A Multi-Touch Interface Circuit for a Large-Sized Capacitive Touch Panel

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***Abstract*—This study presents a multi-touch sensing circuit for large-sized (more than 12 inches) capacitive touch panel. A new AC sensing technique is developed to enable the touch sensing in a large-sized capacitive touch panel. This novel designs of multi-touch sensing circuit lies in the operation principles through a 4X4 ITO film sensor array, a low-disturbance array circuit, a capacitance to voltage converter circuit and the proposed design procedure of chip parameters by circuit simulation. Furthermore, the sequence control for the array is generated by an FPGA module to accomplish the operation of the whole circuit. Some of objectives are to reduce environmental disturbance of the panel and to distinguish multi-touching locations from the panel. The corresponding output voltages of multi-touch sensing circuit are output in proportional to location touched by a human finger. Finally, the whole circuit is implemented by using TSMC 0.35 μm 2P4M process. The circuit output voltages are used to distinguish touch locations by a proposed algorithm.**

***Index Terms*—Projected capacitive touch panel, capacitive sensing circuit, AC sensing technique, multi-touch, readout circuit.**

I. Introduction

TOUCH panels have been commonly featured in applications such as wireless communications, industry monitor, and displays. Most touch panels are directly integrated onto the display and make consumer products lighter and smarter with added portability and convenience. In addition, the touch panels are effective human-machine interfaces which can eliminate unskilled users' fear of using computers and communication products. Nowadays ranges of products applied touch panel, including PDA, ATM, mobile phone, LCD display, GPS, e-book and school education.

The capacitive touch panel consists of two parallel ITO film layers which are separated from a sensor glass layer as shown in Fig. 1(a). The primary sensing component of capacitive touch panel is a vertical capacitor which is composed of an upper ITO layer and a lower ITO layer as shown in Fig. 1(b). Our goal is to design a capable capacitive sensing circuit for large size capacitive touch panel(more than 12in.), where large electrode resistance (> 200kΩ) and capacitance are commonly present to make extreme difficult a successful touch detection.

For the capacitive touch panel, the sensing circuit is similar to the capacitive sensing circuit such as the fingerprint sensors [1,2] and MENS sensors [3]-[6]. The sensing circuit for small-sized (<7in.) projected capacitive touch panel is recently designed [7, 8]. These elements both include amplifier, passive element, MOS switch, and feedback network. The variation of the capacitance between the ITOs is measured by capacitive charge and discharge. The general circuit for measuring capacitance is as shown in Fig. 2(a). The capacitance is charged when the switch is OFF, and discharged when the switch is ON. The speed of the capacitance charged is different from the variable capacitance as show in Fig. 2(b).

A new AC sensing technique is developed herein to make possible the touch sensing in a larger-size (> 12in.) ITO touch panel.

II. Operation Principles

A. System Description

The system is composed of a 12.1" capacitive touch panel, an interface circuit IC and an FPGA module to accomplish the operation of the whole circuit. The interface circuit included a low-disturbance sensing array and a capacitance to voltage converter for differential circuit. By detecting the different intensity of the electrical signal for each ITO electrodes capacitance, the designed interface circuit IC can generate difference output of 8-bits digital signal.

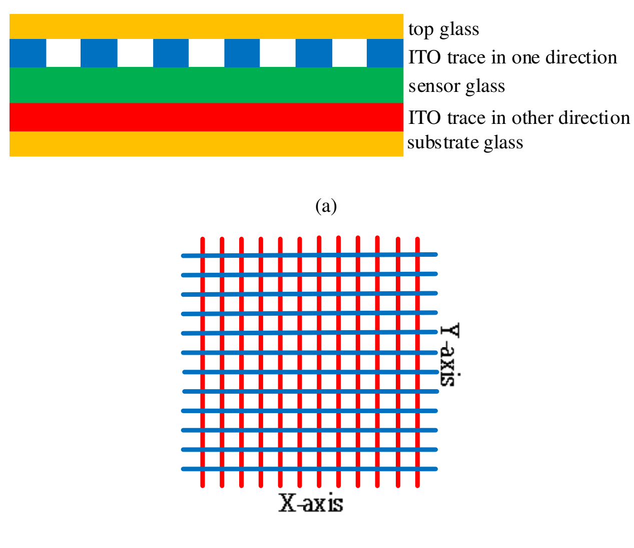
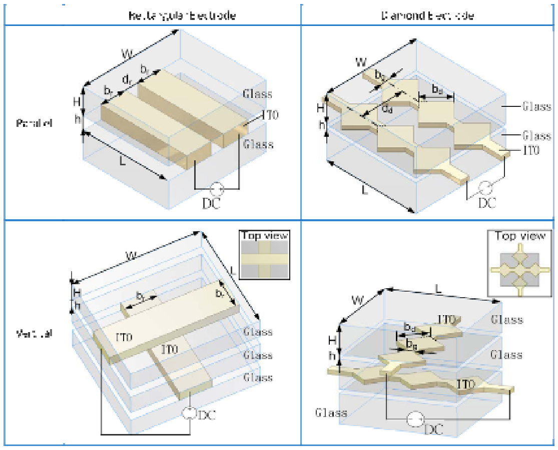


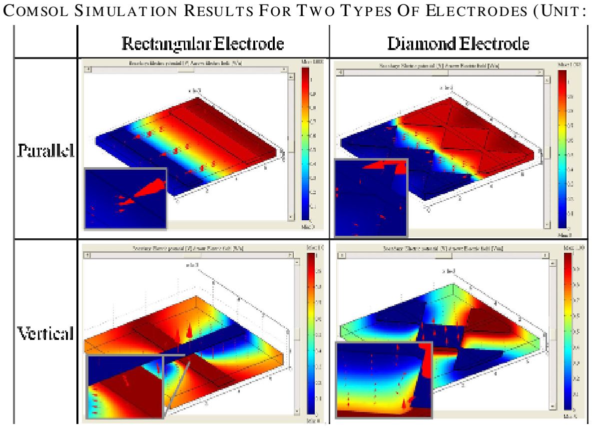
Fig. 1. (a) The side view of capacitive touch panel. (b) The top view of capacitive touch panel.

TABLE I
THE SCHEMATIC OF TWO TYPES OF ELECTRODES AND SIZES



Diamond Electrode		Rectangular Electrode		Glass Thickness	
b_d	2.2	B_r	1	W	7
b_g	0.3	d_r	3	L	7
h_d	0.02	h_r	0.02	H	0.2
d_d	4.79				

TABLE II
COMSOL SIMULATION RESULTS FOR TWO TYPES OF ELECTRODES (UNIT: fF).



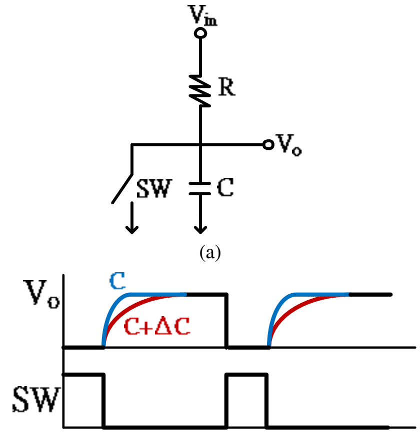
	Rectangular Electrode			Diamond Electrode		
	C	ΔC	ΔC /C	C	ΔC	ΔC /C
Parallel Capacitance	0.33	0.076	23%	0.812	0.029	3.5%
Vertical Capacitance	4.52	0.112	2.5%	11.75	0.057	0.4%

B. Principles of Capacitive Touch Panel

The key of influencing the linearity of electric field is the layout of the electrode pattern. As to the capacitive touch panel, the capacitance is composed of the panel's ITO electrodes. The ITO capacitive sensors are variation with human finger touching. Generally, the ITO capacitive sensors is similar to the parallel-plate capacitance, its mathematics is expressed as

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d} , \quad (1)$$

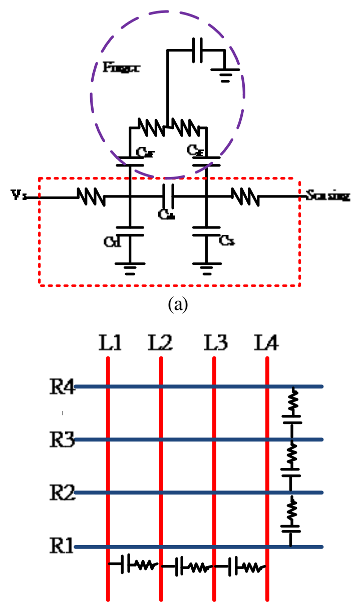
where C behaves as the capacitance composed of ITO, ε_0 is that any dielectric material has an electric permittivity to equal, ε_r is the relative permittivity, A is area of plates, and d is the distance



(a)

(b)

Fig. 2. (a) The normal capacitive sensing circuit. (b) The output waveform of capacitive sensing circuit.



(a)

(b)

Fig. 3. (a) The equivalent model of the capacitive touch panel and human fingertip. (b) The schematic of the simple equivalent model for the capacitive touch panel with parallel sensing.

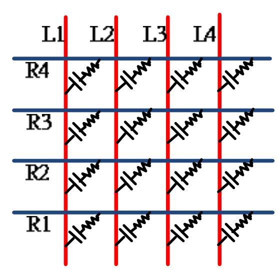


Fig. 4. The schematic of the simple equivalent model for the capacitive touch panel with vertical sensing.

between the two parallel ITO. In Comsol simulation, these two types of pattern are as shown in TABLE I. We assume a small point with zero voltage which is similar to human fingertips. The results of pattern's ITO capacitance(C) is imported to the analysis software from Comsol as shown in TABLE II. For rectangular electrodes, the ratio of parallel capacitance

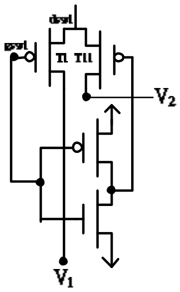


Fig. 5. The low-disturbance array cell.

variation(ΔC) to C is 23% and has good performance than the others. In conclusion, the rectangular pattern with parallel sensing could be used for our interface circuit designed. The proposed commercial 12.1" capacitive touch panel is put in use for testing circuit.

The equivalent model of capacitive touch panel is shown in Fig. 3(a). The equivalent model is composed of the ITO resistance, gap capacitance(C_{ds}) between ITOs, parasitic capacitance, and human finger's model [9]. The ΔC, C_{df} and C_{sf}, are the gap capacitance between the panel and fingertips. Our goal is to detecting the all capacitive tiny variation when human touching. For the circuit design, the parallel sensing of 4X4 ITO electrodes model could be simple to analyze as shown in Fig. 3(b). The capacitance and resistance are to alter with the panel size. For the measurement results, the resistance and capacitance of capacitive touch panel are 250kΩ and 10pf respectively. The capacitance variation is at least 0.2pf when human touching. Besides, the capacitance shift of ITO electrodes has 0.5pf variation with the environments. The drawback of panel's characteristic could be eliminated for follow special circuit design.

C. *Sensing Theory*

For the sensing speed, the parallel sensing could be finer than vertical sensing. There are twenty-five and ten sensors to be sensed for vertical and parallel sensing respectively as shown in Fig. 4 and Fig. 3(b). The time complexity is $O(n^2)$ and $O(2n)$ respectively. The parallel sensing could reduce the most sensing time contrasted to vertical sensing.

Fig.3(b) is capacitive touch panel of 4X4 ITO electrodes with parallel sensing. The top row ITO layer(R1, R2, R3, R4) an lower column layer (L1, L2, L3, L4) are composed of the ten sensors. When sensing parallel capacitance of R1, R2, R3, R4, the row(X-axis) for touch could be detected. When sensing L1, L2, L3, L4, the column(Y-axis) for touch could be also detected. We analyze the signal of X- and Y-axis to find the touch position which has capacitance variation in row and column ITO electrodes.

For the driving signal, we use the AC signal to drive the 12.1" capacitive touch panel. The detected capacitance variation through AC signal transfers to the impedance concerned with driving frequency and capacitance. The driving voltage of our proposed circuit is 3V and lower than other commercial capacitive panel(more than 7") [10].

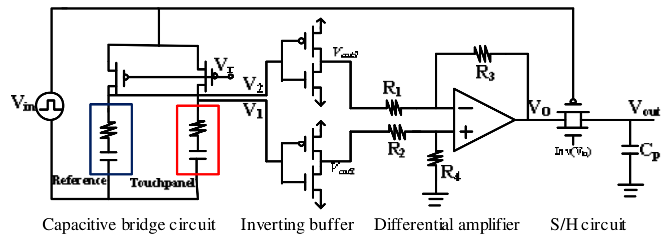


Fig. 6. The schematic of the sensing circuit for the differential method.

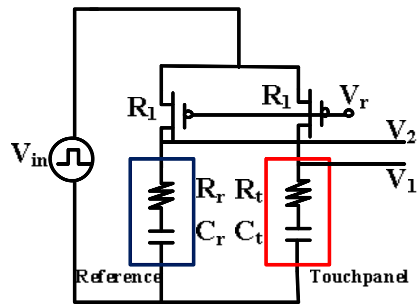


Fig. 7. The schematic of the capacitive bridge circuit.

III. Sensing Circuit and System

A. *Low-Disturbance Array*

A special circuitry is designed to eliminate the effects from different environments, as shown in Fig. 5. The node voltage V_1 is connected to the next stage capacitance to a voltage converter, while V_2 is connected to the reference voltage to eliminate the effect of environment. Two modes of low-disturbance circuit:

(1) Sensing: The row select transistor (T1) is switched ON and the reset transistor (T11) is OFF. The signal is passed through the capacitive touch panel to sense the capacitance variation.

(2) Reset: After sensing mode, the reset transistor (T11) is switched ON and row select transistor (T1) is OFF. The circuit is in the reset mode that signal is passed to the reference voltage.

In this way, the environmental noises could not affect the sensing ITO electrodes, because only one pairs of capacitive touch sensor electrodes are detected by the sensing circuit and the others are connected to the reference voltage.

B. *The Method of Differential Circuit*

This sensing circuit includes four parts: the low-disturbance arrays, capacitive bridge circuit, inverting buffer, differential amplifier, and sample/hold circuit as shown in Fig. 6. The function of capacitive bridge circuit is to compare the capacitance of touch and un-touch. The inverting buffer is to isolate the capacitive bridge circuit and differential amplifier. Finally, the sample/hold circuit could hold the output for the time.

The capacitive bridge circuit is shown in Fig. 7. The PMOS is set to be in the triode region and taken as the variable resistance

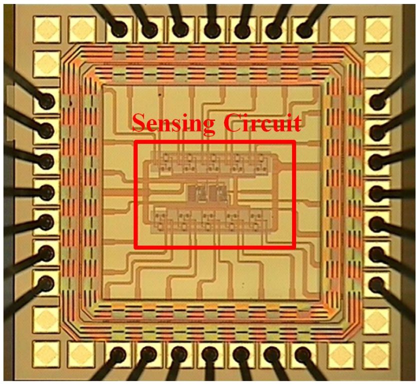


Fig. 8. The micrograph of the IC

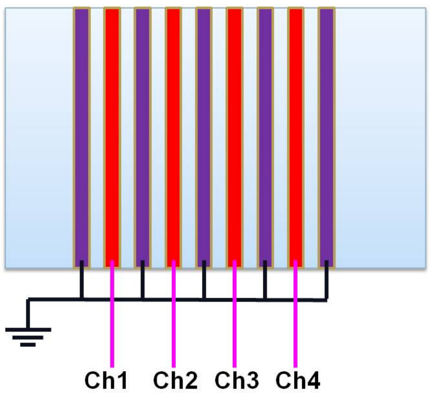


Fig. 9. The four channels of ITO parallel capacitance for multi-touch measurements:

with the change of voltage. Therefore, when the MOSFET operates in the triode region, the current to flow between the drain and the source can express

$$i_d = K_n \frac{W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^{2}}{2}\right], \quad (2)$$

where K_n=$\mu_n Cox$ (μ_n is the charge-carrier effective mobility and C_{ox} is the gate oxide capacitance per unit area), W is the gate width, L is the gate length, and V_T is the threshold voltage. Therefore, the MOS resistance, R_1, could express as

$$R_1 = \frac{1}{\partial i_d / \partial V_{DS}} = \frac{L}{K_n W (V_{Gs} - V_T - V_{DS})}. \quad (3)$$

In the frequency domain, V_{in} is assumed as an AC input signal. The voltages of the capacitive bridge circuit, V_1 and V_2, are given by

$$V_1 = \frac{sC_t R_t + 1}{sC_t (R_t + R_1) + 1} V_{in}, \quad (4)$$

$$V_2 = \frac{sC_r R_r + 1}{sC_r (R_r + R_1) + 1} V_{in}, \quad (5)$$

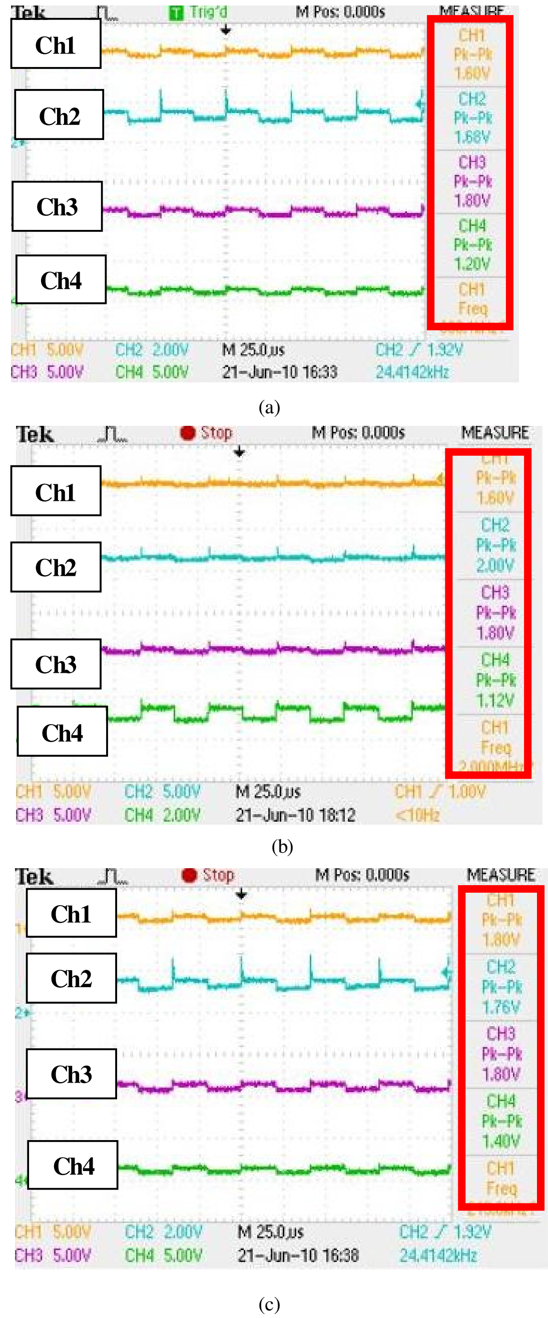


Fig. 10. The multi-touch measurements of (a) un-touch, (b) only touching Ch2 and (c) touching ch1 and ch4.

where the R_t and C_t are the equivalent resistance and capacitance for the touch panel. Identically, the R_r and C_r are the reference resistance and capacitance. The circuit is designed to compare the voltages V_1 and V_2. V_2 is the reference and constant. The node voltage, V_1 , could have the capacitance variation while touching the panel. When human touch the panel, V_1 and V_2 are different.

According to the capacitive bridge circuit, the reference node and touch panel's node are able to change for any ITO sensors or components. When the touch panel's node is connected to any-sized touch panel, the reference node could connect the

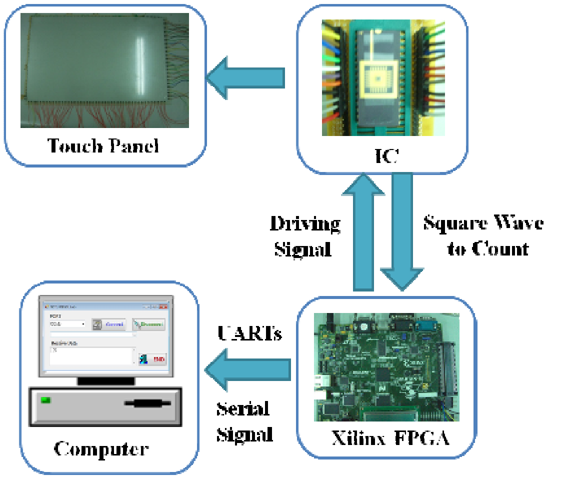


Fig. 11. The system configuration of the test environment.

relative resistance and capacitance. The reference node would connect an ITO sensor which kept off in the panel. In this way, the ITO capacitance shift from environments could be eliminated because the reference's and panel's ITO electrode capacitance are in the same capacitive touch panel.

The next stage in the study is to design an inverting buffer. If the next stage might connect the differential amplifier, the circuit could have serious load effect because the operational amplifier of differential amplifier we designed is not ideal. Therefore, the inverting buffer has to be placed between the capacitive bridge and differential amplifier circuit. After the inverting buffer, the outputs are V_{out1} and V_{out2} . For R_1=R_2 and R_3=R_4, the differential amplifier circuit is given by

$$V_{out} = -\frac{R_3}{R_1}(V_{out1} - V_{out2}) \quad (6)$$

The final stage is a sample hold circuit. Its function is to hold the output for the half cycle and let the signal processed easily. The sensing circuit is designed for 4X4 ITO electrode, and the output is the square wave which its duty cycle is changed by touch or un-touch.

Finally, the IC micrograph of sensing circuit is realized as shown in Fig. 8.

C. Experimental Results of Differential Method

For multi-touch sensing, we measure the capacitance variation of parallel ITO sensors with four channels (Ch1, Ch2, Ch3, Ch4), as show in Fig. 9. At first, the experiment results of the multi-touch sensing circuit are shown in Fig. 9. The orange, blue, purple, and green curves are the output of the Ch1, Ch2, Ch3, and Ch4 respectively as shown in Fig. 10(a). The output peak to peak voltages are 1.6V, 1.68V, 1.8V, and 1.2V, respectively for un-touch. For instance, when the Ch2 is touched alone, the output has voltage variation of positive 0.32V for Ch2 as shown in Fig. 10(b). When the ch1 and ch4 are touched simultaneously, the output have voltage variation of positive 0.2V, 0.08V, and 0.2V for Ch1, Ch2, and Ch4 separately as shown in Fig. 10(c). The output of voltage variation for Ch2 could be neglected. For the four channels sensing, the

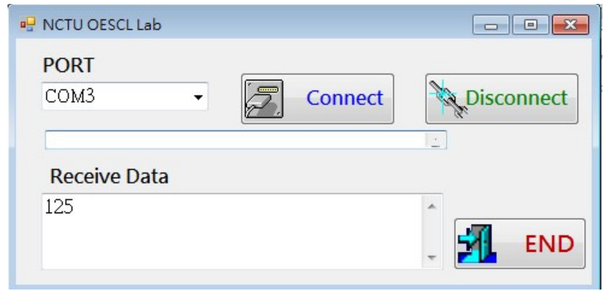


Fig. 12. The computer's software interface using VisualBasic for receiving data from FPGA.

multi-touch is obviously detected.

The sensing system for the computer is realized. Fig. 11. shows the system architecture of the test environment. The 12.1" capacitive touch panel provides the front-end sensors. The signals from the touch panel are received by the specifically-designed IC. The output signal of the IC is read by the counter which is designed by VHDL for Xilinx FPGA. The subsequent calculation is conducted to find out the counts of the high voltage (3V) for output. For the communication of the FPGA and computer, the UART chip is designed by VHDL. We could transmit the data (8 bits) of the counter to the computer with RS232. The data of the counter are expressed by an interface program (Visual Basic) as shown in Fig. 12. The results of the counts are more than 124 while un-touching. The counts are 93 and 103 when touched by finger.

IV. CONCLUSION

A new multi-touch sensing circuit for large-sized capacitive touch panel have been successfully designed and fabricated in a TSMC 0.35μm 2P4M 3.3V mixed-signal CMOS process. The differential circuit is applied to eliminate the capacitance shift of panel ITO electrodes and enlarge the voltage signal of ΔC. For multi-touch sensing, the minimum detectable voltage difference of the proposed circuit is 0.2V for touch/un-touch. For the system, the touch/un-touch of touch panel can be identified as the 8-bits output. The system can detect the ΔC and to transmit the digital signals(8-bits) to a general-purpose computer.

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