# Inverted driving technique for removing display noise in capacitive touch sensors

**Jae Young Park, Jong Kang Park, Chang-Ju Lee, and Jong Tae Kim**[a)]

*College of Information and Communication Engineering, Sungkyunkwan University, 300 Cheoncheon-dong Jangan-gu, Suwon, Gyeonggi-do 440–746, South Korea*

a) *jtkim@skku.edu*

**Abstract:** As the technological advances in mobile display is focusing on thinner and wider structures, capacitive touch recognition suffers from ever-increasing display noise. Realizing reliable touch recognition in thin displays requires a way to remove display noise. We observed that display noise is evident in various patterns and amplitudes according to the display image. In order to remove noise, we applied non-inverse signals and inverse signals across two data frames, in accordance with the periodicity of the noise. With all other conditions remaining the same, the proposed method showed higher signal-to-noise ratio (SNR) for all display noise patterns compared to existing methods. The proposed method showed a SNR that was averagely 5.39 dB higher than the SNR of the existing method. The results shows that the display noise was removed effectively.

**Keywords:** display noise, capacitive touch, inverted TX driving

**Classification:** Electronic displays

## References

[1] J. K. Park, C.-J. Lee, D.-Y. Kim, J.-H. Chun and J. T. Kim: IEEE Trans. Consum. Electron. **61** (2015) 261. DOI:10.1109/TCE.2015.7150602

[2] Y.-S. Ahn, T.-J. Ahn, K. Lee and J.-K. Kang: IEICE Electron. Express **11** (2014) 20140837. DOI:10.1587/elex.11.20140837

[3] I.-S. Yang and O.-K. Kwon: IEEE Trans. Consum. Electron. **57** (2011) 1027. DOI:10.1109/TCE.2011.6018851

[4] K.-D. Kim, S.-H. Byun, Y.-K. Choi, J.-H. Baek, H.-H. Cho, J. K. Park, H.-Y. Ahn, C.-J. Lee, M.-S. Cho, J.-H. Lee, S.-W. Kim, H.-D. Kwon, Y.-Y. Choi, H. Na, J. Park, Y.-J. Shin, K. Jang, G. Hwang and M. Lee: IEEE Proc. of ISSCC (2012) 116. DOI:10.1109/ISSCC.2012.6176943

[5] Y. Sugita, K. Kida and S. Yamagishi: IEICE Trans. Electron. **96** (2013) 1384. DOI:10.1587/transele.E96.C.1384

[6] H. Haga, J. Yanase, Y. Nonaka, D. Sugimoto, K. Takatori and H. Asada: SID DIGEST (2012) 489. DOI:10.1002/j.2168-0159.2012.tb05824.x

[7] H. Klein: White paper. Cypress Semiconductor Corp. (2013).

[8] E. Anderson: White paper. Cypress Semiconductor Corp. (2013).

[9] K. Lim, K.-S. Jung, C.-S. Jang, J.-S. Baek and I.-B. Kang: J. Display Technol. **9** (2013) 520. DOI:10.1109/JDT.2013.2243900


DOI: 10.1587/elex.12.20150683
Received August 6, 2015
Accepted August 26, 2015
Publicized September 9, 2015
Copyedited October 10, 2015

[10] G. Sullivan, J. Ohm, W.-J. Han and T. Wiegand: IEEE Trans. Circuits Syst. Video Technol. **22** (2012) 1649. DOI:10.1109/TCSVT.2012.2221191

## 1 Introduction

Since the development of touch screens devices, various types of touch screens devices have been developed including resistive, infrared, ultrasonic, and capacitive. Among the various types, the mutual capacitive type have rapidly increased mostly for mobile devices, for its advantages including high response time to input, high light transparency and multi-touch capability. However, it is difficult to obtain a high SNR (signal-to-noise ratio) in the mutual capacitive sensors because they should deal with very small signals in limited sensing time [1], making it sensitive to noise. Among the various noise sources that can occur in touch screens [2], display noise is the main cause that lowers touch screen SNR, and many researches has explored to solve this problem [3, 4]. However, the demand for thin and high resolution display has increased display noise, and the demand for lower drive voltage and large screen display reduced signal, making it difficult to obtain an enough SNR resorting to existing methods. Such degradation in SNR is becoming a direct reason that limits the range to which touch screens are applicable, including large screens and in-cell touch [5, 6, 7]. Therefore, a method that effectively removes display noise would increase SNR, enabling touch screen devices in larger screens and thin displays. In this paper, we analyzed display noise and proposed a method that reduces display noise in touch screens devices.

## 2 Display noise characteristics

As the display becomes thinner, the more severe display noise becomes. Touch screen panel is located above the display panel, and comes with a certain capacitance by a fringing electric field between the DE (driving electrode) and SE (sensing electrode) on the ITO (indium-Tin-Oxide) film, as shown in Fig. 1(a). When the human body comes in contact with the touch screen panel, as shown in Fig. 1(b), it steals electrical field. The capacitance variation becomes the signal of the touch screen. In an ideal environment, this variation stays constant. However, in actual situations, parasitic capacitance as shown in $C1$, $C2$ of Fig. 1 is formed. As shown in Eq. (1), even if the dielectric constant $\varepsilon$ between electrodes and the driving voltage $V$ remain constant, the incident charge $Q$ be increased by the increase in capacitance $C$ that is in direct proportion with the area of electrode plate $A$ and in inverse proportion with distance $d$.

$$Q = CV = \varepsilon\left(\frac{A}{d}\right)V \tag{1}$$

Existing touch screens such as Fig. 1(a) are getting thinner such as (b) due to regarding design request such as better optical features and thinner display. As the reduction of $d$ from $d1$ to $d2$ increase the parasitic capacitance $C$ from $C1$ to $C2$.

Also, incident noise charge $Q$ coming from its high capacitive coupling, are increasing due to the absence of the existing air gap and other shielding layer in


DOI: 10.1587/elex.12.20150683
Received August 6, 2015
Accepted August 26, 2015
Publicized September 9, 2015
Copyedited October 10, 2015

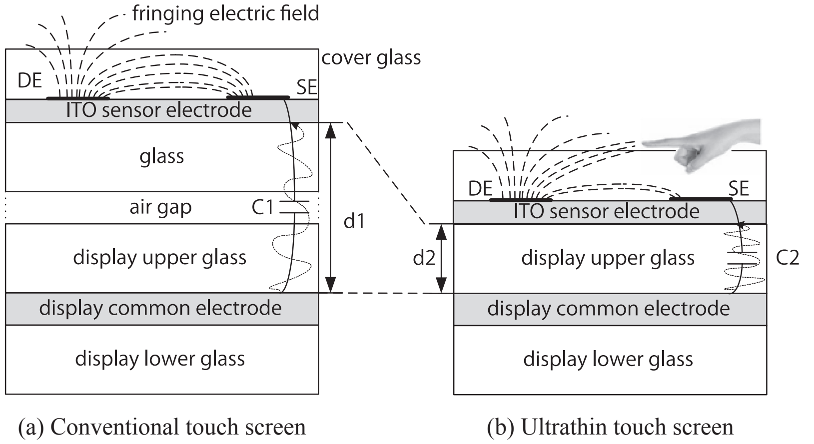



**Fig. 1.** Touch screen panel technical trend.

newer technologies. Especially in-cell touch screen devices, the results above mentioned make noise larger and eventually making touch recognition even more difficult. A Large screen display also increase the parasitic capacitance $C$ due to $A$.

In order to understand the characteristics of display noise, we measured noise in images of 21 different patterns in seven inch $800 \times 400$ resolution LCD with touch screens. The display used in the measurement adopts a normally white LCD panel and 2-dot inversion, 2:1 multiplexing driving, DCVCOM type. We measured display noise with various images because DCVCOM noise largely depends on the image displayed [8]. Fig. 2(a) is the worst noise pattern of the 21 images where all sub-pixels are operated with the same polarity, either of positive or negative voltage. Therefore, the maximum noise can be excited to the touch channel in the experiment. Also, these driving polarities are inverted for each image frame (at every active Vsync signal). As a result, the noise swing manifested across a wide range, from 0.8 V∼−1.5 V. The white pattern image in Fig. 2(b) is a waveform with the least noise, because the white image requires the smallest voltage across all of pixels to operate in the normally-white mode display. It shows a small swing range of 0.16 V∼−0.16 V. As shown in Fig. 2, sizes and patterns of noise varied widely for the display images, and all 21 patterns showed different results. However, these noise figures share a feature in which noise patterns repeat periodically when sharing the same output image. The period of noise depends on the display driving method, and measured noise comes with a period of 32 µs as shown in Fig. 2(a), according to Hsync period. The local peaks of the worst image pattern are appeared

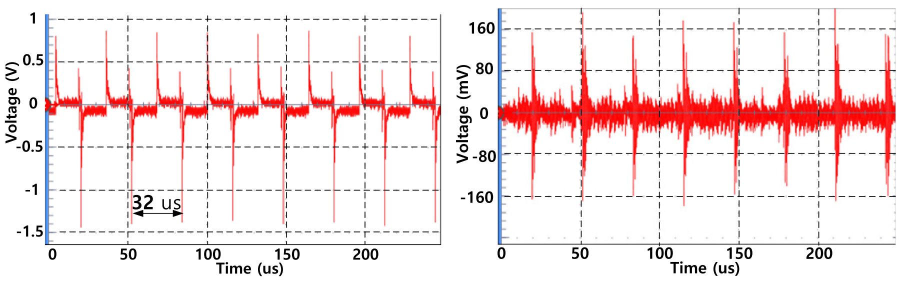



**Fig. 2.** Measured display noise patterns.


DOI: 10.1587/elex.12.20150683
Received August 6, 2015
Accepted August 26, 2015
Publicized September 9, 2015
Copyedited October 10, 2015

on every 16 µs because the 2:1 multiplexer used in operating two adjacent subpixels. Because the most of display noise is coming from the driving signal of the subpixel electrode, its size and patterns are different depending on display resolution, operation method and the display images. This also alters the charge that is transmitted to the touch sensors and makes noise removal difficult.

## 3 Inverted TX driving technique

Capacitive touch sensors determine the user-touch as two sets of co-planar electrodes are aligned orthogonally on a thin ITO film, sensing capacitive signals. Although detailed methods vary, simplifying the general sensing method reveals the following process that is required in order to obtain touch information:

i) *Driving (Modulation)*: stimulating driving electrode (TX)
ii) *Capacitance Sensing*: receiving capacitance at each sensing line as C-to-V conversion
iii) *Analog processing (Demodulation and filtering)*: performing dot-product to calculate capacitance data at each junction
iv) *Analog to digital converter (ADC)*: convert analog to digital
v) *Digital processing*: multi-touch algorithm (ambient compensation, noise suppression and touch position extraction)

A more detailed explanation of procedures i)–iii) which we attempts to cover, could be expressed as Eq. (2–4).

$$r_{jt} = \sum_i (h_{it} \times s_{ij}) \tag{2}$$

$$r'_{jt} = \sum_i (h_{it} \times s_{ij}) + Noise_{jt} \tag{3}$$

$$s'_{ij} = \sum_t (h_{it} \times r'_{jt}) \tag{4}$$

where $h_{it}$ refers to the modulating signals, forming the matrix of driving patterns [1]. $i$ refers to the driving line number, and becomes the row index of the matrix. $t$ refers to the driving time of TX, and becomes the column index of the driving pattern, $h$. $s_{ij}$ refers to the mutual capacitive signal at $(i, j)$, the driving and sensing line location. $r_{jt}$ in Eq. (2) refers to an aggregated capacitive signal acquired from a sensing channel in an ideal environment and $j$ refers to the sensing line number and becomes the row index of $r_{jt}$. $r'_{jt}$ refers to an aggregated capacitive signal in a real environment and it is acquired by adding $Noise_{jt}$ to $r_{jt}$ as shown in Eq. (3). We can get the value of the capacitance for each TX to Rx segment as the result of demodulation when $r'_{jt}$ is demodulated with $h_{it}$ by dot-product, as shown in Eq. (4). We can further determine the existence of touch by obtaining the difference of the capacitance, between the touch and non-touch event.

Here, we reduced the periodic display noise by using the inverted driving patterns. Suppose that there are two time frames for touch data acquisition. To obtain touch information for the first frame, the demodulation results are obtained by the procedures in Eq. (2–4). By the inverted driving signal against the first one, another demodulation results will be obtained. A sensing value for the capacitance, where the noise are added to the $-r_{jt}$ corresponding to the inverted signals, could be


DOI: 10.1587/elex.12.20150683
Received August 6, 2015
Accepted August 26, 2015
Publicized September 9, 2015
Copyedited October 10, 2015

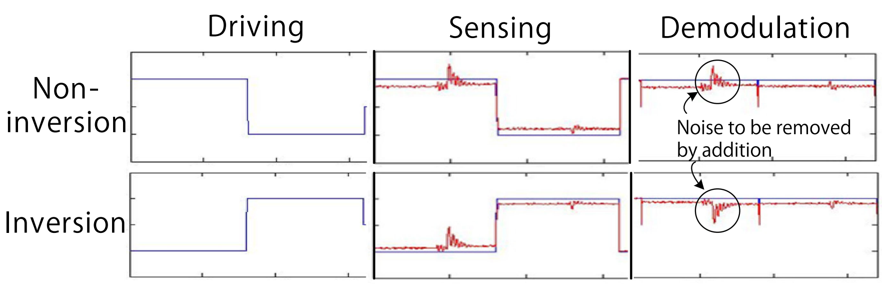
expressed as $I\_r'_{jt}$ as shown in Eq. (5). The $I\_s'_{ij}$ can be expressed as shown in Eq. (6) when the $I\_r'_{jt}$ in Eq. (5) is demodulated with $-h_{it}$ that is inverted to the first frame.

$$I\_r'_{jt} = \sum_i (-h_{it} \times s_{ij}) + Noise_{jt} \tag{5}$$

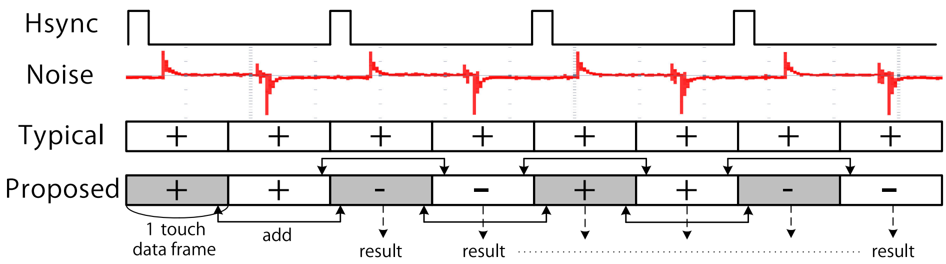
$$I\_s'_{ij} = \sum_t (-h_{it} \times I\_r'_{jt}) \tag{6}$$

Fig. 3(a) illustrates the front-end process that applies inverted driving technique. Inverted TX signals are 180° phase shifted with non-inverse signals such as in *inverse driving* of Fig. 3(a). As the $r_{jt}$, measured through the sensing line, is influenced by the drive signal, it manifests in the format of $-r_{jt}$ due to $-h_{it}$. According to the periodicity of display noise, the two frames results of capacitance sensing step include similar noise figures because the periodic noise is added to $r_{jt}$. As the second frame uses inverted TXs to the first frame, the corresponding demodulated signal restores $r_{jt}$ that is the same as the one when using the non-inverted signal. However, since the noise is added to drive signals, it is inverted by multiplying by $-h_{it}$, and becomes the demodulated $-Noise_{jt}$ in Eq. (6).

Fig. 3(b) is one of the examples to acquire noise periodicity and to set the sensing time for a touch data frame identically between typical and proposed techniques when such noise exists caused by 2:1 multiplexed display. The existing touch procedure is indicated as "Typical" and the proposed two phase driving technique as "Proposed". In Fig. 3(b), squares with '+' or '−' signs means that one touch data frame goes through three steps as driving, sensing and demodulation. In the proposed technique, a gray square is added to the prior gray square and a white square is added to the prior white square to get the present result. The first result can be obtained after the first two touch frames and the present result is obtained by adding the present result to the result of the two touch frames before. When the first




(a) General sensing process of inverted and non-inverted driving signals




(b) An example of two techniques suitable for 2:1 multiplexed driving

**Fig. 3.** Comparison for the existing and the proposed techniques

© IEICE 2015
DOI: 10.1587/elex.12.20150683
Received August 6, 2015
Accepted August 26, 2015
Publicized September 9, 2015
Copyedited October 10, 2015

two touch frames has elapsed, the proposed technique acquires the capacitive signal that is twice as large as in the original one and its periodic noise is removed on the same sensing time because inverted driving only inverts the noise polarity.

## 4 Simulation result

In order to enhance simulation accuracy and replicate the environment so that it closely resembled the actual environment, touch and display panel features including the display noise and the decrement in mutual capacitance due to a touch event, used the real measurement data that was obtained through experiments. To model the conversion process from the driving signal to the sensing value at the analog front-end circuit in a receiver, we obtained the transfer functions of the charge amplifier and TX-to-RX network through SPICE simulations and applied them to the MATLAB simulation. Each driving signal for a unit time was 48 µs with pulse duration of 4 µs. According to integration procedures, accumulated capacitive signal and compared the SNR under the same conditions. A SNR is defined as the average sensing value of the junction capacitance (= average signal level) divided by its standard deviation (= average noise level) [1, 9].

Compared to the results of the conventional method in Table I, the proposed algorithm showed 5.39 dB higher SNR on average and also improved the SNR as 5.64 dB higher in the worst noise pattern. In an environment where all conditions remain the same, the proposed algorithm shows higher SNR in all cases. As the results, the proposed algorithm is demonstrated that it is possible to effectively remove the display noise in all cases. We expect that it can be also effective the environment in which the display images change fast because their spatial and temporal correlation also affect consecutive touch data frames [10].

**Table I.** SNR comparison between a typical touch process and the proposed method

| Display image pattern | White | Black | Red | Green | Blue | Worst (Y-C-B-R) |
|---|---|---|---|---|---|---|
| Typical SNR [dB] | 51.98 | 35.99 | 39.70 | 39.55 | 39.85 | 28.83 |
| Proposed SNR [dB] | 55.57 | 41.89 | 45.46 | 45.25 | 45.59 | 34.47 |

## 5 Conclusions

In this paper, we proposed a method to effectively remove display noise. Whereas touch signals are restored to original signals in the demodulation step according to drive signals, inverted drive and demodulation signals invert the noise in the demodulation step. Therefore, if the same noise figures are excited to successive two acquisition frames, the noise of the first frame can be removed by the noise inverted in the second frame. Since a display noise is characterized by periodicity, it is easy to build up similar noise at each touch frame by synchronizing with the display operation period. Therefore, we were effectively able to remove display noise and obtained 5.39 dB higher SNR averagely compared to typical methods, and it shows higher SNR in all cases.


DOI: 10.1587/elex.12.20150683
Received August 6, 2015
Accepted August 26, 2015
Publicized September 9, 2015
Copyedited October 10, 2015