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고감도 터치스크린 감지를 위한 양방향 센싱과 전압쉬프팅을 이용한 센싱 기법

(Dual Sensing with Voltage Shifting Scheme for High Sensitivity Touch Screen Detection)

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요 약

본 논문에서는 상호 정전용량 터치스크린의 single line sensing 방법에서의 단점을 해결하기 위한 성능향상 구조를 제안한다. 제안 구조는 Dual sensing 기법과 voltage shifting 기법을 도입하여 센싱 신호의 노이즈를 효과적으로 제거하고 터치 유무의 센싱 신호 차이를 증가시킨다. Dual sensing 기법은 구동신호의 양방향 엣지를 사용하여 integration 속도를 2배로 증가시켜 감지시간을 감소시킨다. Voltage shifting은 ADC의 입력신호 동작범위를 최대화하여 신호 대 노이즈비 (SNR)를 개선한다. 23″ 대형 상용 터치스크린을 이용하여 simulation 및 측정한 결과로 제안된 센싱기법은 43dB의 SNR 성능을 가지며, 기존 방식 대비 2배의 스캔 속도를 제공하여 대형 터치스크린을 위한 적합한 기술임을 보인다. 제안된 센싱기법은 현재 매그나칩 CMOS 0.18um 공정으로 TSP 컨트롤러칩으로 구현되었다.

Abstract

This paper proposes a new touch screen sensing method that improves the drawback of conventional single-line sensing methods for mutual capacitance touch screen panels (TSPs). It introduces a dual sensing and voltage shifting method, which reduces the ambient noise effectively and enhances the touch signal strength. The dual sensing scheme reduces the detection time by doubling the integration speed using both edges of excitation pulse signals. The voltage shifting method enhances the signal-to-noise ratio (SNR) by increasing the voltage range of integrations, and maximizing the ADC's input dynamic range. Simulation and experimental results using a commercial 23″ large touch screen show an SNR performance of 43dB and a scan rate 2 times faster than conventional schemes – key properties suited for a large touch screen panels. We implemented the proposed method into a TSP controller chip using Magnachip's CMOS 0.18um process.

Keywords : Projected capacitive touch screen, dual sensing, voltage shifting, integrator

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Ⅰ. Introduction

As projected capacitive touch screen technologies become mature, most smartphones and tablet PCs today employ capacitive touch screens[1~2]. Recently, capacitive touch screens are increasingly being applied to appliances with large screens such as laptops, PC monitors, TVs, projector screen and digital white boards. Large touch screens, however, are facing serious detection performance issues: they are highly susceptible to ambient noise. As the panel size increases, the sheet resistance and self capacitance of ITO (Indium Tim Oxide) film or metal mesh tend to grow. This makes the detection signals (mutual capacitance difference value) suffer from severely attenuation as the signals pass through long paths across the touch screen panel[3~4]. Therefore high voltage TX excitation pulses are often used to accurately distinguish the difference between touched and untouched RX sensing signals -- called signal strength. In addition, many steps of integrations are used to boost the sensing signal strength. However, such boosted sensing signal often exceeds the dynamic range of an ADC (Analog to digital converter), and so the ADC may convey incorrect sensing signal to digital signal processing unit. We, therefore, introduce a voltage shifting technique that overcomes this problem and utilizes an ADC's full range without exceeding its dynamic range[5~6].

Ⅱ. Basic operation of touch screen sensing

In mutual capacitance TSP (Fig. 1), when an object such as a finger contacts the TSP, the mutual capacitance on the contacted intersection of the TX line and RX line decreases. This phenomena occurs

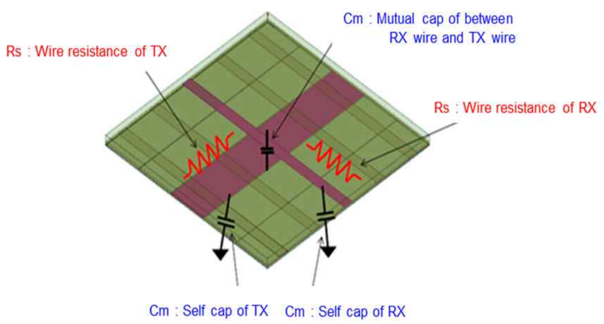

그림 1. 상호커패시턴스 방식의 터치패널[7]
Fig. 1. Mutual capacitive 4touch screen panel[7].

because a finger, acting as ground, takes away the charge accumulated on the mutual capacitor. The sensing circuit detects the reduction of capacitance, and calculates the touch position. A TSP controller applies excitation pulses to each TX (Transmit) line, reads out the charge variation from each RX (Receive) line, and converts the sensed charge variation to a voltage difference.

EQ (1)-(3) gives equations that measure SNR (Signal to Noise Ratio). EQ(1)-(3) are commonly used in touch screen sensor industry to extract accurate sensed signal from the RX signal mixed with ambient and LCD noise. Using this equation, we can calculate the SNR performance of touch screen detection schemes[8~9].

$$SNR(dB) = 20Log(TouchStrength / Noise\,Touched_{\gamma ms100}) \quad (1)$$

$$TouchStrength = Signal\,Touched_{AVG100} - Signal\,Untouched_{AVG100} \quad (2)$$

$$Noise\,Touched_{\gamma ms100} = \sqrt{\frac{\sum_{n=0}^{n=99}(Signal[n] - Signal\,Touched_{AVG100})^2}{100}} \quad (3)$$

Here $SignalTouched_{AVG100}$ and $SignalUntouched_{AVG100}$ are average signal values measured for a large number of frames (e.g. 100 frames) of each TX and RX intersections. $NoiseTouched_{rms100}$ is a root mean square of touched signal variance for 100 frames.

Ⅲ. Conventional touch sensing method

Fig. 2 is a conventional touch sensing scheme. The drive circuit applies a sequence of excitation pulses to each TX line of a TSP. The sensing circuit reads out from each RX line, the charge on the mutual

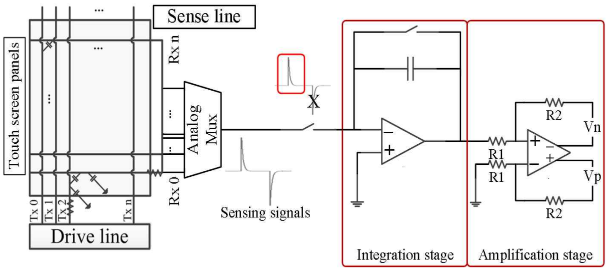

그림 2. 기존의 터치 센싱 구조[5,10]
Fig. 2. Conventional touch sensing scheme[5,10].

capacitance between each TX and RX line.

As another performance metric of a touch detection scheme, EQ(4) gives a scan rate (also called a report rate) in frames per second.

$$Scan\,rate = \frac{1}{T_{drive} \times N_{integration} \times N_{tx} \times N_{rx}} \tag{4}$$

Here, N_{tx} is the number of TX lines, N_{rx} is the number of RX lines, and T_{drive} is a period of one TX pulse. $N_{integration}$ is the number of integration steps (or the number of TX pulses per sensing point). As indicated by EQ(4), a single line sensing scheme sequentially drives each TX line and sequentially senses each RX line.

1. Integration stage

As in Fig. 2, many conventional sensing circuits consist of an integration stage and an amplification stage. The roles of integrators are twofold: converting a sensed charge value to a voltage value, and cancelling the noise from the sensed signal. To cancel the noise more effectively, the integration step is often repeated, which accumulates the sensed signal while cancelling ambient or LCD noise. For each excitation pulse, a mutual capacitor in a TSP experiences a charging process and a discharging process. This effect appears as a positive spike signal and a negative spike signal on the RX line as in Fig. 2. Most conventional touch detection schemes, however, use only the positive spikes, wasting half the signals. In this paper, we propose a scheme utilizing the both spikes.

2. Amplification stage

The amplification stage of Fig. 2 is a single to differential amplifier, which converts the integrated signal to a differential signal. The gain of this amplifier can be configured to fit the output signal swing to the full dynamic range of an ADC. The decision on touch or untouch is concerned with measuring only the difference between touched and untouch signal swing. A differential ADC's input signal swing, however, spans from the V_{cm} to the maximum voltage of the final integration result. Although only a small portion of the integrator's signal swing is useful for the decision on touch, the whole signal swing is taken by the ADC. This wastes most of the ADC dynamic range, and leads to a limited SNR performance. To achieve a high SNR, an ADC of an extremely high resolution is required.

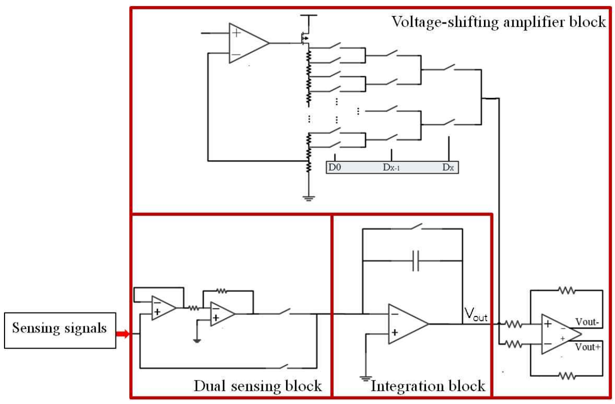

그림 3. 제안된 터치 센싱 구조
Fig. 3. Proposed touch sensing scheme.

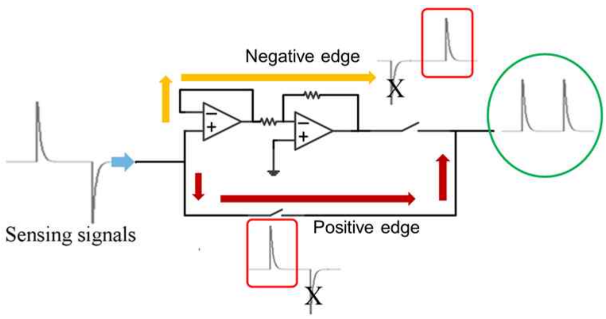

그림 4. 듀얼 센싱 단의 동작원리
Fig. 4. Operation of dual sensing block.

Another problem is that when the number of integrations is increased for better noise cancelation, the integrator's output signal swing increases rapidly and can cause the amplifier output to easily exceed the dynamic range of the ADC. In other words, this limits the number integrations and so limits the detection performance. This is a serious problem for larger TSPs, which usually need more integrations to cancel larger ambient noise and to better distinguish the touched and untouched signals.

Ⅳ. Proposed sensing scheme

1. Dual sensing block

Fig. 3 shows the structure of the proposed touch sensing scheme. The 1st stage is the dual sensing block, which converts the negative spikes to positive spikes, so the integrator can integrate both spike signals monotonically. In this way, we can integrate the RX signals 2 times faster using the same number of TX pulses as conventional methods. Fig. 4 illustrates the operation of the dual sensing block.

The 2nd stage is an integration block, which is similar to conventional touch sensing schemes.

2. Voltage-shifting amplifier block

The final stage in Fig. 3 is a voltage shifting amplifier, which converts V_{out} of the integrator to an ADC's differential input signals V_p and V_n also denoted by V_{out+} and V_{out-}.

Fig. 5 (a) shows an example of ADC input signals V_p, V_n generated by a conventional differential amplifier. The inner 2 curves illustrate the touched case, while the outer 2 curves illustrate the untouched case. This voltage swing increases along with each integration step, and thus it can easily exceed the ADC's input dynamic range if the integration count is increased.

Fig. 5 (b) shows the voltage swing $V_p - V_n$ of the proposed voltage-shifting amplifier. This scheme shifts voltage levels of V_p and V_n such that $V_p - V_n$ = 0 for untouched case (as illustrated by the 2 inner curves), while $V_p - V_n$ gives the touch signal strength for touched case (as illustrated by the 2 outer curves in Fig.5 (b)).

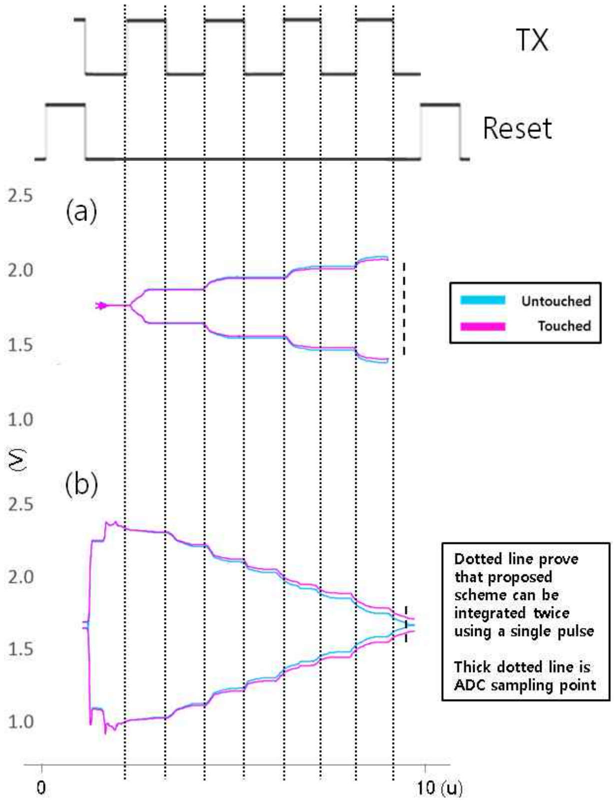

그림 5. 출력 V_p-V_n: ① 기존기법(a), ② 제안된 기법(b) (증폭기 이득 = 1 인 경우).

Fig. 5. Output V_p-V_n of ① conventional scheme(a), ② proposed scheme(b) (Gain = 1.).

To ensure the minimum value of $V_p - V_n = 0$ for untouch case, the proposed scheme calibrates the voltage shifting amount by configuring V_{ref} of the variable voltage LDO in Fig. 3. On the other hand, the maximum value of $V_p - V_n$ for touched case is configured by adjusting the gain of the voltage shifting amplifier to fit to the ADC's maximum dynamic range.

The proposed scheme, therefore, can substantially improve the SNR by allowing more integration cycles and thus cancelling the ambient noise more effectively, and also can use the maximum dynamic range of the ADC.

Ⅴ. Experimental results

This section provides simulation results and measurement results of the proposed touch screen detection scheme.

For the simulation results, we used Cadence SPECTRE with TSP model and noise source (See Fig. 6), which are provided by the World's leading touch screen panel manufacturer[5,11].

Fig. 6 illustrates the TSP model and noise source used in the simulation results. Fig. 7 shows composite noise signal used as the noise model. This noise signal includes power supply noise, LCD generated noise, and Timing controller (H-SYNC, V-SYNC) noise.

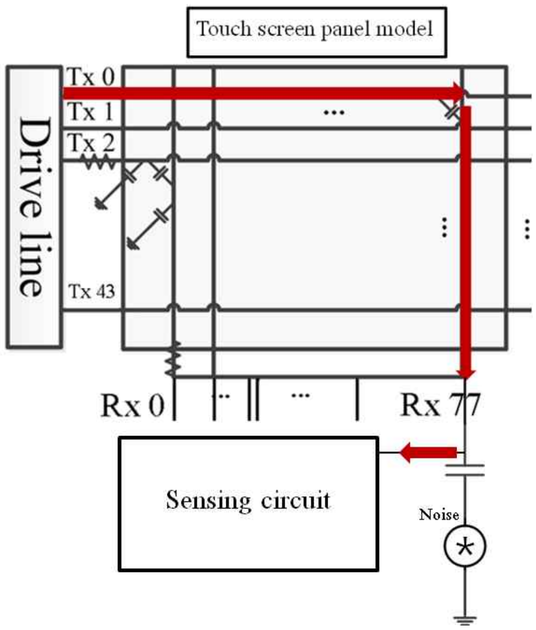

그림 6. TSP model의 최장 신호경로 측정 및 환경 노이즈 데이터 인가 방법

Fig. 6. Measuring the longest path of the TSP with ambient noise data applied.

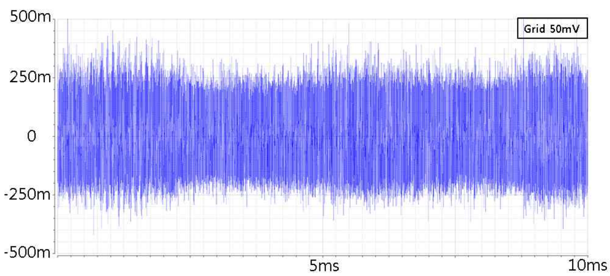

그림 7. 사용된 노이즈 파형 (세계 최대 TSP제조사 제공)

Fig. 7. Applied noise signals (Provided by a world's leading TSP manufacturer).

Fig. 8 compares the output $V_p - V_n$ of conventional scheme (①) and the proposed scheme (②) when the voltage gain of the final amplifier is configured to be greater than 2. In this experiment, an ADC with max. dynamic range of 2 V_{pp} was used. The $V_p - V_n$, therefore, is configured to fit the ADC's dynamic range of 0 – 2 V_{pp}.

In the conventional scheme ① in Fig. 8, $V_p - V_n$ reaches almost 2 Vpp only after 4 integrations when the final amplifier's gain of 2. Any further integration pushes its $V_p - V_n$ out of the ADC dynamic range. On the other hand, the proposed scheme ② can conduct 8 integrations and can still fit its $V_p - V_n$ to the max.

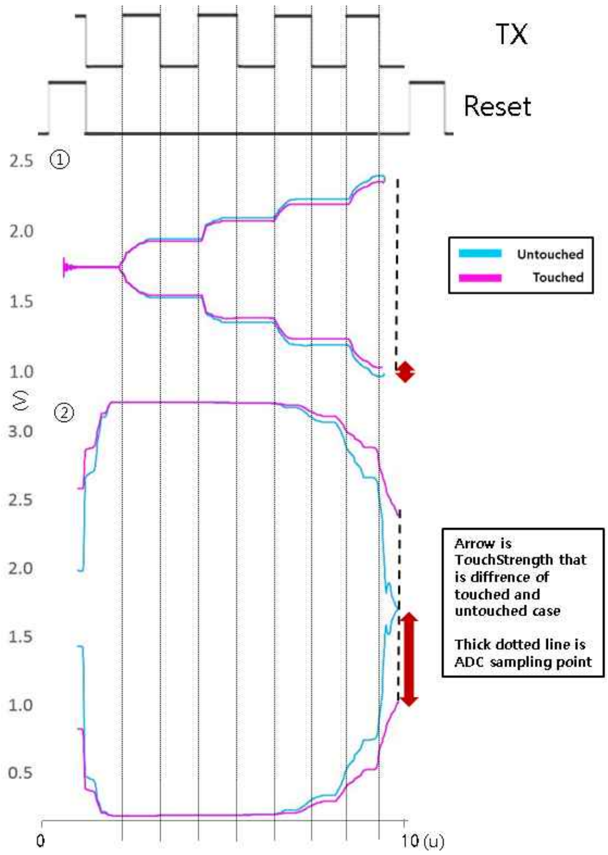

그림 8. 최종출력 V_p-V_n: ① 기존기법, ② dual sensing + voltage shifting

Fig. 8. Output V_p-V_n of ① conventional scheme, ② dual sensing + voltage shifting.

From the result of the proposed scheme ②, we can observe that $V_p - V_n$ of the untouched case is close to 0, while $V_p - V_n$ of the touched case is close to the ADC's dynamic range. Therefore, the signal stength ($V_{untouch} - V_{touch}$) of the proposed scheme can utilize the max. dynamic range of the ADC, and so maintains its high SNR. On the other hand, the signal strength of the conventional scheme utilizes only small portion of the ADC's dynamic range causing degradation of its SNR.

We can observe that while the conventional scheme allows only 4 integrations and suffers from a limited range of ADC's dynamic range, the proposed scheme with dual sensing and voltage shifting allows 8 integrations (2 times) for the same detection duration and also maximizes the performance by utilizing the full dynamic range of the ADC.

Fig. 9 compares the *TouchStrength* (EQ2) and for the two schemes: a conventional scheme ①, and the proposed scheme ② (dual sensing + voltage shifting). Fig. 9 proves that by conducting more integrations the proposed scheme increases the *TouchStrength*, and reduces $NoiseTouched_{rms}$ leading to a substantially improved SNR. Here the TSP SNR is a relative SNR dependent of the noise signal applied. It was measure as -27.86dB for the noise signal we applied. The conventional scheme ① increases this SNR only up to +0.34dB. This SNR is still very low, so it needs additional noise filtering. On the other hand, the propose scheme ② raises this SNR up to

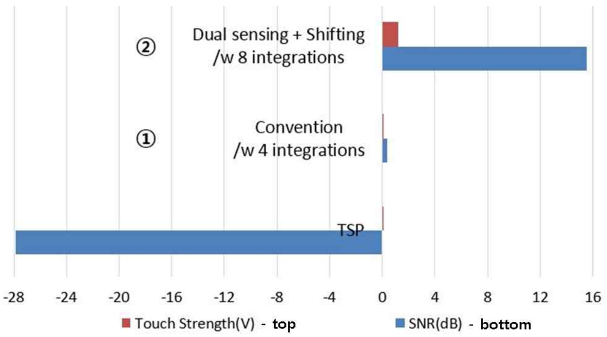

그림 9. 터치강도와 SNR 비교
Fig. 9. Comparison of touch strength, SNR.

+15.52dB. This is high enough so that digital circuits can make a decision of accurate touch positions.

For the measurement, we implemented a digital controller in FPGA, drive and sensing circuits in an analog front-end board, and a finger position calculation algorithm in embedded software on an ARM processor. We used a large TSP (a 23″ commercial TSP product sample) to measure the performance.

Table 1 summarizes the performance comparison of the 2 schemes described in Fig. 8, Fig. 9 and previous work[9]. Compared with the conventional scheme ①, the proposed scheme ② increases the touch signal strength by 12 times (Comparing 0.099V with 1.208V). In this experiment, the proposed scheme achieved an SNR gain of 43.39dB. In contrast, the previous work[9] provided an SNR gain of only 24dB. Here, SNR_{out} is an SNR measured at the sensing circuit output, while the SNR_{TSP} is an SNR measured at the sensing circuit's input. The SNR gain is obtained by $SNR_{out} - SNR_{TSP}$.

표 1. 제안된 구조와 기존구조와의 성능 비교
Table 1. Performance comparison of the proposed scheme and a conventional scheme.

	ASSCC 10' [9]	Conventional scheme ①	Proposed scheme ②
Channel	TX : 20 RX : 16	TX : 44 RX : 78	
Resolution	320	3432	
Scan rate (frame/s)	65	36.42	
Number of integrations	-	4	8
TouchStrengh = $Touched_{avg100}$ - $Untouched_{avg100}$(V)	-	0.099	1.208
Area (mm^2)	4 (Die area)	-	1.665 (Layout area)
SNR_{out} at sensing circuit (dB)	-	0.34	15.52
SNR_{TSP} at TSP (dB)	-	-27.86	-27.86
SNR gain (dB) = SNR_{out} - SNR_{TSP}	24	28.20	43.39

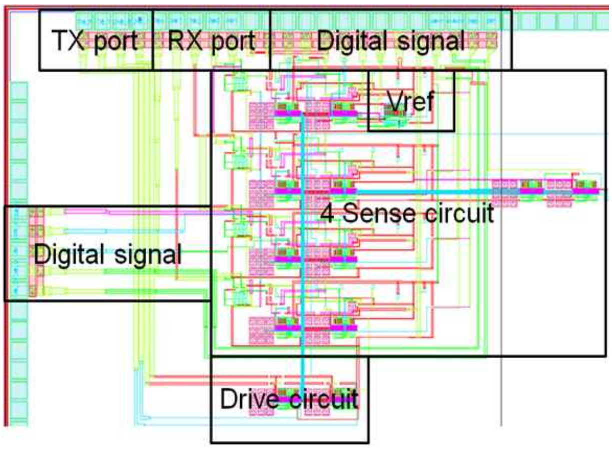

그림 10. 레이아웃 (3 port TX, 4 port RX line)
Fig. 10. Layout results (3 port TX, 4 port RX line).

In this experiment, while the proposed scheme was configured for a scan rate of 36.4 Hz, (slower than the previous work[9]), its TSP size is 10 times larger than the TSP used by previous work[9].

We implemented the proposed scheme in a silicon chip, which was fabricated in a Magnachip CMOS 0.18um process. Fig. 10 shows the layout implementation of the proposed sensing circuit. We integrated 1 drive circuits and 4 sensing circuits for parallel sensing. This parallel circuits can increase the scan rate at the cost of larger chip size. The overall chip area is $1{,}665{,}424.477um^2$. We plan to present the result of this chip, when the chip is available.

Ⅵ. Comparison with differential sensing[12~13] schemes

There are many papers proposing differential sensing circuits that integrate the difference of two RX lines[14]. They usually report a better SNR than single line sensing schemes[15~16]. Most of differential sensing schemes, however, suffer from the self-cancellation problem -- a problem

that the two differential touch signals cancel each other, when the 2 selected RX lines are both touched or the touch position is at the center of the 2 differential RX lines. The proposed scheme is based on single line sensing, and so does not suffer from the self-cancellation problem. With its enhanced scheme, the proposed scheme provides an SNR better than or comparable to many differential sensing schemes, while providing a substantially higher SNR than conventional single-line sensing schemes. As future work, we are studying a method of combining the proposed scheme with a differential sensing scheme to further improve the SNR.

Ⅶ. Conclusion

This paper presented a high SNR sensing scheme for a projected mutual capacitance touch screens. To cancel the ambient noise and improve the SNR performance effectively, we introduced a dual sensing with a voltage shifting scheme. We have shown that the proposed scheme provides an SNR gain of 43 dB, which is an improvement of 15 dB over a conventional single-line sensing circuit.

The proposed scheme requires a small chip size, and thus can be combined with a differential sensing scheme to utilize the advantages of both schemes.

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