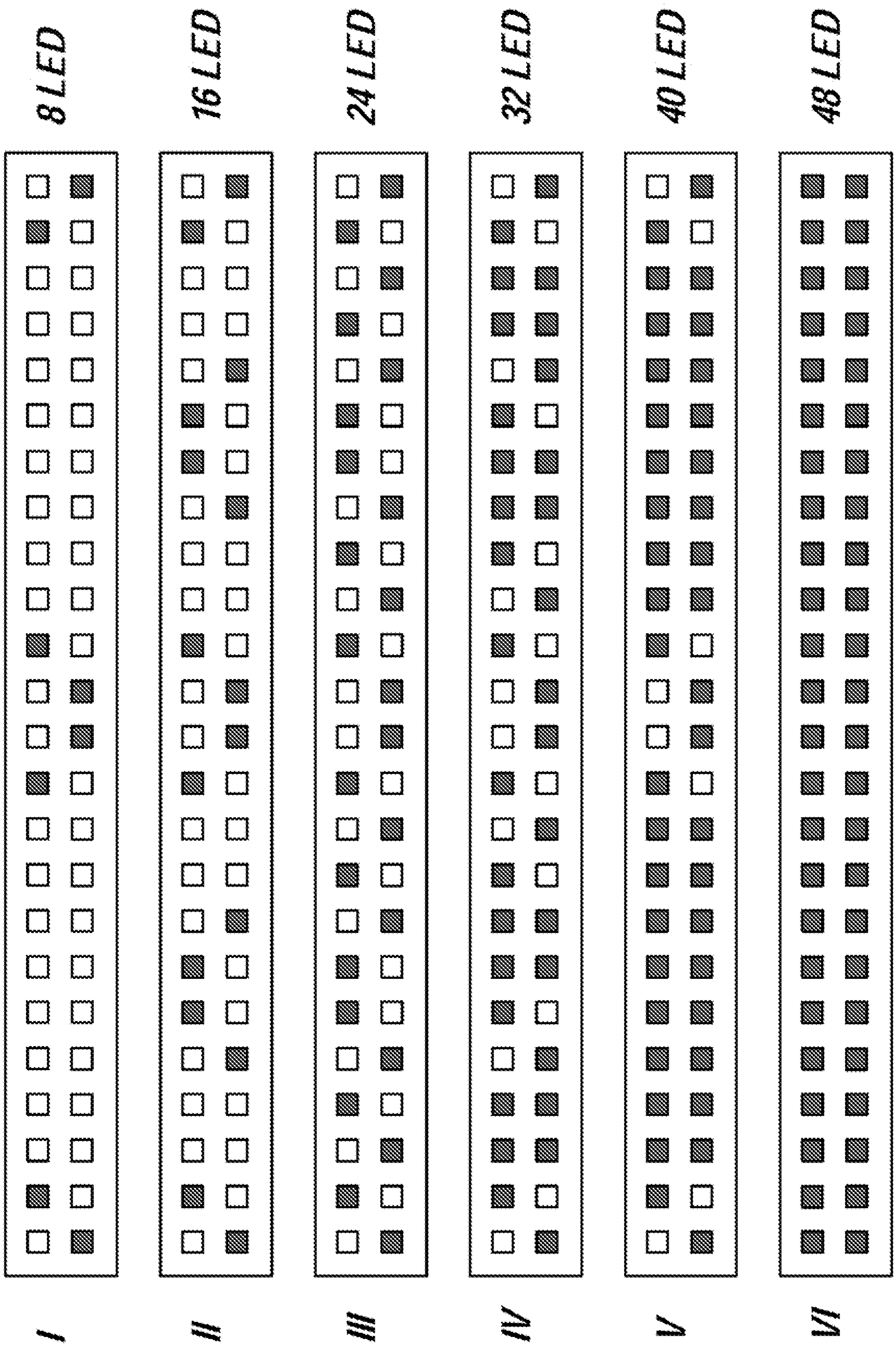


Fig. 6: Dimmable LED Circuit System For Round LED Panel

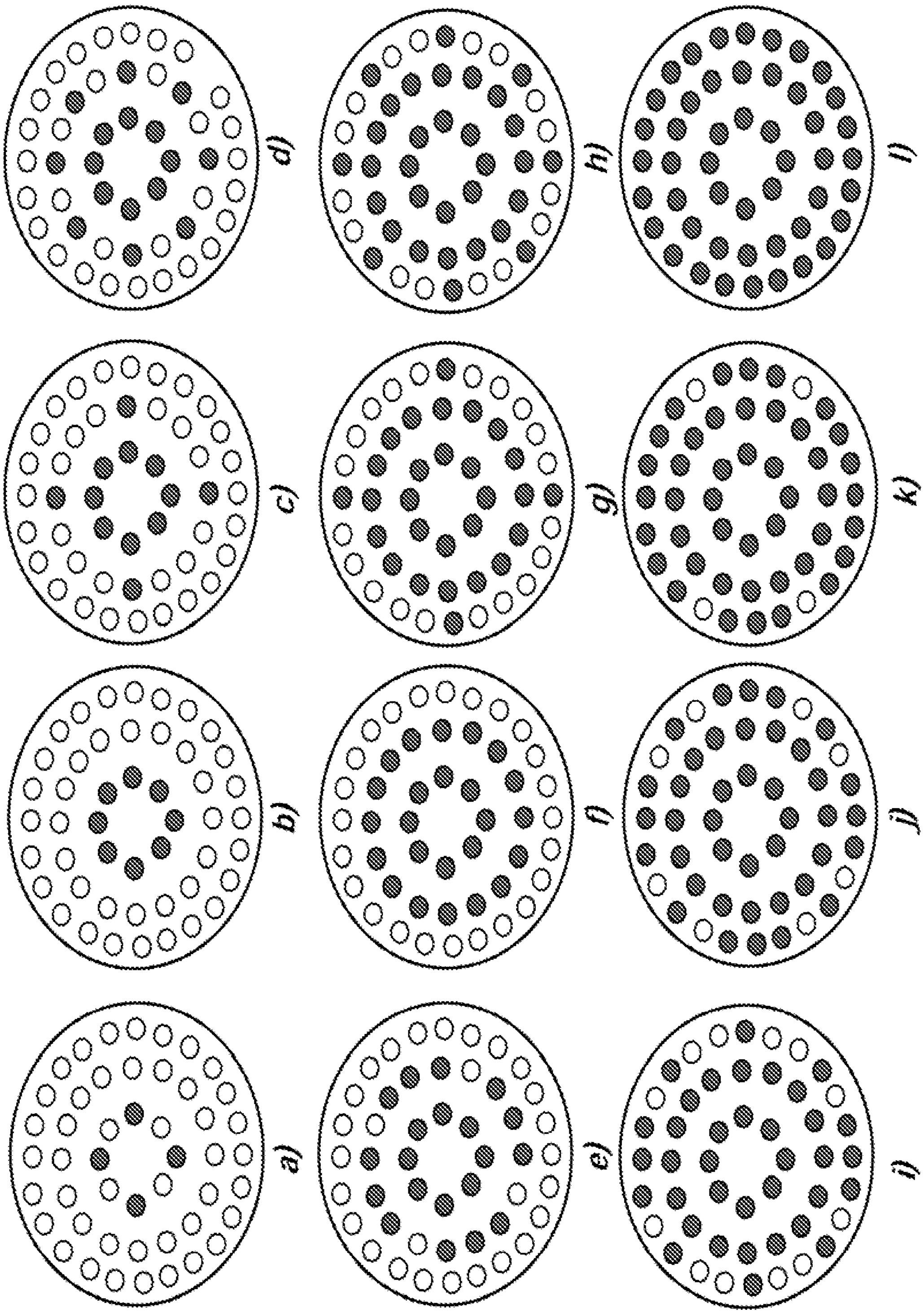


Fig. 7: Dimmable LED Array Display

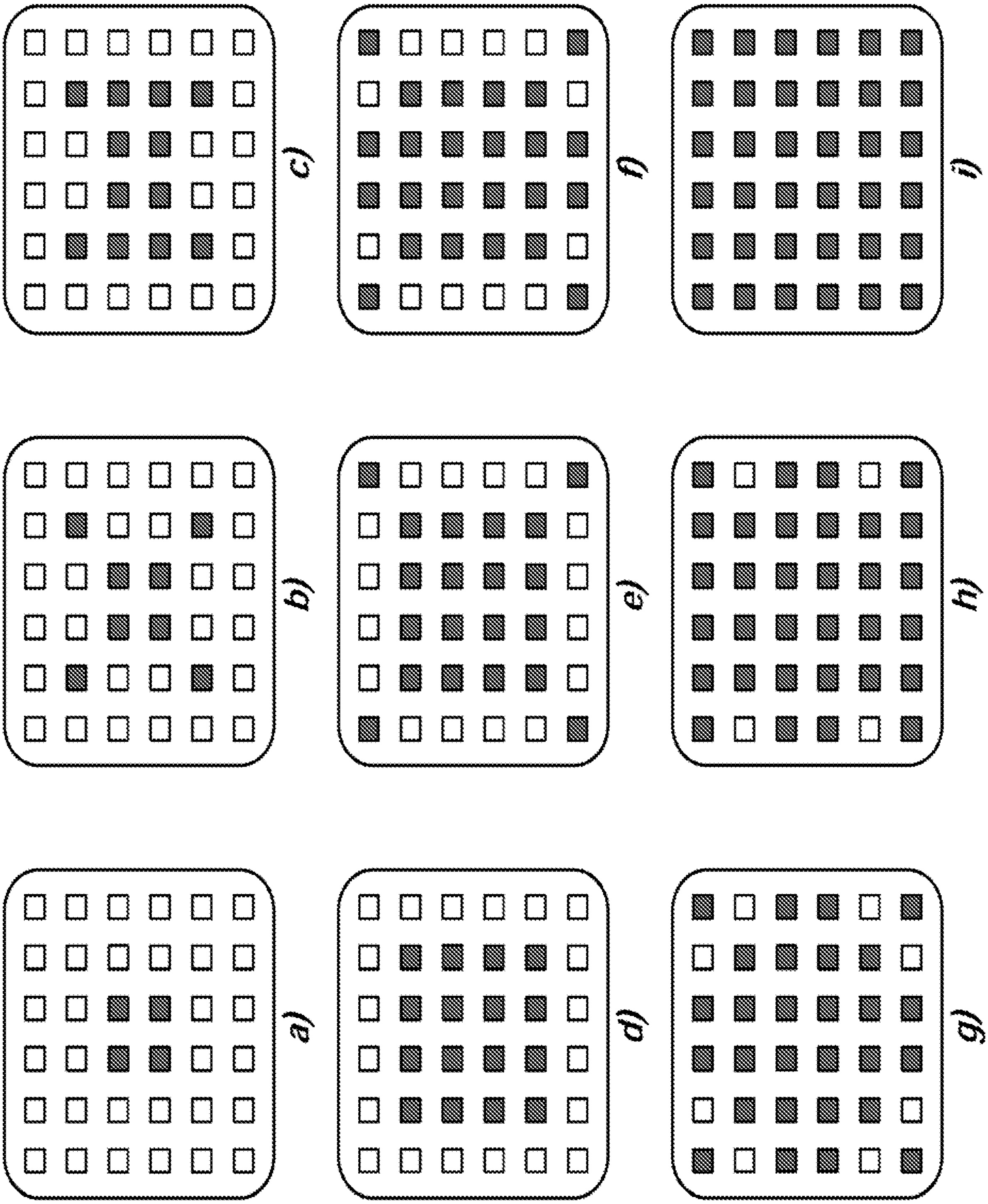
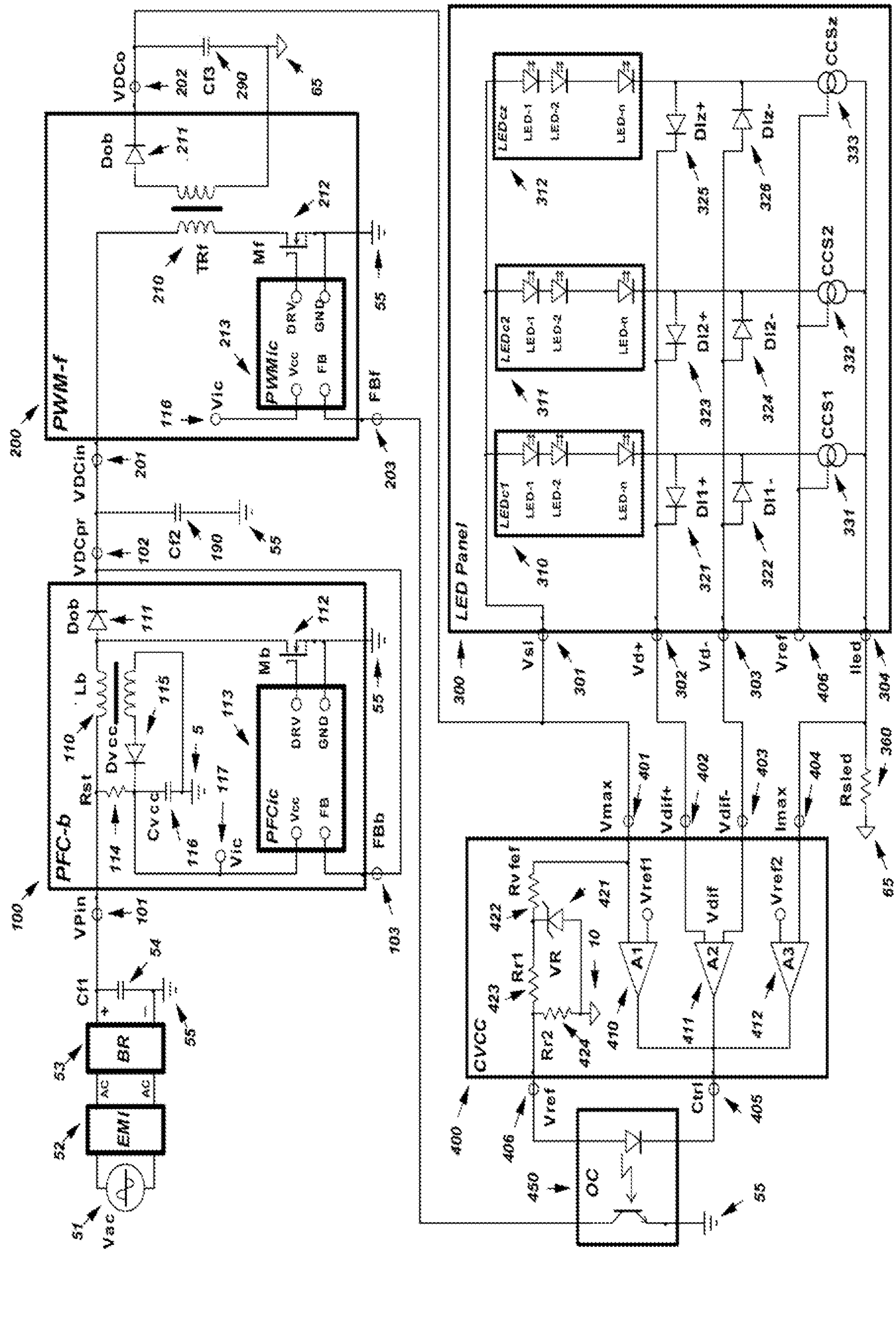


Fig. 8: Double Stage Boost - Isolated Flyback Multi-Columns LED Driver Embodiment



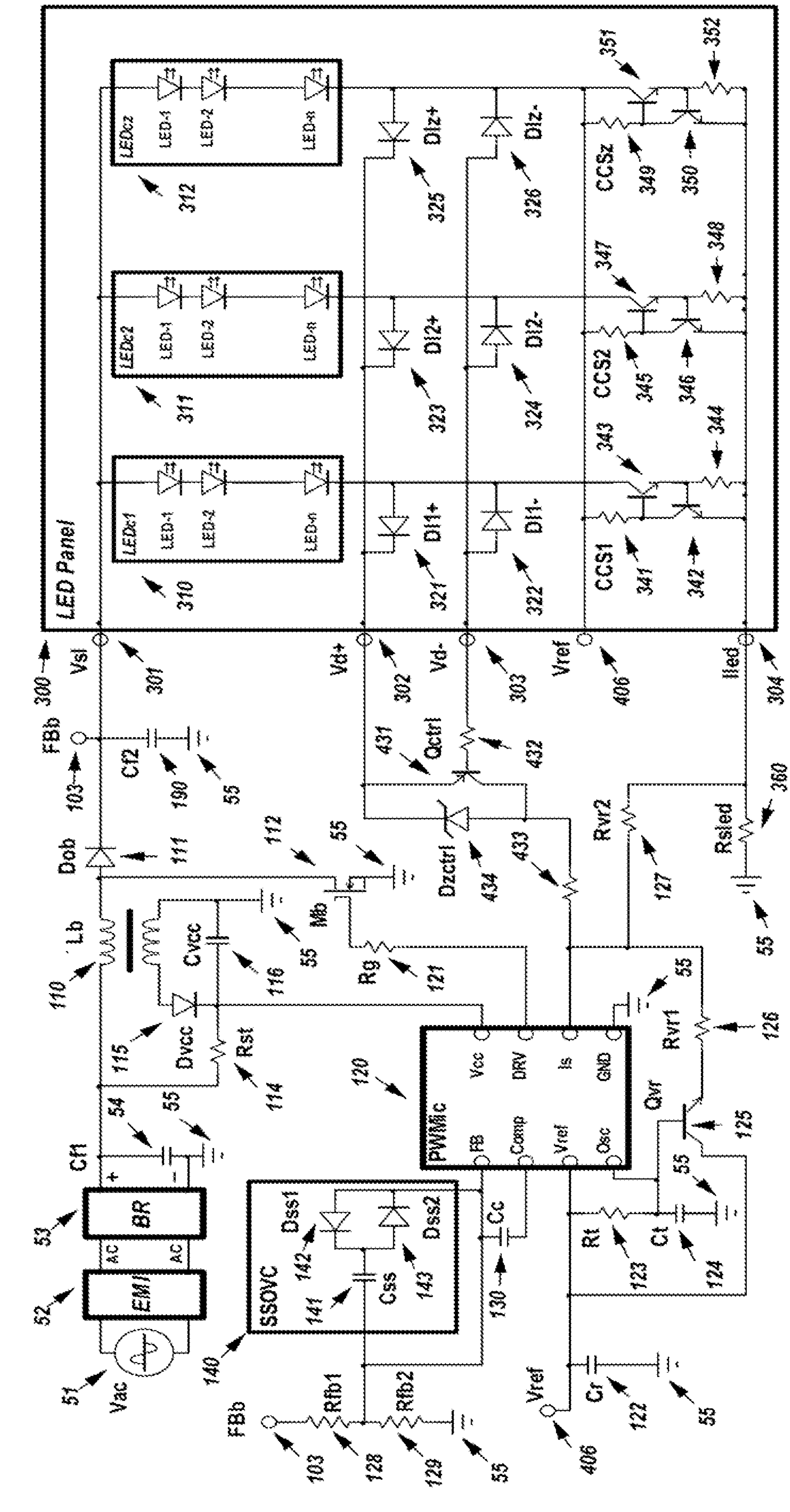


Fig. 9: Single Stage Boost Multi-Columns LED Driver Embodiment

Fig. 10: No Opto-Coupler Isolated Flyback LED Driver Embodiment

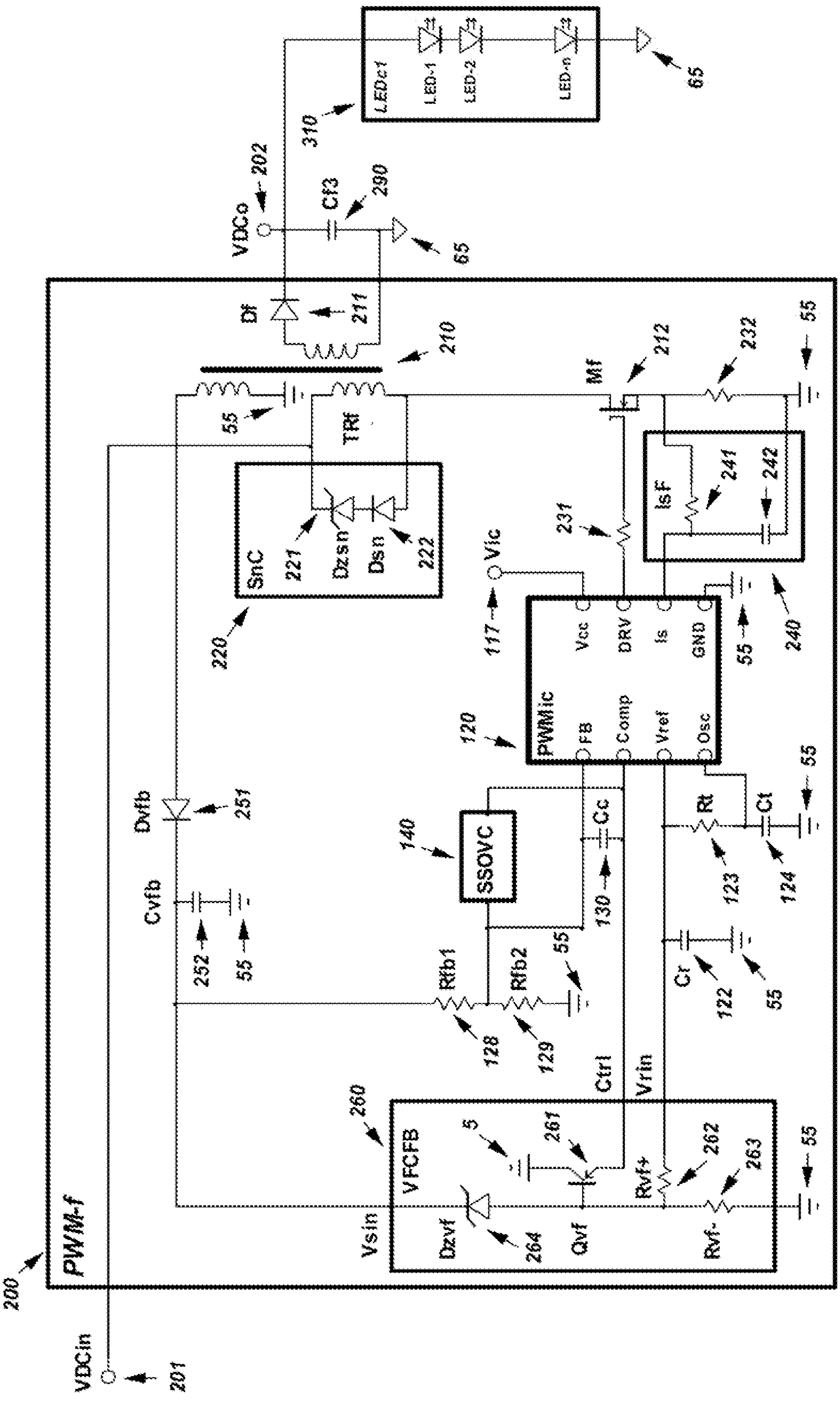


Fig. 11: Single Stage Single Ground Flyback LED Driver Embodiment

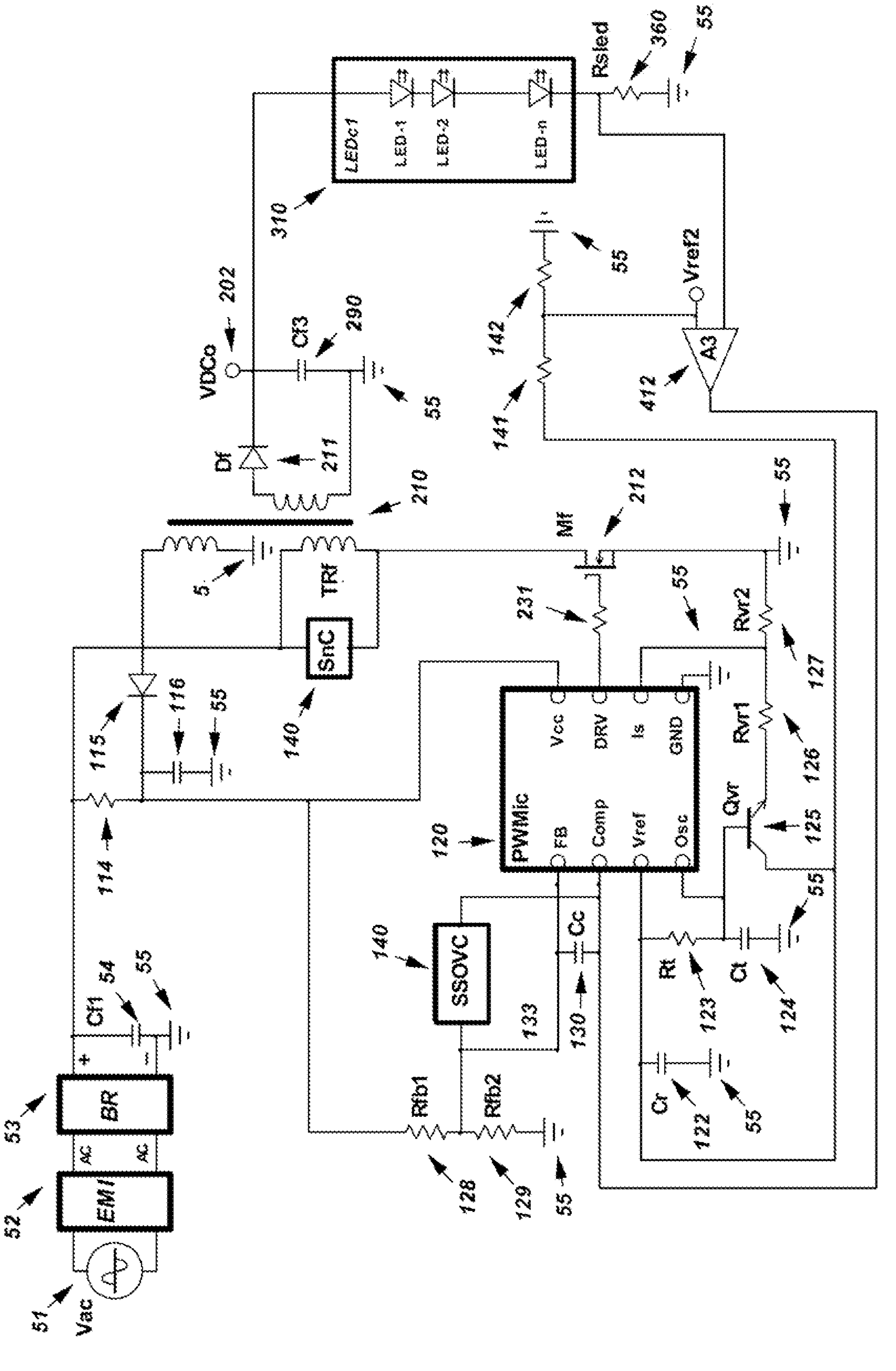


Fig. 12: Single Stage Constant Off Time Buck-Boost LED Driver Embodiment

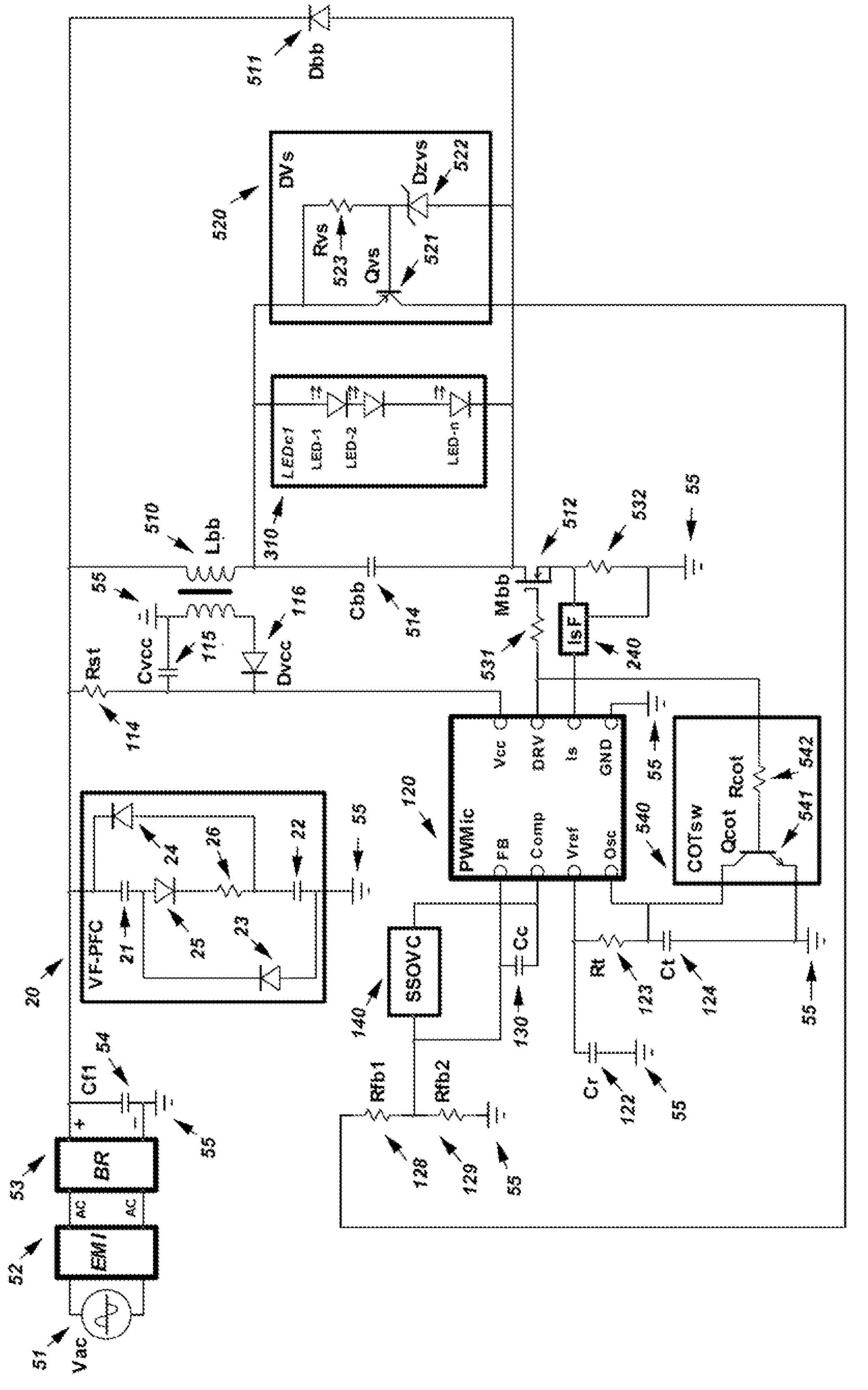


Fig. 13: Single Stage Single Ground Self-Supply Buck-Boost LED Driver Embodiment

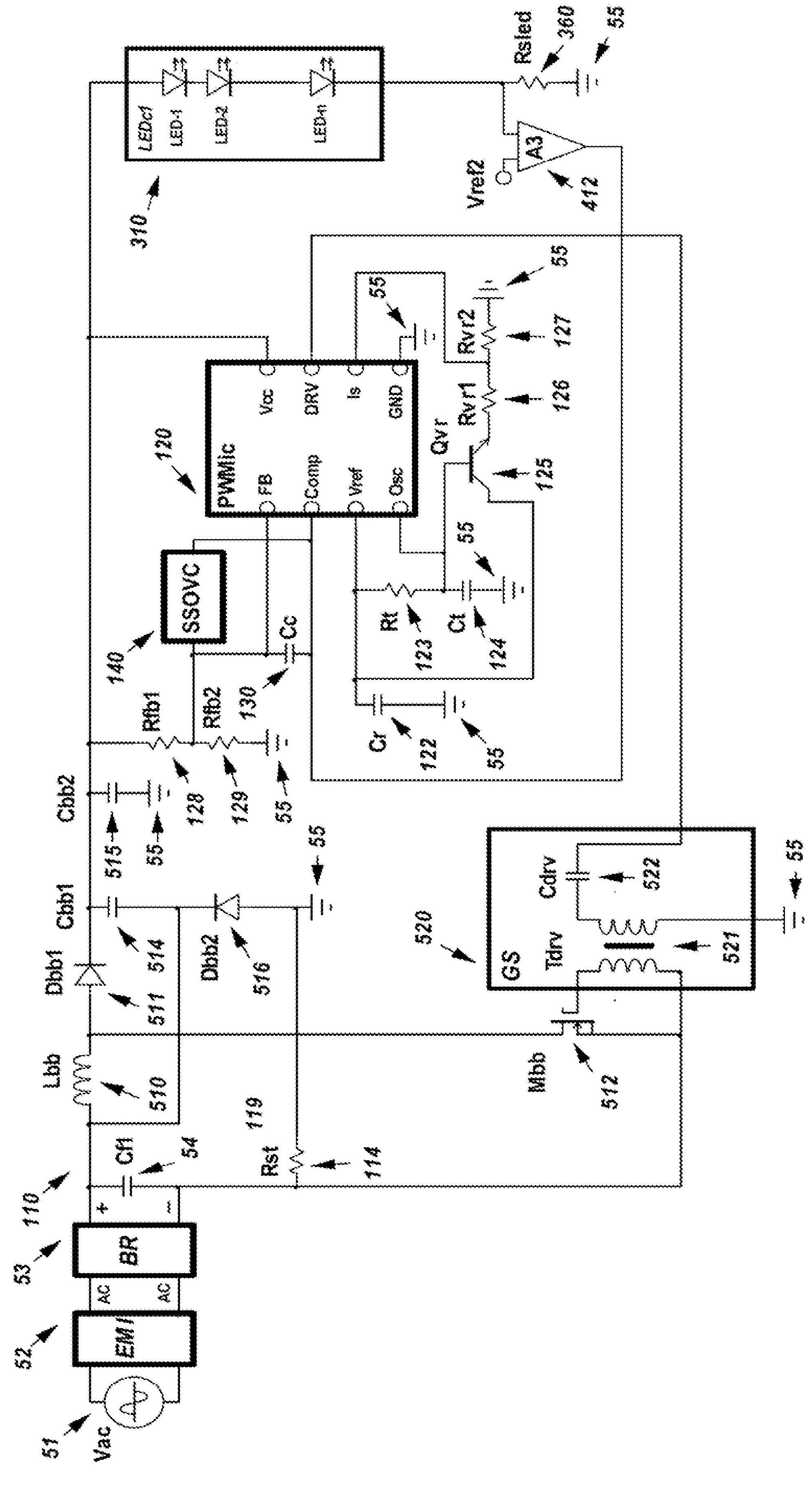


Fig. 14: Pseudo Double Stage Boost-Isolated Flyback LED Driver Embodiment

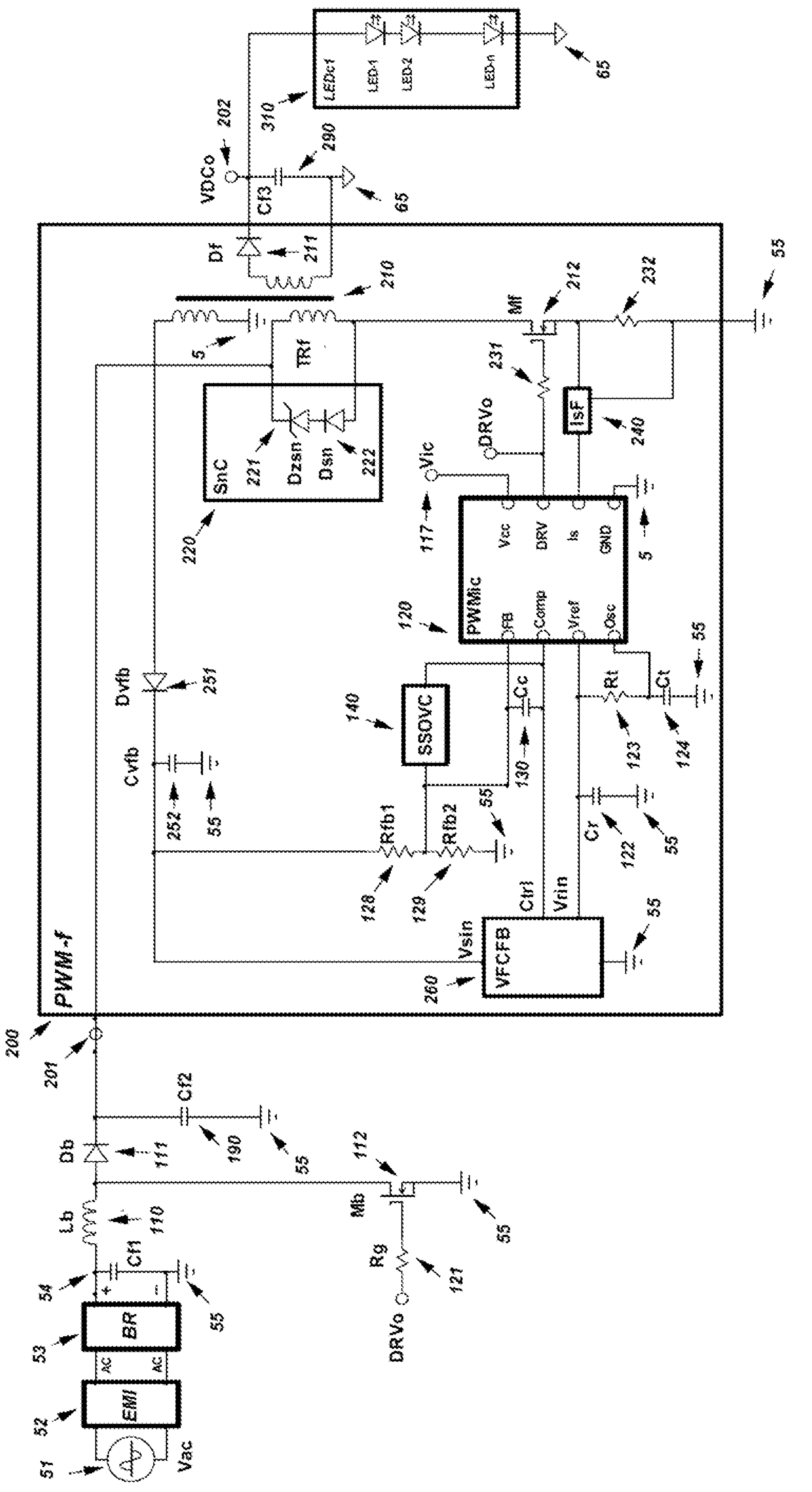


Fig. 15: Pseudo Double Stage Boost - Non Isolated Flyback LED Driver Embodiment

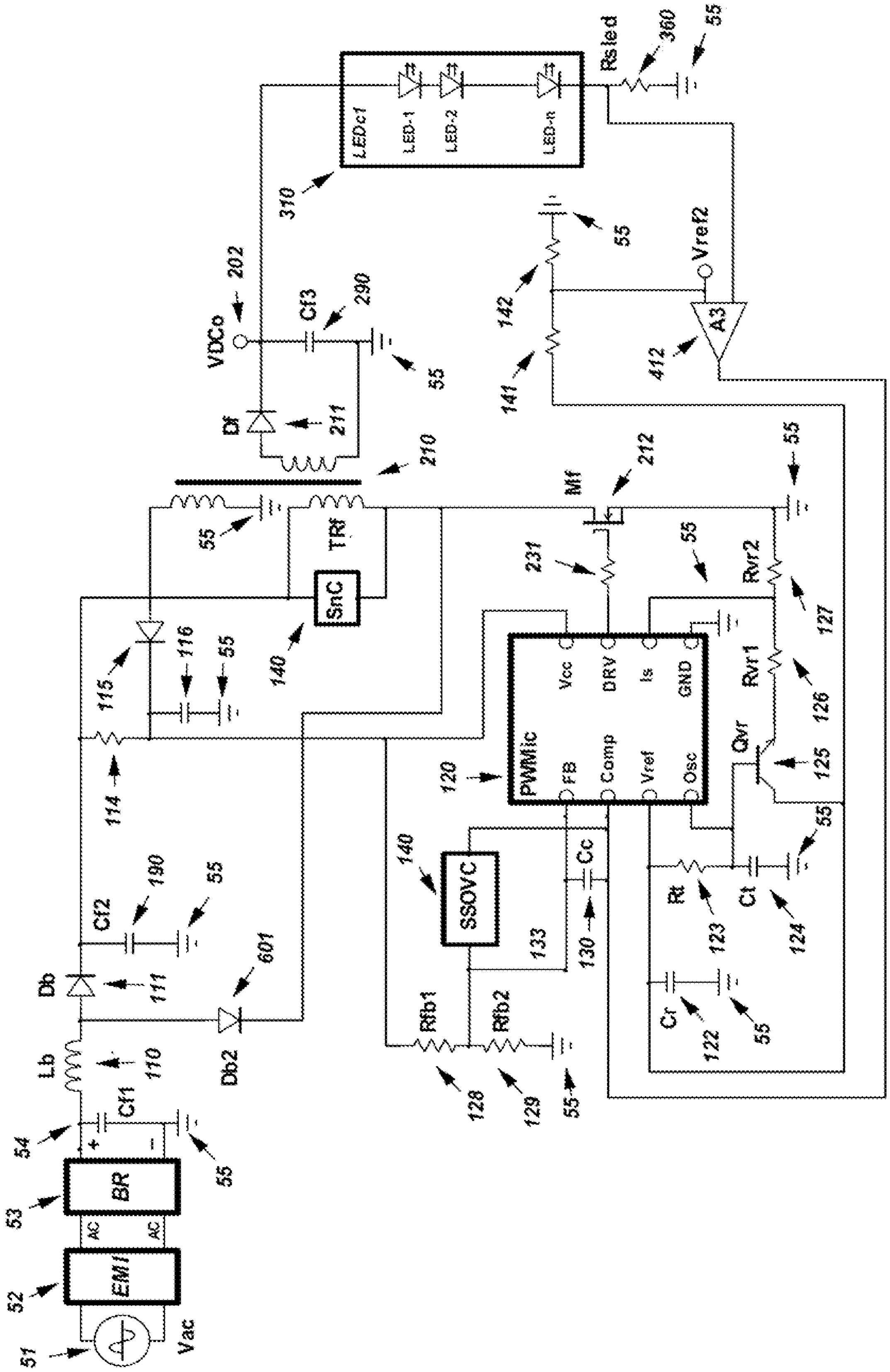


Fig. 16: Pseudo Double Stage Boost – COT Buck-Boost LED Driver Embodiment

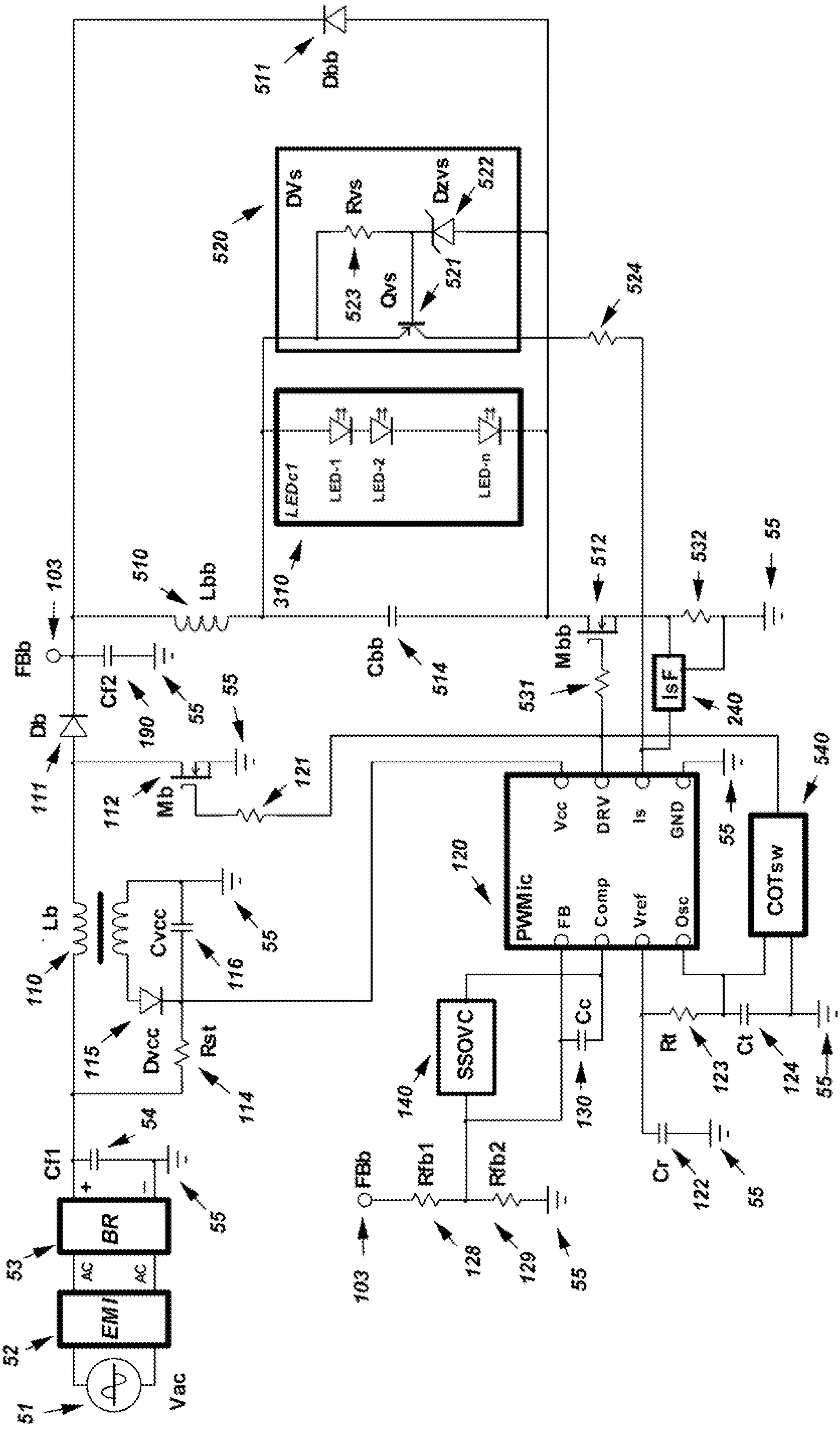


Fig. 17: Pseudo Double Stage Boost – SG Buck-Boost LED Driver Embodiment

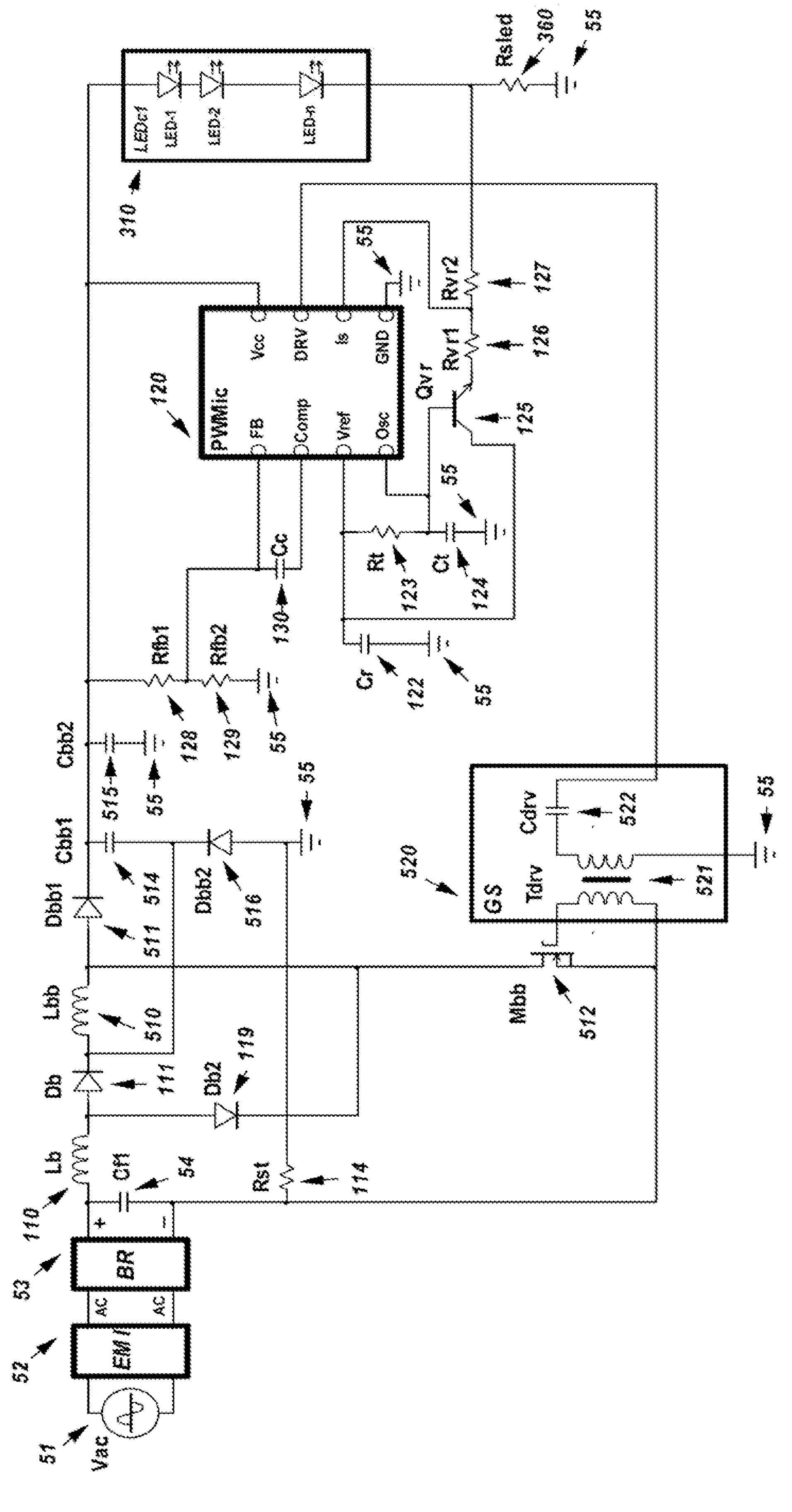
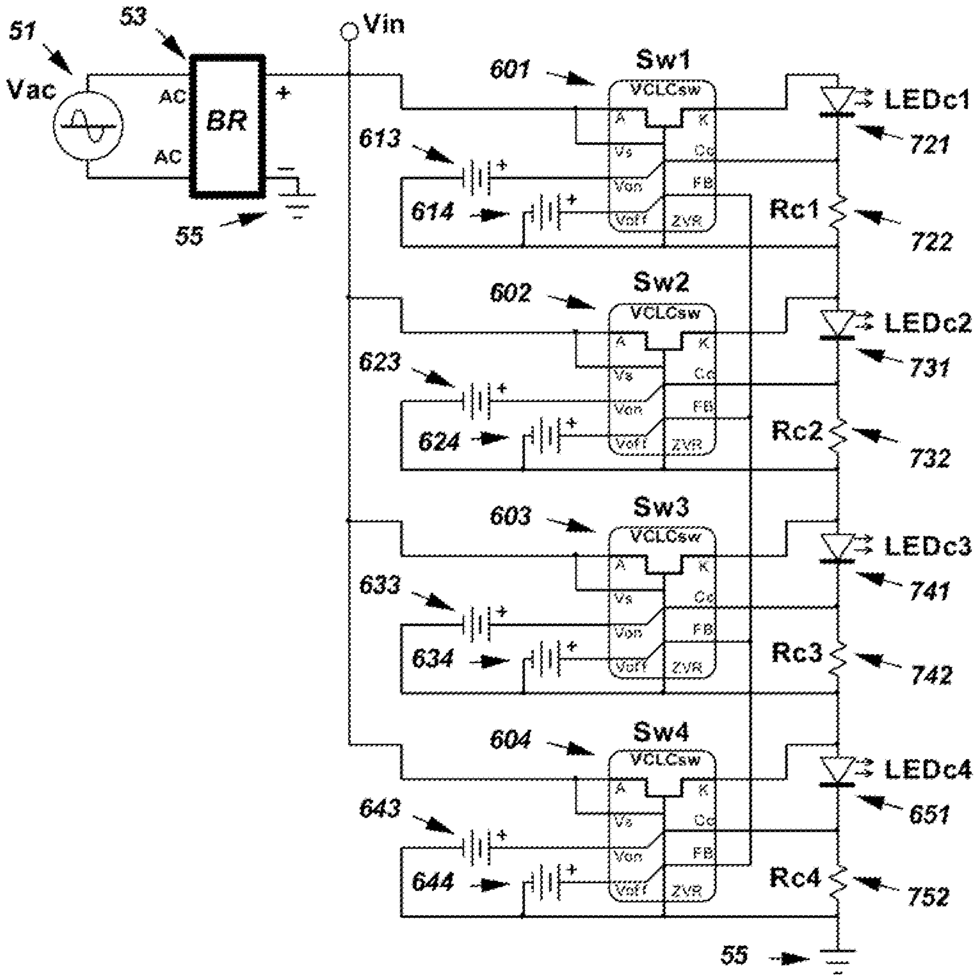


Fig. 18: Monolithic LED Driver – The Series Circuit Method Embodiment

a) Block Schematic Diagram



b) Current/Voltage Graphs

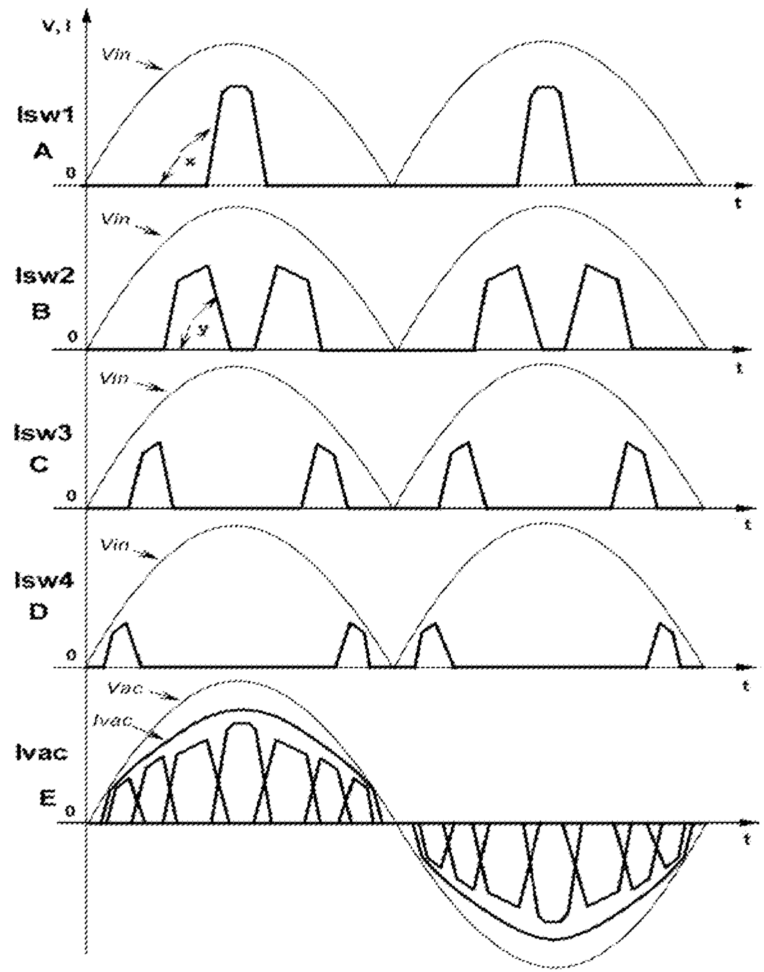
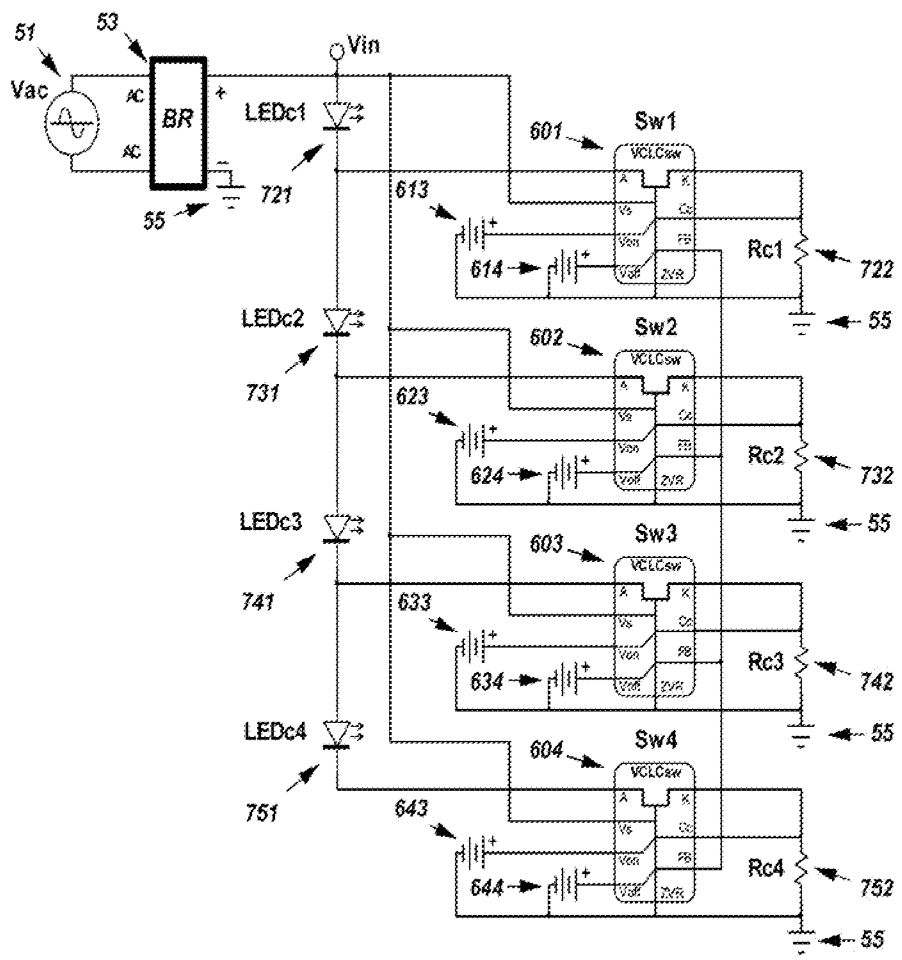
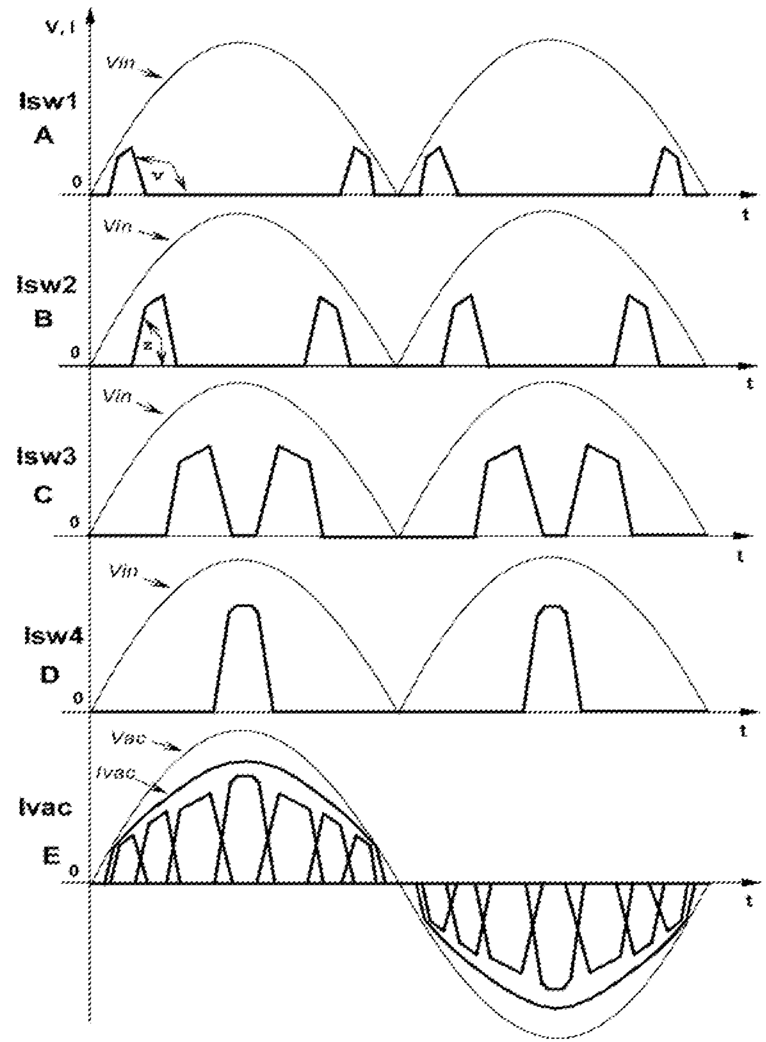


Fig. 19: Monolithic LED Driver – The Parallel Circuit Method Embodiment

a) Block Schematic Diagram



b) Current/Voltage Graphs



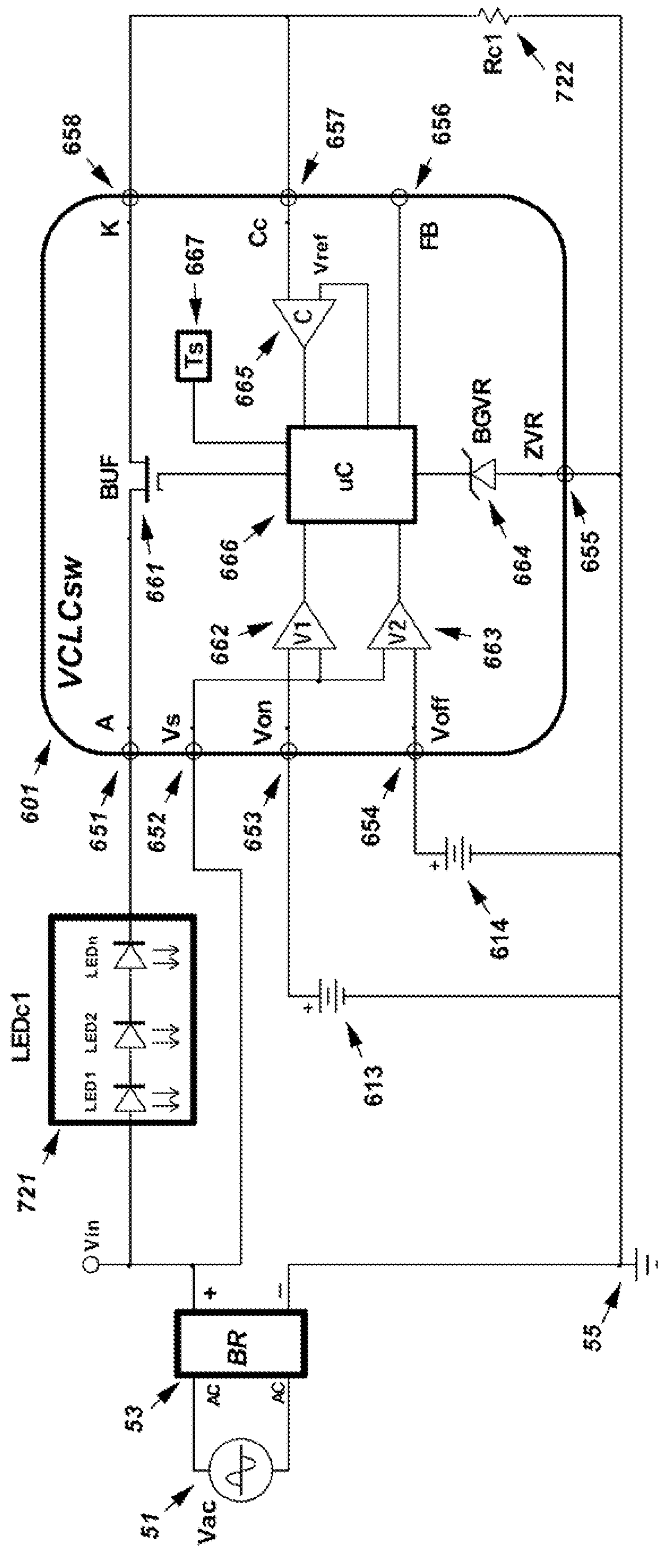


Fig. 20: Single Cell Anode Loaded VCLC Switch LED Driver Circuit Embodiment

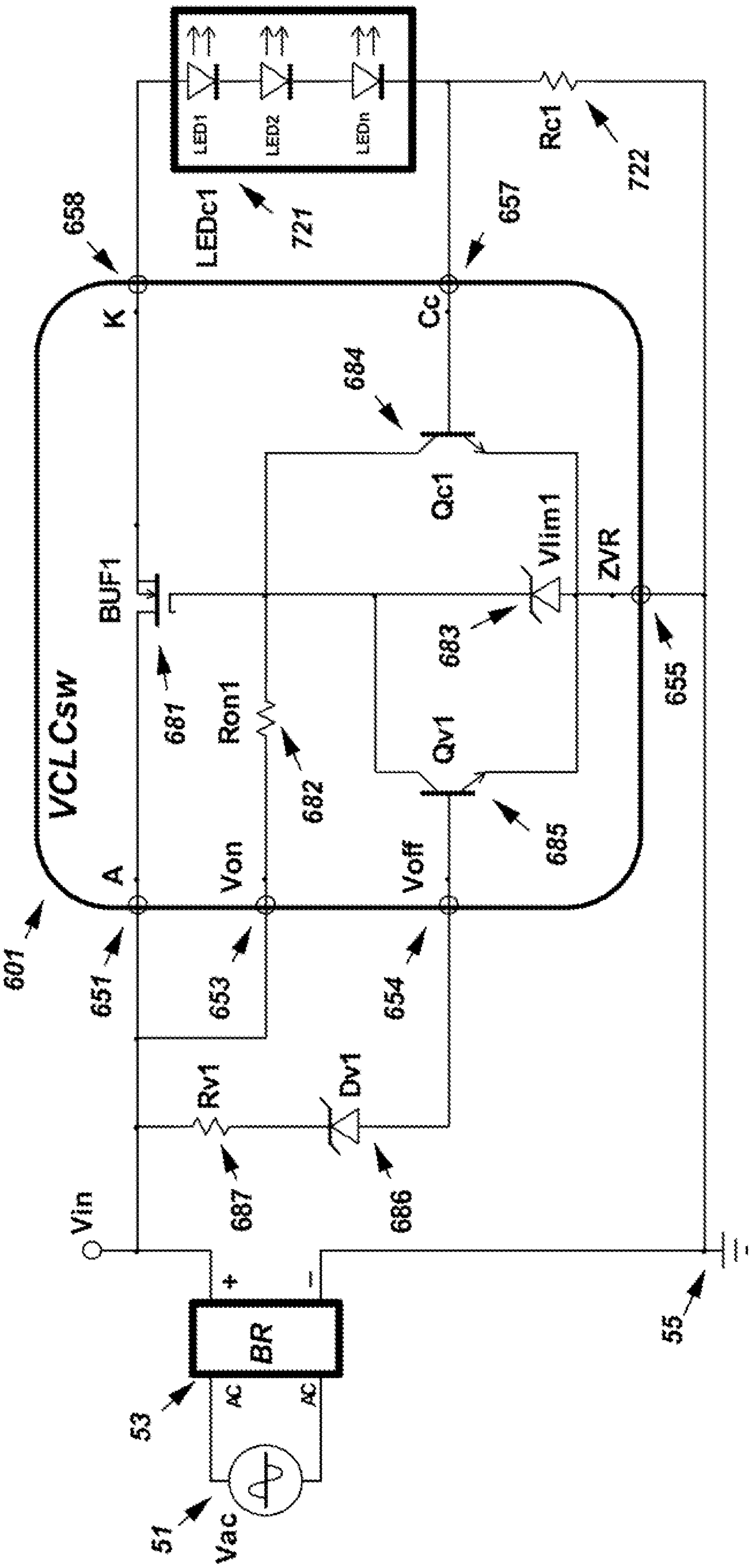


Fig. 21: Single Cell Cathode Loaded VCLC Switch LED Driver Circuit Embodiment

Fig. 22: Monolithic LED Driver – Overall Feedback Series Circuit Method Embodiment

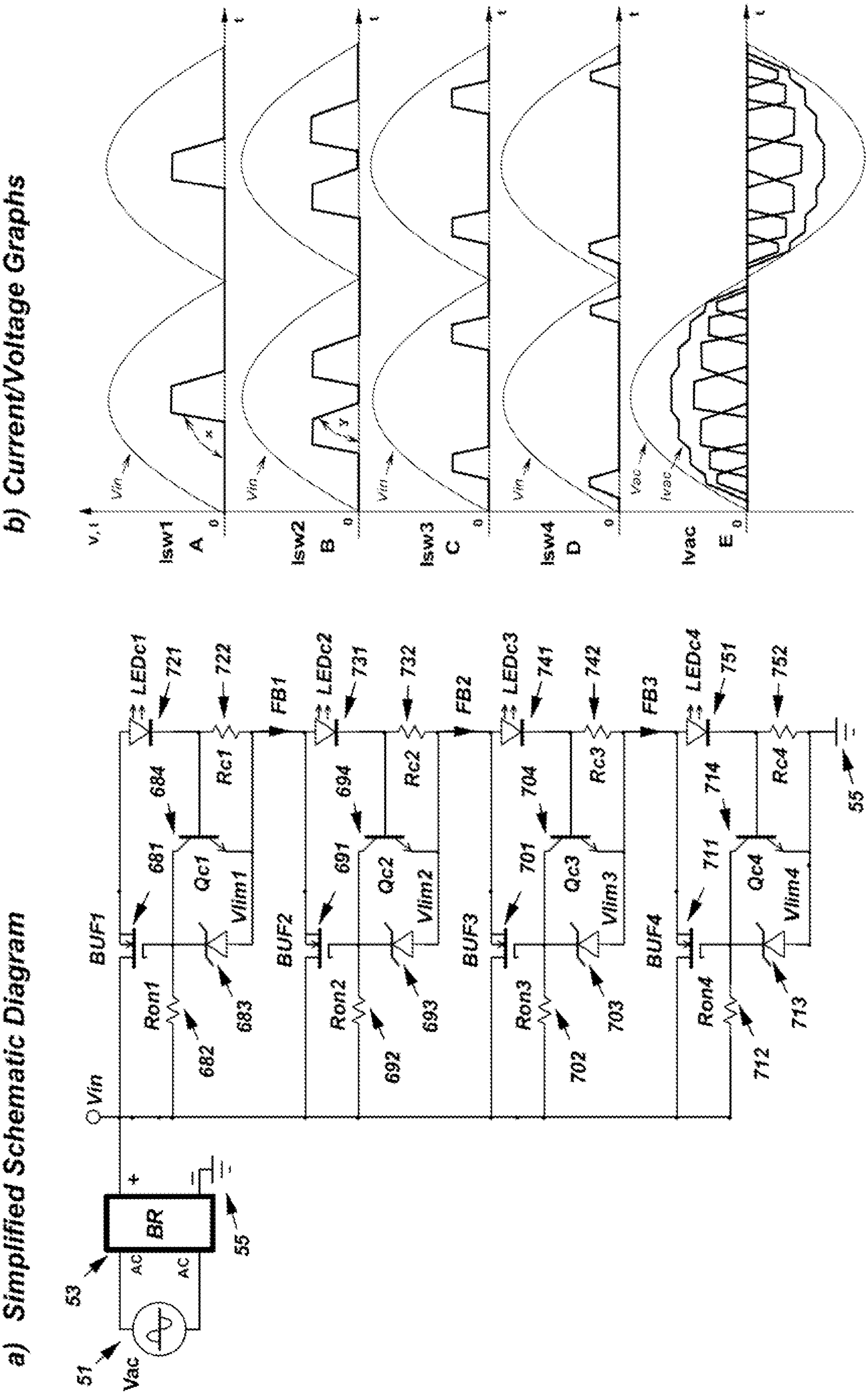


Fig. 23: Monolithic LED Driver – Overall Feedback Parallel Circuit Method Embodiment

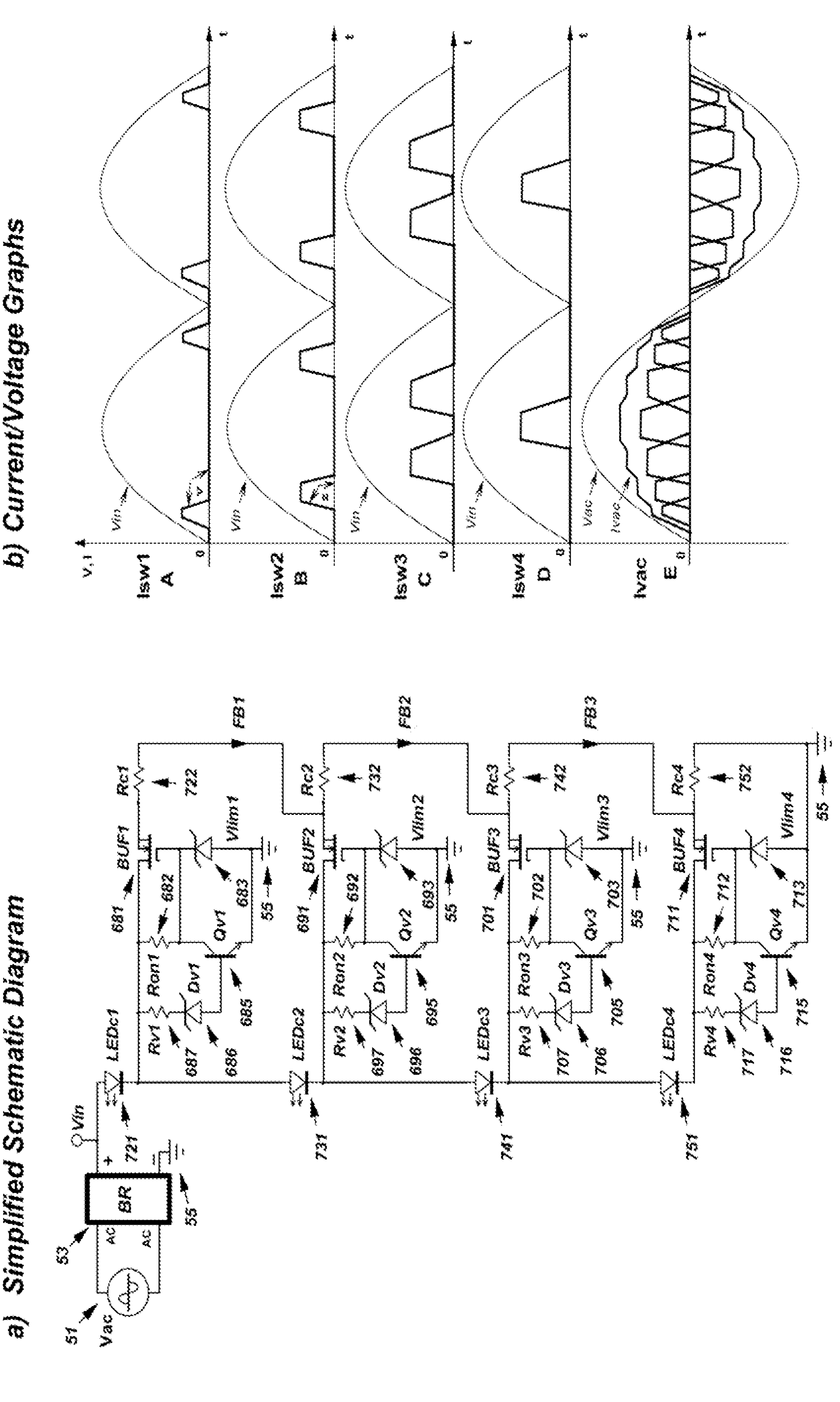


Fig. 24: Monolithic Multi Strips LED Driver -- Series Circuit Embodiment

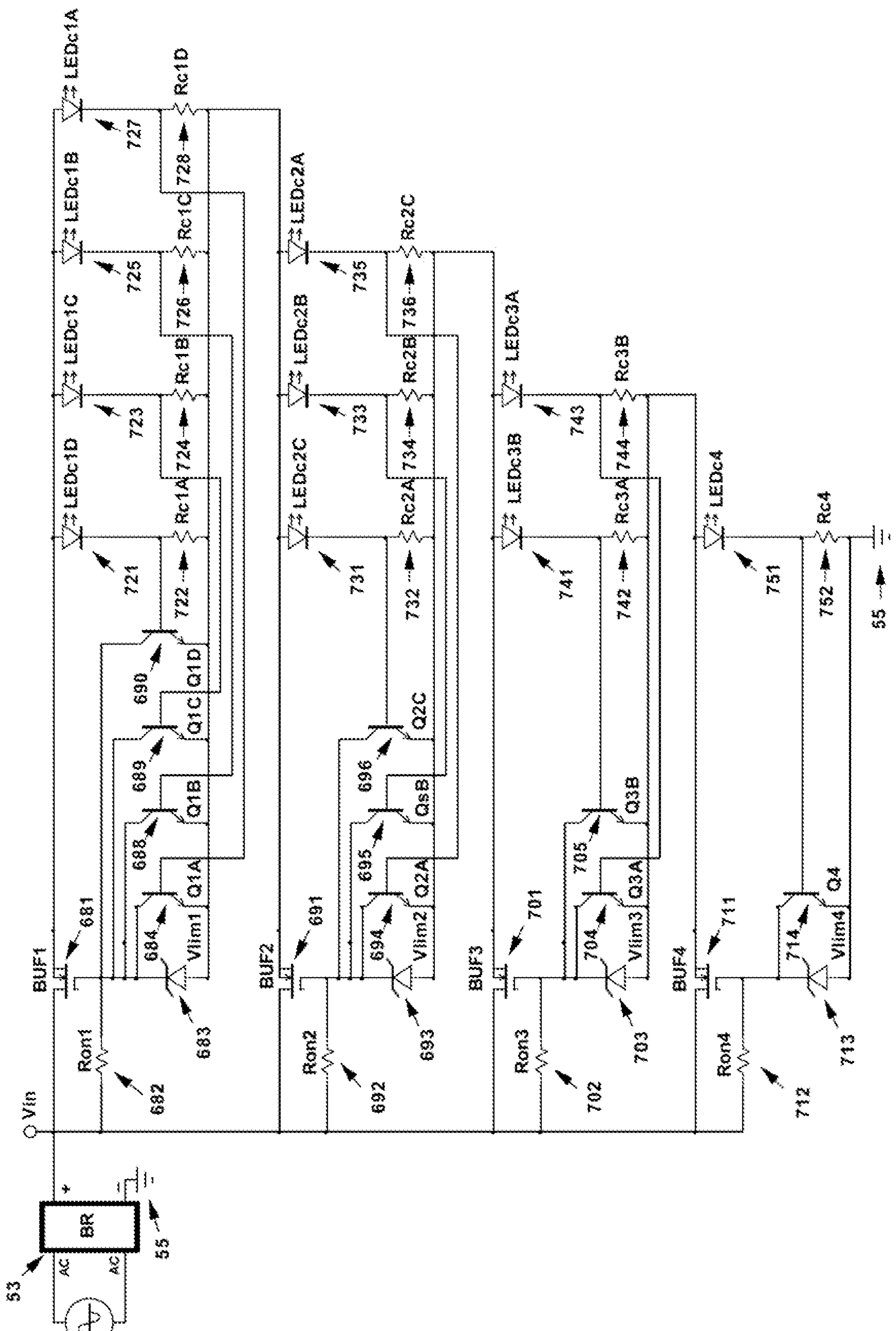


Fig. 25: Monolithic LED Driver – High Reliability Series Circuit Embodiment

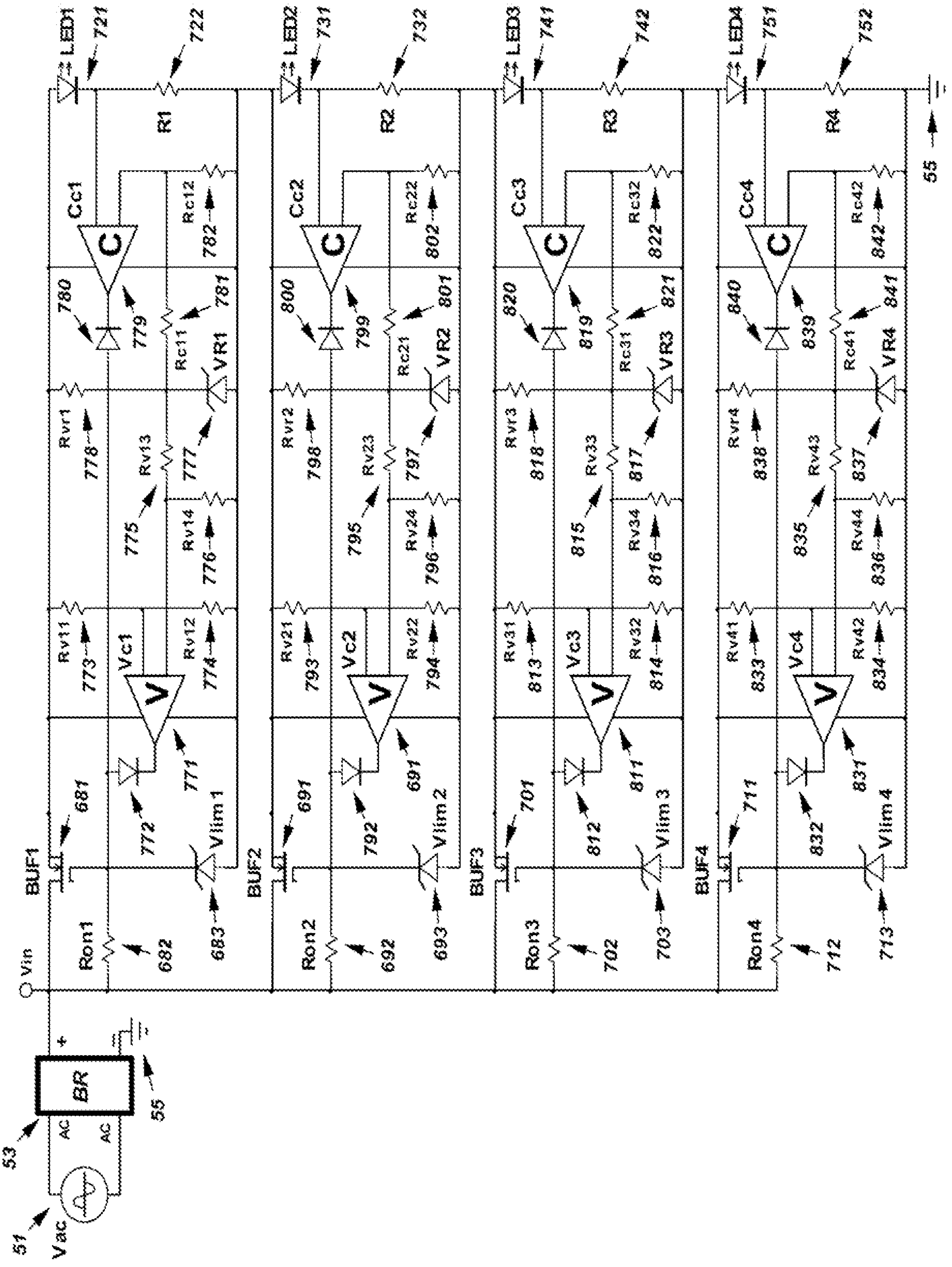
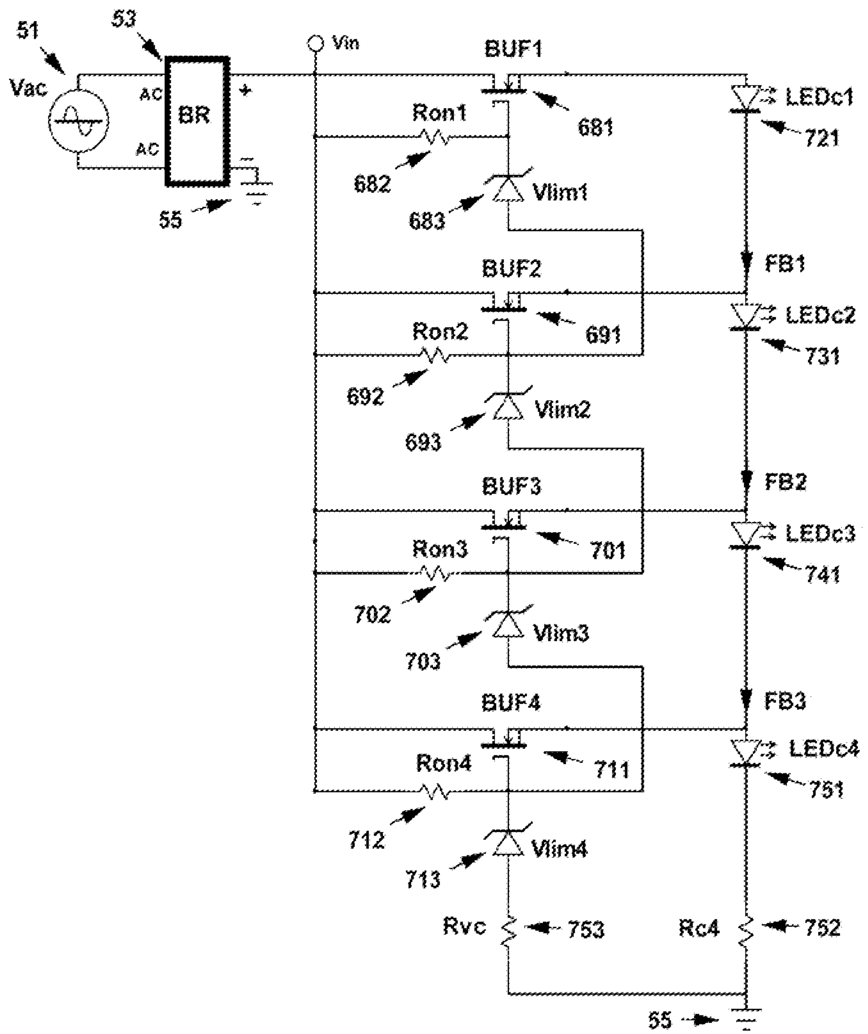


Fig. 26: Monolithic LED Driver – Minimum Parts Series Circuit Embodiment

a) Schematic Diagram



b) Current/Voltage Graphs

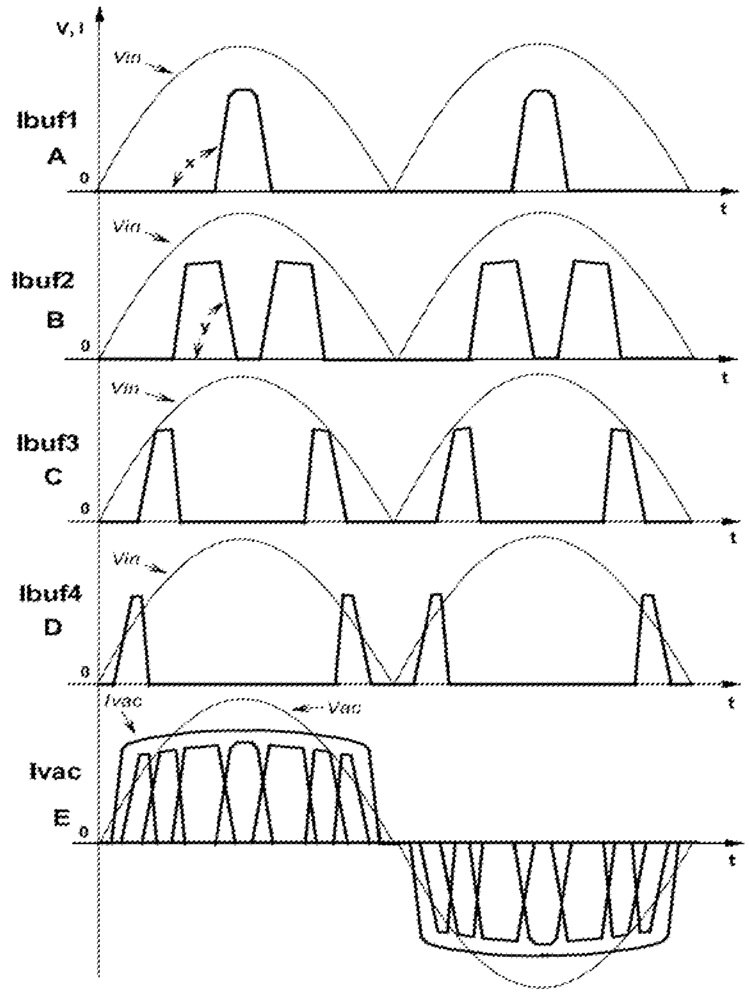
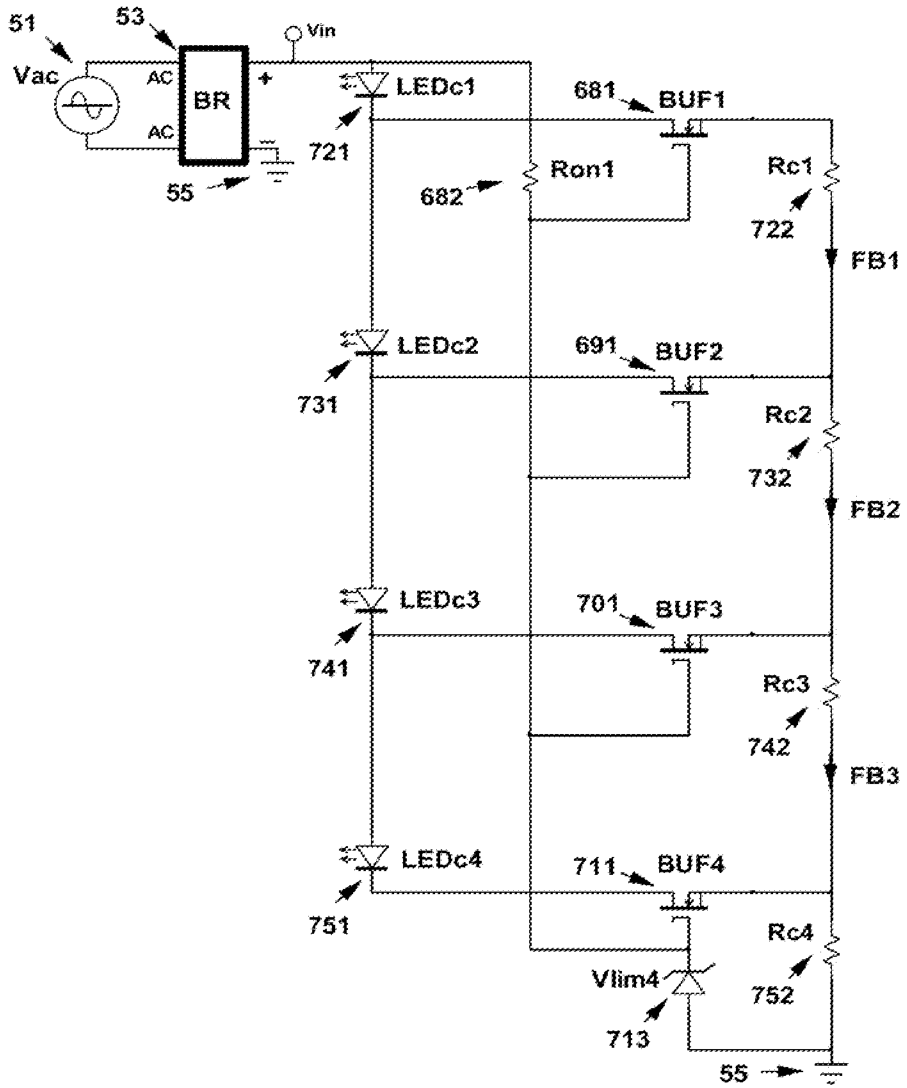


Fig. 27: Monolithic LED Driver – Minimum Parts Parallel Circuit Embodiment

a) Schematic Diagram



b) Current/Voltage Graphs

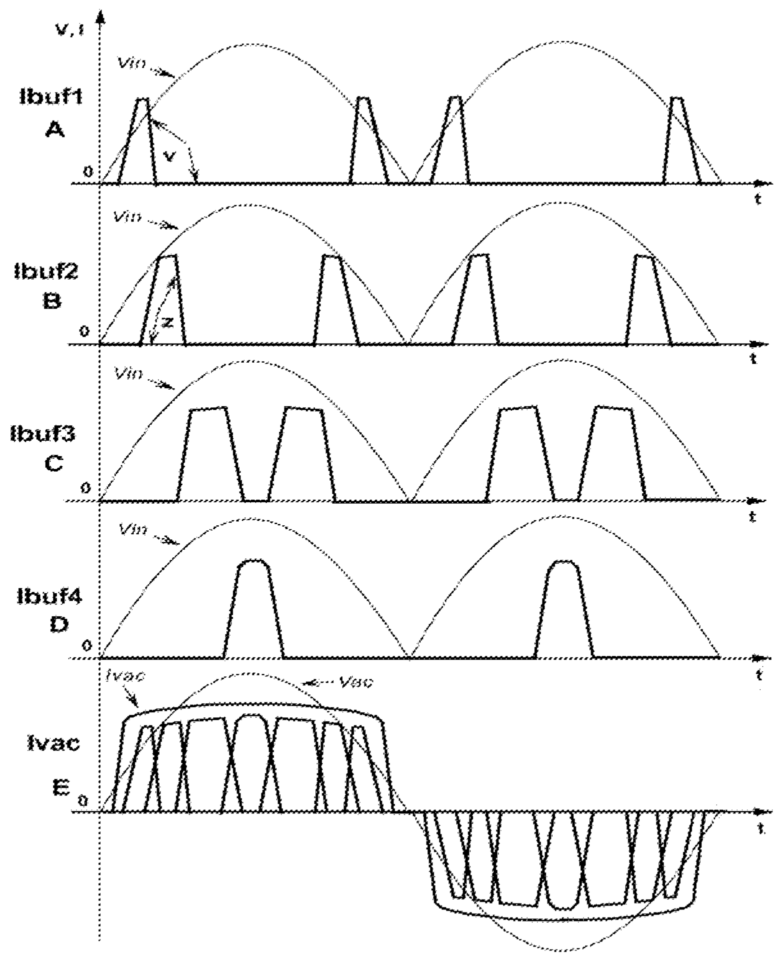


Fig. 28: 120Vac Series Circuit Monolithic LED Driver

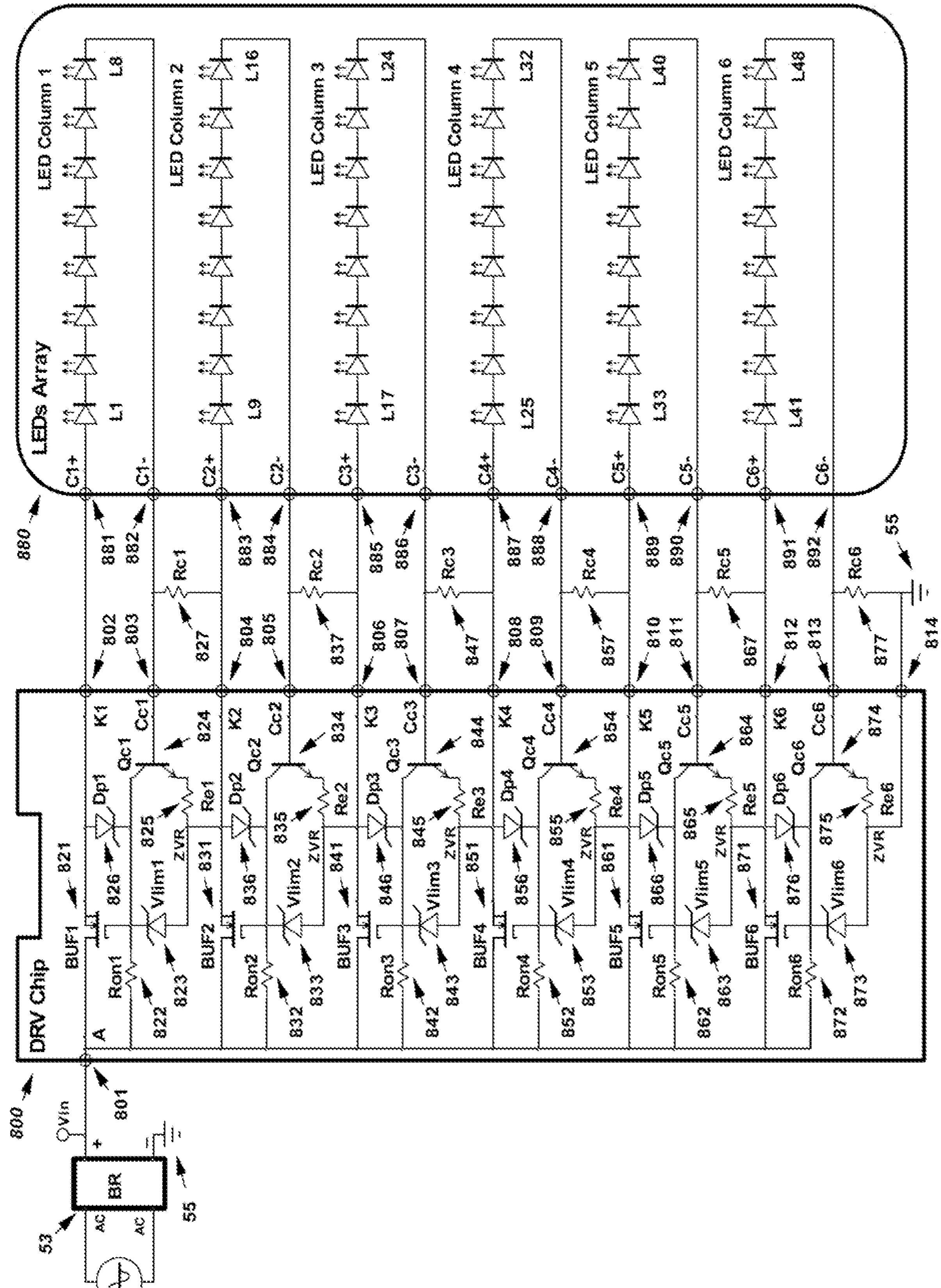


Fig. 29: LED Array & Driver Chip Embedded System – Simplified Series Circuit Embodiment

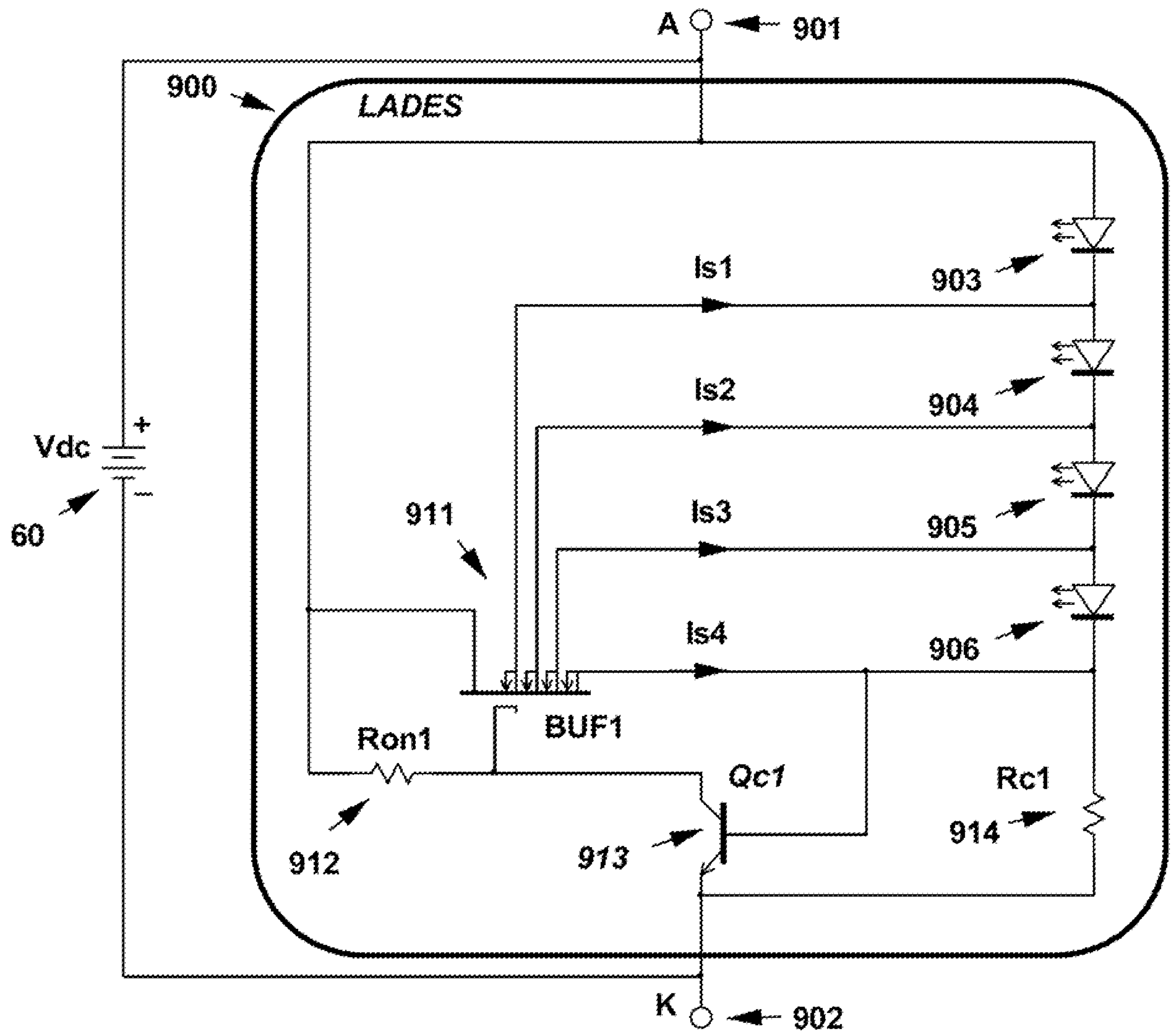


Fig. 30: LED Array & Driver Chip Embedded System – Simplified Parallel Circuit Embodiment

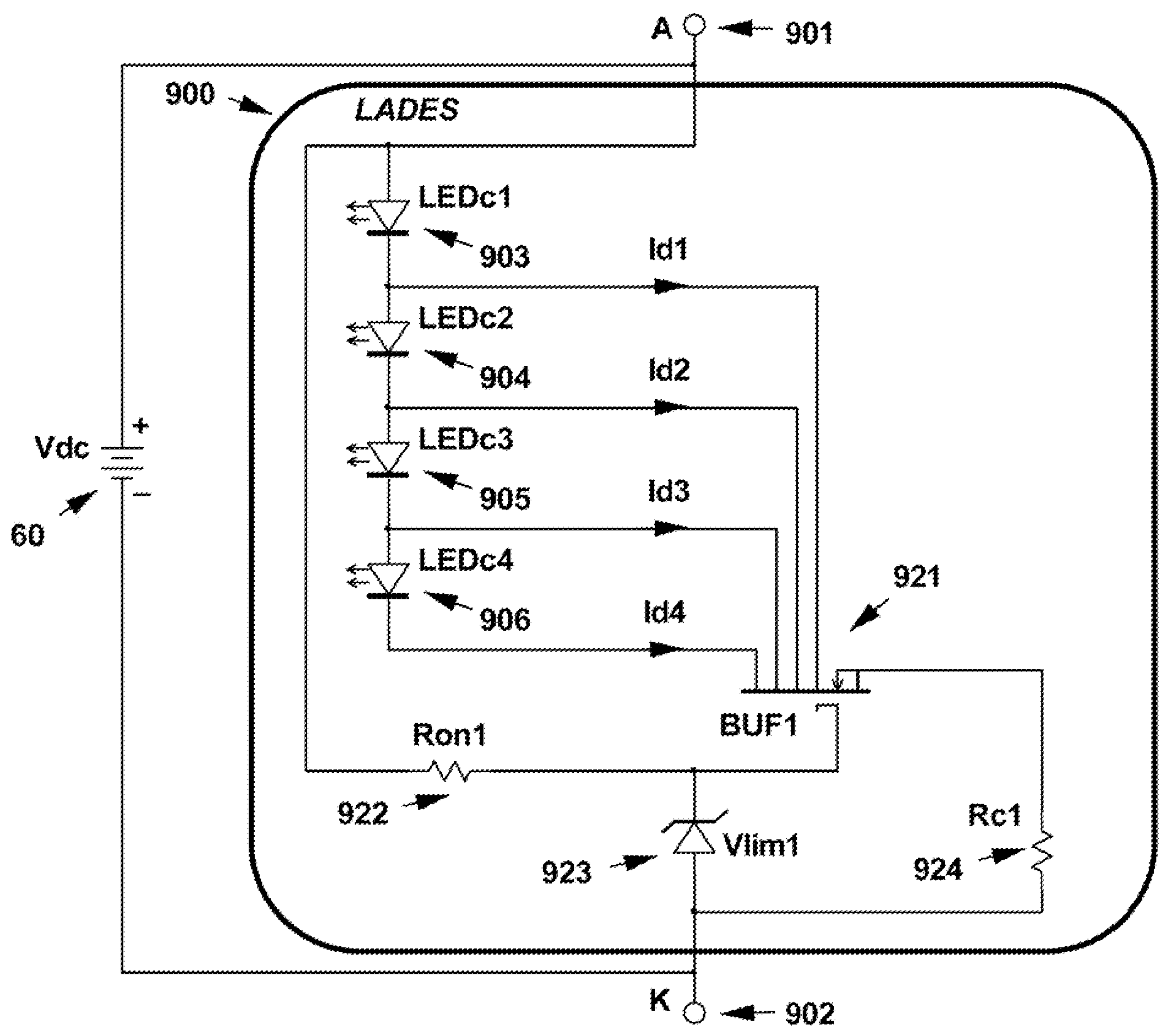


Fig. 31: Monolithic LED Driver – Diodes Source Feedback Parallel Circuit Embodiment

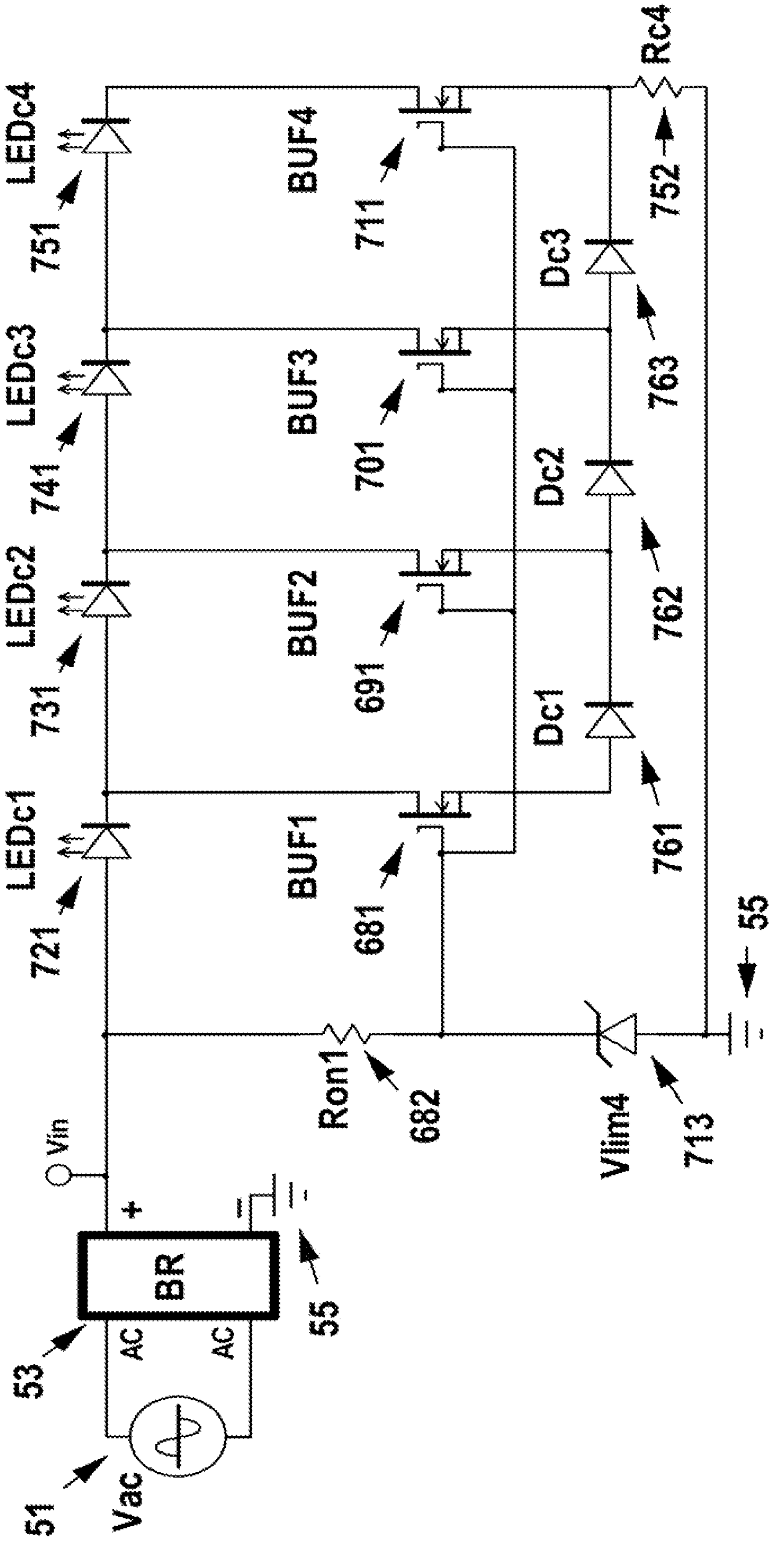


Fig. 32: Monolithic LED Driver – OPAM Current Feedback Parallel Circuit Embodiment

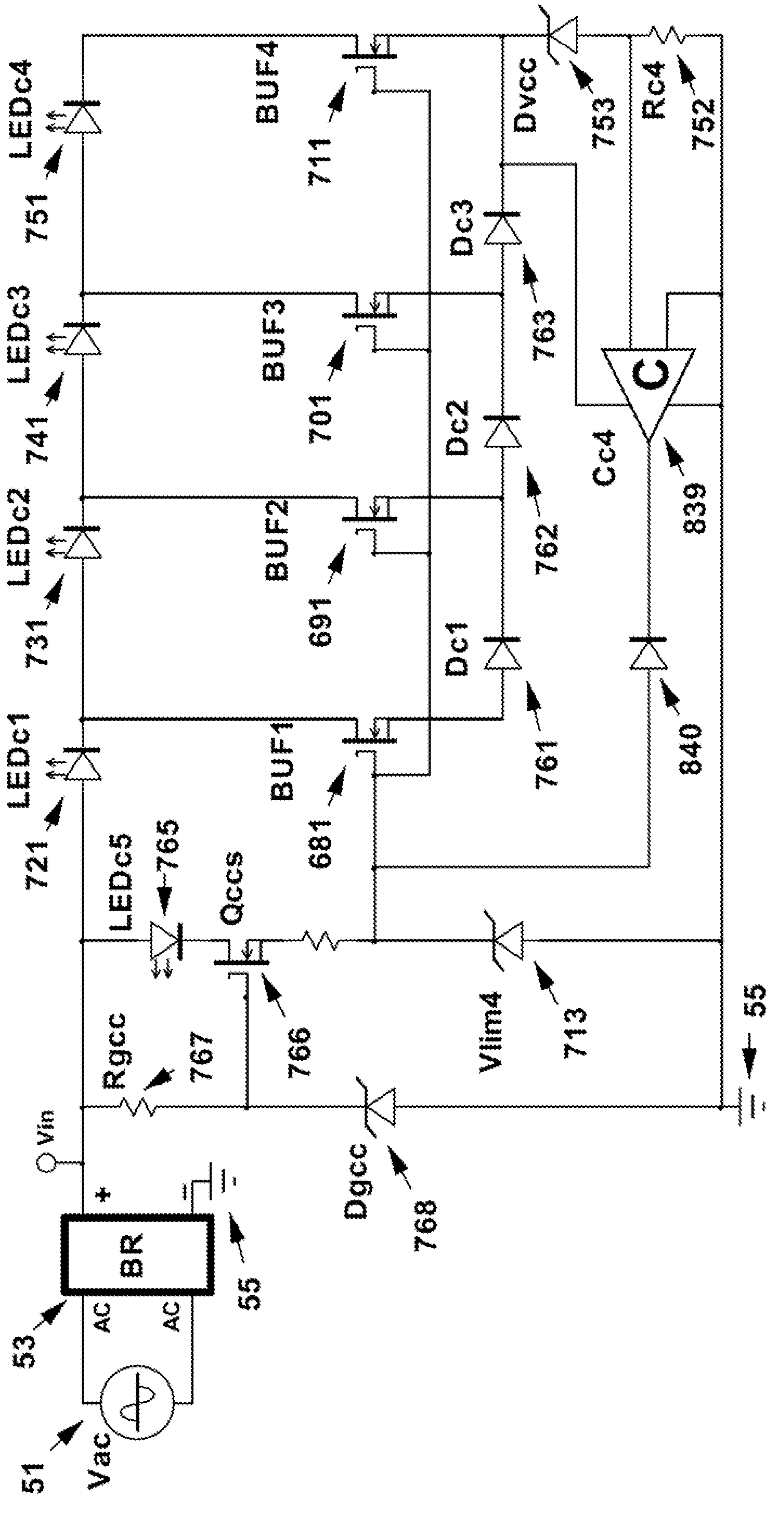


Fig. 33: Monolithic LED Driver – Diodes Gate Feedback Parallel Circuit Embodiment

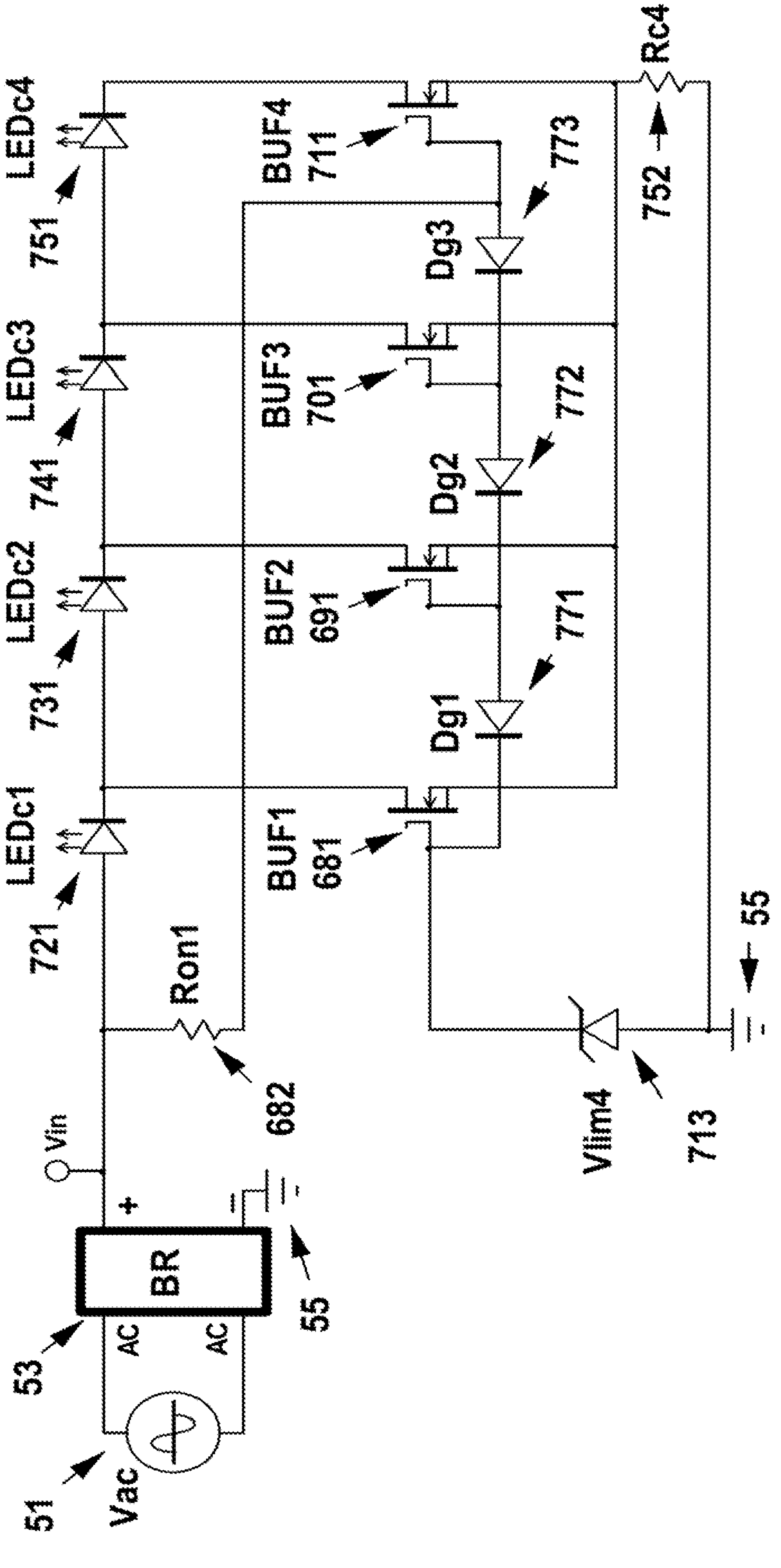


Fig. 34: Monolithic LED Driver – Resistor Gate Feedback Parallel Circuit Embodiment

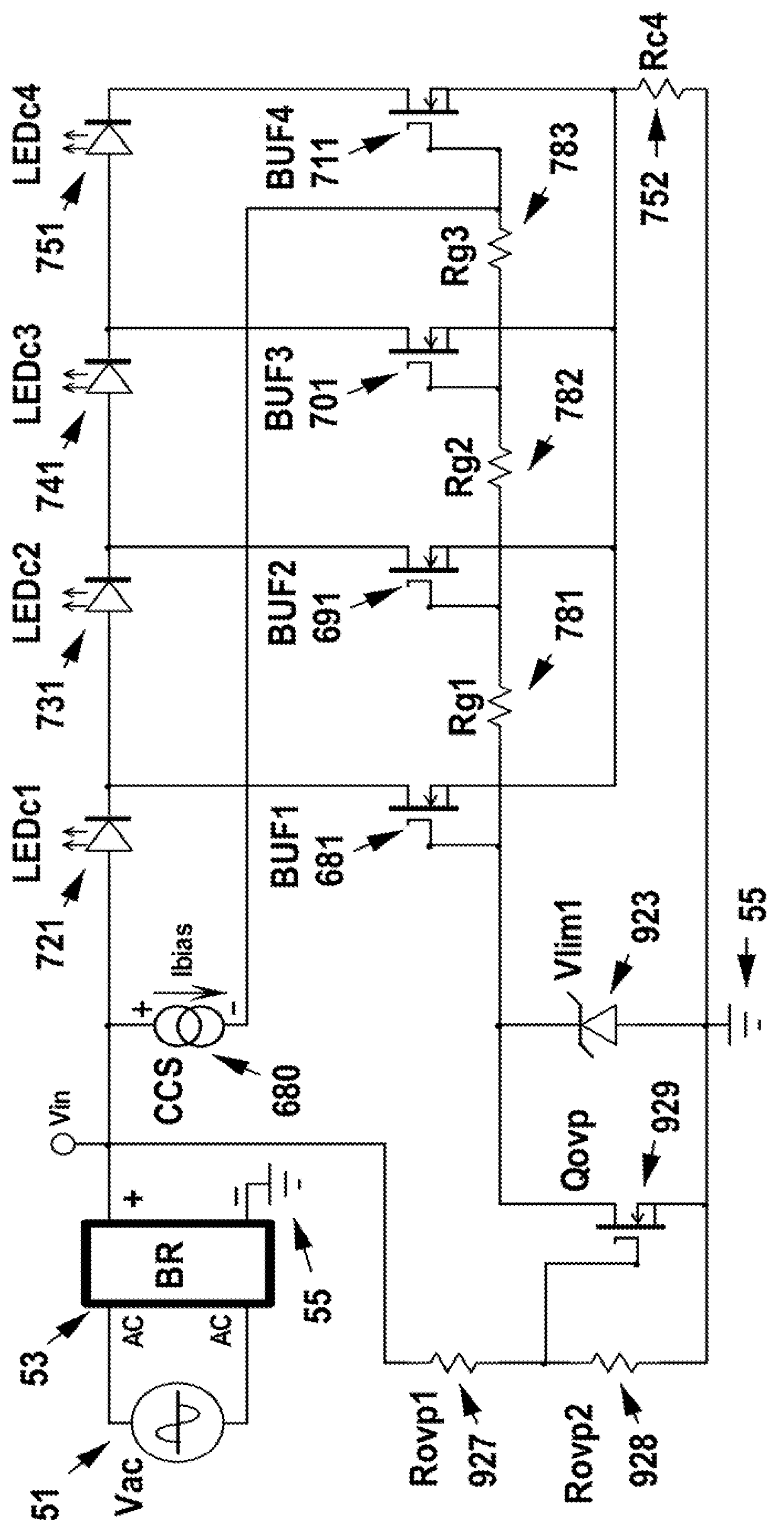


Fig. 35: Monolithic LED Driver – Totem Pole Gate Feedback Parallel Circuit Embodiment

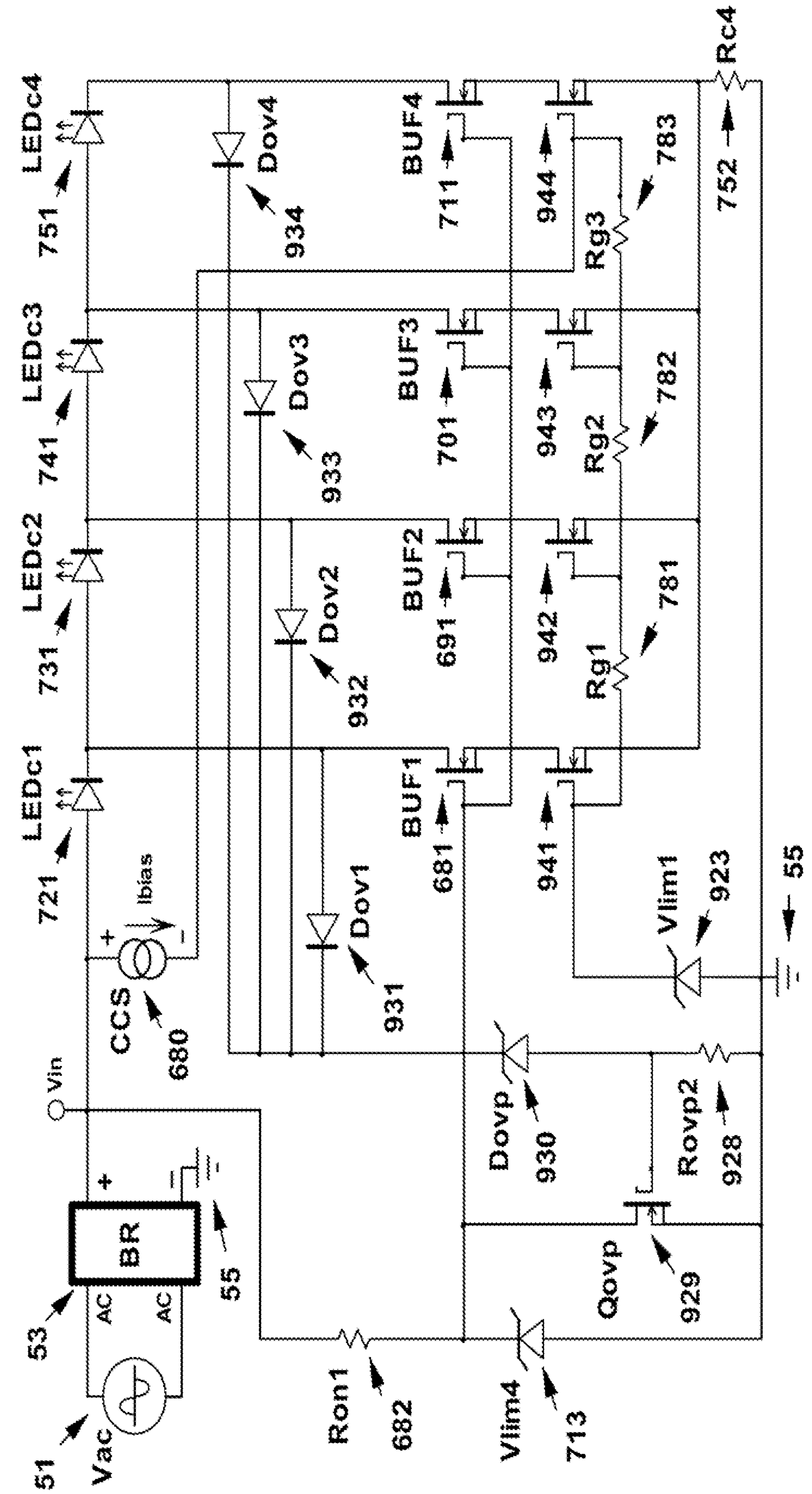


Fig. 36: Monolithic LED Driver – 8 PIN DC Chip Embodiment

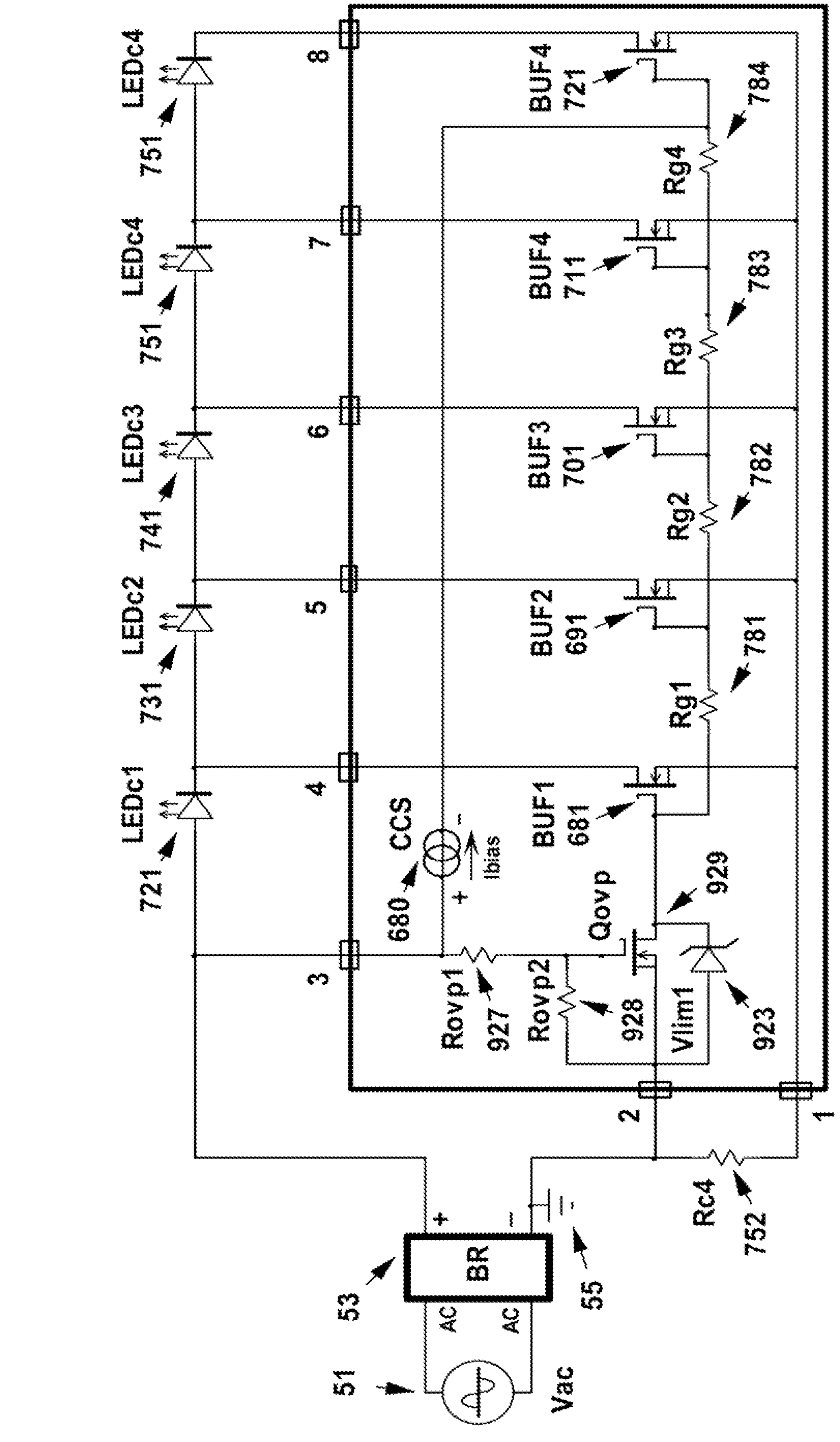
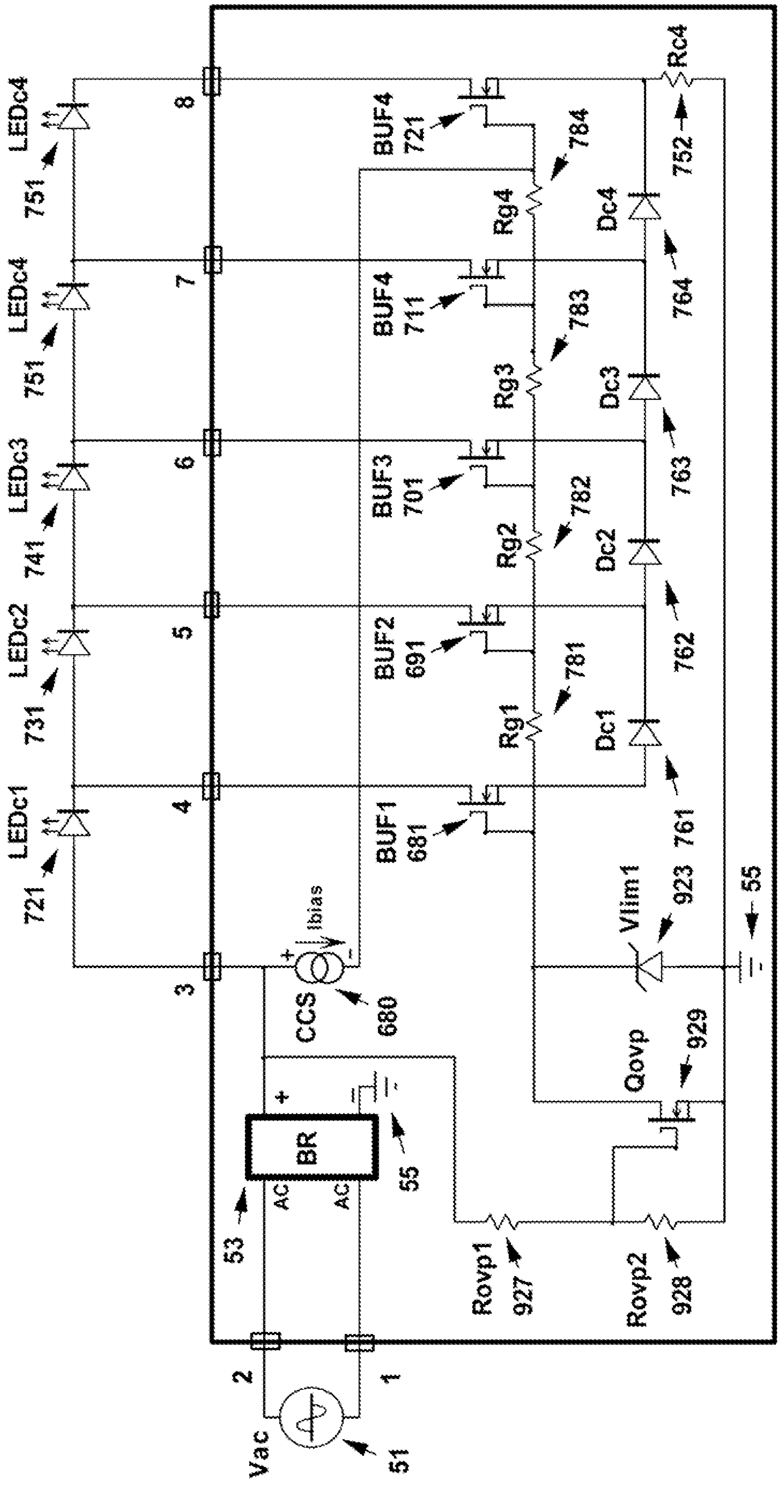
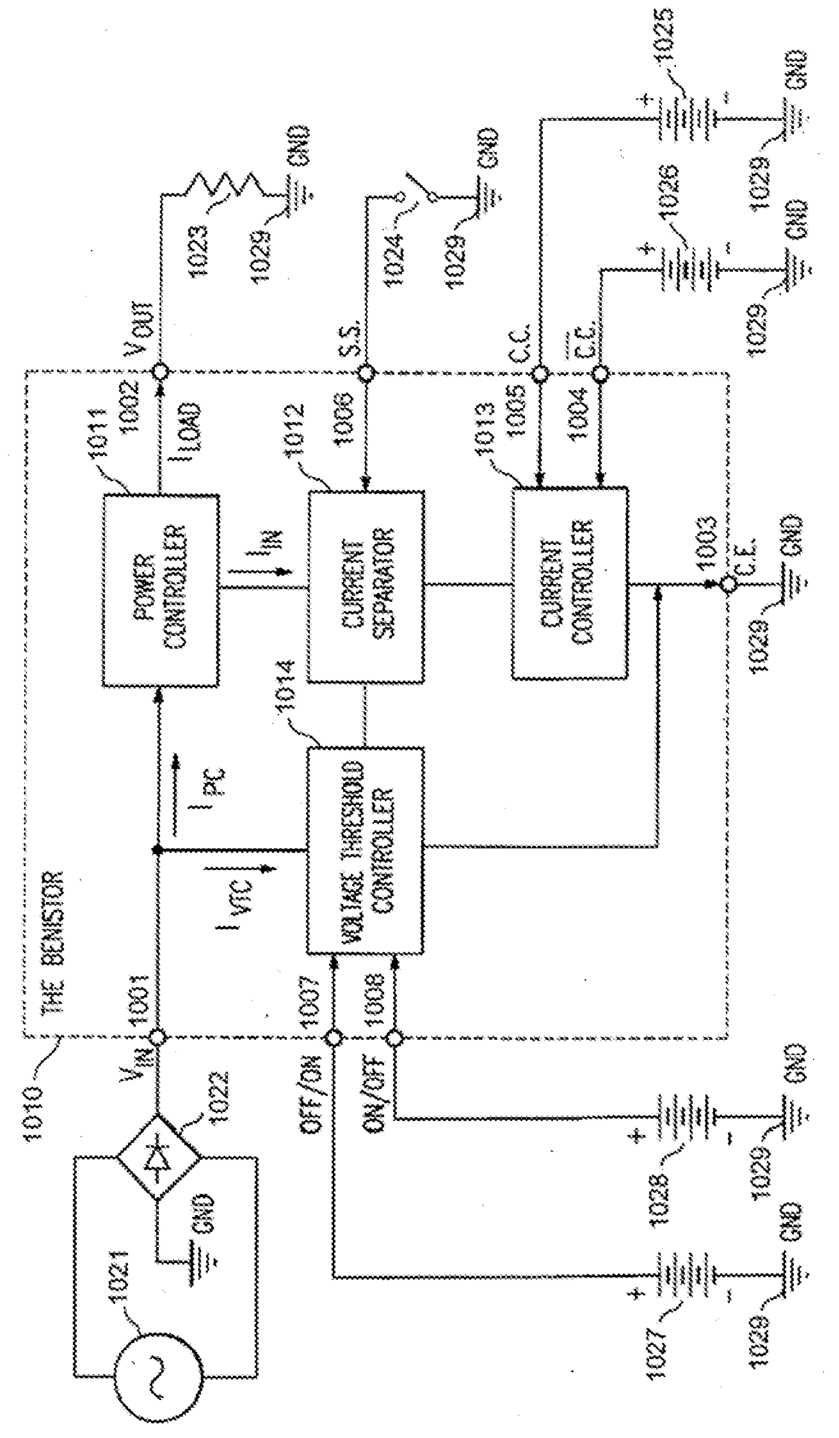


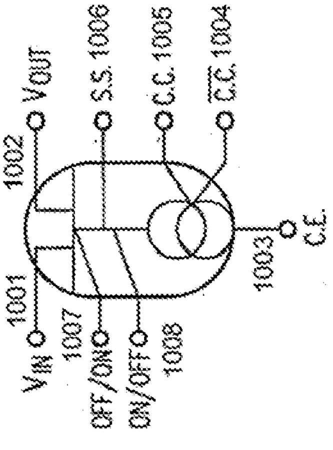
Fig. 37: Monolithic LED Driver – 8 PIN AC Chip Embodiment



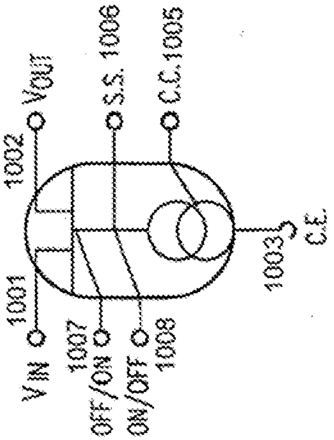


THE BLOCK SCHEMATIC DIAGRAM FOR THE CLASSIC BENISTOR

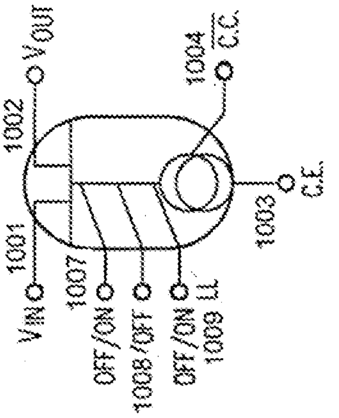
FIG. 38



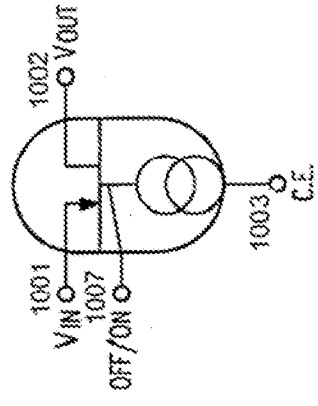
CLASSIC BENISTOR
FIG. 39A



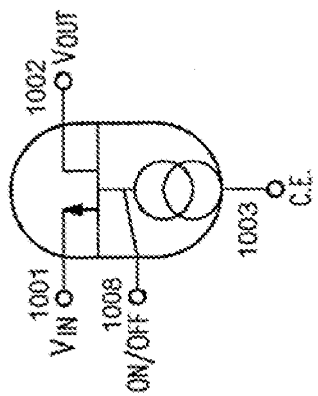
PARALLEL EMBODIMENT
FIG. 39B



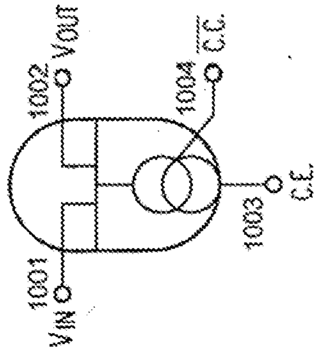
SERIES EMBODIMENT
FIG. 39C



OFF/ON P.BENISTOR
FIG. 39D



ON/OFF N. BENISTOR
FIG. 39E



LINEAR BENISTOR
FIG. 39F

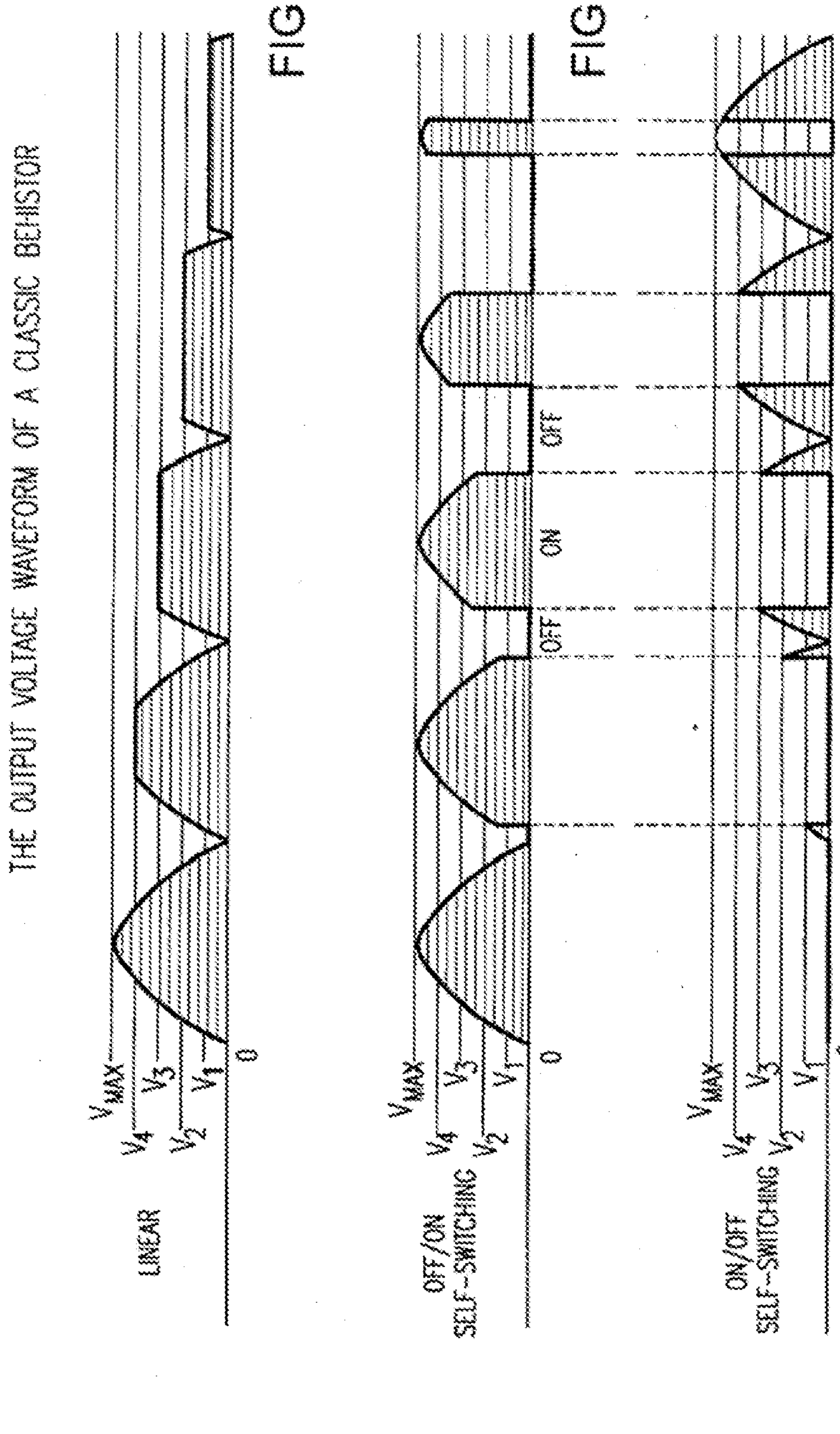


FIG. 40A

FIG. 40B

FIG. 40C

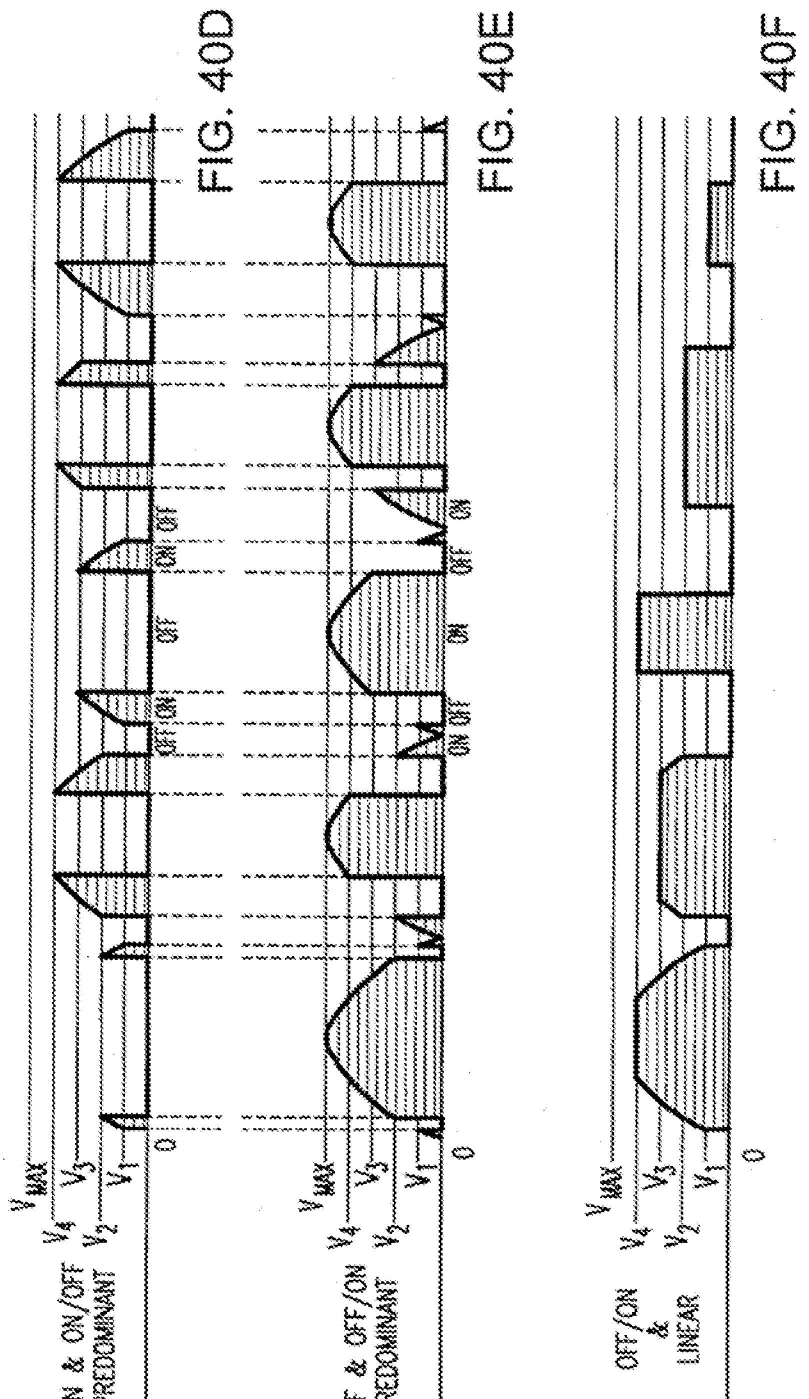


FIG. 40D

FIG. 40E

FIG. 40F

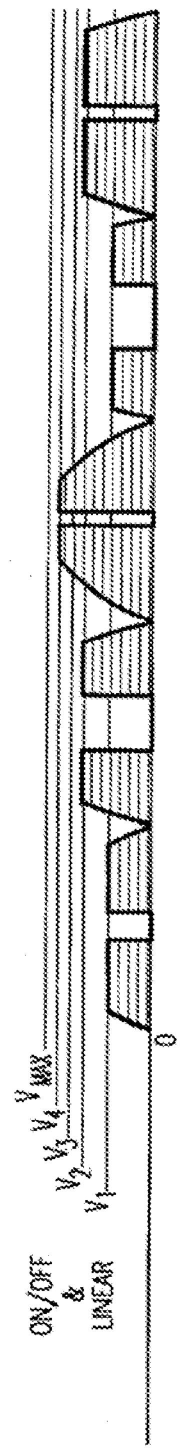


FIG. 40G

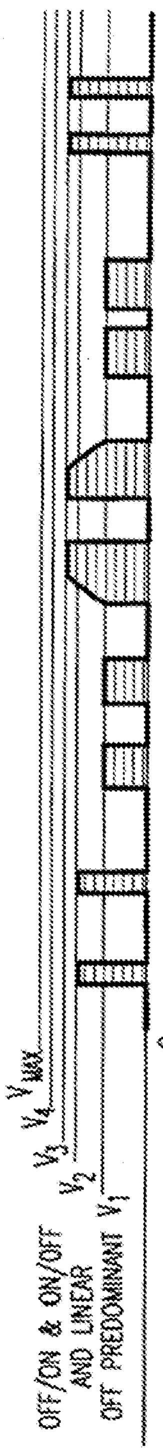


FIG. 40H

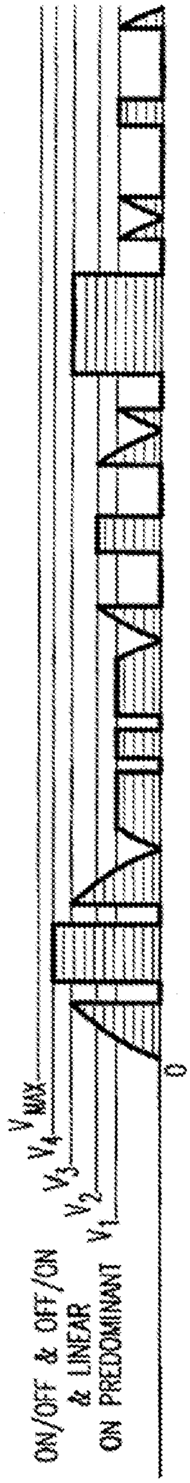


FIG. 40I

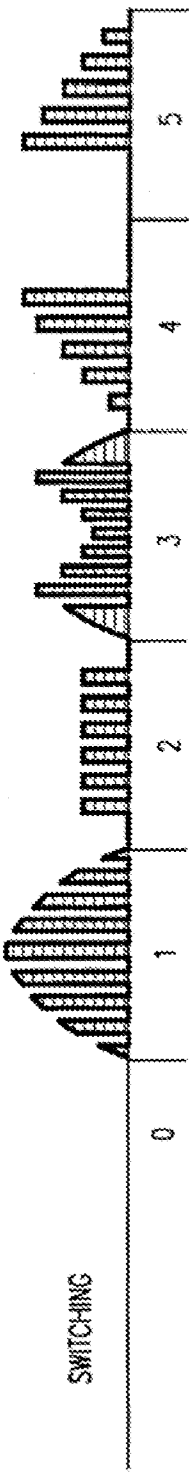


FIG. 40J

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/07Q212

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

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 2 385 747 A2 (EMD TECHNOLOGIES INC [CA]) 9 November 2011 (2011-11-09) paragraphs [0043] - [0051]; figure 3 -----	1-6
A	US 2004/080273 Al (IT0 MASAYASU [JP] ET AL) 29 April 2004 (2004-04-29) paragraphs [0029] - [0039], [0084] - [0093]; figures 1,8 -----	1-6
A	US 2011/149613 Al (LANNI THOMAS W [US]) 23 June 2011 (2011-06-23) abstract; figure 1 -----	1-6

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) orwhich is cited to establish the publication date of another citation or other special reason (as specified)

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

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 February 2013	16/04/2013

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

1

International application No.
PCT/US2012/07Q2 12

INTERNATIONAL SEARCH REPORT

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 64(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

see additional sheets

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees .

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2012/07Q212

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2385747 A2	09-11-2011	EP 2385747 A2	09-11-2011
		US 2011309760 Al	22-12-2011
US 2004080273 Al	29-04--2004	DE 10346528 Al	22-04-2004
		FR 2845559 Al	09-04-2004
		JP 4236894 B2	11-03-2009
		JP 2004134147 A	30-04-2004
		US 2004080273 Al	29-04-2004
US 2011149613 Al	23-06--2011	CA 2725509 Al	23-06-2011
		EP 2339727 Al	29-06-2011
		US 2011149613 Al	23-06-2011

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-6

   a double stage boost-isolated flyback light emitting diode driver circuit

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2. claims: 7-12

   a single stage boost light emitting diode driver circuit

   ---

3. claims: 13-17, 19

   a no opto-coupler isolated flyback light emitting diode driver circuit

   ---

4. claims: 20-25

   a single stage single ground flyback light emitting diode driver circuit

   ---

5. claims: 26-32

   a single stage constant off time buck-boost light emitting diode driver circuit

   ---

6. claims: 33-39

   a single stage single ground self supply buck-boost light emitting diode driver circuit

   ---

7. claims: 40-45

   a pseudo double stage boost isolated flyback light emitting diode driver circuit

   ---

8. claims: 46-51

   a pseudo double stage boost non isolated flyback light emitting diode driver circuit

   ---

9. claims: 52-57

   a pseudo double stage boost constant off time buck-boost light emitting diode driver circuit

   ---

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

10. claims: 58-64

    a pseudo double stage boost single ground buck-boost light emitting diode driver circuit

    ---

11. claims: 65-71

    a series monolithic light emitting diode driver circuit

    ---

12. claims: 72-78

    a parallel monolithic light emitting diode driver circuit

    ---

13. claims: 79-85

    a single cell anode loaded voltage control led limited current switch light emitting diode driver circuit

    ---

14. claims: 86-92, 106

    a single cell cathode loaded voltage control led limited current switch light emitting diode driver circuit

    ---

15. claims: 93-98, 105

    a series connected voltage control led limited current switch light emitting diode driver circuit

    ---

16. claims: 99-104

    a parallel connected voltage control led limited current switch light emitting diode driver circuit

    ---

17. claim: 107

    a monolithic light emitting diode driver overall feedback parallel circuit

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