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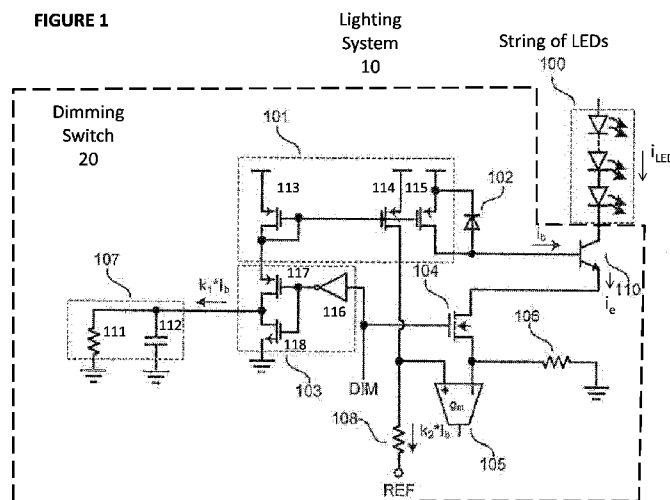
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(54) Title: CASCADE-TYPE DIMMING SWITCH USING A BIPOLAR JUNCTION TRANSISTOR FOR DRIVING A STRING OF LIGHT EMITTING DIODES

FIGURE 1



(S7) Abstract: The invention comprises a dimming switch for use with a string of light emitting diodes (LEDs). The dimming switch comprises a bipolar junction transistor (BJT) driven in a cascode scheme. The dimming switch also comprises circuitry to offset the current that drives the base of the BJT to provide a controlled amount of current to the LEDs when the dimming input signal is high.

CASCODE-TYPE DIMMING SWITCH USING A BIPOLAR JUNCTION TRANSISTOR FOR DRIVING A STRING OF LIGHT EMITTING DIODES

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from U.S. Provisional Application No. 61/907,819, filed on November 22, 2013, and titled “Cascode-Type Dimming Switch Using BJT,” which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The invention comprises a dimming switch for use with a string of light emitting diodes (LEDs). The dimming switch comprises a bipolar junction transistor (BJT). The dimming switch also comprises control circuitry to offset the current that drives the base of the BJT to provide a controlled amount of current to the LEDs when the dimming input signal is high. The invention is useful for numerous applications, including LCD panel backlighting.

BACKGROUND OF THE INVENTION

[0003] The prior art includes some solutions for dimming switches for LEDs. These solutions typically utilize field effect transistors (FETs) to control the current driven through the LEDs. BJTs have not been used in this context because of two drawbacks. First, BJTs have a slow switching speed compared to FETs. Second, because the current through the base of a BJT is added to the current through the emitter of the BJT, the current through the LEDs (which would be connected to the collector of the BJT) cannot be properly sensed and controlled. However, high-voltage BJTs are cheaper and easier to manufacture than FETs, and the overall cost of a dimming switch could be improved by using BJTs instead of FETs.

[0004] A dimming switch for LEDs that utilizes a FET and BJT in a cascode configuration can combine the benefits of the fast switching speed of an FET and the low cost of a BJT. However, the source current of the low-voltage FET in a cascode configuration will not be an accurate representation of the current through the LEDs connected to the BJT collector, as the source current of the FET will be offset by base current of the high-voltage BJT. Therefore, a current sense resistor placed in series with the FET source will produce an erroneous sense voltage. What is needed is control circuitry for driving a BJT-FET cascode while negating the effect of the BJT base current in the current sense resistor.

SUMMARY OF THE INVENTION

[0005] The invention comprises a dimming switch for use with a string of LEDs. The dimming switch comprises a BJT and FET in a cascode configuration. The dimming switch also comprises circuitry to offset the current that drives the base of the BJT to provide a controlled amount of current to the LEDs when the dimming input signal is high.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Figure 1 depicts an embodiment of a dimming switch for LEDs.

[0007] Figure 2 depicts certain current characteristics of different nodes within the embodiment of Figure 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0008] Figure 1 depicts lighting system 10 comprising string of LEDs 100 and dimming switch 20. Dimming switch 20 in this example is a pulse width modulation (PWM) dimming switch.

[0009] Dimming switch 20 comprises FET 104 acting as an emitter driver switch controlled by an input dimming signal DIM (which is a PWM signal) and a high-voltage BJT 110. Dimming switch 20 is connected in series with string of LEDs 100. The current magnitude through string of

LEDs 100 is controlled by a current feedback amplifier 105 receiving a current sense signal from a resistor 106 and regulating the current sense signal to a reference voltage REF.

[0010] Base current i_b is supplied to BJT 110 by a current mirror circuit 101 in proportion with a reference current $k_1 \cdot i_b$ programmed by a current reference network such as resistor-capacitor (RC) network 107. Control switch 103 enables the reference current $k_1 \cdot i_b$ when the dimming signal DIM is received. In this example, control switch 103 comprises inverter 116, transistor 117, and transistor 118 in the configuration shown in Figure 1. One of ordinary skill in the art will appreciate that other types of logic gates can be used instead of inverter 116.

[0011] A second proportional current $k_2 \cdot i_b$ generated by current mirror circuit 101 offsets the reference voltage REF to cancel the effect of the base current i_b in the current i_{LED} through string of LEDs 100. The offset of the reference voltage REF is generated at a resistor 108 by passing the current $k_2 \cdot i_b$ through resistor 108.

[0012] A diode 102 facilitates fast turn off of the BJT 110.

[0013] Dimming switch 20 shown in Figure 1 can be characterized as a means for driving current through a string of LEDs 100 in response to a dimming input signal.

[0014] Operation of lighting system 10 will now be described with reference to Figures 1 and 2. In Figure 2, an exemplary pulse of the input signal DIM is depicted. In lighting system 10, dimming is achieved through the pulse width modulation input signal DIM. Lower light will be emitted from string of LEDs 100 if the width of the pulses of input signal DIM is reduced, or if the frequency of the pulses within input signal DIM is reduced.

[0015] When input signal DIM is low, the output of inverter 116 is high. As a result, transistor 117 is turned off, and transistor 118 is turned on. Any charge stored on capacitor 112 is removed through resistor 111 and through transistor 118 to ground. FET 104 is turned off, and no current flows through the emitter of BJT 110. Any residual current in LED string 100 flows through the base of BJT 110 and through diode 102.

[0016] When input signal DIM goes high, such as at time t_1 , the output of inverter 116 goes low. As a result, transistor 117 is turned on, and transistor 118 is turned off. FET 104 is turned on, and current i_e is drawn through the emitter of BJT 110. Current $k_1 \cdot i_b$ is drawn through transistors 113 and 117 and charges capacitor 112. As shown in Figure 2, the current i_b initially spikes as the capacitor begins to charge and eventually plateaus once the capacitor is charged and the current $k_1 \cdot i_b$ flows through resistor 111. Current mirror 101 generates current $k_2 \cdot i_b$ through resistor 108 and current i_b into the base of BJT 110. Here, k_1 and k_2 are based on the relative matching characteristics of transistors 113, 114, and 115. Arbitrary values for k_1 and k_2 can be selected. Ideally, k_1 and $k_2 \gg 1$ to achieve low current consumption. In this embodiment, cancellation of the base current i_b assumes that $R_{106} = k_2 \cdot R_{108}$.

[0017] In BJT 110, the current i_e through the emitter will equal the sum of i_{LED} through string of LEDs 100 (which is the current through the collector of BJT 110) and i_b (which is the current through the base of BJT 110). As shown in Figure 2, the magnitude of i_{LED} ideally will be unaffected by the base current i_b and will have a fast response to the input signal DIM. Current feedback amplifier 105 adds the offset of $k_2 \cdot i_b \cdot R_{108}$ into the reference REF path, and the turn-on process is accelerated by capacitor 112 and the turn-off process is accelerated by diode 102 and the cascode connection of FET 104 and BJT 110.

[0018] Current feedback amplifier 105 will seek to maintain a voltage of $REF + k_2 \cdot i_b \cdot R_{108}$ at the inverting node, which will develop at resistor 106. The current through resistor 106 therefore will be $i_e = (REF + k_2 \cdot i_b \cdot R_{108}) / R_{106} = (REF / R_{106}) + i_b$. . Hence the LED current $i_{LED} = i_e - i_b = REF / R_{106}$, is unaffected by the base current i_b . The current through the emitter, i_e , is also shown in Figure 2. As can be seen, dimming switch 20 corrects for the current i_b that flows into the base of BJT 110.

[0019] Thus, the embodiment comprises a dimming switch using a cascode connection of a BJT 110 and a source driver MOSFET 104 where the current through the string of LEDs 100 is not affected by the current driving the base of the BJT.

What Is Claimed Is:

1. A dimming switch for use with a string of light emitting diodes, comprising:
a bipolar junction transistor and a field effect transistor coupled in a cascode configuration, the gate of the field effect transistor receiving a dimming input signal and the collector of the bipolar junction transistor capable of driving a string of light emitting diodes; and
a control circuit coupled to the bipolar junction transistor and the field effect transistor, wherein the current through the collector is unaffected by the current through the base of the bipolar junction transistor.
2. The switch of claim 1, further comprising: a current mirror connected to the base of the bipolar junction transistor.
3. The switch of claim 2, wherein the control circuit comprises: a current feedback amplifier comprising an inverting input and a non-inverting input, the non-inverting input connected to the current mirror and one end of a reference resistor and the inverting input connected to the drain of the emitter driver switch and to a sense resistor and another end of the reference resistor connected to a reference voltage, wherein the current feedback amplifier regulates a voltage at the inverting input equal to the reference voltage when the dimming input signal is high.
4. The switch of claim 3, wherein the control circuit further comprises:
a control switch for receiving the dimming input signal and for connecting the current mirror to a current reference network, wherein the current reference network draws a current from the current mirror, and the current mirror provides a proportional current to the reference resistor

and a proportional current to the base; and wherein the current through the collector is a function of the reference voltage and sense resistor when the dimming input signal is high.

5. The dimming switch of claim 4, wherein the current mirror comprises:
three field effect transistors, each comprising a source, a gate, and a drain,
wherein a source of each of the three field effect transistors is coupled to a voltage source
and a gate of each of the three field effect transistors is coupled together.

6. The dimming switch of claim 5, further comprising a diode comprising a first
terminal and a second terminal, the first terminal connected to the base and the second terminal
connected to the voltage source.

7. The dimming switch of claim 4, wherein the control switch comprises:
a logic gate for receiving the dimming input signal;
a first transistor connected in series to a second transistor, the gate of the first transistor
and the gate of the second transistor receiving an output of the inverter; and
the first transistor connected to the current mirror and the second transistor connected to
ground;
wherein a node between the first transistor and the second transistor is connected to the
current reference network.

8. The dimming switch of claim 4, wherein the current reference network comprises
at least one resistor and at least one capacitor.

9. The dimming switch of claim 1, wherein the dimming input signal is a pulse width modulation signal.

10. The dimming switch of claim 4, wherein the dimming input signal is a pulse width modulation signal.

11. The dimming switch of claim 6, wherein the dimming input signal is a pulse width modulation signal.

12. A lighting system responsive to a dimming input signal, comprising:
a bipolar junction transistor and a field effect transistor coupled in a cascode configuration, the gate of the field effect transistor receiving a dimming input signal;
a string of light emitting diodes connected to the collector of the bipolar junction transistor; and
a control circuit coupled to the bipolar junction transistor and the field effect transistor, wherein the current through the collector is unaffected by the current through the base of the bipolar junction transistor.

13. The system of claim 12, further comprising: a current mirror connected to the base of the bipolar junction transistor.

14. The system of claim 13, wherein the control circuit comprises: a current feedback amplifier comprising an inverting input and a non-inverting input, the non-inverting input connected to the current mirror and one end of a reference resistor and the inverting input connected to the drain of the emitter driver switch and to a sense resistor and another end of the

reference resistor connected to a reference voltage, wherein the current feedback amplifier regulates a voltage at the inverting input equal to the reference voltage when the dimming input signal is high.

15. The system of claim 14, wherein the control circuit further comprises:
a control switch for receiving the dimming input signal and for connecting the current mirror to a current reference network, wherein the current reference network draws a current from the current mirror, and the current mirror provides a proportional current to the reference resistor and a proportional current to the base; and wherein the current through the collector is a function of the reference voltage and sense resistor when the dimming input signal is high.

16. The system of claim 15, wherein the current mirror comprises:
three field effect transistors, each comprising a source, a gate, and a drain,
wherein a source of each of the three field effect transistors is coupled to a voltage source and a gate of each of the three field effect transistors is coupled together.

17. The system of claim 16, further comprising a diode comprising a first terminal and a second terminal, the first terminal connected to the base and the second terminal connected to the voltage source.

18. The system of claim 15, wherein the control switch comprises:
a logic gate for receiving the dimming input signal;
a first transistor connected in series to a second transistor, the gate of the first transistor and the gate of the second transistor receiving an output of the inverter; and

the first transistor connected to the current mirror and the second transistor connected to ground;

wherein a node between the first transistor and the second transistor is connected to the current reference network.

19. The system of claim 15, wherein the current reference network comprises at least one resistor and at least one capacitor.

20. The system of claim 12, wherein the dimming input signal is a pulse width modulation signal.

21. The system of claim 15, wherein the dimming input signal is a pulse width modulation signal.

22. The system of claim 17, wherein the dimming input signal is a pulse width modulation signal.

23. A dimming switch for use with a string of light emitting diodes, comprising:
a means for driving current through the string of light emitting diodes in response to a dimming input signal.

24. The switch of claim 23, wherein the dimming input signal is a pulse width modulation signal.

25. A lighting system, comprising:

a string of light emitting diodes;

a means for driving current through the string of light emitting diodes in response to a dimming input signal.

26. The system of claim 25, wherein the dimming input signal is a pulse width modulation signal.

FIGURE 1

Lighting System 10

String of LEDs

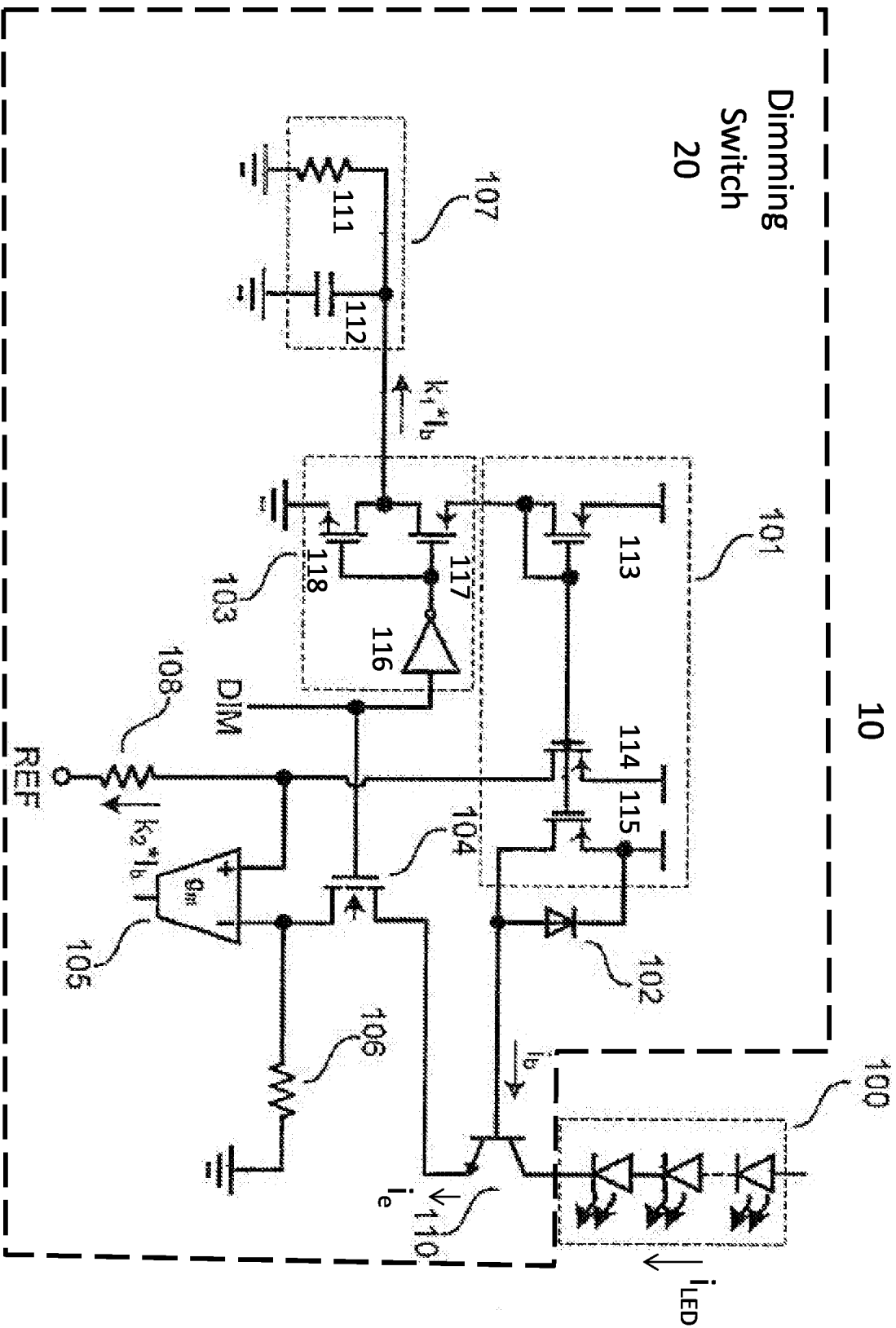
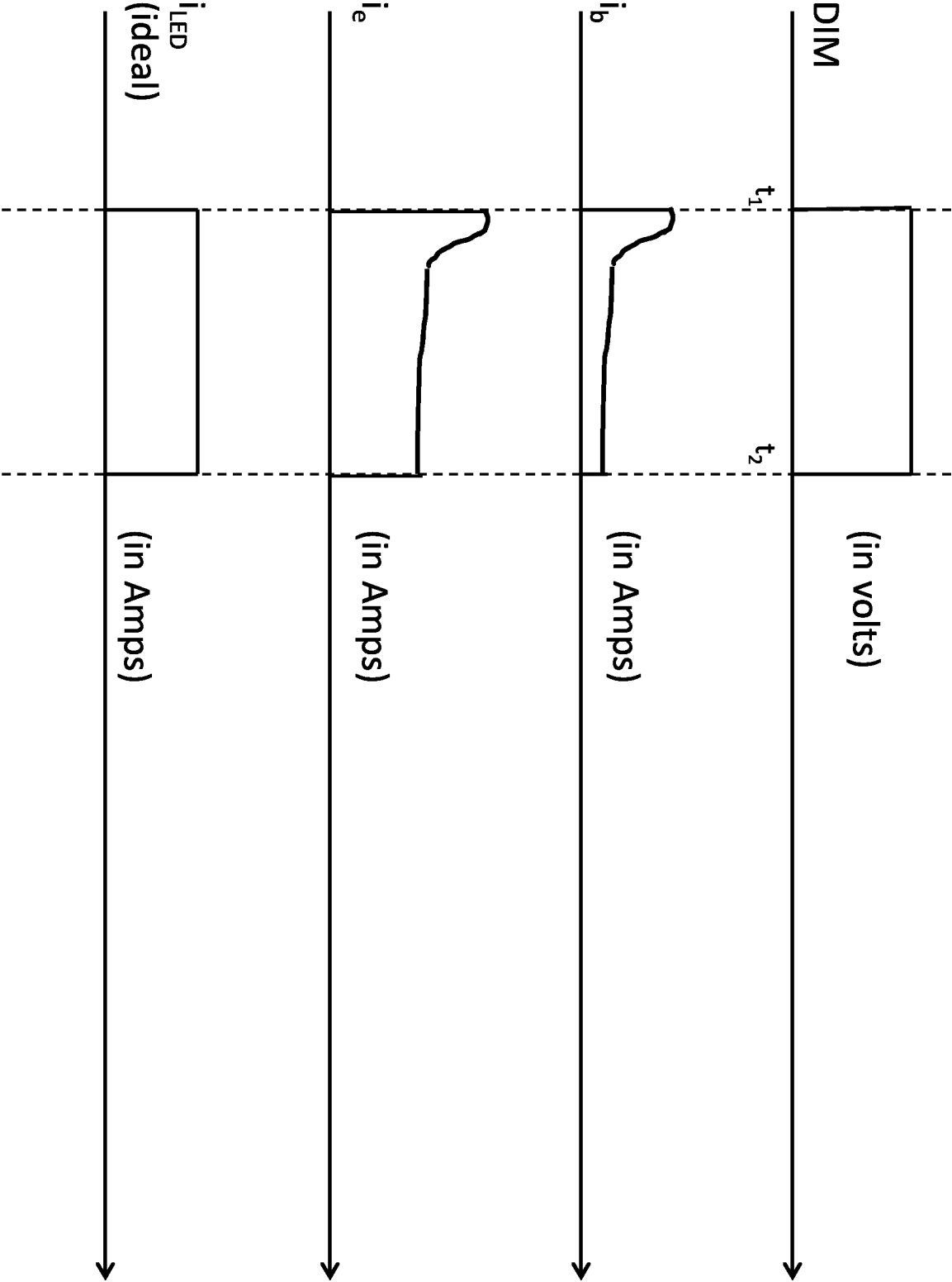


FIGURE 2



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/066936

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B33/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/143266 A1 (LANGER TAMIR [IL]) 19 June 2008 (2008-06-19)	1,9,12, 20,23-26
Y	pages 2-5; figure 3	2-8,10, 11, 13-18, 21,22
Y	----- CN 102 791 062 A (GUANGZHOU ON BRIGHT ELECTRONICS CO LTD) 21 November 2012 (2012-11-21)	2-8,10, 11, 13-18, 21,22
Y,P	the whole document & US 2014/015429 A1 (LUO QIANG [CN] ET AL) 16 January 2014 (2014-01-16)	2-8,10, 11, 13-18, 21,22
	paragraphs [0015] - [0022]; figure 2 ----- -/--	



Further documents are listed in the continuation of Box C.



See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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INTERNATIONAL SEARCH REPORT

International application No
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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 5 966 110 A (VAN ZALINGE KLAAS [FR]) 12 October 1999 (1999-10-12) the whole document -----	1-26

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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