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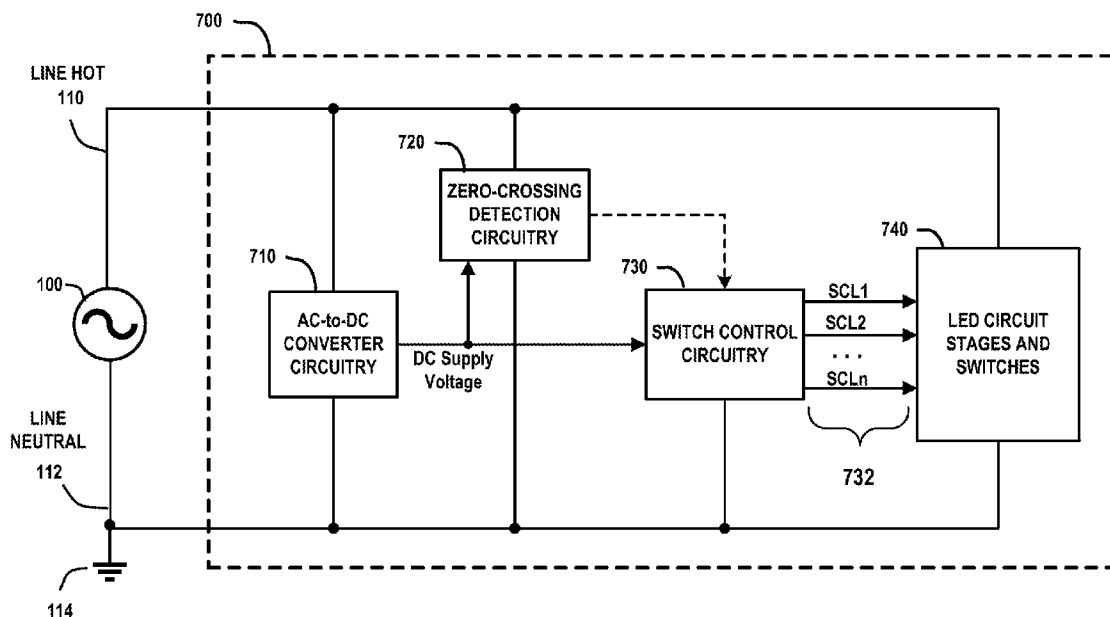
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(54) Title: AC-DRIVEN LIGHT-EMITTING DIODE SYSTEMS

FIG. 7



(57) **Abrégé/Abstract:**

AC-driven light-emitting diode systems and methods are provided for driving LED devices (e.g., LED lighting) using AC power. For example, an integrated circuit includes a first power line and a second power line configured for connection to AC power, and a plurality of LED stages, wherein each LED stage comprises multiple serially-connected LED devices, switches connected to inputs and outputs of the LED stages. The integrated circuit further includes switch control circuitry configured to control the switches to selectively connect one or more of the LED stages to the first and second power lines to empower the LED stages with the AC power.



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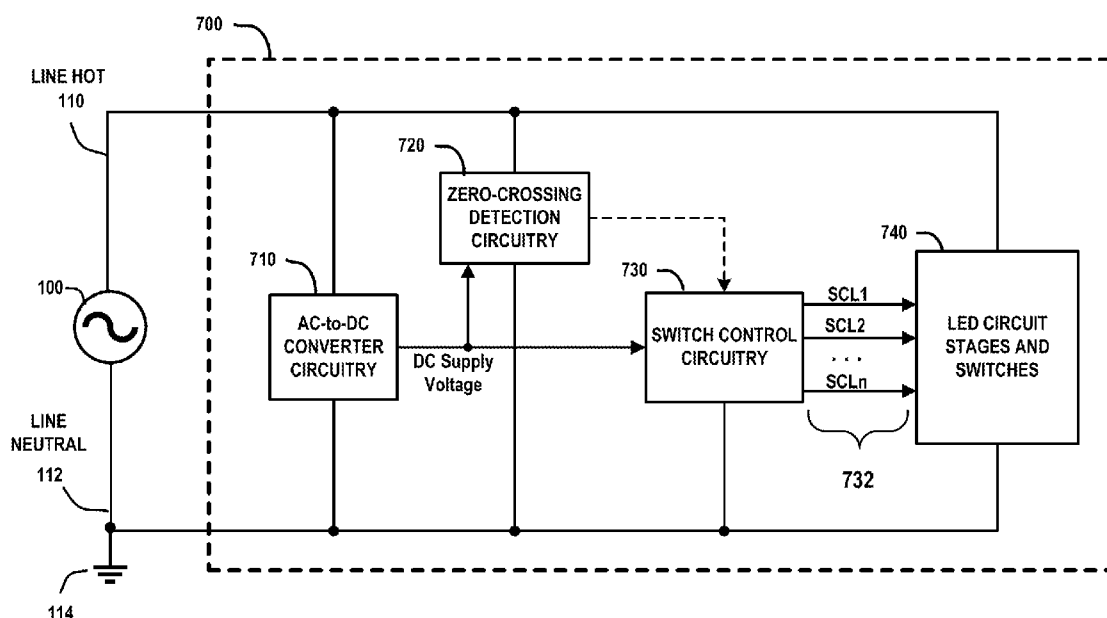
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FIG. 7

(57) **Abstract:** AC-driven light-emitting diode systems and methods are provided for driving LED devices (e.g., LED lighting) using AC power. For example, an integrated circuit includes a first power line and a second power line configured for connection to AC power, and a plurality of LED stages, wherein each LED stage comprises multiple serially-connected LED devices, switches connected to inputs and outputs of the LED stages. The integrated circuit further includes switch control circuitry configured to control the switches to selectively connect one or more of the LED stages to the first and second power lines to empower the LED stages with the AC power.

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AC-DRIVEN LIGHT-EMITTING DIODE SYSTEMS

Cross-Reference to Related Applications

This application claims priority to U.S. Provisional Application Serial No. 62/780,377, filed on December 17, 2018, entitled AC-Direct LED Driver, and U.S. Provisional Application Serial No. 62/791,014, filed January 10, 2019, entitled Monolithically Processed Light Generator, the disclosures of which are fully incorporated herein by reference.

Technical Field

This disclosure relates generally to light-emitting diode (LED) lighting systems and in particular, techniques for driving LEDs of an LED lighting system.

Background

LED lighting systems are becoming increasingly popular for use in buildings and homes as a next-generation lighting solution to replace less efficient incandescent and fluorescent lighting systems. However, LED lighting suffers from energy conversion inefficiency, and bothersome flicker when used with dimmers. In addition, conventional LED lighting is powered using direct-current (DC) power, which requires the use of expensive, bulky, and electromagnetically noisy transformer-based power conversion from AC mains to DC power.

Summary

Embodiments of the disclosure include AC-driven LED systems and methods for driving LED devices (e.g., LED lighting) using AC power.

For example, an embodiment of the disclosure includes an integrated circuit which comprises: a first power line and a second power line configured for connection to AC power; a plurality of LED stages, wherein each LED stage comprises a plurality of serially-connected LED devices; a plurality of switches connected to inputs and outputs of the LED stages; and switch control circuitry configured to control the plurality of switches to selectively connect one or more of the LED stages to the first and second power lines to empower the LED stages with the AC power.

Another embodiment of the disclosure comprises a method for driving LEDs using AC power. The method comprises applying AC power to first and second power lines; and controlling a plurality of switches to selectively connect one or more LED stages of a plurality of LED stages to the first and second power lines to empower the LED stages with the AC power, wherein each

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LED stage comprises a plurality of serially-connected LED devices.

Another embodiment includes a light generating device. The light generating device comprises a semiconductor wafer comprising a monolithic integrated circuit. The monolithic integrated circuit comprises: AC power input terminals configured for connection to an AC power source, and a first power line and a second power line coupled to respective ones of the AC power input terminals; a plurality of LED stages, wherein each LED stage comprises a plurality of serially-connected LED devices; switching circuitry comprising a plurality of switches connected to inputs and outputs of the LED stages; and switch control circuitry configured to control the plurality of switches to selectively connect at least two LED stages to the first and second power lines to empower the LED stages with AC power from the AC power source.

Other embodiments will be described in the following detailed description of embodiments, which is to be read in conjunction with the accompanying figures.

Brief Description of the Drawings

FIG. 1 schematically illustrates an exemplary AC waveform of utility supply power that is used to drive LED lighting.

FIG. 2A-2K schematically illustrate an LED circuit according to an exemplary embodiment of the disclosure, and various switching states of switches of the LED circuit.

FIG. 3A illustrates an exemplary AC voltage waveform which is applied to the LED circuit of FIGS. 2A-2K, wherein the AC voltage waveform is shown to be divided into a plurality of zones in positive and negative half-cycles of the AC waveform, according to an exemplary embodiment of the disclosure.

FIG. 3B schematically illustrates a rectified current waveform of the LED circuit of FIGS. 2A-2K, wherein the rectified current waveform is shown divided into the plurality of zones shown in FIG. 3A, according to an exemplary embodiment of the invention.

FIG. 3C schematically illustrates an exemplary process to achieve a constant brightness by activating a number of LEDs in each zone in a manner that is inversely proportional to the magnitude of the current shown in FIG. 3B.

FIG. 4 schematically illustrates an LED circuit according to an exemplary embodiment of the disclosure.

FIG. 5A is a table that illustrates various switching states of switches in the LED circuit of FIG. 4 over fourteen different and overlapping zones of a an AC voltage waveform that is used to

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VP- is about -170V. The exemplary AC waveform 100 is illustratively a 60 Hz signal with a period of about 16.66 milliseconds, wherein each half-cycle 101 and 102 has a duration of about 8.33 milliseconds.

Furthermore, FIG. 1 schematically illustrates a conventional method for driving LED devices using AC-to-DC conversion of the peak portions 101-1 and 102-1 of the respective positive and negative half-cycles 101 and 102 of the AC waveform 100. More specifically, in a conventional LED lighting system, an AC-to-DC LED driver is used to drive LED devices with DC voltage which is derived from the peak portions of AC main signal 100. This results in lengthy periods of darkness that may or may not be visible. In this regard, conventional LED lighting inefficiently converts high-voltage AC mains to DC with unreliable, costly, heavy magnetics, transformers, and bulky unreliable capacitors, whereby ~~resulting the~~ resulting in the usable portion of the AC main cycle is limited ~~with~~ resulting in relatively long periods of darkness, and added difficulty in providing low levels of dimming without flicker.

LEDs are DC current-source driven devices that are seemingly incompatible with high-voltage AC such as 120 and 240 Vrms utility sources. However, in accordance with embodiments of the disclosure, voltage level or time from zero-crossing switched LED strings of correspondingly varied lengths in series and parallel can be made to be directly compatible with high-voltage AC sources. DC devices, such as low-voltage integrated circuits and diodes, have an operable range of input voltage and can survive connection to high voltage AC sources during the voltage window that corresponds to the allowable input voltage range. For example, a typical LED used for lighting has a nominal operating voltage of 3.5 Volts and an allowable operating range from 2.8 to 4.2 Volts. A string of 10 LEDs, as an example, can be operable from 28 to 42 Volt levels of the AC source. Multiple strings of LEDs continually added in series gradually support correspondingly higher and higher voltages. Alternatively, the switching circuits can be configured to shed energy during each zone such that the current is constant and the voltage variation is consumed by a switching current source instead of stressing the LEDs.

FIG. 2A schematically illustrates an LED circuit 200 comprising a plurality of LED stages, Stage 1 - Stage 10, a plurality of switches S1-S22, a first power line 110 (denoted "Line Hot") and a second power line 112 (denoted "Line Neutral"), which are connected to AC power (e.g. the AC waveform 100 of utility supply power of FIG. 1) that is used to drive the ~~LEDs~~ LED devices of the LED circuit 200. A shown in FIG. 2A, each LED stage, Stage 1 – Stage 10, comprises a respective block of serially-connected LED devices 201-210. For

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illustrative purposes, only 10 stages are shown in FIG. 2A, although in some embodiments, the LED circuit 200 will have more than 10 stages. In some embodiments, as shown in FIG. 2A, each LED stage, Stage 1- Stage 10, 201-210 comprises the same number of serially-connected LED devices, e.g., 10 LED devices, as shown in the exploded view of the LED stage, Stage 4, comprising the block 204 of 10 serially-connected LED devices 204.

The switches, S1-S22, are connected to respective ones of inputs and outputs of the LED stages 201-210, as shown in FIG. 2A. Each LED stage 201-210 comprises (i) an input connected to a first switch and a second switch, wherein the first switch and second switches are configured to selectively connect the input of the LED stage to the first and second power lines 110 and 112, respectively, under control of switch control circuitry, and (ii) an output connected to a third switch and a fourth switch, wherein the third and fourth switches are configured to selectively connect the output of the LED stage to the first and second power lines 110 and 112, respectively. For example, the first block of LEDs 201 in Stage 1 has an input connected to switches S1 and S2, and an output connected to switches S3 and S4. Moreover, the second block of LEDs 202 has an input connected the switches S3 and S4 and to the output of the first block of LEDs 201, and so on.

The configuration of the LED circuit 200 allows the LED devices to be driven directly from the AC power 100 applied to the first and second power lines 110 and 112 by selectively activating the switches S1-S22 according to a switching protocol that is synchronized with the voltage level and phase of the AC power 100. The switching scheme is configured to selectively connect one or more of the blocks of serially-connected LED devices 201-210 to the first and second power lines 110 and 112 to drive the LED stages with the AC power (as opposed to DC power). For example, as explained in further detail below, FIGs. 2B-2K illustrate different switching states of the LED circuit 200 of FIG. 2A, wherein two or more of the blocks of serially-connected LED devices 201-210 are connected in series and/or in parallel between the first and second power lines 110 and 112.

For illustrative purposes, FIGs. 2B-2K will be discussed in the context FIG. 3A, wherein FIG. 3A illustrates an exemplary AC voltage waveform 100 which is applied to the LED circuit 200, and wherein the AC voltage waveform 100 is shown to be divided into a plurality of zones 300 (e.g., Zone 0, Zone 1, Zone 2, Zone 4, and Zone 5) in a positive-half cycle of the AC waveform 100 and a plurality of zones 310 (e.g., Zone 0, Zone 6, Zone 7, Zone 8, Zone 9, and Zone 10) in a negative half-cycle of the AC waveform 100. FIG. 3A illustrates a method for driving the blocks

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of LED devices 201-210 at various times during the positive and negative half-cycles of the AC voltage waveform 100 to illuminate the LED devices during portions of positive and/or negative cycles of the AC voltage waveform 100, with no periods of darkness except for Zone 0 just before and right after zero voltage crossings of the AC voltage waveform 100 where there is insufficient voltage level to drive any of the blocks of LED devices 201-210.

For example, FIG. 2A illustrates a switching state of the LED circuit 200 in which all the switches S1-S22 are open (i.e., not activated) for Zone 0 of the AC voltage waveform 100 such that all LED stages Stage 1-Stage 10 are deactivated. In particular, in this switching state, none of the blocks of serially-connected LED devices 201-210 are connected to the first and second power lines 110 and 112. As shown in FIG. 3A, Zone 0 represents the portions of the positive and negative half-cycles of the AC voltage waveform 100 in which the voltage is less than 30V. In this instance, it is assumed that 30V is insufficient voltage to properly drive any of the blocks of serially-connected LED devices 201-210, which each include 10 LED devices, which would require at least 35V to activate the given block of 10 LED serially-connected devices each with a nominal forward bias voltage of 3.5V.

FIG. 2B illustrates a switching state of the LED circuit 200 in which the switches S1, S4, S5, S8, S9, S12, S13, S16, S17, and S20 are activated for Zone 1 of the positive half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1, Stage 3, Stage 5, Stage 7, and Stage 9 are activated such that the blocks of serially-connected ~~LEDs~~ LED devices 201, 203, 205, 207, and 209 are connected in parallel between the first and second power lines 110 and 112. In this state, there is sufficient voltage ~~for~~ in Zone 1 of the positive half-cycle of the AC voltage waveform 100 (e.g., greater than 30V) to drive ~~a~~ each block of 10 serially-connected LED devices.

FIG. 2C illustrates a switching state of the LED circuit 200 in which the switches S1, S6, S7, S12, S13, and S18 are activated for Zone 2 of the positive half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1, Stage 2, Stage 4, Stage 5, Stage 7, and Stage 8 are activated, wherein (i) the blocks of serially-connected ~~LEDs~~ LED devices 201 and 202 are concatenated to form a first concatenated block of 20 serially-connected LED devices, (ii) the blocks of serially-connected LED devices 204 and 205 are concatenated to form a second concatenated block of 20 serially-connected LED devices, and (iii) the blocks of serially-connected LED devices 207 and 208 are concatenated to form a third concatenated block of 20 serially-connected LED devices. As further shown in FIG. 2C, the first, second and third concatenated

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blocks of LED devices are connected in parallel between the first and second power lines 110 and 112. In this state, there is sufficient voltage (greater than 60V) ~~of in~~ in Zone 2 of the positive half-cycle of the AC voltage waveform 100 to drive each of the first, second and third, concatenated blocks of 20 serially-connected LED devices.

FIG. 2D illustrates a switching state of the LED circuit 200 in which the switches S1, S8, S9, and S16 are activated for Zone 3 of the positive half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1, Stage 2, Stage 3, Stage 5, Stage 6 and Stage 7 are activated, wherein (i) the blocks of serially-connected ~~LEDs~~ LED devices 201, 202, and 203 are concatenated to form a first concatenated block of 30 serially-connected LED devices, and (ii) the blocks of serially-connected LED devices 205, 206 and 207 are concatenated to form a second concatenated block of 30 serially-connected LED devices. As further shown in FIG. 2D, the first and second concatenated blocks of LED devices are connected in parallel between the first and second power lines 110 and 112. In this state, there is sufficient voltage (greater than 90V) ~~of in~~ in Zone 3 of the positive half-cycle of the AC voltage waveform 100 to drive each of the first and second concatenated blocks of 30 serially-connected LED devices.

FIG. 2E illustrates a switching state of the LED circuit 200 in which the switches S1, S10, S11, and S20 are activated for Zone 4 of the positive half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1-Stage 4, and Stage 6-Stage 9 are activated, wherein (i) the blocks of serially-connected ~~LEDs~~ LED devices 201, 202, 203, and 204 are concatenated to form a first concatenated block of 40 serially-connected LED devices, and (ii) the blocks of serially-connected LED devices 206, 207, 208, and 209 are concatenated to form a second concatenated block of 40 serially-connected LED devices. As further shown in FIG. 2E, the first and second concatenated blocks of LED devices are connected in parallel between the first and second power lines 110 and 112. In this state, there is sufficient voltage (greater than 120V) in Zone 4 of the positive half-cycle of the AC voltage waveform 100 to drive each of the first and second concatenated blocks of 40 serially-connected LED devices.

FIG. 2F illustrates a switching state of the LED circuit 200 in which the switches S1 and S12 are activated for Zone 5 of the positive half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1-Stage 5 are activated, wherein the blocks of serially-connected ~~LEDs~~ LED devices 201, 202, 203, 204, and 205 are concatenated to form a first concatenated block of 50 serially-connected LED devices, which is connected between the first and second power lines 110

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and 112. In this state, there is sufficient voltage (greater than 150V) in Zone 5 of the positive half-cycle of the AC voltage waveform 100 to drive the first concatenated block of 50 serially-connected LED devices.

As shown in FIG. 3A, on the falling portion of the positive-half cycle, the Zone sequence Z4, Z3, Z3, Z1 and Z0 results in a repeated reverse sequence of the switching ~~stages~~ states shown in FIGs. 2A-2E. As further shown in FIG. 3A, for the negative half-cycle of the AC voltage waveform 100, the waveform transitions in a Zone sequence of Zone 0, Zone 6, Zone 7, Zone 8, Zone 9, Zone 10, Zone 9, Zone 8, Zone 7, Zone 6 and Zone 0. FIGs. 2G through 2K illustrate ~~illustrates~~ different switching states of the LED circuit 200 in sequence from Zone 6 through Zone 10. FIGs. 2G-2K illustrate a LED stage activation configurations ~~configuration~~ which is similar to those shown in FIGs. 2B-2F, but wherein the inputs to the LED stages are connected to the second power line 112 in the negative half-cycle of the AC voltage waveform 100 to place the LED devices in a forward-biased ~~based~~ state.

In particular, FIG. 2G illustrates a switching state of the LED circuit 200 in which the switches S2, S3, S6, S7, S10, S11, S14, S15, S18 and S19 are activated for Zone 6 of the negative half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1, Stage 3, Stage 5, Stage 7, and Stage 9 are activated such that the blocks of serially-connected ~~LEDs~~ LED devices 201, 203, 205, 207, and 209 are connected in parallel between the first and second power lines 110 and 112. In this state, there is sufficient voltage ~~for in~~ in Zone 6 of the AC voltage waveform (e.g., greater than 30V) to drive a each block of 10 serially-connected LED devices. In this configuration, as shown in FIG. 2G, the input terminals of the blocks of serially-connected LED devices 201, 203, 205, 207, and 209 are connected to the second power line 112 and the output terminals of the blocks of serially-connected LED devices 201, 203, 205, 207, and 209 are connected to the first power line 110, which places the LED devices in a forward-biased state during the negative half-cycle of the AC voltage waveform 100.

FIG. 2H illustrates a switching state of the LED circuit 200 in which the switches S2, S5, S8, S11, S14, and S17 are activated for Zone 7 of the negative half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1, Stage 2, Stage 4, Stage 5, Stage 7 and Stage 8 are activated, wherein (i) the blocks of serially-connected ~~LEDs~~ LED devices 201 and 202 are concatenated to form a first concatenated block of 20 serially-connected LED devices, (ii) the blocks of serially-connected LED devices 204 and 205 are concatenated to form a second concatenated block of 20 serially-connected LED devices, and (iii) the blocks of serially-connected LED devices 207 and 208 are concatenated to form a third concatenated block of 20 serially-

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connected LED devices. As further shown in FIG. 2H, the first, second and third concatenated blocks of LED devices are connected in parallel between the first and second power lines 110 and 112. In this state, there is sufficient voltage (greater than 60V) in Zone 7 of the negative half-cycle of the AC voltage waveform 100 to drive each of the first, second, and third concatenated blocks of 20 serially-connected LED devices.

FIG. 2I illustrates a switching state of the LED circuit 200 in which the switches S2, S7, S10, and S15 are activated for Zone 8 of the negative half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1, Stage 2, Stage 3, Stage 5, Stage 6 and Stage 7 are activated, wherein (i) the blocks of serially-connected ~~LEDs~~ LED devices 201, 202, and 203 are concatenated to form a first concatenated block of 30 serially-connected LED devices, and (ii) the blocks of serially-connected LED devices 205, 206, and 207 are concatenated to form a second concatenated block of 30 serially-connected LED devices. As further shown in FIG. 2I, the first and second concatenated blocks of LED devices are connected in parallel between the first and second power lines 110 and 112. In this state, there is sufficient voltage (greater than 90V) in Zone 8 of the negative half-cycle of the AC voltage waveform 100 to drive each of the first and second concatenated blocks of 30 serially-connected LED devices.

FIG. 2J illustrates a switching state of the LED circuit 200 in which the switches S2, S9, S12, and S19 are activated for Zone 9 of the negative half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1-Stage 4, and Stage 6-Stage 9 are activated, wherein (i) the blocks of serially-connected ~~LEDs~~ LED devices 201, 202, 203, and 204 are concatenated to form a first concatenated block of 40 serially-connected LED devices, and (ii) the blocks of serially-connected LED devices 206, 207, 208, and 209 are concatenated to form a second concatenated block of 40 serially-connected LED devices. As further shown in FIG. 2J, the first and second concatenated blocks of LED devices are connected in parallel between the first and second power lines 110 and 112. In this state, there is sufficient voltage (greater than 120V) in Zone 9 of the negative half-cycle of the AC voltage waveform 100 to drive each of the first and second concatenated blocks of 40 serially-connected LED devices.

FIG. 2K illustrates a switching state of the LED circuit 200 in which the switches S2 and S11 are activated for Zone 10 of the negative half-cycle of the AC voltage waveform 100. In this state, the LED stages Stage 1-Stage 5 are activated, wherein the blocks of serially-connected ~~LEDs~~ LED devices 201, 202, 203, 204, and 205 are concatenated to form a first concatenated block of

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serially-connected LED devices, which is connected between the first and second power lines 110 and 112. In this state, there is sufficient voltage (greater than 150V) in Zone 10 of the negative half-cycle of the AC voltage waveform 100 to drive the first concatenated block of 50 serially-connected LED devices.

Referring again to FIG. 3A, on the rising portion of the negative-half cycle of the AC voltage waveform 100, the Zone sequence Z9, Z8, Z7, Z6 and Z0 results in a repeated reverse sequence of the switching ~~stages~~ states shown in FIGs. 2G-2J. As demonstrated above, FIGs. 2A-2K and FIG. 3A collectively illustrate an exemplary embodiment of the disclosure in which LED blocks of 10 serially-connected LED devices, which comprise LED devices with an operating range of about 2.8V to 4.2V, can support a working range of about 30V to about 40 V, and even higher voltages by concatenating the LED blocks, thereby allowing a relatively stable level of light to be generated by the LED devices for a majority of the positive and negative cycles of the AC mains power. The timing for activating the various switches S1-S22 as shown in FIGs. 2A-2K may be implemented based on, e.g., detection of voltage level, phase, and/or time, e.g., based on line frequency and/or detection of zero-crossing events using one or more zero-crossing detector circuits, or other schemes as discussed in further detail below.

FIG. 3B schematically illustrates a current waveform 320 to show that positive current flows through the blocks of serially-connected LED devices 201-210 of the activated LED stages of the LED circuit 200 in FIGs. 2B-2K during both the positive and negative half-cycles of the AC voltage waveform 100. In this regard, the LED circuit 200 and associated switch fabric and switching configurations as discussed above enables a virtual rectification of the negative half-cycles of the AC voltage waveform 100 as a result of connecting the positive terminals of the blocks of serially-connected LED devices 201-210 to the second power line 112 (e.g., line neutral) during the negative half-cycle of the AC voltage waveform 100. As explained below in conjunction with FIG. 6, in some embodiments, each switch S1-S22 is implemented as a bidirectional solid-state switch which can be controlled in bi-directional fashion with unidirectional current flow, such that the negative half-cycles of the AC mains waveform 100 have substantially the same illumination capability as positive half-cycles of the AC mains waveform 100.

In some embodiments of the disclosure, with non-limiting reference to the exemplary ~~exemplar~~ embodiment of FIGs. 2A-2K, the switching sequence and activation of the LED stages for each of

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the Zones 1-10 is configured to provide a relatively constant illumination level over the various Zones 1-5 and 6-10 of the positive and negative half-cycles of the AC voltage waveform 100. For example, FIG. 3C schematically illustrates an exemplary process to achieve a constant brightness by activating a number N of LEDs in each zone in a manner that is inversely proportional to the magnitude of the current. For In particular, FIG. 3C illustrates the current waveform 320 (of FIG. 3B) superimposed with a first curve 330 and a second curve 340.

The first curve 330 represents a number of LEDs (N) as function of $\frac{1}{\sin(\omega t)}$ (based on the frequency, e.g., 60 Hz of the AC voltage waveform 100). The second curve 340 represents an empirically determined brightness L , which is empirically determined as $L = \frac{I}{N} \times k$, wherein I denotes a magnitude of the current waveform 320, N denotes a number of LEDs to be activated, and k denotes an empirically determined constant. The first and second curves 330 and 340 represent functions that are utilized by a processor to control the switching in the LED circuitry ~~circuit~~ to activate a given number N of LEDs for a given zone based on the magnitude of the current I . In this control process, as the AC power transitions through the Zones 300 and 310 in the positive and negative half-cycles, as the current I increases, the number N of LEDs activated will decrease, and vice versa.

As schematically illustrated in FIG. 3C, the desired brightness waveform 340 provides a constant DC brightness level L over all Zones 1-10, while providing a short dark period for each Zone 0 in the positive and negative half-cycles of the AC power. However, since the darkness period where $L=0$ is very short (e.g., less than 10% of full AC waveform cycle), any flickering due to such short period of darkness will not be visible to the human eye.

In an exemplary non-limiting embodiment, the various switching states of the LED circuit 200 shown in FIGs. 2B-2K can implement a switching function in accordance with the principles of FIG. 3C to achieve relatively constant brightness by the LEDs activated in each of the Zones 1-10. For example, in FIG. 2B, for Zone 1 where the voltage reaches 30V, 15 stages of the 10 serially-connected LED blocks can be activated in parallel to turn on 150 LEDs. In FIG. 2C, for Zone 2 where the voltage increases to about 60V, the total number N of activated LEDs will be about 100. In FIG. 2D, for Zone 3 where the voltage increases to about 90, the total number N of activated LEDs will be about 90. In FIG. 2E, for Zone 4 where the voltage increases to about 120V, the total number N of activated LEDs will be about 80. In FIG. 2F, for Zone 5 where the

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voltage increases to about 150V, the total number N of activated LEDs will be about 50. The same number of LEDs for each of Zones 6-10 will be the same for Zones 1-5. In this manner, as the voltage increases in the sequential Zones (and thus the current I increases, FIG. 3B), the number N of activated LEDs will be decreased to maintain a constant brightness level across the Zones, while as the voltage decreases in sequential Zones, the number N of activated LEDs will be increased to maintain a constant brightness level across the Zones.

FIG. 4 schematically illustrates an LED circuit 400 according to another embodiment of the disclosure. The LED circuit 400 comprises a plurality of LED stages, Stage 1 - Stage 7, a plurality of switches S1-S16, a first power line 110 (denoted "Line Hot") and a second power line 112 (denoted "Line Neutral"), which are connected to AC power (e.g. the AC waveform 100 of utility supply power of FIG. 1) that is used to drive the LEDs stages of the LED circuit 400. ~~A~~ As shown in FIG. 4, each LED stage comprises a respective block of serially-connected LED devices 401-207. For illustrative purposes, only 7 stages are shown in FIG. 4, although in some embodiments, the LED circuit 400 will have more than 7 LED stages.

In the exemplary embodiment of FIG. 4, the blocks of serially-connected LED devices 401-407 have different numbers of serially-connected LED devices. For example, in the first LED stage (Stage 1), the block of serially-connected LED device 401 comprises 10 LED devices. In the second LED stage (Stage 2), the block of serially-connected LED devices 402 comprises 3 LED devices. In the third LED stage (Stage 3), the block of serially-connected LED devices 403 comprises 4 LED devices. In the fourth LED stage (Stage 4), the block of serially-connected LED devices 404 comprises 5 LED devices. In the fifth LED stage (Stage 5), the block of serially-connected LED devices 405 comprises 7 LED devices. In the sixth LED stage (Stage 6), the block of serially-connected LED devices 406 comprises 9 LED devices. In the seventh LED stage (Stage 7), the block of serially-connected LED devices 407 comprises 12 LED devices. In this configuration, the varied number of LED devices in each LED stage ~~provide~~ allows for a more fine-adjustment of the number of ~~LEDs~~ LED devices that are activated or deactivated during different Zones of the AC power cycles based on smaller increases or decreases in voltage over a large number of Zones.

For example, FIG. 5A is a table that illustrates various switching states of the switches S1-S16 in the LED circuit 400 of FIG. 4 over fourteen different and overlapping Zones. In FIG. 5A, is assumed that the ~~LEDs~~ LED devices of FIG. 4 have a 3.5V nominal operating voltages, and the AC voltage waveform 100 comprises a 120 Vrms waveform. As shown in FIG. 5A, the number of activated serially-connected LED devices for Zones 1 ~~to~~ through 7 and Zones 8 - through 14 are shown as: 10, ~~3, 4, 5, 7, 9~~ 13, 17, 22.

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29, 38, and 42 LEDs 50 LED devices, respectively, wherein the Zones are configured to overlap and eliminate potential short periods of darkness between Zones. In this configuration, the LED circuit 400 can have an LED stage that is activated at 9V, rather than 30V (for the 10 LED stages shown in FIGs. 2A-2K). In particular, in the exemplary embodiment of FIG. 4, the following LED stages can be activated with the following voltage levels: (i) the 3-LED stage 402 can be enabled with the AC mains between 9 to 12 Volts; (ii) the 4-LED stage 403 can be enabled with the AC mains between 12V to 15V; (iii) the 5-LED stage 404 can be enabled with the AC mains between 15 to 20V; (iv) the 7-LED stage 405 can be enabled with the AC mains between 21V to 27V (or higher); (v) the 9-LED stage 406 zone can be enabled with the AC mains between 27V to 30 V (or higher); and (vi) the 10-LED stage can be enabled with the AC mains at around 35V (or higher), etc.

FIG. 5B shows one full cycle of an AC voltage waveform 100 with overlapping Zones 1-7 ~~500~~ in the positive half-cycle 500 of the AC voltage waveform 100, and overlapping zones 8-14 in the negative half-cycle 510 of the AC voltage waveform 100. FIG. 5B illustrates an exemplary embodiment for providing time overlap for switching states in the various Zones, to thereby eliminate potential short periods of darkness between adjacent Zones.

FIG. 6 schematically illustrates a solid-state bidirectional switch 600 which can be used to implement the switches shown in the LED circuits 200 and 400 of FIGs. 2A and 4. The solid-state bidirectional switch 600 comprises first and second input/output terminals 601 and 602, and a control terminal 603. The solid-state bidirectional switch 600 is configured to allow a bidirectional flow of current, when the solid-state bidirectional switch 600 is in “switched-on state” by operation of a control signal applied to the control terminal 603.

The solid-state bidirectional switch 600 comprises a first MOSFET switch 610 and a second MOSFET switch 620 which are connected back-to-back in series. In some embodiments, the first and second MOSFET switches 610 and 620 comprise power MOSFET devices and, in particular, N-type enhancement MOSFET devices, having gate terminal (G), drain terminals (D), and source terminals (S) as shown. In the exemplary embodiment of FIG. 6, the solid-state bidirectional switch 600 is implemented using two N-channel MOSFET switches 610 and 620 with commonly connected source terminals. The first and second MOSFET switches 610 and 620 comprises intrinsic body diodes 610-1 and 620-1, respectively, which represent the P-N junctions between the P-type substrate body to N-doped drain regions of the MOSFET devices. The body diodes 610-1 and 620-1 are intrinsic elements of the MOSFET switches 610 and 620 (i.e., not

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discrete elements) and, thus, are shown with dashed-line connections. It is to be noted that the intrinsic body-to-source diodes of the MOSFET switches 610 and 620 are not shown as they are shorted out by the connections between the source regions and the substrate bodies (e.g., N⁺ source and P body junction are shorted through source metallization). The operation of the solid-state bidirectional switch 600 is well known to those of ordinary skill in the art.

FIG. 7 schematically illustrates a light generating circuit 700 according to an exemplary embodiment of the disclosure. The light generating circuit 700 is connected to a utility AC power supply 100 (~~referred to herein as AC mains 10~~) which is utilized by the light generating circuit 700 to drive LED devices using techniques as discussed herein. The light generating circuit 700 is connected to a hot phase 110 (referred to as “line hot”) of the AC mains 100 and a neutral phase 112 (referred to as “line neutral”) of the AC mains 100. As further illustrated in FIG. 7, the line neutral 112 is shown bonded to earth ground 114 (GND), which provides added protections as is known in the art.

The light generating circuit 700 comprises AC-to-DC converter circuitry 710, zero-crossing detection circuitry 720, switch control ~~circuit~~ circuitry 730, and an arrangement of LED circuit stages and switches 740. In some embodiments, the arrangement of LED circuit stages and switches 740 implements an LED circuit which is the same or similar to the LED circuits 200 or 400 as shown in FIGs. 2A and 4. The switch control circuitry 730 implements switching protocols to selectively activate switches within the block of LED circuit stages and switches 740 to selectively connect individual and/or concatenated blocks of serially-connected LED devices to the AC power supply lines, to drive the LED switches using AC power. The switch control circuitry 730 generates and outputs a switch control signals on a plurality (n) of switch control lines SCL1, SCL2, SCLn, which are connected to control terminals of corresponding switches within the switching fabric that is utilized to selectively connect individual and/or concatenated blocks of serially-connected LED devices within the LED stages 740 to the AC power supply lines.

The AC-to-DC converter circuitry 710 is configured to provide DC supply power to various circuitry and elements of the light generating circuit 700 including the zero-crossing detection circuitry 720 and the switch control circuitry 730. However, the AC-to-DC converter circuitry 710 is not configured to provide DC supply voltage for driving LED devices. In some embodiments, the AC-to-DC converter circuitry 710 can be implemented using the same or similar DC power conversion techniques as disclosed in the following co-pending applications: (1) U.S.

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In other embodiments, the switch control ~~circuit~~ circuitry 730 may implement modulation schemes, such as pulse-width modulation (PWM), to ~~module~~ modulate the ~~activating~~ activation of the LED stages in the different zones to implement flicker-free levels of dimming with complete compatibility with the AC-Direct LED driving methods as discussed herein. The modulation can be configured to soften the transition between states when strings of ~~LEDs~~ LED devices are added or removed. Also, the implementation of a computing device, such as CPU core, microcontroller, or other digital/analog device, can facilitate support for overall or local system reconfiguration, e.g., during manufacturing and/or operational use in the field to mitigate AC main ~~transients~~ transient events.

It is to be understood that the various combinations of LED strings, the number of LEDs, whether in series or parallel, and/or with varying switching configurations and LED operating voltages may be a linear and/or non-linear optimization problem that can be determined based on various design and/or cost constraints.

The switch control methods that are implemented by, e.g., the switch control circuitry 730 may be synchronized in time with the AC voltage waveform to divide the AC waveform into discrete Zones, as discussed above. The switch control process may be synchronized with line frequency, with the incremented states beginning from zero voltage switching and zero crossing events as detected by the zero-crossing detection ~~circuit~~ circuitry 720. The LED switching Zones can be determined from initial power-up 0 time/0Vs, optionally divided into multiple zones (e.g., 5 Zones) equally with equal time duration with slide variation.

In some embodiments, each switching zone may be pulse width modulated (or other modulation technique) to provide illumination balance at each zone, during zone overlap, and for dimming control. Also, by steering to control current automatically under algorithmic control, additional LEDs may be added in parallel to increase light output per zone, and number of zones may be adjustable by design and/or configured initially in factory or field subsequently.

In other embodiments, state changes may be timed using, e.g., resistor-capacitor time constant within each zone among the LEDs. Furthermore, to maintain a constant illumination level during rising and falling portions of the AC mains waveform, each subsequent zone (i.e., after initial zone) may be controlled via a PWM scheme that enables a prior-to-previous zone disable operation, whereby the PWM starts with an increasing duty cycle on the rising portion of the AC mains waveform until a previous zone disables, and gradually decreases while the AC mains waveform continues to rise. Accordingly, the PWM gradually increases in duty cycle during a

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downward slope of the AC mains waveform to maintain the intensity with a decreasing voltage level; hence, being possible for PWM at subsequent zones implemented with an intermediate connection to ground.

FIG. 8 schematically illustrates a light generating device 800 which is implemented in a monolithic wafer form, according to an exemplary embodiment of disclosure. The light generating device 800 comprises a semiconductor wafer substrate 802 (e.g., silicon substrate), which comprises a monolithic integrated circuit. The monolithic integrated circuit comprises an LED array 804, switch circuitry 806, AC power input terminals 808, and control circuitry 810. In some embodiments, FIG. 8 illustrates a monolithic wafer implementation of the light generating circuit 700 of FIG. 7.

The AC power input terminals 808 are configured for connection to an AC power source. The AC power input terminals 808 are coupled to first and second power lines that comprise metallization that is used to route and distribute the AC power to various regions of the wafer 802. The LED array 804 comprises a plurality of LED devices 820 that are connected to form a plurality of LED stages, wherein each LED stage comprises a plurality of serially-connected LED devices 820, such as schematically illustrated in FIGs. 2A and 4, for example. The switching circuitry 806 comprises a plurality of switches (e.g., solid-state bi-directional switches) that are coupled to the LED array 804 using a wiring network to connect the switches to the inputs and outputs of the LED stages. The switch control circuitry 810 is configured to control the plurality of switches of the switching ~~circuit~~ circuitry 806 to selectively connect at LED stages to the first and second power lines to empower the LED stages with AC power from the AC power source connected to the AC input terminals 808. The switches within the ~~switch-control-circuitry~~ switching circuitry 806 can be configured in a microcell arrangement, or a functional cell arrangement with well-defined tab positions.

As further shown in FIG. 8, in some embodiments, each LED device 820 comprises an optical filter 822 disposed over the LED device 820 and a lens element 824 disposed over the LED device 820. In some embodiments, the optical filter 822 comprise a phosphor layer to filter the light that is emitted by the LED device 820. The lens element 824 is configured to direct, focus, collimate, etc., or otherwise achieve a desired directionality of the light that is emitted by the LED device 820.

FIG. 8 illustrates an exemplary embodiment wherein the light generating device 800 implemented in monolithic wafer form can be used to implement an LED lighting device or system

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without requiring wafer segmentation for repackaging in different form factors. The wafer substrate 802 can be implemented using various standard wafer sizes to accommodate larger or smaller LED arrays to achieve a desired light output level. Larger wafers can be partitioned into smaller dies, wherein each dies comprises an integrated light generating monolithic circuit.

FIG. 9 schematically illustrates a light generating device 900 which is implemented in a monolithic wafer form, according to another exemplary embodiment of disclosure. The light generating device 900 comprises a semiconductor wafer substrate 902 (e.g., silicon substrate), which comprises a monolithic integrated circuit. The monolithic integrated circuit comprises an LED array 904, switch circuitry 906, AC power input terminals 908, and control circuitry 910. In some embodiments, FIG. 9 illustrates a monolithic wafer implementation of the light generating circuit 700 of FIG. 7. The light generating device 900 is similar to the light generating device 800 of FIG. 8, ~~except~~ except that the light generating device 900 has a different arrangement of LED devices within the LED array 904, wherein the LED array 904 comprises LED devices arranged in circular footprint regions, wherein each circular footprint region is surrounded by ~~a switch circuitry~~ circuitry 906 which comprises an arrangement of switches that are ~~utilized~~ utilized to connect the LED devices, or blocks of serially-connected LED devices, to power lines or otherwise concatenate blocks of serially-connected LED devices to form larger strings of serially-connected LED device, such as discussed above.

Although exemplary embodiments have been described herein with reference to the accompanying figures, it is to be understood that the current disclosure is not limited to those precise embodiments, and that various other changes and modifications may be made therein by one skilled in the art without departing from the scope of the appended claims.

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WHAT IS CLAIMED IS:

1. An integrated circuit comprising:
 - a first power line and a second power line configured for connection to alternating-current (AC) power;
 - a plurality of light-emitting diode (LED) stages, wherein each LED stage comprises a plurality of LED devices that are serially-connected between an input node and an output node of the LED stage;
 - a plurality of switches connected to the input and output nodes of the LED stages and to the first and second power lines, wherein for each LED stage of the plurality of LED stages (i) the input node of the LED stage is coupled to the first power line through a respective first switch of the plurality of switches, (ii) the input node of the LED stage is coupled to the second power line through a respective second switch of the plurality of switches, (iii) the output node of the LED stage is coupled to the first power line through a respective third switch of the plurality of switches, and (iv) the output node of the LED stage is coupled to the second power line through a respective fourth switch of the plurality of switches; and
 - switch control circuitry configured to control the plurality of switches to selectively connect one or more of the LED stages to the first and second power lines to selectively empower the one or more LED stages with the AC power;
 - wherein in controlling the plurality of switches, the switch control circuitry is configured to:
 - (i) during a first half-cycle of AC power applied to the first and second power lines, selectively connect the input node of a given LED stage of the plurality of LED stages to the first power line through activation of the respective first switch, and selectively connect the output node of the given LED stage to the second power line through activation of the respective fourth switch; and
 - (ii) during a second half-cycle of the applied AC power, selectively connect the input node of the given LED stage to the second power line through activation of the respective second switch, and selectively connect the output node of the given LED stage to the first power line through activation of the respective third switch.

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2. The integrated circuit of claim 1, wherein the switch control circuitry is configured to control the plurality of switches to selectively connect at least two LED stages in series between the first and second power lines.

3. The integrated circuit of claim 1, wherein the switch control circuitry is configured to control the plurality of switches to selectively connect at least two LED stages in parallel between the first and second power lines.

4. (Canceled)

5. The integrated circuit of claim 1, wherein the switch control circuitry comprises a hardware processor that is configured to execute a switch timing control program to synchronize activation of the plurality of switches to empower one or more LED stages based on a voltage level of an AC voltage waveform of the AC power.

REPLACEMENT SHEET

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6. The integrated circuit of claim 1, further comprising:
a zero-crossing detection circuit configured to detect zero-voltage crossings of an AC voltage waveform applied on the first and second power lines and output a detection signal which indicates a zero-crossing event and a direction of polarity transition of the AC voltage waveform;
wherein the switch control circuitry utilizes the output detection signal to synchronize activation of the plurality of switches to empower one or more LED stages based on a voltage level of the AC voltage waveform.

7. The integrated circuit of claim 1, wherein each LED stage comprises a same number of serially-connected LED devices.

8. The integrated circuit of claim 7, wherein each LED stage comprises ten serially-connected LED devices, wherein each LED device has an operating range from about 2.8V to about 4.2V.

9. The integrated circuit of claim 1, wherein at least two LED stages have different numbers of serially-connected LED devices.

10. An LED lighting system comprising the integrated circuit of claim 1.

11. A method comprising:
applying alternating-current (AC) power to first and second power lines of a light generating device comprising a plurality of light-emitting diode (LED) stages and a plurality of switches, wherein each LED stage comprises a plurality of LED devices that are serially-connected between an input node and an output node of the LED stage, and wherein the plurality of switches are connected to the input and output nodes of the LED stages and to the first and second power lines, wherein for each LED stage of the plurality of LED stages (i) the input node of the LED stage is coupled to the first power line through a respective first switch of the plurality of switches, (ii) the input node of the LED stage is coupled to the second power line through a respective second switch of the plurality of switches, (iii) the output node of the LED stage is coupled to the first power line through a respective third switch of the plurality of switches, and (iv) the output node

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of the LED stage is coupled to the second power line through a respective fourth switch of the plurality of switches; and

controlling the plurality of switches to selectively connect one or more LED stages of the plurality of LED stages to the first and second power lines to selectively empower the one or more LED stages with the AC power;

wherein controlling the plurality of switches comprises:

(i) during a first half-cycle of the applied AC power, selectively connecting the input node of a given LED stage of the plurality of LED stages to the first power line through activation of the respective first switch, and selectively connecting the output node of the given LED stage to the second power line through activation of the respective fourth switch; and

(ii) during a second half-cycle of the applied AC power, selectively connecting the input node of the given LED stage to the second power line through activation of the respective second switch, and selectively connecting the output node of the given LED stage to the first power line through activation of the respective third switch.

12. The method of claim 11, wherein controlling the plurality of switches comprises selectively connecting at least two LED stages in series between the first and second power lines.

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13. The method of claim 11, wherein controlling the plurality of switches comprises selectively connecting at least two LED stages in parallel between the first and second power lines.

14. (Canceled)

15. The method of claim 11, wherein controlling the plurality of switches comprises synchronizing activation of the plurality of switches to empower one or more LED stages based on a voltage level of an AC voltage waveform.

16. A light generating device, comprising:
a semiconductor wafer comprising a monolithic integrated circuit, wherein the monolithic integrated circuit comprises:

alternating-current (AC) power input terminals configured for connection to an AC power source, and a first power line and a second power line coupled to respective ones of the AC power input terminals;

a plurality of light-emitting diode (LED) stages, wherein each LED stage comprises a plurality of LED devices that are serially-connected between an input node and an output node of the LED stage;

switching circuitry comprising a plurality of switches connected to the input and output nodes of the LED stages and to the first and second power lines, wherein for each LED stage of the plurality of LED stages (i) the input node of the LED stage is coupled to the first power line through a respective first switch of the plurality of switches, (ii) the input node of the LED stage is coupled to the second power line through a respective second switch of the plurality of switches, (iii) the output node of the LED stage is coupled to the first power line through a respective third switch of the plurality of switches, and (iv) the output node of the LED stage is coupled to the second power line through a respective fourth switch of the plurality of switches; and

switch control circuitry configured to control the plurality of switches to selectively connect one or more of the LED stages to the first and second power lines to empower the one or more LED stages with AC power from the AC power source;

wherein in controlling the plurality of switches, the switch control circuitry is configured to:

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(i) during a first half-cycle of AC power applied to the first and second power lines, selectively connect the input node of a given LED stage of the plurality of LED stages to the first power line through activation of the respective first switch, and selectively connect the output node of the given LED stage to the second power line through activation of the respective fourth switch; and

(ii) during a second half-cycle of the applied AC power, selectively connect the input node of the given LED stage to the second power line through activation of the respective second switch, and selectively connect the output node of the given LED stage to the first power line through activation of the respective third switch.

17. The light generating device of claim 16, wherein the switch control circuitry is configured to control the plurality of switches to at least one of (i) selectively connect at least two LED stages in series between the first and second power lines, and (ii) selectively connect at least two LED stages in parallel between the first and second power lines.

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18. The light generating device of claim 16, wherein the switch control circuitry comprises a hardware processor that is configured to execute a switch timing control program to synchronize activation of the plurality of switches to empower one or more LED stages based on a voltage level of an AC voltage waveform.

19. The light generating device of claim 16, wherein each LED stage comprises a same number of serially-connected LED devices.

20. The light generating device of claim 16, further comprising at least one of (i) an optical filter disposed over each LED device, and (ii) a lens disposed over each LED device.

21. The integrated circuit of claim 1, wherein the switch control circuitry comprises a hardware processor that is configured to execute a switch timing control program to synchronize activation of the plurality of switches to empower the one or more LED stages based on a voltage level of the applied AC power to maintain a substantially constant brightness level of light emitted by activated LED devices of the empowered one or more LED stages, wherein as the voltage level of the applied AC power increases during the first and second half-cycles of the applied AC power, a number of activated LED devices decreases to maintain the substantially constant brightness level, while as the voltage level of the applied AC power decreases during the first and second half-cycles of the applied AC power, the number of activated LED devices increases to maintain the substantially constant brightness level.

22. The method of claim 11, wherein controlling the plurality of switches comprises synchronizing activation of the plurality of switches to empower the one or more LED stages based on a voltage level of the applied AC power to maintain a substantially constant brightness level of light emitted by activated LED devices of the empowered one or more LED stages, wherein as the voltage level of the applied AC power increases during the first and second half-cycles of the applied AC power, a number of activated LED devices decreases to maintain the substantially constant brightness level, while as the voltage level of the applied AC power decreases during the first and second half-cycles of the applied AC power, the number of activated LED devices increases to maintain the substantially constant brightness level.

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23. An integrated circuit comprising:

a first power line and a second power line configured for connection to alternating-current (AC) power;

5 a plurality of light-emitting diode (LED) stages, wherein each LED stage comprises a plurality of LED devices that are serially connected between an input terminal and an output terminal of the LED stage;

switching circuitry connected to the input and output terminals of the LED stages and to the first and second power lines; and

10 switch control circuitry configured to control the switching circuitry to selectively connect one or more of the LED stages to the first and second power lines to selectively empower the one or more LED stages with the AC power;

15 wherein the switch control circuitry is configured control the switching circuitry to (i) selectively connect the input terminal of at least one LED stage to the first power line during a first half-cycle of AC power applied to the first and second power lines, and (ii) selectively connect the input terminal of the at least one LED stage to the second power line during a second half-cycle of the AC power applied to the first and second power lines, so that the plurality of LED devices of the at least one LED stage are forward-biased in the first and second half-cycles of the AC power.

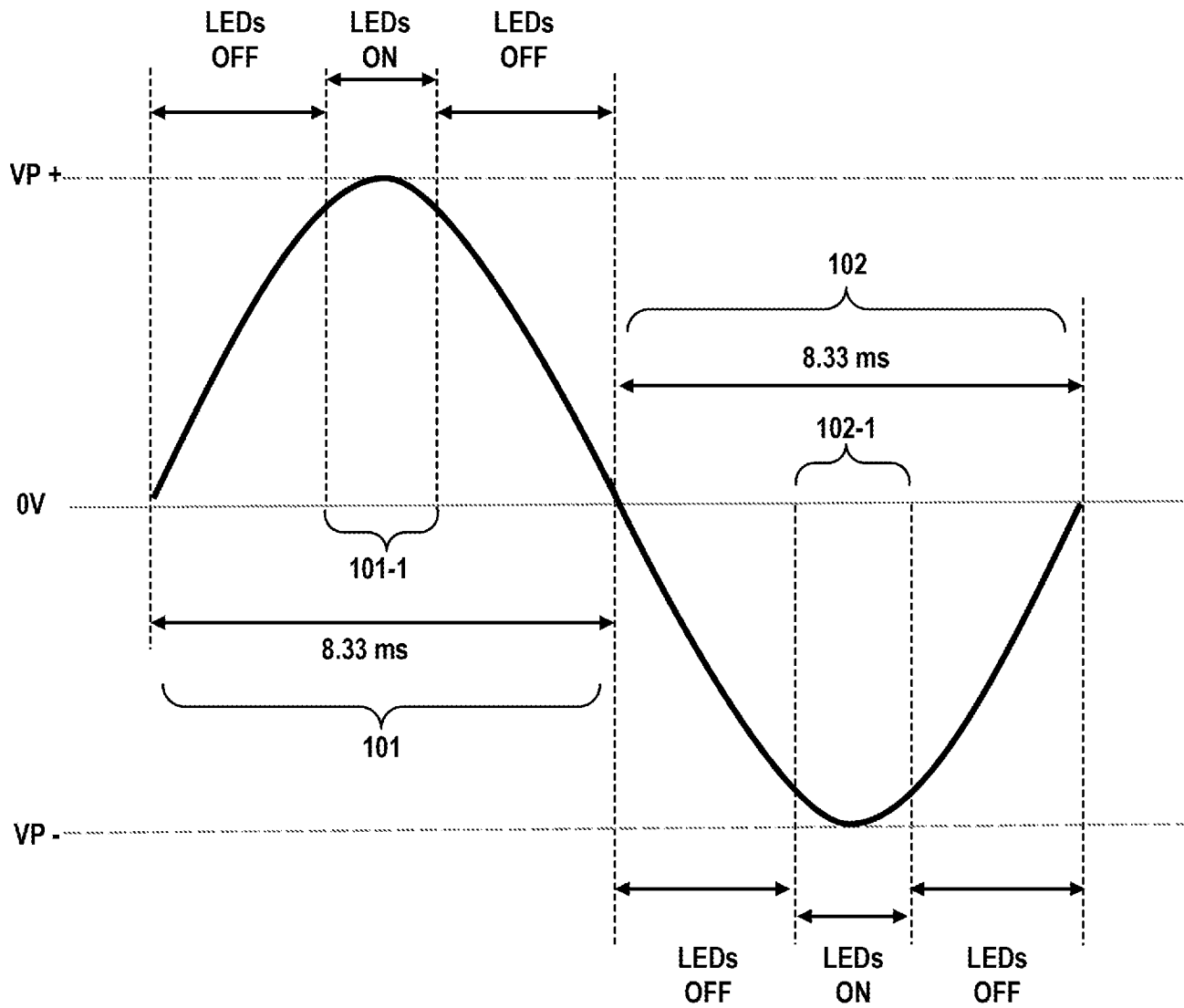
FIG. 1100

FIG. 2A

200

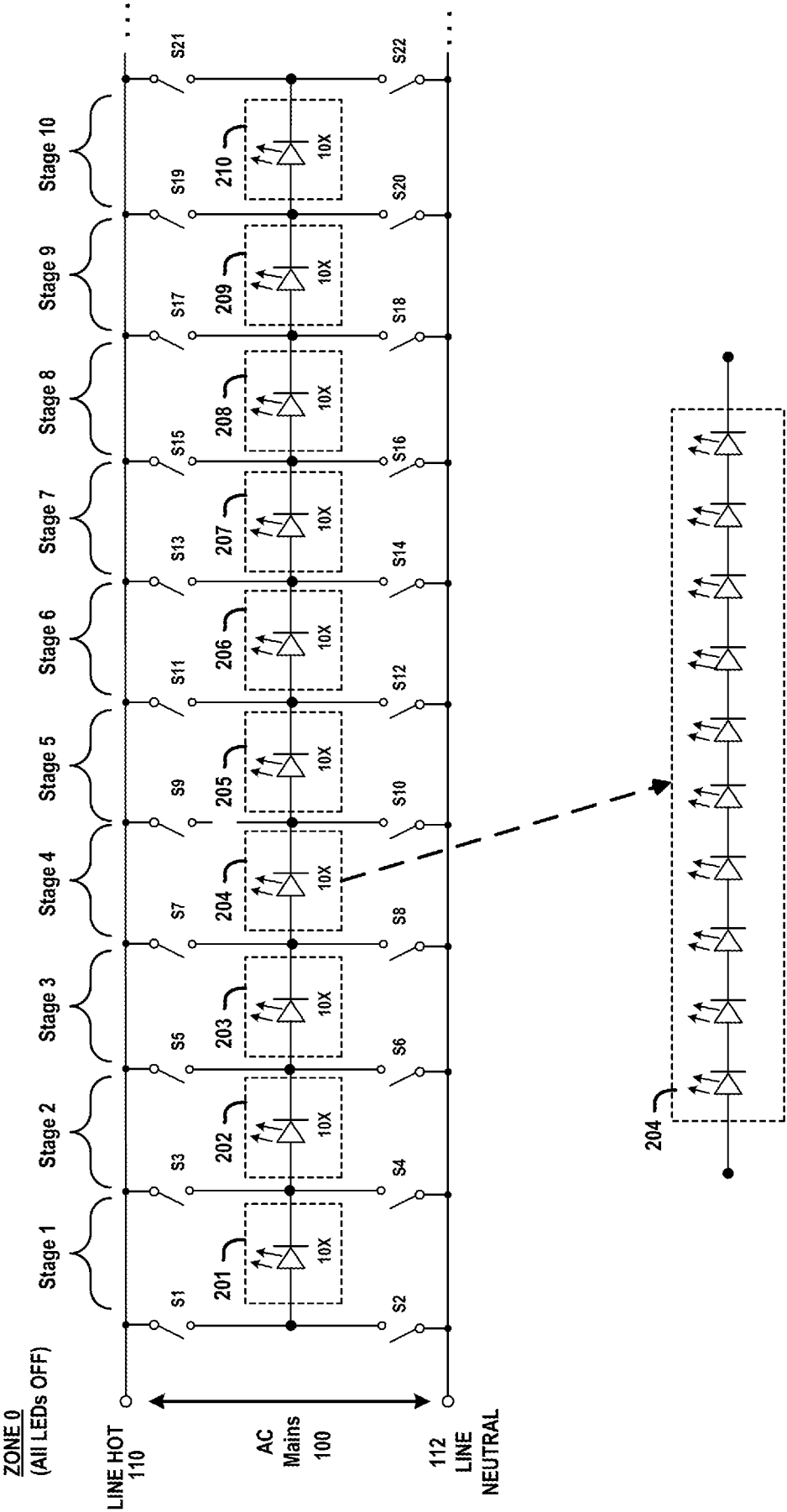


FIG. 2B

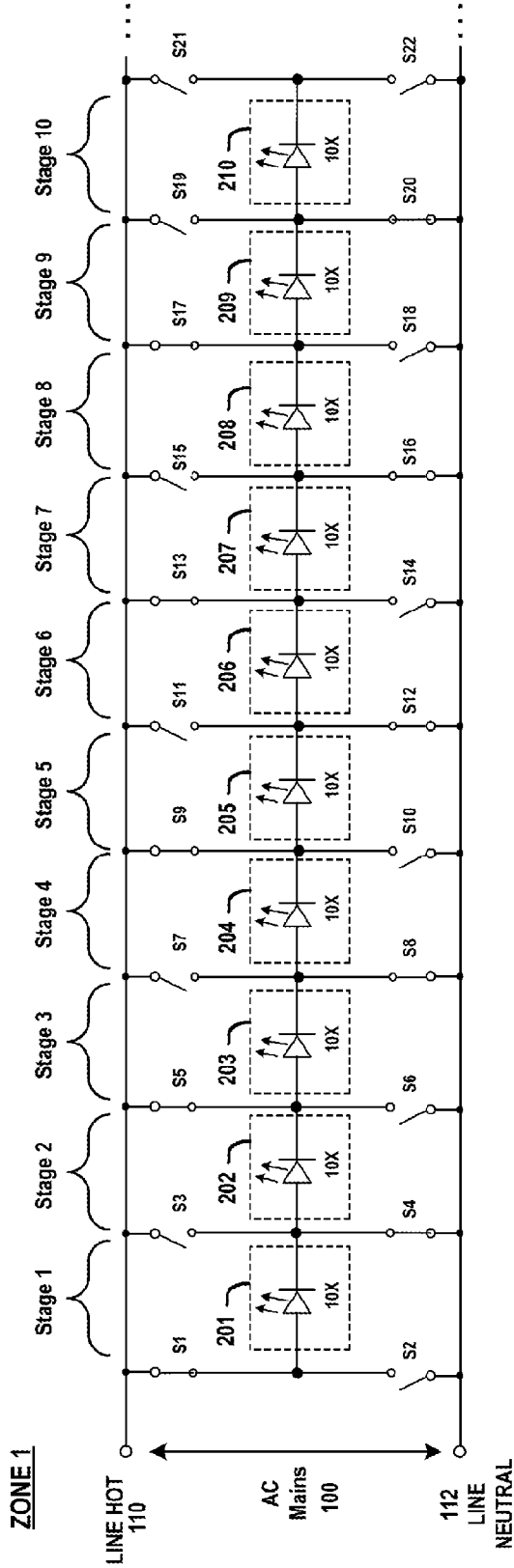


FIG. 2C

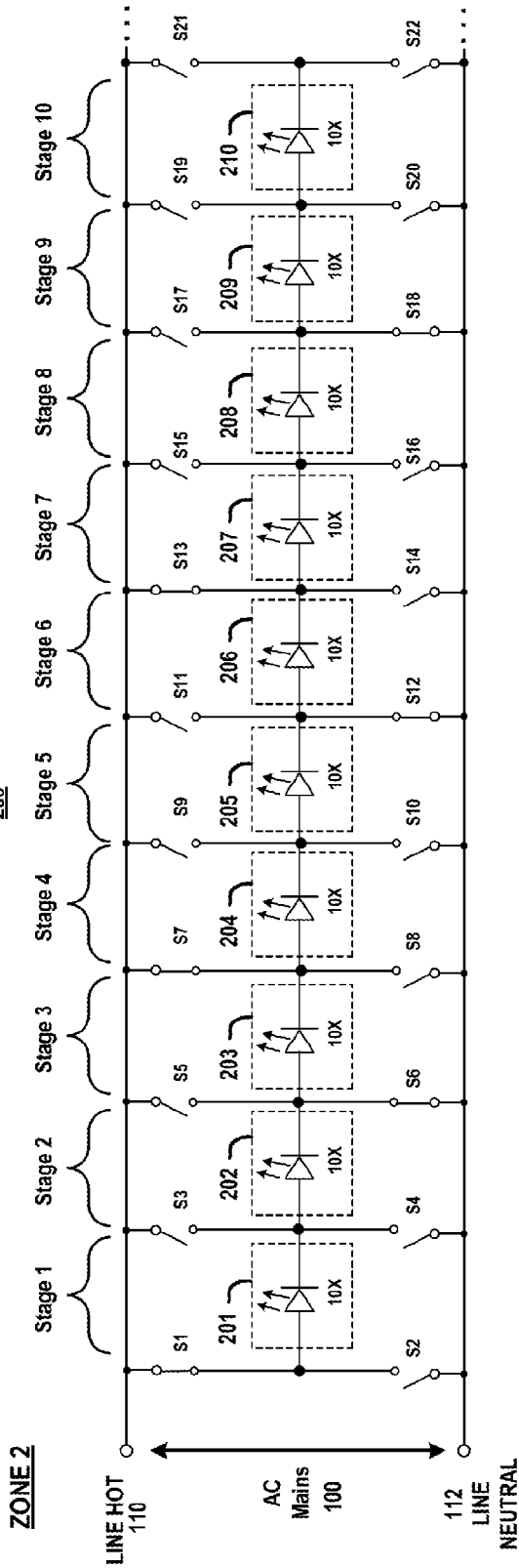
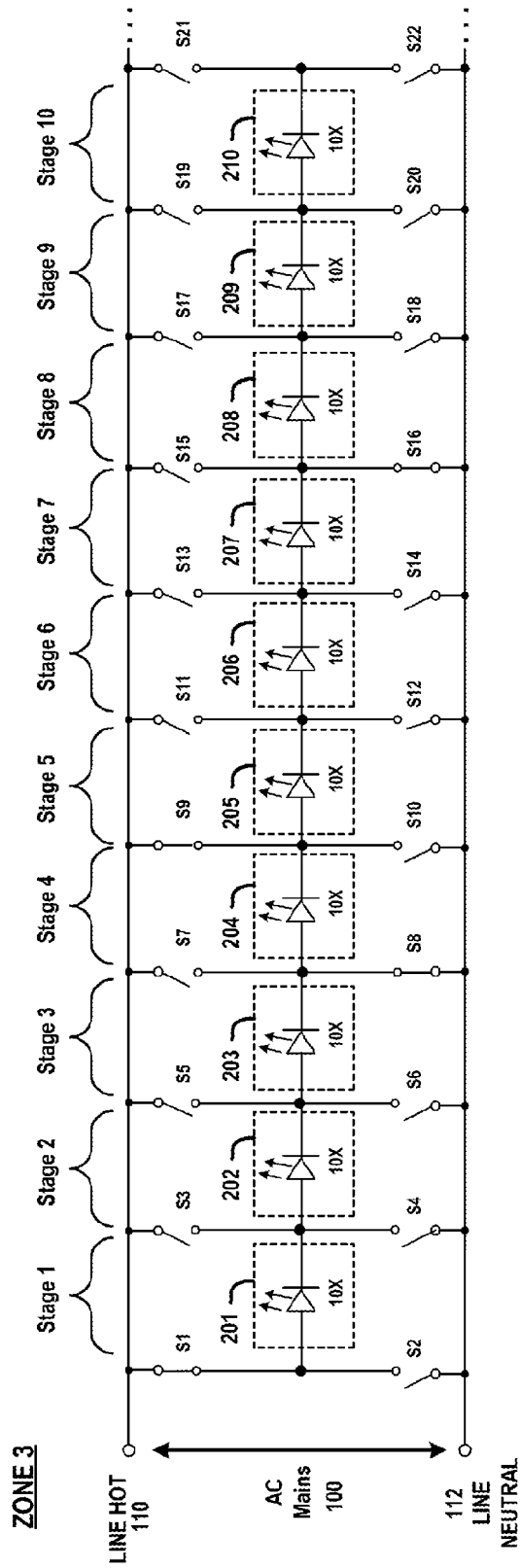


FIG. 2D

200

**FIG. 2E**

200

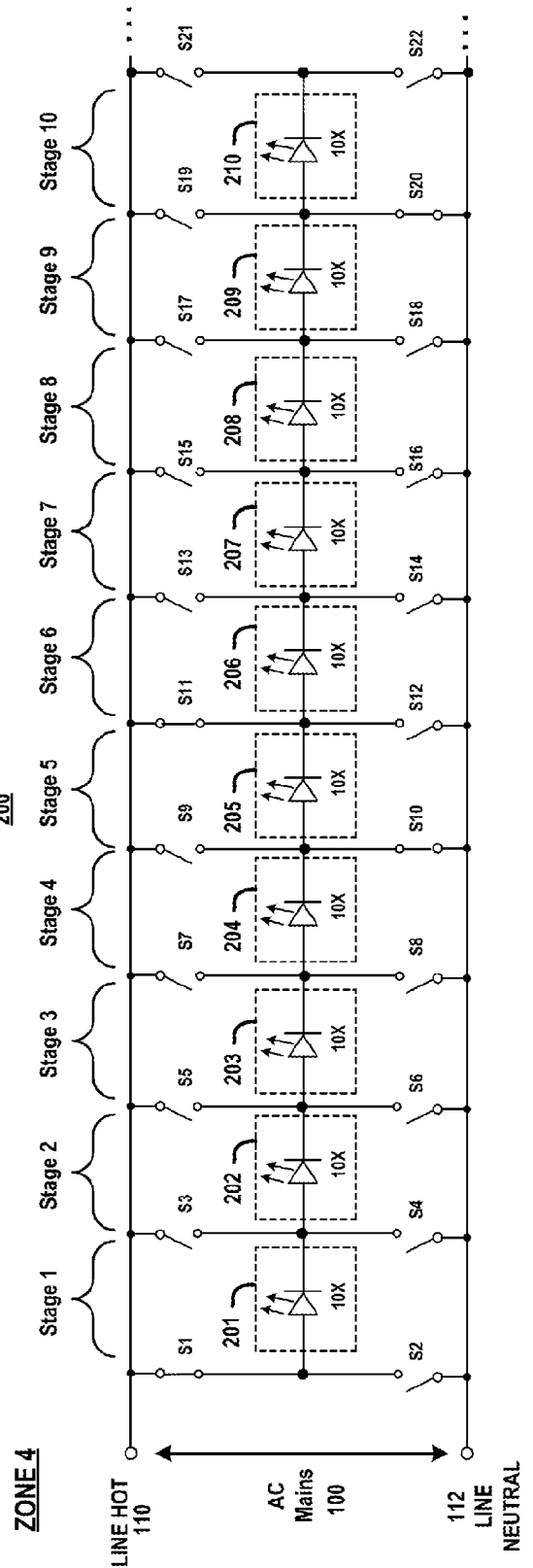


FIG. 2F

200

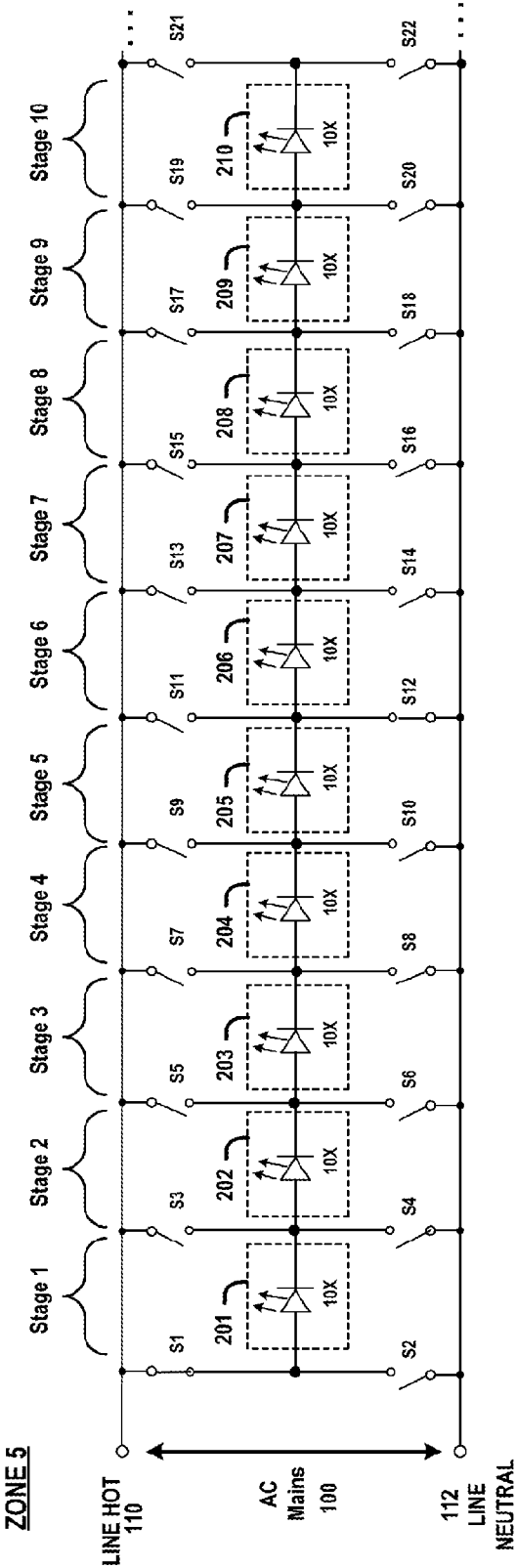


FIG. 2G

200

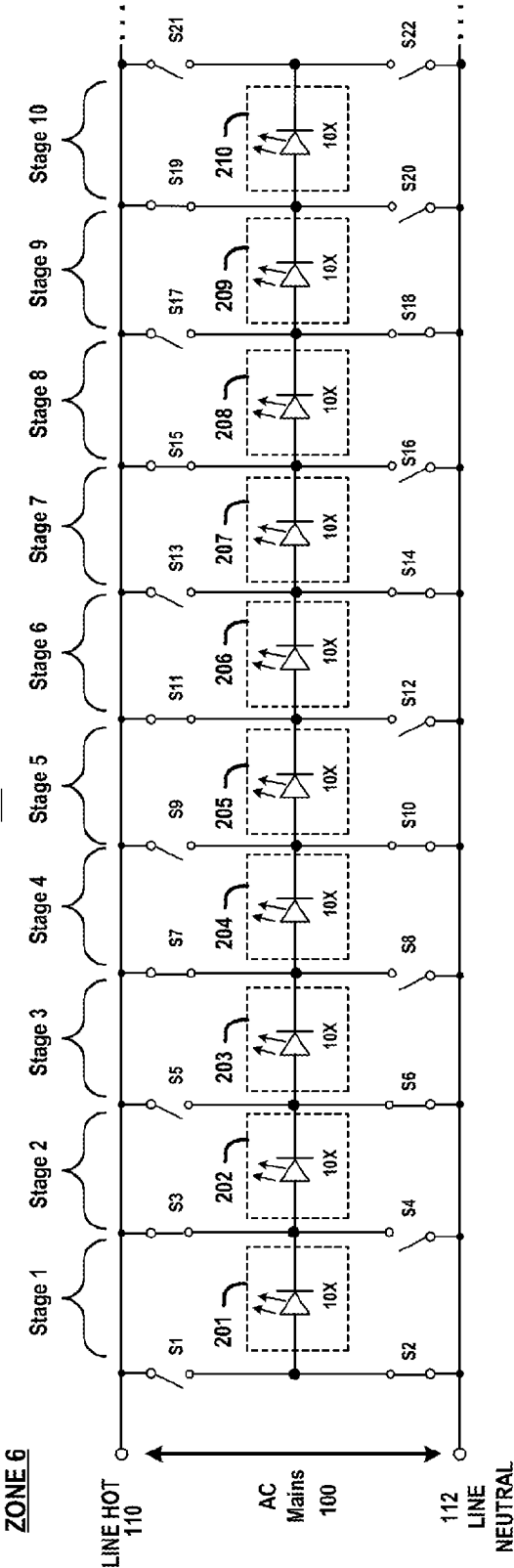


FIG. 2H

200

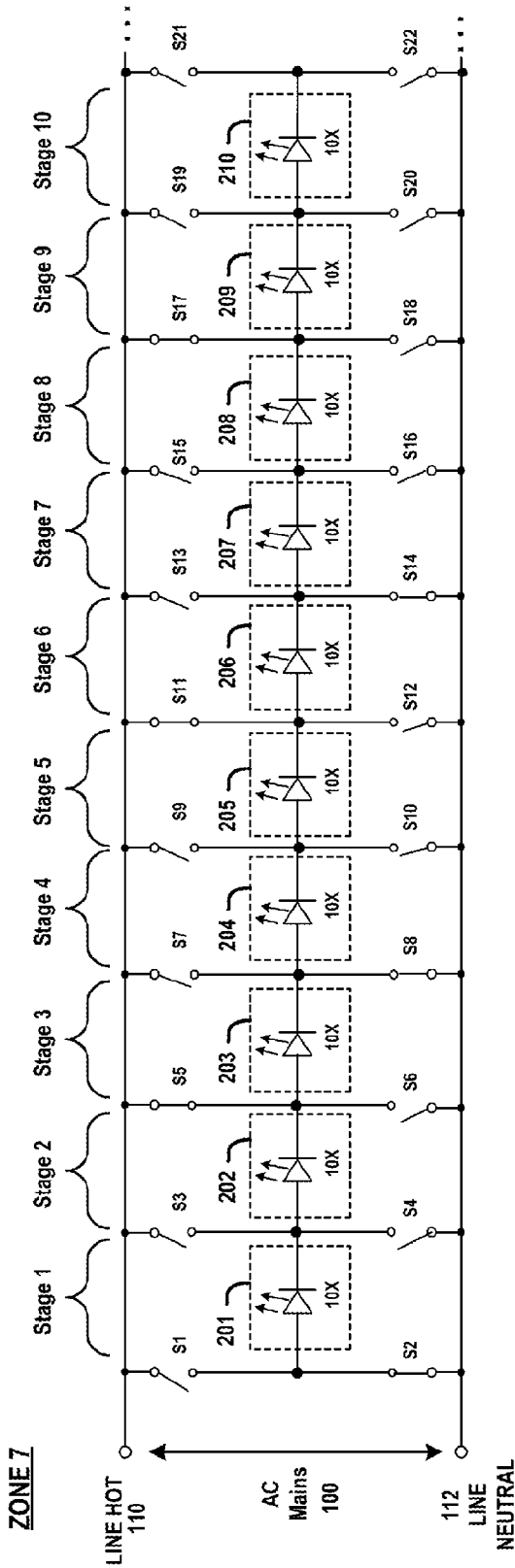


FIG. 2I

200

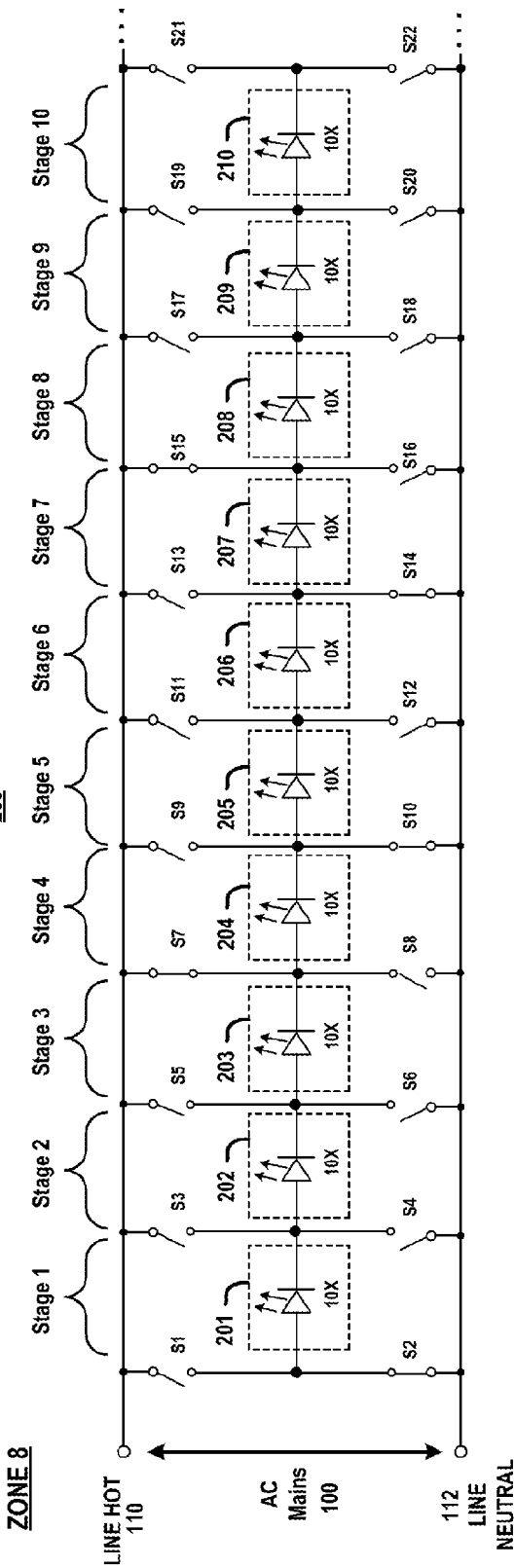


FIG. 2J

200

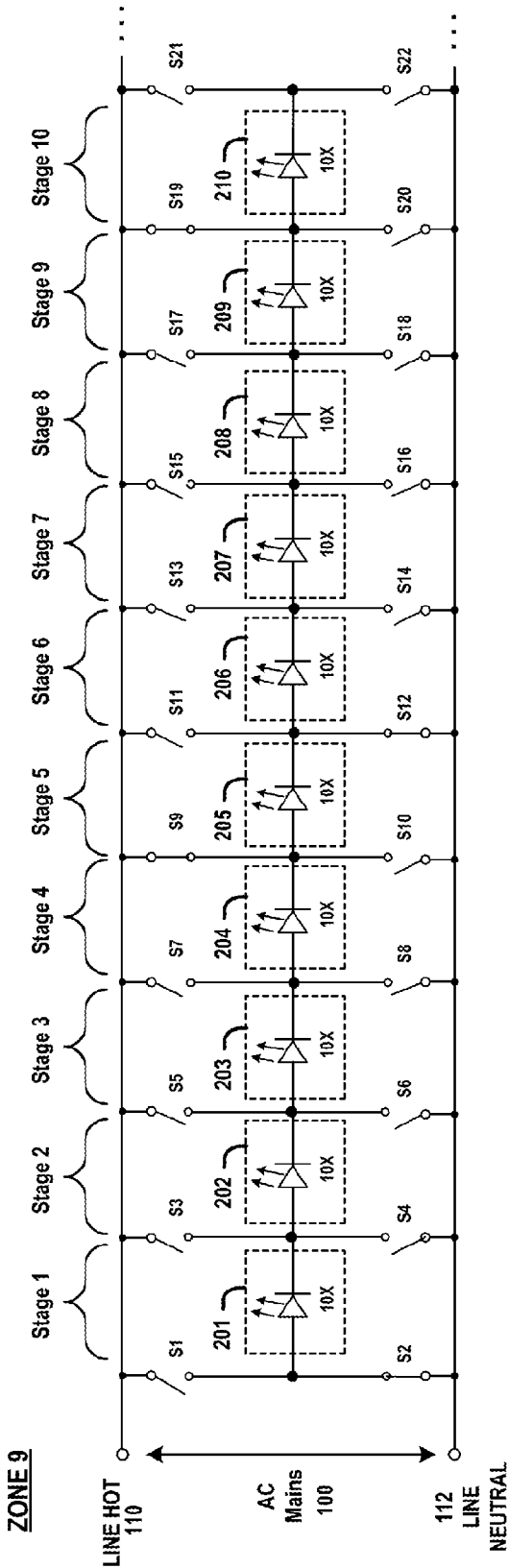


FIG. 2K

200

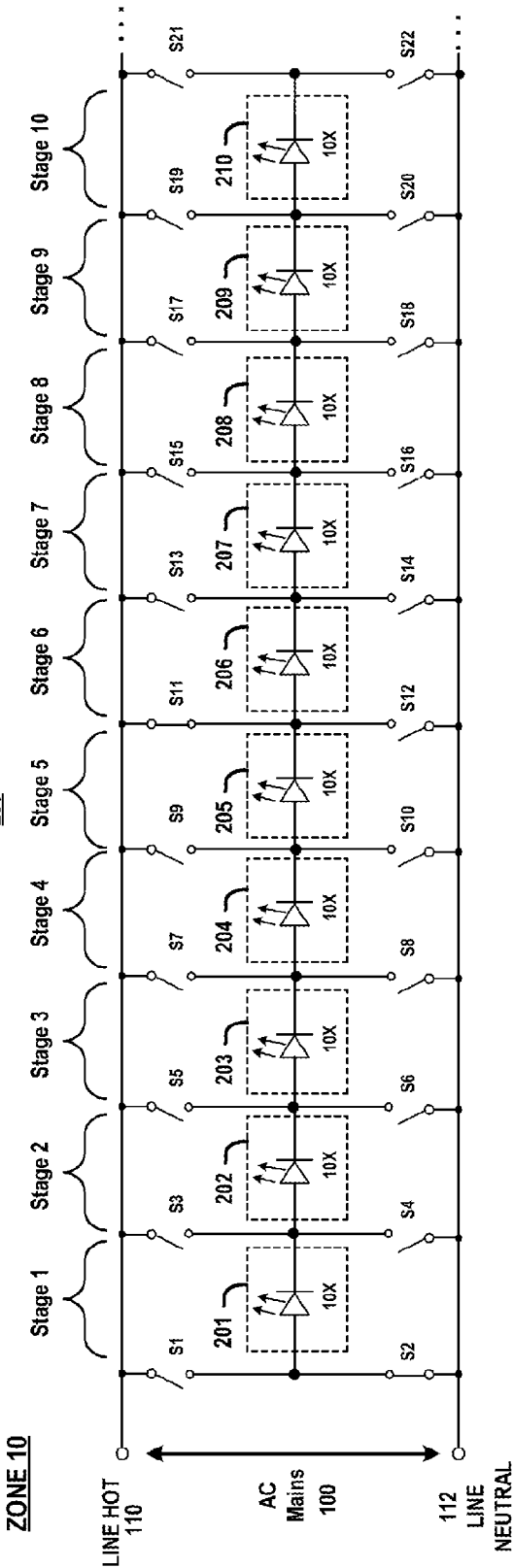


FIG. 3A

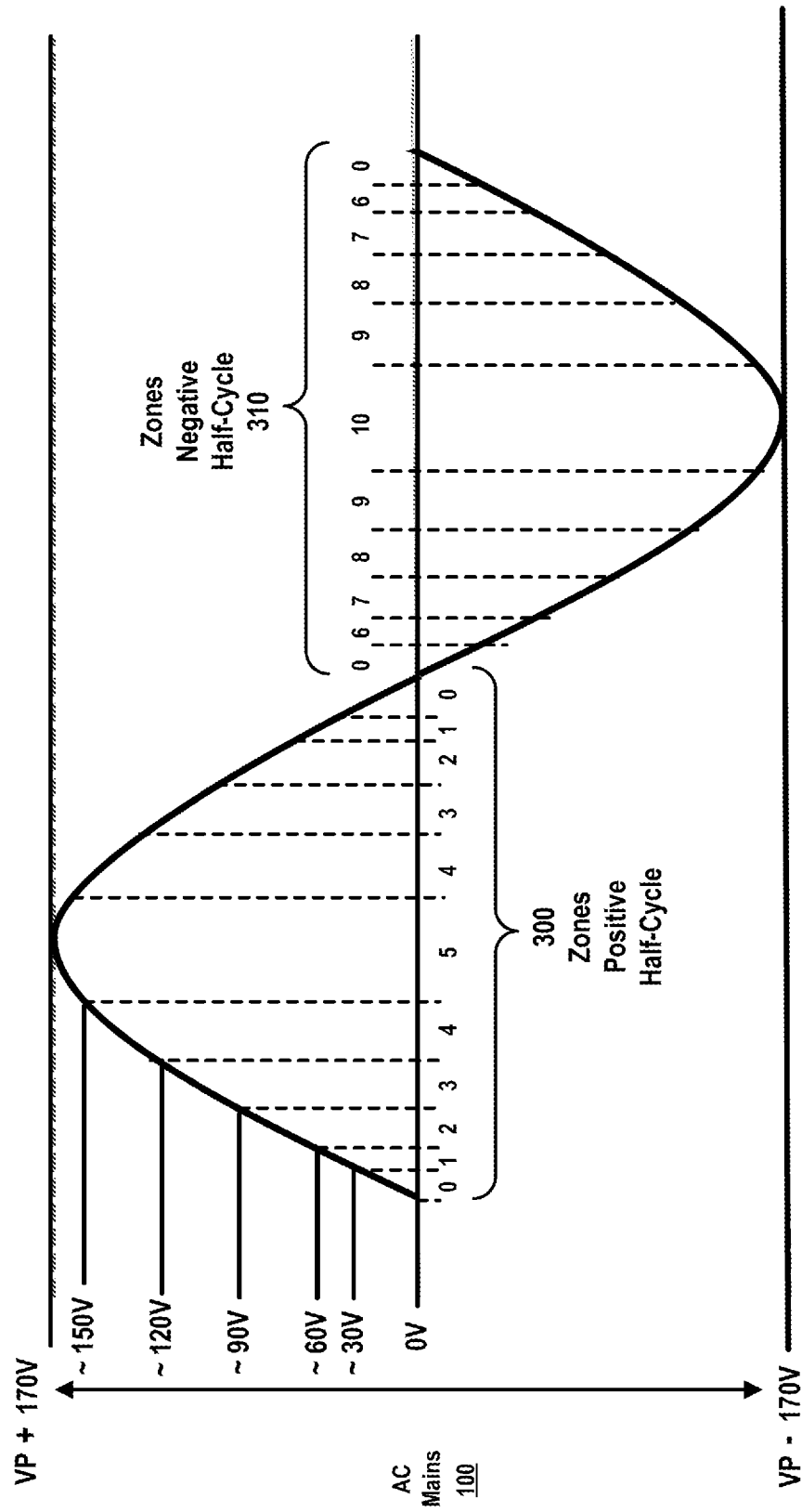


FIG. 3B

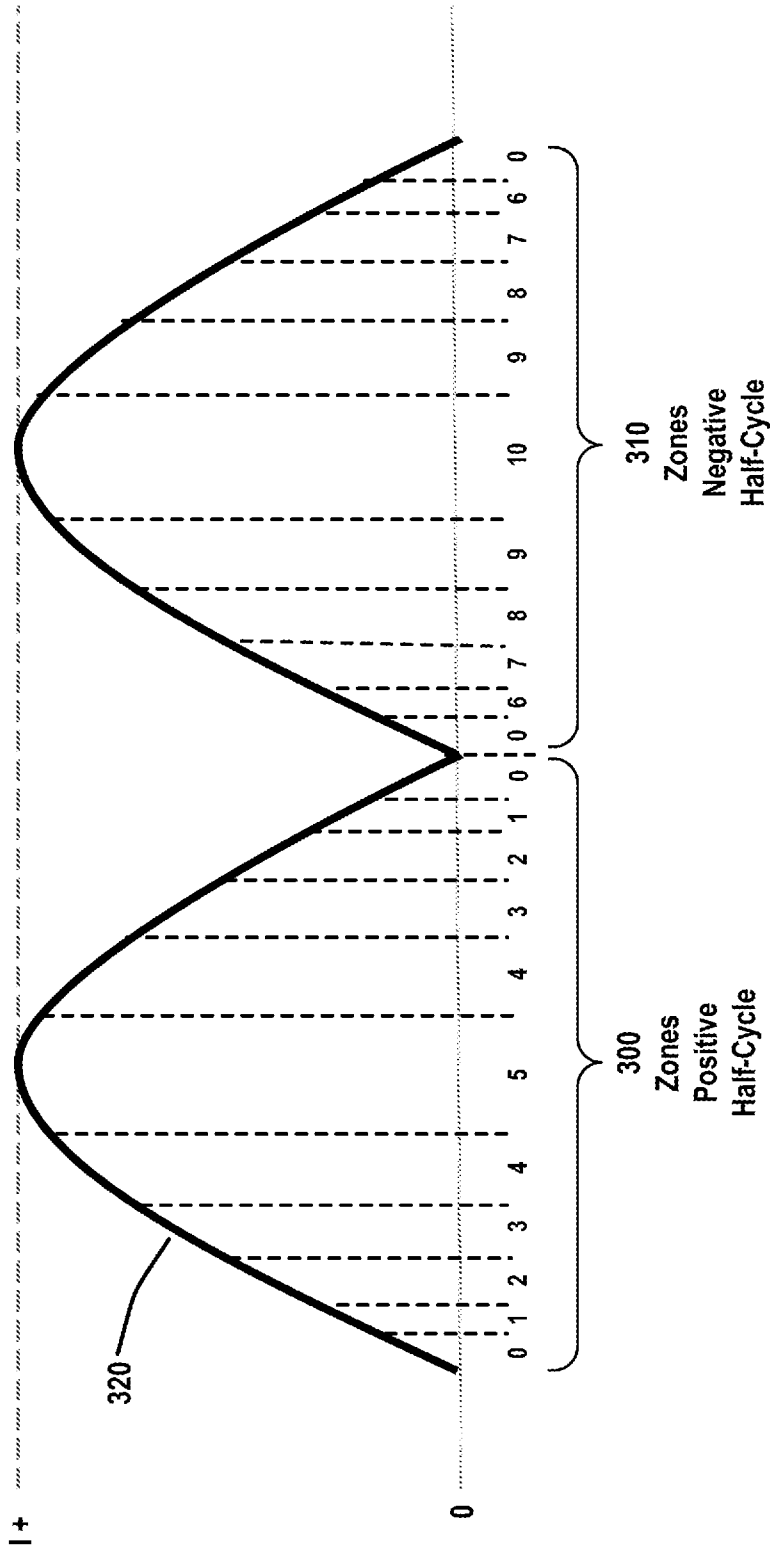


FIG. 3C

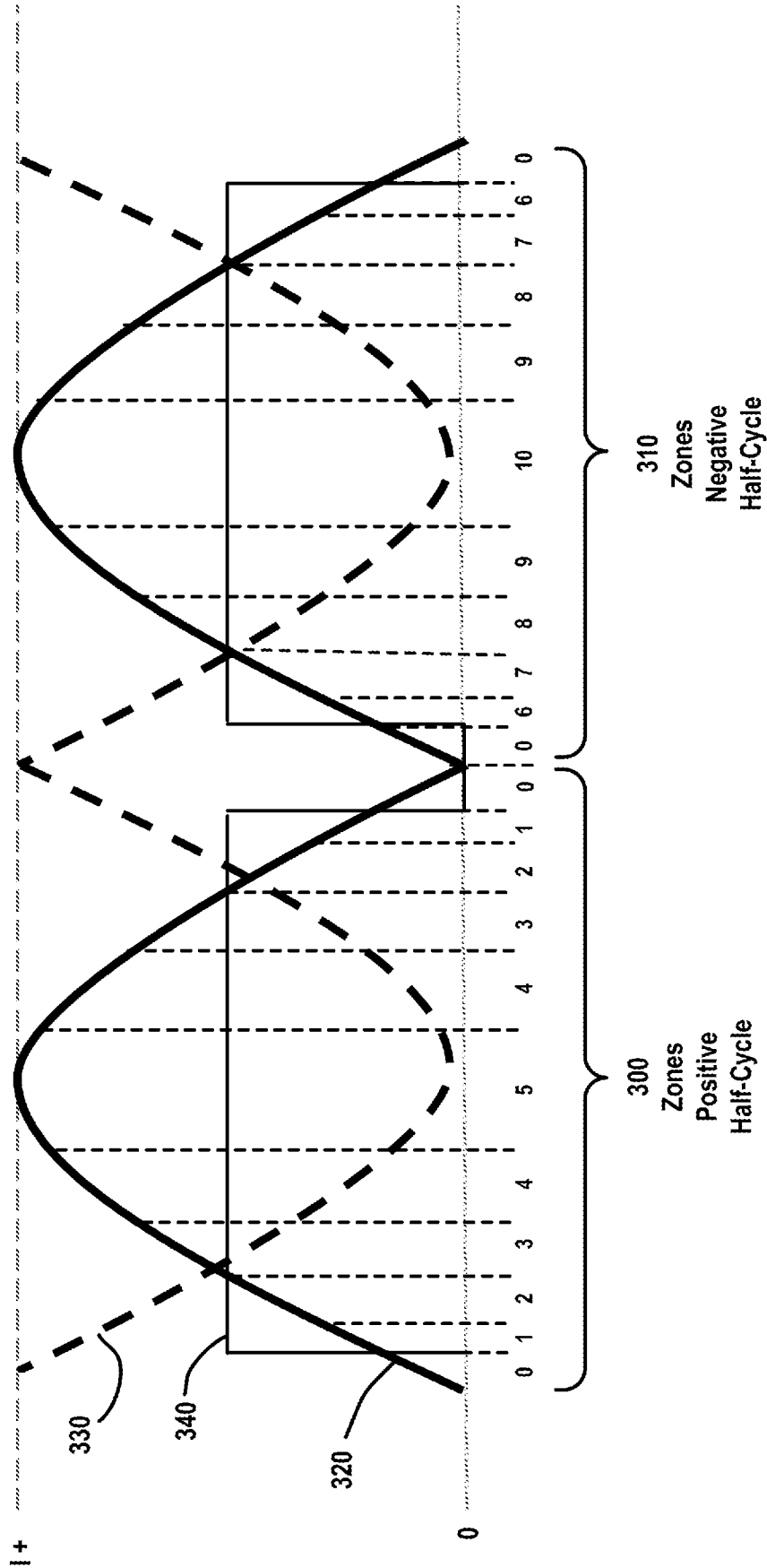


FIG. 4

400

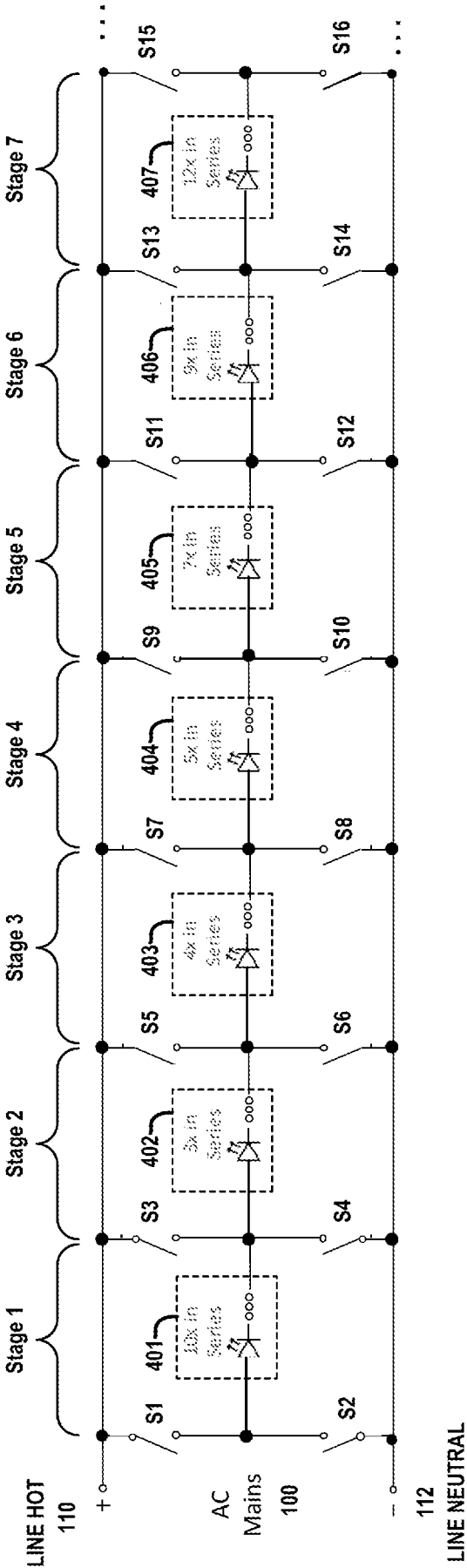


FIG. 5A

SWITCH		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14
S1		ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
S2									ON	ON	ON	ON	ON	ON	ON
S3									ON	ON	ON	ON	ON	ON	ON
S4		ON													
S5									ON						
S6			ON												
S7									ON						
S8				ON								ON			
S9										ON					
S10					ON								ON		
S11														ON	
S12						ON									
S13														ON	
S14							ON								
S15															ON
S16								ON							
Total LEDs ON		10	13	17	22	29	38	50	10	13	17	22	29	38	50
Min ON Voltage		28	36.4	47.6	61.6	81.2	106.4	140	28	36.4	47.6	61.6	81.2	106.4	140
Max OFF Voltage		42	54.6	71.4	92.4	121.8	159.6	210	42	54.6	71.4	92.4	121.8	159.6	210

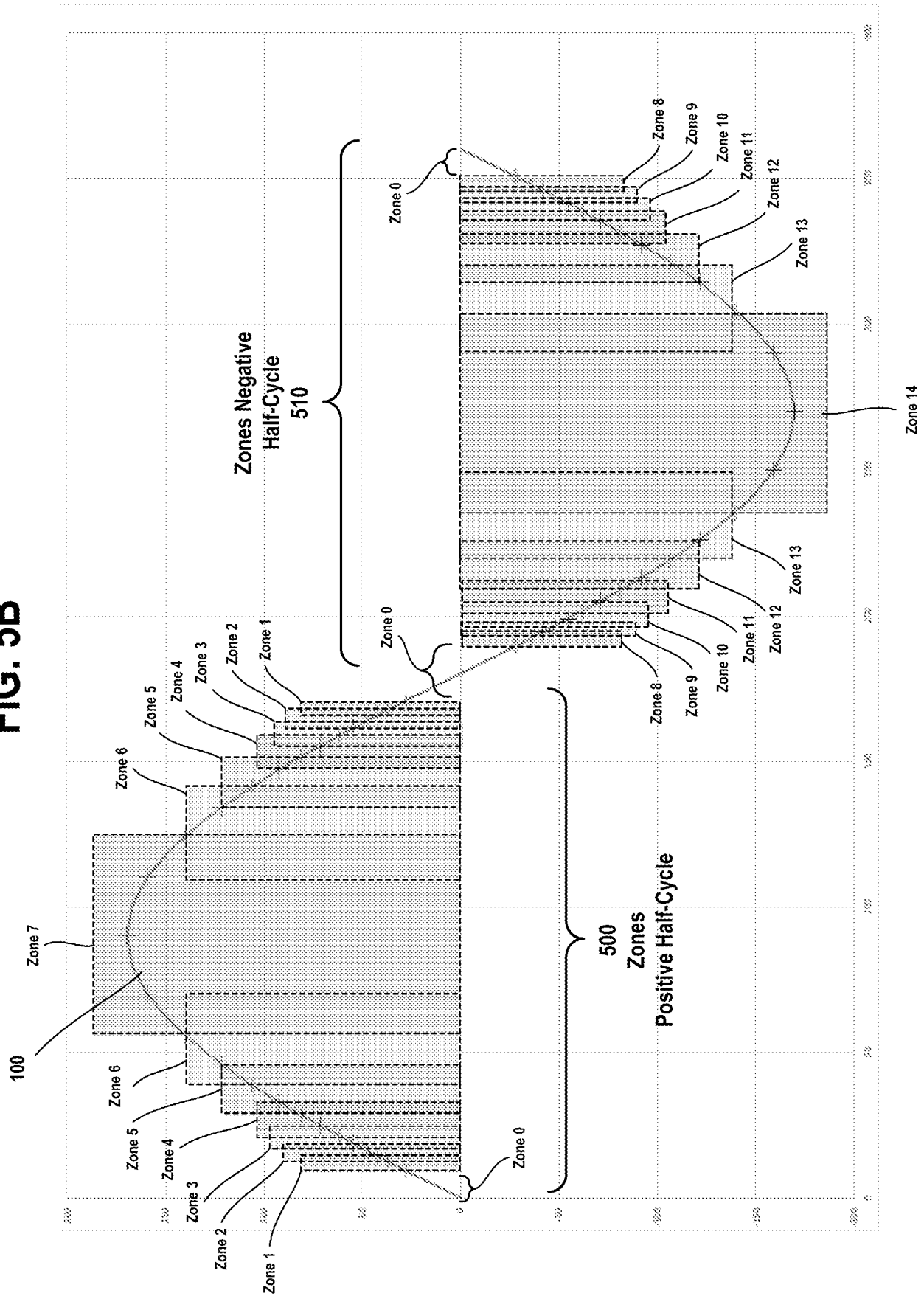
FIG. 5B

FIG. 6

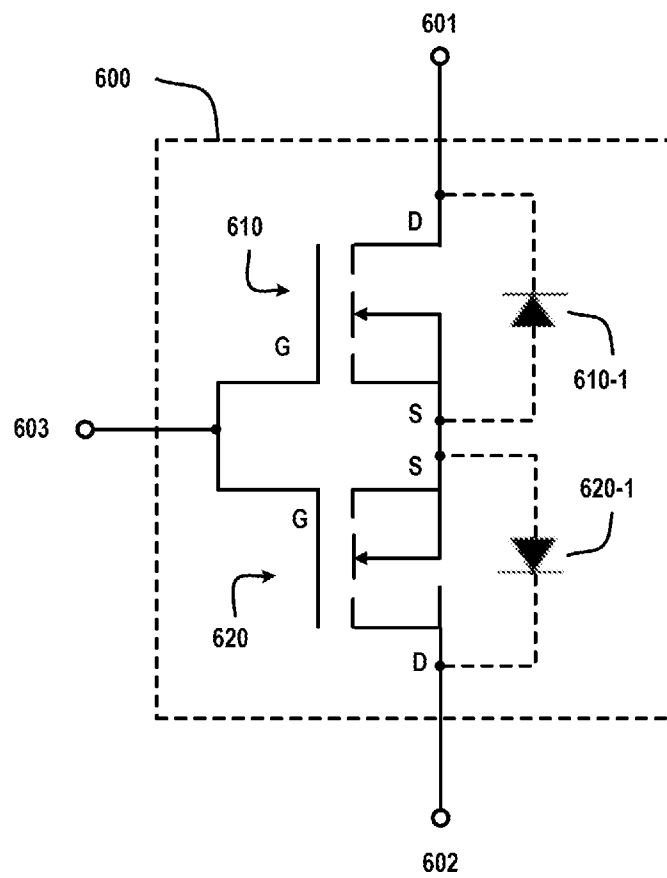


FIG. 7

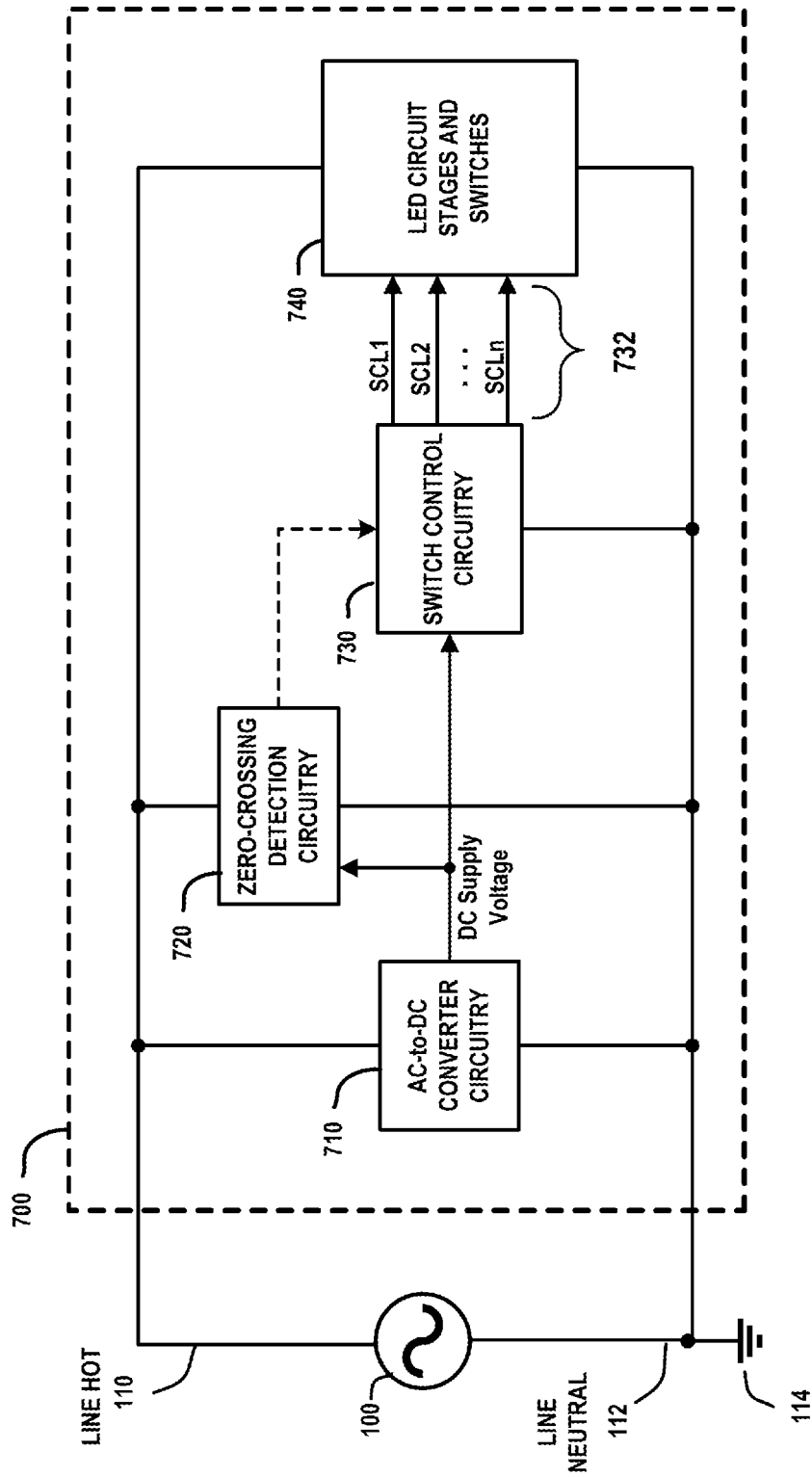
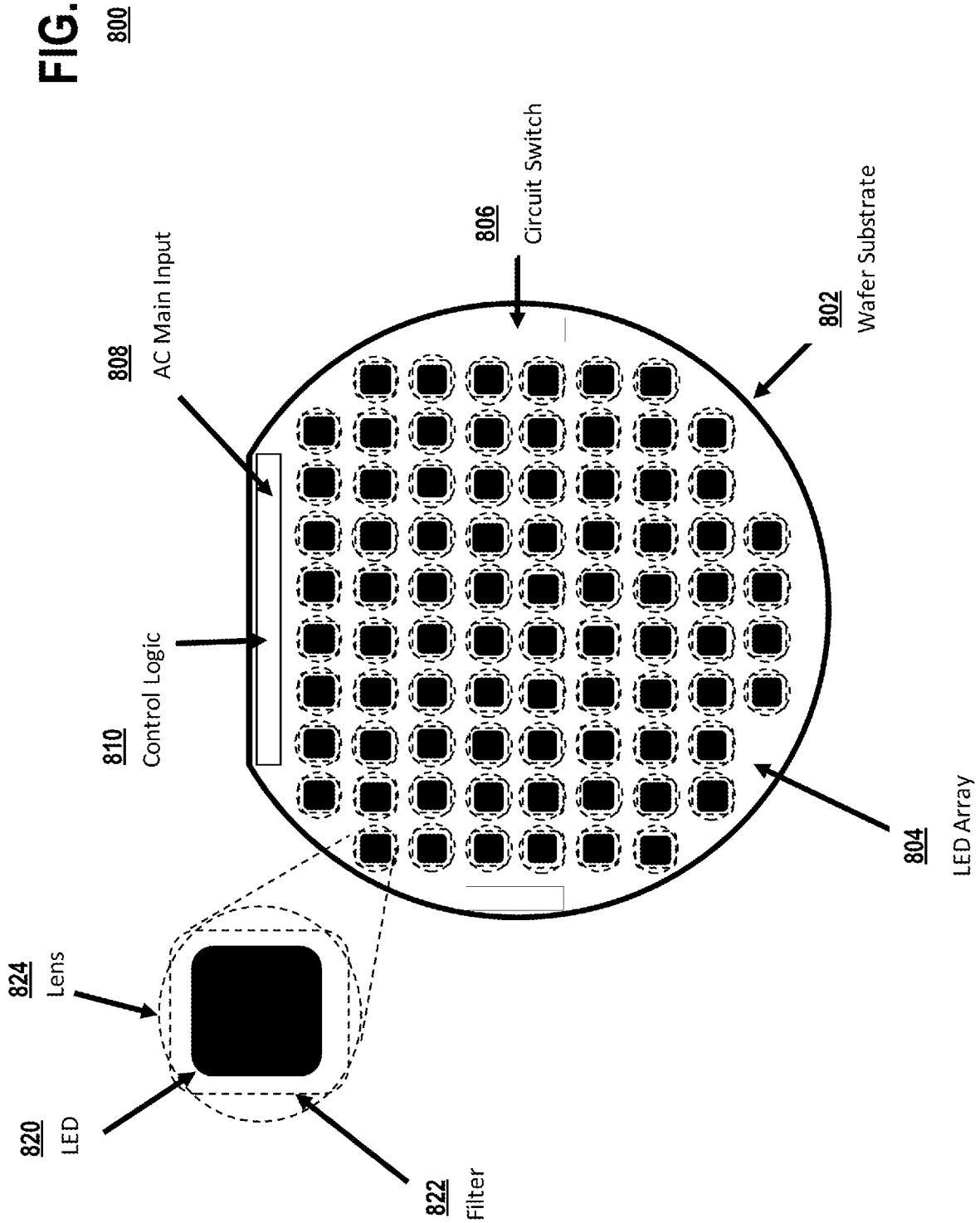


FIG. 8

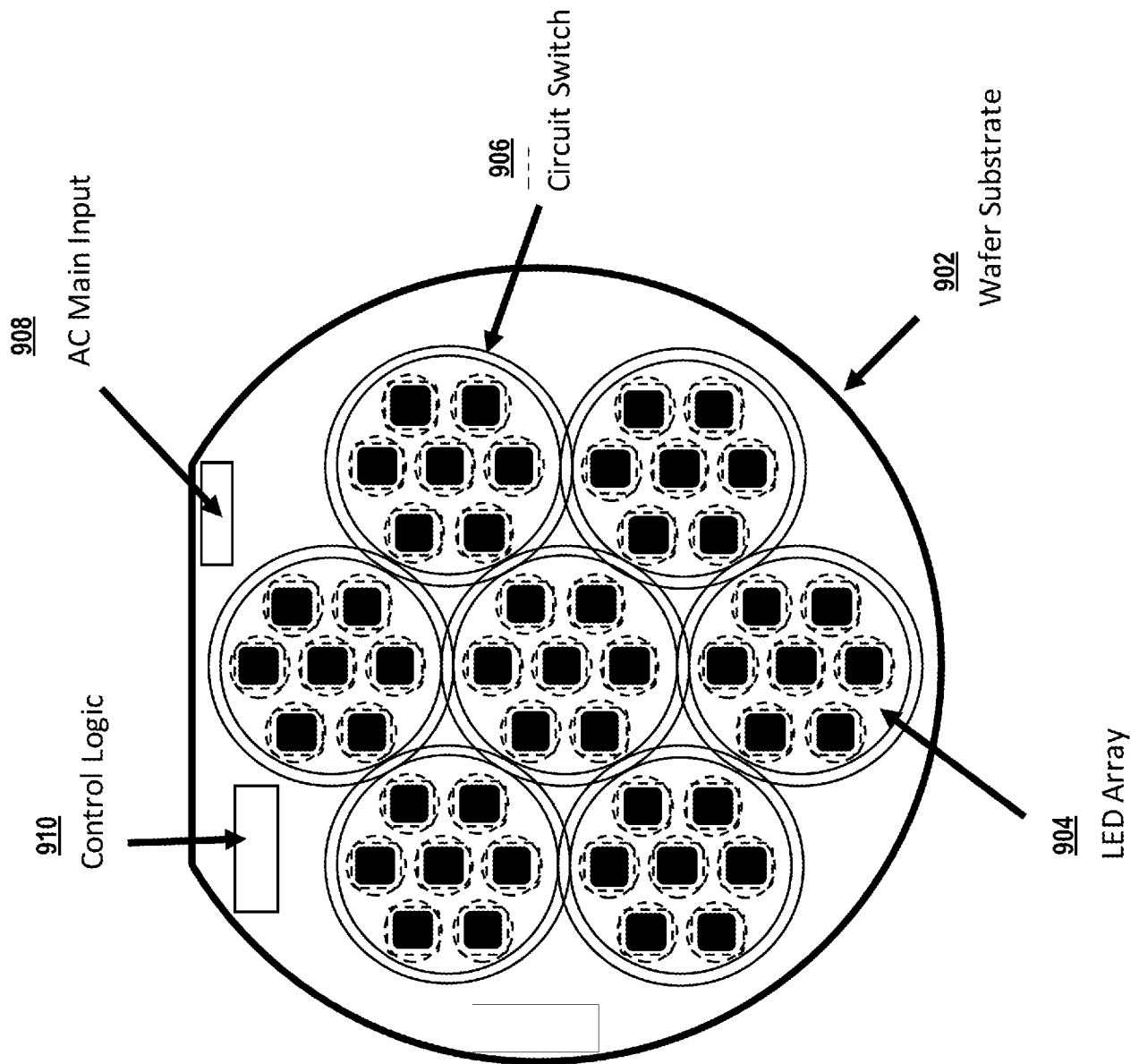
**FIG. 9**900

FIG. 7

