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(54) **CORRECTION OF AGING IN AMOLED DISPLAY**

(75) Inventor: **Koanyel Jeong**, San Jose, CA (US)

Correspondence Address:
FENWICK & WEST LLP
SILICON VALLEY CENTER, 801 CALIFORNIA STREET
MOUNTAIN VIEW, CA 94041 (US)

(73) Assignee: **LEADIS TECHNOLOGY, INC.**, Sunnyvale, CA (US)

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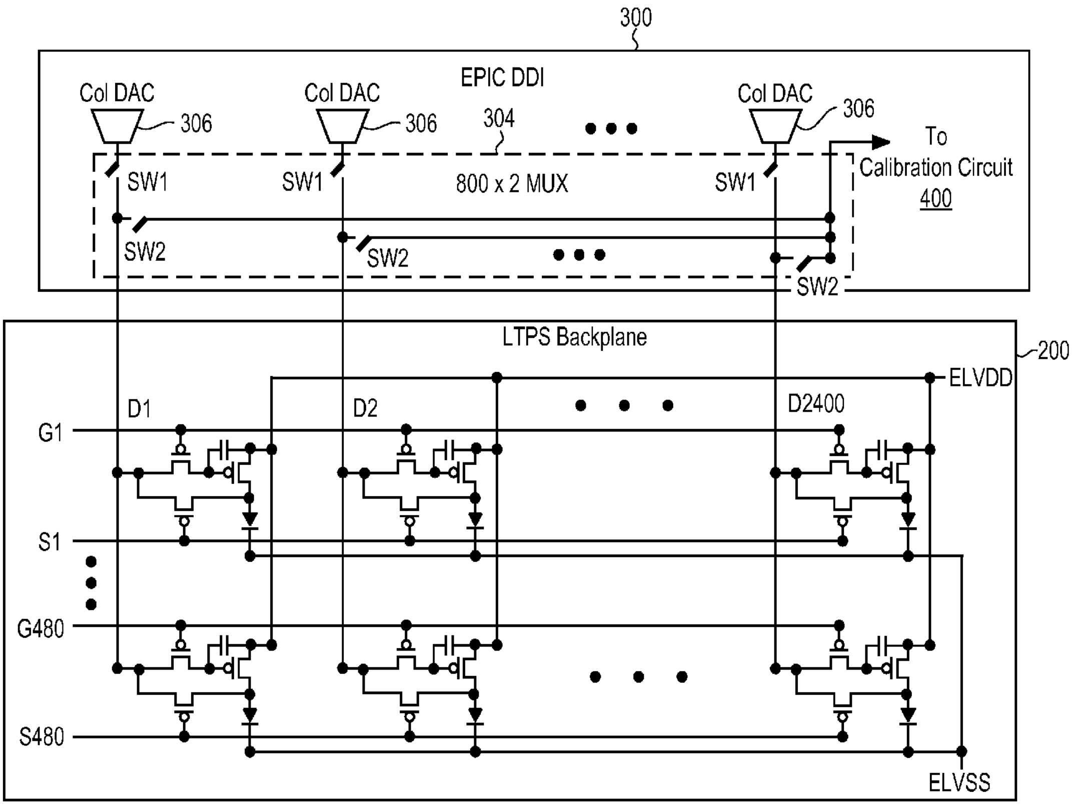
(57) **ABSTRACT**

The data line voltage on the data line of the AMOLED sub-pixels is measured while the OLED is being driven by a reference current, in order to determine the age of the OLED in the sub-pixel. The pixel transistor serves as a current source for driving the OLED in the sub-pixel with the reference current. The data line voltage is substantially equal to the forward voltage VF(aged) of the aged OLED being driven at the reference current. The forward voltage VF (un-aged) of a reference (un-aged) OLED sub-pixel also measured at the reference current, and is subtracted from the measured OLED diode forward voltage VF (aged) to obtain their difference ΔVF=VF(aged)−VF(un-aged). ΔVF is an indicator of the age of the OLED in the sub-pixel, and is used as an index to a look-up-table that stores the corresponding aging offset data for generating the incremental pixel current needed to maintain constant luminance in the aged OLED pixel.



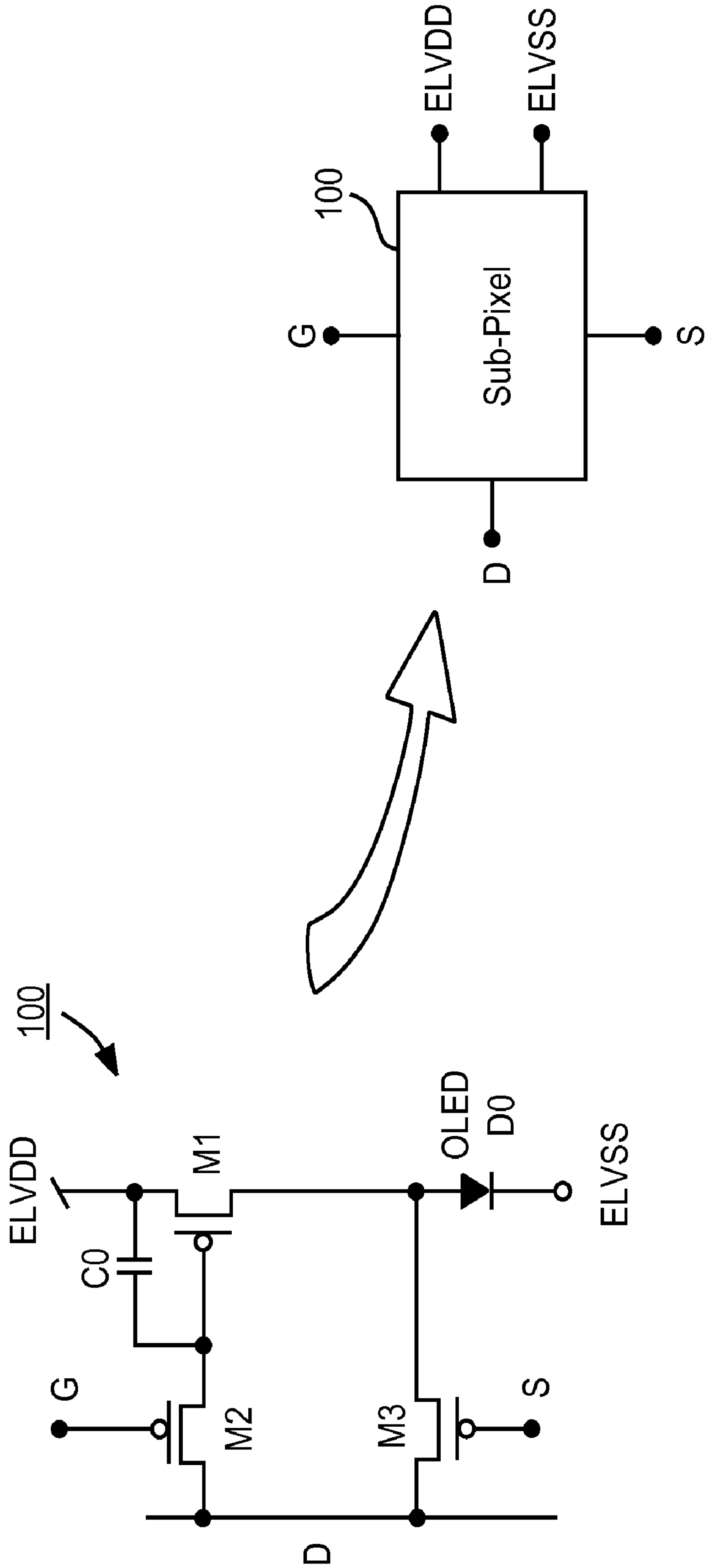

ELVDD
ELVSS
100
Sub-Pixel
G
S
D
100
ELVDD
C0
M1
G
M2
OLED
D0
ELVSS
M3
S
D

FIG. 1

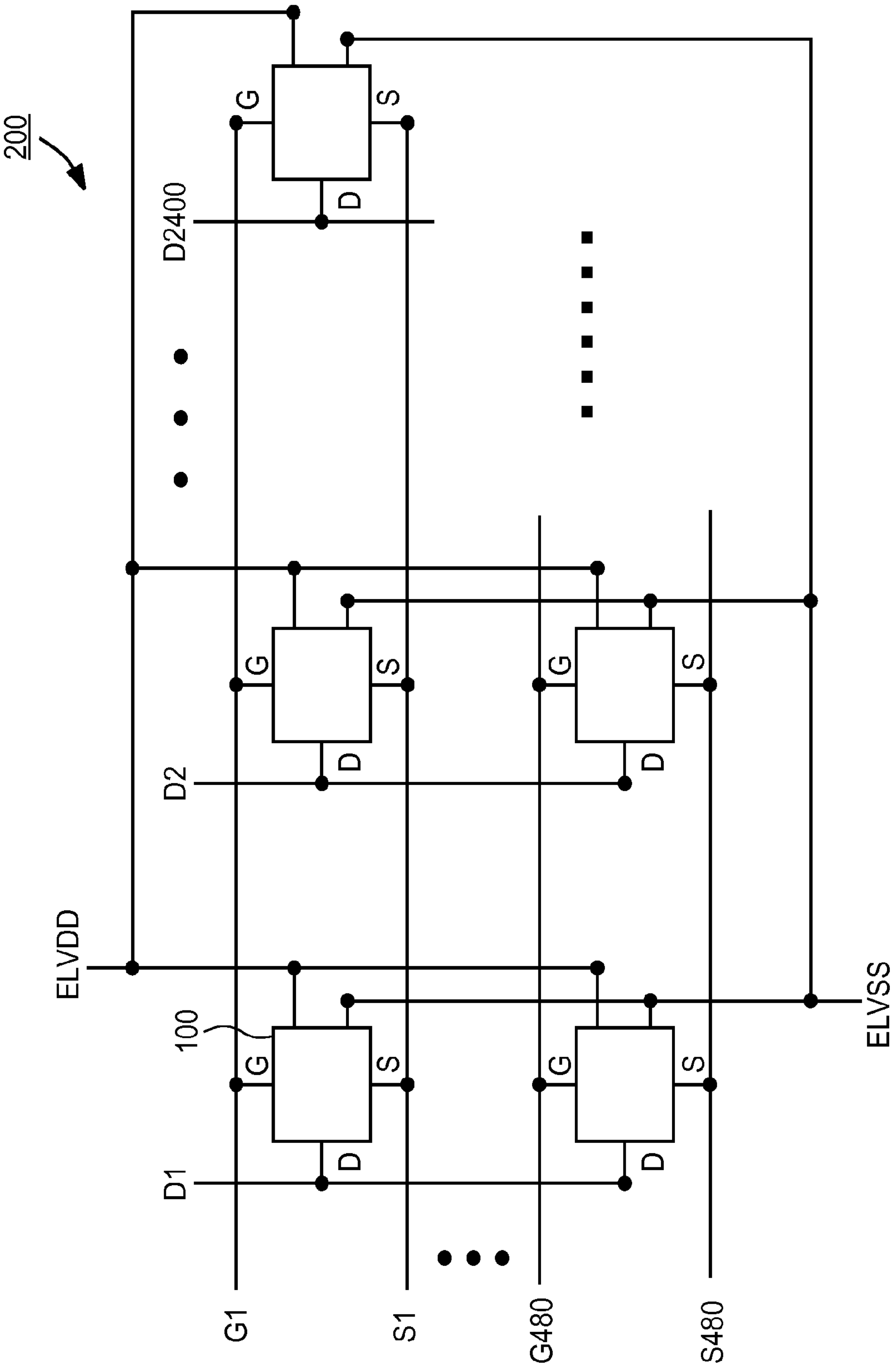


FIG. 2

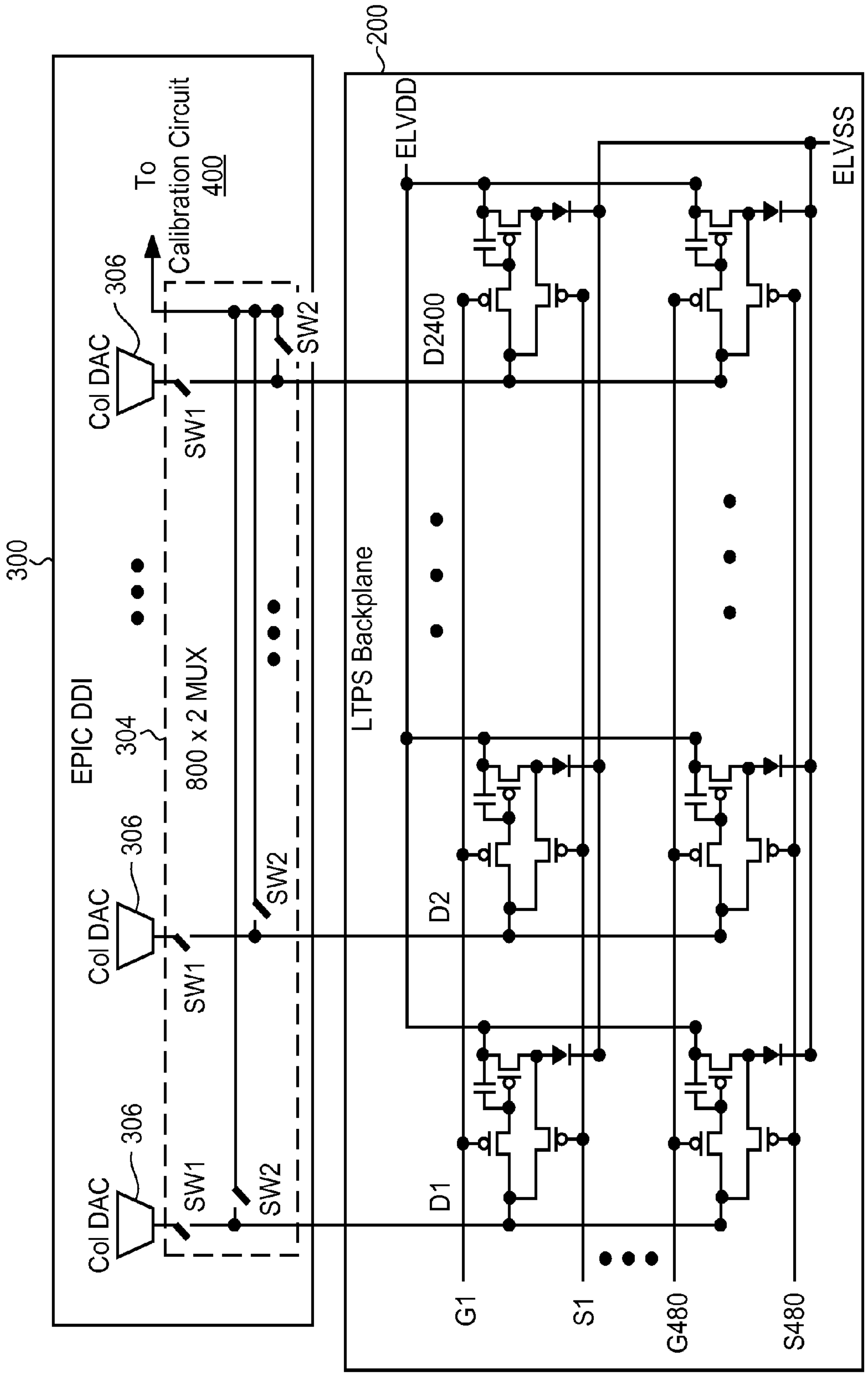

300
EPIC DDI
Col DAC
306
SW1
SW2
304
800 x 2 MUX
To
Calibration Circuit
400
200
LTPS Backplane
ELVDD
ELVSS
D1
D2
D2400
G1
S1
G480
S480

FIG. 3A

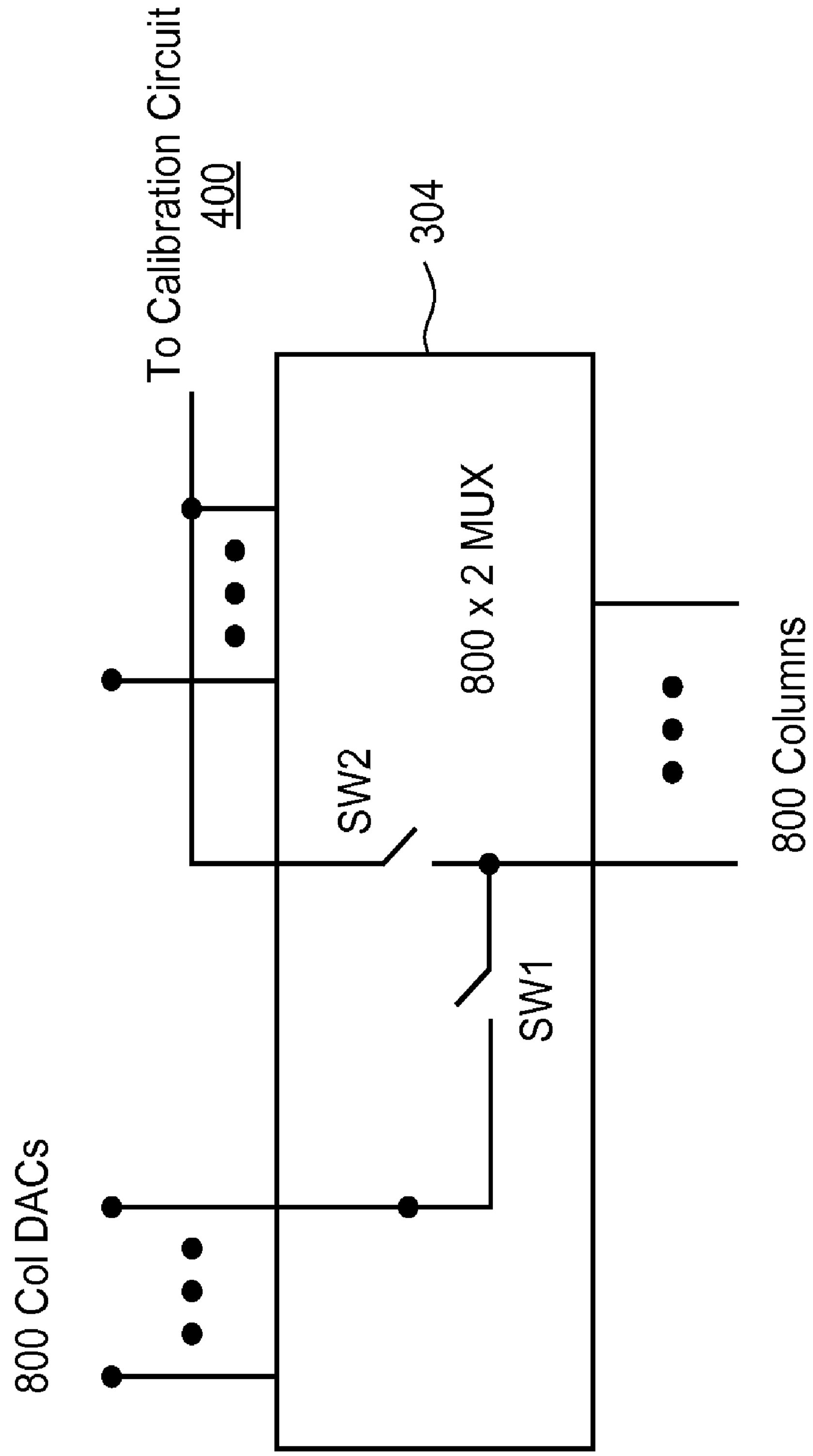

To Calibration Circuit
400
304
800 x 2 MUX
SW2
SW1
800 Col DACs
800 Columns

FIG. 3B

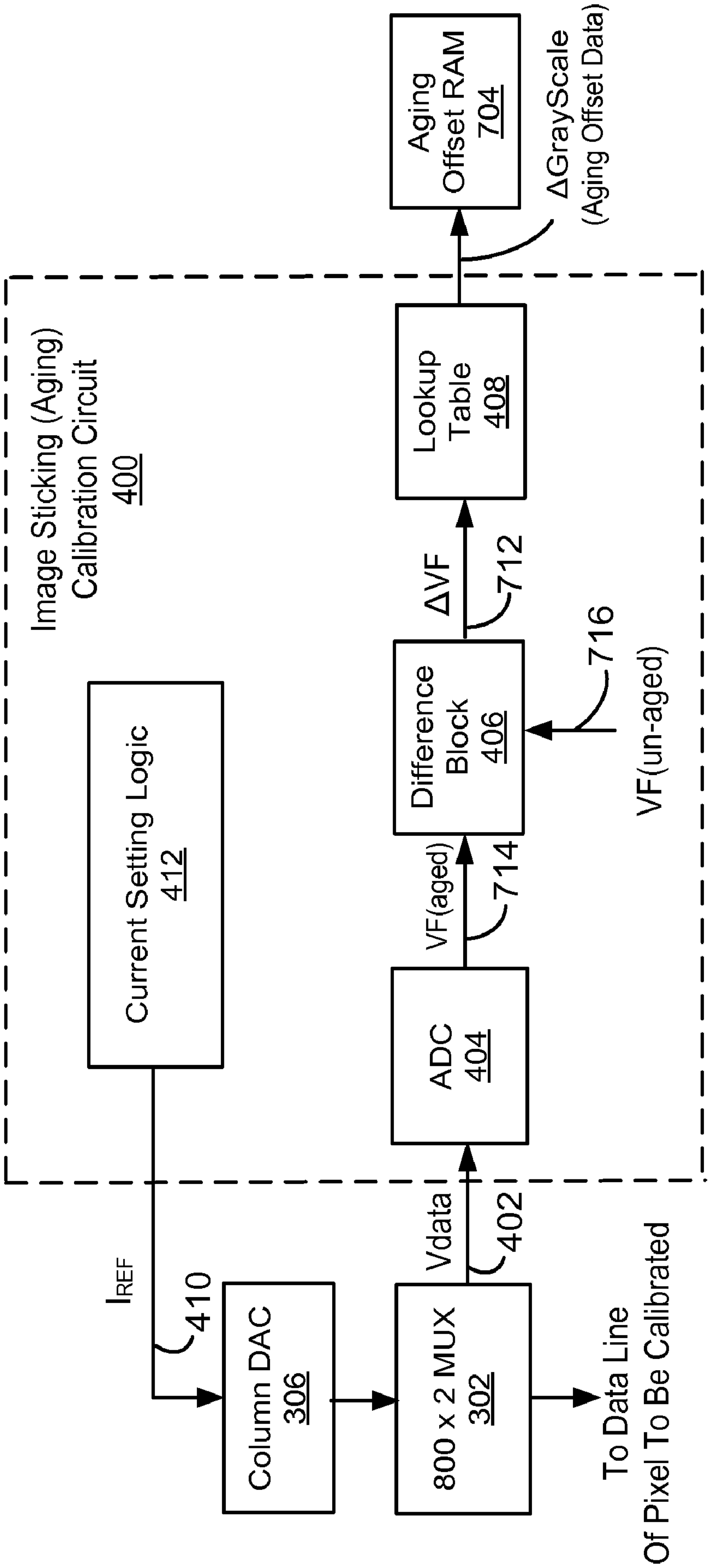


Image Sticking (Aging) Calibration Circuit 400
Current Setting Logic 412
Column DAC 306
800 x 2 MUX 302
ADC 404
Difference Block 406
Lookup Table 408
Aging Offset RAM 704
ΔGrayScale (Aging Offset Data)
ΔVF
712
VF(aged)
714
VF(un-aged)
716
Vdata
402
IREF
410
To Data Line Of Pixel To Be Calibrated

FIG. 4A

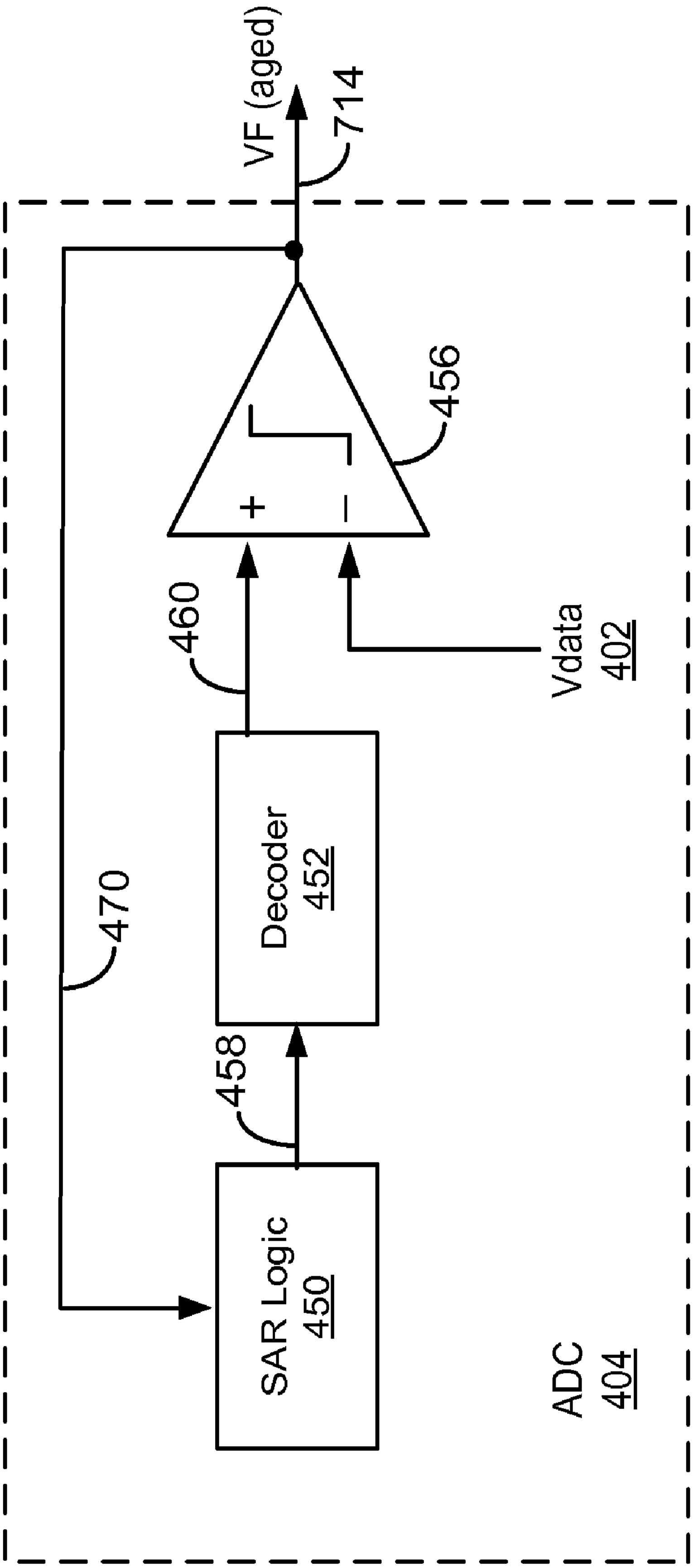

VF (aged)
714
456
+
−
460
Vdata
402
Decoder
452
470
458
SAR Logic
450
ADC
404

FIG. 4B

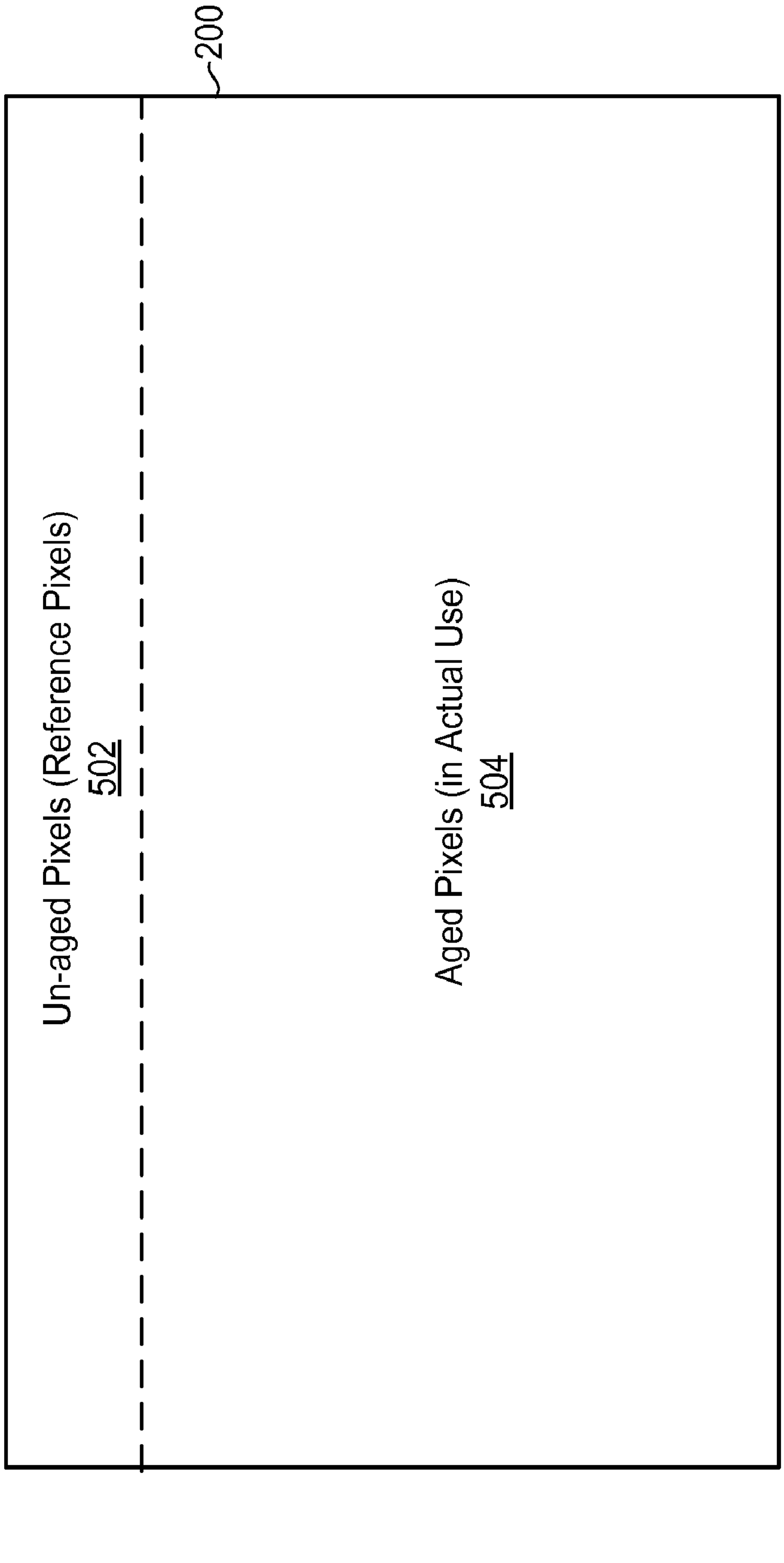

200
Un-aged Pixels (Reference Pixels)
502
Aged Pixels (in Actual Use)
504

FIG. 5

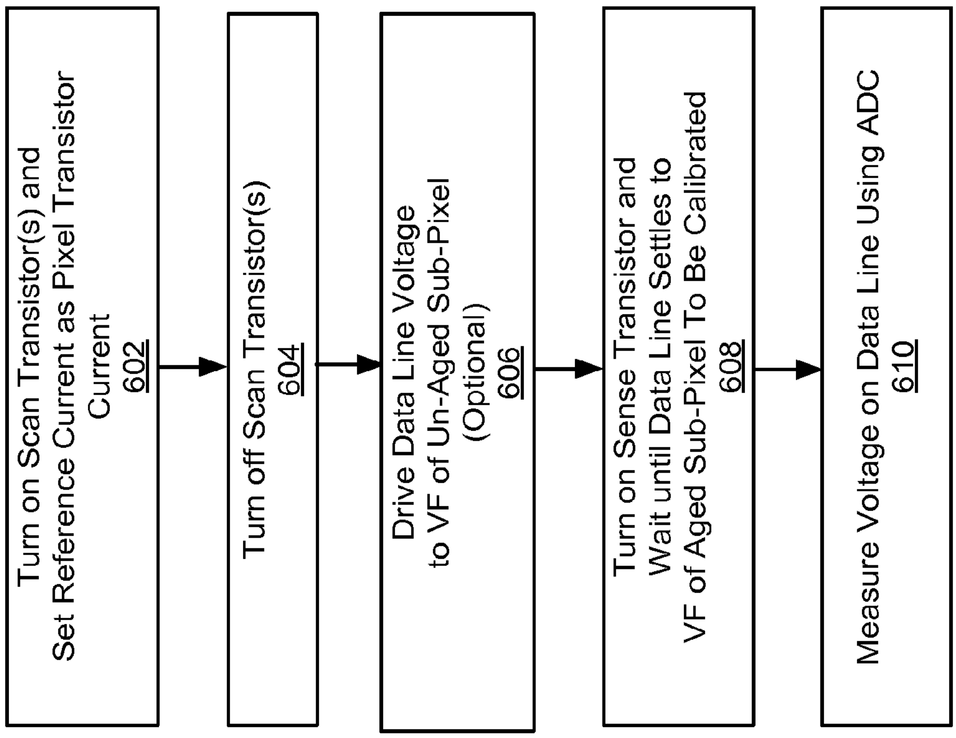

Turn on Scan Transistor(s) and
Set Reference Current as Pixel Transistor
Current
602
Turn off Scan Transistor(s)
604
Drive Data Line Voltage
to VF of Un-Aged Sub-Pixel
(Optional)
606
Turn on Sense Transistor and
Wait until Data Line Settles to
VF of Aged Sub-Pixel To Be Calibrated
608
Measure Voltage on Data Line Using ADC
610

FIG. 6

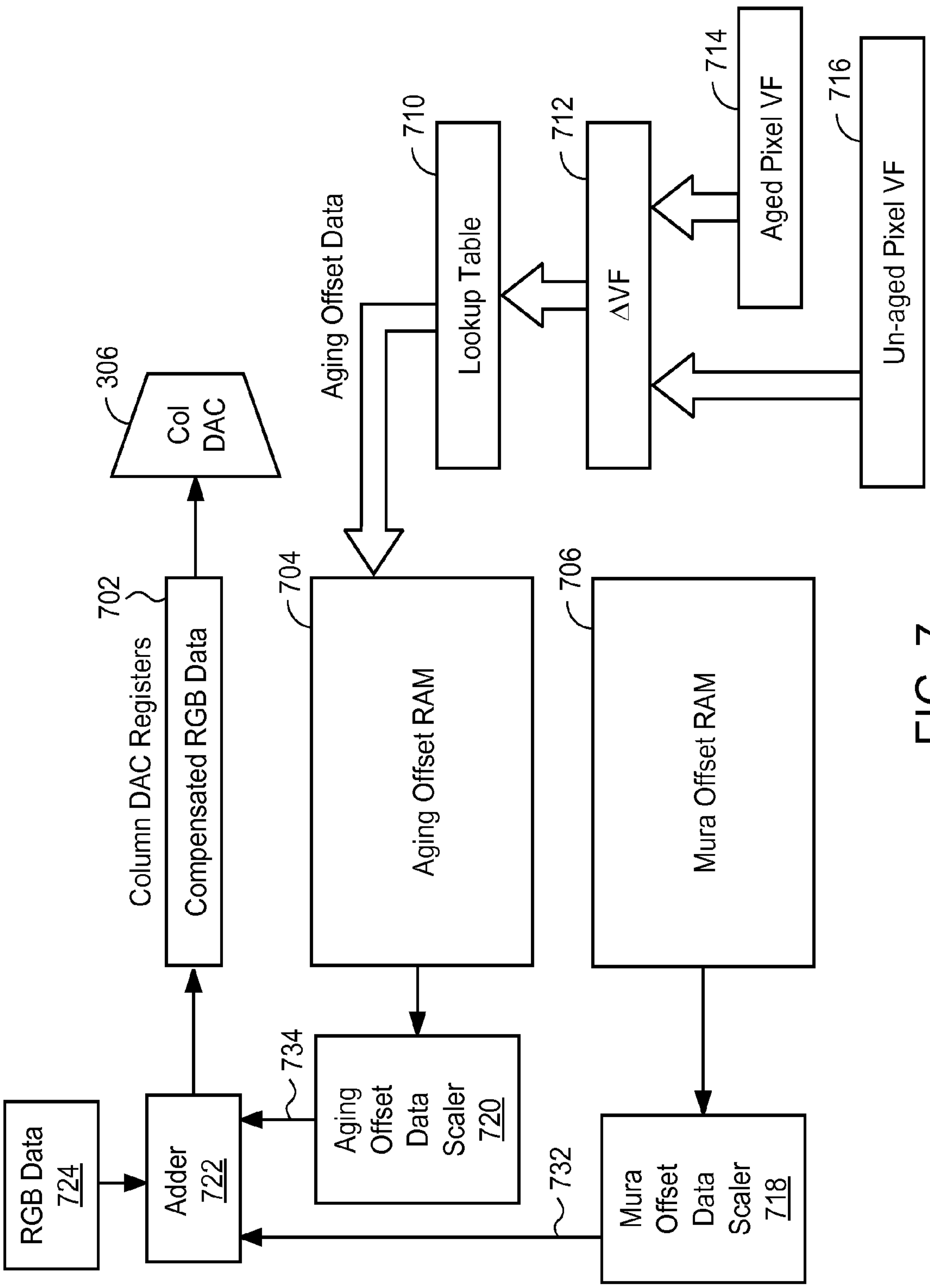

306
Col DAC
702
Column DAC Registers
Compensated RGB Data
Aging Offset Data
710
Lookup Table
712
ΔVF
714
Aged Pixel VF
716
Un-aged Pixel VF
704
Aging Offset RAM
706
Mura Offset RAM
734
Aging Offset Data Scaler 720
732
Mura Offset Data Scaler 718
RGB Data 724
Adder 722

FIG. 7

CORRECTION OF AGING IN AMOLED DISPLAY

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to calibration of current variations in the pixels/sub-pixels of an active matrix organic light-emitting diode (AMOLED) display caused by aging of the organic light-emitting diodes (OLEDs) in the AMOLED sub-pixels.

[0003] 2. Description of the Related Arts

[0004] An OLED display is generally comprised of an array of organic light emitting diodes (hereafter referred to as "OLED diodes") that have carbon-based films deposited between two charged electrodes. Generally one electrode is comprised of a transparent conductor, for example, indium tin oxide (ITO). Generally, the organic material films are comprised of a hole-injection layer, a hole-transport layer, an emissive layer and an electron-transport layer. When voltage is applied to the OLED diode, the injected positive and negative charges recombine in the emissive layer and transduce electrical energy to light energy. Unlike liquid crystal displays (LCDs) that require backlighting, OLED displays are self-emissive devices—they emit light rather than modulate transmitted or reflected light. Accordingly, OLEDs are brighter, thinner, faster and lighter than LCDs, and use less power, offer higher contrast and are cheaper to manufacture.

[0005] An OLED display typically includes a plurality of OLED diodes arranged in a matrix form including a plurality of rows and a plurality of columns, with the intersection of each row and each column forming a pixel of the OLED display. An OLED display is generally activated by way of a current driving method that relies on either a passive-matrix (PM) scheme or an active-matrix (AM) scheme.

[0006] In a passive matrix OLED (PM OLED) display, a matrix of electrically-conducting rows and columns forms a two-dimensional array of picture elements called pixels. Sandwiched between the orthogonal column and row lines are thin films of organic material of the OLEDs that are activated to emit light when current is applied to the designated row and column lines. The brightness of each pixel is proportional to the amount of current applied to the OLED diodes of the pixel. While PM OLEDs are fairly simple structures to design and fabricate, they demand relatively expensive, current-sourced drive electronics to operate effectively and are limited as to the number of lines because only one line can be on at a time and therefore the PM OLED must have instantaneous brightness equal to the desired average brightness times the number of lines. Thus, PM OLED displays are typically limited to under 100 lines. In addition, their power consumption is significantly higher than that required by an active-matrix OLED. PM OLED displays are most practical in alpha-numeric displays rather than higher resolution graphic displays.

[0007] An active-matrix OLED (AMOLED) display is comprised of OLED pixels (that are each comprised of R, G, B sub-pixels) that have been deposited or integrated onto a thin film transistor (TFT) array to form a matrix of pixels that emit light upon electrical activation. In contrast to a PM OLED display, for which electricity is distributed row by row, the active-matrix TFT backplane acts as an array of switches coupled with sample and hold circuitry that control and hold the amount of current flowing through each individual OLED sub-pixel during the total frame time. The active matrix TFT array continuously controls the current that flows to the OLED diodes in each of the sub-pixels, signaling to each pixel how brightly to illuminate.

[0008] AMOLED displays require regulated current in each pixel to produce a desired brightness from the pixel. Ideally, the TFTs in the active matrix TFT array exhibit uniform electrical characteristics, so that the AMOLED display can be precisely controlled in a uniform manner. However, the TFTs in the AMOLED are typically fabricated with polysilicon (p-Si) that is difficult to fabricate in a uniform manner. This is because p-Si is made by converting amorphous silicon (a-Si) to p-Si by laser annealing the a-Si to increase the crystal grain size. The larger the crystal grain size, the faster and more stable is the resulting semiconductor material. Unfortunately the grain size produced in the laser anneal step is not uniform due to a temperature spread in the laser beam. Thus, uniform TFTs are very difficult to produce and thus the current supplied by TFTs in conventional AMOLED displays is often non-uniform, resulting in non-uniform display brightness. TFT non-uniformity throughout the OLED display causes "Mura" (streaking or spots) in the OLED displays made with p-Si TFTs. In other words, TFTs may produce different OLED currents due to their non-uniformities from pixel to pixel, even if the same gate voltage is applied to the TFTs.

[0009] Another problem with AMOLED displays occurs due to aging of the material in the OLEDs. As the OLED diode in each sub-pixel ages with use, it becomes less efficient in converting current to light, i.e., the efficiency of light emission of the OLED diode decreases. Thus, as OLED diode current to light efficiency of the OLED material decreases with use (age), light (luminance) emitted from an OLED diode in each sub-pixel for a given gate voltage applied to the drive TFTs of the OLED display also decreases. As a result, the OLED display emits less light for display than desired in response to a given gate voltage applied to the drive TFTs. In addition, since the OLED diodes on various parts of the AMOLED display do not age (are not used) equally in a uniform manner, OLED aging also causes non-uniformity in the OLED display. In addition, since aging is accelerated at higher currents, a repeating image at a high gray level will appear to remain or stick on the AMOLED panel, hence the term "image sticking" due to aging. As a result of aging, the forward voltage VF of an OLED in a sub-pixel required to generate a given OLED current will increase. Also, given an OLED current, the luminance from the OLED will decrease. The present invention seeks to correct such problems in the AMOLED display that arise from aging of the OLEDs in the AMOLED sub-pixels.

SUMMARY OF THE INVENTION

[0010] According to various embodiments of the present invention, the data line voltage on the data line of the AMOLED sub-pixels is measured while the OLED is being driven by a reference current in order to determine the age of the OLED in the sub-pixel. The pixel transistor serves as a current source for driving the OLED in the sub-pixel with the reference current. The data line voltage is substantially equal to the forward voltage VF(aged) of the aged OLED being driven at the reference current. The forward voltage VF (un-aged) of a reference (un-aged) OLED sub-pixel also measured at the reference current, and is subtracted from the measured OLED diode forward voltage VF (aged) to obtain their difference $\Delta VF = VF(aged) - VF(un\text{-}aged)$. ΔVF is an indicator of the age of the OLED in the sub-pixel, and is used as an index to a look-up-table that stores the corresponding aging offset data for generating the incremental pixel current needed to maintain constant luminance in the aged OLED pixel.

[0011] The features and advantages described in the specification are not all inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings and specification. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The teachings of the embodiments of the present invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawings.

[0013] FIG. **1** illustrates a sub-pixel structure of an AMOLED display, according to one embodiment.

[0014] FIG. **2** illustrates the configuration of an AMOLED panel including OLED sub-pixels with the pixel structure of FIG. **1**, according to one embodiment.

[0015] FIG. **3**A illustrates an EPIC DDI (Electrical Pixel Correction Display Driver IC) driving an AMOLED panel, according to one embodiment.

[0016] FIG. **3**B illustrates the multiplexer in the EPIC DDI of FIG. **3**A in more detail, according to one embodiment.

[0017] FIG. **4**A illustrates an image sticking (aging) calibration circuit in more detail, according to one embodiment.

[0018] FIG. **4**B illustrates one example of the analog-to-digital converter (ADC) that can be used with the image sticking calibration circuit of FIG. **4**A, according to one embodiment.

[0019] FIG. **5** illustrates how un-aged reference pixels are included in the AMOLED display, according to one embodiment.

[0020] FIG. **6** illustrates a method of measuring the forward voltage of an OLED in an AMOLED sub-pixel for aging calibration, according to one embodiment.

[0021] FIG. **7** illustrates the addition of compensation data to real-time display data, according to one embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

[0022] The Figures and the following description relate to preferred embodiments of the present invention by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles of the claimed invention.

[0023] Reference will now be made in detail to several embodiments of the present invention(s), 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 embodiments of the present invention 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 of the invention described herein.

[0024] FIG. **1** illustrates a sub-pixel structure of an AMOLED display, according to one embodiment of the present invention. For a color AMOLED display, each pixel includes 3 sub-pixels that have identical structure but emit different colors (R, G, B). For simplicity of illustration, FIG. **1** illustrates only one sub-pixel corresponding to one of the R, G, B colors per sub-pixel at the intersection of each row and each column of the AMOLED display panel. As shown in FIG. **1**, the active drive circuitry of each sub-pixel **100** includes TFTs M**1**, M**2**, and M**3** and a storage capacitor C**0** for driving the OLED diode D**0** of the sub-pixel. In the following explanation of FIG. **1** and ensuing figures, the type of the TFTs M**1**, M**2**, M**3** is p-channel TFT. However, note that n-channel TFTs may also be utilized in the active matrix.

[0025] The source of TFT M**2** is connected to data line D, and the drain of TFT M**2** is connected to the gate of TFT M**1** (the "pixel transistor") and to one side of storage capacitor C**0**. The source of TFT M**1** is connected to positive supply voltage ELVDD. The other side of storage capacitor C**0** is also connected, for example, to the positive supply voltage ELVDD and to the source of TFT M**1**. Note that the storage capacitor C**0** may be tied to any reference electrode in the pixel, but the connection shown in FIG. **1** has performance benefits in the presence of ELVDD positive supply voltage noise. The drain of TFT M**0** is connected to the anode of the OLED diode D**0**. The cathode of the OLED diode D**0** is connected to negative supply voltage ELVSS. The source of TFT M**3** is connected to the anode of OLED diode D**0**, and the drain of TFT M**3** is connected to data line D. The data line D voltages are downloaded to the AMOLED display a row at a time for display.

[0026] When TFT M**2** is turned on, the analog gate voltage from the data line D is applied to the gate of each TFT M**1** of each sub-pixel, which is locked by storage capacitor C**0**. In other words, the continuous current flow to the OLED diodes is controlled by the two TFTs M**1**, M**2** of each sub-pixel. TFT M**2** is used to start and stop the charging of storage capacitor C**0**, which provides a voltage source to the gate of TFT M**1** at the level needed to create a constant current to the OLED diode. The TFT M**2** samples the data on the data line D, which is then transferred to and held by the storage capacitor C**0**. The voltage held on the storage capacitor C**0** is applied to the gate of the TFT M**1**. In response, TFT M**1** drives current through the OLED diode D**0** to a specific brightness depending on the value of the sampled and held voltage as stored in the storage capacitor C**0**.

[0027] In addition to the two TFTs M**1**, M**2** typically found in conventional AMOLED cells ("2T cell structure"), the AMOLED sub-pixel of the present invention employs a "3T cell structure" that additionally includes a third TFT M**3** with one additional control line S that can be used to control the gate voltage of TFT M**3**. As will be explained in more detail below, TFT M**3**, when turned on, enables the forward voltage of OLED D**0** to be measured via the data line D. Thus, the AMOLED display of the present invention uses "data line sensing" to sense the OLED forward voltage. As shown in FIG. **1**, each sub-pixel **100** may be represented as a circuit block with 5 terminals, i.e., TFT M**2** gate voltage G, data line voltage D, M**3** gate voltage S, and ELVDD and ELVSS.

[0028] FIG. **2** illustrates the configuration of an AMOLED display panel including OLED sub-pixels with the sub-pixel structure of FIG. **1**, according to one embodiment of the present invention. The AMOLED display panel **200** is for a 480×800 RGB AMOLED, although this present invention can be used with AMOLED panels with any other size. Each sub-pixel structure **100** corresponds to that shown in FIG. **1**. Each of 3 sub-pixels is supplied by a dedicated data line D**1**, D**2**, . . . , D**2400** corresponding to each of R, G, B. All the supply voltage lines corresponding to the 2400 columns (800 columns×3 colors) D**1**, D**2**, . . . , D**2400** are powered by a common ELVDD supply voltage line. Thus, one column contains 3 data lines. Also note that one additional control line (S**1**, S**2**, . . . , S**480**) is added to each row, to control the TFTs M**3** in each sub-pixel and achieve data line sensing of the OLED diode current or the pixel transistor current in each sub-pixel via the corresponding data lines D**1**, D**2**, . . . , D**2400**.

[0029] FIG. **3**A illustrates a EPIC DDI (Electrical Pixel Correction Display Driver IC) driving an AMOLED panel **200**, according to one embodiment of the present invention. EPIC DDI **300** includes 800 column DACs (Digital-to-Analog Converters) **306** corresponding to the data lines (D**1**, D**2**, . . . , D**2400**), in groups of 3, of the AMOLED panel **200** (LTPS backplane). Each of 800 column DACs **306** can address **3** data lines by using a 1-to-3 RGB MUX (not shown in FIG. 3A). Thus all 2400 data lines D**1**, D**2**, . . . , D**2400** can be addressed. An 800×2 multiplexer **304** is used to divert pixel current to a calibration circuit **400**. Multiplexer **304** includes switches SW**1**, SW**2** for each column. Switch SW**1** connects or disconnects the column DAC **306** to/from the corresponding column, and switch SW**2** connects or disconnects the calibration circuit **400** to or from the corresponding column (data line) to sense the OLED diode forward voltage for image sticking calibration of each sub-pixel via the selected data line (D**1**, D**2**, . . . D**2400**).

[0030] FIG. 3B illustrates the multiplexer (MUX) **304** in the EPIC DDI of FIG. **3**A in more detail, according to one embodiment of the present invention. As shown in FIG. 3B, the MUX **304** is a 800×2 MUX each having two switches, SW**1** and SW**2** corresponding to each of the 800 columns of the AMOLED. MUX **304** connects the column DAC **306** to the corresponding column for normal operation using switch SW**1**, and connects a selected column to the calibration circuit **400** for OLED forward voltage measurement for aging (image sticking) calibration using switch SW**2**. Specifically, switches SW**1** in MUX **304** connect each of 800 column DACs **306** to each of 800 columns of the AMOLED panel. Switches SW**2** in MUX **304** allow each of the columns to be switched sequentially to a single calibration circuitry **400** so that one calibration circuitry can be used to calibrate all the sub-pixels in the AMOLED panel **200**. Although one calibration circuitry is used in the following description herein, multiple calibration circuitry may also be used to reduce image sticking calibration time at the expense of the additional circuitry.

[0031] Turning to the OLED aging problem, as mentioned briefly above, OLEDs age over time, resulting in increase of the forward voltage VF across OLED diode D**0** for a given OLED diode current (If). Also, even if the OLED diode is operated at constant current (If), the luminance from the OLED diode will decrease as a result of aging. Since aging is accelerated at higher currents, a repeating image at a high gray level will appear to remain or stick on the AMOLED panel, hence the term "image sticking" due to aging. By measuring the forward voltage (VF) across the OLED diode D**0** at a constant current and temperature for each pixel over time as the OLED diode ages, the amount of lost luminance from OLED aging can be inferred from ΔVF, i.e., the change in the OLED diode forward voltage (VF) over time at a constant OLED diode current (If) as the AMOLED display ages. Alternatively, the OLED diode forward voltage VF(un-aged) of an un-aged OLED diode can be measured and then this value can be subtracted from the measured OLED diode forward voltage VF(aged) of an aged, active sub-pixel to obtain ΔVF, i.e., ΔVF=VF(aged)−VF(un-aged), which method is preferred since it cancels temperature dependence. Then, as will be explained in more detail below with reference to FIG. **7**, ΔVF can be used as an index into a look-up-table that stores values of ΔVF and the corresponding aging offset data for generating the incremental sub-pixel current needed to maintain constant luminance in the aged OLED sub-pixel. Such look-up-table data is generated from OLED diode aging characterization data empirically obtained at the manufacturing and testing stage of the AMOLED display. This additional sub-pixel current can be implemented with an Aging Offset RAM that contains the digital offset that is to be added to the average RGB data in order to obtain the desired constant luminance over time. By using a target current equal to the full-scale luminance (full-scale RGB data) the aging offset RAM value can be scaled appropriately for smaller RGB data.

[0032] As can be seen above, the success of the aging compensation technique depends upon the ability to measure the OLED diode forward voltage VF at a constant current over time as the AMOLED ages. It is expected that 5 or more "image sticking" calibrations should be performed over the lifetime of the AMOLED product. Such calibrations may occur at, for example, 100 hours, 200 hours, 300 hours, 500 hours, and 1000 hours of use (depending upon the lifetime of the display). FIG. **4**A illustrates an image sticking (aging) calibration circuit that is used to measure such OLED diode forward voltage VF, according to one embodiment. Referring to FIG. **4**A, aging calibration circuit **400** includes current setting logic **412**, ADC **404**, difference block **406**, and lookup table **408**. Aging calibration circuit **400** also interfaces with column DAC **306**, MUX **302**, and aging offset RAM **704**.

[0033] Current setting logic **412** includes logic that is configured to drive column DACs **306** with a reference voltage V_{REF} that corresponds to reference current I_{REF}, so that the OLED D**0** in the sub-pixel in the AMOLED panel to be corrected for aging is driven with the reference current I_{REF}. The reference current I_{REF} is the constant current to be used for measuring the OLED forward voltage VF. The value of reference current I_{REF} may differ depending on the size of the AMOLED panel. In one embodiment, the reference current I_{REF} is 200 nA. In another embodiment, reference current I_{REF} is 1 μA. The reference voltage V_{REF} is provided to the sub-pixels through MUX **302** by turning on the switches SW**1** (and turning off switches SW**2**) in MUX **302** via the data lines D of the sub-pixel to be calibrated. On the other hand, when the switches SW**2** are turned on (and switches SW**1** are turned off), the voltage (Vdata) **402** on the data line of the sub-pixel to be calibrated becomes coupled to aging calibration circuit **400** for measurement. As will be explained in more detail below with reference to FIG. **6**, the measured data line voltage Vdata **402** may be substantially equal to the forward voltage VF of OLED D**0** of the sub-pixel to be calibrated, under certain conditions. The sensed voltage Vdata is input to ADC **404**, which outputs a digital value VF(aged) corresponding to Vdata. Difference block **406** includes logic circuitry configured to compute the difference in forward voltage ΔVF between VF (aged) and VF (un-aged). VF(un-aged) is digital forward voltage data VF corresponding to an un-aged OLED sub-pixel, that was measured previously using the calibration circuit **400** or by other means. ΔVF is stored in look-up table **408** which converts the ΔVF values to ΔGrayScale indicating the aging offset data in the form of offsets to the grayscale data that is needed to compensate for aging in the OLED sub-pixel to be calibrated. The look-up table **408** can perform such ΔVF to ΔGrayScale conversion using empirical data collected during the manufacture and testing stages of the AMOLED panel. ΔGrayScale is stored in aging offset RAM **704**. Although in the embodiment of FIG. **4**A the lookup table **408** converts ΔVF to ΔGrayScale for use as the aging offset data, in other embodiments the lookup table **408** may convert ΔVF to ×Luminance for use as the aging offset data.

[0034] The operation of FIG. **4**A is explained herein together with reference to FIG. **6**, which illustrates a method of measuring the forward voltage of an OLED in an AMOLED sub-pixel for aging calibration, according to one embodiment. Referring to FIG. **6** together with FIG. **4**A, in step **602** one or more of the scan transistors M**2** of the sub-pixels to be calibrated on a selected row of the AMOLED panel are turned on and current setting logic **412** sets the column DACs **306** corresponding to such sub-pixels with reference voltages V_{REF} that correspond to reference current I_{REF}. Preferably, the reference voltages V_{REF} that correspond to reference current I_{REF} is already calibrated for Mura, sub-pixel to sub-pixel, so that the aging calibration can be completed more efficiently and faster. During step **602**, switches SW**1** of MUX **302** is closed and switches SW**2** of MUX **302** are opened, so that the data lines D of the sub-pixels to be calibrated become coupled to the column DAC **306**. Also, the scan transistors M**2** of the sub-pixels to be calibrated on the selected are turned so that the reference voltage V_{REF} can drive the pixel transistors M**1**. As a result of step **602**, all the pixel transistors TFTs M**1** in the sub-pixels of the selected row are forced to have the same reference current I_{REF} flowing through them.

[0035] In step **604**, the scan transistors M**2** of the sub-pixels to be calibrated in the selected row are turned off. Then, in step **606**, the voltage on the data lines D of the sub-pixels to be calibrated in the selected row are driven to the OLED forward voltage VF of an un-aged pixel corresponding to the reference current I_{REF}, using current setting logic **412**. This OLED forward voltage VF of an un-aged pixel may have been measured previously using the same techniques as described in FIG. **6** with respect to an un-aged sub-pixel of the AMOLED panel and stored. Switches SW**1** are turned on and switches SW**2** are turned off during step **606**. Note that step **606** is optional, but is beneficial in preventing unwanted surge current from flowing through the OLEDs D**0** of the sub-pixels to be calibrated.

[0036] In step **608**, the sense transistor M**3** of the sub-pixels to be calibrated on the selected row are turned on, and the process waits until the data line D of the sub-pixels settle to the forward voltage VF of the OLED D**0** of the aged sub-pixel. Because the data line D of the sub-pixels is a capacitive load, once the data line D settles to the forward voltage VF of the OLED D**0**, all the current from the pixel transistor M**1** flows through the OLED D**0** and no current flows through the sense transistor M**3**, RGB MUX (not shown), and data line D. Thus, the voltage on the data line D becomes substantially equal to the forward voltage VF of the OLED D**0**, since there is no voltage drop on the data line D.

[0037] Then, in step **610**, the voltage on the data line D of the sub-pixels is measured using ADC **404**, as explained above. During step **610**, switches SW**1** are opened and switches SW**2** are closed in the MUX **302** to disconnect the column DACs **306** from the data line D and connect the data line D to the aging calibration circuit **400**. While steps **602**, **604**, **606**, and **608** may be performed on all or multiple sub-pixels of the selected row of the AMOLED panel, step **610** is performed on each sub-pixel one at a time if there is only a single calibration circuit **400** with the ADC **404**. Alternatively, the calibration circuitry **400** can be configured to include multiple ADCs **404** to measure the voltage on data line D of multiple sub-pixels at a time, in order to enhance the speed of image sticking calibration. As explained above, the measured data line voltage in step **610** is the forward voltage VF (aged) **714** of the aged sub-pixel, which is then compared with the forward voltage VF (un-aged) **716** of the un-aged sub-pixel to determine the difference ΔVF **712** between VF (aged) and VF (un-aged). ΔVF **712** is stored in look-up table **408** and converted to ΔGrayScale values indicating the aging offset data for storage in aging offset RAM **704**.

[0038] By performing steps **602**, **604**, **606**, **608**, and **610**, the aging calibration process for one selected row of the AMOLED panel is completed. These steps **602**, **604**, **606**, **608**, and **610** can be repeated for other rows of the AMOLED panel, row by row, to complete the aging calibration process for the entire AMOLED panel. At the end of that process, the aging offset RAM **704** would store aging offset data (ΔGrayScale values) for each of the sub-pixels of the entire AMOLED panel.

[0039] The circuitry and method for measuring the forward voltage VF of OLEDs as described in FIGS. **4**A and **6** have several benefits. First, since in step **602** the pixel transistors M**1** are used as current sources for driving the OLEDs D**0** with the reference current simply by setting the reference voltage V_{REF}, no separate external current source is needed to drive the OLEDs D**0**. Even though data line D is a capacitive load with parasitic capacitance, potentially taking some time to settle to the forward voltage VF on OLED D**0**, it is possible to process aging calibration in all the sub-pixels of the selected row in parallel and thereby speed up aging calibration time, because each of the sub-pixels has its own current source, i.e., the pixel transistor M**1**, and does not need a separate, external current source. In addition, since the current from the pixel transistor M**1** flows through the OLED D**0** and no current flows through the sense transistor M**3**, RGB MUX, and data line D in steps **608** and **610**, the resistance of the data line D does not introduce any inaccuracy in measuring the forward voltage of the OLED D**0** and the voltage on data line D becomes substantially equal to the forward voltage VF of OLED D**0**, thereby providing a convenient point (the data line D) to measure the OLED forward voltage VF. Furthermore, temperature differences in the OLED sub-pixel do not introduce significant error either, because the effects on the forward voltage VF introduced by temperature differences our canceled out by subtracting the same un-aged forward voltage VF (un-aged) from each of the measured aged OLED forward voltage VF (aged). Also, the forward voltage VF (aged) on the data line D can be measured using a very simple ADC **404** without complicated analog circuitry.

[0040] FIG. **4**B illustrates one example of the analog-to-digital converter (ADC) that can be used with the image sticking calibration circuit of FIG. **4**A, according to one embodiment. ADC **404** is a successive-approximation-register (SAR) ADC and includes SAR logic **450**, decoder **452**, and comparator **456**. SAR logic **450** implements a binary search algorithm to determine the digital output VF (aged) **714** corresponding to the measured voltage Vdata **402** on the data line D of the sub-pixel. Decoder **452** converts the binary values **458** output by SAR logic **450** to an analog value **460** comparably scaled to the data line voltage for comparison with the data line voltage Vdata **402** in comparator **456**. Feedback loop **470** provides the output of comparator **456** to SAR logic **450** so that SAR logic continues the binary search until the value **460** approximates the data line voltage Vdata **402**, which is output as VF (aged) **714** for the sub-pixel to be calibrated. Although a SAR ADC is used in FIG. 4B, the aging calibration circuit **400** is not limited to a particular type of ADC and a variety of other types of ADC circuits may be used with the aging calibration circuit **400**.

[0041] FIG. **5** illustrates how un-aged reference pixels are included in the AMOLED display, according to one embodiment. The AMOLED panel **200** may include a section **502** including sub-pixels (reference sub-pixels or replica sub-pixels) that are not used in normal operation. These un-aged OLED sub-pixels **502** are present on the AMOLED panel **200** but are not part of the active display. Since the reference pixels **502** are not used, they retain the initial characteristics of the sub-pixel at the time of manufacture of the AMOLED panel, i.e., they are un-aged. The OLED forward voltage VF (un-aged) of these un-aged sub-pixels **502** may be measured using the same aging calibration circuitry **400** of FIG. **4**A and the method of FIG. **6**, so that the aging calibration circuitry can use VF (un-aged) in difference block **406**. In other embodiments, the OLED forward voltage VF (un-aged) of these un-aged sub-pixels **502** may be measured by other conventional means, not using the aging calibration circuitry **400** of FIG. **4**A. The AMOLED panel **200** also includes a section **504** including sub-pixels that are actually used in normal operation and thus are aged. The sub-pixels **504** are the ones that require aging calibration as they age. The OLED forward voltage VF (aged) of these aged sub-pixels **504** are measured as explained above using the aging calibration circuitry **400** of FIG. **4**A and the method of FIG. **6**.

[0042] FIG. **7** illustrates the generation of compensated RGB data that is stored in column DAC register **702** which drives the column DAC **306** for real-time display by adding the scaled Mura and image sticking (aging) offset data to the RGB data in real time, according to one embodiment of the present invention. The Mura offset RAM **706** and the aging offset RAM **704** store offset gray scale values for correction of the RGB data **724** in order to compensate for Mura and aging, respectively, in the AMOLED display. The offset data for Mura compensation may be determined in a variety of conventional ways, which are not the subject of the invention herein and are not described herein. Data in the aging offset RAM **704** are entered through the aging calibration process described above with reference to FIGS. **4**A and **6**.

[0043] For aging compensation, the un-aged OLED diode forward voltage VF (un-aged) **716** of each sub-pixel for un-aged sub-pixels conducting the predetermined constant OLED diode current (I_{REF}) may be compared with the forward voltage VF(aged) **714** of aged OLEDs needed to have the same predetermined constant OLED current (I_{REF}) flow in aged OLEDs D**0**, to determine the difference ΔVF **712** in such forward voltages and infer how aged the OLED D**0** is. The forward voltage difference ΔVF **712** is used as an index into a look-up table **710** that stores factory-determined full-scale aging offset data needed to compensate for such aging in the OLEDs as a function of the inferred age of the OLED diode indicated by ΔVF **712**. Such aging offset data is stored in the aging offset RAM **704** at a location corresponding to the calibrated sub-pixel.

[0044] The data stored for each sub-pixel in the offset RAMs **704** and **706** corresponds to the correction needed for full-scale pixel current (e.g., M**1** pixel current Ip=200 nA) which corresponds to a full-scale RGB data. For real-time display, the data in the offset RAMs **704** and **706** should be scaled according to the real-time RGB data so that full-scale offsets are scaled accordingly for less than full-scale RGB input data. Mura offset data scaler **718** and aging offset data scaler **720** scale the full-scale Mura offset data and the full-scale aging offset data, respectively, to correspond to the real-time RGB data **724** for the driven sub-pixel. Adder **722** performs real-time addition of the scaled Mura offset value **732** and the scaled aging (image sticking) offset value **734** to the real-time RGB data **724** corresponding to the driven sub-pixel, and the summed result is stored temporarily in column DAC registers **702** as compensated RGB data for driving the column DAC **306** that subsequently drives the sub-pixels for real-time display. Thus, the OLED sub-pixels will illuminate light calibrated for Mura and especially for aging, as determined by the process illustrated above in FIG. **6**.

[0045] Upon reading this disclosure, those of skill in the art will appreciate still additional alternative designs for correction of aging in AMOLED displays. Thus, while particular embodiments and applications of the present invention have been illustrated and described, it is to be understood that the invention is 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 of the present invention disclosed herein without departing from the spirit and scope of the present invention.

What is claimed is:

1. An active matrix organic light-emitting diode (AMOLED) display device, comprising:

a plurality sub-pixels arranged in rows and columns, each sub-pixel including at least an organic light-emitting diode (OLED), a first transistor for driving the OLED, a storage capacitor for turning on or off the first transistor according to charges stored in said storage capacitor, a second transistor for connecting a data line of said each sub-pixel to the storage capacitor and the first transistor, and a third transistor for connecting the OLED to the data line; and

calibration circuitry configurable to be coupled to at least one of the sub-pixels and adapted to measure a forward voltage of the OLED via the data line when a reference current flows through the OLED.

2. The AMOLED display device of claim **1**, wherein the calibration circuitry includes an analog-to-digital converter (ADC) configured to be coupled to the data line of said each sub-pixel to measure a data line voltage on the data line, the data line voltage being substantially equal to the forward voltage of the OLED.

3. The AMOLED display device of claim **2**, wherein the calibration circuitry further includes a difference block configured to determine a forward voltage difference between the measured data line voltage and a predetermined reference forward voltage corresponding to an un-aged reference OLED, the forward voltage difference being an indicator of aging of the OLED.

4. The AMOLED display device of claim **3**, wherein the calibration circuitry is configured to drive the data line to the reference forward voltage prior to measuring the data line voltage on the data line.

5. The AMOLED display device of claim **2**, further comprising multiplexing circuitry including a first switch and a second switch, the first switch configured to be turned on to connect the data line to a reference voltage corresponding to the reference current for driving the OLED while the second switch is turned off, and the second switch configured to be turned on to connect the data line to the analog-to-digital converter for measurement of the data line voltage while the first switch is turned off.

6. The AMOLED display device of claim **2**, wherein the ADC is a successive-approximation-register (SAR) type ADC.

7. The AMOLED display device of claim **1**, wherein the first transistor drives the reference current through the OLED.

8. The AMOLED display device of claim **1**, wherein the second transistor is turned off while the calibration circuitry measures the forward voltage of the OLED via the data line.

9. The AMOLED display device of claim **1**, wherein the third transistor is turned on to connect the OLED to the data line by at least a predetermined time prior to measuring the data line voltage on the data line such that the forward voltage of the OLED settles on the data line.

10. In an active matrix organic light-emitting diode (AMOLED) display device including a plurality sub-pixels arranged in rows and columns, each sub-pixel including at least an organic light-emitting diode (OLED), a first transistor for driving the OLED, a storage capacitor for turning on or off the first transistor according to charges stored in said storage capacitor, a second transistor for connecting a data line of said each sub-pixel to the storage capacitor and the first transistor, and a third transistor for connecting the OLED to the data line, a method of determining an age of said OLED, the method comprising:

driving the first transistor with a reference current, the reference current also being driven through said OLED by the first transistor; and

measuring a data line voltage on the data line of each of said sub-pixel when the reference current flows through the OLED, the data line voltage being substantially equal to a forward voltage of said OLED when the reference current flows through said OLED.

11. The method of claim **10**, wherein the data line voltage is measured using an analog-to-digital converter (ADC) coupled to the data line of said each sub-pixel.

12. The method of claim **11**, further comprising determining a forward voltage difference between the measured data line voltage and a predetermined reference forward voltage corresponding to an un-aged reference OLED, the forward voltage difference being an indicator of the age of the OLED.

13. The method of claim **12**, further comprising driving the data line to a reference forward voltage corresponding to an un-aged OLED, prior to measuring the data line voltage.

14. The method of claim **11**, further comprising turning on the second transistor and connecting the data line to a reference voltage corresponding to the reference current to drive the reference current through the first transistor and said OLED.

15. The method of claim **11**, further comprising turning off the second transistor while the data line voltage is measured.

16. The method of claim **11**, further comprising turning on the third transistor to connect the OLED to the data line by at least a predetermined time prior to measuring the data line voltage such that the forward voltage of the OLED settles on the data line.

17. Calibration circuitry for correcting aging of the organic light-emitting diodes (OLEDs) in an active matrix organic light-emitting diode (AMOLED) display device, the calibration circuitry comprising:

an analog-to-digital converter (ADC) configured to be coupled to a data line of each sub-pixel of the AMOLED display to measure a data line voltage on the data line while an OLED of said each sub-pixel is driven by a reference current, the data line voltage being substantially equal to the forward voltage of the OLED; and

a difference block configured to determine a forward voltage difference between the measured data line voltage and a predetermined reference forward voltage corresponding to an un-aged reference OLED, the forward voltage difference being an indicator of an age of the OLED.

18. The calibration circuitry of claim **17**, wherein the calibration circuitry is configured to drive the data line to the reference forward voltage prior to the ADC measuring the data line voltage.

19. The calibration circuitry of claim **17**, wherein the ADC is a successive-approximation-register (SAR) type ADC.

20. The calibration circuitry of claim **17**, wherein said OLED is connected to the data line prior to the calibration circuitry measuring the data line voltage by at least a predetermined time.

* * * * *

专利名称(译)	校正amoled显示器的老化		
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当前申请(专利权)人(译)	SILICONFILE TECHNOLOGIES，INC.		
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摘要(译)

在OLED被参考电流驱动的同时测量AMOLED子像素的数据线上的数据线电压，以便确定子像素中OLED的年龄。像素晶体管用作用于利用参考电流驱动子像素中的OLED的电流源。数据线电压基本上等于在参考电流下驱动的老化OLED的正向电压VF（老化）。参考（未老化）OLED子像素的正向电压VF（未老化）也在参考电流下测量，并从测量的OLED二极管正向电压VF（老化）中减去，以获得它们的差ΔVF= VF（老化）- VF（未老化的）。 ΔVF是子像素中OLED的年龄的指示符，并且用作查找表的索引，该查找表存储相应的老化偏移数据，用于生成维持老化中恒定亮度所需的增量像素电流。 OLED像素。