**LETTER**

**Evaluation of Large-Sized LCD Touch Panel Using Differential Sensing Circuit and Algorithm**

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SUMMARY In this letter, we evaluate the parasitic capacitance of an LCD touch panel, the description and implementation of a differential input sensing circuit, and an algorithm suitable for large LCDs with integrated touch function. When projected capacitive touch sensors are integrated with a liquid crystal display, the sensors have a very large amount of parasitic capacitance with the display elements. A differential input sensing circuit can detect small changes in the mutual capacitance from the touch of a finger. The circuit is realized using discrete components, and for the evaluation of a large-sized LCD touch panel, a printed circuit board touch panel is used. 

key words: touch, LCD, capacitive touch, differential sensing, large-sized LCD touch panel

1. Introduction

The projected capacitive touch technology has become indispensable for IT applications such as smartphones and smartbooks [1]. A touch solution should satisfy several requirements, including multi-touch, finger touch, and soft feel. Because projected capacitive touch senses the difference in mutual capacitance caused by finger touch, it has several merits, such as being thin, transparent, soft, and suitable for a touch solution. Conventional touch panels are 1–2.4 mm thick, as they have two substrates, or one substrate and a cover plate. The thickness of the touch substrate and cover plate is normally 0.5–1.2 mm. In order to reduce the thickness, touch companies are progressing toward cover-plate integrated touch panels that do not require a separate sensor such as G1F and G2 (G means glass, and F means film). As weight and thickness are very important for mobile applications, we already proposed 13.3” on-cell type touch LCD panel that touch sensors are integrated with display panels [2]. The advantage of integrating a display with such an on-cell-type touch screen is that it does not need any additional substrate because the sensor is deposited on the existing glass of the display [3]. Furthermore, touch panels exhibit good transmission and mechanical performance. Nevertheless, with respect to the touch panel size, the large-sized LCD touch panel has a very large load capacitance and requires a long charging time. The capacitive coupling between touch electrodes and display electrodes is much stronger than that of a conventional touch panel. As the size of the display panel increases, the parasitic capacitance between the display panel and the touch sensor becomes more problematic. In the case when the parasitic capacitance increases, the variation in mutual capacitance does not increase; therefore, it is difficult to detect the touch, and differential sensing methods are suggested [4], [5].

In this paper, we consider the influence of parasitic capacitance when the size of touch LCD increased as monitor application. For the experiment, we used the parasitic capacitance values obtained from simulation. Driving/sensing circuits are implemented on Printed Circuit Board using a differential sensing method and a dedicated algorithm is developed for the proposed sensing method.

2. Evaluation System

A typical touch screen module is composed of three parts: a touch panel, an analog circuit, and a touch controller unit with an algorithm. In the touch panel, the mutual capacitance (Cm) changes when fingers touch the panel. The analog circuit converts Cm to voltage and is composed of a fully differential charge amplifier, integration capacitors, and switches. The touch controller unit consists of a microcontroller, a boot memory, a PC interface (UART), a circuit timing controller, an ADC interface (serial peripheral interface), and other parts.

2.1 Panel Design

The brief structure of a conventional capacitive touch panel and the equivalent circuit are shown in Fig. 1. This panel comprises transmitting sensors (driving lines), receiving sensors (sensing lines), and a cover plate. Mutual capacitance is formed between these two types of sensors. The mutual capacitance is usually a few picofarads. A finger contacting the screen acts as an electrode and decreases the mutual capacitance by altering the electric charge distribution on the sensor electrodes. When a finger touches the cover plate, Cm is reduced by only hundreds of femtofarads. The sensing circuit converts the variation in mutual capacitance to voltage. As the size of the touch panel increases, the parasitic capacitance of the touch sensor also increases at a very high rate. However, it is quite difficult to know the exact finger position because of a large parasitic resi-
Fig. 1  (a) Brief structure of conventional capacitive touch screen panel (b) Equivalent circuit of capacitive touch panel.

stance and capacitance, which decrease the output voltage variation of the sensing circuit. Touch electrodes made of Cu are arranged horizontally and vertically in 5 mm × 5 mm diamond patterns. The electrodes of a touch panel are designed using the conventional PCB design rules. The panel has four layers. The driving and the sensing diamond-shape patterns are on the second layer, and the shield that acts as a ground is on the third and fourth layers. The first layer has bridges that connect each diamond. Bridges and diamonds are connected through via holes from the bridge layer to the pattern layer. The parasitic capacitances of the driving and sensing electrodes are designed using Eq. (1). In SI units, \( \varepsilon \) is the dielectric constant within the gap between the finger and the electrode in Farads, \( s \) is the area of the diamond in square meters, and \( d \) is the distance between the pattern and the ground in meters. The gap between layers is filled with FR-4 (\( \varepsilon_r = 4.6 \)). \( C_m \) is designed to be 1 pF based on mutual capacitance simulations and changes by approximately 10% when touched by a finger. Each electrode has capacitors and resistors on the printed circuit board; thus, the parasitic capacitance and resistance can be changed using discrete components. The panel has 15 driving channels, 20 sensing channels, and 300 touch nodes (15 × 20).

\[
C_{\text{parasitic}} = \varepsilon_r \varepsilon_0 \frac{s}{d}
\]  

(1)

2.2 Analog Circuit

The analog circuit is composed of excitation and sensing circuits. The excitation circuit generates a square pulse with a high-level voltage. The voltage of the excitation pulse can be changed from 3.3 V up to 18 V using a level shifter, and the pulse sequentially drives each sensor in the panel through a 1-to-15 multiplexer. The sensing circuit converts \( C_m \) to voltage, as shown in Fig. 2, which shows a fully differential sensing circuit and a timing diagram. The circuit is composed of a fully differential amplifier, integration capacitors, and switches. The differential output voltage of the sensing circuit is given as follows:

\[
\sum V_{\text{out}} = V^+_{\text{out}} - V^-_{\text{out}} = \frac{1}{C_F} \times \Delta I_n \times t \times N
\]

(2)

Current from mutual capacitance is \( I_n \) during time \( t \) and \( N \) is integration numbers. The circuit also has a 1-pF feedback capacitor, and the value of \( C_m \) decreases by 10% when a finger touches the touch screen. The output voltage variation when a finger touches the panel is in the range of 20–50 mV, as obtained from the SPICE simulation.

2.3 Controller and Algorithm

The digital controller is designed to control analog circuits and an analog-to-digital converter. The board also sends digital output data from the ADC to a computer. In the \( \Delta \Sigma \)-type ADC, differential output voltages are converted to 16-bit digital data. The digitized output data (differentially integrated \( \Delta C_m \)) from the ADC is obtained using a serial peripheral interface (SPI). To synchronize the ADC with excitation and sensing circuits, a timing controller generates control signals. The excitation pulse forms a touch node that is the mutual capacitance \( (C_m) \) between the driving and sensing touch electrodes on the touch panel. All the switches in the circuit board are controlled by the timing controller in the FPGA (Field-Programmable Gate Array). After the controller collected data from 300 touch nodes, the controller sends them to the computer through a universal asynchronous receiver/transmitter (UART) interface.

A touch algorithm was written in Matlab, and Fig. 3 shows a block diagram outlining the algorithmic structure of the touch calculation process used in this study. Before the touch calculation process, a preprocessing filter removes the impulsive noise. Despite the fact that a differential sensing circuit removes the effect of parasitic capacitance, the touch output data shows very large differences among each sensing channel, as shown in Fig. 6 (a). Using prerecorded touch frames, the first step is to remove channel-induced noise from the raw frame data using background subtraction. This operation subtracts a previously defined reference frame from the newly acquired touch data. The reference
frame is initiated with a prerecorded frame and then gradually adjusts the reference frame to changes in the new data. Prior to the labeling algorithm, thresholding removes residual noise. In this step, all those noises that actually do not touch the surface are disappeared using thresholding. After the thresholding removes residual noises, each node of the entire frame is assigned a label representing its connected component. The proposed sensing method produces positive and negative pixels, and the touch position is in the weighted center between these positive and negative peaks.

3. Evaluation Result

For the touch panel, we implemented the equivalent panel load on printed circuit boards, as shown in Fig. 5. The touch panel has a tunable load capacitor and resistor. The panel load is in the range of 0.5 nF to 1.5 nF in the sensing channel (C_Rx) and 1 nF to 2.5 nF in the driving channel (C_Tx). The analog circuit board has excitation and differential sensing blocks. For the high parasitic capacitance, up to 18 V high level excitation voltage is used to enhance signal intensity. The timing controller and interfacing functions are implemented on an FPGA. For analog voltage to digital frame data conversion, a 16-bit ΔΣ-type ADC is used. We evaluated the touch sensing performance by changing the parasitic capacitance from 1.2 nF to 2.5 nF in the driving parasitic capacitance and 600 pF to 1.5 nF in the sensing parasitic capacitance. As the parasitic capacitance increases, the signal-to-noise ratio of touch decreases. However, as the driving voltage changes from 9 to 18 V at the condition of parasitic capacitance 1850 pF (C_Tx) and 790 pF (C_Rx), the increase in signal intensity is nearly twice as shown in Fig. 4. Touch was detected only in the range of the parasitic capacitance within 2 nF in the driving capacitance and 1 nF in the sensing line, which is the same as the parasitic capacitance of a 27” LCD touch panel.

The results for the touch processing algorithm described in the previous section are shown in Fig. 6. Raw data from the differential sensing circuit is shown in Fig. 6 (a), and the filtered and background subtracted results are shown in Fig. 6 (b). Five touches are calculated in Fig. 6 (d).

4. Conclusion

This study assesses the performance of large LCD touch panels using a differential sensing circuit and algorithm. We used a PCB touch panel that comprises tunable parasitic capacitors and resistors. The differential sensing circuit integrates the very small amount of charge difference between two adjacent input channels that have huge size of parasitic capacitance between touch sensor and display components. The evaluation results showed that the size of the integrated touch LCD panel can be extended to 27”, with a parasitic capacitance of 2 nF in the driving line and 1 nF in the sensing...
line, and multi-touch capability using the proposed differential multi-touch algorithm.

Acknowledgments

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