An Excessive Current Subtraction Technique to Improve Dynamic Range for Touch Screen Panel Applications

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Abstract—A current subtraction technique with parallel operation system is proposed to remove excessive current in touch screen application. The proposed current subtraction remove the current which go into the input node of charge amplifier. The value of subtraction current is same with current when touch screen is not touched. As a result, charge amplifier output is only proportional to variation of mutual capacitor, which make dynamic rage is increased. Also, Transmitter (Tx) driving signal and subtraction driving signal are out of phase each other. Thus, noise generated in Tx is cancelled. The proposed IC is implemented in a mixed-mode 0.18-um CMOS process. Overall system is designed for touch screen panel (TSP) with 16 driving lines and 8 sensing lines. 5-V supply voltages are used in the proposed circuits. For multiple Tx driving signal, Walsh codes are used and signal frequency is 300 kHz. By using proposed technique, dynamic range is improved 36 dB.

Index Terms—Touch screen, high voltage, parallel operation, current subtraction

I. INTRODUCTION

Multiple driving signal methods are used to satisfy high signal-to-noise ratio (SNR) in touch screen applications [1-3]. Code-division multiple sensing (CDMS) [3] read-out IC, which transmit multiple coded signal to driving lines simultaneously, is one of the multi touch sensing methods. CDMS read-out IC uses multiple signal, it has higher SNR compared to time-interleaved sensing method. Also, comparing with time-interleaved sensing method on same SNR, CDMS method has higher speed. By using high speed property, CDMS can compensate decreased speed in large load system. In CDMS read-out IC, each sensing channel faces multiple driving channels. Multiple driving signals which simultaneously go into driving channels meets at sensing channel and make large current on each sensing line as shown in Fig. 1. Large current issue reduces the dynamic range [1], which is difference between touched and untouched voltage in touch screen system. Sensitivity and accuracy are related to dynamic range. To ensure high sensitivity and accuracy, wide dynamic range is necessary.

In this paper, a current subtraction method utilizing capacitance and out-phase driving voltage is proposed to cancel the excessive current. By cancelling the current which is generated when touch screen is not touched, dynamic range is effectively increased.

II. PROPOSED CURRENT SUBTRACTION TECHNIQUE

Concept of proposed current subtraction circuit has been depicted in Fig. 2. By using CDMS read-out IC for TSP, a large number of Tx voltage signals go through TSP at the same time. In this circuit, Walsh code is used as multiple driving signals. High value in Walsh code is expressed with in-phase sinusoidal signal and low value
Subtraction current, which is generated by subtraction capacitor, is determined by out-phased Tx voltage signal and subtraction capacitance. A plurality of stimulated current from multiple in-phased Tx voltage signal is mixed at input of charge amplifier. Since polarity between the current from Tx input voltage signal and the current from subtraction circuit is opposite, the mixed current is countervailed. By using this subtraction circuit, excessive current caused by parallel driving method is eliminated.

Furthermore, there are lots of harmonic and switch noise in Tx signal [6]. In this process, noise generated in Tx is cancelled since Tx driving signal and subtraction driving signal are out of phase each other.

Voltage output is expressed by mutual capacitance and impedance of feedback circuits. Shown in Eq. (1), voltage output is proportional to summation of mixed current. If summation current is zero, untouched mutual capacitance can be omitted by subtraction capacitance. As a result, only Δ-mutual capacitance is measured.

Continuous-mode charge amplifier plays role of band-pass filter. It is possible to reduce low frequency noise. In Eq. (1), $C_{\text{offset}}$ is capacitor difference between mutual capacitor in TSP and subtraction capacitor. In case, subtraction capacitor and mutual capacitor are different, subtraction offset is occurred which is caused by difference of mutual capacitor and subtraction capacitor. Even though subtraction offset is occurred, these value is smaller than offset such as un-touched mutual capacitance. Since subtraction offset is small, subtraction offset cannot make output voltage saturated. Also, these subtraction offset is easily removed by digital calibration since subtraction offset value is always same.

\[ V_{\text{out}} = I \times Z_f \]

\[ = \sum_{k=1}^{N} (sC_{r-k}V_{f-r-k} + sC_{m}V_{f-r-k}) \times \frac{Z_f}{C_f} \]

\[ = \sum_{k=1}^{N} (sC_{r-k}V_{f-r-k} + sC_{m}V_{f-r-k}) \times (\frac{R_f}{1+sjR_f C_f}) \]

\[ = \frac{R_f}{1+sjR_f C_f} \sum_{k=1}^{N} (sC_{r-k}V_{f-r-k} + sC_{m}V_{f-r-k}) \]

\[ = \frac{\sum_{k=1}^{N} (C_{r-k}V_{f-r-k} + sC_{m}V_{f-r-k})}{C_f} \]

\[ = \frac{\sum_{k=1}^{N} (C_{\text{offset-k}} + \Delta C_{r-k})}{C_f} \]

(1)
Previous work, current subtraction technique is used in discrete mode [1]. To implement current subtraction technique in discrete mode, current mirror and switches are used to make subtraction current. The advantage of current subtraction technique in discrete mode is that additional capacitors are not used. However, it is necessary to take additional subtraction time in discrete-mode subtraction technique. Also it is hard to control subtraction current as channel length modulation of current mirror and lots of switching noise.

In this paper, current subtraction technique in continuous mode is proposed. The advantage of proposed current subtraction technique in continuous mode, current subtraction is conducted continuously. It means there are no additional current subtraction time. Also, charge amplifier with feedback resistor and capacitor is operated as band-pass filter in continuous mode, which means noise component of which frequency is close to input frequency is attenuated by band-pass filter. Thus, it is possible to get the advantage of current subtraction technique and continuous-mode charge amplifier as band-pass filter.

III. SYSTEM PERFORMANCE

Mutual capacitance becomes smaller when touch screen is touched by 10%. In this simulation, subtraction capacitance is same with sensing capacitance by 1.2 pF. If mutual capacitance is touched, the value of mutual capacitance is changed amount of 1.1 pF. It can be accomplished by controlling subtraction capacitance value. In order to check system performance, 8bit parallel operation system is used [2]. Walsh code is used as orthogonal code signal.

Even though Walsh code is the perfect orthogonal code signal, it has driving energy concentration phase [7]. In that phase, excessive current make output voltage saturated. Current subtraction technique remove excessive current in driving energy concentration phase so that it is possible to use Walsh code.

Fig. 3 shows the charge amplifier output voltage without current-subtraction technique. Current variation is very large between 0 to VDD (Feedback capacitance is 15pF), however, the difference of output voltage when touch screen touched or not is so small that dynamic range of charge amplifier is 15 mV. Fig. 4 shows the charge amplifier output voltage without current-subtraction technique. Since proposed read-out IC remove static value, it is possible to reduce feedback capacitor value. Cf is chosen as 0.4 pF, in that case dynamic range is 990 mV. By utilizing the current subtraction circuit, it is possible to reduce feedback capacitance and make dynamic range increased. Result shows that 36 dB improvement of dynamic range.

By utilizing the current subtraction circuit, it is possible to reduce feedback capacitance and make dynamic range increased. Thus, feedback capacitance is decided as 0.4 pF by applying current subtraction circuit and dynamic range is improved from 15 mV to 1210 mV. Result shows that 36 dB improvement of dynamic range. Fig. 5 show that chip photograph of TX 16 and RX 8 channel and Fig. 6 show that test board TX and RX.
A current-subtraction technique is presented for CDMS type read-out IC in this paper. By applying these circuits to charge amplifier for TSP, it can increase dynamic range by 36 dB and reduce current variation which is generated in CDMS read-out IC. This proposed read-out IC is implemented in a 0.18-μm mixed-mode CMOS process.

**References**


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