



## **ELECTROLUMINESCENT DISPLAY WITH COMPENSATION OF EFFICIENCY VARIATIONS**

### **FIELD OF THE INVENTION**

The present invention relates to solid-state electroluminescent flat-panel displays and more particularly to such displays having ways to compensate for efficiency loss of the electroluminescent display components.

### **BACKGROUND OF THE INVENTION**

Electroluminescent (EL) devices have been known for some years and have been recently used in commercial display devices. Such devices employ both active-matrix and passive-matrix control schemes and can employ a plurality of subpixels. Each subpixel contains an EL emitter and a drive transistor for driving current through the EL emitter. The subpixels are typically arranged in two-dimensional arrays with a row and a column address for each subpixel, and having a data value associated with the subpixel. Subpixels of different colors, such as red, green, blue, and white are grouped to form pixels. EL displays can be made from various emitter technologies, including coatable-inorganic light-emitting diode, quantum-dot, and organic light-emitting diode (OLED).

Solid-state OLED displays are of great interest as a superior flat-panel display technology. These displays utilize current passing through thin films of organic material to generate light. The color of light emitted and the efficiency of the energy conversion from current to light are determined by the composition of the organic thin-film material. Different organic materials emit different colors of light. However, as the display is used, the organic materials in the display age and become less efficient at emitting light. This reduces the lifetime of the display. The differing organic materials can age at different rates, causing differential color aging and a display whose white point varies as the display is used. In addition, each individual pixel can age at a rate different from other pixels, resulting in display nonuniformity.

The rate at which the materials age is related to the amount of current that passes through the display and, hence, the amount of light that has been emitted from the display. One technique to compensate for this aging effect in polymer light-emitting diodes is described in US Patent No. 6,456,016 by Sundahl et al. This approach relies on a controlled reduction of current provided at an early stage of use followed by a second stage in which the display output is gradually decreased. This solution requires that a timer within the controller, which then provides a compensating amount of current, track the operating time of the display. Moreover, once a display has been in use, the controller must remain associated with that display to avoid errors in display operating time. This technique has the disadvantage of not representing the performance of small-molecule organic light emitting diode displays well. Moreover, the time the display has been in use must be accumulated, requiring timing, calculation, and storage circuitry in the controller. Also, this technique does not accommodate differences in behavior of the display at varying levels of brightness and temperature and cannot accommodate differential aging rates of the different organic materials.

US Patent No. 6,414,661 by Shen et al. describes a method and associated system to compensate for long-term variations in the light-emitting efficiency of individual OLED emitters in an OLED display by calculating and predicting the decay in light output efficiency of each pixel based on the accumulated drive current applied to the pixel. The method derives a correction coefficient that is applied to the next drive current for each pixel. This technique requires the measurement and accumulation of drive current applied to each pixel, requiring a stored memory that must be continuously updated as the display is used, and therefore requiring complex and extensive circuitry.

US Patent Application No. 2002/0167474 by Everitt describes a pulse width modulation driver for an OLED display. One embodiment of a video display comprises a voltage driver for providing a selected voltage to drive an organic light-emitting diode in a video display. The voltage driver can receive

voltage information from a correction table that accounts for aging, column resistance, row resistance, and other diode characteristics. In one embodiment of the invention, the correction tables are calculated prior to or during normal circuit operation. Since the OLED output light level is assumed to be linear with respect to OLED current, the correction scheme is based on sending a known current through the OLED diode for a duration sufficiently long to permit the transients to settle out, and then measuring the corresponding voltage with an analog-to-digital converter (A/D) residing on the column driver. A calibration current source and the A/D can be switched to any column through a switching matrix. However, this technique is only applicable to passive-matrix displays, not to the higher-performance active-matrix displays which are commonly employed. Further, this technique does not include any correction for changes in OLED emitters as they age, such as OLED efficiency loss.

US Patent No. 6,504,565 by Narita et al. describes a light-emitting display which includes a light-emitting element array formed by arranging a plurality of light-emitting elements, a driving unit for driving the light-emitting element array to emit light from each of the light-emitting elements, a memory unit for storing the number of light emissions for each light-emitting element of the light-emitting element array, and a control unit for controlling the driving unit based on the information stored in the memory unit so that the amount of light emitted from each light-emitting element is held constant. An exposure display employing the light-emitting display, and an image-forming apparatus employing the exposure display are also disclosed. This design requires the use of a calculation unit responsive to each signal sent to each pixel to record usage, greatly increasing the complexity of the circuit design.

JP 2002-278514 by Numao Koji describes a method in which a prescribed voltage is applied to organic EL elements by a current-measuring circuit, the current flows are measured, and a temperature measurement circuit estimates the temperature of the organic EL elements. A comparison is made with the voltage value applied to the elements, the flow of current values and the

estimated temperature, the changes due to aging of similarly constituted elements determined beforehand, the changes due to aging in the current-luminance characteristics, and the temperature at the time of the characteristics measurements for estimating the current-luminance characteristics of the elements. Then, the  
5 total sum of the amount of currents supplied to the elements in the interval during which display data are displayed is changed, which can provide the luminance that is to be originally displayed, based on the estimated values of the current-luminance characteristics, the values of the current flowing in the elements, and the display data. This design presumes a predictable relative use of pixels and  
10 does not accommodate differences in actual usage of groups of pixels or of individual pixels. Hence, correction for color or spatial groups is likely to be inaccurate over time. Moreover, the integration of temperature and multiple current sensing circuits within the display is required. This integration is complex, reduces manufacturing yields, and takes up space within the display.

15 US Patent Publication No. 2003/0122813 by Ishizuki et al. discloses a display panel driving device and driving method for providing high-quality images without irregular luminance even after long-time use. The light-emission drive current flowing is measured while each pixel successively and independently emits light. Then the luminance is corrected for each input pixel  
20 data based on the measured drive current values. According to another aspect, the drive voltage is adjusted such that one drive current value becomes equal to a predetermined reference current. In a further aspect, the current is measured while an offset current, corresponding to a leak current of the display panel, is added to the current output from the drive voltage generator circuit, and the resultant  
25 current is supplied to each of the pixel portions. The measurement techniques are iterative, and therefore slow.

Arnold et al., in US Patent No. 6,995,519, teach a method of compensating for aging of an OLED device (emitter). This method relies on the drive transistor to drive current through the OLED emitter. However, drive  
30 transistors known in the art have non-idealities that are confounded with the

OLED emitter aging in this method. Low-temperature polysilicon (LTPS) transistors can have nonuniform threshold voltages and mobilities across the surface of a display, and amorphous silicon (a-Si) transistors have a threshold voltage which changes with use. The method of Arnold et al. will therefore not provide complete compensation for OLED efficiency losses in circuits wherein transistors show such effects. Additionally, when methods such as reverse bias are used to mitigate a-Si transistor threshold voltage shifts, compensation of OLED efficiency loss can become unreliable without appropriate and potentially expensive tracking and prediction of reverse bias effects.

10                    There is a need therefore for a more complete compensation approach for electroluminescent displays.

#### **SUMMARY OF THE INVENTION**

It is therefore an object of the present invention to compensate for efficiency changes in OLED emitters in the presence of transistor aging. This is achieved by a method of providing a drive signal to a gate electrode of a drive transistor in an electroluminescent (EL) subpixel, comprising:

- a) providing the EL subpixel having the drive transistor, an EL emitter, and a readout transistor, wherein the drive transistor has a first electrode, a second electrode, and the gate electrode;
- 20                    b) providing a first voltage source and a first switch for selectively connecting the first voltage source to the first electrode of the drive transistor;
- c) connecting the EL emitter to the second electrode of the drive transistor;
- 25                    d) providing a second voltage source connected to the EL emitter;
- e) connecting the first electrode of the readout transistor to the second electrode of the drive transistor;

- f) providing a current source and a third switch for selectively connecting the current source to the second electrode of the readout transistor;
- g) providing a voltage measurement circuit connected to the second electrode of the readout transistor;
- 5 h) opening the first switch, closing the third switch, and using the voltage measurement circuit to measure the voltage at the second electrode of the readout transistor to provide a first emitter-voltage signal;
- i) using the first emitter-voltage signal to provide an aging signal representative of the efficiency of the EL emitter;
- 10 j) receiving an input signal;
- k) using the aging signal and the input signal to produce a compensated drive signal; and
- l) providing the compensated drive signal to the gate electrode of the drive transistor to compensate for changes in efficiency of the EL emitter.

15 An advantage of this invention is an electroluminescent display, such as an OLED display, that compensates for the aging of the organic materials in the display wherein circuitry or transistor aging or nonuniformities are present, without requiring extensive or complex circuitry for accumulating a continuous measurement of light-emitting element use or time of operation. It is a further

20 advantage of this invention that it uses simple voltage measurement circuitry. It is a further advantage of this invention that by making all measurements of voltage, it is more sensitive to changes than methods that measure current. It is a further advantage of this invention that a single select line can be used to enable data input and data readout. It is a further advantage of this invention that

25 characterization and compensation of OLED changes are unique to the specific element and are not impacted by other elements that may be open-circuited or short-circuited.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph showing the relationship between OLED efficiency, OLED age, and OLED drive current density;

FIG. 2 is a schematic diagram of one embodiment of an electroluminescent (EL) display that can be used in the practice of the present invention;

FIG. 3 is a schematic diagram of one embodiment of an EL subpixel and connected components that can be used in the practice of the present invention;

FIG. 4A is a diagram illustrating the effect of aging of an OLED emitter on luminance efficiency;

FIG. 4B is a diagram illustrating the effect of aging of an OLED emitter or a drive transistor on emitter current;

FIG. 5 is a block diagram of one embodiment of the method of the present invention; and

FIG. 6 is a graph showing the relationship between OLED efficiency and the change in OLED voltage.

### DETAILED DESCRIPTION OF THE INVENTION

Turning now to FIG. 2, there is shown a schematic diagram of one embodiment of an electroluminescent (EL) display that can be used in the practice of the present invention. EL display 10 comprises an array of a predetermined number of EL subpixels 60 arranged in rows and columns. EL display 10 includes a plurality of row select lines 20 wherein each row of EL subpixels 60 has a row select line 20. EL display 10 includes a plurality of readout lines 30 wherein each column of EL subpixels 60 has a readout line 30. Each readout line 30 is connected to a third switch 130, which selectively connects readout line 30 to current source 160 during the calibration process. Although not shown for clarity of illustration, each column of EL subpixels 60 also has a data line as is well-known in the art. The plurality of readout lines 30 is connected to one or more multiplexers 40, which permits parallel/sequential readout of signals from EL

subpixels, as will become apparent. Multiplexer 40 can be a part of the same structure as EL display 10, or can be a separate construction that can be connected to or disconnected from EL display 10. Note that "row" and "column" do not imply any particular orientation of the panel.

5                   Turning now to FIG. 3, there is shown a schematic diagram of one embodiment of an EL subpixel that can be used in the practice of the present invention. EL subpixel 60 includes EL emitter 50, drive transistor 70, capacitor 75, readout transistor 80, and select transistor 90. Each of the transistors has a first electrode, a second electrode, and a gate electrode. A first voltage source 140  
10 is selectively connected to the first electrode of drive transistor 70 by first switch 110, which can be located on the EL display substrate or on a separate structure. By connected, it is meant that the elements are directly connected or connected via another component, e.g. a switch, a diode, or another transistor. The second electrode of drive transistor 70 is connected to EL emitter 50, and a second voltage  
15 source 150 can be selectively connected to EL emitter 50 by second switch 120, which can also be off the EL display substrate. The EL emitter 50 can also be connected directly to the second voltage source 150. At least one first switch 110 and second switch 120 are provided for the EL display. Additional first and second switches can be provided if the EL display has multiple powered  
20 subgroupings of pixels. The drive transistor 70 can be used as the first switch 110 by operating it in reverse bias so that substantially no current flows. Methods for operating transistors in reverse bias are known in the art. In normal display mode, the first and second switches are closed, and other switches (described below) are open. The gate electrode of drive transistor 70 is connected to select transistor 90  
25 to selectively provide data from data line 35 to drive transistor 70 as is well known in the art. Each of the plurality of row select lines 20 is connected to the gate electrodes of the select transistors 90 in the corresponding row of EL subpixels 60. The gate electrode of select transistor 90 is connected to the gate electrode of readout transistor 80.

The first electrode of readout transistor 80 is connected to the second electrode of drive transistor 70 and to EL emitter 50. Each of the plurality of readout lines 30 is connected to the second electrodes of the readout transistors 80 in the corresponding column of EL subpixels 60. Readout line 30 is connected to third switch 130. A respective third switch 130 (S3) is provided for each column of EL subpixels 60. The third switch permits current source 160 to be selectively connected to the second electrode of readout transistor 80. Current source 160, when connected by the third switch, permits a predetermined constant current to flow into EL subpixel 60. Third switch 130 and current source 160 can be provided located on or off the EL display substrate. The current source 160 can be used as the third switch 130 by setting it to a high-impedance (Hi-Z) mode so that substantially no current flows. Methods for setting current sources to high-impedance modes are known in the art.

The second electrode of readout transistor 80 is also connected to voltage measurement circuit 170, which measures voltages to provide signals representative of characteristics of EL subpixel 60. Voltage measurement circuit 170 includes analog-to-digital converter 185 for converting voltage measurements into digital signals, and processor 190. The signal from analog-to-digital converter 185 is sent to processor 190. Voltage measurement circuit 170 can also include memory 195 for storing voltage measurements, and a low-pass filter 180. Voltage measurement circuit 170 is connected through multiplexer output line 45 and multiplexer 40 to a plurality of readout lines 30 and readout transistors 80 for sequentially reading out the voltages from a predetermined number of EL subpixels 60. If there are a plurality of multiplexers 40, each can have its own multiplexer output line 45. Thus, a predetermined number of EL subpixels can be driven simultaneously. The plurality of multiplexers permits parallel reading out of the voltages from the various multiplexers 40, and each multiplexer permits sequential reading out of the readout lines 30 attached to it. This will be referred to herein as a parallel/sequential process.

Processor 190 can also be connected to data line 35 by way of control line 95 and source driver 155. Thus, processor 190 can provide predetermined data values to data line 35 during the measurement process to be described herein. Processor 190 can also accept display data via input signal 85 and provide compensation for changes as will be described herein, thus providing compensated data to data line 35 using source driver 155 during the display process. Source driver 155 can comprise a digital-to-analog converter or programmable voltage source, a programmable current source, or a pulse-width modulated voltage ("digital drive") or current driver, or another type of source driver known in the art.

The embodiment shown in FIG. 3 is a non-inverted, NMOS subpixel. Other configurations as known in the art can be employed with the present invention. The EL emitter 50 can be an OLED emitter or other emitter types known in the art. When the EL emitter 50 is an OLED emitter, the EL subpixel 60 is an OLED subpixel. The drive transistor 70, and the other transistors (80, 90) can be low-temperature polysilicon (LTPS), zinc oxide (ZnO), or amorphous silicon (a-Si) transistors, or transistors of another type known in the art. Each transistor (70, 80, 90) can be N-channel or P-channel, and the EL emitter 50 can be connected to the drive transistor 70 in an inverted or non-inverted arrangement. In an inverted configuration as known in the art, the polarities of the first and second power supplies are reversed, and the EL emitter 50 conducts current towards the drive transistor rather than away from it. Current source 160 of the present invention must therefore source a negative current, that is, behave as a current sink, to draw current through the EL emitter 50.

As an EL emitter 50, e.g. an OLED emitter, is used, its luminous efficiency, often expressed in cd/A, can decrease and its resistance can increase. Both of these effects can cause the amount of light emitted by an EL emitter to decrease over time. The amount of such decrease will depend upon the use of the EL emitter. Therefore, the decrease can be different for different EL emitters in a display, which effect is herein termed spatial variations in characteristics of EL

emitters 50. Such spatial variations can include differences in brightness and color balance in different parts of the display, and image "burn-in" wherein an off-displayed image (e.g. a network logo) can cause a ghost of itself to always show on the active display. It is desirable to compensate for such changes in the  
5 threshold voltage to prevent such problems.

Turning now to FIG. 4A, there is shown a diagram illustrating the effect of aging of an OLED emitter on luminance efficiency as current is passed through the OLED emitters. The three curves represent typical performance of different light emitters emitting differently colored light (e.g. R,G,B representing  
10 red, green, and blue light emitters, respectively) as represented by luminance output over time or cumulative current. The decay in luminance between the differently colored light emitters can be different. The differences can be due to different aging characteristics of materials used in the differently colored light emitters, or due to different usages of the differently colored light emitters.  
15 Hence, in conventional use, with no aging correction, the display can become less bright and the color of the display—in particular the white point—can shift.

Turning now to FIG. 4B, there is shown a diagram illustrating the effect of aging of an OLED emitter or a drive transistor, or both, on emitter current. The abscissa of FIG. 4B represents the gate voltage at drive transistor 70,  
20 and the ordinate represents the base-10 logarithm of the current through the drive transistor at that gate voltage. Unaged curve 230 shows a subpixel before aging. As the subpixel ages, a greater voltage is required to obtain a desired current; that is, the curve moves by an amount  $\Delta V$  to aged curve 240.  $\Delta V$  is the sum of the change in threshold voltage ( $\Delta V_{th}$ , 210) and the change in OLED voltage resulting from a change in OLED emitter resistance ( $\Delta V_{OLED}$ , 220), as shown. This change  
25 results in reduced performance. A greater gate voltage is required to obtain a desired current. The relationship between the OLED current (which is also the drain-source current through the drive transistor), OLED voltage, and threshold voltage at saturation is:

$$I_{oled} = \frac{W\mu C_0}{2L} (V_{gs} - V_{th})^2 = \frac{K}{2} (V_g - V_{oled} - V_{th})^2 \quad (\text{Eq. 1})$$

where W is the TFT Channel Width, L is the TFT Channel Length,  $\mu$  is the TFT mobility,  $C_0$  is the Oxide Capacitance per Unit Area,  $V_g$  is the gate voltage,  $V_{gs}$  is voltage difference between gate and source of the drive transistor. For simplicity, we neglect dependence of  $\mu$  on  $V_{gs}$ . Thus, to keep the current constant, changes in  $V_{th}$  and  $V_{OLED}$  must be compensated for.

Turning now to FIG. 5, and referring also to FIG. 3, there is shown a block diagram of one embodiment of the method of the present invention.

To measure the characteristics of an EL emitter 50, first switch 110 is opened, and second switch 120 and third switch 130 are closed (Step 340). Select line 20 is made active for a selected row to turn on readout transistor 80 (Step 345). A current,  $I_{testsu}$ , thus flows from current source 160 through EL emitter 50 to second voltage source 150. The value of current through current source 160 is selected to be less than the maximum current possible through EL emitter 50; a typical value will be in the range of 1 to 5 microamps and will be constant for all measurements during the lifetime of the EL subpixel. More than one measurement value can be used in this process, e.g. measurement can be performed at 1, 2, and 3 microamps. Taking measurements at more than one measurement value permits forming a complete I-V curve of the EL subpixel 60. Voltage measurement circuit 170 is used to measure the voltage on readout line 30 (Step 350). This voltage is the voltage  $V_{out}$  at the second electrode of readout transistor 80 and can be used to provide a first emitter-voltage signal  $V_2$  that is representative of characteristics of EL emitter 50, including the resistance and thus efficiency of EL emitter 50.

The voltages of the components in the subpixel are related by:

$$V_2 = CV + V_{OLED} + V_{read} \quad (\text{Eq. 2})$$

The values of these voltages will cause the voltage at the second electrode of readout transistor 80 ( $V_{out}$ ) to adjust to fulfill Eq. 2. Under the conditions described above, CV is a set value and  $V_{read}$  can be assumed to be constant as the

current through the readout transistor is low and does not vary significantly over time.  $V_{\text{OLED}}$  will be controlled by the value of current set by current source 160 and the current-voltage characteristics of EL emitter 50.

$V_{\text{OLED}}$  can change with age-related changes in EL emitter 50. To  
 5 determine the change in  $V_{\text{OLED}}$ , two separate test measurements are performed at different times. The first measurement is performed at a first time, e.g. when EL emitter 50 is not degraded by aging. This can be any time before EL subpixel 60 is used for display purposes. The value of the voltage  $V_2$  for the first measurement is the first emitter-voltage signal (hereinafter  $V_{2a}$ ), and is measured  
 10 and stored. At a second time different from the first time, e.g. after EL emitter 50 has aged by displaying images for a predetermined time, the measurement is repeated and a second emitter-voltage signal (hereinafter  $V_{2b}$ ) is stored.

If there are additional EL subpixels in the row to be measured, multiplexer 40 connected to a plurality of readout lines 30 is used to permit  
 15 voltage measurement circuit 170 to sequentially measure each of a predetermined number of EL subpixels, e.g. every subpixel in the row (decision step 355), and provide a corresponding first and second emitter-voltage signal for each subpixel. If the display is sufficiently large, it can require a plurality of multiplexers wherein the first and second emitter-voltage signals are provided in a parallel/sequential  
 20 process. If there are additional rows of subpixels to be measured in EL display 10, Steps 345 to 355 are repeated for each row (decision step 360). To accelerate the measurement process, each of the predetermined number of EL subpixels can be driven simultaneously so that any settling time will have elapsed when the measurement is taken.

25 Changes in EL emitter 50 can cause changes to  $V_{\text{OLED}}$  to maintain the test current  $I_{\text{testsu}}$ . These  $V_{\text{OLED}}$  changes will be reflected in changes to  $V_2$ . The two stored emitter-voltage signal ( $V_2$ ) measurements for each EL subpixel 60 can therefore be compared to calculate an aging signal  $\Delta V_2$  representative of the efficiency of the EL emitter 50 (Step 370) as follows:

$$30 \quad \Delta V_2 = V_{2b} - V_{2a} = \Delta V_{\text{OLED}} \quad (\text{Eq. 3})$$

The above method requires that the corresponding first emitter-voltage signal for each subpixel be stored in memory for later comparison. A less memory-intensive method can be used that does not require an initial measurement, but can compensate for spatial variations in  $V_{OLED}$ . After aging, the second emitter-voltage signal ( $V_{2b}$ ) can be recorded for each subpixel with selected values for current source 160, as previously described. Then, the subpixel with the minimum  $V_{OLED}$  shift (that is, the minimum measured  $V_{2b}$ ) is selected from the population of subpixels measured to be a target signal. This target signal serves as the first emitter-voltage signal ( $V_{2a,tgt}$ ) for all subpixels. The aging signals  $\Delta V_2$  for each of the plurality of subpixels can then be expressed as:

$$\Delta V_2 = V_{2b} - V_{2a,tgt} \quad (\text{Eq. 4})$$

The aging signal for an EL subpixel 60 can then be used to compensate for changes in characteristics of that EL subpixel.

For compensating for EL aging, it is necessary to correct as described above for  $\Delta V_{OLED}$  (related to  $\Delta V_2$ ). However, a second factor also affects the luminance of the EL emitter and changes with age or use: the efficiency of the EL emitter decreases with use, which decreases the light emitted at a given current (as shown in FIG. 4A). In addition to the relations above, a relationship has been found between the decrease in luminance efficiency of an EL emitter and  $\Delta V_{OLED}$ , that is, where the EL luminance for a given current is a function of the change in  $V_{OLED}$ :

$$\frac{L_{OLED}}{I_{OLED}} = f(\Delta V_{OLED}) \quad (\text{Eq. 5})$$

An example of the relationship between luminance efficiency and  $\Delta V_{OLED}$  for a tested OLED emitter is shown in the graph in FIG. 6. FIG. 6 shows this relationship at a variety of fade current densities, listed in the legend. As shown, the relationship has been experimentally determined to be approximately independent of fade current density. By measuring the luminance decrease and its relationship to  $\Delta V_{OLED}$  with a given current, a change in corrected signal necessary to cause the EL emitter 50 to output a nominal luminance can be determined. This

measurement can be done on a model system and thereafter stored in a lookup table or used as an algorithm. This modeling can be performed at a variety of fade current densities for more accurate results, or at a single fade current density to reduce cost, using the determination shown in FIG. 6 that the relationship  
 5 between OLED voltage rise and OLED efficiency loss is approximately independent of fade current density.

To compensate for the above changes in characteristics of EL subpixel 60, an input signal  $V_{data}$  is received (Step 375). The aging signals and the input signal can then be used to produce a compensated drive signal (Step 380).

10 An equation of the following form can be used:

$$\Delta V_{data} = f_2(\Delta V_2) + f_3(\Delta V_2) \quad (\text{Eq. 6})$$

where  $\Delta V_{data}$  is an offset voltage on the gate electrode of drive transistor 70 necessary to maintain the desired luminance,  $f_2(\Delta V_2)$  is a correction for the change in EL resistance and  $f_3(\Delta V_2)$  is a correction for the change in EL efficiency. In  
 15 this case, the compensated drive signal  $V_{comp}$  is:

$$V_{comp} = V_{data} + \Delta V_{data} \quad (\text{Eq. 7})$$

The compensated drive signal  $V_{comp}$  is provided to the gate electrode of the drive transistor (Step 385) using source driver 155 to compensate for changes in voltage and efficiency of the EL emitter.

20 When compensating an EL display having a plurality of EL subpixels, each subpixel is measured to provide a plurality of corresponding first and second emitter-voltage signals, and a plurality of corresponding aging signals is provided, as described above. A corresponding input signal for each subpixel is received, and a corresponding compensated drive signal calculated as above using  
 25 the corresponding aging signals. The compensated drive signal corresponding to each subpixel in the plurality of subpixels is provided to the gate electrode of that subpixel using source driver 155 as is known in the art. This permits compensation for changes in efficiency of each EL emitter in the plurality of EL subpixels.

The EL display can include a controller, which can include a lookup table or algorithm to compute an offset voltage for each EL emitter. The offset voltage is computed to provide corrections for changes in current due to changes in the threshold voltage of drive transistor 70 and aging of EL emitter 50, as well as providing a current increase to compensate for efficiency loss due to aging of EL emitter 50, thus providing a complete EL aging compensation solution. These changes are applied by the controller to correct the light output to the nominal luminance value desired. By controlling the signal applied to the EL emitter, an EL emitter with a constant luminance output and increased lifetime at a given luminance is achieved. Because this method provides a correction for each EL emitter in a display, it will compensate for spatial variations in the characteristics of the plurality of EL subpixels, and specifically for changes in efficiency of each EL emitter.

Referring to FIG. 1, an additional relationship has been found between the luminance efficiency of an OLED emitter and the current density with which that emitter is driven. In general, OLED emitters can exhibit variations in OLED efficiency due to drive level, expressed as current, current density, or any other value which maps bijectively to current density for a given OLED emitter. This relationship can be combined with that expressed in Eq. 5, above, for a more accurate model of where the OLED luminance for a given current:

$$\frac{L_{OLED}}{I_{OLED}} = f(\Delta V_{OLED}, I_{ds}) \quad (\text{Eq. 8})$$

where  $\Delta V_{OLED}$  is the change on OLED voltage due to aging, measured at current  $I_{testsu}$ , as described above, and  $I_{ds}$  is the current through the OLED which would ideally result from driving input signal 85 (FIG. 3). The value of the input signal 85, or other drive level values, can be substituted for  $I_{ds}$  in this equation. Each curve in FIG. 1 shows the relationship between current density,  $I_{ds}$  divided by emitter area, and efficiency ( $L_{OLED}/I_{OLED}$ ) for an OLED aged to a particular point. The ages are indicated in the legend using the T notation known in the art: e.g. T86 means 86% efficiency at a test current density of, in this case, 20 mA/cm<sup>2</sup>.

To compensate for the above changes in characteristics of EL subpixel 60, e.g. an OLED subpixel, one can use the aging signals  $\Delta V_2$ , along with the models described above, including Eq. 8 involving the input signal, in an equation of the form:

5 
$$\Delta V_{\text{data}} = f_2(\Delta V_2) + f_3(\Delta V_2, I_{\text{ds}}) \quad (\text{Eq. 9})$$

where  $\Delta V_{\text{data}}$  is an offset voltage on the gate electrode of drive transistor 70 necessary to maintain the desired luminance,  $f_2(\Delta V_2)$  is a correction for the change in EL resistance and  $f_3(\Delta V_2, I_{\text{ds}})$  is a correction for the change in EL efficiency at commanded current  $I_{\text{ds}}$ . Function  $f_3$  can be a fit of curves such as those shown in  
10 FIG. 1. As above, any drive level value may be used in the second term of Eq. 9. The value of  $\Delta V_{\text{data}}$  from Eq. 9 can then be used in Eq. 7 to provide a compensated drive signal. This can provide a more accurate compensation solution.

In a preferred embodiment, the invention is employed in a display that includes Organic Light Emitting Diodes (OLEDs), which are composed of  
15 small molecule or polymeric OLEDs as disclosed in but not limited to US Patent No. 4,769,292, by Tang et al., and US Patent No. 5,061,569, by VanSlyke et al. Many combinations and variations of organic light emitting displays can be used to fabricate such a display.

**PARTS LIST**

10	EL display
20	select line
30	readout line
35	data line
40	multiplexer
45	multiplexer output line
50	EL emitter
60	EL subpixel
70	drive transistor
75	capacitor
80	readout transistor
85	input signal
90	select transistor
95	control line
110	first switch
120	second switch
130	third switch
140	first voltage source
150	second voltage source
155	source driver
160	current source
170	voltage measurement circuit
180	low-pass filter
185	analog-to-digital converter
190	processor
195	memory
210	$\Delta V_{th}$
220	$\Delta V_{OLED}$
230	unaged curve
240	aged curve

**Parts List - continued**

340	step
345	step
350	step
355	decision step
360	decision step
370	step
375	step
380	step
385	step

**CLAIMS:**

1. A method of providing a drive signal to a gate electrode of a drive transistor in an electroluminescent (EL) subpixel, comprising:
- a) providing the EL subpixel having the drive transistor, an EL emitter, and a readout transistor, wherein the drive transistor has a first electrode, a second electrode, and the gate electrode;
  - b) providing a first voltage source and a first switch for selectively connecting the first voltage source to the first electrode of the drive transistor;
  - c) connecting the EL emitter to the second electrode of the drive transistor;
  - d) providing a second voltage source connected to the EL emitter;
  - e) connecting the first electrode of the readout transistor to the second electrode of the drive transistor;
  - f) providing a current source and a third switch for selectively connecting the current source to the second electrode of the readout transistor;
  - g) providing a voltage measurement circuit connected to the second electrode of the readout transistor;
  - h) opening the first switch, closing the third switch, and using the voltage measurement circuit to measure the voltage at the second electrode of the readout transistor to provide a first emitter-voltage signal;
  - i) using the first emitter-voltage signal to provide an aging signal representative of the efficiency of the EL emitter;
  - j) receiving an input signal;

k) using the aging signal and the input signal to produce a compensated drive signal; and

l) providing the compensated drive signal to the gate electrode of the drive transistor to compensate for changes in efficiency of the EL emitter.

2. The method of claim 1, further including providing a second switch for selectively connecting the EL emitter to the second voltage source, and wherein step h includes closing the second switch.

3. The method of claim 1, wherein step h further includes:

10 i) measuring the voltage at the second electrode of the readout transistor at a first time to provide the first emitter-voltage signal;

ii) storing the first emitter-voltage signal;

iii) measuring a second emitter-voltage signal at a second time, wherein the second time is different from the first time; and

15 iv) storing the second emitter-voltage signal.

4. The method of claim 3, wherein step i further includes comparing the stored first and second emitter-voltage signals to provide the aging signal.

5. The method of claim 1, wherein the voltage measurement circuit includes an analog-to-digital converter.

6. The method of claim 5, wherein the voltage measurement circuit further includes a low-pass filter.

7. The method of claim 1, further including providing a plurality of EL subpixels, wherein steps h and i are performed for each EL subpixel to produce a plurality of corresponding aging signals, and wherein steps j through l are performed for each of the plurality of subpixels using the corresponding aging signals.

8. The method of claim 7, wherein step h is performed for a predetermined number of such EL subpixels during which the predetermined number of subpixels are driven simultaneously.

9. The method of claim 7, wherein the EL subpixels are arranged in rows and columns, and further including providing a plurality of row select lines connected to the gate electrodes of corresponding select transistors and a plurality of readout lines connected to the second electrodes of corresponding readout transistors.

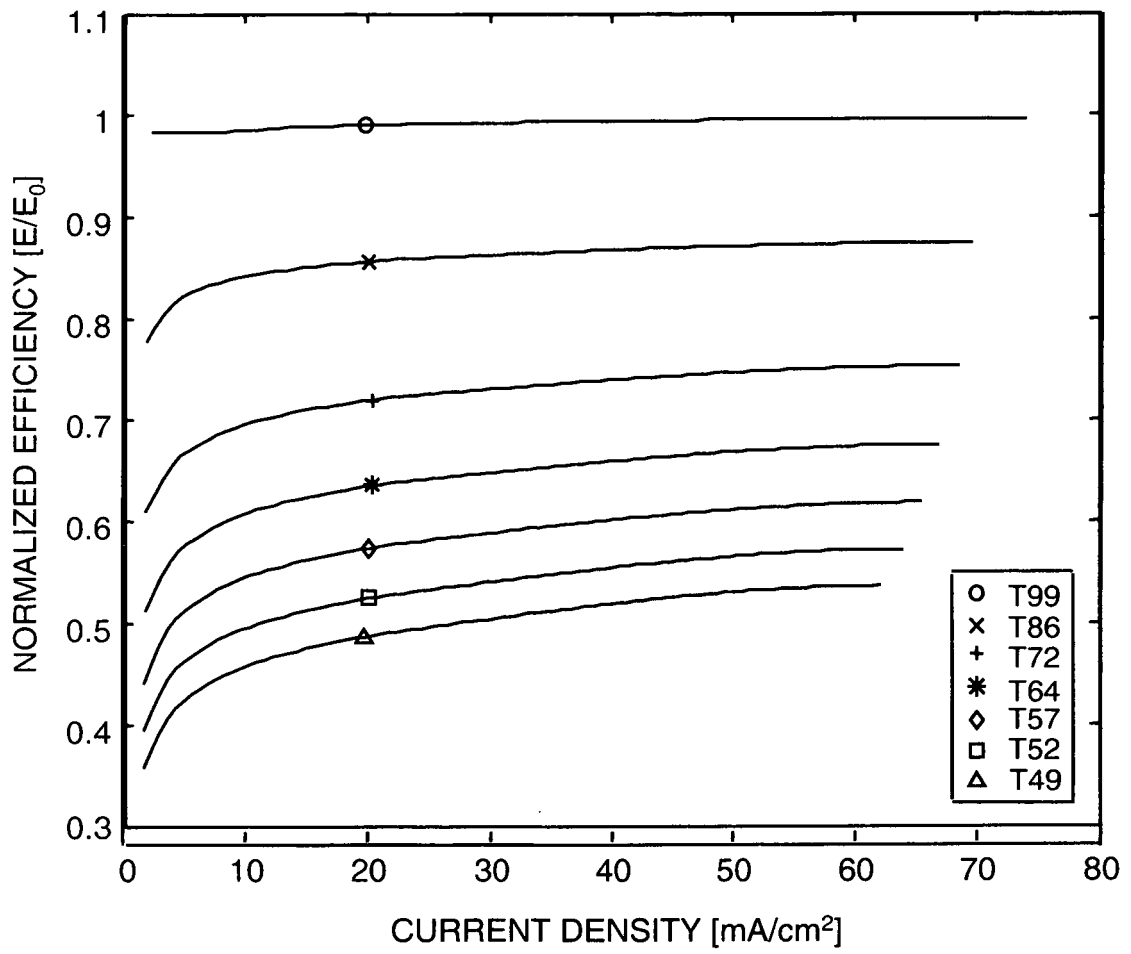
10. The method of claim 9, further including using a multiplexer connected to the plurality of readout lines for sequentially measuring each of the predetermined number of EL subpixels to provide corresponding first emitter-voltage signals.

11. The method of claim 1, further including providing a select transistor connected to the gate electrode of the drive transistor, and wherein the gate electrode of the select transistor is connected to the gate electrode of the readout transistor.

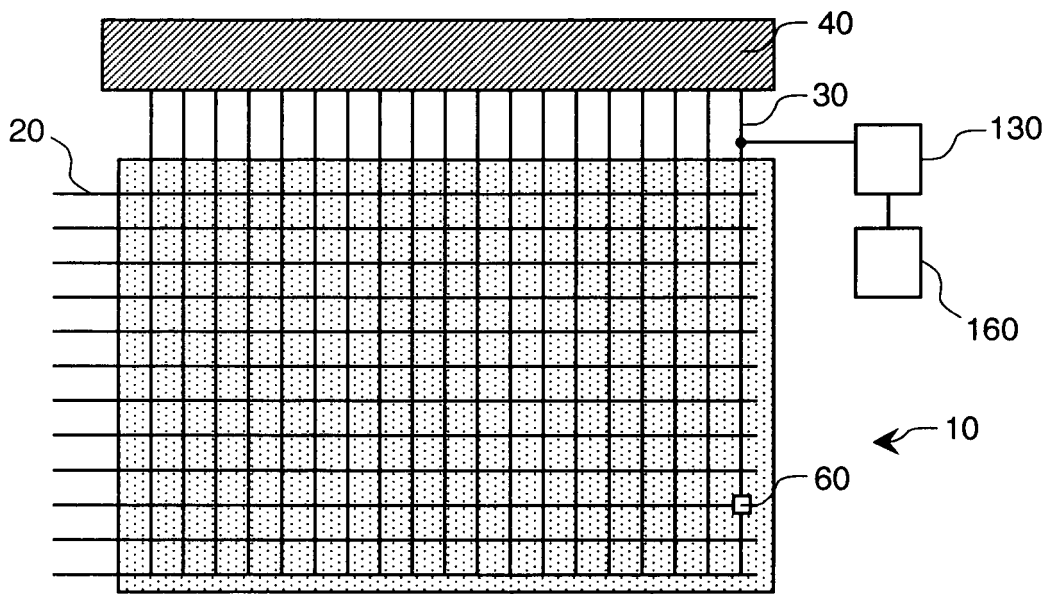
12. The method of claim 1, wherein each EL emitter is an OLED emitter, and wherein each EL subpixel is an OLED subpixel.

13. The method of claim 1, wherein step 1 further includes providing a source driver and using the source driver to provide the compensated  
5 drive signal to the gate electrode of the drive transistor.

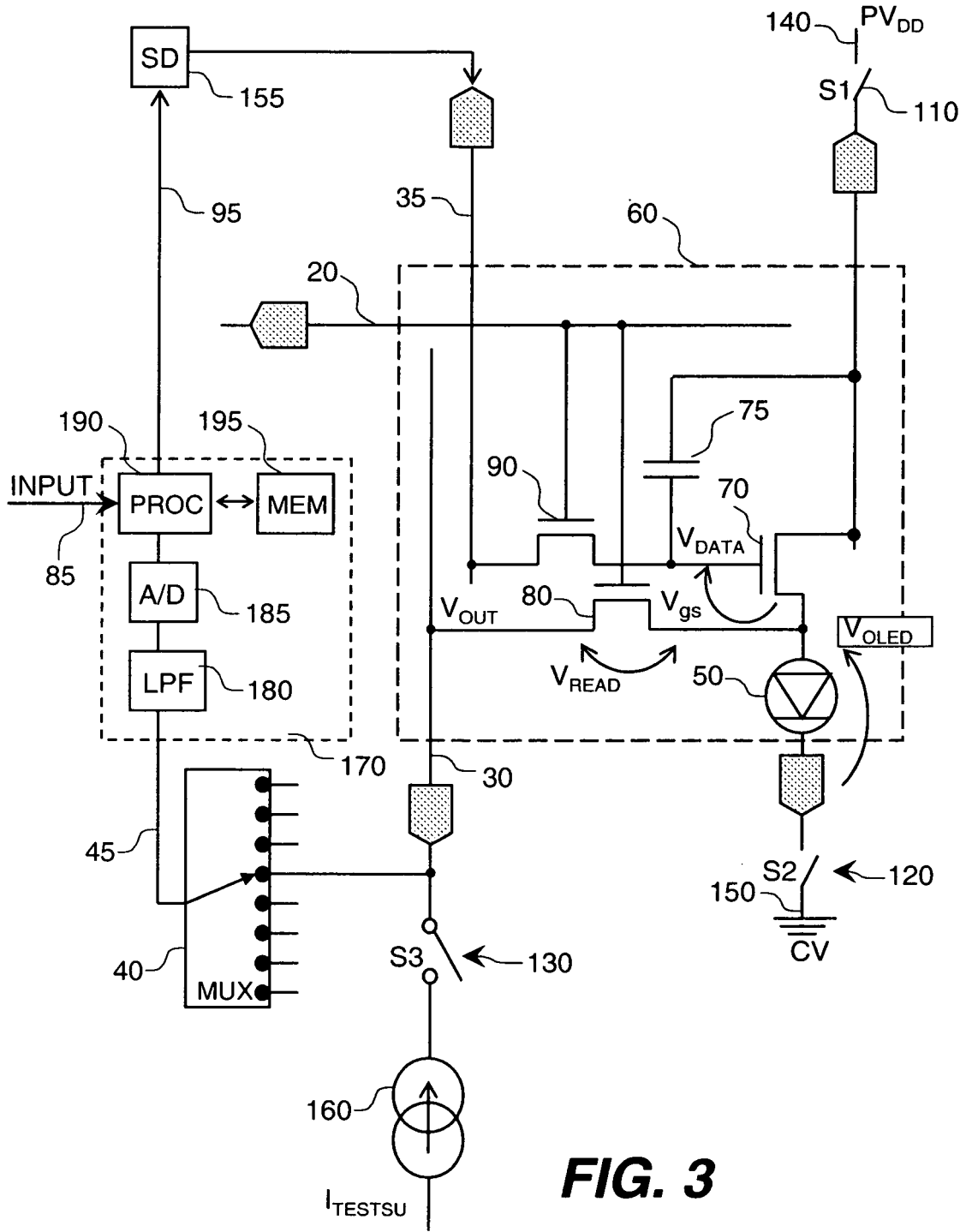
14. The method of claim 13, wherein the source driver comprises a digital-to-analog converter.



**FIG. 1**

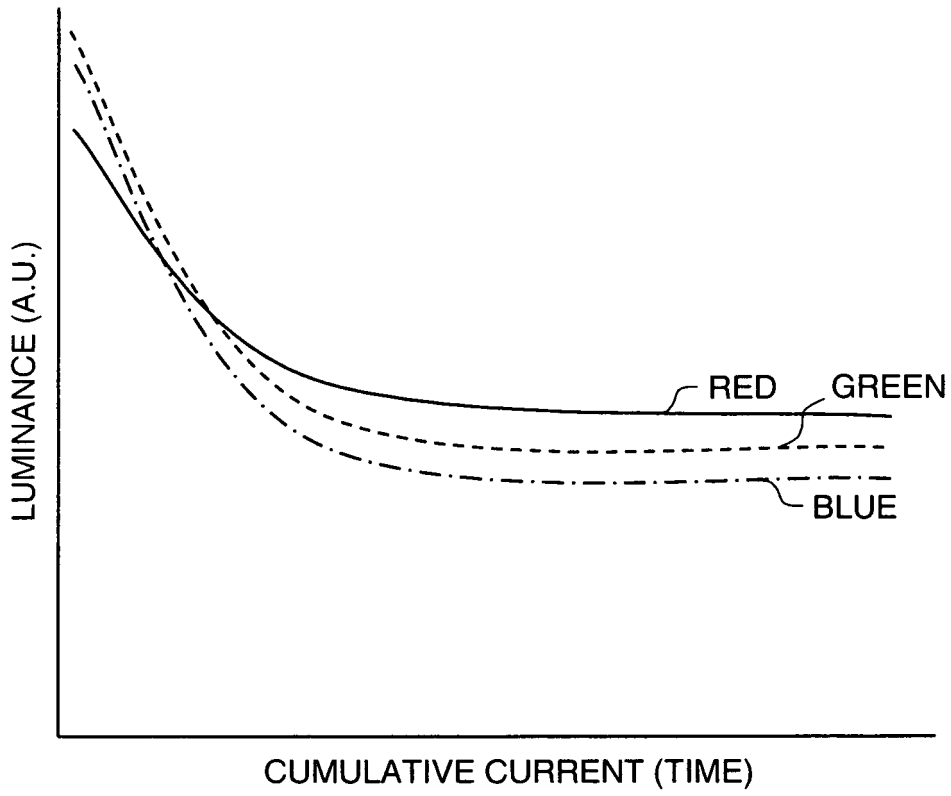


**FIG. 2**

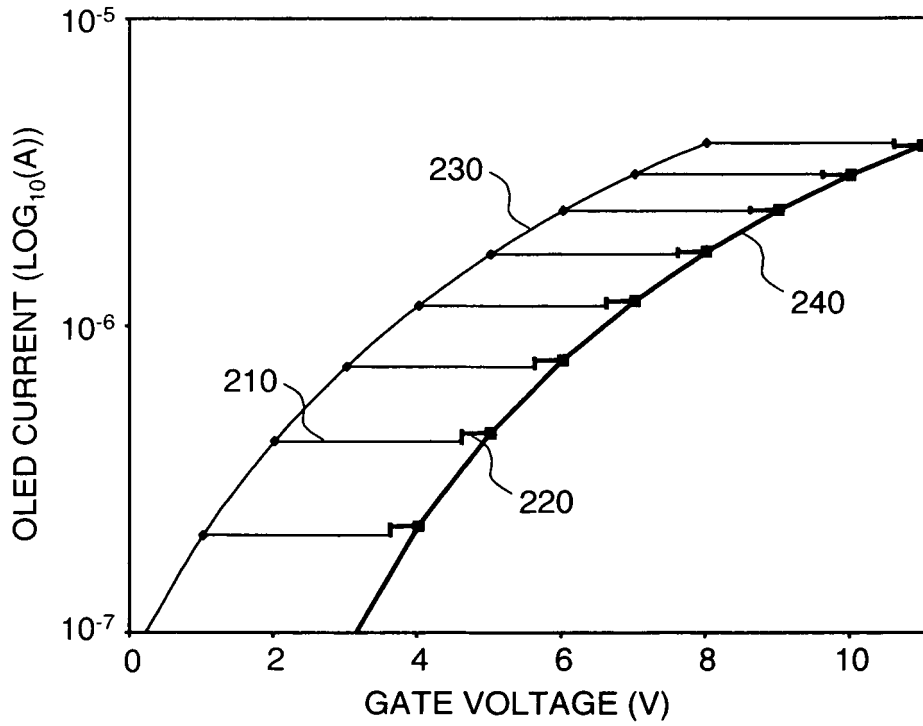


**FIG. 3**

4/6

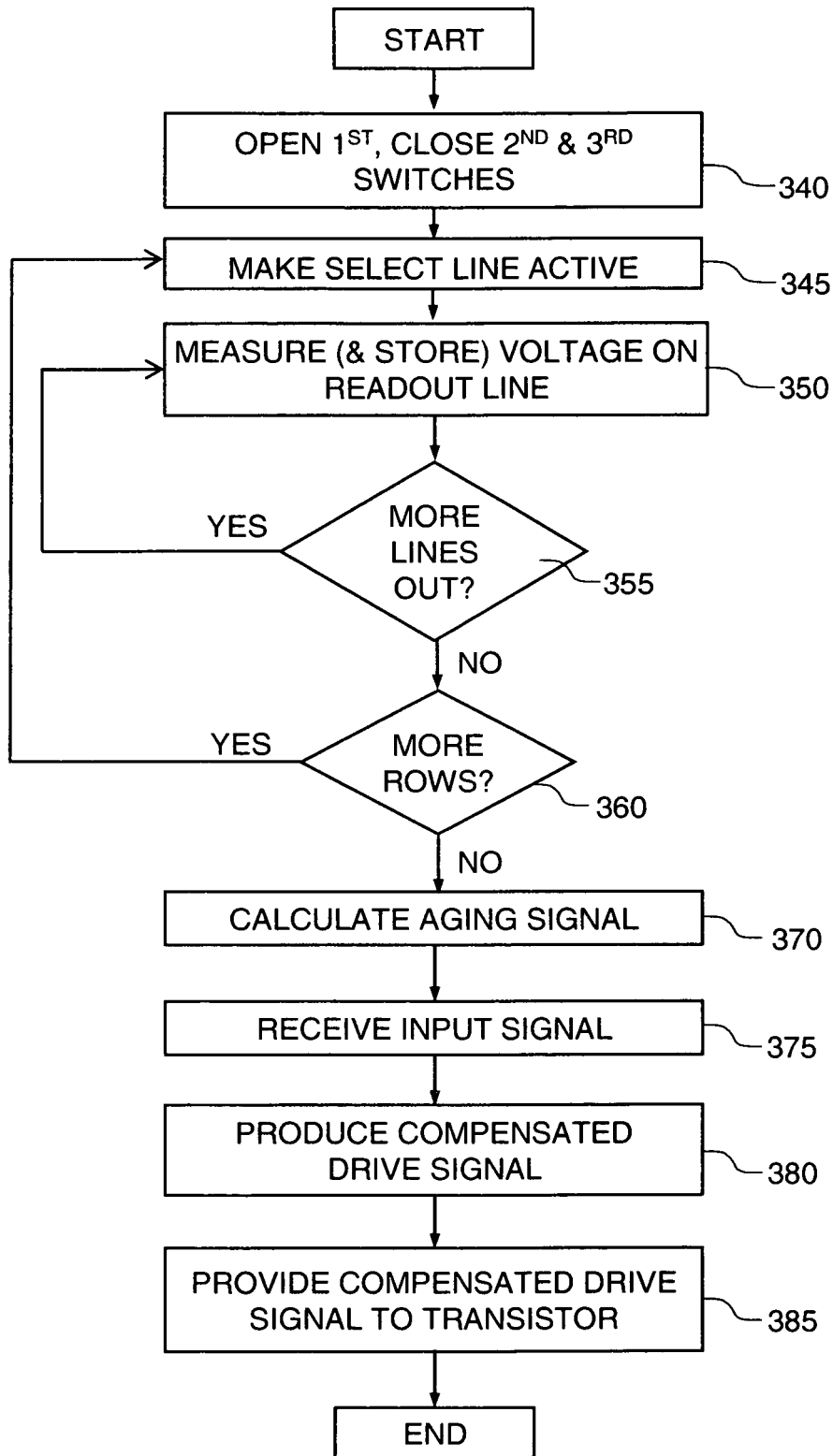


**FIG. 4A**

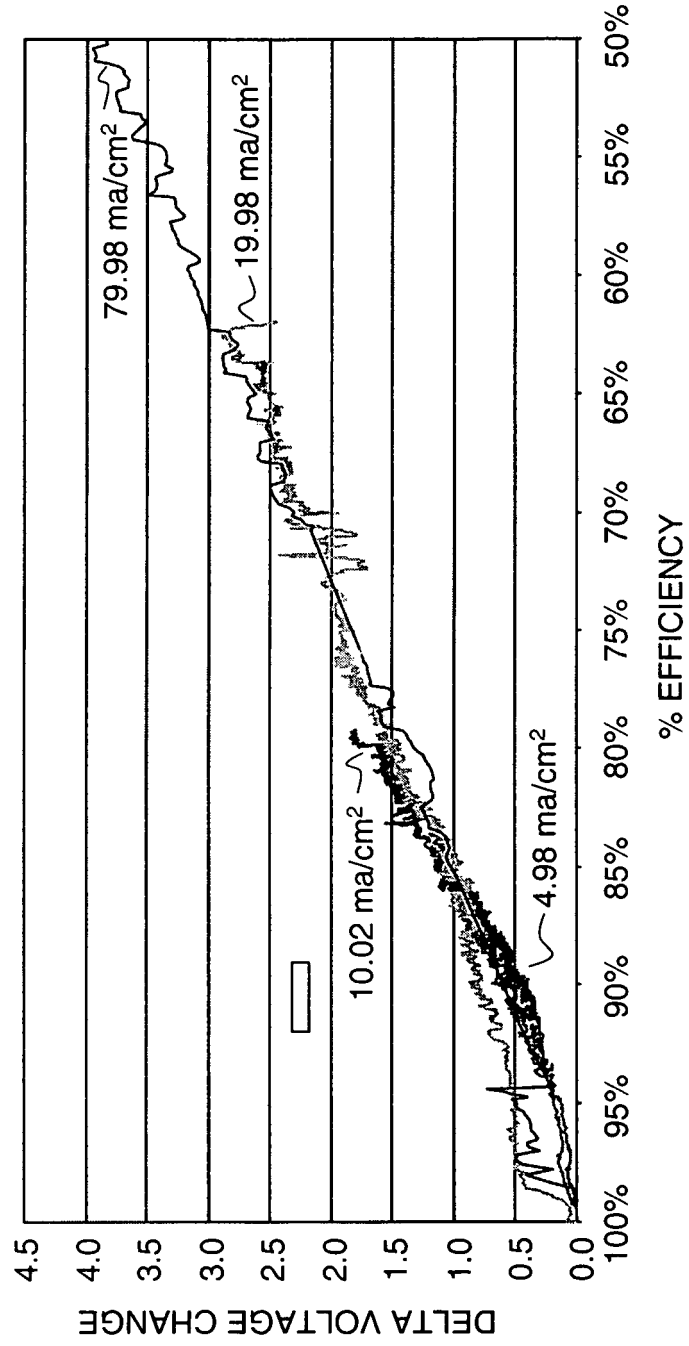


**FIG. 4B**

5/6



**FIG. 5**



**FIG. 6**

**INTERNATIONAL SEARCH REPORT**

International application No  
PCT/US2009/005833

**A. CLASSIFICATION OF SUBJECT MATTER**  
INV. G09G3/32

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
G09G

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

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

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/252570 A1 (KWON OH-KYONG [KR]) 16 October 2008 (2008-10-16) paragraphs [0074] - [0087]; figures 2-4,7 paragraphs [0026] - [0041], [0047] - [0070] -----	1-14
X	US 2008/252569 A1 (KWON OH-KYONG [KR]) 16 October 2008 (2008-10-16) paragraphs [0072] - [0082]; figures 2-4,7 paragraphs [0026] - [0036], [0047] - [0060], [0066] -----	1-14
X	US 2008/218499 A1 (KOHNO TOHRU [JP] ET AL) 11 September 2008 (2008-09-11) paragraphs [0056], [0057], [0062], [0083] - [0086], [0091] - [0098]; figures 1,3,5,6,8-10 -----	1-14

Further documents are listed in the continuation of Box C.

See patent family annex.

\* Special categories of cited documents :

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

Date of the actual completion of the international search

20 January 2010

Date of mailing of the international search report

28/01/2010

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Authorized officer

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2009/005833

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008252570 A1	16-10-2008	KR 100858616 B1	17-09-2008
US 2008252569 A1	16-10-2008	KR 100846969 B1	17-07-2008
US 2008218499 A1	11-09-2008	CN 101261807 A	10-09-2008
		JP 2008224863 A	25-09-2008

专利名称(译)	电致发光显示器，可补偿效率变化		
公开(公告)号	<a href="#">EP2351010A1</a>	公开(公告)日	2011-08-03
申请号	EP2009744239	申请日	2009-10-27
[标]申请(专利权)人(译)	全球OLED TECH		
申请(专利权)人(译)	全球OLED科技有限责任公司		
当前申请(专利权)人(译)	全球OLED科技有限责任公司		
[标]发明人	LEON FELIPE ANTONIO		
发明人	LEON, FELIPE, ANTONIO		
IPC分类号	G09G3/32		
CPC分类号	G09G3/3233 G09G2300/0819 G09G2310/0297 G09G2320/0233 G09G2320/0295 G09G2320/043 G09G2320/045 G09G2320/0693		
优先权	12/260103 2008-10-29 US		
外部链接	<a href="#">Espacenet</a>		

#### 摘要(译)

当驱动晶体管(70)不导通时，具有读出晶体管(80)的电致发光(EL)子像素(60)由电流源(160)驱动。这产生了一个发射极电压信号，从中可以计算出表示EL发射器(50)效率的老化信号。老化信号用于调节输入信号(85)以产生补偿驱动信号(95)以补偿EL发射器效率的变化。