A Level Shifter Using Aluminum-Doped Zinc Tin Oxide Thin Film Transistors with Negative Threshold Voltages

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Keywords: transparent oxide TFT, level shifter, depletion mode TFT, n-channel TFT

Abstract
A new level shifter using n-channel aluminum-doped zinc tin oxide (AZTO) thin film transistors (TFTs) was proposed to integrate driving circuits on qVGA panels for mobile display applications. The circuit used positive feedback loop to overcome limitations of circuits designed with oxide TFTs which is depletion mode n-channel TFTs. The measured results shows that the proposed circuit shifts 10 V input voltage to 20 V output voltage and its power consumption is 0.46 mW when the supply voltage is 20 V and the operating frequency is 10 kHz.

1. Introduction
Oxide thin film transistors (TFTs) are promising devices to replace a-Si:H TFT and poly-Si TFTs as a backplane of displays due to the advantages of high mobility and low-temperature process [1]. Furthermore, oxide TFTs are expected to realize transparent displays due to its transparency.

In mobile display applications, there are many researches for low-cost and value-added functions using system on panel (SOP) technology. Integrating circuits on panel makes the display systems thinner, lighter, and cheaper by reducing connections and external chips. To integrate circuits on panel for transparent displays using oxide TFTs such as zinc oxide (ZnO) [1], indium gallium zinc oxide (IGZO), and aluminum-doped zinc tin oxide (AZTO) [2], it is needed to overcome two issues. First, the circuit consists of only n-channel TFTs [3], which cannot make higher output voltage than input voltage. Second, the oxide TFTs operate in depletion mode. Digital circuits designed with depletion mode TFTs are difficult to be low power push-pull circuits.

In display applications, level shifters are needed between pixels and shift register circuits because the voltage swing of scan signals requires up to 20 V but shift register circuits require lower supply voltage to reduce power consumption.

In this paper, we proposed a new level shifter using positive feedback loop structure with AZTO TFTs to integrate the circuits on panel for transparent active matrix organic light emitting diode (AMOLED) or AMLCD display applications. The proposed level shifter can overcome the limitations of the circuits designed with depletion mode n-channel TFTs.

2. The proposed level shifter and results
Fig. 1 and Fig. 2 show the schematic diagram and timing diagram of the proposed level shifter, respectively. The gate node of N2 and N4 are cross coupled to form positive feedback loop as shown in Fig. 1. The output voltage level, OUT, easily becomes $V_{SS}$ (0 V), when IN and INS2 are $V_{DD}$ (10 V) and N1,
N3, and N5 are turned on. And then N2, N4, and N6 are almost turned off because their gate-source voltage is 0 V. Therefore, OUT maintains VSS. To shift the voltage level to VDDH (20 V), three signals and three steps are required as shown in Fig. 2. In step 1, IN goes down to VSSL (-2 V) and N3 is turned off. In this step, OUT is not changed because the gate of N2 becomes a floating node and its voltage is held by parasitic capacitance. In step 2, the voltage of INS1 becomes VDD and N2 is turned on. Then the current flows from N2 to N1. In step 3, INS2 becomes VSSL and N1 is turned off. The drain node of N1 is charged and the voltage of the node increases. N4 is turned on because the drain node of N1 is the gate node of N4. The current flowing through N4 charges the drain node of N3 to increase the voltage. A latch-like positive feedback loop is formed between N2 and N4, which maintains the output high voltage stably and be higher than the voltages of input signal. N5 and N6 are operated as a buffer to drive the panel load.

Fig. 3 shows the measured waveforms when the operating frequency is 5 kHz and 10 kHz, respectively. Its power consumptions are 0.41mW and 0.46mW, respectively.

3. Conclusions

In this paper, a new level shifter using positive feedback loop with n-channel depletion-mode AZTO TFTs was proposed to integrate the driving circuits on panel for mobile displays. The measurement results show that the proposed level shifter successfully shifts the voltage level from 10 V to 20 V. The power consumption of the proposed level shifter is 0.46 mW when supply voltage is 20 V at 10 kHz. Therefore, the proposed level shifter can be integrated on qVGA panel which operates in 7 kHz for transparent mobile displays.

4. Acknowledgement

This work was supported by the IT R&D program of MIC/IITA. [2006-S079-02, Smart window with transparent electronic devices]

5. References