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(54) **Title**: LED DRIVER WITH COMPREHENSIVE FAULT PROTECTIONS

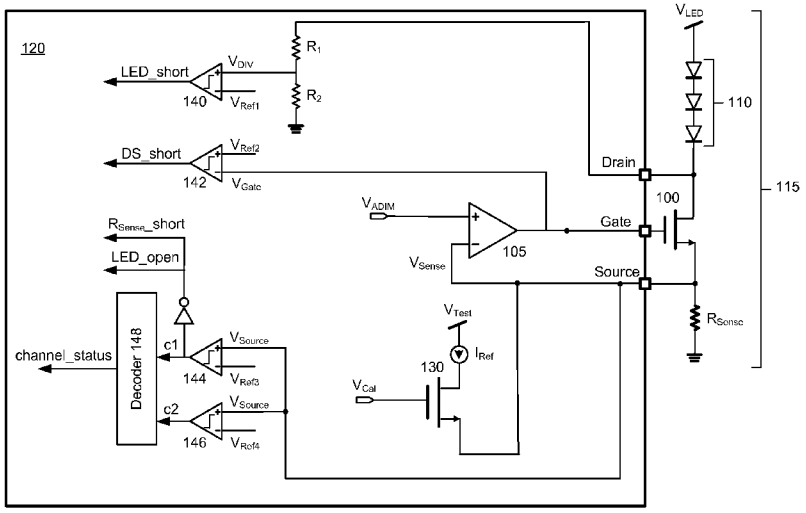


FIG. 3

(57) **Abstract**: The embodiments disclosed herein describe a set of fault detection circuits for LED circuits in an LED channel. A first fault detection circuit is configured to detect a short fault across one or more LEDs. A second fault detection circuit is configured to detect an open fault across an LED. A third fault detection circuit is configured to detect a short across an LED channel transistor. A fourth fault detection circuit is configured to detect an LED channel sense resistor open fault. A fifth fault detection circuit is configured to detect if the LED channel is being intentionally unused. These fault detect circuits can be implemented in a fault detection integrated circuit coupled to the LED channel.

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LED DRIVER WITH COMPREHENSIVE FAULT PROTECTIONS

RELATED APPLICATIONS

[0001] This application claims priority to United States Provisional Application No. 61/837,036, filed June 19, 2013, the contents of which are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

[0002] This invention pertains generally to the field of LED circuits and, more particularly, to LED circuit fault detection.

BACKGROUND

[0003] Three-dimensional televisions and other displays often require increasingly higher current and higher density LED arrays. In some instances, electrical current flowing through each string of LEDS in an LED array for display backlighting ranges from around 100mA to 1A or greater. In order to address the heat produced by such currents and to lower IC cost, display manufacturers can move heat-producing components, such as power MOSFETs and LED current sensing resistors, off chip.

SUMMARY OF THE INVENTION

[0004] The present disclosure describes a set of fault detection circuits for LED circuits. These fault detection circuits can be implemented within a fault detection IC. Two such fault detection circuits are an LED short fault detection circuit and an LED open fault detection circuit. In addition, the fault detection IC can include a MOSFET drain-to-source short fault detection circuit, a sense resistor open fault detection circuit, a sense resistor short fault detection circuit, and an LED channel short detection circuit. The fault detection IC can further include circuitry configured to determine if a particular LED channel is unused. The fault detection IC can include circuits configured to act as a first type of fault detection circuit in a calibration mode, and as a second type of fault detection circuit in an operation mode.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Fig. 1 shows an LED driver circuit, according to one embodiment.

[0006] Fig. 2 illustrates a connector array on a PCB with a short between adjacent connector nodes, according to one embodiment.

[0007] Fig. 3 illustrates a set of fault detection circuits for use in LED circuits, LED driver circuits, and LED channels, according to one embodiment.

Fig. 4 illustrates a timing diagram for fault detection circuits during a calibration mode, according to one embodiment.

[0008] Fig. 5 illustrates a logic table for use in detecting faults in a calibration mode, according to one embodiment.

[0009] Fig. 6 illustrates an LED channel short circuit fault detection circuit, according to one embodiment.

DETAILED DESCRIPTION

[0010] The Figures (Figs.) and the following description relate to various embodiments by way of illustration only. Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict various embodiments for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

[0011] Fig. 1 shows an LED driver circuit, according to one embodiment. The driver circuit of Fig. 1 includes MOSFET 100, amplifier 105, and sense resistor R_{SENSE}. The positive input terminal of the amplifier 105 is coupled to an input V_{ADIM}, and the negative input terminal of the amplifier is coupled to the source node of the MOSFET 100. An LED string 110 is coupled between the voltage source V_{LED} and the drain node of the MOSFET 100.

[0012] The output of the amplifier 105 is coupled to the gate node of the MOSFET 100. The amplifier 105 outputs a signal based on the difference between signals received at the positive and negative input terminals of the amplifier. In one embodiment, the amplifier 105 is a high gain amplifier. The input V_{ADIM} controls the switching of the gate node of the MOSFET 100.

[0013] When the output of the amplifier 105 is high, the MOSFET 100 acts as a closed switch. In such a configuration, current flows from the voltage source V_{LED}, through the LED string 110 (causing the LEDs to emit light), through the drain node of the MOSFET 100 to the source node of the MOSFET, and through the resistor R_{SENSE}. When the output of the

amplifier 105 is low, the MOSFET 100 acts as an open switch, preventing current from flowing from the voltage source V_{LED} through the MOSFET (and thus preventing the LEDs from emitting light).

[0014] In the embodiment of Fig. 1, the resistor R_{SENSE} is generally a low-resistance resistor. For example, the resistance of R_{SENSE} may be equal to or less than 2Ω. The voltage across R_{SENSE} (V_{SENSE}) is used as a feedback signal to control the output of the amplifier 105, which in turn controls the switching of the MOSFET 100 and the current through the LED string 110.

[0015] In one example embodiment, V_{LED} is 70V and the LED string 110 includes 20 LEDs. In this embodiment, when current is flowing through the MOSFET 100, the voltage drop across each LED is approximately 3.3V. As a result, the voltage at the drain node of the MOSFET 100 is approximately 4V.

[0016] Manufacturing defects and gradual degradation over time can occur within off-chip MOSFETs, LED current sensing resistors, and other off-chip components. One or more LEDs in the LED string 110 can be shorted or opened. Shorted LEDs can be particularly problematic, as they can cause additional LEDs to become shorted, and can cause over-heating on an external MOSFET 100. In addition, the source and drain nodes of the MOSFET 100 can be shorted. Further, the nodes of the sensing resistor R_{SENSE} can shorted or opened. Traditional on-chip LED short and open circuit protections generally fall short of addressing such defects for off-chip components.

[0017] In addition, individual LED channels can be shorted. Fig. 2 illustrates a connector array on a PCB with a short between adjacent connector nodes 1 and 2. If an LED string A is coupled to node 1, and an LED string B is coupled to node 2, the power circuit used to control current flow through LED string A can additionally cause current to flow through LED string B. Thus, fault detection and prevention is necessary for LED channel shorts as well.

[0018] As noted above, the present disclosure describes fault detection circuits for use with LED circuits and LED power circuits. It should be noted that in other embodiments, the described circuits can be used in conjunction with other circuits, systems, and devices. The fault detection circuits can detect the presence of one or more types of circuit faults either before circuit operation (for instance, during a calibration mode) or in real-time during circuit operation. Such flexibility can optimize the likelihood that a fatal circuit fault is detected, and can help reduce the likelihood of damaging the circuit or a related circuit or system.

[0019] Fig. 3 illustrates a set of fault detection circuits for use in LED circuits, LED driver circuits, LED channels, and any other suitable LED circuit, according to one embodiment. In the embodiment of Fig. 3, the fault detection circuits are included on a single IC 120, though it should be noted that in other embodiments, the fault detection circuits can be included on separate ICs, or can be implemented in other contexts. Further, it should be noted that in other embodiments, the fault detection IC 120 only includes a subset of the fault detection circuits described herein. In the embodiment of Fig. 3, the fault detection IC 120 is coupled to an LED channel 115 made up of the LED string 110, the MOSFET 100, and the sense resistor R_{Sense}. It should be noted that although the term "fault detection IC" is used, it should be noted that the fault detection functionality described herein can be incorporated into other circuits, such as LED driver circuits, or can be implemented in standalone circuits.

[0020] The fault detection IC 120 can include an LED short detection circuit configured to detect LED short circuit faults. The LED short detection circuit includes a voltage divider, made up of R_1 and R_2, and a comparator 140. The LED short detection circuit detects shorts across one or more LEDs in the LED string 120. The voltage divider is coupled to the drain node of the MOSFET 100. As noted above, the voltage at the drain node of the MOSFET 100 is equal to the difference between the source voltage V_{LED} and the cumulative voltage drops over the LEDs in the LED string 110.

[0021] The comparator 140 receives the voltage divider voltage V_{DIV} and a reference voltage V_{Ref1}, compares the two voltages, and outputs an error signal LED_short based on the comparison. The values of the resistors R_1 and R_2 can be selected to reduce the voltage at the drain node of the MOSFET 100 by a pre-determined percentage. The reference voltage V_{Ref1} can be selected to satisfy the following two conditions:

1. $V_{Ref1} < V_{DIV}$ if one or more LEDs in the LED string 110 is shorted, and
2. $V_{Ref1} > V_{DIV}$ if no LEDs in the LED string 110 are shorted

[0022] For example, if one or more LEDs in the LED string 110 are shorted, the voltage drop across the LED string will decrease, resulting in a greater voltage at the drain node of the MOSFET 100 than if no LEDs were shorted. The comparator 140 detects such a higher voltage by comparing the voltage V_{DIV}, which is based on the drain voltage of the MOSFET 100, to reference voltage V_{Ref1}, and outputs an error signal LED_short if $V_{DIV} > V_{Ref1}$. It should be noted that the LED short detection circuit can beneficially detect LED short circuit faults during real-time operation of the LED string 110 and MOSFET 100.

[0023] The fault detection IC 120 can include an LED open detection circuit configured to detect LED open circuit faults. The LED open detection circuit includes a comparator 144.

The comparator 144 receives the voltage at the source node of the MOSFET 100 and a reference voltage V_{Ref3}, compares the two voltages, and outputs an error signal LED_open based on the comparison. In the event of an LED open circuit fault condition, no current flows through LED channel 115 (from the source voltage V_{LED} through the MOSFET 100 and the sense resistor R_{sense}). When current is not flowing through the sense resistor R_{sense}, there is no voltage drop across R_{sense}, and the voltage at the source node of the MOSFET 100 is zero.

[0024] The reference voltage V_{Ref3} can be selected to satisfy the following two conditions:

1. $V_{Ref3} > 0$, and
2. $V_{Ref3} < V_{Source}$ during normal operation of LED string 110 (no open circuit fault)

[0025] The comparator 144 is configured to output the error signal LED_open when the voltage V_{Source} is less than the reference voltage V_{Ref3}. For example, if current is flowing from the source voltage V_{LED} through the LED string 110 and the MOSFET 100, the voltage V_{Source} is equal to the product of the current and the resistance of R_{sense}. If the current flowing through the MOSFET 100 is 1A and the resistance of R_{sense} is 2Ω, then V_{Source} is 2V. If V_{Ref3} is selected to be 1V, then the comparator 144 will output the error signal LED_open when no current is flowing through the MOSFET 100 (since V_{Source} will be 0V, less than the 1V reference voltage), and will not output the error signal when the 1A current is flowing through the MOSFET (since V_{Source} will be 2V, greater than the 1V reference voltage). It should be noted that the LED open detection circuit can beneficially detect LED open circuit faults during real-time operation of the LED string 110 and the MOSFET 100.

[0026] The fault detection IC 120 can include a MOSFET short detection circuit configured to detect a short circuit fault between the source and drain nodes of the MOSFET 100. The MOSFET short detection circuit includes the comparator 142. If the drain and source nodes of the MOSFET 100 are shorted, current continuously flows from the source voltage V_{LED} and through the LED string 110 and resistor R_{sense}. In such instances, the voltage V_{Sense} stays higher than V_{ADIM}, and the high-gain amplifier 105 outputs the voltage V_{Gate}, which reflects the continuously high voltage V_{Sense}. Accordingly, V_{Gate} tends towards 0V, lower than the voltage V_{Gate} required to cause the MOSFET 100 to act as an open circuit in normal operation.

[0027] The comparator 142 receives the voltage V_{Gate} and the reference voltage V_{Ref2}, compares the two voltages, and outputs an error signal DS_short based on the comparison. The reference voltage V_{Ref2} can be selected to satisfy the following two conditions:

1. $V_{Ref2} > V_{Gate}$ when V_{Sense} stays high (as a result of a short circuit fault between the drain and source nodes of MOSFET 100), and
2. $V_{Ref2} < V_{Gate}$ during normal operation of MOSFET 100 (the voltage required to configure the MOSFET to act as an open switch)

[0028] The comparator 142 is configured to output the error signal DS_short when the voltage V_{Ref2} is greater than the voltage V_{Gate}. It should be noted that the MOSFET short detection circuit can beneficially detect short circuit faults between the drain node and the source node of the MOSFET 100 during real-time operation of the MOSFET 100.

[0029] The fault detection IC 120 can include a sense resistor short detection circuit configured to detect a short circuit fault across R_{Sense}. The sense resistor short detection circuit includes a comparator, and in one embodiment, includes the comparator 144. When a short circuit fault exists across R_{Sense}, the voltage drop across R_{Sense} is 0V. This is a similar result to an LED open circuit fault - both result in a 0V potential across R_{Sense}. Accordingly, the same comparator can be used to detect both faults. V_{Ref3} can be selected to satisfy the same two conditions discussed above, and the comparator 144 can output the error signal R_{Sense}_short in response to a determination that $V_{Source} < V_{Ref3}$. It should be noted that in other embodiments, the sense resistor short detection circuit and the LED open circuit detector can each include a separate comparator. Further, the sense resistor short detection circuit can beneficially detect sense resistor short circuit faults during the real-time operation of the MOSFET 100.

[0030] The fault detection IC 120 can include a sense resistor open detection circuit configured to detect an open circuit fault across R_{Sense}. When R_{Sense} includes an open circuit fault, current cannot flow through the LED channel 115. The fault detection IC 120 can also include an unused LED channel detection circuit configured to detect if the LED channel 115 is unused. If an LED channel is to be unused, the sense resistor R_{Sense} (generally ~2Ω or less) can be replaced with a much larger resistor, for example 100kΩ or more. Both unused channels and sense resistor open circuit faults prevent enough current from flowing through the LEDs in the LED channel 120 to cause the LEDS to emit light.

[0031] In one embodiment, the sense resistor open detection circuit and the unused LED channel detection circuit are implemented by the same circuit. In addition, in some embodiments, the sense resistor open detection circuit and the unused LED channel detection circuit detect open circuit faults and unused LED channels, respectively, before real-time operation of the LED channel 115, for instance in a calibration mode. In such embodiments, such as the embodiment of Fig. 3, the sensor resistor open detection circuit and the unused

LED channel detection circuit can also be implemented in the same circuit as the LED open detection circuit described above. It should be noted that in other embodiments, the sense resistor open detection circuit, the unused LED channel detection circuit, and the LED open detection circuit can be implemented in separate circuits.

[0032] The sense resistor open detection circuit and the unused LED channel detection circuit include the comparator 144, the comparator 146, the MOSFET 130, the current source I_{Ref}, the input V_{Cal}, and the decoder 148. The comparator 144 receives the voltage at the source node of the MOSFET 100, V_{Source}, compares it to the reference voltage V_{Ref3}, and outputs a signal c1 based on the comparison. Since the detection of sense resistor open circuit faults and unused LED channels occurs in a calibration mode (or any other mode prior to real-time operation of the LED channel 115), the value of V_{Ref3} used by the comparator 144 can be different than the value of V_{Ref3} used when detecting LED open circuit faults. The comparator 146 receives the voltage V_{Source}, compares it to the reference voltage V_{Ref4}, and outputs a signal c2 based on the comparison.

[0033] During the calibration mode, the input V_{Cal} goes high, configuring the MOSFET 130 to act as a closed switch, causing the current I_{Ref} to flow through the MOSFET 130. In embodiments where R_{Sense} includes an open circuit fault, the voltage V_{Source} becomes equal to V_{Test}. For example, V_{Test} can be 5V. In embodiments wherein the LED channel 115 is unused, the voltage V_{Source} is equal to $I_{Ref}*R_{sense}$. For example, if $I_{Ref} = 10\mu A$ and $R_{sense} = 100k\Omega$, then $V_{Source} = 1V$.

[0034] Fig. 4 illustrates a timing diagram for the fault detection circuits of the fault detection IC 120 during a calibration mode, according to one embodiment. Calibration mode begins at time t1. At t1, V_{Cal} goes high for a period of 32μs. During this time interval, V_{ADIM} stays low, preventing operation of the LED channel 115. When V_{Cal} is high, the comparators 144 and 146 produce signals c1 and c2, respectively, and the decoder 148 produces a channel status signal based on c1 and c2. At time t2, V_{Cal} goes low, marking the end of calibration mode. After a period of 32μs, at time t3, V_{ADIM} goes high, and the LED channel 115 operates in a normal mode. It should be noted that the periods of time selected herein for calibration mode are merely exemplary, and can be different in other emobidments.

[0035] In one embodiment, the reference voltage V_{Ref3} can be selected to satisfy the following two conditions:

1. $V_{Ref3} < I_{Ref}*R_{sense}$ when $R_{Sense} > 1k\Omega$, and
2. $V_{Ref3} > I_{Ref}*R_{sense}$ when $R_{Sense} < 1k\Omega$

[0036] The comparator 144 is configured to output the signal c1 as high when $V_{Source} > V_{Ref3}$, and to output the signal c1 as low when $V_{Source} < V_{Ref3}$. Continuing with the previous example, if $I_{Ref}*R_{sense} = 1V$ when $R_{sense} = 100k\Omega$ and if $I_{Ref}*R_{sense} = 20\mu V$ when $R_{sense} = 2\Omega$, then selecting $V_{Ref3} = .5V$ will result in the comparator 144 outputting c1 as high when the LED channel is unused, and outputting c1 as low when the LED channel is used. It should be noted that V_{Ref3}, as well as any of the reference voltages described herein, can be selected according to other criteria than those described herein.

[0037] In one embodiment, the reference voltage V_{Ref4} can be selected to satisfy the following two conditions:

1. $V_{Ref4} < V_{Test}$, and
2. $V_{Ref4} > I_{Ref}*R_{sense}$ when $R_{Sense} \geq 100k\Omega$

[0038] The comparator 146 is configured to output the signal c2 as high when $V_{Source} > V_{Ref4}$, and to output the signal c2 as low when $V_{Source} < V_{Ref4}$. Continuing with the previous example, if $V_{Test} = 5v$, $V_{Ref4} = 4.5V$, and R_{Sense} is open, then $V_{Source} = V_{Test}$, and the comparator will determine that $V_{Source} > V_{Ref4}$, outputting c2 as high. Likewise, if $R_{Sense} < 100k\Omega$, then the comparator will determine that $V_{Source} < V_{Ref4}$, outputting c2 as low.

[0039] The decoder 148 is configured to receive the signal c1 and c2, and is configured to output the signal channel_status in response to the values of c1 and c2. Fig. 5 illustrates a logic table for use by the decoder 148 in detecting faults in a calibration mode, according to one embodiment. When c1 and c2 are low, the output signal channel_status indicates that no fault is detected, and that the LED channel 115 is in use (for example, $R_{Sense} \leq 2\Omega$). When c1 is high and c2 is low, the output signal indicates that the LED channel 115 is not intentionally in use (for example, $R_{Sense} > 100k\Omega$). When c1 is low and c2 are high, the output signal indicates that a fault is detected, and that R_{Sense} includes an open circuit. In other embodiments, the comparators 144 and 146 can output c1 and c2, respectively, according to different criteria than those described herein, and the decoder 148 can output different channel_status signals in response to different criteria or different inputs than those described herein.

[0040] The fault detection IC 120 can include an LED channel short detection circuit configured to detect short circuit faults between LED channels, for instance at the PCB level. Fig. 6 illustrates an LED channel short circuit fault detection circuit, according to one embodiment. The embodiment of Fig. 6 includes two LED channels, channel 1 and channel 2. Each LED channel includes a string of LEDs, a MOSFET, and a sense resistor. The gate of the MOSFET of channel 1 is coupled to the amplifier 155, which receives input signal V_1.

The gate of the MOSFET of channel 2 is coupled to the amplifier 150, which receives input signal V_2.

[0041] The LED channel short detection circuit of Fig. 6 includes the comparator 160, which is configured to receive the gate voltage of the MOSFET of channel 1 (V_{Drain1}), and the reference voltage V_{Ref1}. The comparator 160 is further configured to compare V_{Drain1} and V_{Ref1}, and to output the signal channel_short_1 in response to the comparison. Similarly, the LED channel short detection circuit of Fig. 6 includes the comparator 162, which is configured to receive the gate voltage of the MOSFET of channel 2 (V_{Drain2}), and the reference voltage V_{Ref2}. The comparator 162 is further configured to compare V_{Drain2} and V_{Ref2}, and to output the signal channel_short_2 in response to the comparison. It should be noted that in some embodiments the reference voltages V_{Ref1} and V_{Ref2} are the same voltage. In addition, in some embodiments, the signals channel_short_1 and channel_short_2 are the same signal (as a short between channel 1 and channel 2 is detectable by either comparator 160 or 162).

[0042] In the embodiment of Fig. 6, channel 1 and channel 2 include a short circuit fault 165, which couples the drain node of the MOSFET of channel 1 (D_1) to the drain node of the MOSFET of channel 2 (D_2). The short circuit fault 165 in the embodiment of Fig. 6 is shown external to the fault detection IC (for instance, at the PCB level), but it should be noted that in some embodiments, short circuit faults between LED channels can be internal to the fault detection IC. The short 165 causes the voltage on the drain nodes of the MOSFETs to be the same. In embodiments without the short 165, for example, when V_2 is high and V_1 is low, the MOSFET of channel 2 is configured to act as a closed switch and the MOSFET of channel 1 is configured to act as an open switch. Accordingly, current is configured to flow through channel 2, but not channel 1. In such circumstances, the voltage at the drain of the MOSFET of channel 1 is equivalent to the LED supply voltage V_{C1}, since no current is flowing through channel 1. In embodiments with the short 165, current can flow through the LED string of channel 1, through the short 165, and through the MOSFET of channel 2. In such circumstances, the voltage at the drain node of the MOSFET of channel 1 is lower than if no current were flowing through the LED string of channel 1.

[0043] In one embodiment, the reference voltage V_{Ref1} can be selected to satisfy the following two conditions:

1. $V_{Ref1} < V_{C1}$, and
2. $V_{Ref1} > V_{Drain1}$ when current is flowing through the MOSFET of channel 1 (for instance, when V_1 is high)

[0044] Similarly, in one embodiment, the reference voltage V_{Ref2} can be selected to satisfy the following two conditions:

1. $V_{Ref2} < V_{C2}$, and
2. $V_{Ref2} > V_{Drain2}$ when current is flowing through the MOSFET of channel 2 (for instance, when V_2 is high)

[0045] Referring to fault detection embodiments by channel 1, the comparator 160 compares V_{Ref1} and V_{Drain1}, outputs channel_short_1 as high if $V_{Drain1} < V_{Ref1}$ (indicating the presence of short 165), and outputs channel_short_1 as low if $V_{Drain1} > V_{Ref1}$ (indicating that no short is detected between channels). Referring to fault detection embodiments by channel 2, the comparator 162 can output channel_short_2 similarly based on a comparison of V_{Drain2} and V_{Ref2}. The detection of shorts between LED channels can occur before operation, for instance in the calibration mode described above or during PCB manufacture. Accordingly, the LED channel short detection circuit and the LED short detection circuit described above can be implemented with the same comparator. For example, the comparator 140 of Fig. 3 and the comparator 160 of Fig. 6 can be the same comparator. In such embodiments, the reference voltages V_{Ref1} of Fig. 3 and V_{Ref1}/ V_{Ref2} of Fig. 6 can be different, and can change based on the mode of operation (calibration mode vs. normal mode). It should be noted that in calibration mode, every combination of LED channel pairs in an LED channel array can be individually tested as described herein to detect the presence of a short between any two LED channels.

[0046] Upon reading this disclosure, those of skill in the art will appreciate still additional alternative designs for controlling the dimming operation of an LED. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the embodiments discussed herein are not limited to the precise construction and components disclosed herein and that various modifications, changes and variations which will be apparent to those skilled in the art may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope of the disclosure.

WHAT IS CLAIMED IS:

1. An LED fault detection circuit configured to detect one or more faults of an LED channel comprising one or more LEDs coupled to a drain node of a transistor and a resistor coupled to a source node of the transistor, the circuit comprising:

a first fault detection circuit configured to detect a short fault across one or more of the LEDs, the first fault detection circuit coupled to the drain node of the transistor;

a second fault detection circuit configured to detect an open fault within the one or more LEDs, the second fault detection circuit coupled to a source node of the transistor; and

a third fault detection circuit configured to detection a short fault across the drain node and the source node of the transistor, the third fault detection circuit coupled to the gate node of the transistor.

2. The LED fault detection circuit of claim 1, wherein the first fault detection circuit comprises a voltage divider coupled to the drain node of the transistor, the voltage divider comprising a first resistor and a second resistor coupled at a first node, the first fault detection circuit further comprising a comparator coupled to the first node.

3. The LED fault detection circuit of claim 2, wherein the comparator is configured to compare a voltage at the first node to a reference voltage and to output a fault signal indicating the presence or absence of a short fault across one or more of the LEDs based on the comparison.

4. The LED fault detection circuit of claim 1, wherein the second fault detection circuit comprises a comparator coupled to the source node of the transistor.

5. The LED fault detection circuit of claim 4, wherein the comparator is configured to compare a voltage at the source node of the transistor to a reference voltage and to output a fault signal indicating the presence or absence of an open fault within the one or more LEDs based on the comparison.

6. The LED fault detection circuit of claim 1, wherein the third fault detection circuit comprises a comparator coupled to the gate node of the transistor.

7. The LED fault detection circuit of claim 6, wherein the comparator is configured to compare a voltage at the gate node of the transistor to a reference voltage and to output a fault

signal indicating the presence or absence of a short fault across the drain node and the source node of the transistor based on the comparison.

8. The LED fault detection circuit of claim 1, further comprising:

a fourth fault detection circuit configured to detect an open fault across the resistor, the fourth fault detection circuit coupled to the source node of the transistor.

9. The LED fault detection circuit of claim 8, the fourth fault detection circuit comprising:

a second transistor, the source node of the second transistor coupled to the source node of the transistor;

a current source coupled to the drain node of the second transistor; and

a comparator coupled to the source node of the transistor.

10. The LED fault detection circuit of claim 9, wherein the comparator is configured to, when the transistor is configured to operate as an open switch and when the second transistor is configured to operate as a closed switch, compare the voltage at the source node of the transistor to a reference voltage and to output a fault signal indicating the presence or absence of an open fault across the resistor based on the comparison.

11. The LED fault detection circuit of claim 9, further comprising:

a fifth fault detection circuit configured to detect an unused LED channel, the fifth fault detection coupled to the source node of the transistor.

12. The LED fault detection circuit of claim 11, the fifth fault detection circuit comprising:

a second comparator coupled to the source node of the transistor, wherein the second comparator is configured to, when the transistor is configured to operate as an open switch and when the second transistor is configured to operate and when the second transistor is configured to operate as a closed switch, compare the voltage at the source node of the transistor to a second reference voltage greater than the reference voltage, and to output a second fault signal indicating that the LED channel is used or unused.

13. The LED fault detection circuit of claim 12, further comprising:

a decoder coupled to the comparator and to the second comparator and configured to receive the fault signal and the second fault signal, and to output a status signal indicative of a state of the LED channel.

14. An LED fault detection integrated circuit configured to detect faults of an LED channel, the integrated circuit comprising:

a first set of one or more fault detection circuits coupled to a source node of an LED channel transistor and configured to detect one or more LED channel faults when the integrated circuit is configured in a calibration mode; and

a second set of one or more fault detection circuits configured to detect one or more LED channel faults when the integrated circuit is configured in an operating mode, at least one of the second set of fault detection circuits coupled to one of a drain node, a gate node, and a source node of the LED channel transistor.

15. The LED fault detection integrated circuit of claim 14, the first set of fault detection circuits comprising:

a first fault detection circuit configured to detect an open fault at the source node of the LED channel transistor, the first fault detection circuit comprising:

a second transistor, the source node of the second transistor coupled to the source node of the LED channel transistor;

a current source coupled to a drain node of the second transistor; and

a comparator coupled to a source node of the LED channel transistor, the comparator configured to compare a voltage at the source node of the LED channel transistor to a reference voltage and to output a fault signal indicating the presence or absence of an open fault at the source node of the LED channel transistor.

16. The LED fault detection integrated circuit of claim 15, the first set of fault detection circuits further comprising:

a second fault detection circuit configured to detect an unused LED channel, the second fault detection circuit comprising:

a second comparator coupled to the source node of the LED channel transistor, the second comparator configured to compare the voltage at the source node of the LED channel transistor to a second reference voltage and to output a second fault signal indicating that the LED channel is used or unused.

17. The LED fault detection integrated circuit of claim 16, further comprising:

a decoder coupled to the comparator and to the second comparator and configured to receive the fault signal and the second fault signal, and to output a status signal indicative of a state of the LED channel.

18. The LED fault detection integrated circuit of claim 14, wherein the second set of fault detection circuits comprises:

a first fault detection circuit comprising:

a voltage divider coupled to a drain node of the LED channel transistor, the voltage divider comprising a first resistor and a second resistor coupled at a first node; and

a comparator coupled to the first node, the comparator configured to compare a voltage at the first node to a reference voltage and to output a fault signal indicating the presence or absence of a short fault across one or more LEDs in the LED channel.

19. The LED fault detection integrated circuit of claim 18, wherein the second set of fault detection circuits further comprises:

a second fault detection circuit comprising:

a second comparator coupled to the source node of the LED channel transistor, the second comparator configured to compare the voltage at the source node of the transistor to a second reference voltage and to output a second fault signal indicating the presence or absence of an open fault within the one or more LEDs based on the comparison.

20. The LED fault detection integrated circuit of claim 19, wherein the second set of fault detection circuits further comprises:

a third fault detection circuit comprising:

a third comparator coupled to the gate node of the LED channel transistor, the third comparator configured to compare a voltage at the gate node of the LED channel transistor to a reference voltage and to output a third fault signal indicating the presence or absence of a short fault across the drain node and the source node of the LED channel transistor based on the comparison.

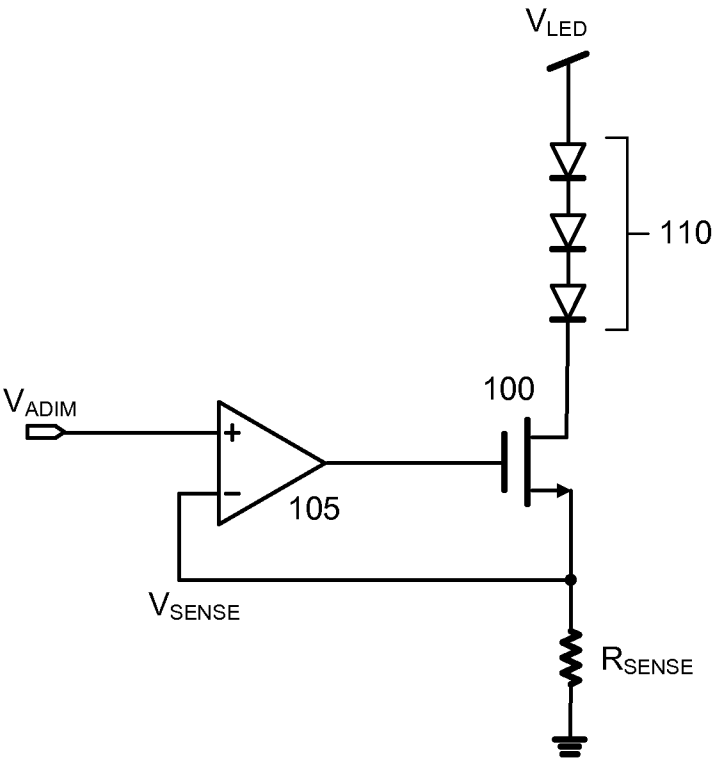

V_{LED}
110
100
V_{ADIM}
+
−
105
V_{SENSE}
R_{SENSE}

FIG. 1

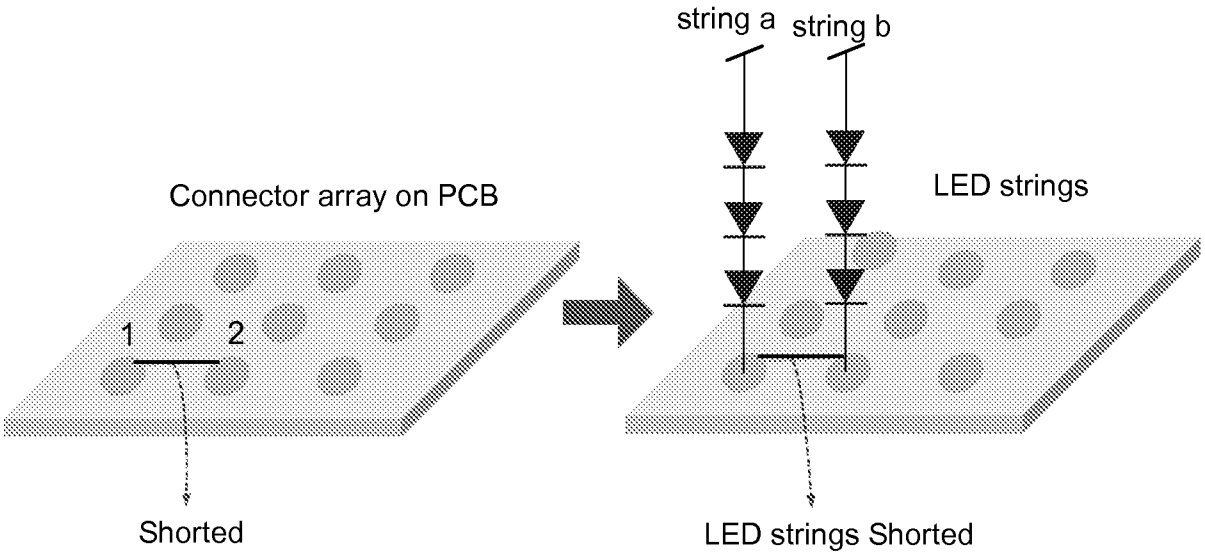

string a
string b
Connector array on PCB
LED strings
1
2
Shorted
LED strings Shorted

FIG. 2

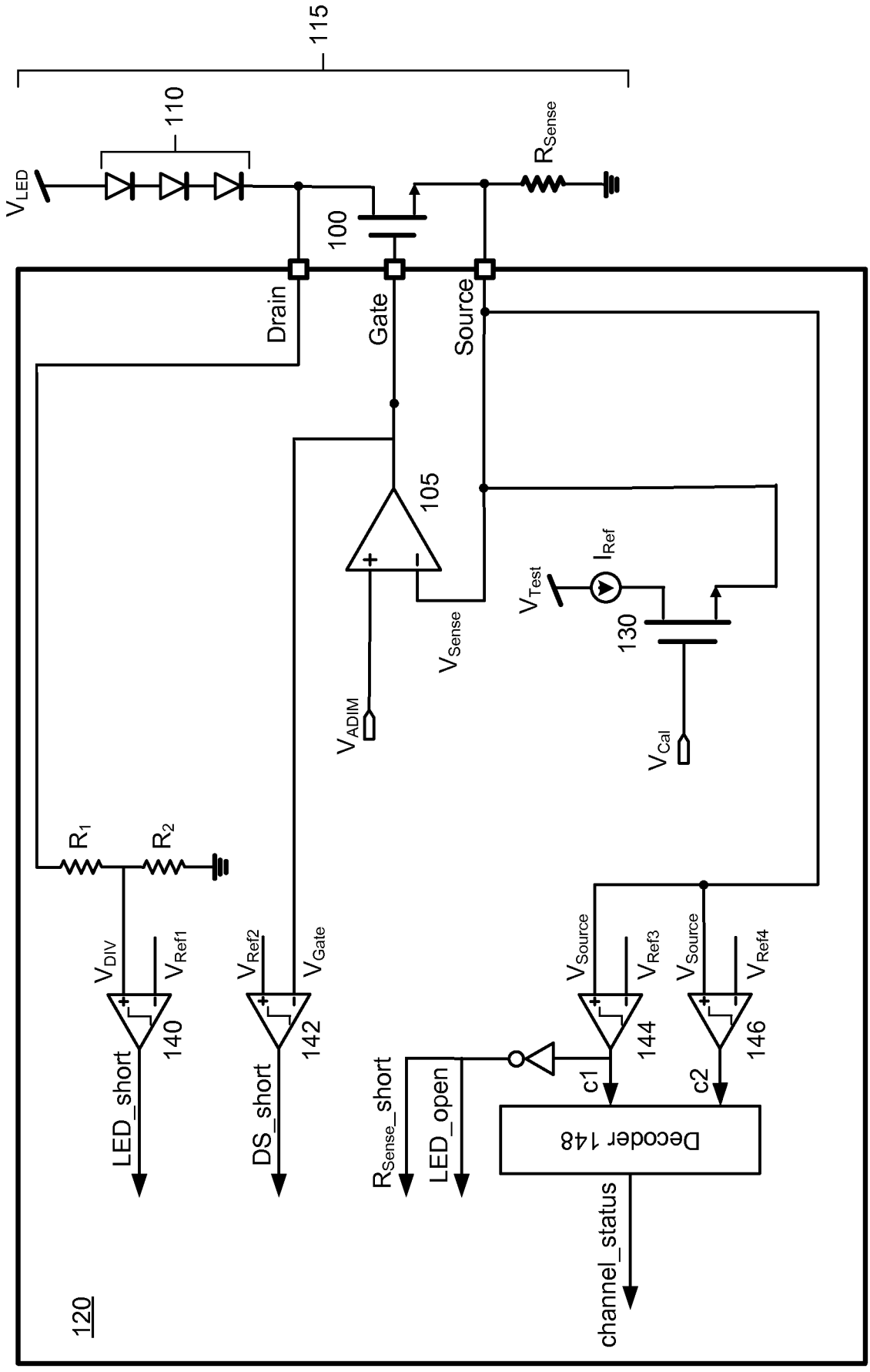

115
110
V_{LED}
R_{Sense}
100
Drain
Gate
Source
105
V_{ADIM}
V_{Sense}
V_{Test}
I_{Ref}
130
V_{Cal}
R_1
R_2
V_{DIV}
V_{Ref1}
140
LED_short
V_{Ref2}
V_{Gate}
142
DS_short
V_{Source}
V_{Ref3}
144
c1
V_{Source}
V_{Ref4}
146
c2
R_{Sense}_short
LED_open
Decoder 148
channel_status
120

FIG. 3

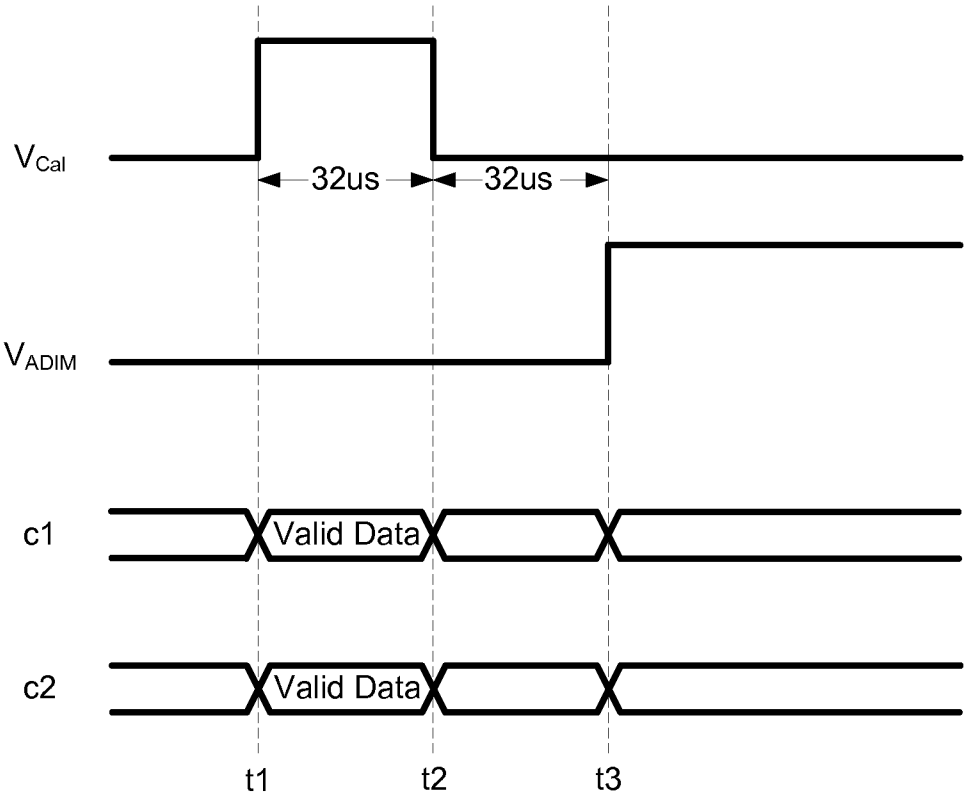


FIG. 4

c1	c2	Conclusion
Low	Low	Channel in use ($R_{Sense} \leq 2\Omega$)
High	Low	Channel unused ($R_{Sense} > 100k\Omega$)
High	High	R_{Sense} = open circuit

FIG. 5

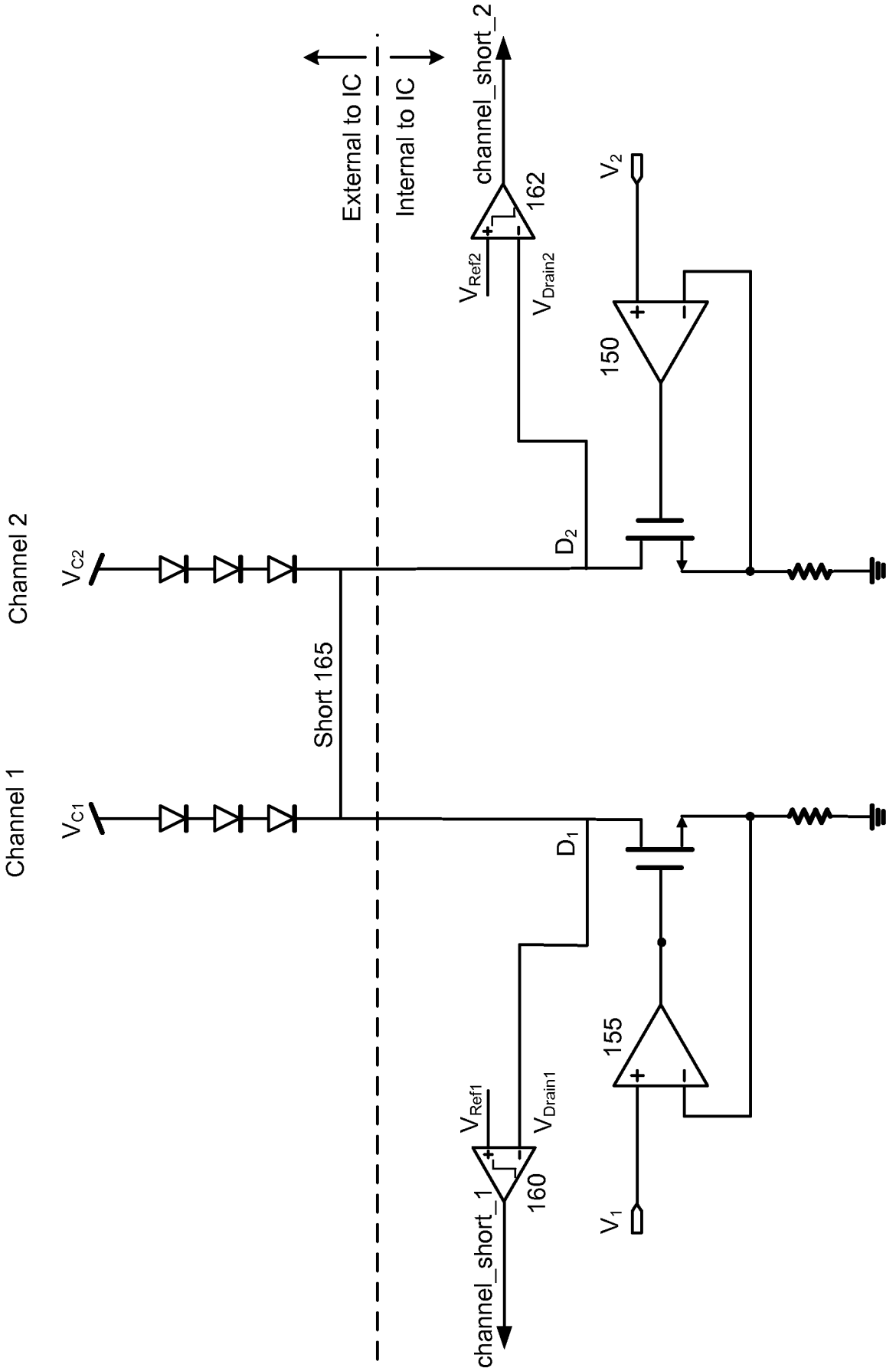

External to IC
Internal to IC
channel_short_2
162
V_{Ref2}
V_{Drain2}
V_2
150
D_2
Channel 2
V_{C2}
Short 165
Channel 1
V_{C1}
D_1
155
V_{Ref1}
V_{Drain1}
160
channel_short_1
V_1

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/042591

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H05B 37/03 (2014.01)
CPC - H05B 37/03 (2014.09)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - H05B 37/03, 37/00; F21S 4/00; F21V 25/00, 25/10; G05B 1/00, 1/01, 1/02, 9/00, 9/02, 9/03, 19/048, 24/00, 24/02 (2014.01)
USPC - 315/32, 51, 185R, 193, 312, 313

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - H05B 37/03, 37/00, 37/032, 37/036; F21S 4/00, 4/001, 4/003, 4/006, 4/007, 4/008; F21V 25/00, 25/10; G05B 1/00, 1/01, 1/02, 9/00, 9/02, 9/03, 9/048, 24/00, 24/02 (2014.09)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Orbit, Google Patents, Google Scholar, Google.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 7550934 B1 (DENG et al) 23 June 2009 (23.06.2009) entire document	1-20
Y	US 2007/0257725 A1 (DE et al) 08 November 2007 (08.11.2007) entire document	1-13, 20
Y	WO 9855880 A1 (HAMIDA et al) 10 December 1998 (10.12.1998) entire document	1-13, 20
Y	US 2013/0093339 A1 (CHEN et al) 18 April 2013 (18.04.2013) entire document	9-13, 15-17
Y	US 2013/0016310 A1 (KANEMITSU et al) 17 January 2013 (17.01.2013) entire document	11-13, 16-17
Y	US 2012/0223648 A1 (JIN et al) 06 September 2012 (06.09.2012) entire document	12-20
A	US 2013/0147375 A1 (WILLIAMS et al) 13 June 2013 (13.06.2013) entire document	1-20
A	US 2013/0099681 A1 (WILLIAMS et al) 25 April 2013 (25.04.2013) entire document	1-20
A	US 2013/0082615 A1 (WILLIAMS et al) 04 April 2013 (04.04.2013) entire document	1-20
A	US 2013/0049599 A1 (LOGIUDICE) 28 February 2013 (28.02.2013) entire document	1-20
A	US 2012/0299483 A1 (LETHELLIER) 29 November 2012 (29.11.2012) entire document	1-20
A	US 2012/0235574 A1 (SUMI et al) 20 September 2012 (20.09.2012) entire document	1-20
A	US 2012/0206146 A1 (AVENEL) 16 August 2012 (16.08.2012) entire document	1-20
A	US 2012/0176039 A1 (SATO et al) 12 July 2012 (12.07.2012) entire document	1-20

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 September 2014	28 OCT 2014
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/042591

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/0068614 A1 (NG et al) 22 March 2012 (22.03.2012) entire document	1-20
A	US 2011/ 0254530 A1 (HULETT) 20 October 2011 (20.10.2011) entire document	1-20
A	US 2011/0169424 A1 (ABOULNAGA) 14 July 2011 (14.07.2011) entire document	1-20
A	US 2011/0068700 A1 (FAN) 24 March 2011 (24.03.2011) entire document	1-20
A	US 2009/ 0322234 A1 (CHEN et al) 31 December 2009 (31.12.2009) entire document	1-20
A	US 2007/0013322 A1 (TRIPATHI et al) 18 January 2007 (18.01.2007) entire document	1-20
A	US 2006/0170287 A1 (ITO et al) 03 August 2006 (03.08.2006) entire document	1-20
A	US 2005/0212459 A1 (PATEL et al) 29 September 2005 (29.09.2005) entire document	1-20
A	US 2005/0057179 A1 (MADHANI et al) 17 March 2005 (17.03.2005) entire document	1-20
A	US 5352937 A (DINGWALL) 04 October 1994 (04.10.1994) entire document	1-20