US Patent & Trademark Office
Patent Public Search | Text View

United States Patent	12387652
Kind Code	B2
Date of Patent	August 12, 2025
Inventor(s)	Farrokh Baroughi; Mahdi et al.

Dynamic Vreset and VSSEL tuning for better low gray accuracy and power saving

Abstract

A control circuit adjusts a value of a source supply voltage VSSEL provided to a display area in an electronic display. The control circuit also adjusts a voltage Vreset applied to the display area to cause the display area to emit light more uniformly under various ambient conditions (e.g., temperature) surrounding the display area. Dynamically changing Vreset is employed to make anode charging dynamics independent of temperature. The control circuit adjusts the source supply voltage VSSEL and the voltage Vreset together to compensate display pixel hysteresis effects and display artifacts caused by temperature changes and brightness changes of the display area and collectively produce images. Dynamically tuning the Vreset and the VSSEL voltages also saves power and improves gray level accuracy for the electronic display.

Inventors: **Farrokh Baroughi; Mahdi (Santa Clara, CA), Bae; Hopil (Palo Alto, CA), Rim; Seung B (Pleasanton, CA), Li; Haitao (Mountain View, CA), Jang; Sunmin (Sunnyvale, CA), Zhang; Ce (Cupertino, CA)**

Applicant: **Apple Inc.** (Cupertino, CA)

Family ID: **1000008749051**

Assignee: **Apple Inc. (Cupertino, CA)**

Appl. No.: **18/204927**

Filed: **June 01, 2023**

Prior Publication Data

Document Identifier	Publication Date
US 20240005833 A1	Jan. 04, 2024

Related U.S. Application Data

Publication Classification

Int. Cl.: **G09G3/20** (20060101); **G09G3/3233** (20160101)

U.S. Cl.:

CPC **G09G3/2007** (20130101); **G09G3/3233** (20130101); G09G2300/0842 (20130101); G09G2310/08 (20130101); G09G2320/041 (20130101); G09G2330/021 (20130101); G09G2354/00 (20130101)

Field of Classification Search

CPC: G09G (3/2007); G09G (3/3233); G09G (2300/0842); G09G (2310/08); G09G (2320/041); G09G (2330/021); G09G (2354/00)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
7230596	12/2006	Guo et al.	N/A	N/A
10229636	12/2018	Kim et al.	N/A	N/A
10522084	12/2018	Zhang et al.	N/A	N/A
10665157	12/2019	Lin et al.	N/A	N/A
11263967	12/2021	Nielsen et al.	N/A	N/A
2002/0000962	12/2001	Miura	345/87	G09G 3/3651
2006/0044234	12/2005	Shimonishi	N/A	N/A
2007/0132674	12/2006	Tsuge	345/77	G09G 3/2074
2007/0222743	12/2006	Hirakata	N/A	N/A
2011/0102410	12/2010	Cho	345/212	G09G 3/3291
2018/0061311	12/2017	Lin	N/A	G09G 3/32
2019/0096337	12/2018	Zhu	N/A	G09G 3/3258
2019/0304372	12/2018	Pyo	N/A	G01K 3/10
2019/0325816	12/2018	Lin	N/A	G09G 3/3208
2019/0378454	12/2018	Jin	N/A	G09G 3/3225
2021/0225275	12/2020	Cho	N/A	G09G 3/3233
2021/0305353	12/2020	Ono	N/A	H10K 59/1213
2022/0076627	12/2021	Kim et al.	N/A	N/A
2022/0180819	12/2021	Ono	N/A	G09G 3/3233
2023/0144298	12/2022	Koo	345/204	G09G 3/3291

OTHER PUBLICATIONS

P. Stanley-Marbell, “A mobile client platform for sensor networks,” ES reports, vol. 2008-04, Jan. 1, 2008, Eindhoven: Technische Universiteit Eindhoven, accessed via: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1039.8177&rep=rep1&type=pdf. cited by applicant

Primary Examiner: Balaoing; Ariel A

Attorney, Agent or Firm: Fletcher Yoder, P.C.

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims priority to and benefit of U.S. Provisional Application No. 63/357,493, filed Jun. 30, 2022, and entitled “DYNAMIC VRESET AND VSSEL TUNING FOR BETTER LOW GRAY ACCURACY AND POWER SAVING,” which is incorporated herein by reference in its entirety for all purposes.

SUMMARY
(1) This disclosure relates to systems, methods, and devices to improve gray level accuracy and save power by dynamically tuning VSSEL and/or Vreset voltages applied to display pixels on electronic displays.
(2) A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure.
(3) Electronic displays may be found in numerous electronic devices, from mobile phones to computers, televisions, automobile dashboards, and augmented reality or virtual reality glasses, to name just a few. Electronic displays with self-emissive display pixels produce their own light. Self-emissive display pixels may include any suitable light-emissive elements, including light-emitting diodes (LEDs) such as organic light-emitting diodes (OLEDs) or micro-light-emitting diodes (μLEDs). By causing different display pixels to emit different amounts of light, individual display pixels of an electronic display may collectively produce images.
(4) In certain electronic display devices, light-emitting diodes such as organic light-emitting diodes (OLEDs), micro-LEDs (μLEDs), or micro display-based OLEDs may be employed as pixels to depict a range of gray levels for display. However, due to various properties associated with ambient conditions (e.g., temperature) surrounding a display panel, display properties (e.g., display usage, aging) of the display panel or pixels within the display panel, an expected gray level output by one or more pixels in a display device may be different from an actual gray level output by the pixels in the display device upon receiving a certain electrical input. For example, as the ambient temperature in which a display panel operates changes, a bias voltage associated with the components within a pixel driving circuit may also change. As such, the current provided to illuminate a pixel may change due to the change in the bias voltage. As a result, the pixel may illuminate differently than expected.
(5) To ensure that the pixels of a display device accurately depict the desired gray levels in accordance with the provided image data, a control circuit may be disposed within the display device. The control circuit may adjust a voltage of a supply voltage (e.g., VSSEL) that provides a voltage to various components (e.g., light-emitting diode) within the control circuit. By dynamically adjusting the voltage of the supply voltage (VSSEL), the control circuit may adjust the driving current received by the LED. In certain embodiments, the adjusted supply voltage (VSSEL) may be coupled to pixel circuits that are used to drive each pixel in the display device. In this way, the control circuit may compensate for bias voltage effects present in the pixel driving circuits of the display that may be caused by ambient conditions or the like.
(6) The control circuit may also adjust a voltage Vreset (e.g., a reset voltage added to an anode of a display pixel) applied to the display pixel to cause the display pixel to emit light more uniformly under various ambient conditions (e.g., temperature) surrounding the display pixels. For example, temperature changes anode charging dynamics of the display pixels, which in turn change the

emitted light from the display pixels. Dynamically changing Vreset may be used to make anode charging dynamics independent of temperature.
(7) By dynamically changing the Vreset and the VSSEL voltages, the electronic display may save power. For instance, the Vreset and the VSSEL may use smaller values of voltage at higher temperatures than lower temperatures. VSSEL and Vreset may be provided by the same or different sources. Accordingly, less power may be needed at higher temperatures than at lower temperatures.
(8) The voltage Vreset and the supply voltage VSSEL may be determined through calibration by testing different turn on voltages and source voltages for different conditions to reduce or eliminate image artifacts. Different conditions that may be considered include, among other things, a current display panel temperature, a current global brightness setting, a current refresh rate, and properties of the image content of the image frame to be displayed on the electronic display, display panel age, and so forth. Once calibration has been used to determine the Vreset and the VSSEL for different conditions, the voltages may be stored and used by the electronic display while in operation.
(9) The voltages may be stored in a lookup table on a display driver integrated circuit (DIC). The lookup table may take any suitable form. In one example, the lookup table may be a two-dimensional lookup table that receives a current global brightness setting and a current display panel temperature and outputs a sequence of bias voltages for those conditions. When the sequence of bias voltages is applied to display pixels for a corresponding sequence of subframes, the display pixel hysteresis effects may be counteracted and display artifacts may be reduced or eliminated.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) Various aspects of this disclosure may be better understood upon reading the following detailed description and upon reference to the drawings described below.
(2) FIG. **1** is a schematic block diagram of an electronic device, in accordance with an embodiment;
(3) FIG. **2** is a front view of a mobile phone representing an example of the electronic device of FIG. **1**, in accordance with an embodiment;
(4) FIG. **3** is a front view of a tablet device representing an example of the electronic device of FIG. **1**, in accordance with an embodiment;
(5) FIG. **4** is a front view of a notebook computer representing an example of the electronic device of FIG. **1**, in accordance with an embodiment;
(6) FIG. **5** are front and side views of a watch representing an example of the electronic device of FIG. **1**, in accordance with an embodiment;
(7) FIG. **6** is a block diagram of an electronic display of the electronic device, in accordance with an embodiment;
(8) FIG. **7** is a circuit diagram of a display pixel of the electronic display, in accordance with an embodiment;
(9) FIG. **8** is a plot showing example characteristics of an electronic display of the electronic device, in accordance with an embodiment;
(10) FIG. **9** is a plot showing example characteristics of an electronic display of the electronic device, in accordance with an embodiment;
(11) FIG. **10** is a diagram illustrating power saving by VSSEL tuning for different characteristics of the electronic display, in accordance with an embodiment;
(12) FIG. **11** is a timing diagram for providing Vreset to display pixels of the electronic display, in accordance with an embodiment;
(13) FIG. **12** is a timing diagram showing light pulse characteristics affected by Vreset, in

accordance with an embodiment;
(14) FIG. **13** is a plot showing example characteristics for an electronic display of the electronic device without VSSEL and Vreset tuning, in accordance with an embodiment;
(15) FIG. **14** is a plot showing example characteristics for an electronic display of the electronic device with VSSEL and Vreset tuning, in accordance with an embodiment;
(16) FIG. **15** is a plot showing example characteristics for an electronic display of the electronic device with VSSEL and Vreset tuning, in accordance with an embodiment;
(17) FIG. **16** is block diagram of an electronic display of the electronic device implementing VSSEL and Vreset tuning, in accordance with an embodiment;
(18) FIG. **17** is a block diagram of voltage look up tables (LUTs) to implement VSSEL and Vreset tuning, in accordance with an embodiment;
(19) FIG. **18** is a plot showing example characteristics for an electronic display of the electronic device with VSSEL and precharge voltage (V.sub.PRCH) tuning for changes in temperature (T) with a fixed global display brightness value (DBV), in accordance with an embodiment;
(20) FIG. **19** is a plot showing example characteristics for an electronic display of the electronic device with VSSEL and V.sub.PRCH tuning for changes in global display brightness value (DBV) with a fixed temperature (T), in accordance with an embodiment; and
(21) FIG. **20** is a schematic block diagram of circuitry for implementing VSSEL and VPRCH tuning for an electronic display of the electronic device, in accordance with an embodiment.

DETAILED DESCRIPTION

(22) One or more specific embodiments will be described below. In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.
(23) When introducing elements of various embodiments of the present disclosure, the articles “a,” “an,” and “the” are intended to mean that there are one or more of the elements. The terms “including” and “having” are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to “some embodiments,” “embodiments,” “one embodiment,” or “an embodiment” of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Furthermore, the phrase A “based on” B is intended to mean that A is at least partially based on B. Moreover, the term “or” is intended to be inclusive (e.g., logical OR) and not exclusive (e.g., logical XOR). In other words, the phrase A “or” B is intended to mean A, B, or both A and B.
(24) This disclosure relates to electronic displays that use dynamic tuning of source voltage (e.g., VSSEL) and dynamic tuning of precharge voltage (e.g., Vreset) to accurately depict the desired gray levels in accordance with the provided image data under various ambient conditions (e.g., temperature), particularly at low gray levels. This dynamic Vreset and VSSEL tuning may save power, and may reduce or eliminate certain image artifacts, such as flicker or variable refresh rate luminance difference.
(25) With the preceding in mind and to help illustrate, an electronic device **10** including an electronic display **12** is shown in FIG. **1**. As is described in more detail below, the electronic device **10** may be any suitable electronic device, such as a computer, a mobile phone, a portable media device, a tablet, a television, a virtual-reality headset, a wearable device such as a watch, a vehicle dashboard, or the like. Thus, it should be noted that FIG. **1** is merely one example of a particular

implementation and is intended to illustrate the types of components that may be present in an electronic device **10**.
(26) The electronic device **10** includes the electronic display **12**, one or more input devices **14**, one or more input/output (I/O) ports **16**, a processor core complex **18** having one or more processing circuitry(s) or processing circuitry cores, local memory **20**, a main memory storage device **22**, a network interface **24**, and a power source **26** (e.g., power supply). The various components described in FIG. **1** may include hardware elements (e.g., circuitry), software elements (e.g., a tangible, non-transitory computer-readable medium storing executable instructions), or a combination of both hardware and software elements. It should be noted that the various depicted components may be combined into fewer components or separated into additional components. For example, the local memory **20** and the main memory storage device **22** may be included in a single component.
(27) The processor core complex **18** is operably coupled with local memory **20** and the main memory storage device **22**. Thus, the processor core complex **18** may execute instructions stored in local memory **20** or the main memory storage device **22** to perform operations, such as generating or transmitting image data to display on the electronic display **12**. As such, the processor core complex **18** may include one or more general purpose microprocessors, one or more application specific integrated circuits (ASICs), one or more field programmable logic arrays (FPGAs), or any combination thereof.
(28) In addition to program instructions, the local memory **20** or the main memory storage device **22** may store data to be processed by the processor core complex **18**. Thus, the local memory **20** and/or the main memory storage device **22** may include one or more tangible, non-transitory, computer-readable media. For example, the local memory **20** may include random access memory (RAM) and the main memory storage device **22** may include read-only memory (ROM), rewritable non-volatile memory such as flash memory, hard drives, optical discs, or the like.
(29) The network interface **24** may communicate data with another electronic device or a network. For example, the network interface **24** (e.g., a radio frequency system) may enable the electronic device **10** to communicatively couple to a personal area network (PAN), such as a Bluetooth network, a local area network (LAN), such as an 802.11x Wi-Fi network, or a wide area network (WAN), such as a 4G, Long-Term Evolution (LTE), or 5G cellular network. The power source **26** may provide electrical power to one or more components in the electronic device **10**, such as the processor core complex **18** or the electronic display **12**. Thus, the power source **26** may include any suitable source of energy, such as a rechargeable lithium polymer (Li-poly) battery or an alternating current (AC) power converter. The I/O ports **16** may enable the electronic device **10** to interface with other electronic devices. For example, when a portable storage device is connected, the I/O port **16** may enable the processor core complex **18** to communicate data with the portable storage device.
(30) The input devices **14** may enable user interaction with the electronic device **10**, for example, by receiving user inputs via a button, a keyboard, a mouse, a trackpad, a touch sensing, or the like. The input device **14** may include touch-sensing components (e.g., touch control circuitry, touch sensing circuitry) in the electronic display **12**. The touch sensing components may receive user inputs by detecting occurrence or position of an object touching the surface of the electronic display **12**.
(31) In addition to enabling user inputs, the electronic display **12** may be a display panel with one or more display pixels. For example, the electronic display **12** may include a self-emissive pixel array having an array of one or more of self-emissive pixels. The electronic display **12** may include any suitable circuitry (e.g., display driver circuitry) to drive the self-emissive pixels, including for example row driver and/or column drivers (e.g., display drivers). Each of the self-emissive pixels may include any suitable light emitting element, such as a LED or a micro-LED, one example of which is an OLED. However, any other suitable type of pixel, including non-self-emissive pixels

(e.g., liquid crystal as used in liquid crystal displays (LCDs), digital micromirror devices (DMD) used in DMD displays) may also be used. The electronic display **12** may control light emission from the display pixels to present visual representations of information, such as a graphical user interface (GUI) of an operating system, an application interface, a still image, or video content, by displaying frames of image data. To display images, the electronic display **12** may include display pixels implemented on the display panel. The display pixels may represent sub-pixels that each control a luminance value of one color component (e.g., red, green, or blue for an RGB pixel arrangement or red, green, blue, or white for an RGBW arrangement).

(32) The electronic display **12** may display an image by controlling pulse emission (e.g., light emission) from its display pixels based on pixel or image data associated with corresponding image pixels (e.g., points) in the image. In some embodiments, pixel or image data may be generated by an image source (e.g., image data, digital code), such as the processor core complex **18**, a graphics processing unit (GPU), or an image sensor. Additionally, in some embodiments, image data may be received from another electronic device **10**, for example, via the network interface **24** and/or an I/O port **16**. Similarly, the electronic display **12** may display an image frame of content based on pixel or image data generated by the processor core complex **18**, or the electronic display **12** may display frames based on pixel or image data received via the network interface **24**, an input device, or an I/O port **16**.

(33) The electronic device **10** may be any suitable electronic device. To help illustrate, an example of the electronic device **10**, a handheld device **10**A, is shown in FIG. **2**. The handheld device **10**A may be a portable phone, a media player, a personal data organizer, a handheld game platform, or the like. For illustrative purposes, the handheld device **10**A may be a smart phone, such as any IPHONE® model available from Apple Inc.

(34) The handheld device **10**A includes an enclosure **30** (e.g., housing). The enclosure **30** may protect interior components from physical damage or shield them from electromagnetic interference, such as by surrounding the electronic display **12**. The electronic display **12** may display a graphical user interface (GUI) **32** having an array of icons. When an icon **34** is selected either by an input device **14** or a touch-sensing component of the electronic display **12**, an application program may launch.

(35) The input devices **14** may be accessed through openings in the enclosure **30**. The input devices **14** may enable a user to interact with the handheld device **10**A. For example, the input devices **14** may enable the user to activate or deactivate the handheld device **10**A, navigate a user interface to a home screen, navigate a user interface to a user-configurable application screen, activate a voice-recognition feature, provide volume control, or toggle between vibrate and ring modes.

(36) Another example of a suitable electronic device **10**, specifically a tablet device is shown in FIG. **3**. The tablet device **10**B may be any IPAD® model available from Apple Inc. A further example of a suitable electronic device **10**, specifically a computer is shown in FIG. **4**. For illustrative purposes, the computer **10**C may be any MACBOOK® or IMAC® model available from Apple Inc. Another example of a suitable electronic device **10**, specifically a watch **10**D, is shown in FIG. **5**. For illustrative purposes, the watch **10**D may be any APPLE WATCH® model available from Apple Inc. As depicted, the tablet device **10**B, the computer **10**C, and the watch each also includes an electronic display **12**, input devices **14**, I/O ports **16**, and an enclosure **30**. The electronic display **12** may display a GUI **32**. Here, the GUI **32** shows a visualization of a clock. When the visualization is selected either by the input device **14** or a touch-sensing component of the electronic display **12**, an application program may launch, such as to transition the GUI **32** to presenting the icons **34** discussed in FIGS. **2** and **3**.

(37) As shown in FIG. **6**, the electronic display **12** may receive image data **48** for display on the electronic display **12**. The electronic display **12** includes display driver circuitry that includes scan driver circuitry **50** and data driver circuitry **52** that can program the image data **48** onto display pixels **54**. The display pixels **54** may each contain one or more self-emissive elements, such as a

light-emitting diodes (LEDs) (e.g., organic light emitting diodes (OLEDs) or micro-LEDs (μLEDs)). Different display pixels **54** may emit different colors. For example, some of the display pixels **54** may emit red light, some may emit green light, and some may emit blue light. Thus, the display pixels **54** may be driven to emit light at different brightness levels to cause a user viewing the electronic display **12** to perceive an image formed from different colors of light. The display pixels **54** may also correspond to hue and/or luminance levels of a color to be emitted and/or to alternative color combinations, such as combinations that use cyan (C), magenta (M), or others.
(38) The scan driver **50** may provide scan signals (e.g., pixel reset, data enable, on-bias stress) on scan lines **56** to control the display pixels **54** by row. For example, the scan driver **50** may cause a row of the display pixels **54** to become enabled to receive a portion of the image data **48** from data lines **58** from the data driver **52**. In this way, an image frame of image data **48** may be programmed onto the display pixels **54** row by row. Other examples of the electronic display **12** may program the display pixels **54** in groups other than by row.
(39) The display pixels **54** may use any suitable circuitry. A simplified example of a display pixel **54** appears in FIG. **7**. The display pixel **54** of FIG. **7** includes an organic light emitting diode (OLED) **70** that emits an amount of light that varies depending on the electrical current through the OLED **70**. A driving transistor DTFT provides this electrical current. The electrical current thus varies depending on a programming voltage at a node **72** stored in a storage capacitor C.sub.ST. The programming voltage at the node **72** is based on the image data and is applied to a gate of the driving transistor DTFT. This causes the driving transistor DTFT to permit a particular amount of current to flow from a positive electroluminance supply voltage VDDEL and a negative electroluminance supply voltage VSSEL through the OLED **70**. In this way, the image data **48** may be programmed into the display pixel **54**. Before continuing, it is noted that the driving transistor DTFT appears in FIG. **7** as a low-temperature polysilicon (LTPS) PMOS transistor. However, the driving transistor DTFT may take any suitable form, such as an LTPS or LTPO PMOS, NMOS, or CMOS transistor.
(40) The programming voltage may be stored onto the storage capacitor CST through a switch **74** that may be selectively opened and closed. The switch **74** is closed during programming at the start of an image frame to allow the programming voltage to be stored in the storage capacitor CST. After the programming voltage to be stored in the storage capacitor CST, the switch **74** may be opened. The switch **74** thus may represent any suitable transistor (e.g., an LTPS or LTPO transistor) with sufficiently low leakage to sustain the programming at the lowest refresh rate used by the electronic display **12**. A switch **76** may selectively provide a bias voltage Vbias from a first bias voltage supply **78**. A switch **80** may selectively provide an anode reset voltage Vreset through a second voltage supply **82**. The switches **76** and **80** may likewise take the form of any suitable transistors (e.g., LTPS or LTPO PMOS, NMOS, or CMOS transistors).
(41) The voltage Vreset is related to the turn on voltage for the OLED **70**. OLEDs generally have a slow charging regime when turned on (e.g., at low gray levels), and Vreset is used to improve the charging process in the OLED. Since temperatures affect the pixel driver current, OLED efficiency, OLED current and voltage shifts, etc., the turn on voltage changes with temperature. For example, the turn on voltage decreases with higher temperatures for a fixed current through the OLED **70**, as will be illustrated in FIG. **11**.
(42) FIG. **8** illustrates a plot **90** showing that, for the same electric current density of an OLED (JOLED) J1, a voltage of the OLED (VOLED) may have different values at different temperatures. Here, JOLED is associated with the electrical current density through the OLED **70**, and VOLED is associated with the electrical voltage across the OLED **70**. A curve **92** illustrates a relationship between the VOLED and the JOLED at a temperature T1, a curve **94** illustrates a relationship between the VOLED and the JOLED at a temperature T2, and a curve **96** illustrates a relationship between the VOLED and the JOLED at a temperature T3. In the illustrated embodiment, the temperature T1 is higher than the temperature T2, and the temperature T2 is higher than the

temperature T3. At a certain value J1 of the JOLED, VOLED corresponds to different values Vj1, Vj2, and Vj3 on the curves **92**, **94**, and **96**, respectively. In the illustrated diagram, the value Vj1 is smaller than Vj2, and Vj2 is smaller than Vj3. That is, at higher temperatures, for the same current through the OLED (i.e., a same brightness level), a lower VOLED may be needed, which may improve gray level accuracy and save power, as will be illustrated in FIG. **10**.

(43) FIG. **9** illustrates plot **100** showing that, for a same brightness, the VOLED voltage may have different values at different temperatures. A curve **102** illustrates a relationship between the VOLED and a brightness of the OLED **70** at the temperature T1, a curve **104** illustrates a relationship between the VOLED and the brightness of the OLED **70** at the temperature T2, and a curve **106** illustrates a relationship between the VOLED and the brightness of the OLED **70** at the temperature T3. In the example of FIG. **9**, the temperature T1 is higher than the temperature T2, and the temperature T2 is higher than the temperature T3. At a certain brightness Bl, VOLED corresponds to different values Vb1, Vb2, and Vb3 on the curves **102**, **104**, and **106**, respectively. In the illustrated example, the value Vb1 is smaller than Vb2, and Vb2 is smaller than Vb3. That is, at higher temperatures, for the same brightness of the OLED, a lower VOLED may be used, which may save power, as will be illustrated in FIG. **10**.

(44) FIG. **10** shows an example diagram **110**, which illustrates power saving (ΔP) by VSSEL tuning with respect to brightness and temperature. The diagram **110** illustrates that higher power saving may be achieved at higher temperatures and/or higher brightness values by performing VSSEL tuning.

(45) FIG. **11** shows a timing diagram **120**A, which illustrates fixed Vreset with respect to temperatures, and a timing diagram **120**B, which illustrates Vreset tuning with respect to temperature. In the diagram **120**A, a curve **122**A illustrates a relationship between the VOLED and the Vreset of the OLED **70** at the temperature T1, a curve **124**A illustrates a relationship between the VOLED and the Vreset of the OLED **70** at the temperature T2, and a curve **126**A illustrates a relationship between the VOLED and the Vreset of the OLED **70** at the temperature T3. In the illustrated embodiment, the temperature T1 is higher than the temperature T2, and the temperature T2 is higher than the temperature T3. Before the light emission that occurs when the OLED **70** is turned on, Vreset is on and VOLED has a fixed value Vr for different temperatures corresponding to the curves **122**A, **124**A, and **126**A, respectively. After the light emission begins as the OLED **70** is turned on and the intensity of the resulting light pulse is stabilized at a certain gray level (e.g., achieves a settled current density JOLED through the OLED **70**), the VOLED may have different values Vr4, Vr5, and Vr6 for the same value of the current density JOLED (as illustrated in FIG. **8**) at different temperatures corresponding to the curves **122**A, **124**A, and **126**A, respectively. In the illustrated diagram, the value of Vr4 is smaller than Vr5, and Vr5 is smaller than Vr6.

(46) In the diagram **120**B, by contrast, the Vreset voltage uses different values at different temperatures. A curve **122**B illustrates a relationship between the VOLED and the Vreset of the OLED **70** at the temperature T1, a curve **124**B illustrates a relationship between the VOLED and the Vreset of the OLED **70** at the temperature T2, and a curve **126**B illustrates a relationship between the VOLED and the Vreset of the OLED **70** at the temperature T3. In the illustrated diagram, the temperature T1 is higher than the temperature T2, and the temperature T2 is higher than the temperature T3. Before the light emission begins as the OLED **70** is turned on, the Vreset is on and has different values at different temperatures corresponding to the curves **122**B, **124**B, and **126**B, respectively; accordingly, the VOLED has different values Vr1, Vr2, and Vr3 at different temperatures corresponding to the curves **122**B, **124**B, and **126**B, respectively. After the light emission begins as the OLED **70** is turned on and the intensity of the resulting light pulse is stabilized at a certain gray level (e.g., achieves a settled current density JOLED through the OLED **70**), the VOLED may have different values Vr4, Vr5, and Vr6 for a same value of the current density JOLED (as illustrated in FIG. **8**) at different temperatures, corresponding to the curves **122**B, **124**B, and **126**B, respectively. In the illustrated diagram, the value Vr1 is smaller than Vr2,

and Vr2 is smaller than Vr3; Vr4 is smaller than Vr5, and Vr5 is smaller than Vr6. That is, at higher temperatures, a lower Vreset voltage may be used to obtain the same gray level light emission, which may improve light pulse accuracy at low gray levels, as will be illustrated in FIG. **12**.

(47) FIG. **12** shows a timing diagram **130**A, which illustrates a light pulse without using Vreset tuning, and a timing diagram **130**B, which illustrates a light pulse compensated by Vreset tuning with respect to temperature. In diagram **130**A, a curve **132**A illustrates a relationship between the current density JOLED and the time during the light pulse of the OLED **70** at the temperature T1, a curve **134**A illustrates a relationship between the current density JOLED and the time during the light pulse of the OLED **70** at the temperature T2, and a curve **136**A illustrates a relationship between the current density JOLED and the time during the light pulse of the OLED **70** at the temperature T3. In the illustrated diagram, the temperature T1 is higher than the temperature T2, and the temperature T2 is higher than the temperature T3. Before the light emission of the OLED **70** is turned on, the Vreset is on and the VOLED has the fixed value Vr at different temperatures (as illustrated in diagram **120**A). After the light emission begins as the OLED **70** is turned on and before the intensity of the resulting light pulse is stabilized at a gray level Jr (e.g., achieves a settled current through the OLED **70**), the current density JOLED may have different values JrA3, JrA2, and JrA1 at a time tr for the curves **132**A, **134**A, and **136**A corresponding to different temperatures, respectively. Accordingly, the light emitted from the OLED **70** may erroneously correspond different gray levels, corresponding to different current values JrA3, JrA2, and JrA1, at the time tr at different temperatures.

(48) Diagram **130**B illustrates a light pulse compensated by Vreset tuning with respect to temperature. In diagram **130**B, a curve **132**B illustrates a relationship between the current density JOLED and the time during the light pulse of the OLED **70** at the temperature T1, a curve **134**B illustrates a relationship between the current density JOLED and the time during the light pulse of the OLED **70** at the temperature T2, and a curve **136**B illustrates a relationship between the current density JOLED and the time during the light pulse of the OLED **70** at the temperature T3. In the illustrated diagram, the temperature T1 is higher than the temperature T2, and the temperature T2 is higher than the temperature T3. Before the light emission of the OLED **70** is turned on, the Vreset is on and the VOLED has different values Vr1, Vr2, and Vr3 at different temperatures T1, T2, and T3, respectively (as illustrated in diagram **120**B). After the light emission begins as the OLED **70** is turned on and before the intensity of the resulting light pulse is stabilized at the gray level Jr (e.g., achieves a settled current through the OLED **70**), the JOLED may have different values JrB3, JrB2, and JrB1 at the time tr for the curves **132**B, **134**B, and **136**B corresponding to different temperatures, respectively. Since the turn on voltage decreases with higher temperatures (as illustrated in diagram **120**B), the differences among the values of JrB3, JrB2, and JrB1 are significantly reduced by using Vreset tuning with respect to temperature when compared to the differences among the values of JrA3, JrA2, and JrA1 in diagram **130**A, thereby increasing the accuracy at low gray levels despite changes in temperature.

(49) FIG. **13** illustrates a plot **140** without VSSEL and Vreset tuning, in which the voltage VOLED has different values at different temperatures for a brightness associated with a value of a current IOLED through the OLED **70**. A curve **142** illustrates a relationship between the brightness (associated with log(IOLED)) of the OLED **70** and the VOLED at the temperature T1 and a curve **144** illustrates a relationship between the brightness (associated with log(IOLED)) of the OLED **70** and the VOLED at the temperature T2. In the plot **140**, the temperature T1 is higher than the temperature T2. As discussed above, the voltage Vreset decreases with higher temperatures for a fixed current through the OLED **70**. In FIG. **13**, VSSEL and Vreset (both VRESET-HOT for the curve **142** and VRESET-COLD for the curve **144**) have negative values, and VDDEL has a positive value. For a given brightness level, VOLED has smaller values at higher temperatures. For example, the difference between VSSEL and V.sub.RESET-HOT is smaller than the difference between VSSEL and VRESET-COLD, and the difference between VSSEL and V.sub.255@Bmax-

Hot (e.g., the voltage at the maximum brightness value of gray level **255** at high temperature for curve **142**) is smaller than the difference between the VSSEL and the V.sub.255@Bmax-Cold (e.g., the voltage at the maximum brightness value of gray level **255** at low temperature for curve **144**), as shown by curve **142** and curve **144**. Accordingly, the difference V.sub.BD-HOT between the VDDEL and the V.sub.255 @Bmax-Hot is bigger than the difference V.sub.BD-COLD between the VDDEL and the V.sub.255 @Bmax-Cold. In addition, the difference between VRESET-HOT and V.sub.255 @Bmax-Hot is smaller than the difference between the VRESET-COLD and V.sub.255 @Bmax-Cold. Indeed, as illustrated in FIG. **13**, at the same brightness level, VOLED has different values at different temperatures. For example, at the maximum brightness level, V.sub.255 @Bmax-Hot at the temperature T1 is smaller than V.sub.255@Bmax-Cold at the temperature T2, and the temperature T1 is higher than T2.

(50) FIG. **14** illustrates a timing diagram **150** when VSSEL and Vreset tuning are performed. A curve **152** illustrates a relationship between the brightness (associated with log(IOLED)) of the OLED **70** and the VOLED at the temperature T1 and a curve **154** illustrates a relationship between the brightness (associated with log(IOLED)) of the OLED **70** and the VOLED at the temperature T2. In the illustrated embodiment, the temperature T1 is higher than the temperature T2. As discussed above, the turn on voltage for the OLED **70** decreases with higher temperatures for a fixed current through the OLED **70**. In FIG. **14**, the VSSEL and the Vreset (both the V.sub.RESET-HOT for the curve **152** and the VRESET-COLD for the curve **154**) have negative values, and VDDEL has a positive value. In FIG. **14**, both VSSEL and the Vreset are adjusted corresponding to the temperature (e.g., the VSSEL.sub.HOT and the V.sub.RESET-HOT for the curve **152** and the VSSEL.sub.COLD and the VRESET-COLD for the curve **154**) so that the voltage at the maximum brightness value of gray level **255** at high temperature T1 for curve **152** has the same value V.sub.255@Bmax as the voltage at the maximum brightness value of gray level **255** at low temperature T2 for curve **154**, as will be illustrated in FIG. **15**. As described above, tuning VSSEL and Vreset with respect to temperature may improve the gray level accuracy and save power.

(51) FIG. **15** illustrates a plot **160** showing the effect of VSSEL and Vreset tuning with respect to temperature. In FIG. **15**, VSSEL and Vreset have negative values, and VDDEL has a positive value. In the plot **160**, both VSSEL and Vreset are adjusted corresponding to the temperature. For example, VSSEL and Vreset have values of VSSEL.sub.HOT and V.sub.RESET-HOT at T1 and VSSEL.sub.COLD and VRESET-COLD at T2. In FIG. **15**, the voltage at the maximum brightness value of gray level **255** at high temperature T1 has the same value V.sub.255@Bmax as the voltage at the maximum brightness value of gray level **255** at low temperature T2. In addition, the difference dV2 between the value of VSSEL.sub.COLD and the VRESET-COLD at T2 is bigger than the difference dV1 between the value of VSSEL.sub.HOT and the V.sub.RESET-HOT at T1. The VSSEL and Vreset voltages with respect to temperature may be stored in a lookup table on a display driver integrated circuit (DIC). The lookup table may take any suitable form.

(52) FIG. **16** illustrates an embodiment for an electronic display **170** of an electronic device implementing VSSEL and Vreset tuning. The electronic display **170** has a display panel **172** and a control circuit **174**. A temperature sensor **176** is used to measure a temperature T of the area of the display panel **172** and transmit temperature data to the control circuit **174**. The control circuit **174** is configured to adjust the supply voltage VSSEL and the voltage Vreset based on the temperature data received from the temperature sensor **176**. In one embodiment, the control circuit **174** may obtain the dynamic supply voltage VSSEL(T) and the dynamic voltage VRESET (T) for the temperature T from a lookup table **178** and **180**, respectively. The lookup tables **178** and **180** (e.g., as illustrated in FIG. **17**) may include voltage data for display pixels associated with different colors (e.g., red (R), green (G), and blue (B)), which may be transmitted to corresponding Low Dropout Linear Regulators, VSSEL-LDOs (R,G,B) **179** and V.sub.RESET-LDOs (R,G,B) **181**, respectively. The VSSEL-LDOs (R,G,B) **179** may output a corresponding regulated value of VSSEL(T) to an active area **182** on the display panel **172**. The V.sub.RESET-LDOs (R,G,B) **181**

may output regulated voltage data VRESET (T) associated with different colors to corresponding driving circuits **184** (red), **186** (green), and **188** (blue) on the active area **182**, respectively.

(53) FIG. **17** illustrates an embodiment of a structure **190** of voltage lookup tables for storing voltage data for display pixels associated with different colors, e.g., red (R), green (G), and blue (B), with respect to temperature and brightness. The structure **190** may include a lookup table **192** for storing voltage data for display pixels associated with red color, a lookup table **194** for storing voltage data for display pixels associated with green color, and a lookup table **196** for storing voltage data for display pixels associated with blue color. Each lookup table may be a two-dimensional lookup table that receives a current global brightness setting (e.g., display brightness value (DBV) taps such as DBV<1>, DBV<2>, DBV<3> . . . DBV<N>) and a current display panel temperature (e.g., temperature taps such as TO, T1, T2, T3) and outputs associated voltages (e.g., VSSEL and/or Vreset) for those conditions.

(54) FIG. **18** illustrates a plot **200** showing the effect of VSSEL and precharge voltage (V.sub.PRCH) tuning with respect to temperature for a fixed brightness (e.g., a fixed DBV). In FIG. **18**, VSSEL and V.sub.PRCH have negative values. In the plot **200**, both VSSEL and V.sub.PRCH are adjusted corresponding to the temperature (e.g., VSSEL and V.sub.PRCH have values of VSSEL.sub.HOT and V.sub.PRCH-HOT at T1 and VSSEL.sub.COLD and V.sub.PRCH-COLD at T2). In FIG. **18**, the difference dV.sub.2 between the value of VSSEL.sub.COLD and V.sub.PRCH-COLD at T2 is bigger than the difference dV.sub.1 between the value of VSSEL.sub.HOT and V.sub.PRCH-HOT at T1. The VSSEL and V.sub.PRCH voltages with respect to temperatures may be stored in a lookup table on a display driver integrated circuit (DIC). The lookup table may take any suitable form (e.g., as illustrated in FIG. **17**).

(55) FIG. **19** illustrates a plot diagram **210** showing the effect of VSSEL and V.sub.PRCH tuning with respect to brightness for a fixed temperature. In FIG. **19**, the VSSEL and the V.sub.PRCH have negative values. In diagram **210**, both VSSEL and the V.sub.PRCH are adjusted corresponding to the brightness (e.g., VSSEL and V.sub.PRCH have values of VSSEL.sub.MAX and V.sub.PRCH-Max at Bmax and VSSEL.sub.MIN and V.sub.PRCH-MIN at Bmin). In FIG. **19**, the difference dVBmin between the value of VSSEL MIN and V.sub.PRCH-MIN at Bmin is smaller than the difference dVBmax between the value of VSSEL.sub.MAX and V.sub.PRCH-Max at Bmax. The VSSEL and V.sub.PRCH voltages with respect to brightness may be stored in a lookup table on a display driver integrated circuit (DIC). The lookup table may take any suitable form (e.g., as illustrated in FIG. **17**).

(56) FIG. **20** illustrates a schematic block diagram **220** for implementing VSSEL and V.sub.PRCH tuning for an electronic display **222** of an electronic device. The electronic display **220** has an active area **224** with display pixels associated driving circuitry and a control circuit **226**. The control circuit **226** adjusts various voltages (e.g., VSSEL, Vreset, V.sub.PRCH) based on temperature data and brightness data received from the processor core complex **18**. The temperature data received by the control circuit **226** may be selected, via a multiplexer **228**, from a virtual temperature data calculated by the processor core complex **18** and sensor data obtained from temperature sensors installed on the active area **224**. The control circuit **226** may be triggered by a DBV change in the active area **224**, or a temperature change in the active area **224** being more than a threshold, or a fixed time period (e.g., every second) for a routine tuning, via a multiplexer **230** and an OR gate **232**. In one embodiment, the control circuit **226** may obtain the value of various voltages from lookup tables **234** and transmit the various voltage values to a PGIC **236** (programmable integrated circuit). The PGIC **236** may transmit corresponding voltage values (e.g., VREF, VPRCH, VRST, VNEG, AVDD) to corresponding circuits in the active area **224**. The control circuit **226** may generate gamma correction by using a gamma generation circuit **238** based on a gamma lookup table **240**. The generated gamma correction may be transmitted to a timing controller (TCON) **242**, which may input the generated gamma correction into the active area **224** for displaying image with the corresponding voltage values received from the PGIC **236**. By tuning

the VSSEL and the Vreset/V.sub.PRCH voltages, the gray level accuracy may be improved, especially at the low gray levels. Dynamic tuning of the VSSEL and the Vreset/V.sub.PRCH voltages may also save power.
(57) The specific embodiments described above have been shown by way of example, and it should be understood that these embodiments may be susceptible to various modifications and alternative forms. It should be further understood that the claims are not intended to be limited to the particular forms disclosed, but rather to cover all modifications, equivalents, and alternatives falling within the spirit and scope of this disclosure.
(58) The techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible or purely theoretical. Further, if any claims appended to the end of this specification contain one or more elements designated as “means for [perform]ing [a function] . . . ” or “step for [perform]ing [a function] . . . ”, it is intended that such elements are to be interpreted under 35 U.S.C. 112(f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. 112(f).
(59) It is well understood that the use of personally identifiable information should follow privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining the privacy of users. In particular, personally identifiable information data should be managed and handled so as to minimize risks of unintentional or unauthorized access or use, and the nature of authorized use should be clearly indicated to users.

Claims

1. An electronic display device, comprising: one or more self-emissive pixels comprising respective light-emitting elements; a temperature sensor configured to determine a temperature of the electronic display device; and a control circuit configured to cause different values of a reset voltage to be supplied to the one or more self-emissive pixels based at least in part on the temperature, wherein the reset voltage comprises a precharge voltage applied to the respective light-emitting elements, wherein the precharge voltage has a value higher than a source supply voltage, and wherein the control circuit is configured to vary the precharge voltage at least in part based on the temperature.
2. The electronic display device of claim 1, wherein the control circuit is configured to control a value of the source supply voltage to increase in response to an increase in the temperature of the electronic display device.
3. The electronic display device of claim 1, wherein the control circuit is configured to control a value of the reset voltage to increase in response to an increase in the temperature of the electronic display device.
4. The electronic display device of claim 1, wherein the control circuit is configured to control the reset voltage in a voltage mirror operation with respect to the source supply voltage so that a value of the reset voltage increases when a value of the source supply voltage increases and the value of the reset voltage decreases when the value of the source supply voltage decreases.
5. The electronic display device of claim 1, wherein the control circuit is configured to cause different values of the source supply voltage or a respective reset voltage, or both, to be supplied to the one or more self-emissive pixels based at least in part on a gray level associated with the one or more self-emissive pixels.
6. The electronic display device of claim 5, wherein the control circuit is configured to control a value of the source supply voltage to increase in response to a decrease in the gray level associated with the one or more self-emissive pixels.
7. The electronic display device of claim 5, wherein the control circuit is configured to control a

respective value of the reset voltage to increase in response to a decrease in the gray level associated with the one or more self-emissive pixels.

8. Electronic display circuitry comprising: a temperature sensing circuit to determine a temperature of a display area, wherein the display area comprises one or more self-emissive pixels comprising respective light-emitting elements; a source voltage circuit configured to adjust a value of a source supply voltage provided to the display area based at least in part on the temperature; and a reset voltage circuit configured to adjust a value of a reset voltage provided to the display area based at least in part on the temperature, wherein the reset voltage comprises a precharge voltage applied to the respective light emitting elements, wherein the precharge voltage has a value higher than the source supply voltage, and wherein the reset voltage circuit is configured to vary the precharge voltage at least in part based on the temperature.

9. The electronic display circuitry of claim 8, wherein the source voltage circuit is configured to increase the value of the source supply voltage in response to an increase in the temperature of the display area.

10. The electronic display circuitry of claim 9, wherein the reset voltage circuit is configured to increase the value of the reset voltage in response to the increase in the temperature of the display area.

11. The electronic display circuitry of claim 8, wherein the reset voltage circuit is configured to perform a voltage mirror operation with respect to the source supply voltage so that the value of the reset voltage increases when the value of the source supply voltage increases and the value of the reset voltage decreases when the value of the source supply voltage decreases.

12. The electronic display circuitry of claim 8, wherein the source voltage circuit is configured to adjust the value of the source supply voltage provided to the display area based at least in part on a gray level of the display area.

13. The electronic display circuitry of claim 12, wherein the reset voltage circuit is configured to adjust the value of the reset voltage provided to the display area based at least in part on the gray level of the display area.

14. The electronic display circuitry of claim 13, wherein the reset voltage circuit is configured to perform a voltage mirror operation with respect to the source supply voltage so that the value of the reset voltage increases when the value of the source supply voltage increases and the value of the reset voltage decreases when the value of the source supply voltage decreases.

15. An electronic display device, comprising: an electronic display comprising a plurality of pixels, wherein each of the plurality of pixels comprises a respective light-emitting element; and a control circuit configured to adjust a plurality of reset voltages and a plurality of source supply voltages provided to the plurality of pixels based on one or more temperatures associated with the plurality of pixels of the electronic display, wherein each of the plurality of reset voltages comprises a respective precharge voltage applied to the respective light emitting element, wherein the respective precharge voltage has a respective value higher than a respective source supply voltage of the plurality of source supply voltages for the respective light emitting element, wherein the control circuit is configured to vary the respective precharge voltage at least in part based on the one or more temperatures.

16. The electronic display device of claim 15, wherein the control circuit is configured to increase at least a portion of the plurality of reset voltages and a portion of the plurality of source supply voltages when the one or more temperatures increase.

17. The electronic display device of claim 15, wherein the control circuit is configured to decrease at least a portion of the plurality of reset voltages and a portion of the plurality of source supply voltages when the one or more temperatures decrease.

18. The electronic display device of claim 15, wherein each of the plurality of reset voltages comprises a respective red component, a respective green component, and a respective blue component, wherein each component of each of the plurality of reset voltages is configured to

perform respective voltage mirror operation with respect to a respective source supply voltage of the plurality of source supply voltages, so that a value of each component of each of the plurality of reset voltages increases when a value of the respective source supply voltage of the plurality of source supply voltages increases and the value of each component of each of the plurality of reset voltages decreases when the value of the respective source supply voltage of the plurality of source supply voltages decreases.

19. The electronic display device of claim 18, wherein the control circuit is configured to adjust each component of each of the plurality of reset voltages independently.

20. The electronic display device of claim 15, wherein the control circuit is further configured to adjust the plurality of reset voltages and the plurality of source supply voltages provided to the plurality of pixels based on respective brightness levels of the plurality of pixels.

21. The electronic display device of claim 15, comprising a temperature-sensing circuit configured to detect the one or more temperatures associated with the plurality of pixels.

22. The electronic display device of claim 15, comprising processing circuitry configured to estimate the one or more temperatures associated with the plurality of pixels.