Readout Circuit Based on Differential Offset Cancellation Technique for Projected Mutual-Capacitance Large Touch Screens

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***Abstract* – This paper proposes an efficient method to improve the performance of the projected mutual capacitance large touch screen panels (TSPs) based on differential offset cancellation technique. To achieve high scan rate the proposed architecture uses concurrent and continuous sine waves as driving technique. In contrast to the conventional offset compensation topologies cannot handle such a concurrent or continuous signals properly, however, the proposed architecture overcomes such switching noise. In addition to, it provides an effective noise cancellation for such signals. The proposed architecture has been implemented using a Magnachip/SK Hynix 0.18 µm CMOS process. However, the measured results show a 14 dB improvement I SNR compared to conventional architectures. Also, the proposed readout circuit shows a good performance after mismatch condition applied to input stage of the differential amplifier to show the effectiveness of the proposed cancellation technique.**

I. INTRODUCTION

In last two decades touch screens are becoming an essential components for the most of the portable devices such as smart phones, tablets, laptops, e-Book readers, and MP3 players. TSPs can be classified into three categories depend on the location of touch sensors: add-on, on-cell, and in-cell [1]. Generally, the in-cell TSPs show the best performance when the device thickness and power consumption are concerned.

However, large touch screens are still facing serious detection issues, where they are susceptible to ambient noise and various environment noise. Furthermore, there is another issue which is related to limited readout speed due to large sheet resistance and self-capacitance of their indium tin oxide (ITO) layer.

In contrast to the conventional touch detection method uses single sensing by using single-ended amplifier, which amplifies the desired signal as well as the ambient noise, in other words, the conventional single sensing line architectures is susceptible to noise, thereby it may leads to wrong detection. Therefore, the proposed architecture uses differential sensing method using fully differential amplifier thus, by exploiting the advantages of differential architecture we can achieve improvement in SNR by removing the common mode noise of TSP and the power supply noise as well.

However, the differential amplifiers usually suffer from DC offset at the output common mode as a result of devices mismatch of the amplifier and process variation. So this paper presents an offset cancellation technique based on rotating auto-zeroing to compensate the offset that produced from mismatch and process variation as well. This paper is organized as follows: the TSP architecture is presented in section II. Section III presents the proposed readout circuit to overcome the offset problem. The experimental and measurement results are provided in section IV. Finally, the conclusions are presented in section V.

II. TSP ARCHITECTURE

While most of the existing touch detection schemes use pulse waves for excitation signals, they have a limited scan rate since they apply the excitation pulses sequentially. Recently, a new scheme called frequency division concurrent sensing (FDCS) has been proposed, which applies concurrent sine waves of different frequencies. This scheme can significantly improve the scan rate and the signal-to-noise ratio (SNR).

In this paper, we present the touch driving circuit with offset compensation, the touch sensing circuit with offset compensation for integrator and gain amplifier in FDCS mode. Offset compensation architecture can reduce the offset that occurred by process variation, mismatch, flicker noise and low frequency noise.

A. Frequency division concurrent sensing method (FDCS)

Excitation pulse is driving signal of TX lines. In touch panel signal detection scheme used pulse wave, triangular wave driving in TX lines. Most of controller gradually apply the pulse wave, triangular wave to TX lines and also RX line can gradually sense the output signals. However, as the panel size increases, also TX and RX lines increases. So, the

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touch controllers need higher resolution. This way takes long time to process the sensing data, because TX lines drive gradually each TX lines. Also, when touch panel is touched multiply over the 20 fingers, touch controller take long time for handling the touched signal.

Frequency division concurrent sensing method (FDCS) can process the detected signal in frequency domain. FDCS can reduce the overall driving time by applying the different frequency sinusoidal waves to each TX lines, TX 0 − TX n. In RX part, signals of adjacent RX lines are amplified difference value using one gain amplifier. Fig. 1. is basic architecture of FDCS method and touched and untouched case of simulation result in frequency domain. Fig. 2. is Touch detection with FFT results.

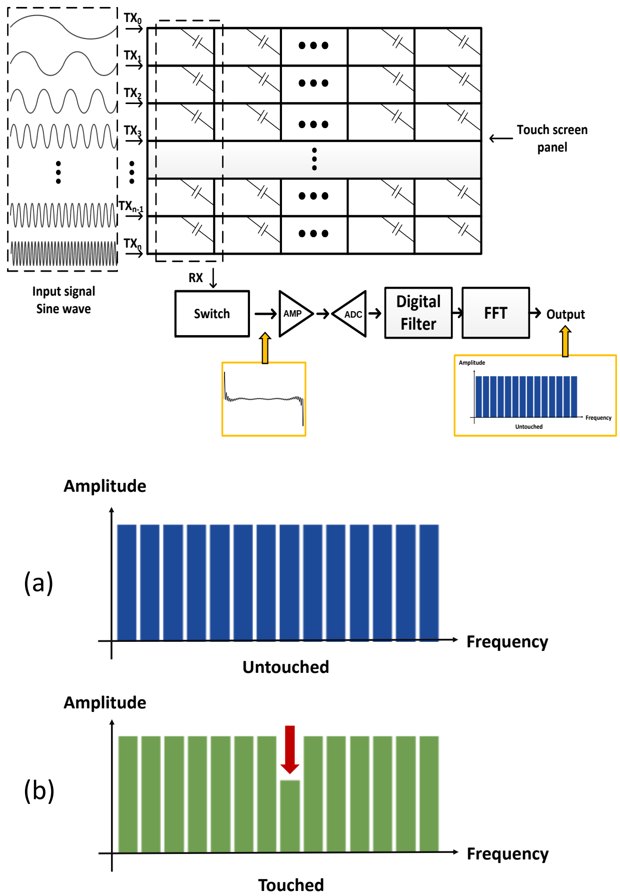

Fig. 1. Architecture of FDCS and comparison result of untouched, touched.

B. Offset compensation circuit

Fig. 2. illustrates a differential sensing circuit for FDCS, which uses a conventional offset compensation circuit. The differential amplifier in Fig. 2. has a strong advantage over one without an offset compensation circuit in that it can remove the common-mode noise of the TSP or the power supply noise. However, differential amplifiers often suffer from a mismatch or an offset of the input and the output bias level and the device mismatch of the amplifier's differential pair due to process variation.

The basic operation of offset compensation is the sampling of the unwanted noise and the offset value, and its subtraction from the contaminated signal at the input or the output of and amplifier. The basic offset compensation circuit can be used for removing the offset and the low-frequency noise.

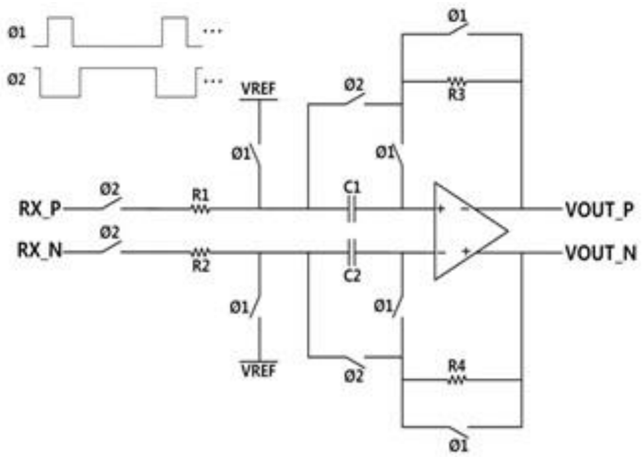

Fig. 2. Architecture and timing diagram of differential offset compensation circuit

The correlated double sampling (CDS) technique is an extension of the offset compensation method with the sample and hold steps.

The offset compensation circuit shown in Fig. 2. cancels the offset as follows: it captures the offset value of the OP Amp during Φ1 and amplifies the input signal during Φ2. During Φ1, C1 and C2 store the voltage difference between VREF and the positive input of the OP Amp. During Φ2, the OP Amp operates in the normal mode and amplifies the voltage difference between RX_P and RX_N along with the captured offset voltage.

EQ 1 is basic equation of offset compensation scheme. This architecture have 1 pole that operates like LPF. RL is output load resistance of offset compensation.

$$\frac{VOUT}{VIN} = \frac{R_L / C_{1,2}(R_L{*}R_{1,2} + R_{3,4}R_{1,2})}{S + [(R_{1,2} + R_{3,4} + R_L)/C_{1,2}(R_L R_{1,2} + R_{3,4}R_{1,2})]} \quad (1)$$

C. SNR (Signal to Noise ratio) calculation

Touch panels receive various types of noise, such as noise from the power supply, LCD, and the surrounding environment. Such noise tends to be more prominent in large touch screens. A considerable amount of noise can corrupt the small RX signals from touch panels and make it difficult for touch detection techniques to achieve a high SNR. Eqs. (2)-(4) present the SNR calculation. We can determine the scan rate of frame number by seconds using EQ. (5). This SNR calculation method is commonly used in the touch sensor industry. It accurately estimates the strength of the sensed signals and the noise power from a large number of RX signal samples, including the ambient and LCD noise. By using these equations, we measure the SNR performance of various sensing circuits.

$$SNR(dB) = 20Log\frac{Touch\,Strength}{Noise\,Touched_{RMS100}} \quad (2)$$

$$TouchStrength = SignalTouched_{AVG100} - SignalUntouched_{AVG100} \quad (3)$$

$$NoiseTouched_{S100} = \sqrt{\frac{\sum_{n=0}^{n=99} (Signal[n] - SignalTouched_{AVG100})^2}{100}} \quad (4)$$

$$ScanRate = \frac{1}{T_{drive} \times N_{integration} \times N_{TX} \times N_{RX}} \quad (5)$$

III. PROPOSED ARCHITECTURE OF TOUCH SENSING CIRCUIT

A. Gain amplifier with rotating offset compensation circuit

Rotating offset compensation: To improve the drawback of the conventional offset compensation described in Section Ⅰ-1.1, we propose a rotating offset compensation scheme. As illustrated in Fig. 3, it consists of an analog mux, an analog de-mux, and two offset compensation amplifiers.

The proposed scheme alternates the two offset compensation amplifiers to avoid losing the signal during the offset capturing process. It uses one offset compensation amplifier to capture its offset while using the other offset compensation amplifier to amplify the signal. In Fig. 3. Φ1 and Φ2 are non-overlapping opposite control signals that select the operation modes. When Φ1 is high, offset compensation amplifier 1 is in the amplify mode and offset compensation amplifier 2 is in the offset capture mode. In contrast, when Φ2 is high, offset compensation amplifier 1 is in the offset capture mode, while offset compensation amplifier 2 is in the amplify mode.

The analog de-mux in Fig. 3. feeds the input signals to either offset compensation amplifier 1 or 2. When Φ1 is high and Φ2 is low, RX lines are connected to offset compensation amplifier 1′s IN_P and IN_N, and thus, offset compensation amplifier 1 conducts its amplification. During this time, offset compensation amplifier 2 captures its offset. On the other hand, when Φ1 is low and Φ2 is high, RX lines are connected to offset compensation amplifier 2, allowing offset compensation amplifier 2 to conduct its

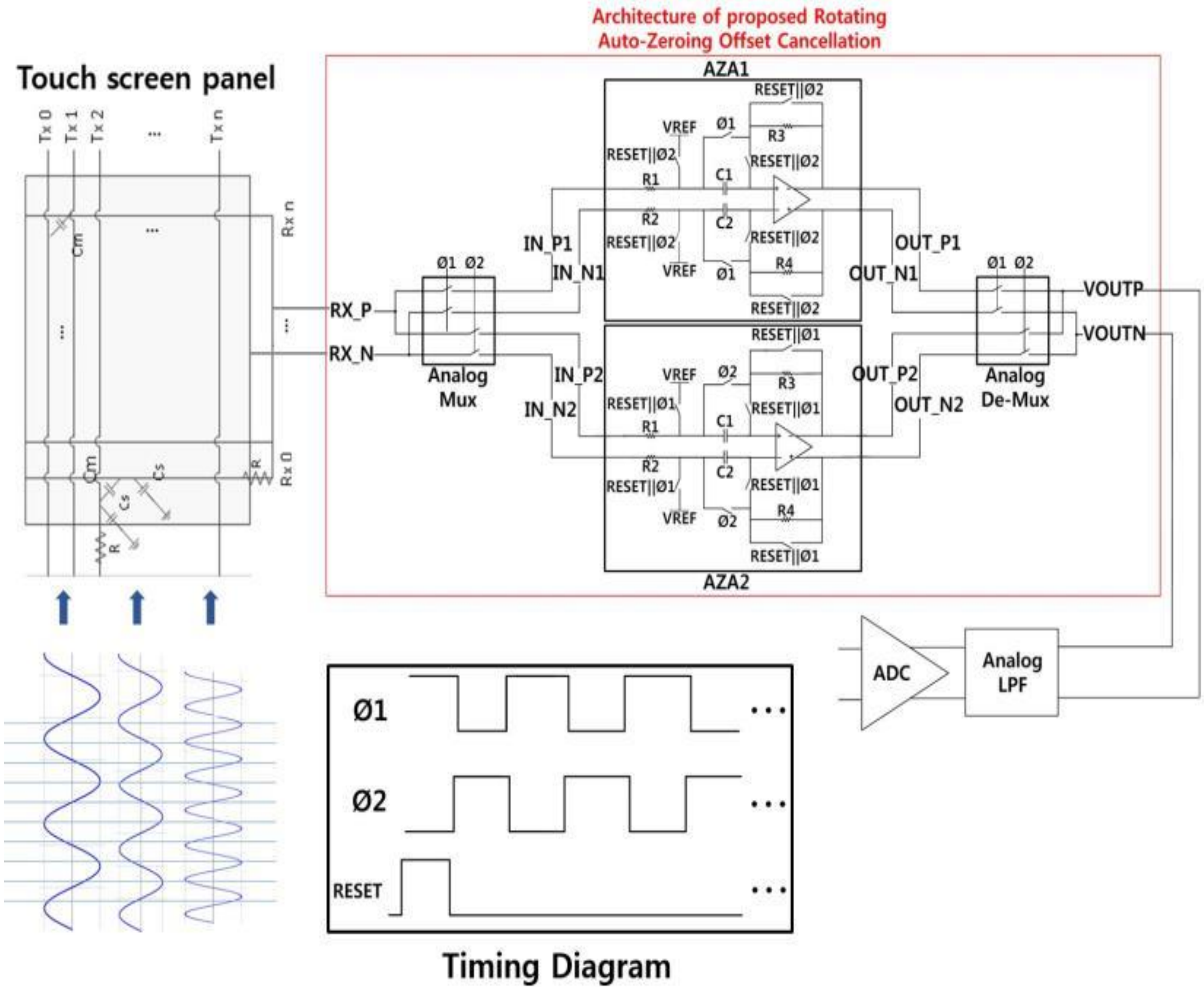

Fig. 3. Architecture and timing diagram of the proposed gain amplifier with rotating offset compensation circuit

amplification. The analog mux in Fig. 3. forwards offset compensation amplifier 1′s or offset compensation amplifier 2′s outputs to the analog LPF. The analog LPF removes the aliasing of high-frequency noise before the ADC process.

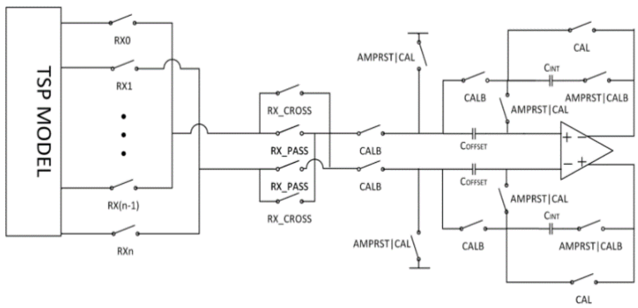

Fig. 4. Architecture of proposed integrator with 4 offset compensation.

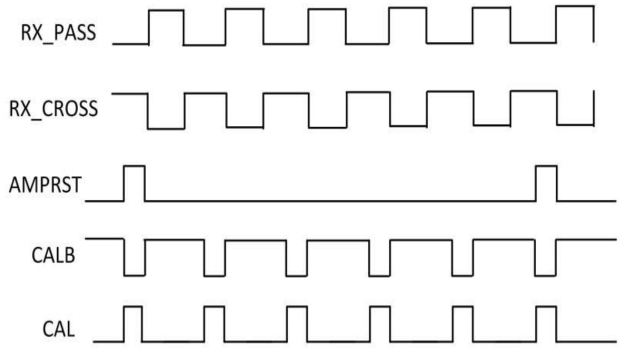

Fig. 5. Timing diagram of proposed integrator 4 offset compensation.

Therefore, the proposed scheme can effectively cancel the offset without incurring signal interruption and switching noise and is well suited for touch sensing methods using continuous analog signals.

B. Integrator with 4 offset compensation

Fig. 4. illustrates the proposed integrator with 4 offset compensation and Fig. 5. shows timing diagram of whole control signals. This proposed integrator used in pulse wave mode that is integrated the positive and negative peak signals of difference between touched, untouched case. Also, it can sense single line sensing mode and differential line sensing mode. Conventional architecture already had differential integrator. In this proposed architecture, we propose the architecture that calibrates 4 times offset during 1 integration period, conventional integrator used 1 offset compensation during 1 integration period.

We used crossing switches which are illustrated in Fig. 4. that controlled by RX_PASS, RX_CROSS. When RX_PASS is high, this proposed integrator integrates the positive peak signal. When this signals are reversed, it integrates the negative peak signal. Control signal of CAL means that compensation. When this signal is activated, this proposed integrator charges the amplifier′s unwanted offset value in the Coffset capacitor. However, when CAL is high, Cint which retains when disconnected by CALB is low. AMPRST signal resets the charged offset capacitor (Coffset) and feedback capacitors (Cint).

When only CALB is activated, it integrates the signal. In untouched case, 2 differential RX lines have same amplitude, so, this output signal is zero (Common voltage, VCM). However, one of the RX line is touched, amplitude of touched RX line signal is reduced. In this case, integrator integrates signal difference between two RX lines.

This proposed architecture of integrator with 4 offset compensation has advantage of efficiency to cancel the amplifier′s offset better than conventional integrator. Also, it can remove the flicker noise and power supply noise. So, ADC captures big difference value between touched, untouched cases by removing offset and improving SNR gain.

IV. EXPERIMENTS AND MEASUREMENT RESULTS

*A. Testing result (*Gain amplifier with rotating offset compensation)

TABLE I.
SNR Comparison of different sensing circuits

Architecture	SNR + TSP(dB)
Conventional Method: Differential Sensing without Auto-Zeroing	37.74 dB
Differential Line Sensing using Conventional Auto-Zeroing Amplifier	45 dB
Differential Line Sensing using RAZA with Offset cancellation	56.88 dB

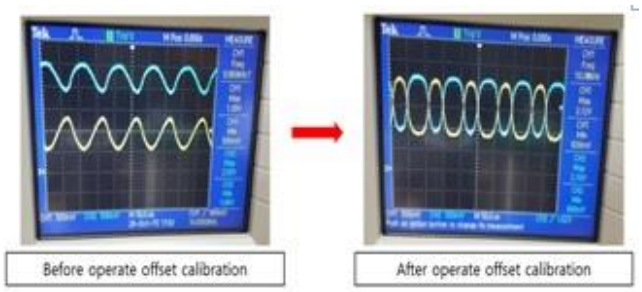

Fig. 6. Comparison result of before and after operates the offset compensation

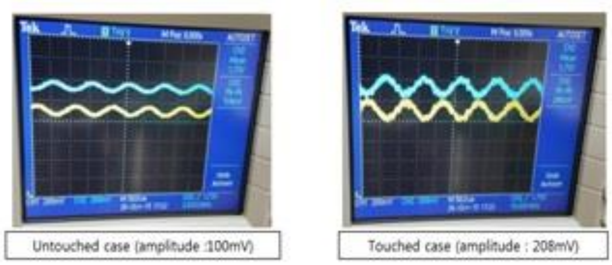

Fig. 7. Chip testing result of untouched and touched cases

TABLE I. compares the SNR measurement of 3 differential sensing schemes. The proposed scheme provides an SNR gain of 56.88dB (46.84 - (-10.04)dB), which was measured using the touch panel model and the noise source described. It presents an SNR improvement that is required for the FDCS touch screen detection method to provide high performance for large touch panels. The conventional offset compensation scheme shows a lower SNR because it loses sensing signal during offset capture period

Fig. 6. shows comparison result at the output of proposed architecture of before and after operates the offset compensation. This result is implemented like single to differential amplifier and applied 10kHz sine wave by function generator at the IN_P side, IN_N is connected to VREF. Before operating the proposed architecture has around 1.28V of the offset value and after operating the proposed architecture has around 0.06V of the offset value. We can check the correct result of offset compensation architecture.

Fig. 7. shows chip testing result of untouched and touched cases. RX input signals are connected to touch panel. Untouched case has small amplitude (100mV) of gain amplifier′s differential output and if one RX line is touched(208mV), output is amplified by gain of input resistor/feedback resistor′s ratio. We applied 100kHz input sine wave at the one TX line. Also, this chip is implemented by Magnachip / SK Hynix 0.18um CMOS process and power supply voltage is 3V, output offset is 0.06V, Common voltage is 1.75V.

B. Integrator with 4 offset compensation

Fig. 8. shows schematic simulation result of conventional architecture of 1 offset compensation. This result implemented symmetric MOS device sizes. Amplitude of untouched case is common voltage (1V). In contrast, amplitude of touched case is 0.3V~1.65V. In Section 5.3, we use 1MHz clock frequency of the input pulse wave.

Fig. 9. shows PEX result of conventional integrator of 1 offset compensation. Also, that has 10% mismatch of MOS device sizes. The untouched case of simulation result is almost same amplitude with touched case because of offset. In untouched case, integrator can be integrated by offset. So,

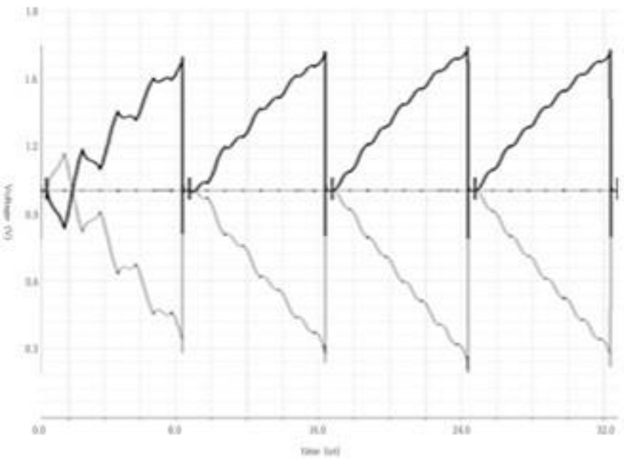

Fig. 8. Expectation simulation result of conventional architecture of 1 offset compensation (untouched, touched cases).

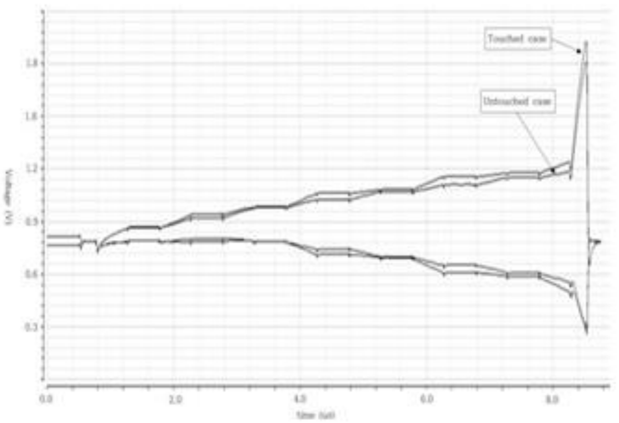

Fig. 9. PEX simulation result of conventional integrator architecture of 1 offset compensation.

difference between touched and untouched case is around 50mV.

Fig. 10. shows PEX corner simulation results of proposed integrator of 4 offset compensation. Also, these simulation results have 10% mismatch of MOS device sizes. Amplitude is 0.3V~1.7V (touched case), around 0.95V(untouched case). This architecture can effectively cancel the offset value.

C. Testing result (Integrator with 4 offset compensation)

Fig. 11. shows chip testing result of conventional integrator of 1 offset compensation (left) and proposed integrator of 4 offset compensation (right). We directly connected with real touch panel and real chip. Touch panel is ITO and 23 inches size. Simulation result of conventional architecture has integrated result by offset in untouched case like touched. So, touched case is already saturated. Amplitude of conventional architecture is 0.75V~1.25V (untouched), 0.67V~1.43V (touched). In contrast, proposed architecture is around common voltage of untouched case and touched case is integrated the signal difference between two RX lines. Amplitude of proposed architecture is 1.01V (untouched), 0.71V~1.41V (touched).

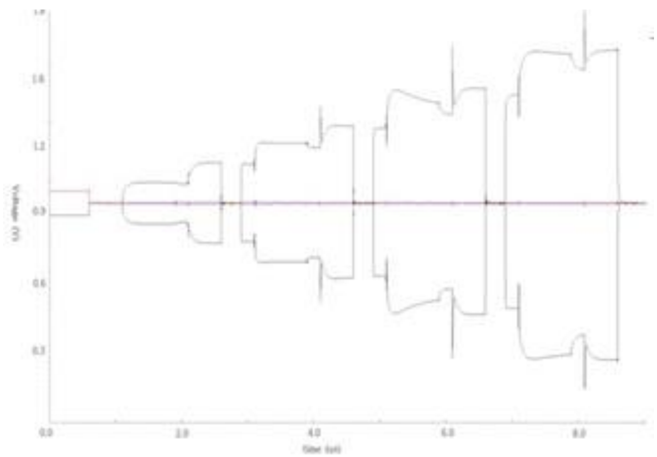

Fig. 10. PEX simulation result of proposed integrator architecture of 4 offset compensation.

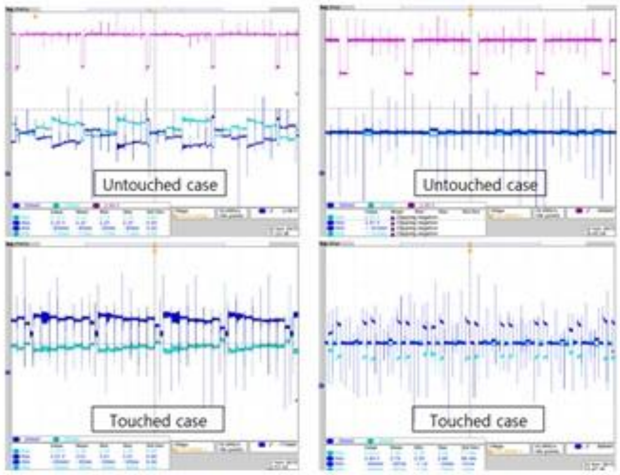

Fig. 11. Comparison testing result of conventional integrator of 1 offset compensation (left), proposed integrator of 4 offset compensation(right).

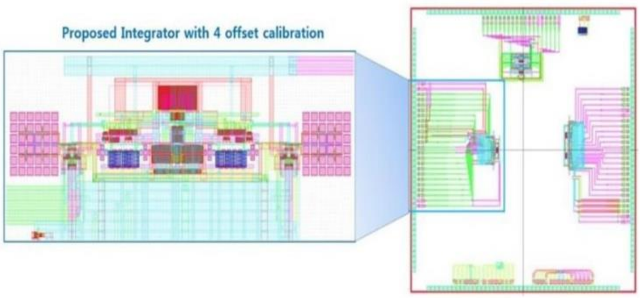

Fig. 12. Layout of proposed integrator with 4 offset compensation in Magnachip / SK Hynix 0.18um CMOS process

V. CONCLUSIONS

We proposed an efficient sensing circuit with offset compensation scheme that is suited well for differential sensing circuits with continuous analog excitation signals. The proposed offset compensation architecture can cancel the offset of sensing circuits without losing the signal during offset capture cycle. This allows a touch panel sensing method like FDCS to drive and sense continuous analog sine waves, which was not possible with the conventional offset compensation schemes. Also, integrator can efficienctly cancel the offset and integrate the signals. Experimental results show that the proposed gain amplifier in sine wave mode provides an SNR gain improvement of 12dB compared with the conventional offset compensation scheme. Therefore, the proposed schemes can be considered as a key component of high performance touch panel detention methods with continuous analog signals.

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