



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication: **16.01.2008 Bulletin 2008/03** (51) Int Cl.: **G09G 3/32 (2006.01)**

(21) Application number: **06300785.0**

(22) Date of filing: **10.07.2006**

(84) Designated Contracting States: AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR Designated Extension States: AL BA HR MK YU (71) Applicant: Thomson Licensing 92100 Boulogne-Billancourt (FR) (72) Inventors: • Le Roy, Philippe 35830 Betton (FR)	• Schemmann, Heinrich 78052 Villingen-Schwenningen (DE) • Haas, Gunther 35760 St Gregoire (FR) (74) Representative: Lindemann, Robert Deutsche Thomson-Brandt GmbH European Patent Operations Karl-Wiechert-Allee 74 30625 Hannover (DE)
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(54) **Current drive for light emitting diodes**

(57) The present invention relates to a current drive for light emitting diodes, in particular organic light emitting diodes. The current drive according to the present invention comprises a current source. The current source is

adapted to provide a predetermined current. The current drive further comprises modulation means adapted to modulate the predetermined current in such a way that one or plural consecutive current pulses are output by the modulation means to the light emitting diode.

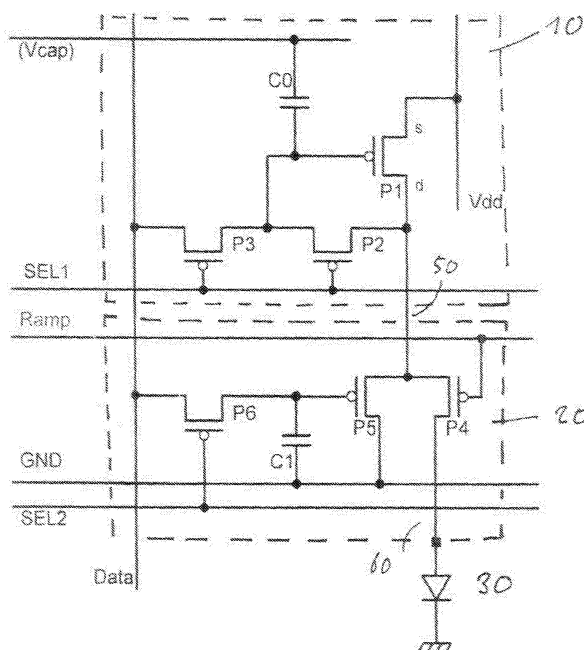


Fig. 1

Description

[0001] The present invention relates to a current drive for light emitting diodes, in particular organic light emitting diodes (OLED). The current drive comprises a current source, which is adapted to provide a predetermined current.

[0002] Organic light emitting diodes form part of displays, which are commonly used in flat-panel displays such as video headsets, portable computers, and digital cameras. They have a superior optical performance and lower power consumption in comparison with competing display technologies.

[0003] OLED technology is based on organic chemical compounds that emit light when an electric current flows through the device. Using OLED-on-Silicon technology, the OLEDs are arranged in an array and constitute the pixels of the micro-displays. Each OLED is a light emitting device, wherefore a light source is not required opposed to conventional liquid crystal displays. A CMOS integrated circuit is coupled to each OLED in the array. The CMOS integrated circuit controls the power to each OLED and controls the light emitted by each pixel at very high speed. A colour display is provided by using OLEDs emitting white light and appropriate colour filters. OLED displays use less power and provide brighter and more colourful pictures than liquid crystal displays.

[0004] The light intensity emitted by each OLED is proportional to the current density flowing through the diode. Light emission begins at about 2.5 to 2.8 V and continuously increases with the bias voltage. The currents needed for controlling the brightness of the OLED, in particular in a Microdisplay, range from hundreds of Pico amperes (pA) to tens of nano amperes (nA), depending on pixel size and required luminance. The luminance of an OLED is proportional to its current density. Therefore current drivers are conventionally used for controlling the brightness of the display.

[0005] A field effect transistor may be used as current source in order to control the current density and the respective brightness of the OLED. The source of the field effect transistor is connected to the OLED. The gate of the field effect transistor controls the source-drain-current, which is provided to the diode. But, the required currents are extremely small. Traditional MOSFET current sources operating in the saturation region are not compatible with such small currents.

[0006] Therefore, the field effect transistor must be operated in the sub threshold region. The output current characteristic of a field effect transistor is conventionally divided into distinct regions, wherein each region displays a different current voltage dependency. The first region is called the sub threshold region, because the gate source voltage V_g is below a threshold voltage V_{th} . If the gate voltage is below the threshold voltage, the transistor is turned off and ideally there is no current from the drain to the source of the transistor. However, in reality the remaining output current of the FET is in the region of Pico amperes (pA) and nano amperes (nA).

[0007] The drain current in the sub threshold region is described by the following equation:

$$I_{DS} = I_{D0} (W/L) e^{(V_{gs} - V_{t0}) / (\eta kT/q)}$$

Equation 1

V_{t0} is the sub threshold voltage

I_{D0} is the drain current for sub threshold voltage normalized to W/L

W is the width of the gate

L is the length of the gate

η is the sub threshold slope ranging from 1.4 to 1.6

[0008] Hence, the output current of the FET operated as current source depends exponentially on the input gate source voltage V_g . The resulting brightness of the OLED is very sensitive to fluctuations in the gate voltage of the FET. Furthermore, each OLED used in a display should render the same luminance, when operated with the identical input voltage. However, the matching of the threshold voltage V_{t0} is a function of the area $W \cdot L$. The standard deviation of the threshold voltage is given by $A_{V_{t0}} / (W \cdot L)^{1/2}$. $A_{V_{t0}}$ is approximately equal to 10 mV $\cdot\mu$ m. If the transistor is sized with a width W equal to 6 μ m and length L equal to 400 nm, then the resulting voltage offset of 6.5 mV. In return, the drain current I_{DS} may change by up to 65%.

[0009] In order to address the problem of variations for drive current FETs, it has been proposed to calibrate the FETs in a display device. Thereby, differences in the output drain current I_{DS} may be compensated.

[0010] The publication "An 852*600 Pixel OLED-on-Silicon Colour Micro display using CMOS Sub threshold-Voltage-Scaling Current Drivers", Gary B. Levy et. Al, IEEE Journal of Solid-State Circuits, Vol. 37, No. 12, December 2002 discloses a current driver, which is calibrated. The current driver comprises a current source FET, which is operated in the sub threshold region. A capacitor is used as a storage device, which holds the pixel data for the OLED. Several transistors are configured as minimum sized switches in order to connect/disconnect the current source FET and storage capacitor to/from the OLED and a programming line. The current source transistor is separated from the OLED during calibration. A fixed voltage offset is applied from the capacitor to the gate of the current source transistor. The offset is

equal to $\eta kT/(q \ln 100)$. Therefore, the drain current is increased by 100 times. The sampled program current is set 100 times greater than the desired pixel current. The respective gate voltage is established and then shifted back by the fixed voltage offset.

[0011] Although the calibration procedure does address the problem of differing output currents of a current source FET due to process variations, the use of such current sources still poses formidable problems. In particular, the brightness of the OLED and consequently the input current is supposed to be changed according to input control signals. This could be done by increasing or decreasing the voltage provided by the capacitor, which is connected to the gate of the current source FET. Due to the exponential relationship between the gate voltage and the output current, slight changes in the voltage lead to very strong changes in the output current. Capacitor leakage currents can significantly change the drain current of the current source FET. Therefore, it is not desirable to add/subtract charge carriers to the capacitor. Recalibrating the current drive each time a new output current needs to be supplied does not represent a feasible solution, since the access time to the OLED would be considerably reduced.

[0012] It is an object of the present invention to provide a current drive for light emitting diodes, which is suited for providing ultra small currents in the region of Pico amperes (pA) and nano amperes (nA) in order to adjust the brightness of the light emitting diode.

[0013] The problem is solved by the current drive for light emitting diodes, in particular organic light emitting diodes according to claim 1. The current drive comprises a current source, which is adapted to provide a predetermined current. The current drive further comprises a modulation means adapted to modulate the predetermined current in such a way that one or plural consecutive current pulses are output by the modulation means to the light emitting diode. In this way, the brightness of the current drive is adjusted without recalibrating the current source. The impact of capacitor leakage currents in current source FETs operated in the sub threshold region is reduced.

[0014] The state of the art control of brightness is based on the assumption that a predetermined constant output current must be supplied to the organic light emitting diode. The size of the constant output current should relate to the brightness of the display. However, the same brightness may also be provided by current pulses. If the pulses reoccur fast enough, then a change in the brightness is imperceptible and the organic light emitting diode appears to be just as bright as an OLED driven with a constant current. Furthermore, the output voltage of the current source may be increased. The perceptible average brightness due to pulse modulated input currents is lower than the brightness provided by driving the OLED with a constant current equal to the peak current of the modulation pulse.

[0015] Preferably, the modulation means has a modulation signal input for receiving a signal, which is to be modulated onto the predetermined current. Thereby, any convenient waveform may be chosen for modulating the current input to the OLED.

[0016] The modulation means may comprise a first modulation transistor having a gate, a source and a drain. The gate of the modulation transistor is connected to the modulation signal input. The source is connected to the current source. The drain is designed to be connected to the light emitting diode. The first modulation transistor represents a controllable resistor. By controlling the gate voltage, the electrical resistance for the current flowing from the current source to the OLED may be adjusted. Therefore, the current may be adjusted. The modulation signal is a voltage signal fed to the gate of the first modulation transistor.

[0017] Preferably, the modulation means comprises a second transistor having a gate, a source and a drain. The second transistor's source is connected to the current source. The first and second transistors constitute a differential amplifier. A voltage difference between the first transistor gate and the second transistor gate determines the output current of the modulation means. The current from the current source is directed through the first or second transistor depending on the gate voltage applied to the respective gates. If the source drain channel of the first transistor is closed due to the gate voltage, then the output current of the current source is directed through the second transistor.

[0018] The brightness of an organic light emitting diode may be controlled using the current source driver. The first step is to calibrate the current source used for providing a current to the light emitting diode to a predetermined calibration current. Thereby, the output current from the current source may be set to a predetermined level. Variations in the electrical properties of the current source may be compensated using the calibration step. The output current from the current source is modulated in order to provide one or plural consecutive current pulses. These current pulses are output by the modulation means to the light emitting diode. Consequently, the radiation intensity of the OLED depends on the alternating current made up of a plurality of current pulses. If the frequency of the input current is large enough, then variations in the radiation intensity are imperceptible. The brightness appears to be a non-changing constant value. This is in particular the case, if the current frequency is well above 60 Hz.

[0019] The brightness of the organic light emitting diode is preferably adjusted by adjusting width and/or height of the consecutive current pulses. The waveform may also take into account nonlinear characteristics of the light emitting diode. If the brightness of the OLED does not depend in a linear fashion on the diode current, then the waveform of the current pulses may compensate for the nonlinear dependence.

[0020] The consecutive current pulses preferably constitute a ramp or saw tooth waveform having a predetermined inclination. The brightness of the organic light emitting diode is adjusted by adjusting the inclination of the ramp or saw

tooth waveform.

[0021] In one embodiment of the inventive current drive circuit and method the modulation means is adapted to at least partly divert the current away from the light emitting diode in response to the modulation signal. This advantageously allows for essentially maintaining a constant current from the current source.

[0022] A preferred embodiment of the present invention is described with reference to the accompanied drawings. The preferred embodiment merely exemplifies the invention. Plural possible modifications are apparent to the skilled person. The gist and scope of the present invention is defined in the appended claims of the present application.

[0023] Fig. 1 shows a schematic diagram of a current drive for light emitting diodes according to the preferred embodiment of the present invention, which is connected to an organic light emitting diode.

[0024] Fig. 2 shows a diagram of a ramp wave used in the current drive of Fig. 1. The current drive shown in Fig. 1 comprises two main functional components, namely a current source 10 and a current modulator 20. The current source 10 outputs a predetermined constant current to the modulator 10 via line 50. A modulated current is input to an OLED 60 via line 60. The waveform of the output current running through line 60 is determined by the signal input to the current modulator 20 via the line "Ramp".

[0025] The current source 10 comprises a current source transistor P1, which is operated in the sub threshold region. The drain current of the current source transistor P1 is the output current of the current source 10. The size of the current source output current is determined by the voltage applied to the source, drain and gate of current source transistor P1. The source voltage is defined by supply voltage Vdd in Fig. 1. Capacitor C0 is connected to the gate of the current source transistor P1. The charge stored in the capacitor C0 defines the gate voltage of the current source transistor. Furthermore two further transistors P2 and P3 are provided in the current source 10 of Fig. 1. These transistors P2 and P3 are switches, which either connect or disconnect the drain of the current source transistor P1 to the line "Data".

[0026] Prior to the use of the current source 10, the output current on line 50 from the current source is set to a predetermined level. This is achieved by finding the appropriate gate voltage for providing the desired output current. In order to define the correct sub threshold voltage, the gate voltage is calibrated for a high drain current and then shifted to the corresponding calibration voltage for the corresponding low drain current. This is accomplished by applying the shifted high voltage signal to the capacitor C0 via line Vcap. Then the switch transistors P3 and P2 are closed. Consequently, the gate of current source transistor is connected to the line designated with "data" in Fig. 1. The gate voltage is adjusted until the desired high current is detected flowing through the current source transistor. Then, the switches P3 and P2 are closed, in order to store the charge carriers on the capacitor C0. Finally, the gate voltage of the current source transistor P1 is shifted by changing the voltage on line Vcap. The resulting drain current is determined by the exponential function given in equation 1.

[0027] Once the output voltage of the current source has been established, the current source is left unchanged during the operation of the OLED 30. Switch transistors P2 and P3 make sure, that the output current is not altered due to leakage currents from capacitor C0. The actual brightness of the OLED is controlled by the modulation circuit. If the OLED 30 forms part of an array of OLEDs, then the brightness of the OLED corresponds to the gray scale of the corresponding picture element.

[0028] The decisive components of modulation means (20) in Fig. 3 are transistors P4 and P5. Both transistors in Fig. 5 are identical, i.e. they provide essentially the same Drain current, if the same Gate and Source/Drain voltage is applied to them. The source of both transistors is connected to line 50 carrying the output current from current source 10. The constant output current from the current source 10 is equal to the sum of the currents flowing through the source of transistors P4 and P5. Therefore, the amount of current depends essentially on the electrical resistance of transistors P4 and P5. The resistance may be controlled by the gate voltage applied to transistors P4 and P5. If the gate voltage of transistor P4 is greater than the gate voltage of transistor P5, then the majority of the current from the current source 10 will flow through transistor P5 to the Ground. Capacitor C1 provides a constant voltage to the gate of transistor P5 during operation. It may be connected and disconnected using switch transistor P6 from line Date in order to store charge carriers. The Drain of transistor P5 is connected to the opposite side of capacitor C1, which is connected to line GND, which is connected to ground voltage.

[0029] The line Ramp is connected to the gate of transistor P4. An alternating voltage signal is applied in operation to line Ramp. The voltage drop between line "Ramp" and capacitor C1 determines the current flowing through OLED 30. The peak voltage on line 60 is equal to the voltage on line 50 supplied by current source 10. Therefore, the modulator circuit 20 effectively scales down the current from current source 10.

[0030] Fig. 2 shows schematically the ramp signal, which may be applied to the line "Ramp" in order to control the current flowing to the OLED 30. In Fig. 2 the abscissa designates the time in seconds and the axis of ordinate represents the Ramp voltage. The signal is essentially periodic having a period T.

[0031] The waveform during a single period resembles a ramp. The slope of the ramp is given by angle α and the peak voltage is represented by Vp. Different modifications of the signal may be used for changing the brightness of the OLED. In particular the peak voltage Vp may be increased. Thereby, the brightness tends to increase. The period T may be changed. Preferably, the resulting Signal frequency $f=1/T$ is chosen in such a way that the resulting brightness

flicker is imperceptible. This is the case, if the frequency is well above 60 Hz. Finally, the slope of the ramp signal may be adjusted by increasing or decreasing the angle α .

[0032] It is apparent to the skilled person that other waveforms than in Fig. 2 may be chosen. In particular, the waveform used as a modulation signal may also be a double slope ramp or any arbitrary signal. The resulting brightness largely depends on the average Voltage that is applied as signal. The average voltage is represented by the area under the signal pulse divided by the period T.

[0033] The drive circuit and method described in the foregoing is particularly suitable for an OLED microdisplay, or for an OLED on IC device. In an OLED on IC device, the drive circuitry is produced on a silicon substrate like known from common ICs, and the active OLED layer is applied thereon.

Claims

1. A current drive for light emitting diodes (30), in particular organic light emitting diodes, comprising:
 - a current source (10), said current source (10) being adapted to provide a predetermined current, and
 - modulation means (20) adapted to receive the predetermined current from the current source (10) and modulate the predetermined current in such a way that one or plural consecutive current pulses are output by the modulation means (20) to the light emitting diode (30).
2. The current drive according to claim 1, said modulation means (20) having a modulation signal input (Ramp) for receiving a signal, which is to be modulated onto the predetermined current.
3. The current drive according to claim 1 or 2, wherein the modulation means (20) is adapted to at least partly divert the current away from the light emitting diode in response to the modulation signal (Ramp).
4. The current drive according to any one of claims 1 to 3, said modulation means (20) comprising a first modulation transistor (P4) having a gate, a source and a drain, the gate of the modulation transistor (P4) being connected to the modulation signal input (Ramp), the source being connected to the current source (10) and the drain being designed to be connected to the light emitting diode (30).
5. The current drive according to claim 4, said modulation means (20) comprising a second transistor (P4) having a gate, a source and a drain, the second transistor's source being connected to the current source (10), wherein the first and second transistors (P4 and P5) constitute a differential amplifier, wherein a voltage difference between the first transistor gate and the second transistor gate controls the output current of the modulation means.
6. Light emitting display comprising a light emitting diode and a current drive according to one of the claims 1 to 5.
7. Method for controlling the brightness of a light emitting diode, preferably an organic light emitting diode, comprising the step of
 - calibrating a current source used for providing a current to the light emitting diode to a predetermined calibration current, and
 - modulating the predetermined current in such a way that one or plural consecutive current pulses are output by the modulation means to the light emitting diode.
8. Method for controlling the brightness of a light emitting diode according to claim 7, wherein the brightness of the light emitting diode is adjusted by adjusting width and/or height of the consecutive current pulses.
9. Method for controlling the brightness of a light emitting diode according to claim 7 or 8, wherein the consecutive current pulses constitute a ramp or saw tooth waveform having an inclination, and wherein the brightness of the light emitting diode is adjusted by adjusting the inclination of the ramp or saw tooth waveform.
10. Method for controlling the brightness of a organic light emitting diode according to any one of claims 7 to 9, wherein the modulation includes at least partly diverting the calibrated current away from the light emitting diode.

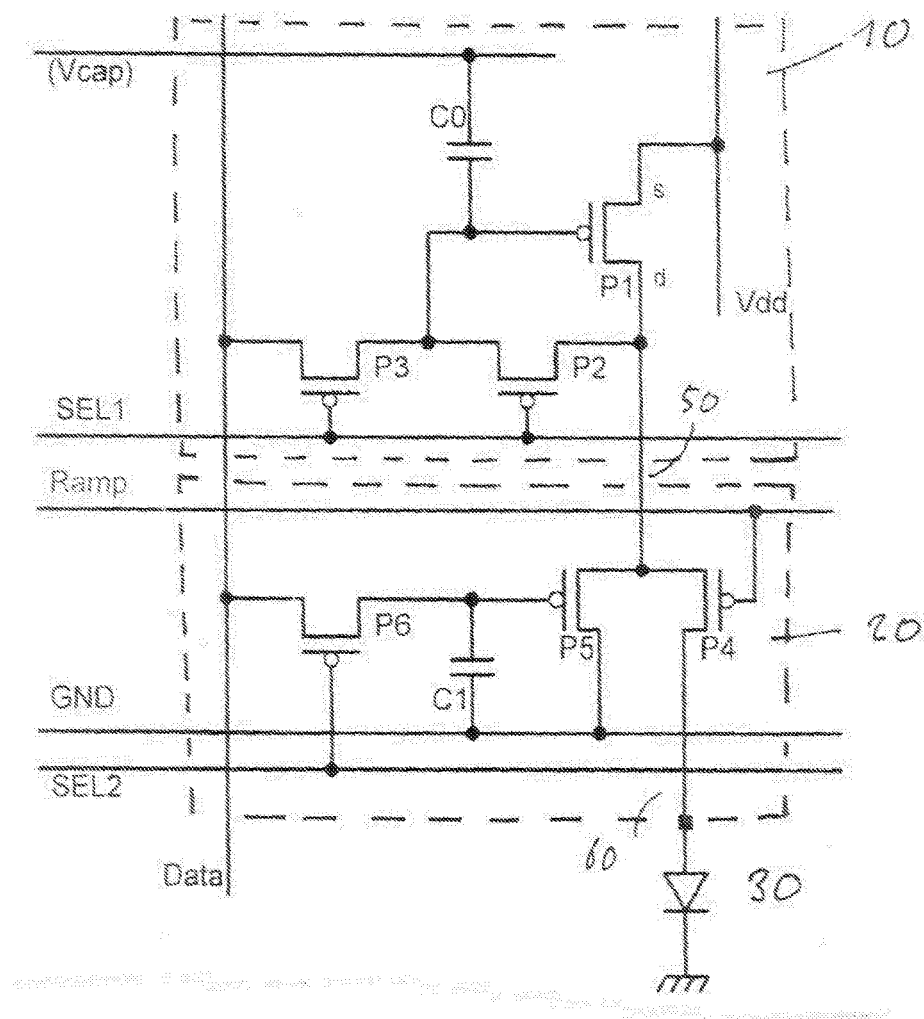


Fig. 7

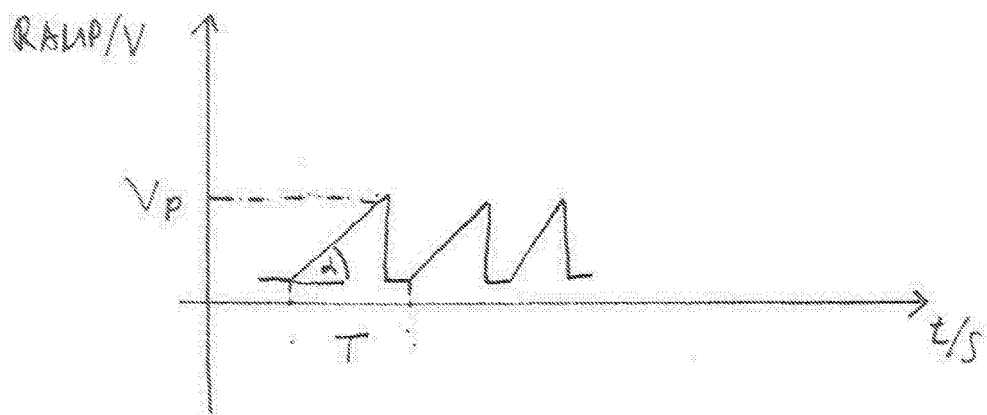


Fig. 2



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 06 30 0785

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 1 455 335 A (SANYO ELECTRIC CO., LTD) 8 September 2004 (2004-09-08) * paragraph [0048]; figure 15 *	1-10	INV. G09G3/32
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 11 October 2006	Examiner LE CHAPELAIN, B
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 06 30 0785

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- **GARY B. LEVY.** An 852*600 Pixel OLED-on-Silicon Colour Micro display using CMOS Sub threshold-Voltage-Scaling Current Drivers. *IEEE Journal of Solid-State Circuits*, December 2002, vol. 37 (12) [0010]