# A Dual-Output Scan Driver Circuit employing LTPO TFTs for Mobile Displays

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Keywords: low-temperature polycrystalline silicon and oxide (LTPO), scan driver circuit, thin-film transistor

**ABSTRACT**

*We propose a novel dual-output scan driver circuit employing low-temperature polycrystalline silicon and oxide (LTPO) thin-film transistors (TFTs). It was confirmed that the output is stably generated at a threshold voltage of -5 V to +8 V. The proposed circuit has a very simple structure of 7T1C and generates two outputs in one circuit, so it is suitable for narrow-bezel mobile displays.*

## 1 Introduction

Recently, various portable devices have been released. Displays for portable electronic devices require high resolution, narrow bezels, and low power consumption [1]. The higher the resolution, the smaller the pixels, so the pitch of the scan driver circuit must be reduced. Therefore, it is necessary to reduce the layout area by simplifying the structure of the scan driver circuit [2]. In addition, a narrow bezel can be realized by reducing the number of scan driver circuits by designing a circuit with multiple outputs in one circuit.

So far, low-temperature polycrystalline silicon (LTPS) TFTs have been widely used in mobile displays due to their high mobility and good stability [3]. However, there is an issue in that power consumption increases because the off current is large [4]. On the other hand, amorphous indium-gallium-zinc-oxide (a-IGZO) thin-film transistors (TFTs) have good uniformity and low off current [5]. However, since a-IGZO TFTs operate in depletion mode, it may cause malfunction of the scan driver circuit. Therefore, recently, LTPO TFTs-based active-matrix organic light-emitting diode (AMOLED) displays utilizing the advantages of LTPS TFTs and a-IGZO TFTs have been adopted for mobile applications.

LTPO TFTs-based pixel circuits are currently used in commercial smartwatches and smartphones to enable display operation at low refresh rates [6]. The a-IGZO TFTs are used as a switching TFT to maintain voltage at the gate node of the driving TFT even at low refresh rate. Therefore, for such a pixel circuit to operate, a scan driver circuit capable of turning on/off the n-type oxide TFTs and the p-type LTPS TFTs is required.

In this paper, we propose a scan driver circuit with two outputs employing LTPO TFTs. The proposed scan driver circuit has two scan outputs that are output oppositely. In addition, the outputs are stably generated even in the depletion mode of the a-IGZO TFTs. Therefore, the proposed scan driver circuit can be applied to displays requiring high resolution, narrow bezels, and low power consumption.

## 2 Proposed Scan Driver Circuit

Fig. 1 shows the circuit schematic, timing diagram, and block diagram of the proposed scan driver circuit. The proposed circuit consists of 4 LTPS TFTs, three a-IGZO TFTs and a capacitor. The circuit has two clock signals and three bus lines (VDD, VSS, and VSSL). The clock signals of CLK and CLKB are operated in the swing range of −5 to 10 V. The voltages of VDD, VSS, and VSSL were 10, −5, and −8 V, respectively. The operation of the proposed circuit can be divided into three sections, as shown in Fig. 1(b).

### 2.1 Operation of the Scan Driver Circuit

(A) Pre-charge Period

In the precharging period, as CLK becomes VDD, which is the high level of the clock signal, T1 is turned on. At this time, since Scanb[n-1] has a low voltage VSS, it is charged to the voltage VSS-$V_{TH\_T1}$ through T1. The QB[n] node maintains the voltage VSSL of the previous period. Accordingly, since the gate-source voltage of T7, which is the pull-down TFT of Scanb[n], has a negative voltage, it is completely turned off even in the depletion mode. At this time, since T4 and T6 are turned on, Scan[n] maintains VSS and Scanb[n] maintains VDD.

(B) Bootstrapping Period

As CLK becomes VDD, T1 turns off, and Q[n] enters a floating period. At this time, since Scan[n-1] becomes the voltage from VDD to VSS, Q[n] is bootstrapped by C1. As a result, the driving capability of the pull-up TFT (T4) is improved so that Scan[n] outputs the VDD voltage stably. Also, since Q[n] is bootstrapped, the gate voltages of T3 and T5 have a lower voltage than VSSL. Therefore, the through current does not flow because the pull-down TFTs (T3, T5) are completely turned off even in the depletion mode. At this time, QB[n] is charged with VDD, which is the high voltage of CLK, through T2. Therefore, T6 turns off and T7 turns on, so Scanb[n] outputs VSS.

(C) Reset and Low-Holding Period

During this period, CLK becomes VSS and T1 turns on, so Q[n] is charged to VDD by Scanb[n-1]. Since Q[n] has a high voltage, T2 and T4 are turned off and T3 and T5 are turned on. Therefore, Scan[n] is discharged to

VSS, and QB[n] is discharged to VSSL. When QB[n] becomes VSSL, T6 turns on and T7 turns off, so Scanb[n] outputs VDD. In the low holding period, Q[n] is charged with a 50% duty ratio because it is charged by T1 having CLK as a gate. In the floating state having a 50% duty ratio, Q[n] stably maintains the VDD voltage by C1.

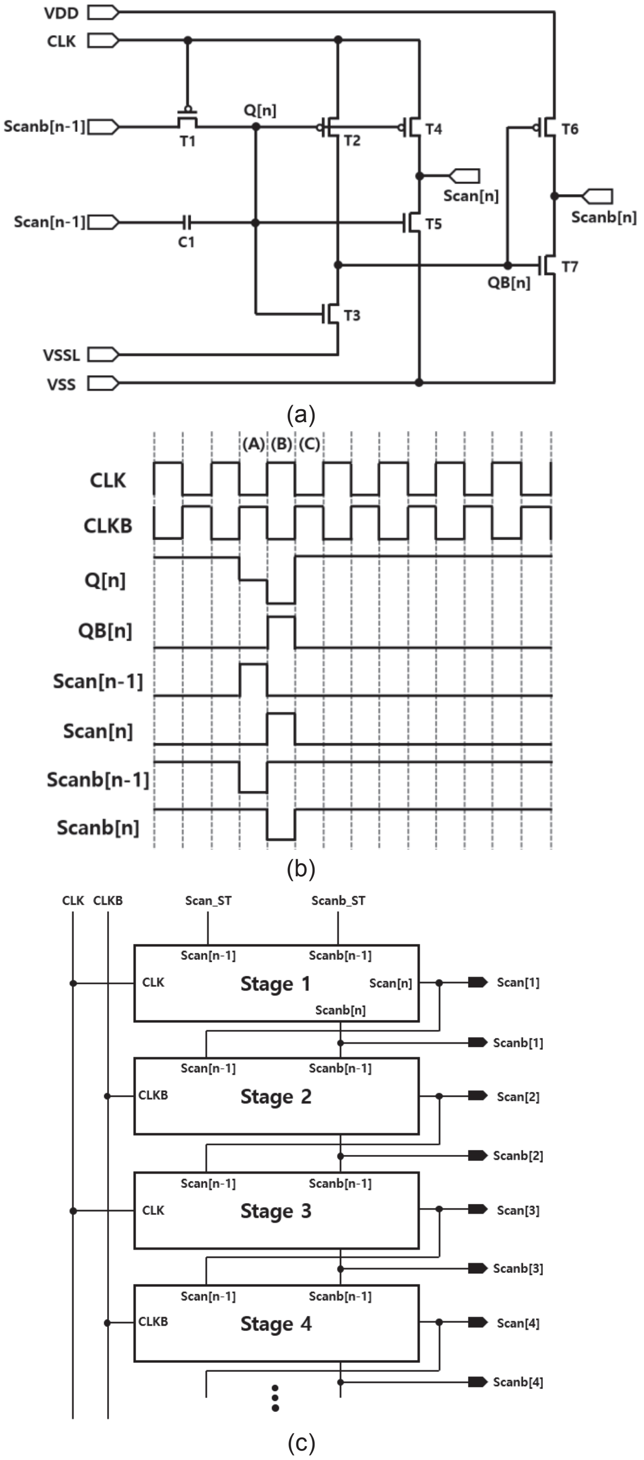


**Fig. 1 Proposed scan driver circuit: (a) circuit schematic, (b) timing diagram, and (c) block diagram.**

### 2.2 Simulation

We simulated the proposed scan driver circuit using the Smartspice simulation with RPI (level = 36) model. The 1H time is 2.6 μs based on the display panel (3200 gate lines) and the frame rate is 120 Hz. Also, we modeled the gate-line load by attaching a 10 kΩ resistor and a 30 pF capacitor to each output node of the proposed scan driver circuit. Fig. 2(a) and (b) show the simulated I-V transfer curves of the LTPS TFT and a-IGZO TFT used in the proposed scan driver circuit, respectively.

## 3 Results and Discussion

Fig.3 shows the simulated voltage waveforms of Q[n], QB[n], Scan[n], and Scanb[n] of the proposed circuit when the $V_{TH}$ value of a-IGZO TFT is -0.5 V. The proposed circuit showed stable outputs even when the a-IGZO TFTs operate in the depletion mode. In particular, the voltage of Q[n] has -10.1 V as shown in Fig. 3(a), which is bootstrapped to a lower voltage than VSSL. Therefore, no through current flows in the pull-down TFT (T5) of Scan[n] even in the depletion mode. Also, QB[n] keeps the VSSL voltage of -8V stable most of the time, so T7, the pull-down TFT of Scanb[n], does not flow through current in the depletion mode. As a result, the output signals Scan[n] and Scanb[n] stably showed the outputs with a voltage range of -5 to 10 V as shown in Fig. 3(c) and (d).

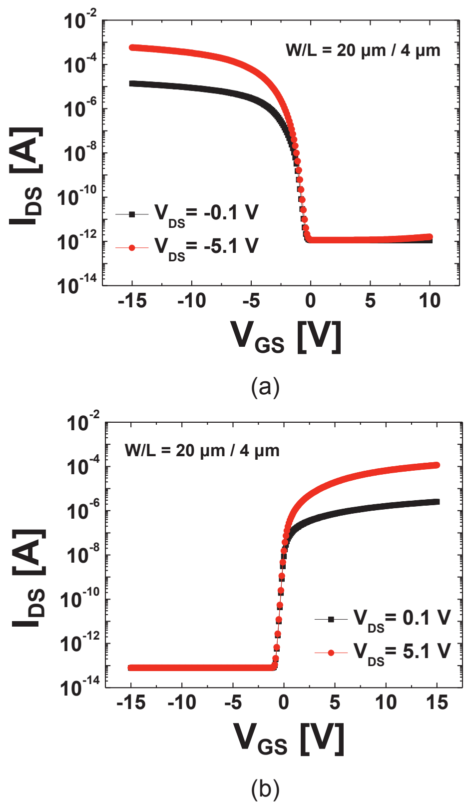


**Fig. 2 Simulated transfer characteristics (a) LTPS TFT, and (b) a-IGZO TFT.**

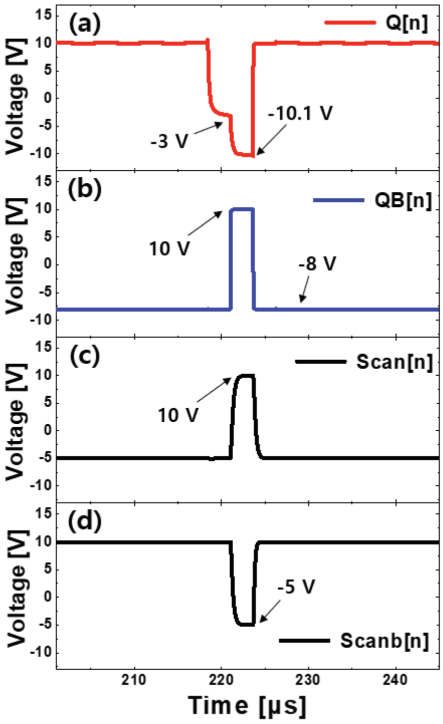


**Fig. 3 Simulated voltage waveforms of (a) Q[n], (b) QB[n], (c) Scan[n], and (d) Scanb[n].**

As shown in Figure 4, the multi-stage operation of the last 5 stages of the proposed circuit was verified. The proposed circuit showed stable sequential operation with shift register without ripple voltage under multi-stage operating conditions. The $V_{TH}$ margin of the proposed circuit was also investigated. The proposed scan driver circuit can operate in the $V_{TH}$ range from -5 to 8V. Figure 4(a) and (b) show the Scan[n] and Scanb[n] output waveforms when $V_{TH}$ is -5 and 8V, respectively. For both outputs, although the rising and falling times increased as $V_{TH}$ increased, the circuit exhibited a stable Scan[n] without output voltage degradation.

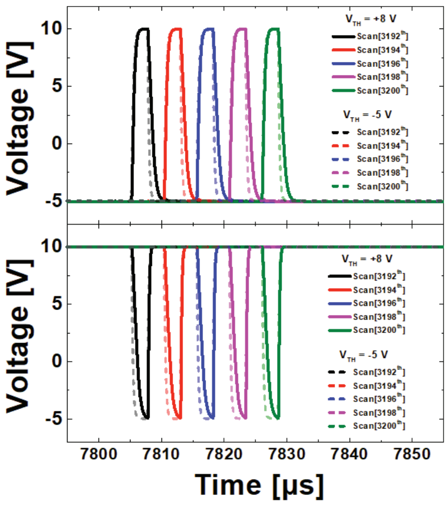


**Fig. 4 (a) Simulated voltage waveforms in a multistage structure (a) Scan[n], and (b) Scanb[n].**

## 4 Conclusion

In this paper, we proposed a novel dual-output scan driver circuit employing LTPO TFTs for mobile displays. The simulation results for the proposed circuit exhibit a stable Scan[n] and Scanb[n] waveforms without output voltage degradation when the threshold voltage of a-IGZO TFT is -5 V to +8 V. Consequently, the proposed circuit has a very simple structure of 7T1C and generates two outputs in one circuit, so it is suitable for narrow-bezel mobile displays.

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