Voltage Reference Circuitry operating in Weak Inversion Region with reduced Fluctuations of Supply Voltage and Ambient Temperature for LTPS TFT

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Abstract : In this paper, a modified voltage reference circuitry using LTPS TFT is proposed. The new modified voltage reference circuitry is unaffected by fluctuations of the power supply voltage and the ambient temperature due to the utilization of enhancement-depletion (E-D) reference circuit and the operation in the weak inversion region for generation of a stable reference voltage. To verify the performance of the new modified circuitry, the circuit simulation is carried out by using SPICE. As a result of the simulation, the supply voltage dependability (*SVD*) and the temperature coefficient (*TC*) achieves to values of 0.08967 [%/V] and 0.00203[%/°C], respectively, when the ambient temperature (*Ta*) is +25°C and the supply voltage (V_{DD}) is +8V. In brief, these characterisitcs of the new modified circuitry are improved comparing with that of the conventional circuit.

1. Introduction

Recently, some drivers, controller and some peripheral circuits etc. for TFT-LCD (thin film transistor-liquid crystal display) panel can be integrated on one glass substrate because the mobility of LTPS (low temperature poly silicon) TFT have value of about one hundred of times comparing with that of a-Si (amorphous silicon) TFT. Consequently, TFT-LCD panel become light weight, smaller size and so on.

By the way, it is difficult to generate a stable reference voltage for the operating of TFT-LCD panel due to the existence of “Kink Effect” in LTPS TFT [1]. In short, a drain-source current in the saturation region can not keep a constant value by the “Kink Effect” in LTPS TFT. Therefore, a stable reference voltage can not be obtained due to the change of drain-source currents in TFT with the increase of the supply voltage (V_{DD}). Furthermore, the reference voltage also changes by the variation of the threshold voltage because the threshold voltage changes with the variation of the ambient temperature (*Ta*). In other words, the stable reference voltage can not be obtained by the change of the ambient temperature. In this paper, a new modified voltage reference circuitry unaffected by fluctuations of the supply voltage and the ambient temperature is described for LTPS TFT LCD panel.

2. Conventional Circuit

The schematic diagram of the conventional voltage reference circuit is shown in Fig.1. It is called “Widlar Self Bias Circuit (WSBC)”[2]. The output voltage (V_{OUT}) of WSBC using CMOS devices is given as follow equation.

$$V_{OUT} = \frac{1}{Rs} \cdot \frac{1}{K_{N2}} \left(1 - \sqrt{\frac{K_{N2}}{K_{N1}}} \right) + V_{TNE} \qquad (1)$$

Here, K_{N1} and K_{N2} are conductance coefficient of MOS-N1 and MOS-N2, respectively, V_{TNE} is a threshold voltage of MOS-N2 and Rs is a resistance.

The output voltage (V_{OUT}) of equation (1) is not change by fluctuations of the supply voltage because equation (1) does not contain a term of the supply voltage (V_{DD}).

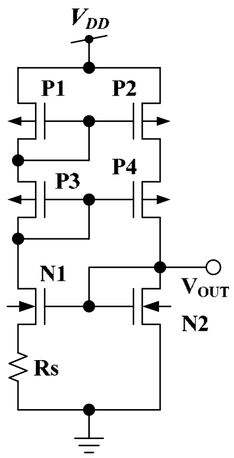

Fig.1 Conventional Circuit

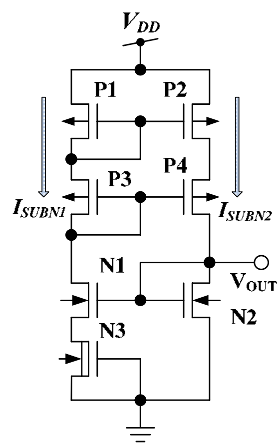

Fig.2 Modified Circuit

On the other hand, if WSBC is constructed by using LTPS TFT, the output voltage (V_{OUT}) of WSBC is affected by fluctuations of the supply voltage and the ambient temperature due to the "Kink Effect" and variation of the threshold voltage including TFT devices. Moreover, the output voltage (V_{OUT}) of WSBC also changes with the variation of the ambient temperature because the value of resistance Rs varies with the variation of the ambient temperature.

3. Modified Voltage Reference Circuitry

The schematic diagram of a new modified voltage reference circuitry is shown in Fig. 2. The output voltage (V_{OUT}) is a voltage difference between the threshold voltages of enhancement (E)-type nTFT-N2 (V_{TNE}) and depletion (D)-type nTFT-N3 (V_{TND}) [3]. In general, the threshold voltage of D-type nTFT is a negative voltage like a nMOS transistor. However, the threshold voltage of D-type nTFT becomes a positive voltage, slightly, due to the decrease of the manufacturing process steps of TFT-LCD panel. As the results, nTFT-N1, nTFT-N2 and nTFT-N3 always operates in weak inversion region.

The sub-threshold current of LTPS TFT in weak inversion region (I_{SUB}) is formulated by the follow equation (2) [2][4].

$$I_{SUB} = KV_T^{\,2}\left[\exp\left(\frac{V_{GS}-V_{TH}}{\zeta V_T}\right)\right]\cdot\left[1-\exp\left(-\frac{V_{DS}}{V_T}\right)\right] \tag{2}$$

Here, ζ is the sub-threshold ideality factor, K is a conductance coefficient and V_T is a thermal voltage as a function of Boltzmann's constant (K), absolute temperature (T) and electron charge (q).

The 2nd terms of equation (2) can be neglected because the thermal voltage V_T is very small. Therefore, the sub-threshold current of LTPS TFT in weak inversion region (I_{SUB}) can be simplified like equation (3).

$$I_{SUB} = KV_T^{\,2}\left[\exp\left(\frac{V_{GS}-V_{TH}}{\zeta V_T}\right)\right] \tag{3}$$

By the way, the current I_1 is equal to the current I_2 due to the current mirror circuit composed of from E-type pTFT-P1 to pTFT-P4. To be short, the sub-threshold current (I_{SUBN3}) of D-type nTFT-N3 is equal to the sub-threshold current (I_{SUBN2}) of E-type nTFT-N2 as shown in below equation (4).

$$I_{SUBN2} = I_{SUBN3} \tag{4}$$

Also, the sub-threshold currents I_{SUBN3} and I_{SUBN2} flowing to the nTFT-N3 and nTFT-N2 can be formularized like equation (5) and equation (6), respectively, by using equation (3).

$$I_{SUBN2} = K_{N2}V_T^{\,2}\left[\exp\left(\frac{V_{OUT}-V_{TNE}}{\zeta V_T}\right)\right] \tag{5}$$

$$I_{SUBN3} = K_{N3}V_T^{\,2}\left[\exp\left(\frac{-V_{TND}}{\zeta V_T}\right)\right] \tag{6}$$

Here, V_{TNE} and V_{TND} are the threshold voltages of E-type nTFT-N2 and D-type nTFT-N3, respectively.

Also, because equation (5) is equal to equation (6), the output voltage (V_{OUT}) can be rewritten like equation (7).

$$V_{OUT} = \zeta V_T\cdot\ln\left(\frac{K_{N3}}{K_{N2}}\right) - V_{TND} + V_{TNE} \tag{7}$$

If the conductance coefficient K_{N2} is equal to the conductance coefficient K_{N3}, the output voltage (V_{OUT}) is simplified as following equation (8).

$$V_{OUT} = V_{TNE} - V_{TND} \tag{8}$$

In other words, the output voltage (V_{OUT}) is a voltage difference between the threshold voltages of E-type nTFT-N2 (V_{TNE}) and D-type nTFT-N3 (V_{TND}) as previously mentioned.

The drain-source current of TFT in saturation region increases in proportion to increase of the drain-source voltage. However, the drain-source current of TFT in weak inversion region increases only a little in spite of the variation of the drain-source voltage. From this reason, the output voltage (V_{OUT}) of the new modified circuitry keeps a constant stabled voltage even if the deviation of the supply voltage applies to the new modified circuitry. To be brief, "Kink Effect" can be suppressed by utilizing of TFT in weak inversion region.

The output voltage (V_{OUT}) is unaffected by deviations of the ambient temperature (Ta) because the temperature coefficient of E-type nTFT-N2 is approximately equal to the that of D-type nTFT-N3 [5]. It is called "enhancement-depletion (E-D) reference circuit" [6]. To summalize previously mentioned, the new modified voltage reference circuitry have a current mirror circuit and the enhancement-depletion (E-D) reference circuit and it is unaffected by fluctuations of the supply voltage (V_{DD}) and the ambient temperature (Ta). That is to say, the new modified circuitry can generates a constant stabled reference voltage.

4. Simulation Results

To verify the perfomance of the new modified voltage reference circuitry using LTPS TFT, the circuit simulation is carried out by using SPICE. The channel width/length (W /L) from E-type pTFT-P1 to pTFT-P4 are 4 μm/5.5 μm, respectively, W/L of E-type nTFT-N1 is 100 μm/7.5 μm, W/L of E-type nTFT-N2 and D-typ nTFT-N3 are 4 μm/7.5 μm, respectively and the resistance Rs is 1MΩ.

Under the conditions that the supply voltage (V_{DD}) changes from +6V to +10V and the ambient temperature (*Ta*) is +25°C, the characteristics of the output voltage (V_{OUT}) vs. the supply voltage (V_{DD}) is shown in Fig.3.

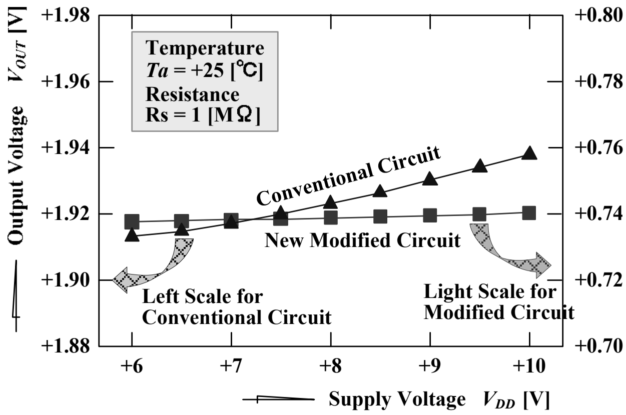

Fig.3 Supply Voltage vs. Output Volatge

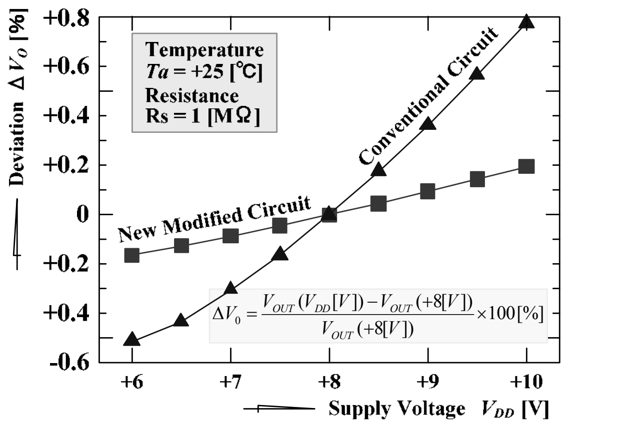

Fig.4 Supply Voltage vs. Deviation of V_{OUT}

The output voltage (V_{OUT}) of the conventional circuit is about +1.92 V at V_{DD} = +8 V as formulated by equation (1). On this contrary, the output voltage (V_{OUT}) of the new modefied circuitry is about +0.74 V at V_{DD} = +8 V as given by equation (8).

The deviations (ΔV_O) of these output voltages is illustrated in Fig.4. As understood in Fig.4, the deviations (ΔV_O) depended on the supply voltage reduces within ±0.2 % imcomparing the new modefied circuitry with the conventional circuit

Here, deviations ΔVo depended on the supply voltage of the output voltage is defined as follows;

$$\Delta V_0 = \frac{V_{OUT}(V_{DD}[V]) - V_{OUT}(+8[V])}{V_{OUT}(+8[V])} \times 100 \quad [\%] \qquad (9)$$

On the other hand, the characteristics of the output voltage (V_{OUT}) vs. the ambient temperature (*Ta*) is shown in Fig.5 when the ambient temperature (*Ta*) changes from -30°C to +70°C at +8V supply voltage (V_{DD}).

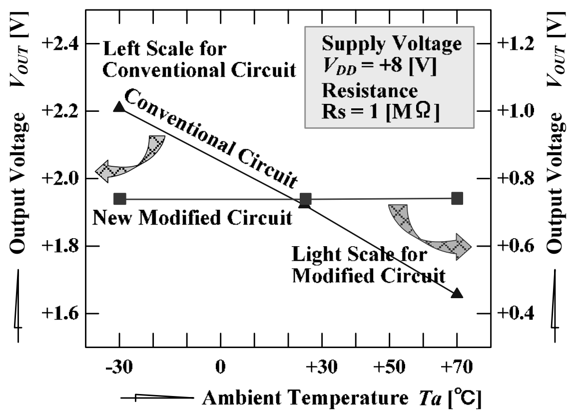

Fig.5 Ambient Temperature vs. Output Voltage

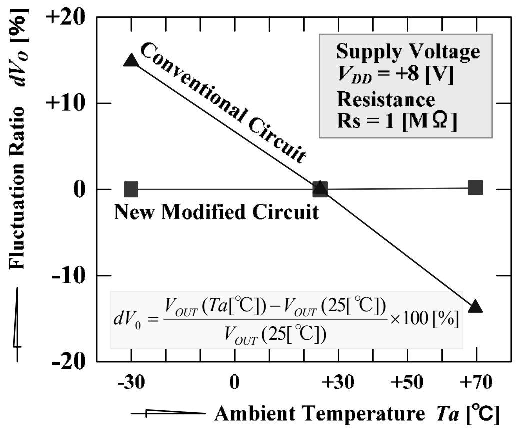

Fig.6 Ambient Temperature vs. Deviation of V_{OUT}

Also, the fluctuation ratio (dV_O) depended on ambient temperature of the output voltage is shown in Fig.6.

Here, fluctuation ratio (dV_O) depended on the ambient temperature of the output voltage is defined as following equation (10).

$$dV_0 = \frac{V_{OUT}(Ta[℃]) - V_{OUT}(25[℃])}{V_{OUT}(25[℃])} \times 100 \quad [\%] \qquad (10)$$

As seen in Fig.5-Fig.6, the fluctuation ratio (dVo) depended on the ambient temperature of the new modified circuitry is very small value comparison with that of the conventional circuit.

Additionally, the performances comparing the new modified circuitry with the conventional circuit is summarized in Table.1. Here, the supply voltage dependability (SVD) and the ambient temperature coefficient (TC) are defined as equations (11) and (12), respectively.

$$SVD = \frac{\{V_{OUT}(MAX) - V_{OUT}(MIN)\} / V_{OUT}(+8[V])}{V_{DD}(MAX) - V_{DD}(MIN)} \quad [\%/V] \qquad (11)$$

$$TC = \frac{\{V_{OUT}(MAX) - V_{OUT}(MIN)\} / V_{OUT}(+25[℃])}{T(MAX) - T(MIN)} \quad [\%/℃] \qquad (12)$$

Table.1 Supply voltage dependability and temperature coefficient

		Conventional Circuit	Modified Circuit
***SVD* [%/V]**	***Ta* = -30℃**	**0.35320**	**0.09172**
	***Ta* = +25℃**	**0.32110**	**0.08967**
	***Ta* = +70℃**	**0.40563**	**0.08478**
***TC* [%/℃]**	**V_{DD} = + 6 V**	**0.28480**	**0.00221**
	V_{DD} = + 8 V	**0.28626**	**0.00203**
	V_{DD} = +10 V	**0.28338**	**0.00193**

From these result of simulation, the supply voltage dependability (SVD) and the temperature cofficient (TC) of the new modified circuitry are improved compariing with that of the conventional circuit. Consequently, the new modified circuitry unaffectes by their fluctuations even if the variations of the supply voltage and deviations of the ambient temperature applies to the voltage reference circuit.

5. Conclusion

Though it is difficult to compose the voltage reference circuit due to existence of "Kink Effect" in TFT, the new modified voltage reference circuitry using LTPS TFT is proposed in this paper. The new modified circuitry can be suppressed fluctuations of the supply voltage due to operation of TFT in the weak inversion region. Accordingly, the new modified circuitry can be obtained a stable reference voltage. Furthermore, the new modified circuitry also unaffected by fluctuations of the ambient temperature due to the using of E-D reference circuit.

From these reason, the supply voltage dependability (SVD) and the ambient temperature coefficient (TC) of the new modified circuitry can be achived 0.08967 [%/V] and 0.00203[%/°C], respectively.

To summarize these results, the new modified circuitry is unaffected by fluctuations of the supply volatge and the ambient temperature due to the utilization of E-D reference circuit and the operation of TFT in the weak inversion region for generation of a stable reference voltage.

References

[1] Yasoji Suzuki, "New High-Speed Logic Circuitry and Power Supply Systems using LTPS-TFT technology for SOG/SOF", The Thin Film Materials and Devices Meeting, No.3, Nara Japan, 2006-11-10, pp.18-21,

[2] Behzad Razavi, "Design of Analog CMOS Integrated Circuits", McGraw-Hill Companies Inc., pp.459-464, pp.710-713, 2001,

[3] Kentaro Kawabata et al., "All CMOS Multi-Output Voltage Reference Circuitry unaffected by fluctuation of Ambient Temperature and Supply Voltage", ITC-CSCC 2005, Vol.1, pp.13-14, 2005,

[4] SILVACO catalog, "Smart Spice / UTMOST III Modeling Manual", Vol.3, pp.2-47-2-57, Dec. 2002,

[5] BANG-SUP SONG et al., "Threshold-Voltage Temperature Drift in Ion-Implanted MOS Transistor" IEEE J. of Solid State Circuits, Vol.SC-17, No.2, pp. 291-298, APRIL 1982,

[6] ROBEAT A.BLAUSCHILD et al., "A New NMOS Temperature-Stable Voltage Reference", IEEE J. of Solid-State Circuits, Vol.SC-13, No.6, pp.767-774, DEC. 1978,