10.3 Multi-Way Interactive Capacitive Touch System with Palm Rejection of Active Stylus for 86" Touch Screen Panels

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There have been many recent advances in capacitive touch systems (CTSs) [1-5]. Multiple-way interactive CTSs (MI-CTSs) that can simultaneously communicate with each other on a real-time basis have been demanded; however, such MI-CTSs have not yet been reported. In addition, palm rejection in an active stylus would be a very useful feature for when the palm inevitably touches a touch screen panel (TSP) [5]. In this paper, an MI-CTS with the palm rejection for an active stylus is reported. This allows simultaneous interaction between CTSs on a real-time basis, while lessening the computational load.

Figure 10.3.1 shows a block diagram of the MI-CTS with multiple CTSs, each of which consists of a TSP, display, analog front-end (AFE) IC, and MCU. The MCU is implemented with the touch coordinate extraction block and multiple-way control block including the touch coordinate transform and display blocks, the touch coordinate TX and RX, and a Wi-Fi block. When the AFE IC sends FFT data to the MCU in CTS<1>, the touch coordinate extraction block extracts the touch coordinates of CTS<1> (TC_1<1>), where CTS<i> is the ith CTP in the MI-CTS, and TC_i<j> is the coordinates touched at CTS<i> and displayed in CTS<j>. TC_1<1> are then sent to the multiple-way control block. The touch coordinate transform block, which has all the display resolutions of CTS<1> to CTS<N>, converts TC_1<1> to TC_1<2>~TC_1<N> to be fitted to the corresponding display resolutions of the remaining CTSs. TC_1<2>~TC_1<N> are then sequentially transferred to the corresponding CTSs through the touch coordinate TX and Wi-Fi block. In addition, the touch coordinate RX serially receives TC_2<1>~TC_N<1> through the Wi-Fi block from the remaining CTSs. The touch coordinate display block then combines TC_1<1>~TC_N<1> and sends them to the display of CTS<1> so that the touch coordinates of all the CTSs can be simultaneously displayed in CTS<1>. The wireless communication between the CTSs is carried out by transferring only the information on the coordinates of finger, and the coordinates and colors of stylus to identify the corresponding CTS, thus lessening the data traffic between the CTSs. The MI-CTS, in which 3,596 CTSs are configured to be interactively communicable with each other when 1 finger and 4 styli are simultaneously used, adopts an 802.11ac Wi-Fi protocol.

Figure 10.3.2 shows the block diagram and operational principle of the CTS using the modified multiple frequency driving method (MFDM) [4], which allows the palm rejection and erase features. The FFT processor acquires a spectrum of external noises, and then the MCU locates the frequencies of excitation ($f_{EXT1-112}$), stylus, palm, and eraser signals (f_{S1-3}, f_P, and f_E) in the low-noise region. The excitation circuits of the AFE IC and active stylus concurrently send the excitation signals (V_{EXT}s), and the stylus, palm, and eraser signals (V_{STY}, V_{PALM}, and V_{ERASE}), respectively, to the TSP. The AFE IC then acquires a spectrum of charge signals (Q_S) of V_{EXT}, V_{STY}, V_{PALM}, and V_{ERASE} to extract the coordinates of finger and active stylus as well as the pressure and tilt of the active styli, and to identify the presence of the palm and eraser, respectively. As the MCU detects a capacitance profile of f_P corresponding to V_{PALM} and removes it, the palm rejection is carried out without a heavy computational load. In the same way, the MCU detects a capacitance profile of f_E corresponding to V_{ERASE} and erases the displayed touch coordinates. In the MI-CTS, the CTS requires an additional frame time to extract the coordinates of the active stylus, palm, and eraser from the TX and RX electrodes.

Figure 10.3.3 (top) shows a block diagram of the active stylus. When the active stylus is used, the MCU in the stylus sends f_{S1-3}, f_P, and f_E to the excitation circuits<1:5>. The excitation circuits<1:3> generate respective sinusoidal waves having f_{S1-3}, which represent the coordinates, pressure, and tilt angle of the active stylus [4]. The mixer then combines these sinusoidal waves and emits them to the TSP via the buffer. The excitation circuit<4> sends V_{PALM} having f_P to the TSP through the human body. In addition, the excitation circuit<5> sends V_{ERASE} to the TSP via the conductive eraser to perform the erase operation. To reduce the power consumption, the active stylus emits V_{STY}, V_{PALM}, and V_{ERASE} only when the inertial motion unit (IMU) sensor detects the movements of the active stylus. The excitation circuits<1:4> generate V_{STY} and V_{PALM} when the active stylus moves in the forward direction. On the other hand, the excitation circuits<4:5> send V_{PALM} and V_{ERASE} to the side electrode and conductive eraser, respectively, when the active stylus is rotated in the backward direction. To verify the operation of the active stylus with palm rejection, the coordinates of the active stylus and palm of the hand were measured and depicted as a combined FFT data at the RX and TX electrodes as shown in Fig. 10.3.3 (bottom). When a V_{PALM} signal is injected into the human body, the amplitude of V_{PALM} can be altered according to the impedance of human body. Nonetheless, the MCU simply detects the existence of f_P and removes such coordinates of the palm from the raw FFT data, thus achieving the palm rejection without a heavy computational load.

Figure 10.3.4 shows a block diagram of the AFE IC. The 64-channel excitation circuits generate the sinusoidal waves using the direct digital synthesizer (DDS), low-pass filter (LPF), and the programmable gain amplifier (PGA). The readout circuit consists of 104-channel CCIIs, high-pass filter (HPF), and PGA, and 26-channel 8:2 MUXs with SAR-ADCs. To achieve a high frame rate while preventing a charge overflow, each excitation circuit sends $V_{EXT1-56}$ and $V_{EXT57-112}$ for two frame times to all the TX electrodes, and the current conveyor II (CCII) adjusts its input impedance at port X according to the sizes of MP and MN. Since the AFE IC is heavily affected by the display noises in the large-sized TSP, a differential sensing method [2] using two CCIIs is adopted in the AFE IC to filter out the display noise, and realized simply by connecting the nodes ZP and ZN of the two adjacent CCIIs. In addition, a combination of the TSP and CCII, which operates as a band-pass filter [4], is combined with the HPF to filter out the external noises, which are mainly distributed up to tens of kHz, and thus the cut-off frequency of the HPF is designed to be 100kHz. The signal gain is adjusted by the output resistors of the CCII (R_{OUT}s) and the PGA. Because the fabricated 86″ TSP has a cut-off frequency of 1MHz, the output of the PGA should be sampled with 2MHz frequency per channel considering the Nyquist theorem, and thus the SAR-ADC is designed to have an 8MHz sampling frequency when an 8:2 MUX is used. The 1024-point FFT processor receives 1024 ADC data and converts it to 1024 FFT data, which is distributed from -1MHz to +1MHz, and thus the frequency resolution is determined to be 1.95kHz.

As shown in Fig. 10.3.5 (top-left), the raw data of the CTS with an 86″ TSP shown in Fig. 10.3.6 (top-right) was measured in a real environment when the 1 and 10mm metal pillars, and active stylus were touched on the TSP. Figure 10.3.5 (bottom-left) shows the demonstration of the MI-CTS using an 86″ and two 32″ TSPs. When the finger and active stylus touched a CTS, the remaining CTSs simultaneously displayed the coordinates of the finger and active stylus. Figure 10.3.5 (bottom-right) shows the test results of the palm rejection, showing that the touched area of the palm was not displayed on the TSP, thus the palm rejection properly worked.

Figure 10.3.6 shows the performance summary of the AFE IC in comparison with previous works. Although a large-sized 86″ TSP with a 5.0mm thickness glass was used, the measured SNRs were comparable or higher than those in previous works owing to the use of the differential sensing method. Figure 10.3.7 shows the die micrograph of the AFE IC.

References:
[1] C. Park, et al., "A Pen-Pressure-Sensitive Capacitive Touch System Using Electrically Coupled Resonance Pen," *ISSCC Dig. Tech. Papers*, pp. 124-125, Feb. 2015.
[2] M. Hamaguchi, et al., "A 240Hz-Reporting-Rate Mutual-Capacitance Touch-Sensing Analog Front-End Enabling Multiple Active/Passive Styluses with 41dB/32dB SNR for 0.5mm Diameter," *ISSCC Dig. Tech. Papers*, pp. 120–121, Feb. 2015.
[3] H. Hwang, et al., "A 6.9 mW 120 fps 28×50 Capacitive Touch Sensor with 41.7 dB SNR for 1 mm Stylus Using Current-Driven ΔΣ ADCs," *ISSCC Dig. Tech. Papers*, pp. 170-171, Feb. 2017.
[4] J. S. An, et al., "A 3.9kHz-Frame-Rate Capacitive Touch System with Pressure/Tilt Angle Expressions of Active Stylus Using Multiple-Frequency Driving Method for 65" 104×64 Touch Screen Panel," *ISSCC Dig. Tech. Papers*, pp. 168-169, Feb. 2017.
[5] S. Yoshida, et al., "An 87×49 mutual capacitance touch sensing IC enabling 0.5 mm-diameter stylus signal detection at 240 Hz-reporting-rate with palm rejection," *ASSCC*, pp. 217-220, Nov. 2014.
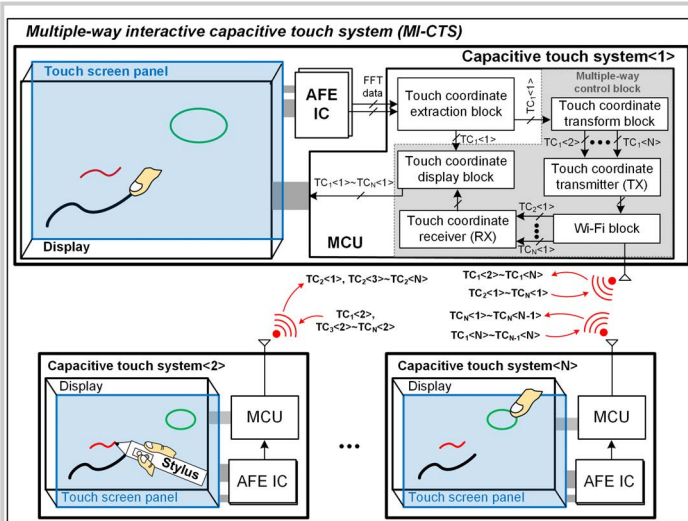
Figure 10.3.1: Block diagram of the multiple-way interactive capacitive touch system (MI-CTS) having multiple CTSs.
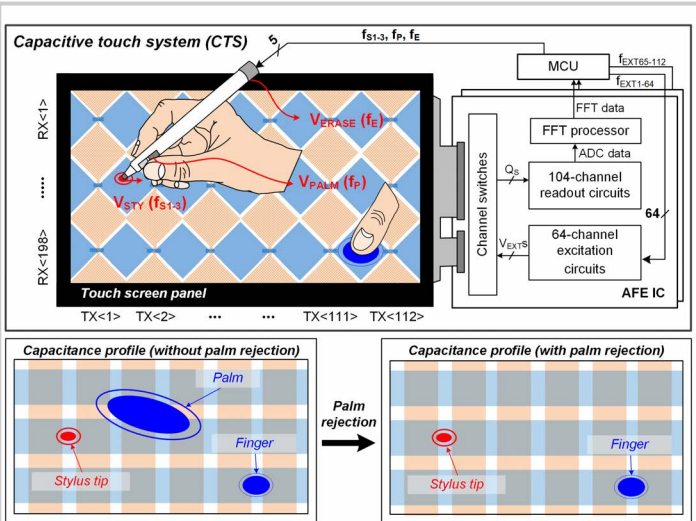

Figure 10.3.2: Block diagram and operational principle of the CTS using the modified multiple-frequency-driving method.
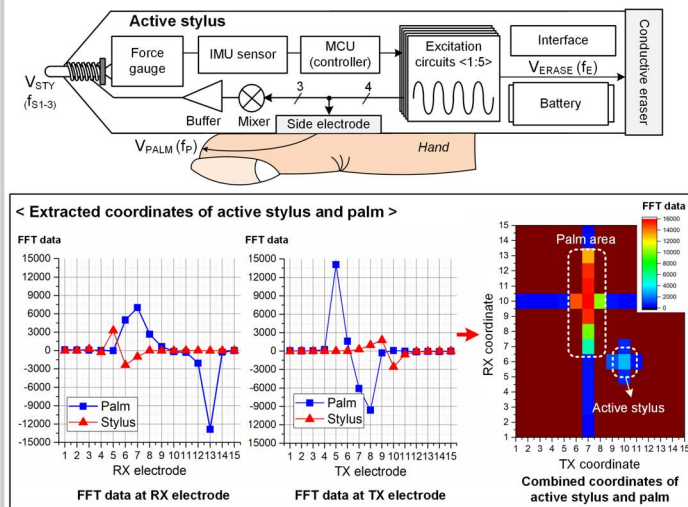
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Figure 10.3.3: Block diagram of the active stylus (top) and the measured and depicted coordinates of the active stylus and palm of the hand (bottom).
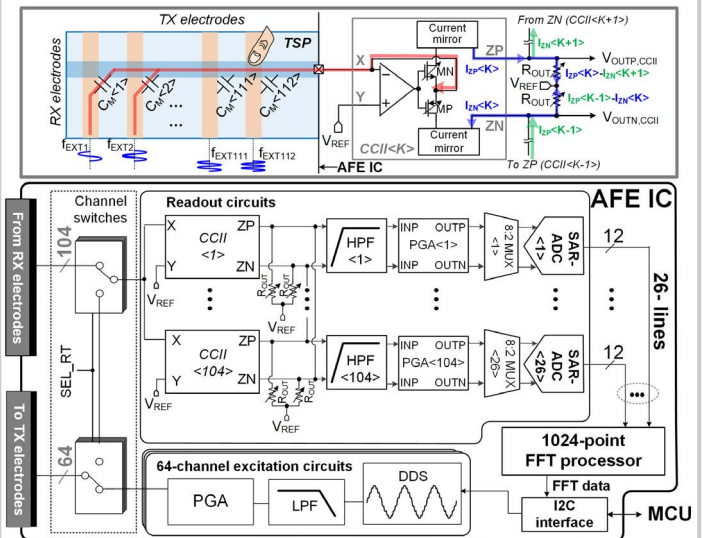

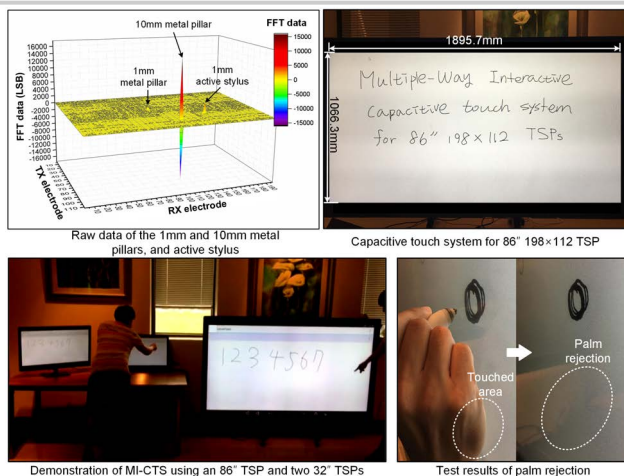Figure 10.3.4: Block diagram of the AFE IC.

Figure 10.3.5: Measured raw touch data (top-left), and the demonstration of the proposed CTS with a 86″ 198×112 TSP (right), MI-CTS using an 86″ 198×112 TSP and two 32″ 104×64 TSPs (bottom-left), and test results of the palm rejection (bottom-right).

		This work	ISSCC 2015 [1]	ISSCC 2015 [2]	ISSCC 2017 [3]	ISSCC 2017 [4]
Process		0.13-μm CMOS	0.18-μm BCD	85-nm CMOS	0.18-μm CMOS	0.13-μm CMOS
TSP	Size	86-inch[1]	10.1-inch	13-inch	10.1-inch	65-inch
	Cover glass	5.0 mm	N/A	1.1 mm	N/A	4.0 mm
	Air gap	3.0 mm	N/A	1.5 mm	N/A	3.0 mm
# of electrodes		TX: 112 RX: 198	TX: 48 RX: 32	TX: 35 RX: 57	TX: 28 RX: 50	TX: 64 RX: 104
Electrode		Metal Mesh	ITO	Metal Mesh	AgNW	Metal Mesh
Frame rate		977 Hz	120 Hz	240 Hz	120 Hz	3.9 kHz
SNR (dB)	Stylus (1mm)	Active: 45.5 Passive: 39.0	Active: N/A Passive: 49.0	Active: 41.0 (0.5mm) Passive: 38.0	Active: N/A Passive: 41.7	Active: 50.1 Passive: 41.0
	Finger	60.1 (@10mm)	62.0 (@6mm)	N/A	53.3	61.0 (@10mm)
Stylus Function[1]	Pressure	Yes (7.4-bit)[2]	Yes (6.5-bit)	No	No	Yes (6-bit)
	Tilt	Yes (7.4-bit)[2]	No	No	No	Yes (6-bit)
	Palm rejection	Yes	No	No	No	No
	Eraser	Yes	No	Yes	No	No
Multiple-way interactive operation		Yes	No	No	No	No
Supply		1.5/3.3 V	N/A	1.2/3.3 V	1.8/3.3 V	1.5/3.3 V
Power consumption		797.4 mW (Analog+digital)	30 mW	N/A	6.9 mW	246.3 mW (Analog+digital)
Chip area		74.17 mm² (Analog+digital)	14.7 mm²	12.5 mm²	1.96 mm² (Readout circuit)	42.25 mm² (Analog+digital)
Chip area / # of electrodes		6689.0 μm²	9570.3 μm²	6265.7 μm²	37.0 μm²	6347.7 μm²

[1]The CTS was implemented with an 86″ 198×112 TSP using a 12.0μm thickness Cu metal mesh structure, where the TSP was covered with 5.0mm thickness glass and mounted on the ultra-HD LCD with 3.0mm air gap.
[2]Resolutions of pressure and tilt of the proposed active stylus is derived when the one active stylus is used in the CTS.

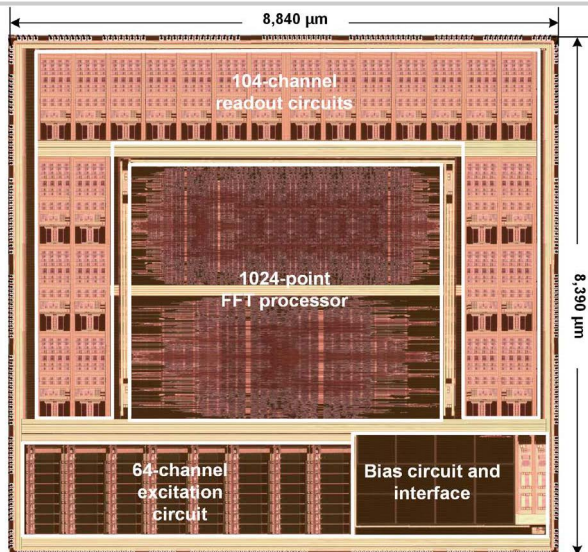Figure 10.3.6: Performance summary for the AFE IC in comparison with previous works.

Figure 10.3.7: Die micrograph of the AFE IC.