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A touch sensor readout circuit using switched-capacitor charge pump

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Abstract: This paper presents an on-chip touch sensor readout circuit using charge pump based switched-capacitor scheme. For the proposed touch sensor readout circuit, the touch panel capacitance is directly converted into a voltage level by the switched-capacitor charge pump, which does not require additional signal conditioning for detection. The additional circuitry following the charge pump such as the comparator and flip-flop does not consume any static current. Therefore, the suggested touch sensor can lead to a compact and low power on-chip solution with fast detection time. The prototype circuit is fabricated using CMOS 0.35 μm technology, where the consumption current is only 2.2 μA.

Keywords: charge pump, switched-capacitor, touch panel, touch sensor

Classification: Integrated circuits

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1 Introduction

In recent years, due to the increased demand for user friendly interface, touch screens and touch panels are frequently used for multi-media systems. Besides, the touch screen market has shown a rapid growth during the past several years, where the applications are expending to multi-touch based electronic white boards, conference tables, books, and virtual games. To this day, the low cost resistive type touch screens were generally used. However, capacitive type touch screens that can realize multi-touch feature with upgraded accuracy are becoming more popular [1, 2]. Basically, the capacitive type touch screen requires a touch sensor readout circuit that can sense the variation of the touch panel capacitance. Conventional capacitive type touch sensor readout circuits are realized based on charge transfer or the relaxation oscillators. But, charge transfer strategies require additional off-chip capacitors and resistors that limit the complete on-chip implementation. Even though the relaxation oscillator based touch sensor circuits are easier to integrate, since they detect the frequency variation due to the panel capacitance change, component mismatch limits the accuracy and additional digital logics such as the counters can increase the power consumption and area of the readout circuitry.

In this paper, a complete on-chip switched-capacitor (SC) charge pump based touch sensor circuit is suggested. The proposed scheme can lead to small size and low power consumption touch sensor readout circuits with rapid detection time compared to conventional schemes. The consumption current (2.2 μA) of the proposed circuit is significantly less than the conventional circuits – [1] 348 μA and [2] 7.2 mA.

2 Proposed touch sensor readout circuit

Fig. 1 (a) shows the concept of the proposed touch sensor interface which includes the SC charge pump, comparator, and detection logic. The charge pump senses the variation of the touch panel capacitance C_P, and generates a different output level depending on the value of C_P, where one side of C_P is connected to the ground potential. In addition, for the actual touch panel, there will be multiple panel capacitances C_P which require an additional selection circuitry. Furthermore, the comparator compares the output level of the charge pump with a given threshold V_{TH}, and the detection logic generates a binary output that indicates the condition of touch panel (un-touched or touched). The final output will be logic high for the un-touched case and logic low for the touched case. The advantage of the proposed scheme is fast detection time and simple circuitry compared to the conventional schemes which convert capacitance into a frequency or time domain quantity that require longer detection time and additional circuitry such as counters. This makes the proposed touch sensor readout circuit suitable for large sized touch panels as well.

Fig. 1 (b) describes the operation of the SC charge pump which is divided into two operation phases [3, 4]. C_P and C represents the panel and the

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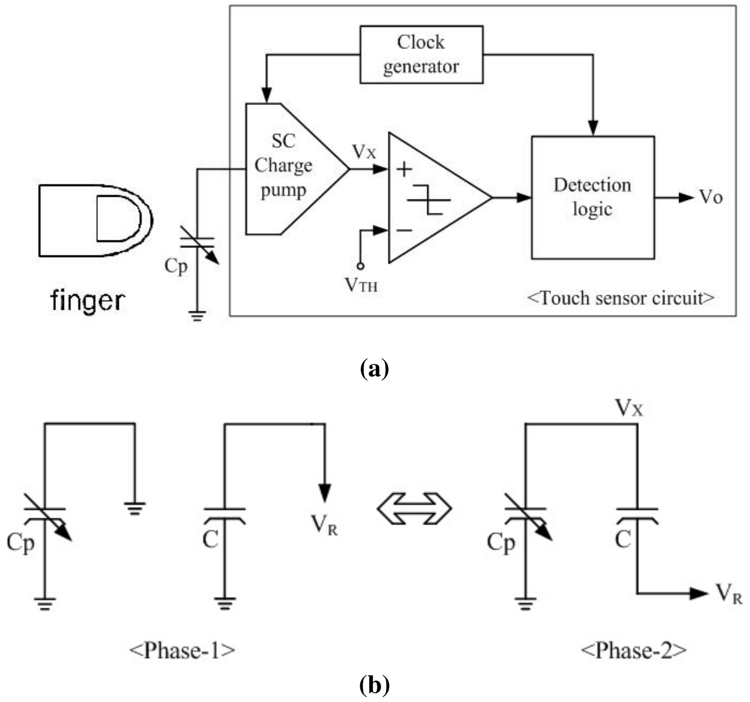

Fig. 1. (a) Proposed touch sensor interface (b) SC charge pump operation

charging capacitor, respectively. In the first phase, C is pre-charged to the reference voltage V_R, and C_P is discharged. During the second phase, C_P is connected to the top plate of C, whereas the bottom plate of C is connected to V_R. As a result, charge sharing between C_P and C will happen, and the node voltage V_X is given as

$$V_x = \frac{C}{(C_P + \Delta C_P) + C} \cdot (2V_R)$$

where V_X will be compared with the threshold voltage V_{TH}. If C is fixed, V_X will have a different level depending on the value of the touch panel capacitance C_P. Generally, the variation of C_P in the touch panel is around 10 pF [1].

Fig. 2 (a) shows the SC charge pump circuit which includes six switches and the charging capacitor C. CMOS switches are used for S_2, S_3, and S_4 for proper charge transfer. However simple NMOS and PMOS switches are used for S_1, S_6, and S_5, since these switches are connected to the ground or reference voltage. The size of each switch is set such that the nominal on resistance is around 50 Ω. Also, all the switches used minimum length transistors to minimize the parasitic capacitance and channel charge injection which can reduce the level of the charge pump output voltage. Moreover, CMOS switch S_3 is used to disconnect the charge pump from the comparator input node when the top plate of C is connected to V_R (pre-charging phase). This prevents the charge leakage to the comparator input parasitic capacitance. Fig. 2 (b) shows the self-biased comparator circuit which is comprised of the master inverter (M_1~M_4) and the slave inverter (M_5~M_8) [5]. This configuration is good for low power applications, since there is no static current

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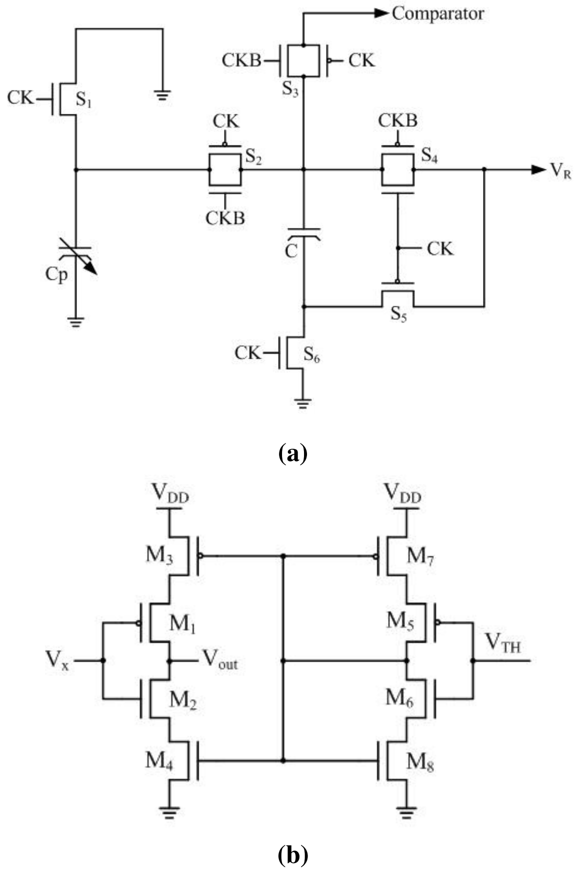

Fig. 2. (a) SC charge pump circuit and (b) Self-biased comparator circuit [5]

flow.

The charge pump is controlled by clock CK and the complimentary clock CKB. When CK is logic high, C is pre-charged to V_R and C_P is discharged. On the other hand, when CK is logic low, the bottom plate of C is connected to V_R and at the same time, the top plate of C is connected to the panel capacitance C_P. As a result, the valid output of the charge pump is generated during the CK low period.

3 Simulation and measurement results

The operation of the proposed touch sensor interface was verified through circuit level simulations. The control clock (CK) frequency was set to 100 kHz and V_R and V_{TH} were set to 3.3 V and 1.65 V, respectively. The output voltage level of the charge pump and the detection logic was verified with touch panel capacitance that changes from 10 pF to 20 pF, where $C_P = 10$ pF is assumed for the un-touched case and $C_P = 20$ pF is assumed for the touched case.

Fig. 3 (a) is the output waveform of the charge pump (red) and detection logic output (blue) with C_P changing from 10 pF (un-touched) to 20 pF (touched). The charge pump output represents to node V_X shown in Fig. 2 (a). When CK is low the value of Vx shows 2.02 V for $C_P = 10$ pF and

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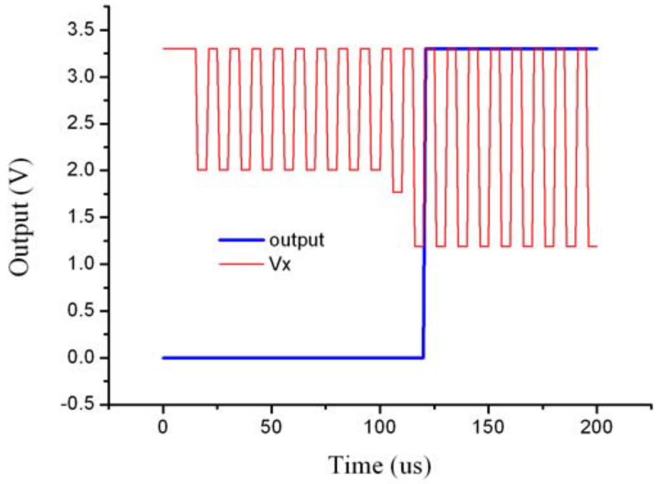
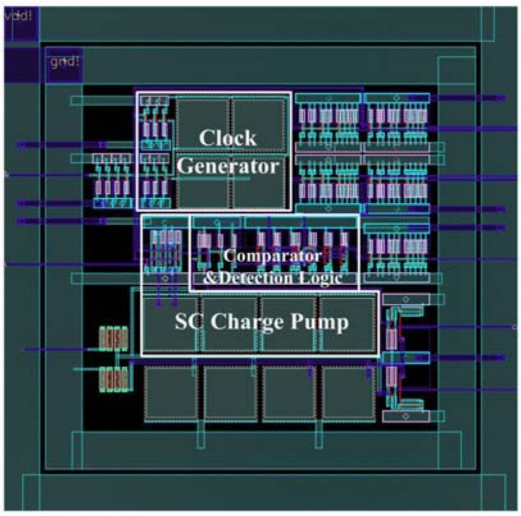


(a)

(b)

(c)



(d)

Fig. 3. (a) Simulated output waveforms (b) Measured output waveform in touched condition (c) Measured output waveform in un-touched condition (d) Layout of the proposed touch sensor readout circuit

1.19 V for $C_P = 20$ pF, respectively. Moreover, the detection logic output is high in case $C_P = 10$ pF, and changes to low as soon as C_P changes to 20 pF. This output is triggered at the falling edge of CK_inB (Fig. 2). The opera-

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tion of the self-biased comparator was verified with different process corners. But, the worst case variation range of the transition point was within 0.1 V of the nominal value (1.65 V). This verifies the usage of the comparator in extreme environments.

Fig. 3 (b) shows the measured output waveform with touch panel capacitance that changes from 10 pF to 20 pF and Fig. 3 (c) shows the opposite result. Yellow line shows the output and green line shows the input of the comparator. When the panel capacitance is 20 pF, the final output is high level (3.3 V). The prototype circuit was fabricated in CMOS 0.35 μm technology with core size of 0.0324 mm^2.

4 Conclusion

In this work, an on-chip capacitive touch sensor interface using SC charge pump based capacitance-to-voltage converter is proposed. The proposed scheme can directly convert the touch panel capacitance into a voltage level, which does not require additional circuitry for detection. Moreover, the power consumption of the detection circuit is decreased by using a self-biased comparator that has zero static current. Overall because of the simple circuitry, low power consumption and rapid detection time, the proposed scheme is suitable for complete on-chip capacitive touch sensor interface circuits.

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