Design of Analog Circuits on Glass Substrate

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Abstract—In the near future, the liquid crystal display (LCD) fabricated in the low-temperature poly-silicon (LTPS) process is promising toward system-on-panel (SOP) or system-on-glass (SOG) applications, especially for achieving a compact, low-cost, and low-power display system. Therefore, it has a tendency towards integrating digital and analog circuits on the glass substrate. In this paper, an on-glass digital-to-analog converter (DAC) with gamma correction, and an on-glass bandgap reference circuit, have been designed and fabricated in a 3-μm low-temperature poly-Si (LTPS) technology.

I. INTRODUCTION

Low-temperature poly-silicon (LTPS) thin-film transistors (TFTs) have been widely used for portable systems, such as digital camera, mobile phone, personal digital assistants (PDAs), notebook, and so on. The electron mobility of LTPS TFTs is about 100 times larger than that of the conventional amorphous silicon TFTs [1], so LTPS technology can achieve slim, compact, and high-resolution display by integrating the driver circuits on peripheral area of display. This LTPS technology will become more suitable for realization of system-on-panel (SOP) applications [2]. Fig. 1 shows the system integration roadmap of LTPS TFT-LCD [3].

SOP technology also has a potential of integration of input/output function of display, which will pave the way for future displays. The input display technology opens opportunities for new applications for personal and business use. The new technology is scalable up and down, and can be applied to diverse products, from cellular phones to personal computers. The full scope is to our imagination concerning future use of “Input Display.” Its wide range of usage includes recording of text or images for on-line shopping, without a scanner device saving personal data and images to a computer, and personal identification, auto-power control with photo-sensor, suitable for extremely low power cellular phone, detecting the position of finger or pen for some touch-sensing, and so on.

At present, various functional circuits are implemented on glass substrate, including static random access memory (SRAM) in each pixel [4]. When SRAMs and a liquid crystal AC driver are integrated in a pixel area under the reflective pixel electrode, the LCD is driven by only the pixel circuit to display a still image. This result is more suitable for ultra low power operation. Eventually, it may be possible to combine the keyboard, CPU, memory, and display into a single “sheet computer” [5].

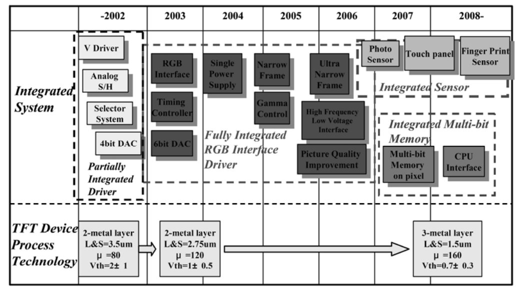


Fig. 1: System roadmap of LTPS TFT-LCD [3].

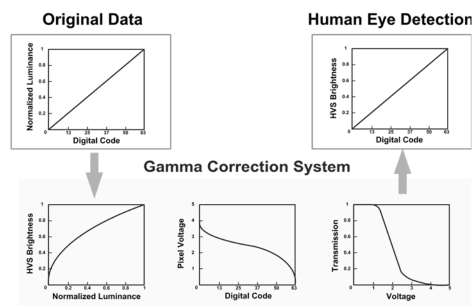


Fig. 2: The operation of the gamma correction for the normally white TN type LCD panel [6].

Besides, fabrication cost will gradually be lowed and SOP will be implemented step by step in the future. Such integration technology contributes to shorten the product lead-time because lengthy development time of ICs can be eliminated. Moreover, LTPS technology is compatible with OLED, which is another promising display device. Therefore, design of various functional circuits for SOP in LTPS technology is worthy expecting in the future.

In this paper, an on-glass digital-to-analog converter (DAC) with gamma correction, which is composed of folded R-string circuit, segmented digital decoder, and reordering decoding circuit, and an on-glass bandgap reference circuit, which has temperature coefficient (TC) of 195 ppm/°C between 25°C and 125°C, have been designed and fabricated in a 3-μm low-temperature poly-Si (LTPS) technology

II. ON-GLASS DIGITAL-TO-ANALOG CONVERTER WITH GAMMA CORRECTION

A. Gamma Correction

Gamma correction of liquid crystal displays is involved due to the nonlinearity between luminance and human visual system (HVS). The pupils of the human’s eyes would vary automatically for the change of the ambient light. For this reason, a data driver with gamma correction is necessary in TFT-LCD panel. The data driver circuit is often required to compensate for the human visual system's transfer function. Moreover, it must also compensate for the LCD transfer function. Fig. 2 shows the operation of the gamma correction for the normally white TN type LCD panel [6]. The gamma correction system is composed of three relationships: luminance vs. HVS brightness, input digital code vs. pixel voltage, and the V-T curve of the NW-TN type liquid crystal. In general, the input digital codes (media codes) are designed to be direct proportion to brightness in human eye linear with this system. In data driver circuit, DAC is used to convert the digital RGB signal to analog gray level, so Gamma Correction System in Fig. 2 can be implemented by DAC with gamma correction.

B. New Folded R-String DAC with Gamma Correction

Fig. 3 shows the new proposed folded R-string DAC with gamma correction for panel data driver in LTPS technology [7]. The lower area and lower complexity can be achieved in this new design. The proposed DAC is composed of folded R-string circuit, switch array, two identical segmented decoders, and reordering decoding circuit. The input signal Din is segmented into two parts (MSBs and LSBs). The MSBs and the LSBs of the input signal are assigned to two identical segmented decoders. The output signal of one decoder turns on the switches on the top row of the switch array while the other decoder turns on the switches in the reordering decoding circuit. Therefore, the output voltage (Vo) matches correct gray level.

For a 6-bit R-string DAC with gamma correction design, the transform function of this system is shown in Fig. 4 [6]. The nonlinearity between gray level domain and luminance domain can be corrected by gamma correction design. For a 6-bit gamma correction, the transform function of this system can be expressed as following

$$\frac{T(GL)-T_{\min}}{T_{\max}-T_{\min}}=(GL/63)^{\gamma}, \quad (1)$$

$$L(GL)=T(GL)\times K_{backlight} \quad . \quad (2)$$

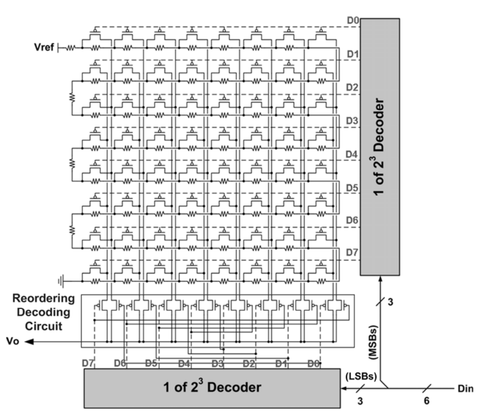


Fig. 3: The proposed on-glass folded R-string DAC with gamma correction in LTPS technology [7].

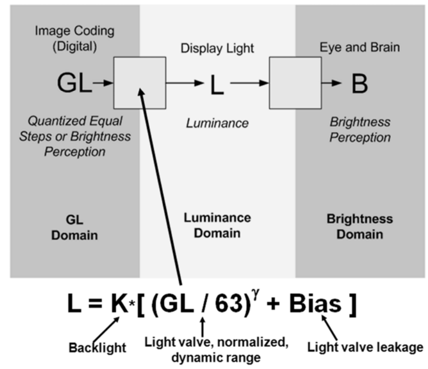


Fig. 4: The transform function of display system [6].

Pixel value can be derived with gamma value of 2.2 by using the transform function with proper resistance ratio. With the R-string approach, the DAC has guaranteed monotonicity and also has higher accuracy, because the accuracy of the R-string DAC is dependent on the ratio of resistors, not dependent on absolute resistor values. Furthermore, the area of the proposed folded R-string DAC with gamma correction is smaller because the reordering decoding circuit can simplify the decoder circuit. The partial decoding function is replaced by the signal paths routing of the reordering decoding circuit. For this reason, the fundamental decoders can be utilized for the two identical segmented digital decoders.

C. Experimental Results

The proposed on-glass folded R-string DAC with gamma-correction has been designed and fabricated in a 3-μm LTPS process. The die photo of the fabricated circuit is shown in Fig. 5, where the area is 1110μm x 1180μm. Fig. 6 shows the measurement result of output voltage in the on-glass folded R-string DAC with gamma correction in 3-μm LTPS process under five different samples. With the transform function and proper resistance ratio, the simulation result is similar to measurement result with gamma value of 2.2. However, the measurement result is not well consistent with the simulation result due to the variation of on-glass resistance in LTPS process. With suitable adjustment on the resistance of R-string in the LTPS process, a more precise result of the proposed on-glass DAC can be achieved.

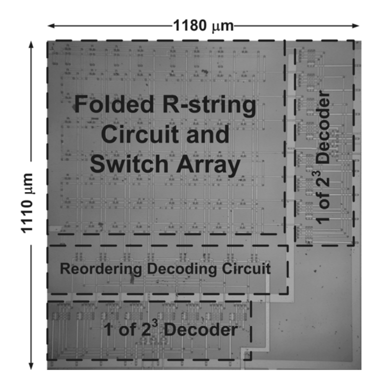


Fig. 5: The die photo of on-glass folded R-string DAC with gamma-correction realized in 3-μm LTPS process.

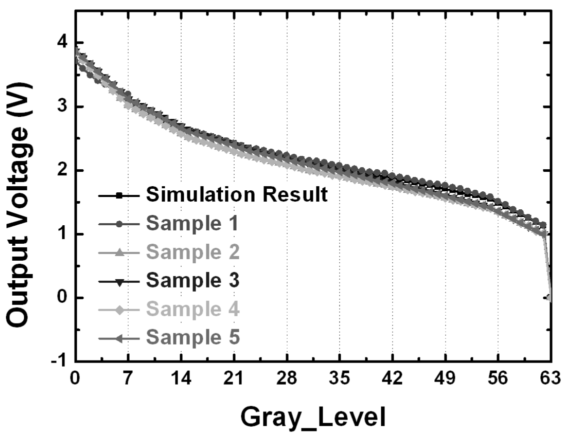


Fig. 6: The measurement result of output voltage in fabricated folded R-string DAC with gamma-correction under 5 samples in 3-μm LTPS process.

III. ON-GLASS BANDGAP REFERENCE CIRCUIT

A. Temperature Coefficient

In LTPS TFTs, the drain current I_D of devices operated in saturation region can be expressed as

$$I_{DS} = \frac{W}{2L}\mu_0 C_{ox}\left(V_{GS} - V_{TH}\right)^2 \exp\left(-\frac{V_B}{V_T}\right). \tag{3}$$

where μ_0 is the carrier mobility within the grain, L denotes the effective channel length, W is the effective channel width, C_{ox} is the gate oxide capacitance per unit area, V_{TH} is the threshold voltage of TFT device, and V_{GS} is the gate-to-source voltage of TFT devices. V_B is the potential barrier at grain boundaries and is associated with the crystallization quality of the poly-Si film. Under small V_{GS}, V_B is large. When the V_{GS} increases, V_B decreases rapidly from a NTFT device. When the devices in circuit are operated under small V_{GS} and a variation of temperature ΔT, the variation of V_B is derived:

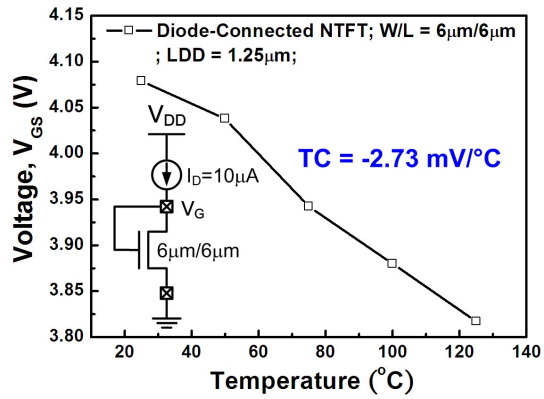
$$\Delta V_B = \frac{k\Delta T}{q}\ln\left(\frac{W\alpha}{I_{DS}}\right). \tag{4}$$

Assume that the variation of V_{GS} (ΔV_{GS}) is very small that a negative linearity approximation can be given between ΔV_B and ΔV_{GS} as

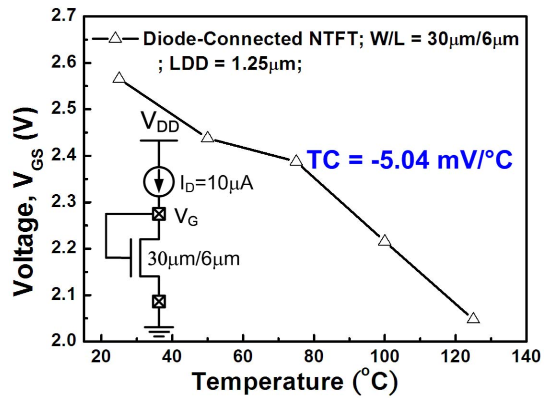
$$\Delta V_{GS} = -\frac{1}{m}\Delta V_B = -\frac{k\Delta T}{mq}\ln\left(\frac{W\alpha}{I_{DS}}\right) = -\frac{V_B \Delta T}{mT}. \tag{5}$$

where m is the absolute value of the slope of the linear approximation. Enlarge the channel width makes the devices biased at small V_{GS} and exhibits large V_B. Compared to the significant dependence between V_B and V_{GS} under small V_{GS}, the variation of m can be ignored.

As a result, the LTPS TFTs with larger channel width exhibit larger absolute value of TC. The assumption is verified by measurements in Fig. 7 [8]. All the devices are n-type poly-Si TFTs fabricated in the same run by using commercial excimer laser annealing process. The channel length is fixed as 6 μm and the LDD length is 1.25 μm.



(a)



(b)

Fig. 7: The comparison on temperature coefficient (TC) of diode-connected TFTs under a constant drain current of 10-μA with (a) channel width of 6-μm, and (b) channel width of 30-μm, in 3-μm LTPS process [8].

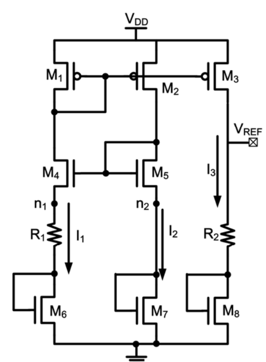


Fig. 8: The implementation of the new proposed on-glass bandgap reference circuit in 3-μm LTPS process [8].

B. On-Glass Bandgap Reference Cricuit

After the evaluation on the TC of poly-Si TFTs with different channel widths, the new on-glass BGR circuit can be implemented in Fig. 8 [8]. In this design, the TFTs M1, M2, M4, and M5 are biased in saturation region. The diode-connected NTFTs M6, M7, and M8 with different channel width are biased in saturation region. The nodes n1 and n2 are designed to have equal potential by the current mirror circuit.

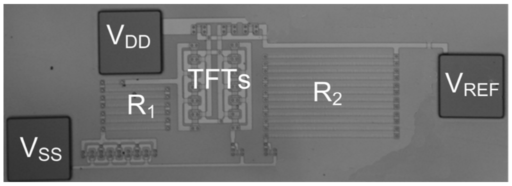


Fig. 9: The die photo with PAD of the new proposed on-glass bandgap reference circuit fabricated in 3-μm LTPS process.

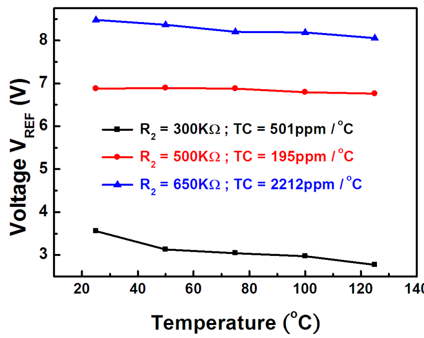


Fig. 10: The measured result of the new proposed on-glass bandgap reference circuit fabricated in 3-μm LTPS process.

The channel width of M_6 (W_6) is larger than the channel width of M_7 (W_7), so the TC of M_6 is more negative than the TC of M_7. The voltage drop on the resistor R_1 (V_{R1}) therefore exhibits a positive TC. If the dependence of m on V_{GS} is neglected, the variation of V_{R1} (ΔV_{R1}) as a function of ΔT can be expressed as

$$\Delta V_{R1} = \frac{k\Delta T}{mq}\ln(\frac{W_6}{W_7}) = \frac{k\Delta T}{mq}\ln N. \quad (6)$$

Obviously, ΔV_{R1} is proportional to the absolute temperature (PTAT). Hence, a PTAT loop is formed by M_6, M_7, and R_1. The PTAT current variation ΔI_1 can be written as

$$\Delta I_1 = \frac{k\Delta T}{mqR_1}\ln N. \quad (7)$$

where N is the channel width ratio of M_6 and M_7. The current mirror which is composed of M_1, M_2, and M_3 imposes equal currents in these three branches I_1, I_2, and I_3 of the circuit. In this circuit, the output is the sum of a gate-source voltage of TFT M_8 (V_{GS8}) and the voltage drop across the upper resistor (V_{R2}). Therefore, the output voltage variation (ΔV_{REF}) of the new proposed on-glass bandgap reference circuit can be expressed as

$$\Delta V_{REF} = \Delta I_3 R_2 + \Delta V_{GS8} = \frac{R_2}{R_1}\frac{k\Delta T}{mq}\ln N + \Delta V_{GS8}. \quad (8)$$

where R_1 and R_2 are the resistances shown in Fig. 8. The resistance ratio is chosen in order to compensate the negative temperature dependence of ΔV_{GS8}. Hence, an output voltage with very low sensitivity to temperature can be obtained if a proper ratio of resistors is matched.

C. Experimental Results

Fig. 9 shows the die photo with PAD of the new proposed on-glass bandgap reference circuit fabricated in 3-μm LTPS technology. The threshold voltage is about Vthn ≈ Vthp ≈ 1.25 V at 25 °C. The ratio between the gate areas of M_6 and M_7 is 6. The resistors in this chip are formed by ploy resistors, which have minimum process variation to improve the accuracy of resistance ratio. The measured result of the output voltage (V_{REF}) is shown in Fig. 10. Apparently, the resistance R_2 is the critical design in bandgap reference circuit. As R_2 is equal to 500 kΩ, the measured temperature coefficient of the new proposed bandgap reference circuit is around 195 ppm/°C under the 10 V supply voltage between 25°C and 125°C, whereas the output voltage is kept at 6.87 V.

IV. CONCLUSIONS

In this paper, an on-glass digital-to-analog converter (DAC) with gamma correction, which is composed of folded R-string circuit, segmented digital decoder, and reordering decoding circuit has been successfully designed and fabricated in 3-μm LTPS technology. Furthermore, the proposed architecture is also more suitable for gamma correction design in different kinds of LTPS processes. Besides, an on-glass bandgap reference circuit has been successfully verified in a 3-μm LTPS process without trimming procedure. The measurement results of the bandgap voltage reference are V_{REF} of 6.87 V and temperature coefficient of 195 ppm/°C, which consumes a maximum current of 8.97 μA at 10 V supply. Both new proposed on-glass circuits can be used for system-on-panel (SOP) or system-on-glass (SOG) applications.

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