

In-cell Capacitive Touch Panel Structures and Their Readout Circuits

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This paper proposes an in-cell capacitive touch panel structure and a readout circuit (ROIC) to sense the variation in self-capacitance using a small number of sensing lines. The proposed touch panel structure sequentially senses the variation in self-capacitance by adding a thin-film transistor and a scan signal line into each touch sensor so that the number of sensing lines can be reduced. In addition, the proposed ROIC enhances the signal-to-noise ratio (SNR) by compensating for the stray capacitance. The simulation results show that the proposed ROIC achieves an SNR of 57 dB. Moreover, the number of sensing lines per inch is 6.7 and 230.8 using the proposed active self-capacitive sensing method and the advanced in-cell touch (AIT) technology, respectively. Therefore, the proposed active self-capacitive sensing method reduces the number of sensing lines by 97.10 % compared with the AIT technology, while maintaining high sensitivity and multi-touch sensing capability.

1. Introduction

Touch screen panel (TSP) as an input device laid on the top of a display is widely used for various applications such as tablet PCs, notebook computers, and smart phones because of its intuitive user interface.¹⁻⁵⁾

Recently, several TSP structures such as add-on, on-cell, and in-cell touch structures have been researched.²⁾ The add-on touch structure, of which the TSP is directly attached on a display panel, has been most widely used, but has several problems such as many manufacturing processes, low optical transmittance, and thick additional layer.⁶⁾ To overcome the above problems, the on-cell and in-cell touch structures have been developed.⁴⁾ The on-cell touch structure has a touch panel between the color filter and the cover glass, but suffers from thick display module and complex fabrication process. On the other hand, the in-cell touch structure embeds touch sensor electrodes into display pixels so that it can have a compact and simple display module, resulting in a promising next-generation TSP solution.³⁻⁴⁾

The in-cell touch structure has two capacitive sensing methods; self- and mutual-capacitive sensing methods.²⁾ In general, the variation in self-capacitance between the touched and untouched states is larger than that in mutual-capacitance since a large capacitance is formed between the finger and the touch sensor electrode in the touched state. In addition, since the distance between the finger and the touch panel in the in-cell touch structure is greater than that in the other touch structures, it is difficult to sense variations in mutual-capacitance in the in-cell touch structure. Therefore, the self-capacitive sensing method which has sensitivity

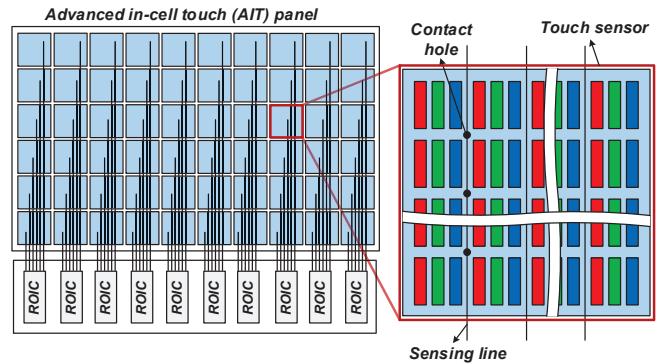


Fig. 1. Capacitive touch panel and readout ICs of advanced in-cell touch (AIT) technology²⁾

is largely adopted for the in-cell capacitive touch panel structure.

Fig. 1 shows the capacitive touch panel and readout integrated circuits (ROICs) of advanced in-cell touch (AIT) technology.²⁾ The touch sensor in the touch panel has a unit cell to connect the common electrode of pixels to the sensing line. When a conductor or a conductive object such as finger or stylus pen approaches a touch panel, the amount of self-capacitance of touch sensors increases due to the capacitance between the conductor and the touch sensor, and thereby the variation in self-capacitance can be easily sensed using ROICs. However, to achieve high sensitivity and multi-touch sensing capability, the AIT technology requires a lot of sensing lines, resulting in high cost and large area.

To overcome the aforementioned problems, we propose an active self-capacitive sensing method and a readout circuit to reduce the number of sensing lines in the capacitive touch panel and enhance the signal-to-noise ratio (SNR) as well.

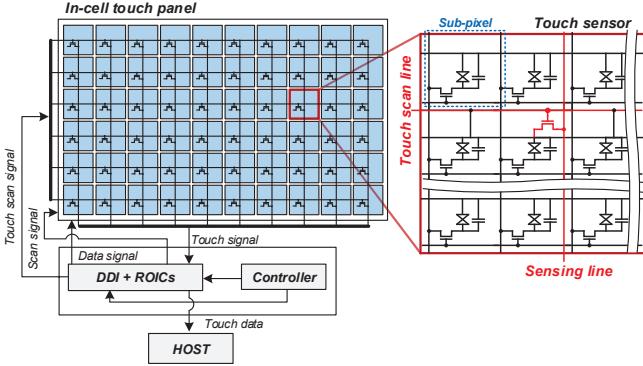


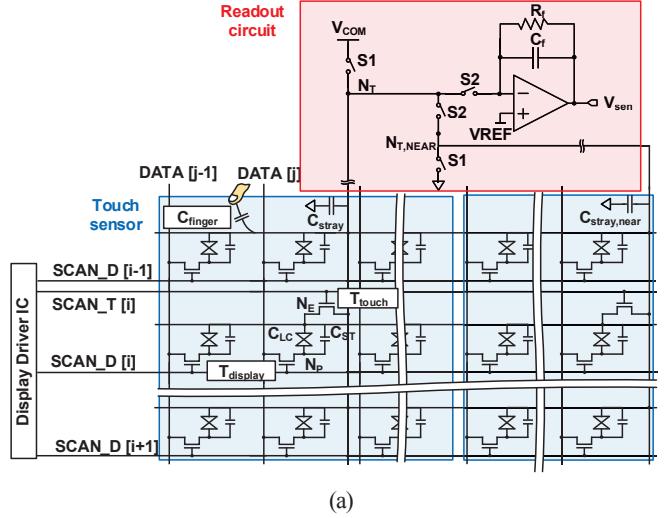
Fig. 2. System architecture of the proposed touch sensing system

2. Operation principle and architecture of the proposed in-cell touch sensing system

Fig. 2 shows the system architecture of the proposed touch sensing system, which consists of an in-cell touch panel, a display driver IC (DDI), ROICs, a host, and a controller.⁶⁾ The controller controls the timing of the DDI and ROICs. The DDI transfers the scan and data signals to each touch sensor so that the data signal can be sequentially programmed into the corresponding touch sensor. In the proposed touch sensing system, a thin film transistor (TFT), a touch scan line, and a sensing line are added to the touch sensor. Unlike the conventional self-capacitive sensing method that senses the touch signal of all touch sensors at the same time, the proposed active self-capacitive sensing method senses the touch signal in a row-by-row using a touch scan signal. As the touch scan signal is applied to the touch sensor, the ROICs sense the touch signals of each touch sensor and transfer them to HOST.

Fig. 3(a) shows the schematic of the touch sensor and readout circuit. The touch sensor consists of a display TFT ($T_{display}$), a liquid crystal capacitance (C_{LC}), a storage capacitance (C_{ST}), a touch TFT (T_{touch}), the i-th row touch scan line ($SCAN_D[i]$), the i-th row scan line ($SCAN_T[i]$), the j-th column sensing line ($SEN_T[j]$), a stray capacitance at the sensing line (C_{stray}), and a stray capacitance at the adjacent sensing line ($C_{stray,near}$). The readout circuit is configured with an operational amplifier, a feedback capacitor (C_f), a feedback resistor (R_f), selection switches ($S1, S2$). To eliminate the influence on the self-capacitance from C_{stray} effectively, $C_{stray,near}$ compensates for C_{stray} in the touch phase.⁴⁾ Therefore, the readout circuit can easily determine the touch data by digitizing the change in the output of the ROIC.

Fig. 3(b) shows the timing diagram of the self-capacitive sensing system, which operates in the display and touch phases. In the display phase, $T_{display}$ is turned on and a data voltage is applied to N_p of the pixel electrode. A voltage of V_{COM} is applied to N_E through T_{touch} and $S1$.



(a)

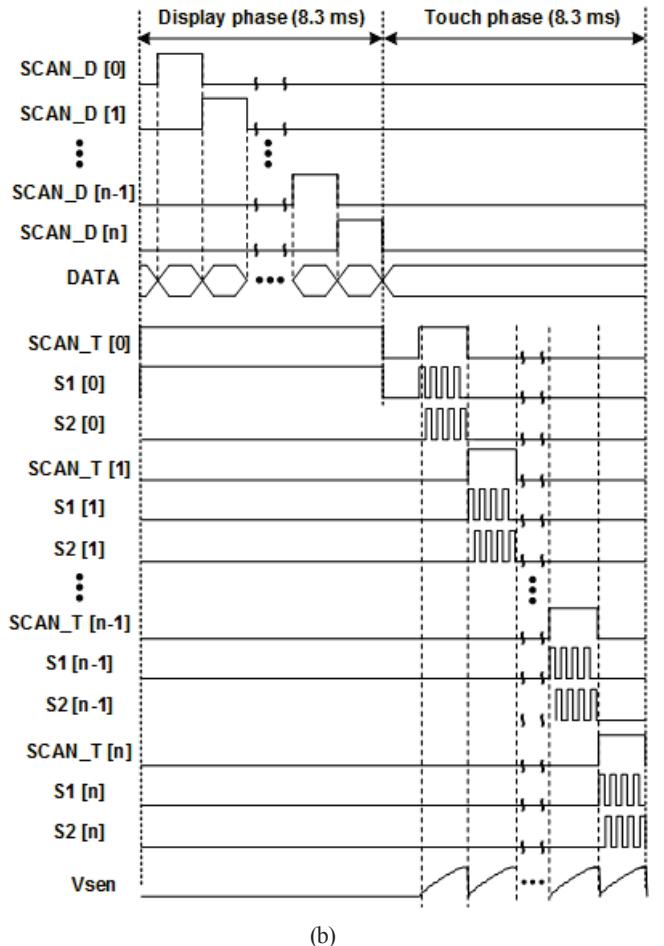


Fig. 3. (a) Schematic of touch sensor and readout circuit and (b) timing diagram of self-capacitive sensing system.

In the touch phase, the self-capacitance data is obtained in two steps. In the first step, when T_{touch} and $S1$ are turned on, and $S2$ is turned off, N_T and $N_{T,NEAR}$ are charged to VDD and VSS , respectively. The total charges at N_T and $N_{T,NEAR}$ are expressed as

$$Q_{N_T} = VDD \times (C_{\text{stray}} + C_{\text{finger}}) \quad (1)$$

$$Q_{N_{T,\text{NEAR}}} = 0 \times (C_{\text{stray},\text{near}})$$

In the second step, when T_{touch} and S_2 are turned on, and S_1 is turned off, the charges accumulated in C_{stray} and $C_{\text{stray},\text{near}}$ are shared because N_T and $N_{T,\text{NEAR}}$ are connected together. Since the C_{stray} and $C_{\text{stray},\text{near}}$ are the same, the voltage at the input of the ROIC (V_T) can be derived by

$$V_T = \frac{VDD \times (C_{\text{stray}} + C_{\text{finger}})}{C_{\text{stray}} + C_{\text{finger}} + C_{\text{stray},\text{near}}} \quad (2)$$

$$= \frac{VDD \times (C_{\text{stray}} + C_{\text{finger}})}{2 \times C_{\text{stray}} + C_{\text{finger}}} \quad (2)$$

$$\approx \frac{VDD}{2} + \frac{VDD \times C_{\text{finger}}}{2 \times C_{\text{stray}}} \quad (2)$$

Since the charge variation at the negative input of the ROIC between the untouched and touched states is approximately $VDD \times C_{\text{finger}}$, the voltage variation at the output of the ROIC (ΔV_{SEN}) is determined by

$$\Delta V_{\text{SEN}} = \frac{C_{\text{finger}}}{C_f} \times \frac{VDD}{2} \quad (3)$$

Therefore, in the proposed active self-capacitive sensing method, the touch signal can be sensed according to ΔV_{SEN} .

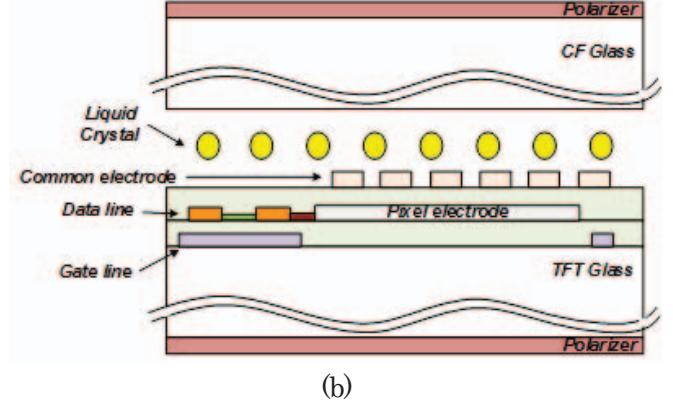
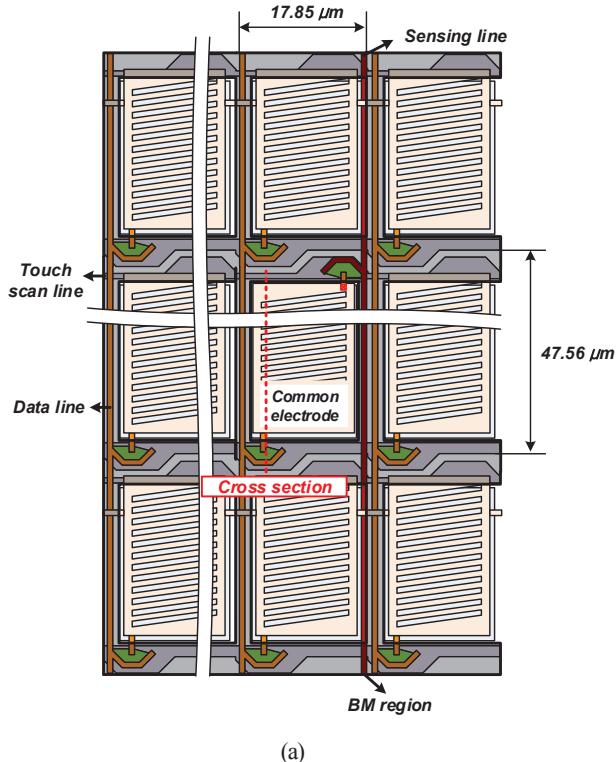


Fig. 4. (a) Top view and (b) cross-sectional view of the proposed LCD touch sensor structure.

3. Simulation results

Fig. 4 (a) and (b) respectively show the top-view and cross-sectional view of the proposed sub-pixel structure of liquid crystal display (LCD) in the AH-IPS mode, where both display and touch TFTs use a bottom-gate structure.²⁾ To maintain the aperture ratio of a display, the touch TFT and sensing line are added to the black matrix (BM) region.

Table I shows the simulation results using a Raphael simulator which extracts the capacitance of a sub-pixel.⁷⁾ The extracted capacitances include a storage capacitance (C_{ST}), a capacitance between data lines (C_{DD}), a capacitance between gate line and source (C_{GS}), a capacitance between gate lines (C_{GG}), a capacitance between common electrode and data line (C_{CD}), a capacitance between common electrode and gate line (C_{CG}), and a capacitance between touch scan line and display scan line (C_{TD}).

Table I. Simulation results of sub-pixel capacitances

Capacitances	Extracted value
C_{ST}	2.731 fF
C_{DD}	0.116 fF
C_{GS}	0.414 fF
C_{GG}	0.157 fF
C_{CD}	1.316 fF
C_{CG}	0.152 fF
C_{TD}	0.108 fF

Fig. 5 shows the simulation results of the readout circuit using extracted capacitance values in Table I. During one touch scan time, the output voltages of the ROIC in the untouched and touched states are 2.814 V and 2.921 V, respectively, representing that the touch signal is properly sensed using the proposed sensing method.

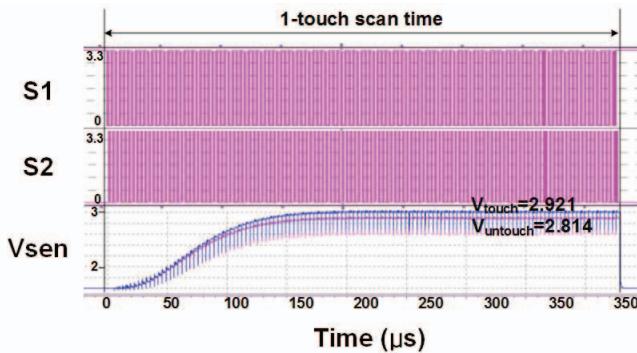


Fig. 5. Simulation result of the readout circuit.

The performance of the proposed in-cell capacitive touch sensor is compared with that of the AIT technology as shown in Table II. The size and resolution of the proposed in-cell touch panel are 5.5" and quad high definition (QHD), respectively. The touch sensor occupies an area of 5 by 5 mm² and its resolution is 24 by 13. The number of additional sensing lines of the AIT technology is about 230.8 per inch, whereas that of proposed in-cell touch sensor is 6.7 per inch, which is reduced by 97.10 %. In addition, the SNR is improved to be 57 dB, which is higher than that of the AIT technology.

Table II. Performance Comparisons

	Lists	AIT ²⁾	Proposed in-cell touch sensor
Display	Size	15.6" FHD	5.5" QHD
	Resolution	1920 x 1080	2560 x 1440
Touch	Pitch of touch sensor (mm)	4.3	5
	Touch sensor resolution	80 x 45	24 x 13
	The number of additional lines for touch sensing	3600	24+13
	SNR (dB)	52	57
	Report rate	120 Hz	120 Hz

Fig. 6 shows the number of sensing lines of the AIT technology and the proposed in-cell touch sensor with respect to the panel size. The number of sensing lines of the AIT technology exponentially increases as the panel size increases, whereas that of the proposed in-cell touch sensor slightly increases.

4. Conclusions

A simple active self-capacitive sensing method is proposed for the in-cell touch sensing system of the LCD. The proposed touch

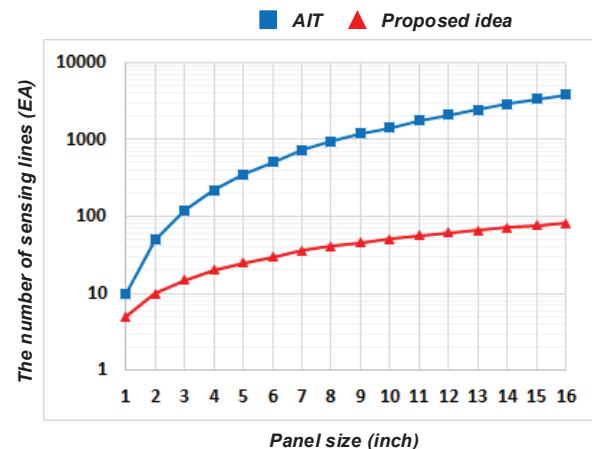


Fig. 6. The number of sensing lines versus panel size

panel structure sequentially senses the variation in self-capacitance touch sensor so that the number of sensing lines can be reduced. The simulation results show that the SNR of the proposed ROIC achieves an SNR of 57 dB. In addition, the number of additional sensing lines of the AIT technology is about 230.8 per inch, whereas that of proposed in-cell touch sensor is 6.7 per inch, which is reduced by 97.10 %.

Therefore, the proposed active self-capacitive sensing method, which uses a small number of sensing lines, is suitable for high sensitivity and multi-touch in-cell touch sensing systems.

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