Impact of Kink effect on performance of Poly-Silicon Based TFT Differential Amplifiers

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Abstract: *The concept of complete Display system on Glass requires implementation of analog and digital circuits using Poly-Silicon thin film transistors. In the present work we describe design of differential amplifiers with current mirror load, a fundamental building block of analog circuits. It is shown that unlike differential pairs implemented using bulk MOS transistors, the voltage gain in TFT based amplifier does not degrade significantly with increase in biasing current. It is shown that this unique behavior occurs due to presence of Kink in the output characteristics of the TFT. Results are presented that highlight that unlike conventional differential pairs, the tradeoff between voltage gain and bandwidth is not significant in TFT based circuits.*

Keywords: Thin Film Transistor; Kink effect; Differential Amplifiers

Introduction

Polysilicon thin film transistors (TFT) constitute a key technology for active matrix Flat Panel displays. Although the TFT performs a relatively simple function of a switch in LCD active matrix displays, in new system-on-glass display technologies [1], both digital as well as analog circuits need to be implemented using TFTs as well [2-4]. Since TFT device characteristics can differ significantly from their bulk MOS counterpart, it is important to revisit design techniques developed for MOS transistors and examine their usefulness and limitations for TFT based circuits. With this viewpoint, we address the issue of design of differential amplifiers with current mirror load, a key building block of analog circuits. In particular we examine the impact of kink [5] in the output characteristics of TFT on the performance of differential amplifier. In order to clearly illustrate the resulting changes, the performance of TFT amplifier is compared with that of a conventional MOS based amplifier.

Comparative analysis OF TFT & MOS Differential Amplifier

MOS based circuit: Fig. 1 shows a schematic of CMOS differential amplifier with current mirror load. Fig. 2 shows the variation of differential mode gain with bias current I_{SS}. The results were obtained through simulations using AIMSPICE circuit simulator and BSIM3 models corresponding to 0.5μm cmos technology. The transistor sizes were chosen as $(W/L)_1 = (W/L)_2 = 50\mu/1\mu$, $(W/L)_3 = (W/L)_4 = 1\mu/1\mu$, $(W/L)_5 = 100\mu/1\mu$. The supply voltages were taken as Vdd = +3.3V and Vss = -3.3V. The gain initially increases with decrease in supply current but eventually saturates. The gain can be expressed in terms of transconductance (gm) and output resistances (r_o) of transistors.

$$Adm = -g_{m1} \times r_{O2} \| r_{O4} \tag{1}$$

The reasons for the observed trend in gain are that for larger current values, transistors M1 and M2 operate in strong inversion region for which $g_{m1} \propto \sqrt{I_{SS}}$ and $r_{O1,2} \propto 1/I_{SS}$ so that $Adm \propto 1/\sqrt{I_{SS}}$. For very low currents, the transistor operates in subthreshold region for which $g_{m1} \propto I_{SS}$ so that gain saturates. Another important characteristics of a differential pair is unity gain frequency (UGF) which for a load capacitance of C_L can be expressed as

$$UGF = g_{m1}/2\pi C_L \tag{2}$$

From (1-2) it can be easily shown that a tradeoff exists between voltage gain and unity gain frequency [6] as illustrated in Fig. 3.

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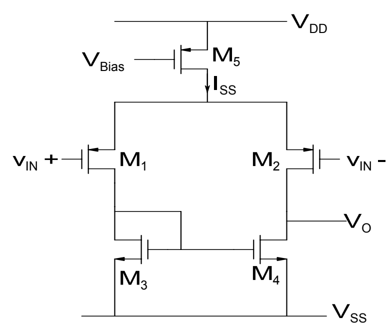

Figure 1. CMOS differential amplifier

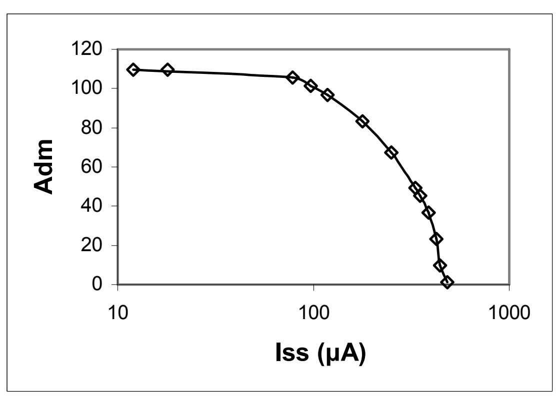

Figure 2. Variation of differential gain of MOS differential amplifier with bias current

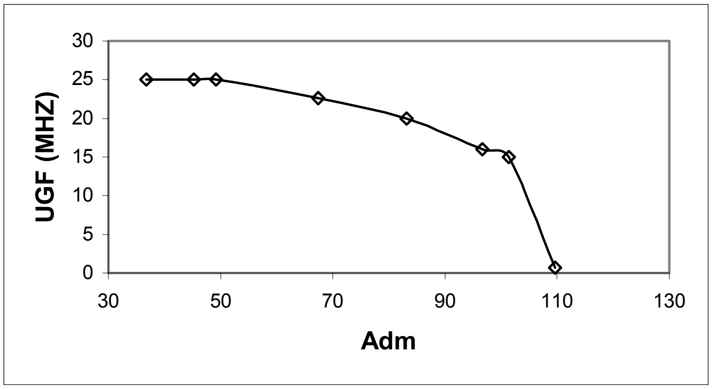

Figure 3. Variation of unity gain frequency of MOS differential amplifier with differential gain

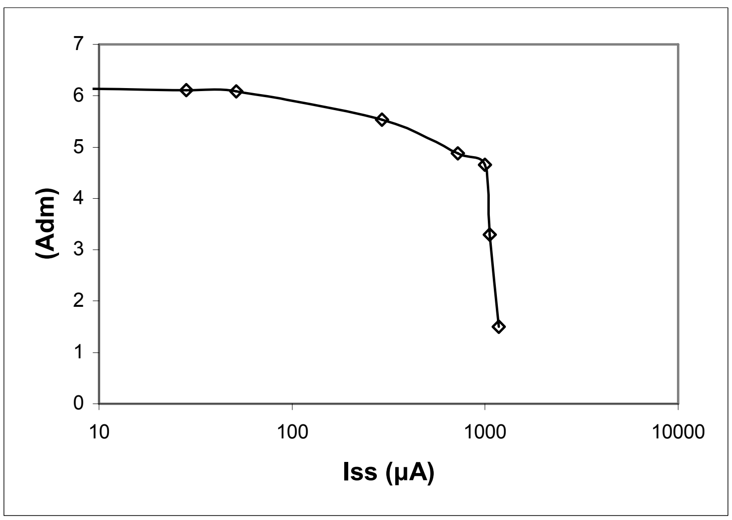

Figure 4. Variation of differential gain of TFT differential amplifier with bias current

TFT based circuit: A TFT based differential amplifier was designed with transistors having same aspect ratio as those in MOS differential amplifier for ease of comparison. Simulations were carried out using AIMSPICE simulator using Level-16 ASIA2 model with parameters used in earlier studies [7]. Supply voltages of ± 15V were used. Figure 4 shows the variation of differential gain with bias current. A comparison of Fig. 4 with Fig. 2 shows that TFT amplifier has a much smaller gain. The reasons for this are two fold. Due to smaller carrier mobility, the transconductance of TFT is smaller than that of MOS transistor and due to Kink effect; the output resistance is also significantly reduced.

Fig. 4 also shows that gain of TFT amplifier remains relatively constant with increase in bias current and drops sharply only when transistors come out of saturation mode of operation. As an example, when Iss increases from 28µA to 996 µA, that is by a factor of ~35, differential gain decreases from 6.1 to 4.6 only (~ factor of 1.3). To understand the reasons for this behavior, transconductance of transistor m1 was computed as a function of current and is shown in Fig. 5. It can be seen that transconductance g_{m1} increases from 55 to 348 $\mu\Omega^{-1}$ (by a factor of 6.3) as current changes from 28 to 996 µA in accordance with expectations. This implies that output resistance does not scale with current in a conventional manner. Fig. 6 shows variation of output resistance of m2 with Iss. One can note that in the current range of interest, output resistance reduces from 128K to 77K (a factor of 1.67) only . The sharp fall in output resistance at around 10^3 μA occurs due to transistor coming out of saturation into triode region of operation. The relatively constant value of output resistance of transistor m2 despite increase in current occurs due to kink in the output characteristics as illustrated in Fig. 7. As bias current increases, the source-drain voltage of m2 decreases causing the quiescent biasing point to move from A at low currents to D at higher current values. It can be seen from Fig. 7 that in this process, one moves from a region of higher slope in I-V to regions of lower slope. In other words, the channel length modulation parameter (defined as $\lambda = I_{SD}^{-1} \times (\partial I_{SD} / \partial V_{SD})$ decreases with increase in current as illustrated in Fig. 8. Therefore, even though current increases, the output resistance ($r_{O2} = 1/\lambda I_{SD}$) does not reduce much due to a mutual cancellation effect.

An interesting consequence of gain remaining constant with increase in bias current is that unity gain frequency can be improved without degradation in gain as illustrated in Fig. 9. For example, even though UGF increases from .63 MHZ to 6.24 MHZ (a factor of 10), gain reduces only by 30%. In contrast, for the case of MOS differential amplifier, when UGF changes from 15 MHZ to 25 MHZ (a factor of ~1.67) , the differential gain changes from 101 to 49 (by a factor of ~ 2).

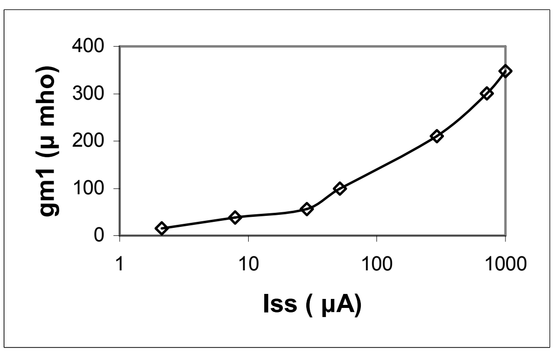

Figure 5. Variation of transconductance of TFT m1 with bias current

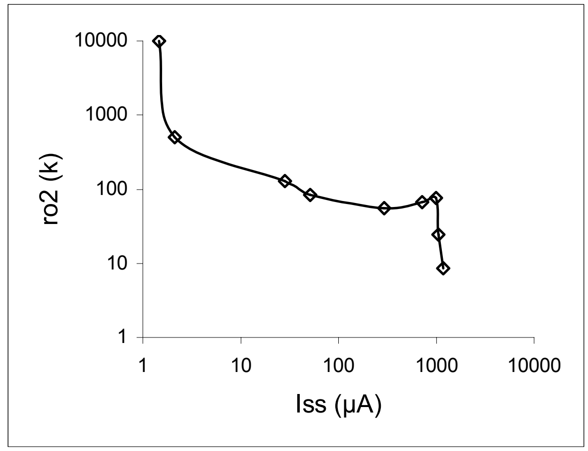

Figure 6. Variation of output resistance of TFT m $_2$ with bias current

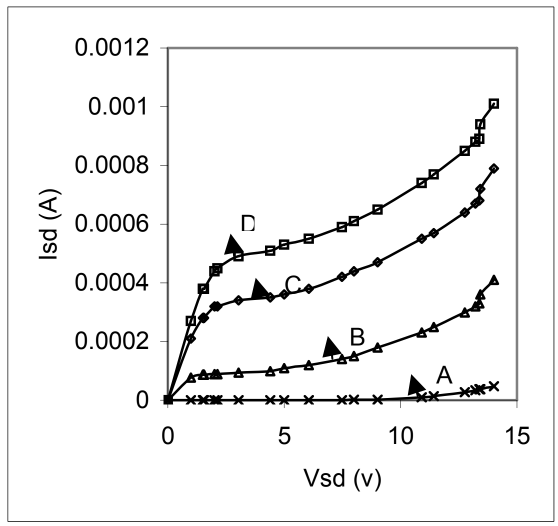

Figure 7. I-V curve of TFT m_2. Points A-D show shift in biasing point with increase in current.

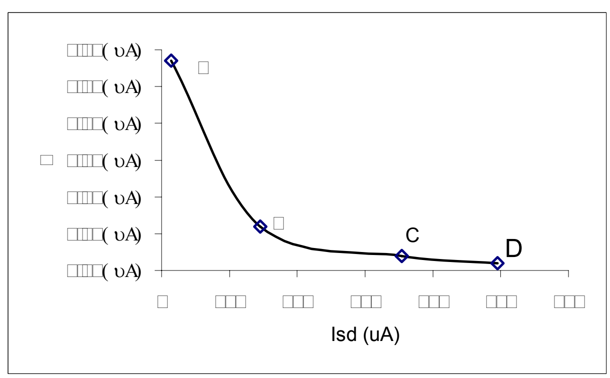

Figure 8. Channel length modulation Parameter (λ) vs Isd of m_2

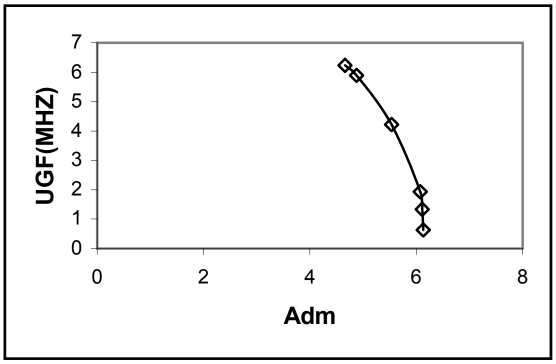

Figure 9. UGF vs differential gain of TFT differential amplifier

Conclusion

To summarize, the performance of a polysilicon TFT differential amplifier was compared with that of a bulk MOSFET circuit. It is shown that presence of kink in output characteristics of TFT leads to unexpected behavior in amplifier results. The differential gain does not reduce significantly with increase in bias current like in conventional MOSFET circuits. This occurs due to output resistance remaining constant as a result of decrease in channel length modulation parameter with increase in current. As a result of insensitivity of gain to current, the tradeoff between differential mode gain and unity gain frequency commonly observed in conventional circuits, does not occur in polysilicon TFT circuits in a significant manner.

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