Implementation of a Touch Screen Panel With Triangle Twist Sensor Pattern and Controller IC

Hyeokjin Lim, Youngjun Jun, Sanghyun Han, Sukky Ha, Yunho Jung, *Senior Member, IEEE*, and Seongjoo Lee, *Senior Member, IEEE*

***Abstract*—In this paper, a cost-effective touch screen panel with triangle twist (TAT) sensor pattern and its calibration algorithm are proposed. For touch detection, the proposed touch screen panel consists of one drive line to receive sensing information from two sensing lines. The proposed touch screen panel reduces the number of signal lines and bonding pads by about 42% compared to conventional touch screen panels, which decrease both the manufacturing difficulty and costs. By a simple calibration algorithm for the proposed touch screen panel with a TAT sensor pattern in a micro controller unit, the touch performance with respect to accuracy, precision, and linearity is considerably enhanced. The proposed touch screen panel shows reliable touch accuracy with errors less than 2 mm. As shown in the implementation results, the proposed touch screen panel is very effective in reducing manufacturing costs of touch devices, which suffer from implementation issues of signal lines caused by adopting a huge number of touch sensors.**

***Index Terms*—Triangle twist (TAT), touch screen panel, touch controller, touch calibration.**

I. Introduction

WITH the development of electrical engineering and information technologies, the importance of electronics in everyday life including the work environments is growing. Consequently nowadays, various kinds of electronics are available in the market. Especially for mobile electronics such as laptops, cell phones, portable multimedia players, and tablet PCs, there appear to be a number of new designs every day.

As the number of kinds of electronics increases and their functions become high-technologized and complex, there is an increasing need for the development of an easy and intuitive user-interface. As such, input devices for the demand touch screen devices are increasingly used in numerous electronics.

Touch screen devices can detect the location contacted by the user on the display and use the information as an input to control many functions of the electronics including display control. In manufacturing the touch screen device, the amount of signal lines and bonding pads contribute to increasing of manufacturing difficulties [11].

Conventional touch screens use two sensor panels to acquire *X*- and *Y*-axis sensing values which are then calibrated to find the touch point [1]–[8]. Due to the usage of multiple panels that require tact time and bridge inserts, however, touch sensitivity and visibility are low and yet the manufacturing is costly [20], [21].

Recently, low cost touch screens such as plastic film and cover glass film multi-touch sensor [12], which are composed of one touch pattern panel layer and use a touch controller for calibration, have formed the majority of the touch screen market [13]–[20]. Existing sensor pattern methods detect contact using multiple drive lines and sensing lines arranged in pixel shapes, and the contact data are computed through a touch controller to find the touch point. Thus, the conventional methods require many signal lines that raise resistance problems, expand bonding pad areas contributing to manufacturing difficulty, and lower the performance of touch accuracy due to increased dead zones [9].

In this paper, triangle twist (TAT) sensor pattern is proposed to address the problems of the 2-layer and the single touch screen panel. For touch detection, the TAT pattern shares one drive line (sensor) to receive sensing information from two sensing lines for each touch pixel. By sharing one drive line for two sensing lines to receive touch sensitivity, the proposed touch screen panel can reduce the number of signal lines and bonding pads by 42% compared to conventional single-layer touch screen panels, and also diminish the manufacturing difficulty and costs and the number of dead zones. Additionally, the touch performance is increased by using a simple TAT pattern calibration algorithm which can be easily implemented as software working in the micro controller unit (MCU).

In Section II, the previous touch screen technology and their problems are introduced. In Section III, the structure of the proposed touch screen panel and the difference from the previous touch screen panels are explained. In Section IV, the calibration method implemented on the touch controller for the proposed touch screen panel is explained. In Section V, the performance of proposed touch screen and detailed specification of touch controller integrated circuits (ICs) are shown, and in Section VI, the study is summarized and concluded.

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H. Lim, J. Jun, and S. Lee are with the Department of Electrical Engineering, Sejong University, Seoul 143-747, South Korea (e-mail: budlbudl@itsoc.sejong.ac.kr; jdancor@itsoc.sejong.ac.kr; seongjoo@sejong.ac.kr).

S. Han is with Leading UI Co., Ltd., Seoul 135-080, South Korea (e-mail: fixfault@leadingui.com).

S. Ha is with Chipsbrain Co., Ltd., Seoul 03193, South Korea (e-mail: ares@chipsbrain.co.kr).

Y. Jung is with the School of Electronics, Telecommunication and Computer Engineering, Korea Aerospace University, Goyang 412-791, South Korea (e-mail: yjung@kau.ac.kr).

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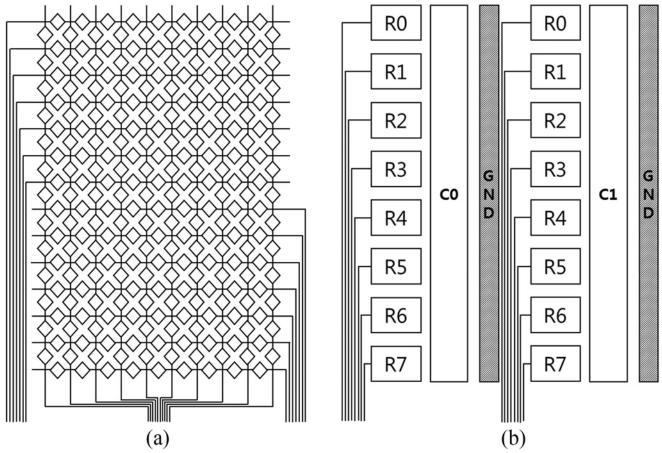

Fig. 1. Conventional touch screen panels; (a) 2-layer with three mask [23], (b) single layer with one mask [24].

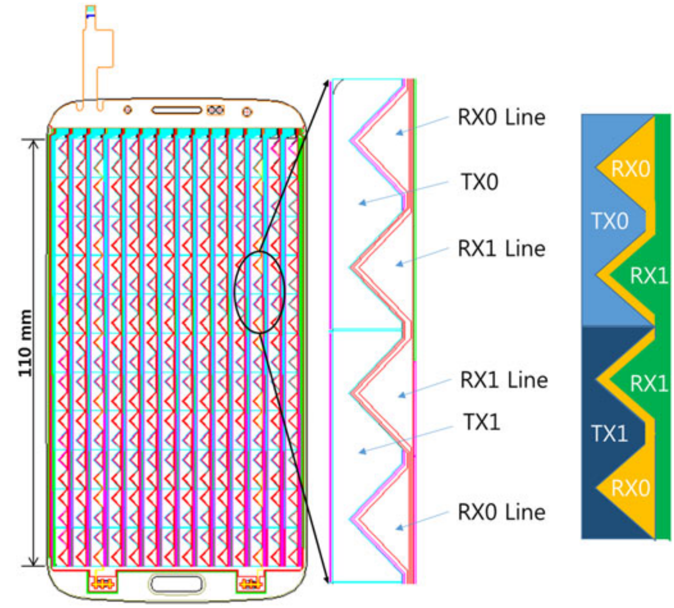

Fig. 2. TAT pattern circuit of 5-inch touch screen panel.

II. Conventional Touch Screen Panel

Conventional touch screens require a process with more than three masks [23]. To acquire *X*-(vertical) and *Y*-(horizontal) axis sensor values, 2-layer sensor pattern is employed as shown in (a) of Fig. 1. With the *X*- and *Y*-axis data, a touch controller finds touch points by utilizing simple calibration algorithms such as scaling or rotation [21], [22]. But as they require more than three masks, the cost is high and a bridge to connect the masks is necessary, which results in lowering visibility and increasing calibration tact time.

Thus recently, the touch screens that use a touch controller and a single layer touch pattern panel such as single Plastic Film (PF1) and single cover Glass Film (GF1) multi-touch sensors have drawn much attention in industrial fields [24]. Conventional touch screen panels, called mutual capacitance touch screen panels [10], have the structures of shown in (b) of Fig. 1.

The mutual capacitance touch screen panels have multiple drive lines and sensing lines crossing each other, which are arranged in pixels. The touch event is detected by the capacitance difference of the drive and sensing lines in the touch screen panel, and the touch controller is used to find the touch point [13]–[20]. The touch screen panels also improve touch event detection with a ground (GND) isolation bar that reducing the unintended mutual capacitance difference. A single touch pattern panel layer shows high touch sensitivity, and yet require less number of masks and can be manufactured thinly in volume.

However, as shown in (b) of Fig. 1, the touch screen panels require many wires for drive lines (R#) and sensing lines (C#) because they are arranged in pixels. The number of wires mountable is limited by the size requirement, causing RC delay due to wire resistance problem and expanding bonding pad area. An increased number of wires also results in an extended area of dead zone where wires are placed and cannot be detected by touch sensors. This consequently decreases performance with respect to accuracy, precision, and linearity. Accuracy is closeness of the measured indicator to the actual coordinate. Precision measures the extent to which the same coordinate is repeatedly shown for every trial. Linearity represents the extent to which measures value connected in a line diverging from the desired values. The units are in ±mm. Also, placing many lines with small spatial gaps requires high manufacturing technology, which increases the manufacturing costs or decreases the sensor yield.

III. Proposed Touch Screen Panel

The proposed touch screen panel in this study adopts a TAT sensor pattern. For touch detection, the TAT sensor pattern consists of one drive line (TX0) to receive the sensing information from two sensing lines (RX0 and RX1) for each touch pixel. The proposed TAT touch screen panel is operated by the mutual capacitance method which utilizes the difference between capacitance of the TX and RX lines in the panel. The mutual capacitance method is proceeded in consecutive order. First, when the signal is permitted to TX0, TX1 holds GND and the abandoned current is measured by the parasitic capacitance of RX0 and RX1. Next, the signal is applied to TX1 while TX0 maintains GND. If the touch event is occurred through insulator film, it can be detected from the value of current which varies with the difference of parasitic capacitance between TX and RX. Fig. 2 shows the proposed TAT sensor pattern circuit of the 5-inch touch screen panel. The drive lines and sensing lines of conventional patterns in Fig. 1 are utilized as TX and RX in Fig. 2, respectively.

Fig. 3 presents the structure of 5-inch touch screen panels with bonding pads. The difference between the conventional and proposed touch screen panels is in the numbers of TX and RX, which are respectively 20 and 12 in the conventional touch screen panel and 10 and 24 in the proposed touch screen panel as shown in Fig. 3.

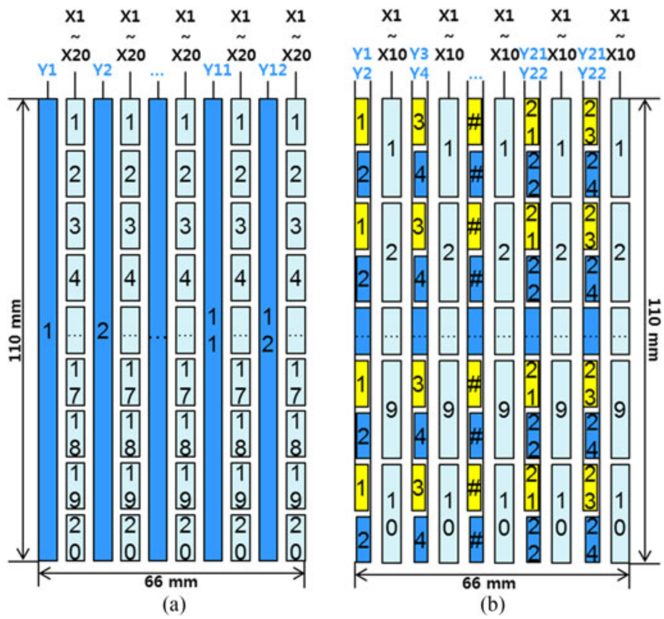

Fig. 3. Structure of 5-inch touch screen panels; (a) with conventional bonding pads [24], (b) with proposed bonding pads.

TABLE I
SPECIFICATION SUMMARY OF CONVENTIONAL AND PROPOSED TOUCH SCREEN PANELS

Properties	Conventional[24]	Proposed	Note
Sensor type	GF1	GF1	
ITO pattern type	Linear	Triangle twist	
Pattern pitch	6.1mm	6.5mm	
Diagonal size	5-inch	5-inch	
Channel	TX = 20,RX = 12	TX = 10,RX = 24	
Numberof Line	252	144	Reduced 42%
Number of FPCB bonding pad	252	144	Reduced 42%

The number of wires and bonding pads required for the conventional and proposed touch screen panels as the follows:

$$N_{\text{Conventional}} = N_{\text{Tx}} \times N_{\text{Rx}} + N_{\text{Bus}} \tag{1}$$

$$N_{\text{Proposed}} = N_{\text{Tx}} \times (N_{\text{Rx}}/2) + N_{\text{Bus}} \tag{2}$$

where, $N_{\text{Conventional}}$ and N_{Proposed} denote the sum of the number of signal line by equation (1) and (2). N_{Tx}, N_{Rx} and N_{Bus} are the number of TX lines, RX lines, and bus lines, respectively.

The number of signal lines is the sum of the number of lines connected to TX and RX and the number of bus lines connected to RX. The number of bus lines is the same as the number of RX, and the number of full printed circuit board (FPCB) bonding pads is the same as the number of signal lines.

The Specification summary of conventional and proposed touch screen panels is shown in Table I. The proposed touch screen panel has about 42% less number of wires and bonding pads compared to the conventional touch screen panel, and has the advantage of reducing manufacturing costs and difficulties.

In the proposed architecture, however, the RX0 and RX1 are placed in different positions from the TX0 sensor as shown in Fig. 2. This causes differences in touch sensitivity of RX0 and RX1. Since the signal from RX1 travels via the RX0 wire, the sensitivity of RX0 has been significantly higher than that of RX1 for the same touch input given.

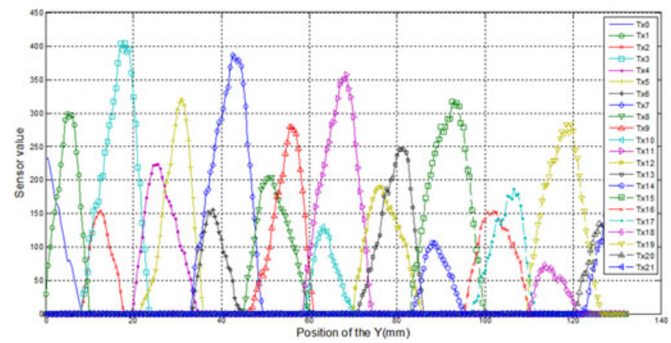

Fig. 4. Sensor value of each position of the Y.

Due to the different touch sensitivity design, when a mathematical mean value is used to find the touch coordinate, the touch performance is decreased compared to that of the conventional touch screen panel in Fig. 1. In this case, there are two methods to improve the performance of the touch screen panel with an asymmetric pattern. One is adding a GND dummy between the TX and RX sensors to reduce the sensitivity difference between RX0 and RX1. The other is applying a calibration algorithm to enhance the asymmetric sensitivities between RX0 and RX1. Inserting the GND dummy may reduce the overall sensor sensitivity, and therefore, the calibration algorithm is proposed in this paper to improve sensitivity.

IV. Calibration Algorithms

The touch screen panel with the proposed TAT sensor pattern can reduce manufacturing costs, but may reduce the touch sensitivity. To solve this problem, a touch sensor calibration algorithm is proposed, which can be easily implemented as software working in a simple MCU.

Fig. 4 shows the raw sensor value when the touch screen is touched with 0.5 mm intervals by using an 8 mm round conductor. This read sensor data is processed by the calibration algorithms. The calibration undergoes two steps. In the first step, the weighted average of each sensor data is obtained from the mathematical mean with equations (3) and (4). The weighted average is used in order to reduce sampling noise of sensor data which is generated when the touch screen panel turns on and off. Next, the first calibration touch data are estimated by the interpolation of weighted data

$$X(k) = \sum_{n=0}^{N-1} b_n * x(k-n) \tag{3}$$

$$b_n = \begin{cases} 0 & \text{for the first on or more data x(k)} \\ 1/M & \text{for the later x(k)} \end{cases} \tag{4}$$

where, X(k) is the refined touch data, x(k) is the raw touch data, b_n is the coefficient or weight factor, N is the number of

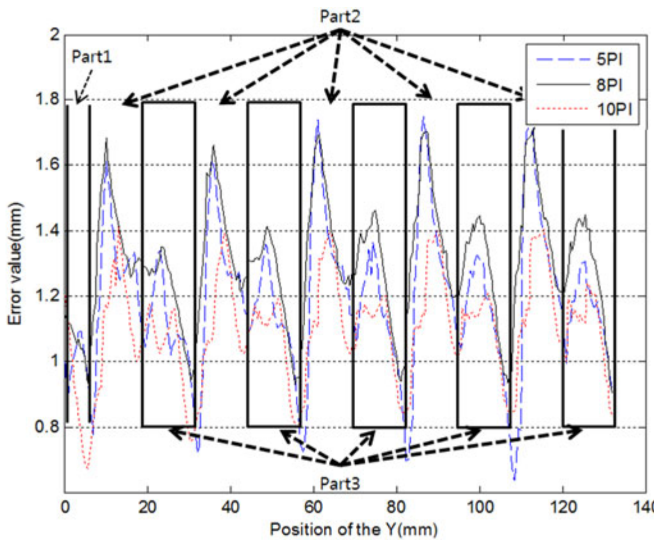

Fig. 5. Errors of each PI touched data after the first calibration.

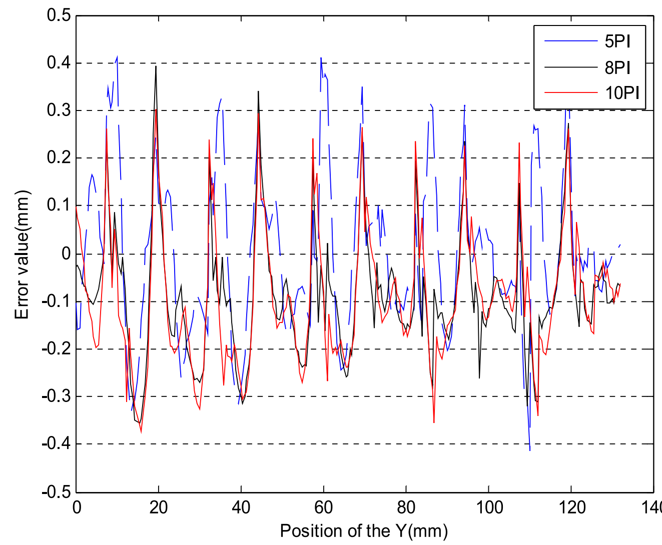

Fig. 6. Errors of each PI touched data after the second calibration.

TABLE II
PART DIVISION FOR CORRECTION

Type	Repeat	Magnitude	Equation
Part 1	No	-	(5)
Part 2	Yes	Big	(5)
Part 3	Yes	Small	(5)

TABLE III
RMSE OF EACH PI TOUCHED DATA

	5 PI	8 PI	10 PI	Total
Coventional [24]	1.7045	1.5805	1.6897	1.6858
Proposed	0.1640	0.1493	0.1591	0.1574

the multiple samples for each touch coordinate, and M is the number of averaged multiple data $(\mathrm{M} < \mathrm{N})$.

Fig. 5 shows the error values of *Y* after the first calibration for vertically downwards touches at 0.5 mm intervals by using 5, 8, and 10 PI poles (diameter of round conductor). The second calibration utilizes the statistics of errors for the touches of Fig. 5. Then the initially calibrated *Y* location data are subtracted from error values for each *Y* location. Therefore, the calibration can be done easily if a simple formulation can describe the waveform in Fig. 5

$$Y_{\text{compensated}} = \begin{cases} A_1 \times Y + B_1, & \text{when } Y \text{ in Part1} \\ A_2 \times \sin(B_2 \times Y + C_2), & \text{otherwise} \end{cases} \quad (5)$$

where, A1 and B1 denote a scaling factor and an offset value of the linear equation, respectively. A2, B2 and C2 are a scaling factor, a frequency value, and a phase offset of the sinusoidal equation, respectively.

To describe the waveform in Fig. 5 with a first-order equation, the characteristics of the waveform is divided into three parts as in Table II.

Part 1 can be described by a simple linear equation (5) as it is a waveform not repeated on the front of the bonding pads. Parts 2 and 3 are waveforms with high and low powers, respectively, and can be described with a sinusoidal equation (5). In both cases, the final value of $Y_{\text{compensated}}$ having to be adjusted depending on the value of calibrated in the first step.

The variables can be found with the values that confer the minimum root mean square error (RMSE) value for each size PI. Since the similar patterns are repeated in Parts 2 and 3, the equations for the smallest RMSE values are used. Variables are found by changing the scaling factor and calculated RMSE repeatedly. From the experimental results, the optimum values of variables are found as follows: $\mathrm{A1} = -0.044$, $\mathrm{B1} = 1.104$, $\mathrm{A2} = 1.588$, $\mathrm{B2} = 0.185$ and $\mathrm{C2} = 0.3963$ in Part 2 and $\mathrm{A2} = 1.286$, $\mathrm{B2} = 0.124$ and $\mathrm{C2} = 0.8767$ in Part 3.

To reduce the number of computations and the complexity of the calibration algorithm, instead of floating the calculation to find the values to be calibrated from Y data, the resulting values of Parts 1, 2, and 3 are pre-calculated for all Y locations, saved in the ROM, and accessed for the corresponding Y values.

Fig. 6 shows the errors of the location actually touched and estimated data for each *Y* value with errors less than ± 0.4 mm. Table III presents the RMSE of each PI touched data. The total performance, with respect to RMSE, of the conventional and the proposed methods are 1.6858 and 0.1574 mm, respectively. Unlike the conventional technique with more than 1.0 mm of RMSE, the proposed one shows significant performance enhancement by reducing RMSE to about 0.15 mm with adopting the smaller number of signal lines.

V. IMPLEMENTATION RESULTS

Fig. 7 shows an image of the final product employing the proposed touch screen and touch controller. The proposed calibration algorithm runs as the touch controller IC software on a

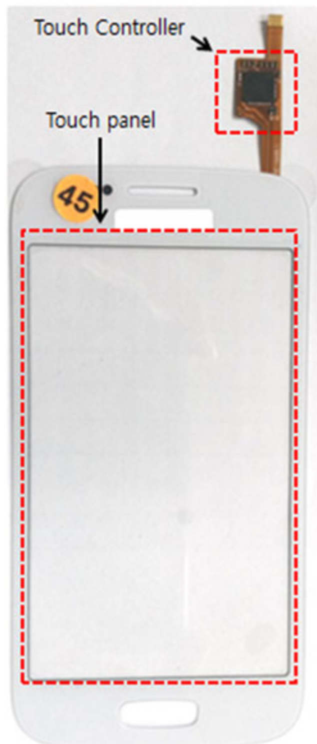

Fig. 7. Image of final product employing the proposed touch screen panel and controller.

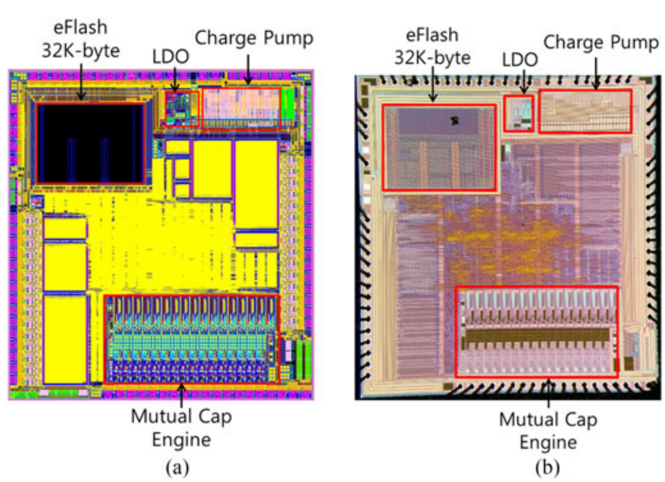

Fig. 8. Touch controller IC (a) Layout image (b) Decapsulated image of Touch controller IC.

32-bit MCU. Fig. 8 shows the layout and decapsulated images of the proposed touch controller IC. The chip is manufactured through 0.13um eFlash technology with the size of 3100 um and a 66 pin package. A low drop out gets 2.6-3.6 V to generate the supply voltage of 1.5 V. A charge pump amplifies 2.6-3.6 V of input voltage to about 16 V to increase TX pad output voltages, which increase the SNR. Mutual cap engines are in an analog front end connected to RX signal lines, measuring electrostatic capacity and detecting capacity changes for the touch. It is the most important part of the touch screen controller IC. The total current consumed in the touch controller IC is about 18 mA in active mode and is less than 20 uA in idle mode when the external general purpose IOs are only activated.

VI. Conclusion

In this paper, a cost-effective touch screen panel with a TAT sensor pattern and its calibration algorithm were proposed. By sharing one drive line for two sensing lines to receive touch sensitivity, the proposed touch screen panel reduced the number of signal lines and bonding pads by 42% compared to conventional touch screen panels, and also reduced the manufacturing difficulty and costs. The reduced number of signal lines lowered the manufacturing difficulty by reducing RC delay and the number of bonding pads and reduced the area of the dead zone. By utilizing the simple calibration method for the proposed TAT sensor pattern, which were easily implemented as software in the low-cost MCU, errors were reduced to less than 2 mm and the touch accuracy was considerably enhanced. From the implementation results, it was found that the proposed touch screen panel was very effective in reducing the manufacturing costs of touch devices, which suffered from implementation issues of signal lines caused by adopting the huge number of touch sensors.

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Hyeokjin Lim was born in Mokpo, Korea, in 1988. He received the B.S. and M.S. degrees in electrical engineering from Sejong University, Seoul, Korea, in 2012 and 2014, respectively. He is currently working toward the Ph.D. degree at Sejong University.

His current research interests include SoC design for digital spectrum analyzer and touch screen devices.

Youngjun Jun was born in Suwon, Korea, in 1989. He received the B.S. degree in electrical engineering from Sejong University, Seoul, Korea, in 2014. He is currently working toward the M.S. degree at Sejong University.

His current research interests include SoC design for touch screen device.

Sanghyun Han was born in Seoul, Korea, in 1970. He received the bachelor's degree in electronic engineering from Ajou University, Suwon, Gyeonggi-do, Korea, in 1996.

He worked for Leading UI Co., Ltd. He has been in charge of SoC architecture and analog and digital mixed design.

Sukky Ha receives the B.S. and M.S. degrees in electronic engineering from Sunchon National University, Sunchon, Korea, in 1998 and 2000, respectively.

From 2004 to 2011, he was an Engineer in the System LSI Division, Neowine Co., Ltd., Seongnam, Korea. He is currently a Chief Research Engineer of Chipsbrain Co., Ltd., Seoul, Korea. His current research interests include SoC design for security authentication and image processing systems.

Yunho Jung (M'04–SM'13) received the B.S., M.S., and Ph.D. degrees in electrical and electronic engineering from Yonsei University, Seoul, Korea, in 1998, 2000, and 2005, respectively.

From 2005 to 2007, he was a Senior Engineer in the Wireless Device Solution Team, Communication Research Center, Telecommunication Network Division, Samsung Electronics Co. Ltd., Suwon, Korea. From 2007 to 2008, he was a Research Professor at the Institute of TMS Information Technology, Yonsei University, Seoul, Korea. He is currently an Assistant Professor in the School of Electronics, Telecommunication, and Computer Engineering, Korea Aerospace University, Goyang-si, Korea. His research interests include the signal processing algorithm and SoC/VLSI implementation for the wireless communication systems and image processing systems.

Seongjoo Lee (M'96–SM'11) received the B.S., M.S., and Ph.D. degrees in electrical and electronic engineering from Yonsei University, Seoul, Korea, in 1993, 1998, and 2002, respectively.

From 2002 to 2003, he was a Senior Research Engineer at the IT SoC Research Center and the ASIC Research Center, Yonsei University, Seoul, Korea. From 2003 to 2005, he was a Senior Engineer in the Core Tech Sector, Visual-Display Division, Samsung Electronics Co. Ltd., Suwon, Korea. He was a Research Professor at the IT Center and the IT SoC Research Center, Yonsei University, Seoul, Korea from 2005 and to 2006. He is currently a Professor in the Department of Electrical Engineering at Sejong University, Seoul, Korea. His current research interests include SoC design for high-speed wireless communication systems and image processing systems.