US 20200053269A1

(19) **United States**

(12) **Patent Application Publication**

Dorai et al.

(10) **Pub. No.: US 2020/0053269 A1**

(43) **Pub. Date: Feb. 13, 2020**

(54) **ELECTRONIC DEVICE WITH ADJUSTABLE ILLUMINATION**

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(21) Appl. No.: **16/552,748**

(22) Filed: **Aug. 27, 2019**

Related U.S. Application Data

(63) Continuation of application No. 16/268,396, filed on Feb. 5, 2019, now Pat. No. 10,397,490, which is a continuation of application No. 15/863,567, filed on Jan. 5, 2018, now Pat. No. 10,218,916, which is a continuation of application No. 15/403,132, filed on Jan. 10, 2017, now Pat. No. 9,866,760, which is a continuation of application No. 14/723,276, filed on May 27, 2015, now Pat. No. 9,544,485.

Publication Classification

(51) **Int. Cl.**

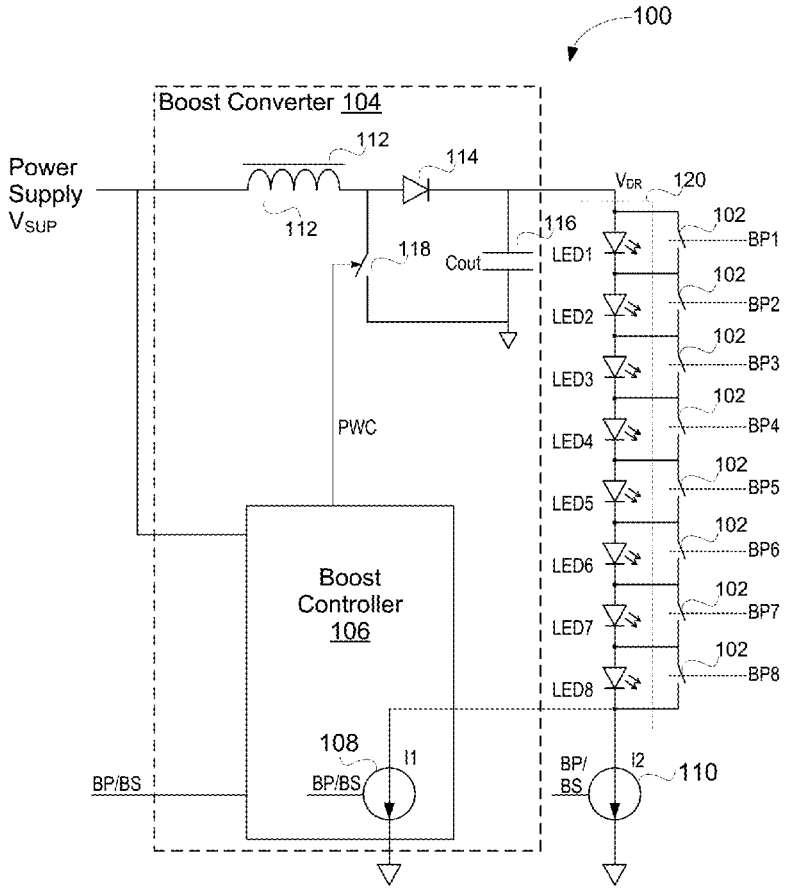
H04N 5/235	(2006.01)
H05B 33/08	(2006.01)
H04N 5/33	(2006.01)
H04N 5/232	(2006.01)
G03B 15/05	(2006.01)
H04N 5/225	(2006.01)

(52) **U.S. Cl.**

CPC ***H04N 5/2354*** (2013.01); ***H05B 33/0818*** (2013.01); ***H04N 5/33*** (2013.01); ***H04N 5/23245*** (2013.01); ***H05B 33/0809*** (2013.01); ***G03B 15/05*** (2013.01); ***H04N 5/2256*** (2013.01); ***H05B 33/0845*** (2013.01); ***H05B 33/083*** (2013.01)

(57) **ABSTRACT**

This application discloses an electronic device (e.g., a camera) that a plurality of light sources and a light source driver. The light sources are configurable to a plurality of light source subsets to illuminate a field of view. At least two of the light source subsets include distinct light source members and are configured to illuminate different regions of the field of view. The light source driver is coupled to the plurality of light sources and configured to drive the plurality of light source subsets. In some embodiments, the electronic device includes or is coupled to a camera module configured to capture visual data of the field of view, and the plurality of light sources is configured to provide illumination for the camera module.



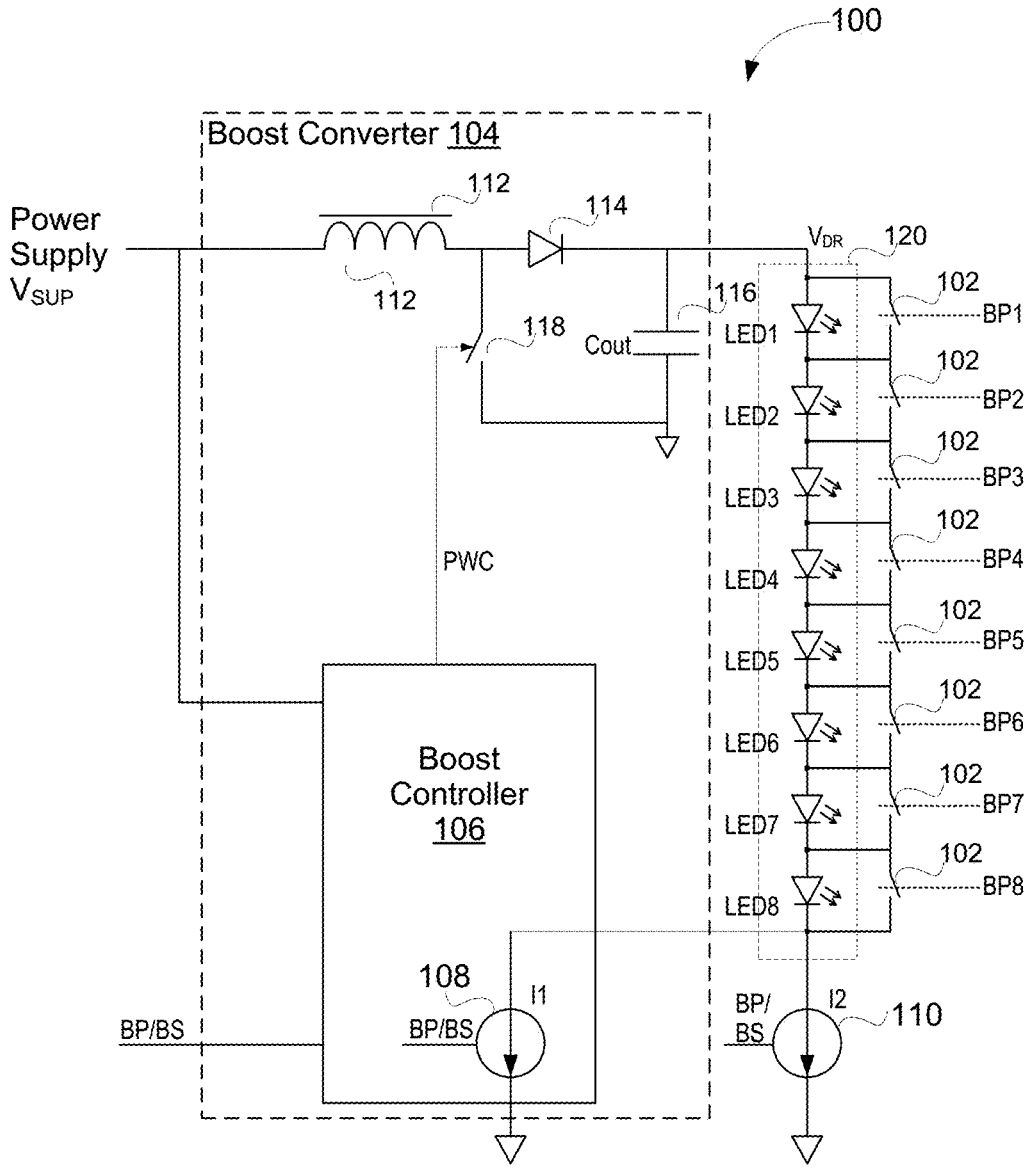

100
Boost Converter 104
112
114
Power Supply V_{SUP}
112
V_{DR}
120
116
118
Cout
LED1
LED2
LED3
LED4
LED5
LED6
LED7
LED8
102
BP1
BP2
BP3
BP4
BP5
BP6
BP7
BP8
PWC
Boost Controller 106
108
I1
BP/BS
BP/BS
BP/BS
I2
110

Figure 1

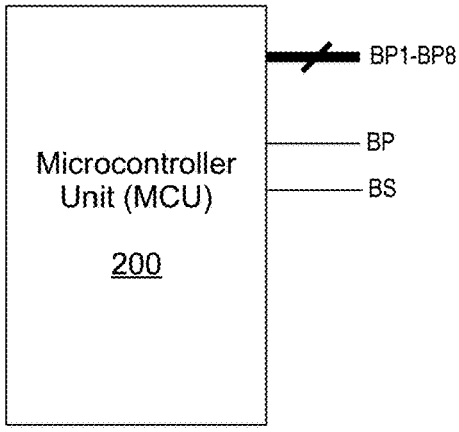


Figure 2A

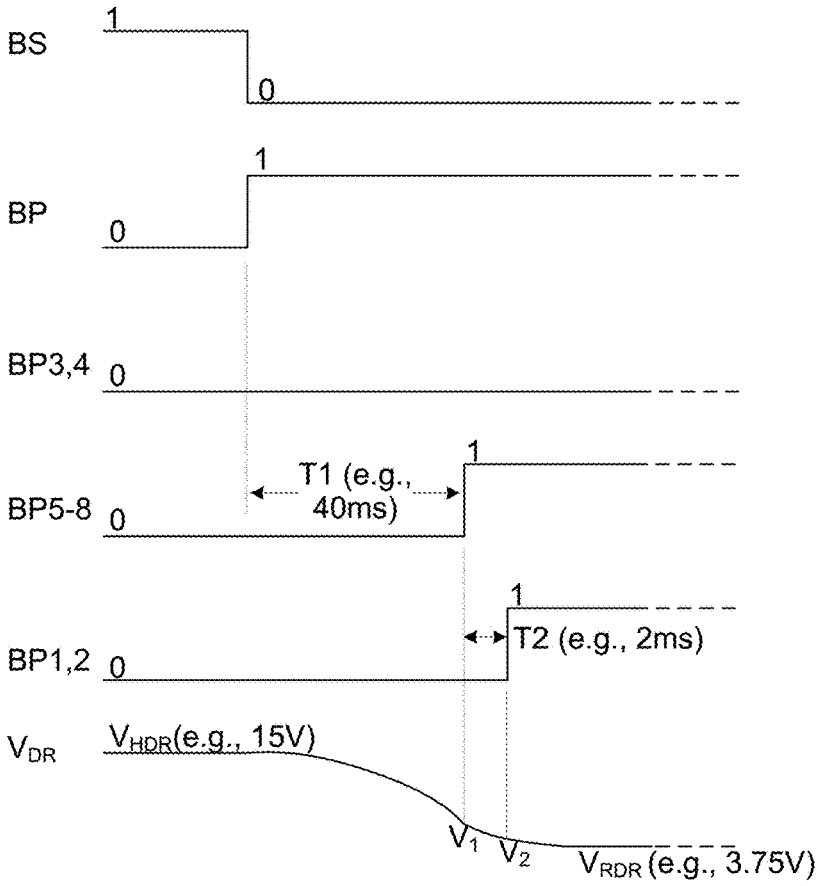


Figure 2B

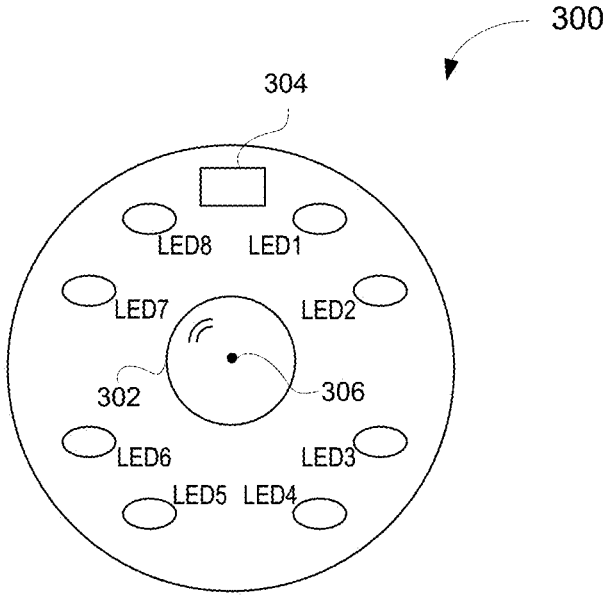


Figure 3A

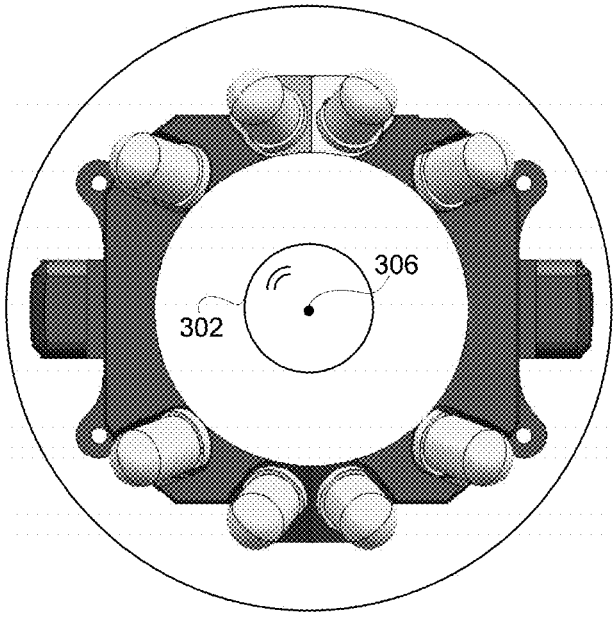


Figure 3B

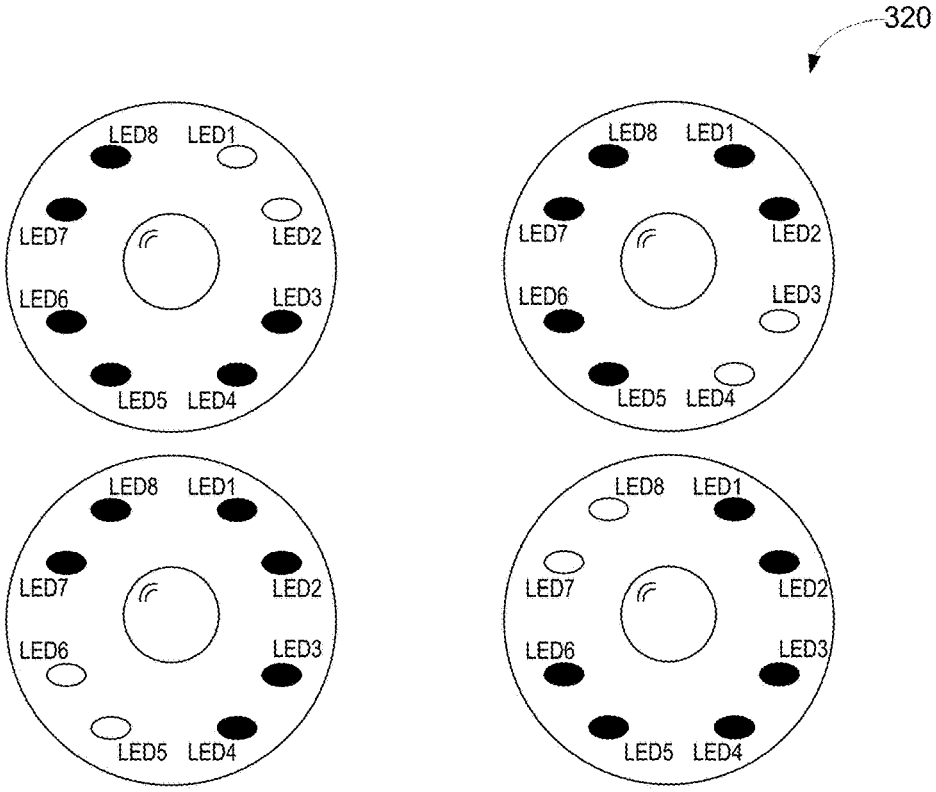


Figure 3C

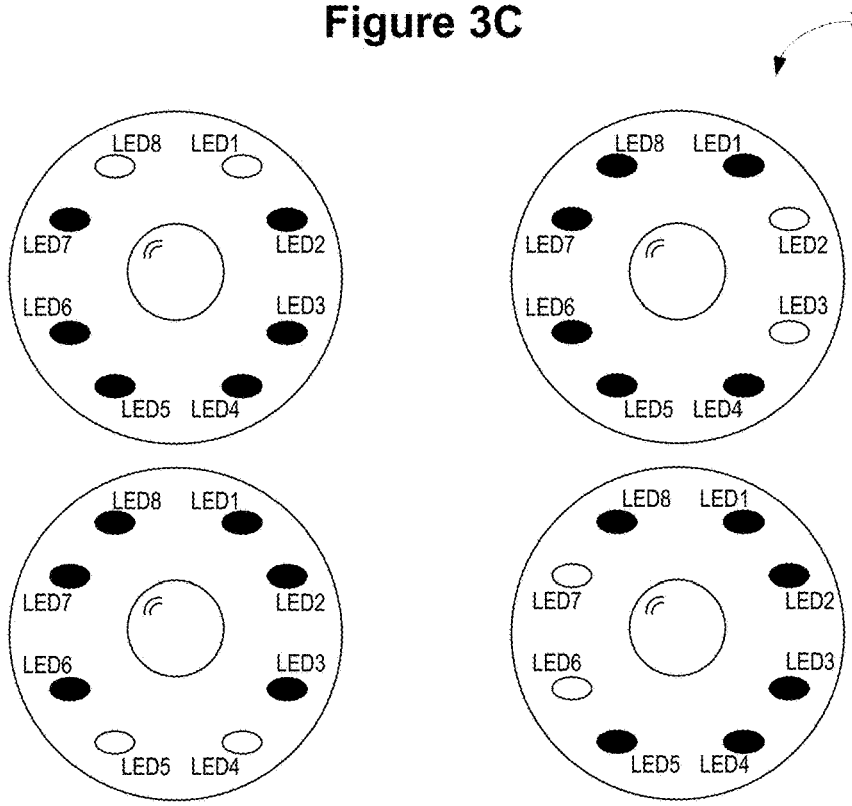


Figure 3D

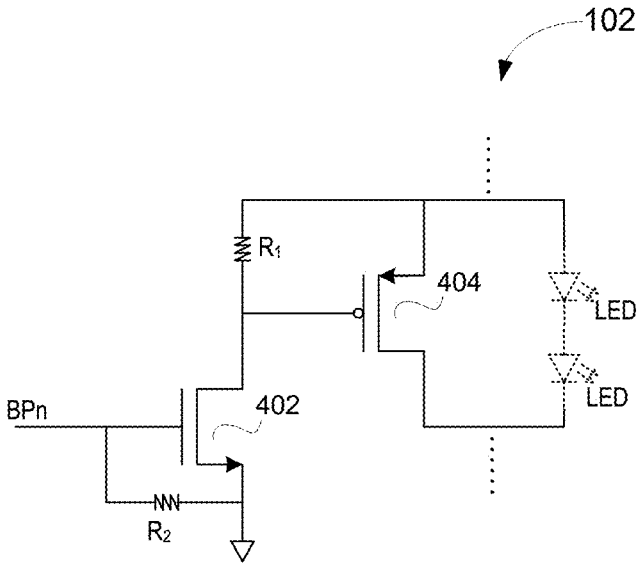


Figure 4

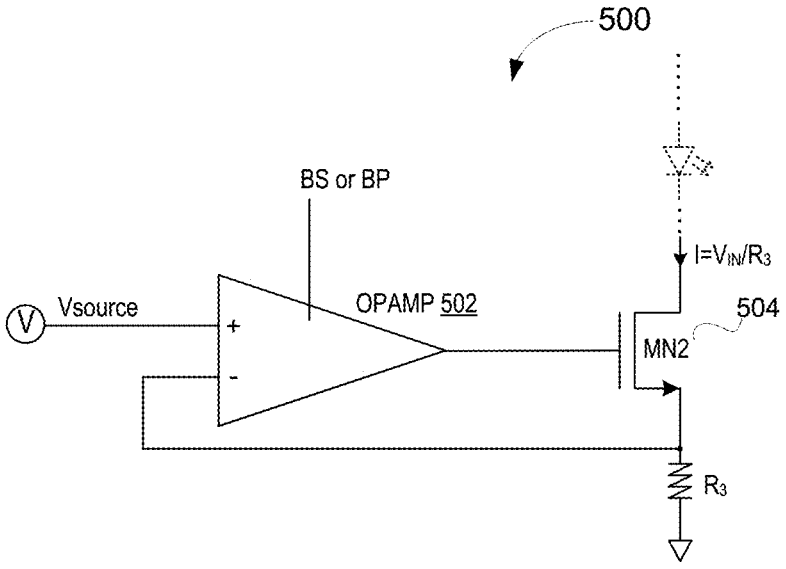


Figure 5

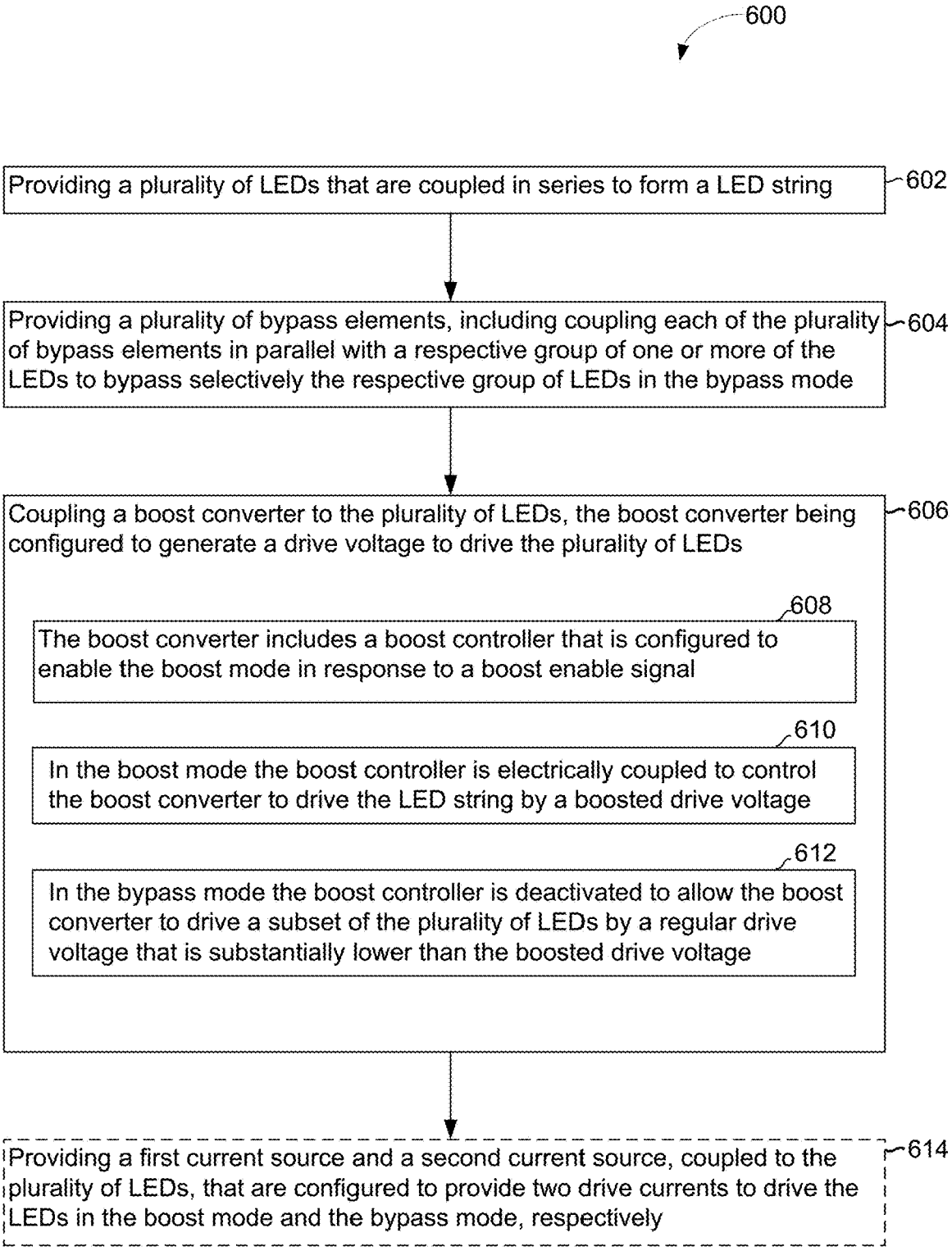

600
Providing a plurality of LEDs that are coupled in series to form a LED string
602
Providing a plurality of bypass elements, including coupling each of the plurality of bypass elements in parallel with a respective group of one or more of the LEDs to bypass selectively the respective group of LEDs in the bypass mode
604
Coupling a boost converter to the plurality of LEDs, the boost converter being configured to generate a drive voltage to drive the plurality of LEDs
606
608
The boost converter includes a boost controller that is configured to enable the boost mode in response to a boost enable signal
610
In the boost mode the boost controller is electrically coupled to control the boost converter to drive the LED string by a boosted drive voltage
612
In the bypass mode the boost controller is deactivated to allow the boost converter to drive a subset of the plurality of LEDs by a regular drive voltage that is substantially lower than the boosted drive voltage
Providing a first current source and a second current source, coupled to the plurality of LEDs, that are configured to provide two drive currents to drive the LEDs in the boost mode and the bypass mode, respectively
614

Figure 6

ELECTRONIC DEVICE WITH ADJUSTABLE ILLUMINATION

RELATED APPLICATIONS

[0001] This application is a continuation of and claims priority to U.S. patent application Ser. No. 16/268,396, filed Feb. 5, 2019, titled "Camera Illumination," which is a continuation of U.S. patent application Ser. No. 15/863,567, filed Jan. 5, 2018, titled "Camera with LED Illumination," now U.S. Pat. No. 10,218,916, issued on Feb. 26, 2019, which is a continuation of U.S. patent application Ser. No. 15/403,132, filed Jan. 10, 2017, titled "Multi-mode LED Illumination System," now U.S. Pat. No. 9,866,760, issued on Jan. 9, 2018, which is a continuation of U.S. patent application Ser. No. 14/723,276, filed May 27, 2015, titled "Multi-mode LED Illumination System," now U.S. Pat. No. 9,544,485, issued on Jan. 10, 2017, all of which are incorporated by reference herein in their entirety.

TECHNICAL FIELD

[0002] This application relates generally to semiconductor devices and circuits, including but not limited to methods and systems for driving light emitting devices for illumination at two or more operational modes associated with different device configurations.

BACKGROUND

[0003] Light emitting diodes (LEDs) are applied to provide a wide variety of illumination solutions, e.g., environmental lighting and backlight in mobile devices, because they offer advantages on energy consumption, lifetime, physical robustness, size and switching rate. The LEDs are electrically coupled to a certain configuration (e.g., a string or an array) to enable a desirable illumination level. Oftentimes, the LEDs are driven by an enhanced LED voltage that is raised from a regular power supply voltage by a boost type voltage regulator. The enhanced LED voltage is specifically determined according to the configuration and operation voltages of the LEDs. This boost type voltage regulator is implemented as a switch mode power supply (SMPS). When its duty cycle varies, the SMPS allows the enhanced LED voltage to be modulated within a voltage range thereof, thereby enabling the dimming effect on illumination delivered by the LEDs.

[0004] However, the boost type voltage regulator merely allows a limited voltage variation for the enhanced LED voltage, and cannot be used to drive the LEDs and provide a desirable illumination level when the coupling configuration of the LEDs varies (e.g., the number of the LEDs coupled within a string or array increases or decreases). For example, when a subset of LEDs are decoupled from a LED string, the enhanced LED voltage has to be reduced by one or more diode junction voltages, which could not be provided by the small voltage variation of the enhanced LED voltage. In this situation, the voltage regulator would fail to drive the LEDs having the new coupling configuration, because the enhanced LED voltage would overdrive and damage the LEDs. It would be beneficial to have a more flexible and tolerant LED driver than the current practice.

SUMMARY

[0005] Accordingly, there is a need for driving a plurality of LEDs that has more than one coupling configuration in association with different operation modes (e.g., a boost mode and a bypass mode). Specifically, such LEDs are driven by a boost voltage converter that provides a drive voltage according to each of the more than one coupling configuration. This LED driving method optionally complements or replaces conventional methods of using a single drive voltage with a limited voltage variation to enable dimmable LED illumination by a specific LED coupling configuration.

[0006] In accordance with one aspect of this application, a LED illumination system operates in a boost mode and a bypass mode. The LED illumination system includes a plurality of LEDs, a plurality of bypass elements, a boost converter, a first current sink and a second current sink. The plurality of LEDs is coupled in series to form a LED string. Each bypass element is coupled in parallel with a respective group of one or more of the LEDs, and configured to bypass selectively the respective group of LEDs in the bypass mode. The boost converter is coupled to the plurality of LEDs, and configured to generate a drive voltage to drive the plurality of LEDs. The boost converter includes a boost controller that is configured to enable the boost mode in response to a boost enable signal. The first and second current sinks are coupled to the plurality of LEDs, and configured to provide two drive currents to drive the LEDs in the boost mode and the bypass mode, respectively. In the boost mode, the boost controller is electrically coupled to control the boost converter to drive the LED string by a boosted drive voltage. Alternatively, in the bypass mode, the boost controller is deactivated to allow the boost converter to drive a subset of the plurality of LEDs by a regular drive voltage that is substantially lower than the boosted drive voltage.

[0007] In accordance with another aspect of this application, a camera device operates in two or more modes. The camera device includes a camera portion and a LED illumination system that operates in a boost mode and a bypass mode that are associated with a first mode and a second mode of the two or more modes of the camera device, respectively. The LED illumination system further includes a plurality of LEDs, a plurality of bypass elements, and a boost converter. The plurality of LEDs is coupled in series to form a LED string. Each bypass element is coupled in parallel with a respective group of one or more of the LEDs, and configured to bypass selectively the respective group of LEDs in the bypass mode. The boost converter is coupled to the plurality of LEDs, and configured to generate a drive voltage to drive the plurality of LEDs. The boost converter includes a boost controller that is configured to enable the boost mode in response to a boost enable signal. In the boost mode, the boost controller is electrically coupled to control the boost converter to drive the LED string by a boosted drive voltage. Alternatively, in the bypass mode, the boost controller is deactivated to allow the boost converter to drive a subset of the plurality of LEDs by a regular drive voltage that is substantially lower than the boosted drive voltage.

[0008] In accordance with another aspect of this application, a method is applied to manufacture a LED illumination system that operates in a boost mode and a bypass mode. The method includes providing a plurality of LEDs that is coupled in series to form a LED string, and providing a plurality of bypass elements. The operation of providing a plurality of bypass elements further includes coupling each of the plurality of bypass elements in parallel with a respec-

tive group of one or more of the LEDs to bypass selectively the respective group of LEDs in the bypass mode. The method further includes coupling a boost converter to the plurality of LEDs, and the boost converter is configured to generate a drive voltage to drive the plurality of LEDs. The boost converter includes a boost controller that is configured to enable the boost mode in response to a boost enable signal. In the boost mode, the boost controller is electrically coupled to control the boost converter to drive the LED string by a boosted drive voltage. In the bypass mode, the boost controller is deactivated to allow the boost converter to drive a subset of the plurality of LEDs by a regular drive voltage that is substantially lower than the boosted drive voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] For a better understanding of the various described implementations, reference should be made to the Description of Implementations below, in conjunction with the following drawings in which like reference numerals refer to corresponding parts throughout the figures.

[0010] FIG. **1** is a circuit diagram illustrating a LED illumination system that operates in a boost mode and a bypass mode in accordance with some implementations.

[0011] FIG. **2**A is a block diagram illustrating a microcontroller unit (MCU) and its output interface in accordance with some implementations.

[0012] FIG. **2**B is a temporal diagram of a plurality of boost-bypass control signals and a generated LED drive voltage associated with a LED illumination system in accordance with some implementations.

[0013] FIGS. **3**A and **3**B illustrate two examples of a top view of a camera module that includes a plurality of LEDs in accordance with some implementations, respectively.

[0014] FIGS. **3**C and **3**D illustrate two sets of exemplary LED illumination patterns associated with a depth imaging mode of the camera shown in FIG. **3**A in accordance with some implementations, respectively.

[0015] FIG. **4** is a circuit diagram illustrating an exemplary bypass element for bypassing one or more LEDs within a LED string in accordance with some implementations.

[0016] FIG. **5** is a circuit diagram illustrating a current sink that is electrically coupled in a LED illumination system in accordance with some implementations.

[0017] FIG. **6** is a flow diagram illustrating a method of manufacturing a LED illumination system that operates in a boost mode and a bypass mode in accordance with some implementations.

[0018] Like reference numerals refer to corresponding parts throughout the several views of the drawings.

DESCRIPTION OF IMPLEMENTATIONS

[0019] A smart home environment is created at a venue by integrating a plurality of devices, including intelligent, multi-sensing, network-connected devices, seamlessly with each other in a local area network and/or with a central server or a cloud-computing system to provide a variety of useful smart home functions. In some implementations, the smart home environment includes one or more network-connected cameras that are configured to provide video monitoring and security in the smart home environment. In addition to video recording at the daytime, such a camera needs to operate at a night vision mode to detect any trespass or burglary activities that often happen at night when visible light illumination is unavailable. In some situations, the camera also operates at a depth imaging mode to develop a depth map related to an interior view of a room, and this depth imaging mode is preferably implemented at night when the activity level is relatively low in the room. Under some circumstances, given that visible light illumination is limited or unavailable at night, the camera therefore has to incorporate a series of infrared LEDs to illuminate the room when it operates under the night vision mode or the depth imaging mode. Such infrared LEDs are coupled differently according to the operation mode of the camera.

[0020] In accordance with various implementations of the application, a series of LEDs of an electronic device could be arranged according to different LED coupling configurations, when the electronic device operates under different modes (e.g., when a camera operates in the night vision mode and the depth imaging mode). In a specific example, eight or more infrared LEDs are coupled in series to form a LED string in a first operation mode, and only two of these eight or more infrared LEDs are coupled and involved (i.e., six of the LEDs are bypassed) in a second operation mode. When the operation voltage of each LED is assumed to be 1.5V and above, a corresponding drive voltage that drives the LEDs could vary between 12V and 4V when the electronic device operates at the two distinct operation modes. As explained below with reference to FIGS. **1-6**, a LED illumination system is configured to accommodate the relatively large variation of the drive voltage caused by the variation of LED coupling configurations.

[0021] Specifically, in some implementations, a plurality of boost-bypass controls is determined according to an operation mode of an electronic device, and controls a LED illumination system to operate in one of a boost mode and a bypass mode. In the boost mode, a series of LEDs including a first number of LEDs are electrically coupled in series to form a LED string, and a boost controller is coupled to control a boost converter to drive the whole LED string by a boosted voltage. In the bypass mode, a subset of the series of LEDs is electrically coupled according to a different LED coupling configuration, and the other LEDs of the series of LEDs are bypassed. The subset of LEDs including a second number of LEDs, and the second number is substantially smaller than the first number. The boost controller is deactivated to allow the boost converter to drive the subset of LEDs by a regular drive voltage that is substantially lower than the boosted drive voltage. The boost-bypass controls are generated by a microcontroller unit (MCU), and thereby applied to control one or more of: bypassing of LEDs in the LED string, deactivating the boost controller, and selecting a current sink according to the operation mode.

[0022] FIG. **1** is a circuit diagram illustrating a LED illumination system **100** that operates in a boost mode and a bypass mode in accordance with some implementations. The LED illumination system **100** includes a plurality of LEDs (LED**1**-LED**8**), a plurality of bypass elements **102**, a boost converter **104**, a first current sink **108** and a second current sink **110**. The boost converter **104** further includes a boost controller **106**. The LED illumination system **100** further includes a plurality of boost-bypass control signals, e.g., BP**1**-BP**8**, BS and BP, which are synchronized to control the components **102-110** and enable the boost or bypass mode for the LED illumination system **100**.

[0023] The plurality of LEDs is electrically coupled in series to form a LED string **120**. Each of the plurality of bypass elements **102** is coupled in parallel with a respective group of one or more of the plurality of LEDs, and configured to bypass selectively the respective group of LEDs in the bypass mode. In the specific implementations as shown in FIG. **1**, each of the plurality of LEDs is coupled in parallel with a respective bypass element. The respective bypass element **102** receives a LED bypass control signal, and is configured to selectively bypass the corresponding LED from the LED string **120** when the LED illumination system **100** operates in the bypass mode. In some implementations not shown in FIG. **1**, one of the plurality of bypass elements is arranged in parallel with a series of two or more LEDs in the LED string **120**, and selectively bypasses the series of two or more LEDs in the bypass mode. More details on the coupling configuration of the plurality of LEDs are explained below with reference to FIGS. **3**A-**3**D. In some implementations, the plurality of LEDs is infrared LEDs.

[0024] The boost converter **104** is coupled to the plurality of LEDs, and configured to generate a drive voltage V_{DR} for driving the plurality of LEDs. In some implementations, the boost converter **104** is implemented as a switch mode power supply. The boost converter **104** receives a power supply voltage V_{SUP} and a pulse width control signal PWC, and generates a boosted drive voltage V_{BDR}. The boost drive voltage V_{BDR} is substantially higher than the power supply voltage V_{SUP}, and varies within a fixed voltage range. The pulse width control signal PWC has a variable duty cycle, and determines the variation of the drive voltage V_{DR}. Specifically, in some implementations, the boost converter **104** includes an inductor **112**, a diode **114**, a load capacitor **116**, and a switching component **118**. The pulse width control signal PWC is used to control the switching component **118** to enable charging and discharging of the load capacitor **116**, and thereby renders the boosted and variable drive voltage V_{BDR}.

[0025] The boost controller **106** of the boost converter **104** is configured to enable the boost mode in response to a boost enable signal BS of the plurality of boost-bypass control signals. In some implementations, the boost controller **106** is driven by the power supply voltage V_{SUP} that drives the boost converter **104**. In the boost mode, the boost enable signal BS is enabled, and the boost controller **106** is activated. The activated boost controller **106** thereby controls the boost converter **104** to drive the LED string **120** by the boosted drive voltage V_{BDR}. For example, when the boost converter **104** is implemented as a switch mode power supply, the boost controller **106** generates the pulse width control signal PWC and varies its duty cycle for the purposes of controlling the boost converter **104** to generate a desirable drive voltage level.

[0026] Conversely, in the bypass mode, the boost enable signal BS is disabled, and the bypass enable signal BP is enabled. The boost controller **106** is deactivated to allow the boost converter **104** to drive a subset of the plurality of LEDs by a regular drive voltage V_{RDR} that is substantially lower than the boosted drive voltage V_{BDR}. In some implementations, in accordance with the deactivation of the boost controller **106**, the pulse width control signal PWC has a null duty cycle, and the boost converter **104** generates a regular drive voltage V_{RDR} substantially equal to the power supply voltage V_{SUP} that drives the boost converter **104** or the entire LED illumination system **100**.

[0027] The first current sink **108** and the second current sink **110** are coupled to the plurality of LEDs, and configured to provide two drive currents to drive the LEDs in the boost mode and the bypass mode, respectively. The first current sink **108** and the second current sink **110** are controlled by the boost enable signal BS and another bypass enable signal BP of the plurality of boost-bypass control signals. In some implementations, the first current sink **108** is part of the boost controller **106**. In the boost mode, the first current sink is electrically coupled to the whole LED string **120**, and enables a first drive current. Alternatively, in the bypass mode, the second current sink is electrically coupled to a subset of the plurality of LEDs, and enables a second drive current.

[0028] Optionally, the two drive currents provided by the first and second current sinks **108** and **110** are substantially equal. Optionally, the two drive currents are distinct. In an example, the first current sink **108** provides to the whole LED string **120** the first drive current that is substantially equal to 50 mA in the boost mode. The second current sink **110** provides to the subset of selected LEDs the second drive current that is substantially equal to 100 mA in the bypass mode. As such, the distinct drive current levels at the boost and bypass modes are associated with distinct LED coupling configurations and render distinct brightness levels for each coupled LED. When the LED illumination system **100** is applied in a camera, the boost and bypass modes could be associated with different camera operation modes, and the camera could achieve unique camera features based on the illumination configuration and brightness level associated with the boost or bypass mode of the LEDs.

[0029] In some implementations, the boost converter **104**, the first current sink **108**, and the second current sink **110** are integrated on an integrated circuit substrate. In some implementations, one or more of the boost converter **104**, the first current sink **108**, and the second current sink **110** are off-the-shelf components, and assembled on a printed circuit board substrate.

[0030] It is also noted that the LED illumination system **100** could also operate at an idle mode that is distinct from the boost mode and the bypass mode. In the idle mode, none of the plurality of LEDs is enabled to provide illumination. When the LED illumination system **100** is part of a camera, the idle mode is activated to disable infrared LED illumination during the daytime.

[0031] FIG. **2**A is a block diagram illustrating a microcontroller unit (MCU) **200** and its output interface in accordance with some implementations. In some implementations, the MCU **200** is configured to generate the plurality of boost-bypass control signals in a synchronous manner for the purposes of configuring the LED illumination system **100** to operate in a boost mode or a bypass mode. Specifically, the MCU **200** is configured to generate the boost enable signal BS, and a plurality of LED bypass control signals BP**1**-BP**8**. The boost enable signal BS is applied to enable the boost controller **106** and activate the first current sink **108** in the boost mode. Each of the plurality of LED bypass controls is applied to control one of the plurality of bypass elements for bypassing the corresponding group of LEDs in the bypass mode. In some implementations, the MCU **200** is also configured to generate a bypass enable signal BP that enables the second current sink in the bypass mode. Optionally, the bypass enable signal BP is a complementary signal of the boost enable signal BS, and in some

implementations, can be generated internally from the boost enable signal BS within the LED illumination system **100**. Optionally, the bypass enable signal BP is enabled with a delay or an overlap with an active cycle of the bypass enable signal BS.

[0032] In some implementations, the first current sink **108** is controlled by the boost enable signal BS to enable and disable the first drive current in the boost and bypass modes, respectively. The first current sink **108** is thus enabled during the active cycles of the boost enable signal BS to provide the first drive current, and disabled from providing the first drive current during the inactive cycles of the boost enable signal BS. Alternatively, in some implementations, the first current sink **108** is controlled by both the boost enable signal BS and the bypass enable signal BP. The first current sink **108** is enabled by the boost enable signal BS to provide the first drive current, but disabled by the bypass enable signal BP from providing the first drive current. Similarly, in some implementations, the second current sink **110** is controlled by the bypass enable signal BP to enable and disable the second drive current in the bypass and boost modes, respectively. As such, the second current sink **110** is enabled during the active cycles of the bypass enable signal BP to provide the second drive current, and disabled from providing the second drive current during the inactive cycles of the bypass enable signal BP. In some implementations, the second current sink **110** is controlled by both the boost enable signal BS and the bypass enable signal BP. The second current sink **110** is enabled by the bypass enable signal BP to provide the second drive current, but disabled by the boost enable signal BS from providing the second drive current.

[0033] FIG. **2**B is a temporal diagram of a plurality of boost-bypass control signals and a generated LED drive voltage associated with a LED illumination system **100** in accordance with some implementations. In some implementations, when the LED illumination system **100** transitions between the boost mode and the bypass mode, the MCU **200** introduces delay times among the plurality of boost-bypass control signals to avoid the LEDs or the current sinks from being overstressed. For example, when the LED illumination system **100** switches from the boost mode to the bypass mode, both the boost controller **106** and the first current sink **108** are deactivated, and the second current sink **110** is electrically coupled to the whole LED string **120**. The MCU **200** does not enable the bypass of a subset of unselected LEDs to follow the enable signals BS and BP immediately. Rather, the MCU **200** introduces one or more delay times (e.g., T**1** and T**2**) to delay the bypass of the unselected LEDs, such that the boost drive voltage V_{BDR} does not drop on and overstress a subset of selected LEDs having a smaller number of LEDs than the whole LED string **120**.

[0034] In some implementations, the one or more delay times (e.g., T**1** and T**2**) are associated with a plurality of bypass factors, e.g., a boost control delay during which the boost controller **106** converts an input bypass enable signal to the pulse width control signal PWC for the purposes of controlling the boost converter **104**. In an example, a delay time is substantially small, when the boost controller **106** introduces a substantially small or negligible boost control delay for converting the input bypass enable signal to the pulse width control signal PWC. Additionally, another example bypass factor that affects the delay times is a discharge period during which the boost converter **104** is gradually discharged for reducing the voltage level of the drive voltage at its output. A large load capacitor **116** contains more charges, and takes a longer time to discharge. As such, the delay times are associated with the length of the discharge period of the boost converter **104** which is further associated with the capacitance of its load capacitor **116**.

[0035] In some implementations, the MCU **200** introduces a uniform delay time to LED bypass controls corresponding to all unselected LEDs of the LED string **120** in the bypass mode. The LED bypass controls are enabled after the delay time passes with respect to the transition edges of the boost enable signal BS and bypass enable BP. This delay time represents a length of a predetermined discharge period in which the boost drive voltage V_{BDV} could drop to a tolerable drive voltage that is safe for biasing the subset of selected LEDs. Optionally, the tolerable drive voltage is substantially equal to the regular drive voltage V_{RDR}. Optionally, the tolerable drive voltage is larger than the regular drive voltage V_{RDR}, but safe for biasing the selected LEDs.

[0036] In some implementations, the MCU **200** introduces two or more delay times to the LED bypass controls corresponding to the unselected LEDs of the LED string **120**. The unselected LEDs are bypassed sequentially for the purposes of reducing the number of the LEDs biased under the drive voltage sequentially. When the subset of the plurality of LEDs that are selected for illumination in the bypass mode includes a first subset of LEDs, a second subset of the plurality of LEDs are electrically coupled to the boost converter during the predetermined discharge period. The second subset of LEDs including more LEDs than the first subset of LEDs.

[0037] As shown in FIG. **2**B, in some implementations, two LEDs (LED**3** and LED**4**) need to be selected for illumination in the bypass mode. When the LED illumination system **100** switches from the boost mode to the bypass mode, the boost enable signal BS is disabled and the bypass enable BP is enabled. A first delay time T**1** is introduced to the LED bypass signals BP**5**-BP**8** with respect to the enable signals BS and BP. The LED bypass signals BP**5**-BP**8** are therefore enabled after the delay time T**1** to bypass a first set of unselected LEDs (LED**5**-LED**8**). An exemplary delay time T_1 is equal to 40 ms, and the drive voltage V_{DR} drops from a boost drive voltage of 15 V to a first intermediate voltage V_1 (e.g., 7.5 V). Then, a second delay time T_2 is introduced to the LED bypass signals BP**1** and BP**2** with respect to the bypass signals BP**5**-BP**8**. The LED bypass signals BP**1** and BP**2** are therefore enabled to bypass a second set of unselected LEDs (LED**1** and LED**2**). An exemplary delay time T_2 is equal to 2 ms, and the drive voltage V_{DR} drops further to a second intermediate voltage V_2 (e.g., 5 V) that does not overstress the selected LEDs (LED**3** and LED**4**). Optionally, the intermediate voltage V_2 is substantially equal to the regular drive voltage V_{RDR}. Optionally, the intermediate voltage V_2 is higher than the regularly drive voltage V_{RDR}, but safe for biasing the selected LEDs.

[0038] On the other hand, in some implementations, when the LED illumination system **100** transitions from the bypass mode to the boost mode, the MCU **200** introduces delays to the boost enable signal BS and the bypass enable BP with respect to the LED bypass control signals. The LED bypass control signals are disabled for the unselected LEDs in the bypass mode, and the plurality of LEDs is electrically coupled within the LED string **120** and biased by the drive voltage generated by the boost converter **104**. Then, the

boost enable signal BS is enabled to activate the boost controller **108** after a predetermined delay time passes with respect to the transition edge of the boost enable signal BS. The boost converter **108** increases the drive voltage from the regular drive voltage V_{RDR} to the boost drive voltage V_{BDR}, and the whole LED string **120** is biased under the increased drive voltage.

[0039] Under some circumstances, when the boost enable signal BS is enabled to activate the boost controller **108**, the boost converter **108** increases the drive voltage from the regular drive voltage V_{RDR} to the boost drive voltage V_{BDR} at a relatively slow rate. The MCU **200** does not need to introduce the delay times to the boost enable signal BS and the bypass enable BP with respect to the LED bypass control signals. In some implementations, when the boost enable signal BS is enabled to activate the boost controller **108**, the LED bypass control signals transitions substantially concurrently with the boost enable signal BS.

[0040] FIGS. **3**A and **3**B illustrate two examples of a top view of a camera module **300** that includes a plurality of LEDs in accordance with some implementations, respectively. In some implementations, the camera module **300** includes camera lens **302**, high definition image sensors, a microphone, a speaker, and one or more antennas. In accordance a regular monitor mode, the camera module **300** is configured to provide video monitoring and security in a smart home environment that is illuminated by visible light sources (e.g., the sun or light bulbs). The camera module **300** captures multimedia data (video and audio data) in real-time, and communicates raw or processed multimedia data to its users via a remote surveillance server. The captured raw multimedia data are optionally processed locally in the camera module **300** or remotely within the remote surveillance server.

[0041] In some implementations, the camera module **300** includes alternative operation modes, such as a night vision mode and a depth imaging mode. Each of the alternative operation modes is associated with a respective illumination condition. For example, in the night vision mode, the camera module **300** is configured to capture activities in the smart home environment at night when no or limited visible light illumination is available. In the depth imaging mode, the camera module **300** is configured to create a depth map or image for the corresponding field of view in the smart home environment. The depth map could be subsequently used in the regular monitor mode for accurate identification of objects in the smart home environment. In some implementations, the depth image is created based on one or more images captured when part of the field of view is selectively illuminated. Therefore, in some implementations, the camera module **300** is configured to include a LED illumination system **100** as shown in FIG. **1**, and use it as an internal light source to provide illumination in the smart home environment according to the respective illumination condition associated with each alternative operation mode of the camera module **300**.

[0042] Specifically, in some implementations, the plurality of LEDs includes infrared LEDs. The infrared LEDs are enclosed within a dark-colored, infrared-transparent plastic cover of the camera module **300**, and therefore invisible from the exterior of the camera module **300**. Given that the plastic cover permits infrared light to pass through it, the camera module **204** could rely on the infrared LEDs **308** to provide illumination at night. In the night vision mode, the plurality of LEDs is powered on to illuminate the field of view with infrared light at night. The camera module **300** includes infrared image sensors that capture infrared images or video clips of the field of view.

[0043] Alternatively, in some implementations, the plurality of LEDs is a mix of infrared and visible light LEDs, including at least one infrared LED and at least one visible light LED. In the night vision mode, the at least one infrared LED of the plurality of LEDs is powered on to illuminate the field of view with infrared light.

[0044] In some implementations, as shown in FIG. **3**A, the plurality of LEDs of the LED illumination system **100** is disposed on an internal assembly structure of the camera module **300**, and configured to surround the camera lens **302** of the camera module **300**. In this example, the plurality of LEDs includes eight LEDs that are grouped in four pairs of LEDs. The four pairs of LEDs are disposed symmetrically within four quadrants surrounding the camera lens **302**. In some implementations, a mechanical or electrical component **304** is placed between two LED pairs or between two LEDs within a LED pair. In another example, the plurality of LEDs includes six LEDs. Three LEDs are disposed on one side of the camera lens **302**, and three LEDs are disposed on the other side. Also, it is noted that the camera lens **302** could be surrounded by a number of LEDs having a physical arrangement that is distinct from those of the above implementations or examples (e.g., the camera lens **302** is surround by a hundred LEDs distributed uniformly in three layers surrounding the camera lens **302**).

[0045] In some implementations, as shown in FIG. **3**B, each LED is optionally tilted with an angle with respect to the optical axis that passes through a center **306** of the camera lens **302**. Here, the optical axis is perpendicular to the lens surface at the center **306** of the camera lens **302**. In some implementations, each LED is tilted away from the optical axis of the camera with the angle in the range of 20-40 degrees.

[0046] In some implementations related to the depth imaging mode, the plurality of LEDs is grouped into a number of LED sets, and each LED set is selectively powered up to illuminate respective part of a field of view associated with a venue where the camera module **300** is located. Images captured in association with these LED sets are combined to generate a depth map of the entire field of view at the venue. The camera module **300** operates in this depth imaging mode, when the camera module **300** is not busy with other operation modes (e.g., the regular monitor mode). Thus, in some implementations, the camera module **300** operates the depth imaging mode at night using infrared LED illumination without interrupting normal camera operations or disturbing regular human activities.

[0047] FIGS. **3**C and **3**D illustrate two sets of exemplary LED illumination patterns **320** and **340** associated with a depth imaging mode of the camera **300** shown in FIG. **3**A in accordance with some implementations, respectively. The plurality of LEDs includes eight LEDs that are grouped in four pairs of LEDs. The four pairs of LEDs are disposed symmetrically within four quadrants surrounding the camera lens **302**. The eight LEDs are electrically coupled in series to form a LED string **120**, and driven in a LED illumination system **100** as shown in FIG. **1**. In some implementations, the LED illumination system **100** operates at a boost mode, and the boost controller **106** is electrically coupled to control the boost converter **104** to drive the LED string **120** by a

boosted drive voltage V_{BDR}. In accordance with that the whole LED string **120** are powered up, the plurality of LEDs illuminates the field of view at the venue where the camera module **300** is located, and the camera module **300** could operate at a night vision mode to capture images or video clips of the entire field of view.

[0048] Alternatively, in the depth imaging mode, the LED illumination system **100** powers up the four LED pairs in the four quadrants (LED**1** and LED**2** in quadrant I, LED**3** and LED**4** in quadrant II, LED**5** and LED**6** in quadrant III, and LED**7** and LED**8** in quadrant IV) separately. Each LED pair illuminates their respective part of the field of view associated with the corresponding quadrant. Such partial illumination involves subsets of selected LEDs, and is enabled by controlling the bypass elements **102** in the LED illumination system **100**. For example, the bypass elements **102** for LED**3**-LED**8** are enabled by the LED bypass controls BP**3**-BP**8** to bypass LED**3**-LED**8**, when the LED**1**-LED**2** pair is electrically coupled and driven to illuminate the part of the field of view associated with quadrant I.

[0049] In some implementations, the plurality of LEDs is grouped according to another coupling configuration to provide a distinct illumination pattern. For example, as shown in FIG. **3**D, the plurality of LEDs is still grouped into four LED pairs, but are paired up differently: LED**2** and LED**3**, LED**4** and LED**5**, LED**6** and LED**7**, and LED **8** and LED**1**. In the depth imaging mode, the LED illumination system **100** powers up these four LED pairs to illuminate part of the field of view that is distinct from that associated with FIG. **3**A. This distinct illumination pattern of FIG. **3**D is also enabled by controlling the bypass elements **102** in the LED illumination system **100**. For example, the bypass elements **102** for LED**1**, and LED**4**-LED**8** are enabled by the LED bypass controls BP**1**, and BP**4**-BP**8** to bypass LED**1**, and LED**4**-LED**8**, respectively, when the LED**2**-LED**3** pair is electrically coupled and driven to illuminate the corresponding part of the field of view.

[0050] It is noted that when a subset of the plurality of LEDs (e.g., LED**1** and LED**2** in FIG. **3**C) is powered for illumination, the LED illumination system **100** operates in a bypass mode in association with an exemplary depth imaging mode of the camera module **300**. As explained above, in the bypass mode, the boost controller **106** of the LED illumination system **100** is deactivated to allow the boost converter **104** to drive a subset of the plurality of LEDs by a regular drive voltage V_{RDR} that is substantially lower than the boosted drive voltage V_{BDR} associated with the boost mode. More details on the LED illumination system **100** are explained above with reference to FIGS. **1**, **2**A and **2**B.

[0051] FIG. **4** is a circuit diagram illustrating an exemplary bypass element **102** for bypassing one or more LEDs within a LED string **120** in accordance with some implementations. The bypass element **102** is coupled in parallel with the one or more LEDs, and configured to bypass the one or more LEDs by shorting two end terminals thereof. The bypass element **102** includes an N-type metal-oxide-semiconductor field effect transistor (MOSFET) **402**, a P-type MOSFET **404**, and two resistors R_1 and R_2. The MOSFET **402** is coupled to receive a LED bypass control signal BPn, where n identifies the one or more LEDs of the LED string **120**. When the LED bypass control signal BPn is enabled, the MOSFET **402** is switched off, and the MOSFET **404** is switched on. The MOSFET **404** shorts two terminals of the one or more LEDs, and thereby bypasses the one or more LEDs from the LED string **120**. As such, the bypass element **102** is enabled by the corresponding LED bypass control to provide a low impedance path for bypassing the one or more LEDs.

[0052] FIG. **5** is a circuit diagram illustrating a current sink **500** that is electrically coupled in a LED illumination system **100** in accordance with some implementations. The current sink **500** is optionally implemented as the first current sink **108** or the second current sink **110**. In accordance with the operation mode of the LED illumination system **100** (the boost mode or the bypass mode), the current sink **500** is enabled by a boost enable signal BS or a bypass enable signal BP, respectively. The current sink includes a voltage source **502**, an operational amplifier (OPAMP) **504**, a MOSFET **506** and a resistor R_3. In some implementations, the voltage source **502** is a resistive voltage divider driven between a power supply V_{SUP} and the ground. The voltage source **502** generates a DC voltage V_{IN}, and the resistor R_I has resistance R_I. As such, the current sink provides a current level that is substantially equal to V_{IN}/R_I.

[0053] It is noted that FIGS. **4** and **5** merely illustrate examples of a bypass element **102** and a current sink used in the LED illumination system **100**, and that implementations of the bypass element and the current sink are not limited to these examples.

[0054] FIG. **6** is a flow diagram illustrating a method **600** of manufacturing a LED illumination system **100** that operates in a boost mode and a bypass mode in accordance with some implementations. A plurality of LEDs is provided (**602**), and coupled in series to form a LED string **120**. In some implementations, the plurality of LEDs is disposed in a camera module to surround a camera lens, and each LED is tilted with an angle with respect to the optical axis of the camera lens. Further, in some implementations, each LED is tilted away from the optical axis of the camera with the angle in the range of 20-40 degrees. In some implementations, the plurality of LEDs includes infrared LEDs.

[0055] A plurality of bypass elements **102** are provided (**604**), such that each of the plurality of bypass elements **102** is coupled in parallel with a respective group of one or more of the LEDs to bypass selectively the respective group of LEDs in the bypass mode. In some implementations, each of the plurality of LEDs is coupled in parallel with a respective bypass element configurable to bypass the respective LED in the bypass mode.

[0056] A boost converter **104** is coupled (**606**) to the plurality of LEDs, and configured to generate a drive voltage to drive the plurality of LEDs. The boost converter **104** further includes a boost controller **106** for controlling the boost converter **104** and enabling the boost mode in response to a boost enable signal. In the boost mode, the boost controller is electrically coupled (**610**) to control the boost converter to drive the LED string by a boosted drive voltage, and in the bypass mode the boost controller is deactivated (**612**) to allow the boost converter to drive a subset of the plurality of LEDs by a regular drive voltage that is substantially lower than the boosted drive voltage. In some implementations, the voltage level of the regular drive voltage is substantially equal to that of a power supply of the LED illumination system.

[0057] In some implementations, a first current sink and a second current sink are provided (**614**) for coupling to the plurality of LEDs and providing two drive currents to drive the LEDs in the boost mode and the bypass mode, respec-

tively. In some implementations, the first current sink is part of the boost controller. In the boost mode, the first current sink is electrically coupled to the whole LED string and enables a first drive current, and in the bypass mode, the second current sink is electrically coupled to the subset of the plurality of LEDs and enables a second drive current. In some implementations, the first and second drive currents are distinct.

[0058] In some implementations, the boost converter, the boost controller, and the first and second current sinks are integrated on an integrated circuit substrate.

[0059] In some implementations, the method **600** further includes providing a MCU **200** that is configured to generate the boost enable signal and a plurality of LED bypass controls. The boost enable signal is applied to control the boost controller and select one of the first and second current sinks, and each of the plurality of LED bypass controls is applied to control one of the plurality of bypass elements for bypassing the corresponding group of LEDs in the bypass mode.

[0060] In some implementations, the plurality of LEDs includes eight LEDs. In the bypass mode, six of the eight LEDs are bypassed, and two remaining LEDs are coupled in series between the boost converter and the second current sink.

[0061] In some implementations, the plurality of LEDs are grouped into four subsets of LEDs that are configured to illuminate four quadrants of a field of view, respectively, and depth information of the field of view is recovered at night time according to the variation of the field of view illuminated by these four subsets of LEDs.

[0062] In some implementations, when the LED system switches from the boost mode to the bypass mode, both the boost controller and the first current sink are deactivated, and the second current sink is electrically coupled to the whole LED string for at least a predetermined discharge period, before the subset of the plurality of LEDs are electrically coupled and biased by the regular drive voltage. Further, in some implementations, the predetermined discharge period is substantially equal to or longer than 40 msec. Alternatively, in some implementations, the subset of the plurality of LEDs include a first subset of LEDs, and a second subset of the plurality of LEDs are electrically coupled to the boost converter during the predetermined discharge period. The second subset of LEDs includes more LEDs than the first subset of LEDs.

[0063] It is noted that the LED illumination system **100** could also operate at an idle mode that is distinct from the boost mode and the bypass mode. In the idle mode, none of the plurality of LEDs is enabled to provide illumination.

[0064] Reference will now be made in detail to implementations, examples of which are illustrated in the accompanying drawings. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the various described implementations. However, it will be apparent to one of ordinary skill in the art that the various described implementations may be practiced without these specific details. In other instances, well-known methods, procedures, components, circuits, and networks have not been described in detail so as not to unnecessarily obscure aspects of the implementations.

[0065] It will also be understood that, although the terms first, second, etc. are, in some instances, used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first current sink could be termed a second current sink, and, similarly, a second current sink could be termed a first current sink, without departing from the scope of the various described implementations. The first current sink and the second current sink are both current sinks, but they are not the same current sink.

[0066] The terminology used in the description of the various described implementations herein is for the purpose of describing particular implementations only and is not intended to be limiting. As used in the description of the various described implementations and the appended claims, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms "includes," "including," "comprises," and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0067] As used herein, the term "if" is, optionally, construed to mean "when" or "upon" or "in response to determining" or "in response to detecting" or "in accordance with a determination that," depending on the context. Similarly, the phrase "if it is determined" or "if [a stated condition or event] is detected" is, optionally, construed to mean "upon determining" or "in response to determining" or "upon detecting [the stated condition or event]" or "in response to detecting [the stated condition or event]" or "in accordance with a determination that [a stated condition or event] is detected," depending on the context.

[0068] It is to be appreciated that "smart home environments" may refer to smart environments for homes such as a single-family house, but the scope of the present teachings is not so limited. The present teachings are also applicable, without limitation, to duplexes, townhomes, multi-unit apartment buildings, hotels, retail stores, office buildings, industrial buildings, and more generally any living space or work space.

[0069] The foregoing description, for purpose of explanation, has been described with reference to specific implementations. However, the illustrative discussions above are not intended to be exhaustive or to limit the scope of the claims to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The implementations were chosen in order to best explain the principles underlying the claims and their practical applications, to thereby enable others skilled in the art to best use the implementations with various modifications as are suited to the particular uses contemplated.

What is claimed is:

1. An illumination system, comprising:

a plurality of light sources configured to illuminate a field of view, wherein the plurality of light sources is configurable to a plurality of light source subsets, and at least two of the plurality of light source subsets include distinct light source members and are configured to illuminate different regions of the field of view; and

a light source driver coupled to the plurality of light sources and configured to drive the plurality of light source subsets.

2. The illumination system of claim **1**, wherein the light source driver has a first mode in which all of the plurality of light sources are electrically coupled to each other and the light source driver is configured to drive the plurality of light sources by a first drive voltage.

3. The illumination system of claim **2**, wherein in the first mode, the plurality of light sources is electrically coupled in series to form a string that is driven by the first drive voltage.

4. The illumination system of claim **2**, wherein the light source driver has a second mode in which the light source driver is configured to drive each of the plurality of light source subsets with a second drive voltage, and the second drive voltage is less than the first drive voltage.

5. The illumination system of claim **1**, wherein each of the plurality of light source subsets includes one or more light source members, further comprising:

a bypass circuit coupled to the plurality of light sources and configured to enable each of the plurality of light source subsets by bypassing a respective set of light sources that is distinct from the respective one or more light source members of the respective light source subset, allowing the respective one or more light source members to be electrically coupled in series and form the respective light source subset.

6. The illumination system of claim **5**, wherein the bypass circuit includes a plurality of bypass elements, and each of the plurality of light sources is coupled in parallel with one of the plurality of bypass elements configurable to bypass the respective light source to form the plurality of light source subsets.

7. The illumination system of claim **1**, wherein the illumination system is coupled to a camera module that is configured to capture visual data of the field of view, and is configured to provide illumination to the camera module.

8. The illumination system of claim **1**, wherein the plurality of light sources includes a plurality of light emitting diodes (LEDs) disposed to surround a camera lens.

9. The illumination system of claim **8**, wherein each LED is tilted with an angle with respect to an optical axis of the camera lens.

10. The illumination system of claim **9**, wherein each LED is tilted away from the optical axis of the camera with the angle in a range of 20-40 degrees.

11. The illumination system of claim **1**, wherein the plurality of light sources is disposed symmetrically with respect to a camera lens.

12. An electronic device, comprising:

a plurality of light sources configured to illuminate a field of view, wherein the plurality of light sources is configurable to a plurality of light source subsets, and at least two of the plurality of light source subsets include distinct light source members and are configured to illuminate different regions of the field of view of the electronic device; and

a light source driver coupled to the plurality of light sources and configured to drive the plurality of light source subsets.

13. The electronic device of claim **12**, wherein the plurality of light source subsets includes a first plurality of light source subsets, and the plurality of light sources is configurable to a second plurality of light source subsets, and wherein each of the first plurality of light source subsets is distinct from the second plurality of light source subsets.

14. The electronic device of claim **12**, further comprising:

a microcontroller configured to control selection of one of the plurality of light source sub sets.

15. The electronic device of claim **12**, wherein the plurality of light sources includes a plurality of infrared LEDs.

16. The electronic device of claim **15**, further comprising:

a dark-colored infrared-transparent cover enclosing the plurality of infrared LEDs, wherein the plurality of infrared LEDs is not visible from an exterior of the electronic device.

17. The electronic device of claim **15**, wherein in a night mode, one or more of the plurality of infrared LEDs is driven to illuminate at least part of the field of view with infrared light.

18. The electronic device of claim **12**, further comprising:

a camera lens and image sensors configured to capture visual data of the field of view; and

one or more of a microphone, a speaker, and one or more antennas;

wherein the electronic device is configured to communicate the visual data to a client device via a remote surveillance server in real time while capturing the visual data.

19. The electronic device of claim **12**, wherein the plurality of light sources is grouped into four subsets of light sources that are configured to illuminate four quadrants of the field of view, respectively.

20. The electronic device of claim **19**, wherein depth information of the field of view is recovered at night time according to a variation of the field of view illuminated by the four subsets of light sources.

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