Small-Area and High-Accuracy Calibration Technique for Sensing Capacitor in the Touch Screen Panel

Wen-Hai Cui, Tong-Hun Hwang, Min-Seok Shin, Ik-Seok Yang and Oh-Kyong Kwon*
Division of Electrical and Computer Engineering, Hanyang University, Seoul, Korea
Phone: +82-2-2220-0359, e-mail: okwon@hanyang.ac.kr

Abstract:
In this paper, a small-area and high-accuracy calibration technique for sensing capacitor in the touch screen panel is proposed. It uses 10-bit C-2C structure in calibration analog-to-digital converter (ADC) to get higher accuracy and small area just in one frame time. By boosting and comparing, the varied outputs of the charge amplifier are held at a reference voltage. Compared to previous calibration technique that adjusts feedback capacitor of the charge amplifier, it has advantage of faster speed, smaller area and higher accuracy. Simulation result shows that 10% variation of the sensing capacitance causes the variation of the output of charge amplifier less than 3mV in 3.5 inch touch screen panel.

Keywords: Touch screen panel, projected capacitive sensor, capacitance variation calibration.

I. Introduction
The touch screen panel, as one of the most popular human-machine interface, has been used in many applications such as ATM, note PC, mobile produces, and etc. By touching or moving cursor on the screen, we can execute many functions more easily without external input devices such as keyboard and mouse. Therefore, touch screen panel technology attracts more interests and wider market is predicted.

In the touch screen panel, there are several methods for sensing the touch events such as resistive, infrared, surface acoustic wave (SAW), acoustic pulse recognition (APR), infrared image and capacitive sensing method. Capacitive sensing method can also be divided into projected and surface capacitive sensing method [1].

The projected capacitive sensing method is drawing much attention because it can recognize multi-touch events. But there are several problems causing sensing errors, one of them is process variation of sensing capacitors.

As shown in Fig.1, the touch screen panel has matrix structure [2]. The row lines and column lines work as driving lines and sensing lines, respectively, and they are patterned on different layers that are separated by a transparent dielectric layer. The parasitic capacitors between driving lines and sensing lines work as a sensing capacitor. When a driving line is stimulated, the same voltage should be held at all outputs of the charge amplifiers when the panel is untouched. But due to the process variation of the panel, the output voltages of sensing amplifiers vary channel by channel, and the variation of the output voltages can cause sensing error. To overcome this problem, the calibration technique is needed.

There is a calibration technique for the variation of sensing capacitor by adjusting the feedback capacitor, Cfb, of charge amplifier to make the output of the charge amplifier the same voltage [3]. In this method, binary weighted feedback capacitor array can be used but, its resolution can be limited by large area. When using successive approximation analog-to-digital converter (SAR ADC) [4] to calibrate, it takes N frame times to finish the calibration period because it requires stimulation of the driving line to measure the error at each cycle, where N is the resolution of the ADC.

In this paper, we proposed a new method to compensate the variation of sensing capacitance. It boosts the output of the charge amplifier to a reference voltage. By adopting C-2C structure, the proposed technique can achieve small area high resolution. The proposed technique takes less time than the previous technique because it requires only one frame time for initial stimulation at the beginning of the calibration. The proposed technique can further reduce the area by sharing the ADC in both calibration and normal operation.
II. Proposed calibration system

The proposed calibration system is shown in Fig.2. The goal of the calibration is to equalize the outputs of the charge amplifiers when untouched even there are the variations in the sensing capacitors. As shown in Fig.1 and 2, $C_{\text{sig}}$ is the sensing capacitor and connected between driving and sensing lines which is connected to the negative node of the charge amplifier. $C_{\text{stray}}$ is the sum of the sensing line’s self capacitance and all the sensing capacitance of the sensing line. To minimize the effect of $C_{\text{stray}}$ on the sensing operation, a charge amplifier is needed. The positive input node of the charge amplifier is connected to a reference voltage, therefore, the negative input node of the charge amplifier is a virtual ground and the output voltage of the charge amplifier can be expressed as

$$V_{\text{out}} = \frac{C_{\text{sig}}}{C_{\text{fb}}} \times V_{\text{stim}}$$ (1),

where $V_{\text{stim}}$ is the stimulation voltage of the driving line and $C_{\text{fb}}$ is the feedback capacitor, respectively. Therefore, there is no relationship between $C_{\text{stray}}$ and the output of the charge amplifier. The effect of the $C_{\text{stray}}$ on the sensing operation can be eliminated. According to equation (1), by adjusting the value of $C_{\text{fb}}$ carefully, we can change the gain of the charge amplifier to get the expected amplification on the output of the charge amplifier and ensure the charge amplifier operates in its dynamic range at the same time. When these output voltages of the charge amplifiers are sampled at the MUX at the same time, the MUX sends these sampled data to the input of the ADC in series. When one of the sampled data is sent to the input of the ADC, the calibration operation begins to work and this calibration operation can be divided into two phases. Fig.3 conceptually shows the overall calibration phases. $C_S$ is the C-2C capacitor array and $S$ is the switch array.

For simplicity, we neglect the MUX. First phase is the sampling phase as shown in Fig.3 (a). In this phase SW1 is ‘ON’ and the switch array $S$ is connected to ground to sample the output of the charge amplifier at the capacitor array. According to the output state of the comparator, the SAR logic decides whether the switch connects to $V_{\text{ref2}}$ or ground. At the end of the calibration, ideally, the node voltage of $V_X$ is $V_{\text{ref1}}$ and the amount of $V_{\text{ref1}} - V_{\text{out}}$ is stored in the capacitor array $C_S$. We can express this relationship as
Fig. 4 Timing diagram and output waveforms of the proposed calibration system.

Fig. 5 Simulation result of the proposed calibration system.

183

\[ \frac{1}{2^2}b_2 + \cdots + \frac{1}{2^9}b_9 \] 

\[ \frac{1}{2^9}b_9 + \cdots + \frac{1}{2^0}b_0 \]

\[ 3C(V_{\text{ref}} - V_{\text{die}}) = \frac{1}{3}C \times V_{\text{ref}} \cdot (b_9 + \frac{1}{2}b_1 + \frac{1}{2^2}b_2 + \cdots + \frac{1}{2^9}b_9) \] 

\[ C_{\text{sig}} = \frac{C \cdot \frac{1}{V_{\text{cap}}} \cdot \frac{1}{V_{\text{ref}}} \cdot V_{\text{ref}}}{b_0} + \frac{1}{2}b_1 + \frac{1}{2^2}b_2 + \cdots + \frac{1}{2^9}b_9 \]

As different \( C_{\text{sig}} \), different \( b_0 \) to \( b_9 \) is obtained and stored in the memory to ensure the output of the charge amplifier equal. Till now, the extraction of the calibration data is finished and the calibration data is stored in the memory. In normal operation, we will use these calibration data to execute summing or subtraction to perform calibration operation when a driving line is stimulated.

### III. Simulation Results

Table 1 shows the specifications of the touch screen panel. We use 8 x 8 resolution projected capacitive method to ensure the multi-touch function. Driving IC is connected to the driving lines of the touch screen panel, and sends stimulation signal to the driving lines sequentially with 60 Hz frequency. The calibration and normal analog to digital conversion-use ADC uses 10 bit SAR ADC structure and its sampling rate is 4kS/s.

Fig. 4 shows timing diagram and output waveforms of the calibration system. SW1 and SW2 are switching signals. When SW1 is ‘ON’, the system samples the data on the capacitor array, when SW2 is ‘ON’, the system begins to perform calibration operation. Clock signal, CLK, is provided to generate the scan signal and the sampling signal of the SAR logic. SO1 to SO10 are the scanning signal from the

<table>
<thead>
<tr>
<th>Table 1 Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensing</strong></td>
</tr>
<tr>
<td>Resolution</td>
</tr>
<tr>
<td><strong>Driving IC</strong></td>
</tr>
<tr>
<td>Frame rate</td>
</tr>
<tr>
<td>Line time</td>
</tr>
<tr>
<td><strong>ADC</strong></td>
</tr>
<tr>
<td>Resolution</td>
</tr>
<tr>
<td>Sampling rate</td>
</tr>
</tbody>
</table>
SAR logic to sequentially connect S1 to S10 to $V_{\text{ref}2}$, and O1 to O10 are outputs of the SAR ADC which are connected to both memory and the switch array. When SO1 is in high state, it connects the switch, S1, to $V_{\text{ref}2}$. After comparison, if output of the comparator is in high state, O1 goes high and S1 maintains to be connected to $V_{\text{ref}2}$. If output of the comparator is in low state, O1 goes low and switch S1 will be connected to ground. So on till the LSB is decided.

Fig. 5 shows the simulation result. As calibration progressed, the voltage of the sensing node is more and more closed to $V_{\text{ref}1}$ and the output of the ADC, O1 to O10, are also stored in the memory. The simulation result shows that 10% variation of sensing capacitance causes the voltage variation of 30mV at the output of charge amplifier. When we use the proposed calibration technology to perform the calibration, the error is reduced less than 3mV which is less than one LSB of the ADC.

IV. Conclusion

In this paper, we proposed a new calibration technique to calibrate the variation of sensing capacitance due to process variation of touch screen panel. The proposed structure uses 10 bit SAR ADC structure to calibrate the variation of the sensing capacitance more accurately and just in one frame time. When we use this technique to calibrate the variation of the sensing capacitance, the simulation results show that, 30mV variations caused by 10% variation of the sensing capacitor is reduced to less than 3mV after calibration. With the proposed calibration system, we can calibrate the error more quickly and more accurately to ensure the exact sensing of the touch event.

V. Acknowledgement

This work was sponsored by ETRI SoC Industry Promotion Center, Human Resource Development Project for IT-SoC Architect.

VI. References