A New Capacitive Sensing Circuit using Modified Charge Transfer Scheme

Hyeopgoo Yeo, *Member*, *KIMICS*

***Abstract*— This paper proposes a new circuit for capacitive sensing based on Dickson's charge pump. The proposed touch sensing circuit includes three stages of NMOS diodes and capacitors for charge transfer. The proposed circuit which has a simplified capacitive touch sensor model has been analyzed and simulated by Spectre using Magna EDMOS technology. Looking from the simulation results, the proposed circuit can effectively be used as a capacitive touch sensing circuit. Moreover, a simple structure can provide maximum flexibility for making a digitally-controlled touch sensor driver with low-power operations.**

***Index Terms*— Capacitive sensing, touch sensor, Dickson's charge pump, touch sensor driver.**

I. INTRODUCTION

RECENT mobile technologies, such as smart phones, are changing paradigms of our life style rapidly. The development of semiconductor technologies can make a system integrated into one chip. And low-power, high-performance processor technologies enable mobile devices to be more powerful while having low-voltage and low-power consumption.

The critical limitation of input devices for mobile applications is its size and weight. Therefore, input devices, such as a keyboard, a keypad and a mouse, are not suitable for mobile applications when they are normally used as input devices for electronic systems. From this point of view, a touch screen has a unique advantage that there is no additional room is required - strictly it needs very small space but it is negligible- for the system. Moreover, the touch screen enables the mobile system to be more exclusive by providing effective and interactive input control, such as multi-touch and proximity sensing.

There are several types of touch screens, such as resistive-type, capacitive-type, and so on. Recently, a capacitive touch screen has become more popular because it gives more sensitive touch control and a better transparency than those of the resistive-type touch screen.

This paper proposes a new sensing circuit for capacitive touch and analyzes the performance of the proposed. Additionally, a digitally-controlled touch sensor driver architecture with the proposed circuit will be introduced.

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Hyeopgoo Yeo is with the Department of Information Science & Telecommunications, Hanshin University, Osan, 447-791, Korea (Email: hgyeo@hs.ac.kr)

II. TOUCH SCREEN SENSING

This section reviews conventional touch sensing techniques and their circuits widely used in mobile devices. Also, the proposed sensing circuit based on Dickson's charge pump circuit is discussed.

A. Conventional touch sensors

Fig.1 shows the circuit modeling of a resistive type touch screen [1]. Two flexible plates with patterned conductive material, such as Indium-Tin Oxide (ITO), are separated with an air gap. The ADC detects the variation of the resistance of the material when contact is made on the two flexible sheets (one for vertical resistive line, the other is for horizontal resistive line). Since only one unique ADC value is assigned to a certain position, this resistive detection method has difficulties in recognizing multi-position contact and also has low accuracy. In addition, the resistive touch sensor has lower sensitivity and transparency compared to those of the capacitive touch sensor.

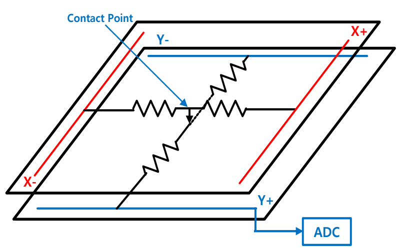

Fig. 1 A resistive-type touch sensor structure and detection scheme.

There are several types of capacitive touch sensors. Fig. 2 shows one of the capacitive touch sensor structures and the concept of touch sensing [2]. A capacitive touch sensor senses a change of capacitance on the surface of the sensor when a touch is made on it. To build electrodes, the surface of the capacitive touch sensor is coated with ITO. Since ITO has high transparency (more than 90%), it gives a clearer appearance on the screen compared to that of a resistive one. It also has very accurate detection of the touch position as well as a high reaction speed. However, the capacitive sensor only recognizes a touch action only when a conductive material, such as a finger, is contacted.

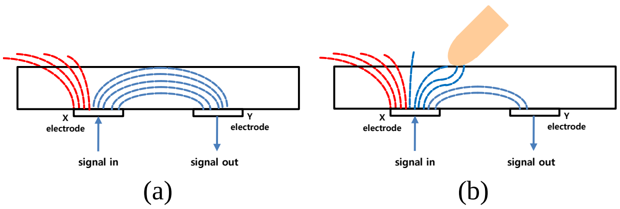

Fig. 2 A capacitive-type touch sensor structure and conceptual detection scheme. (a) non-touch, (b) touch.

To increase the sensitivity of the touch sensor and stabilize the operation with digital control, a couple of strategies are introduced. Fig 3 shows the capacitive detection strategy and its circuit structure for a capacitive touch sensor, which is proposed by Quantum [2]. An X drive signal passing through the touch screen is sampled at the Y receive line to accumulate charges. The voltage formed at Cs is amplified for touch decision. For digital operation of touch decision, an Analog-to-Digital Converter (ADC) is used. To increase accuracy, a cancellation scheme using q cancellation capacitor and switch are used, as shown in Fig. 3.

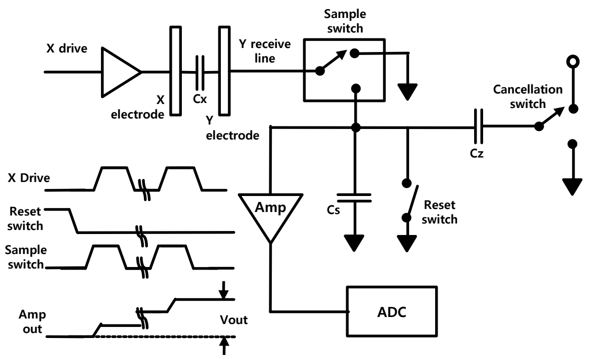

Fig. 3 A capacitive sensing scheme using charge transfer by Quantum [2].

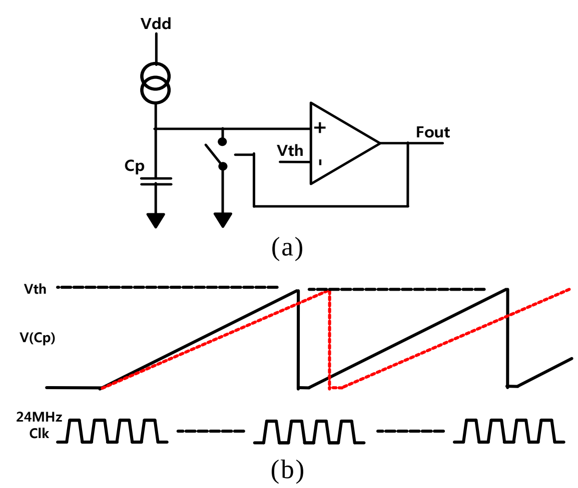

Fig. 4 Simplified relaxation oscillator: (a) a circuit structure (b) operations.

The other circuit by Cypress is shown in Fig. 4(a). A relaxation oscillator is used to evaluate the change of the capacitance of the touch sensor. As the capacitance of the touch sensor (Cp) changes, the period of the oscillator will vary as shown in Fig. 4(b). The input voltage is compared to the threshold voltage (Vth) to evaluate the touch operation by counting clock pulses [3].

B. Charge transfer capacitive touch sensor circuit

Fig. 5 shows a conventional Dickson Chare pump circuit structure. As shown in Fig. 5, diodes implemented with NMOS are simply cascaded and capacitors are connected to each node. Two phase clock signals are applied to the capacitors of odd and even stages, respectively. The first node of the circuit is pulled up to Vdd-Vth. The voltage goes up to 2Vdd-Vth when the clock goes high, and this turns the first NMOS diode on, and the next node charges to 2Vdd-2Vth. Similar approaches lead to the maximum output voltage of the charge pump which can be found through (1) [4],[5].

$$(N+1)\cdot V_{DD} - N\cdot V_{TH} \qquad (1)$$

The output swings from $(N+1)\cdot V_{DD}-N\cdot V_{th}$ to $(N+1)\cdot V_{DD}-(N+1)\cdot V_{th}$. As expressed in Eq.(1), the number of cascaded diodes determines the output voltage. If a N number of diodes are used in the charge pump, the output voltage is degraded by N times of the threshold voltage.

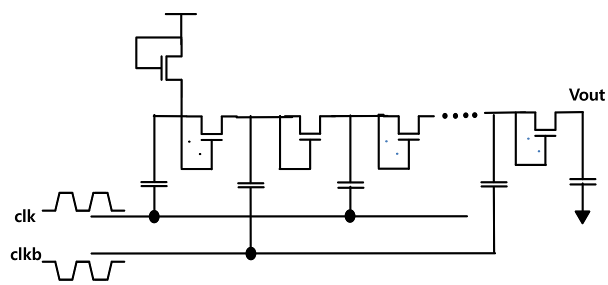

Fig. 5 A conventional Dickson's charge pump circuit structure.

Fig. 6 shows the proposed sensing circuit structure based on Dickson's charge pump. It is consisted of three stages of NMOS diode with a pull-up. The pull-up diode may be replaced with a resistor for this sensing circuit. The overall scheme of detecting the capacitive touch signal is that two opposite-phases of clocks are applied to odd or even states of the NMOS gates. The total stages of the proposed circuit in this paper are three, however, the stages can be increased to achieve higher output voltage.

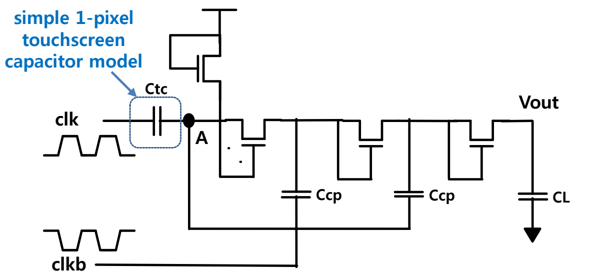

Fig. 6 The proposed capacitive touch sensor circuit structure based on Dickson's charge pump.

The proposed sense circuit uses a clock signal for charge pump operation. One pickup electrode of the touch sensor is modeled with a simple capacitor as shown in Fig. 6. For this proposed circuit, the amplitude of the applied signal to the odd and even stages are different because the amplitude of the clock signal is degraded after passing through the capacitor of the touch sensor, whose amount is mainly determined by the frequency response of the touch sensor shown in Fig. 8. The charges of the clock signal pass through the touch sensor and then are transferred to a three-stage charge transfer circuit. As a result, the charges accumulated to the output of the circuit causes a gradual increasing of voltage.

Although Dickson's charge pump circuit uses two signal sources of opposite-phases with the same amplitude, the proposed sensing circuit uses a signal passed through the touch senor for the odd stage and an opposite-phase signal source for the even stage of the sense circuit. Since the even stage of the circuit uses a signal source generated from a clock, even stages of the sense circuit do not contribute to the touch decision. The even stage conveys the charges from the former stage to the next stage. In other words, the difference of the sense output between a touch and a non-touch operation is determined only by odd stages of the circuit. As a result, the maximum output voltage of the proposed sensing circuit can be obtained as $2(V_{DD}+V_A)-3V_{th}$. Also, the maximum output voltage of the N-stage circuit can be derived as (2), which is different from that of the conventional charge pump circuit.

$$\frac{N+1}{2}\cdot\left(V_{DD}+V_A\right)-N\cdot V_{TH} \qquad (2)$$

The touch will change the capacitance of the touch sensor modeled Ctc in Fig. 6. This variation of the capacitance will affect the voltage transfer characteristic of the node A in the sensing circuit shown in Fig. 6, and the charging time needed to reach a certain (reference) voltage will also be affected. When a touch is made on the surface of the screen, the output of the sense circuit is increased faster than when it is not touched because the capacitance is decreased. That is, the time required to reach a specific voltage is different between the two cases. As a result, the difference of the time to reach the reference voltage can contain information of the touch and approximation operation.

III. SIMULATIONS

Fig. 7 shows the touch panel and its model of one pickup electrode. ITO is the material which is normally formed on the surface of the capacitive touch screen sensor as an electrode. Suppose a signal is detected at the column line while a clock signal is applied to the row line of the touch screen to support multi-touch. For the simulation purpose, the ITO electrode formed on the surface of the capacitive touch panel is modeled with series resistors and capacitors. The resistance of 500Ω per square, the parasitic capacitance (Cp) of 0.5pF and the capacitance of 1pF (Ctc) are used for the simple model of the touch sensor as shown in Fig. 7. It is assumed that the touch panel has 24 touch sensors for one column which means about 24 squares of ITO on the touch panel surface. Also the capacitance variation of 100% (0.5pF) from the initial value is assumed when a touch is made on the touch sensor.

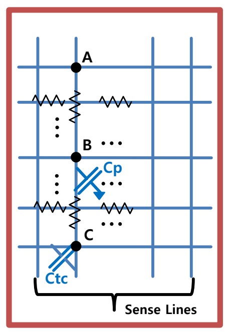

Fig. 7 Touch panel and simplified model with resistors and capacitance

Fig. 8 shows the simulated frequency response of the touch panel model. The frequency response of high-pass characteristics has been shown in low-frequency areas (below 100Hz) in three positions, A, B, and C. This is because the Ctc mostly contribute to the high-pass frequency response at low frequency range. However, different frequency responses have been seen for the high frequency range, which are more than 1MHz. The position A, far-end from the sense line, has a low-pass frequency response as shown in Fig. 8 due to the series resistance of ITO and parasitic capacitance of the sensor line. Meanwhile, the position C, closest to the sense line, has high-pass frequency response rather than the low-pass frequency response of position A because the parasitic resistance and the capacitance are not seen at position C. Although a high frequency signal source is required to get fast evaluation of the output voltage (Vout of the sensing circuit shown in Fig. 6), the degradation of the signal source caused from frequency response shown in Fig. 8 should be avoided for all positions of the touch panel. Therefore, a maximum frequency without degradation of 625KHz signal has been chosen in this simulation.

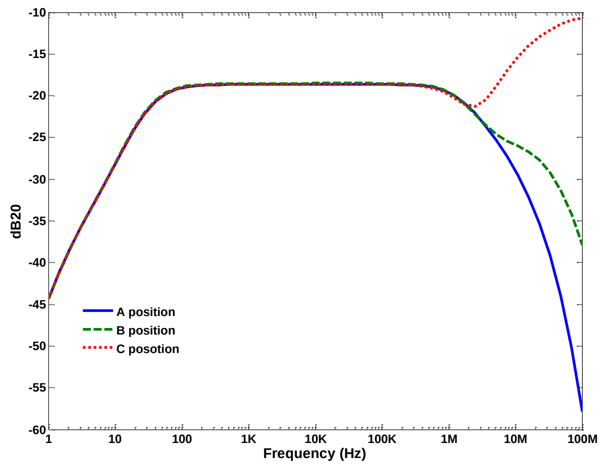

Fig. 8 Simulation results of frequency response of the touch panel model for three different positions.

Fig. 9 shows the simulated charging characteristics of the output voltage of the sensing circuit. The Ccp, C_L of the sensing circuit in Fig. 6 should be chosen carefully because it determines the voltage charging characteristic of the output node. The capacitance of 2pF and 50pF are chosen for Ccp and C_L respectively in this simulation.

As shown in Fig.9, it is observed that the voltage increases more slowly when a touch is made on the sensor than that of non-touch because the capacitance of the touch sensor (Ctc) is decreased. Therefore, the time to reach a reference voltage of the sense output is different between touch and non-touch cases as shown in Fig. 9. The time difference of about 140μs is obtained if the reference voltage of 2.5V is set in this simulation.

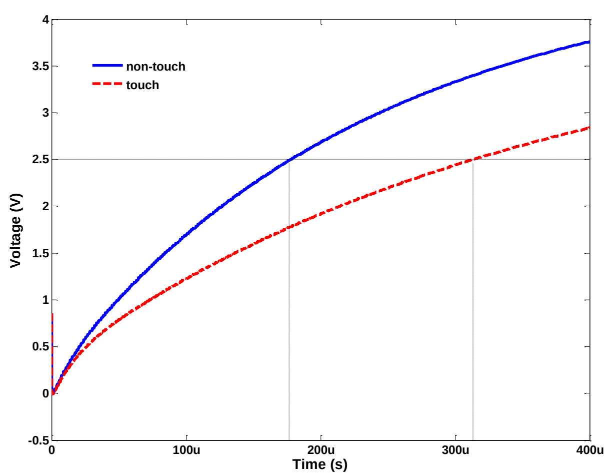

Fig. 9 Voltage charging characteristics of the output node of the proposed sensing circuit using 625KHz signal source.

From the simulation result, the power consumption of the proposed circuit (excluding touch driver) is less than 10μW at 3.3V operation. Since the proposed sensing circuit based on charge transfer architecture offers very low power consumption, the power consumption is mainly determined by the touch driver controller in which the sensing circuit is applied. Therefore, the power consumption is not a big concern for the sensing circuit.

Fig. 10 shows an example of the touch decision by clocking a counter. Touch will increase the count value by decreasing the charging speed of the sensing output. A comparator output will reset the value of counter. A driver architecture based on the scheme in Fig. 10 will be discussed in the next section.

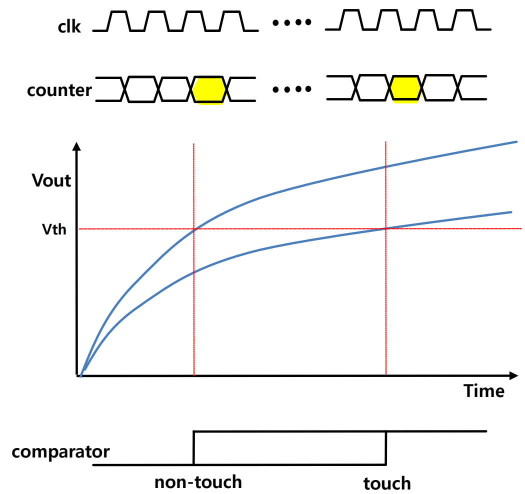

Fig. 10 Touch decision method using a comparator for the proposed sensing circuit

IV. TOUCH SENSOR DRIVER ARCHITECTURE

Fig. 11 shows the general capacitive touch driver structure that enables multi-touch function.

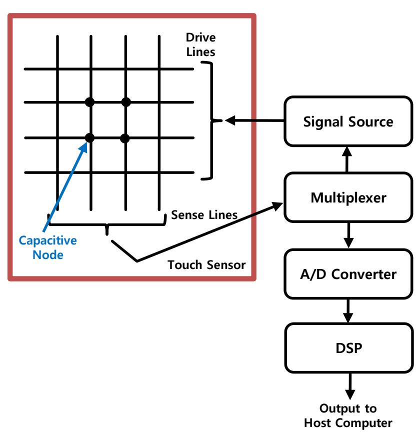

Fig. 11 A general touch sensing scheme of two-dimensional detection for multi-touch operation.

The touch sensor has a 2-D structure, a drive line and a sense line, as shown in Fig. 11. A source signal is fed into the drive lines and detection of the signal is made at the sense lines. A multiplexer controls the timing of the signal source scanning and sensing at the sense line.

Fig. 12 shows the touch driver architecture using the proposed sensing circuit. The clock signal is fed into the drive lines of the sensing circuit and it is also used as a clock for the counter. As described before, a clock signal goes into the driver lines while the opposite-phase clock signal is directly fed into the sensing circuit as shown in Fig. 12. Because the signal passing through the touch panel may have delay, a non-overlapping clock signal is effectively used to avoid the loss of charge pumping. The comparator output will be in logical-high state when the voltage output reaches the reference voltage, and then the counter will stop counting the clock. The counting number of the non-touch(initial) state is stored at memory. Then, the counter number will be compared to the initial value every period of scanning the touch pixel. After evaluation, the counter will be reset. A flip-flop may be added to help improve noise characteristics generated from the comparator due to the charge pump operation.

For this scheme, there is no need to convert an output signal using ADC because it can be digitally controlled with the output of the comparator. Multi-touch can also be implemented by scanning input signal at row line and detecting signals passing through electrodes at column lines.

However, detail simulations of the touch driver and its implementation are kept in next research topics as they are out of scope for this paper.

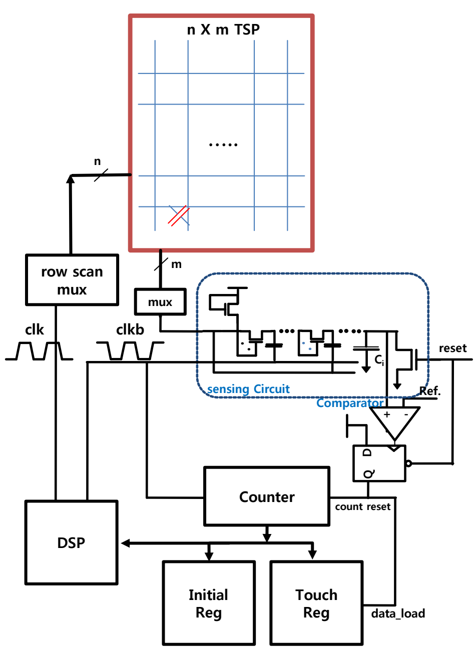

Fig. 12 Touch driver architecture using the proposed capacitive sensing circuit.

IV. CONCLUSIONS

A new circuit for capacitive sensing based on Dickson's charge pump has been proposed. The proposed circuit using modified charge transfer scheme with a simplified touch panel model has been simulated by Spectre using Magna EDMOS technology. From the simulation, the proposed circuit can be used successfully as a capacitive touch sensor circuit with a simple structure. Additionally, this paper introduced an architecture for a touch sensor driver using the proposed capacitive sensing circuit. A digitally-controlled touch sensor driver can provide great flexibility for the realization of sensing functions, such as multi-touch or proximity sensing.

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Hyeopgoo Yeo (M'09) received his B.S. and M.S. degrees in electronic engineering from Yonsei University in Seoul, South Korea, in 1991 and 1993, respectively. He also received his M.S. and Ph.D. degrees in electrical and computer engineering from the University of Florida in Gainesville, FL, USA, in 2003 and 2007, respectively. From 1993 to 1999, he worked as a design engineer at Samsung Electronics Co., Ltd, where he performed ASIC cell library and high-speed digital I/O design using various CMOS technologies for gate-array and standard cell. In 2008, Dr. Yeo joined the hardware R&D group at Samsung, where he was involved with mobile hardware design for wireless communications. In March 2009, he joined Hanshin University as a faculty member. His research interests include high-speed serial link systems, wireless communication systems, and RF/analog circuit design.