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An 87×49 mutual capacitance touch sensing IC enabling 0.5 mm-diameter stylus signal detection at 240 Hz-reporting-rate with palm rejection

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***Abstract*— A touch sensing system capable of stylus input should have "palm rejection" function which allows the user to place one's palm on the surface of the touch sensor while writing with a stylus. In order to realize "palm rejection", it is necessary to detect the small stylus while neglecting large signal from the palm. However this is not sufficient because small electrical noise injected through the palm into the touch sensor impedes stylus input signal in real use. This issue is because the injected noise propagates onto the touch sensor's sense channels which are capacitively-coupled with the palm and degrades the SNR of the stylus signal on the channels. A simple and effective technique to eliminate this issue is implemented in a newly developed 87×49 mutual capacitance touch sensing IC which is fabricated in an 85 nm CMOS technology. It achieves an SNR over 33 dB for a 0.5 mm-diameter stylus when a 10 Vp-p sinusoidal noise is injected to the stylus and the palm. Both the die area and the power consumption of a unit charge-to-voltage converter (CVC) designed for the IC are reduced to approximately 50% compared to those of the previous implementation [4]. In order not to report unwanted touches due to palm signals, a palm detection filter is implemented in the digital signal processor on the IC.**

Keywords—mutual capacitance; touch sensing; stylus; palm rejection; alternating drive

I. Introduction

High SNR mutual capacitance touch sensing systems have been developed [1]-[5], and some of them are capable of realizing passive stylus input with small tips [1], [4]. When writing with a stylus, it is preferable to put one's palm on the surface of the touch sensor. The distribution of capacitance changes induced by a touch of a stylus together with a touch of a palm in noise free environment is shown in Fig. 1, where the palm is represented by a 100×100 mm² metal plate. The distribution has negative values because it is captured with a differential sensing scheme of the AFE IC [4]. In order to recognize the handwriting, the small stylus signal has to be detected while neglecting the palm signal.

In real usage environment of the touch systems, there are several noise sources such as AC adaptors and fluorescent lamps. The distribution of Fig. 1 deforms as shown in Fig. 2 when a small noise is injected through the palm, where the stylus signal is buried in the propagated noise.

A technique to eliminate this issue of SNR degradation due to the noise injection from palms is implemented in an 87×49 mutual capacitance touch sensing IC.

In order to neglect the palm, a palm detection filter which discriminates between palm and finger by detecting the spread of the signal is also implemented.

II. Stylus Signal Detection

A typical architecture of mutual capacitance touch sensing system is shown in Fig. 3. When the touch sensor is touched, a change is induced in the distribution of M×N mutual capacitances between the drive channels and the sense channels. When a noise is injected from a touch into the sense channels capacitively-coupled with the touch as shown in Fig. 3, false capacitance changes spread onto the sense channels as shown in Fig. 2.

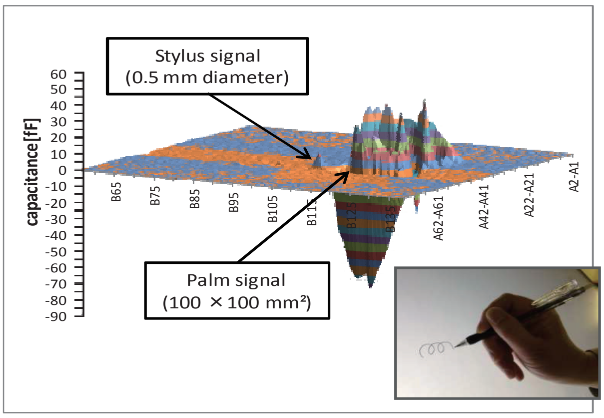


Fig. 1. The distribution of capacitance changes induced by a touch of a stylus together with a touch of a palm in noise free environment.

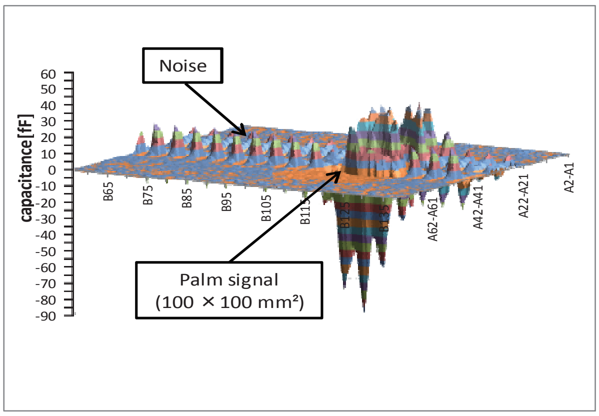


Fig. 2. The stylus signal buried in the propagated noise injected through the palm.

Therefore the SNR of a stylus degrades if the stylus is on the sense channels capacitively-coupled with a palm. Because of the driver's low output impedances, the noise does not spread onto the drive channels.

The issue of the SNR degradation is resolved by adopting the alternating drive technique which changes the drive channels and the sense channels between A-mode and B-mode alternately as shown in Fig. 4.

Fig. 5 (a)-(d) show the distribution of capacitance changes induced by a touch of a stylus together with a touch of an artificial palm, when a 10 Vp-p sinusoidal noise of 50 kHz is injected to the artificial palm and the stylus. When the stylus is placed on the same sense channels with the palm, the stylus signal is buried in the propagated noise as shown in Fig. 5 (b) in B-mode and Fig. 5 (c) in A-mode. On the other hand, when the stylus is placed on the same drive channels with the palm, the stylus signal can be detected against the propagated noise as shown in Fig. 5 (a) in A-mode and Fig. 5 (d) in B-mode.

With the alternating drive technique, the stylus placed out of the rectangular area surrounding the palm becomes free of noise in either A-mode or B-mode to enable touch recognition.

III. PALM DETECTION FILTER

The palm signal has to be discriminated from either a stylus signal or a finger signal for the touch system not to generate unwanted false touch reports. It is easy to distinguish a stylus signal from a palm signal because the stylus signal is much smaller than the palm signal as shown in Fig. 1. On the other hand, it is not easy to discriminate a finger signal from a palm signal by signal level only because the finger signal and the palm signal have almost the same levels as shown in Fig. 6.

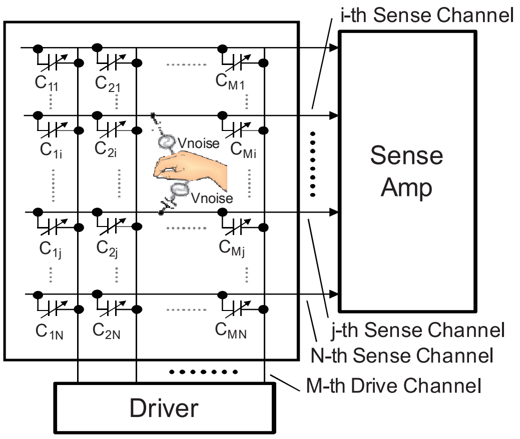


Fig. 3. Typical architecture of mutual capacitance touch sensing system and noise injection model

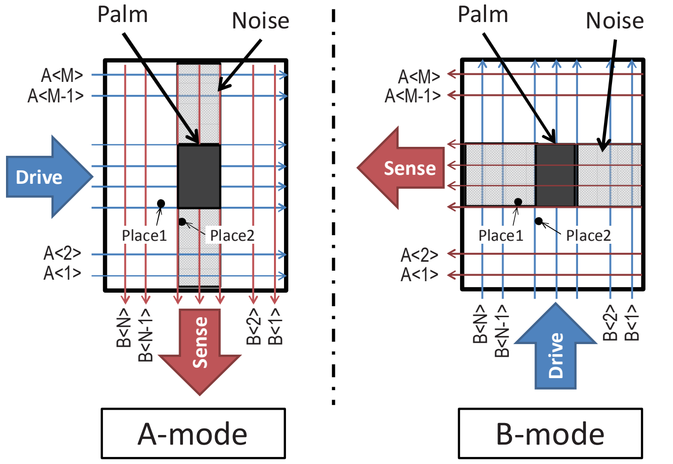
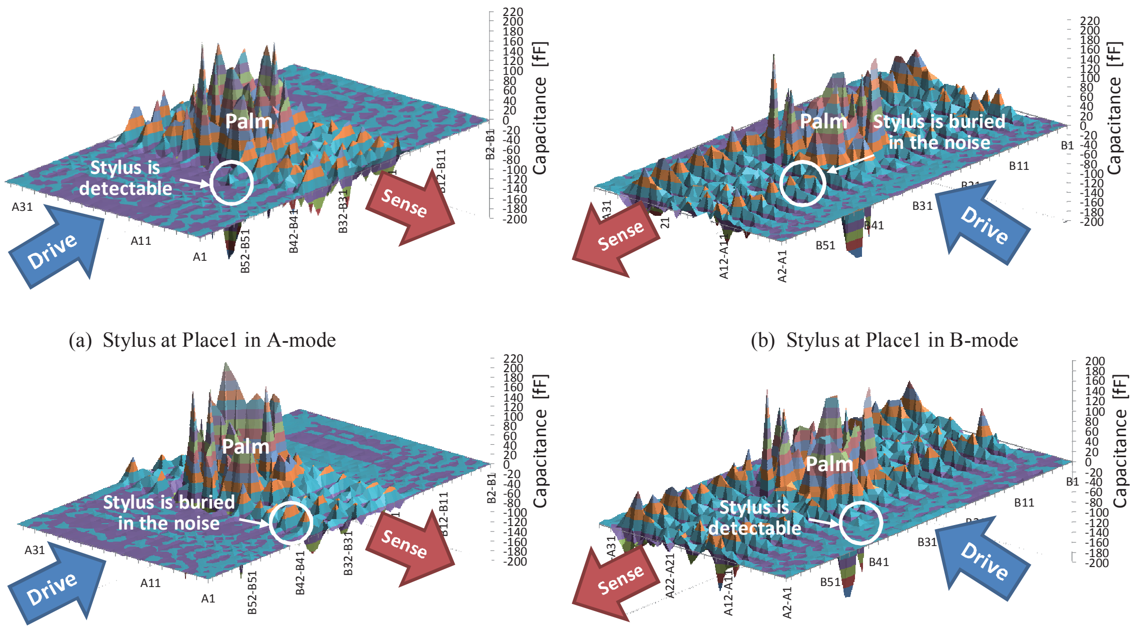


Fig. 4. Alternating drive operation between A-mode and B-mode.



(a) Stylus at Place1 in A-mode

(b) Stylus at Place1 in B-mode

(c) Stylus at Place2 in A-mode

(d) Stylus at Place2 in B-mode

Fig. 5. The stylus signal with a touch of a palm in noise injected environment.

Fig. 6 exemplifies the notion of a palm detection filter which discriminate a palm from a finger. In order to detect the palm, the signals at a certain distance away from the peak are checked. Let N_{BASE} be the number of the signal whose absolute value exceeds a predetermined threshold (TH_{BASE}) at a certain distance away from the peak. For $TH_{BASE} = 3.0$, N_{BASE} of the finger touch is 1 although N_{BASE} of the palm touch is 18 as shown yellow cells in Fig. 6 (a) and Fig. 6 (b). In this case, the threshold (TH_N) which distinguishes a finger touch and a palm touch should be set to around 10. The threshold has to be carefully defined not to misjudge multiple fingers as a palm.

The processing flow of the palm detection filter is shown in Fig. 7. After a peak in the distribution of capacitance changes is found, the palm detection filter calculates N_{BASE}. If N_{BASE} exceeds TH_N, the peak is determined as a palm and rejected.

IV. IC Implementation and Measured Results

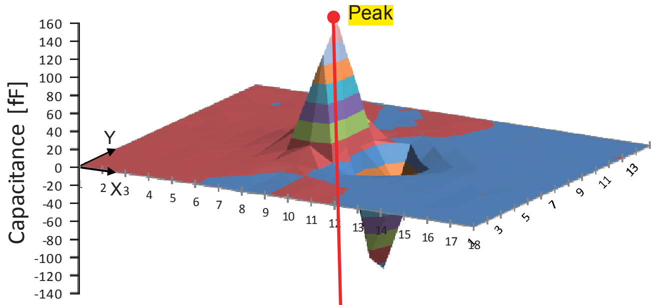
Fig. 8 shows the block diagram of the IC which implemented the technique described in section II and III. The IC has 136 sensor channel connections, 87 channel drivers with 3.3V driving voltage, and 43 CVCs. Each of the sensor channels can be connected to either a driver or a CVC via a channel switch as shown in Fig. 8. The alternating drive operation between A-mode and B-mode is realized by changing the switch connections dynamically.

The output voltage signals from the CVCs are transferred to the dual 12b 17.5MHz SAR ADCs through two multiplexers, where ADCs take 1.26 µs (=22×1/17.5 MHz) to convert all the signals from 43 CVCs. The capacitance distribution of the touch sensor is reconstructed in the decoder with a linear algebra algorithm and then transferred to the following digital signal processor, where the palm detection filter is implemented. The reconstruction calculation of 87×49 mutual capacitances takes L×1.6 µs, if the time constant of an accompanied touch sensor is small enough, where L is the length of the parallel drive sequences. The supply voltages of the analog circuit block and digital circuit block are 3.3 V and 1.2 V respectively.

Fig. 9 shows the schematic of a CVC block. In order to reduce die area and power consumption, the number of stages is decreased from three [4] to two. The first stage is a charge integrator with switchable feedback capacitances. The next stage is a sample-and-hold circuit to feed the differential signal to the ADCs. Both the unit die area and the unit power consumption of CVC are reduced to approximately 50% compared to the previous implementation [4].

Performance verification is carried out with a 15.6-inch touch system which is built up from the mutual capacitance touch sensing IC, a 5.7 mm channel pitch 35×61 metal mesh sensor laminated to a 0.55 mm thickness cover glass, and mounted on a Full HD LCD with 1.0 mm air gap. The cycle time to capture each capacitance frame is 0.23 ms and 16 consecutive frames are summed to obtain one reporting frame at 240 Hz. The system specification and measured performances are compared with previous works in TABLE I.

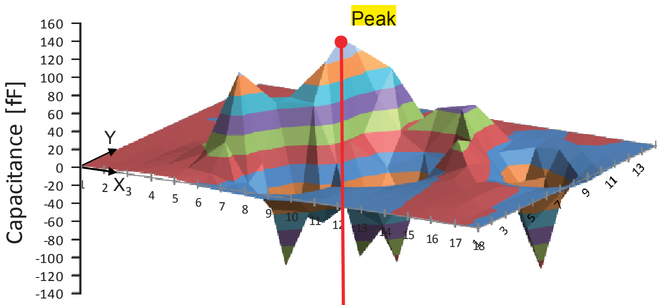
The SNRs of the stylus at place1 and place2 are better than 35 dB in noise free environment for both A-mode and B-mode, where place1 and place2 are located at 20 mm in horizontal and vertical directions from the lower left corner of the palm as shown in Fig. 4. When a 10 Vp-p sinusoidal noise of 50 kHz is injected to the artificial palm and the stylus, the SNR at place1 degrades down to 1.2 dB in B-mode however stays 37.7 dB in A-mode, and the SNR at place2 degrades down to -3.9 dB in A-mode however stays 33.8 dB in B-mode. By doing



$N_{BASE} = 1$

0.51	0.02	0.33	0.19	0.40	0.28	0.40	0.49	0.30	0.16	0.37	0.28	0.40	0.19
0.37	0.26	0.19	0.30	0.35	0.51	0.40	0.07	0.30	0.65	0.14	0.33	0.26	0.23
0.16	0.40	0.26	0.00	0.23	0.51	0.42	0.44	0.21	0.14	0.21	-0.07	0.09	0.28
0.26	0.16	0.40	0.65	0.89	0.65	0.96	0.98	0.26	0.19	0.12	0.30	0.09	0.14
0.23	0.21	0.16	0.51	0.77	1.21	2.33	3.08	1.03	0.33	-0.02	0.12	0.21	0.37
0.05	0.00	0.28	0.61	1.44	2.38	6.13	7.95	3.19	0.89	0.21	0.09	0.23	-0.02
-0.28	-0.51	0.14	0.91	2.10	6.76	24.16	35.51	9.30	1.49	0.21	0.12	-0.05	-0.09
-1.30	-1.12	-1.35	-0.14	1.61	16.15	110.82	140.58	43.69	1.42	-0.40	-0.23	-0.72	0.07
-0.14	-0.09	-0.05	0.00	-0.40	-0.19	11.88	5.06	4.31	0.09	0.26	-0.05	0.16	0.23
0.86	0.84	0.75	-0.33	-1.72	-16.05	-108.44	-127.48	-45.62	-2.31	0.07	0.40	0.89	0.12
0.42	0.12	0.26	-0.77	-1.72	-6.73	-37.38	-53.15	-11.18	-1.30	-0.09	0.07	0.28	0.00
-0.09	-0.19	-0.51	-0.54	-1.12	-2.49	-7.55	-8.71	-3.43	-0.93	-0.21	-0.37	-0.19	-0.21
-0.16	-0.14	-0.49	-0.47	-0.84	-1.00	-2.17	-2.87	-1.19	-0.63	-0.26	-0.40	-0.30	-0.09
-0.09	-0.49	-0.51	-0.21	-0.37	-0.63	-0.72	-0.75	-0.42	-0.49	-0.28	-0.14	0.00	-0.19
-0.21	-0.28	-0.54	-0.65	-0.37	-0.56	-0.47	-0.54	-0.56	-0.35	-0.23	0.00	-0.23	-0.12
-0.09	-0.23	-0.16	-0.21	0.02	-0.51	-0.28	-0.54	-0.40	-0.16	-0.40	-0.14	-0.16	-0.30
-0.23	-0.02	-0.12	-0.30	-0.12	-0.19	-0.40	-0.26	-0.42	-0.07	-0.14	-0.19	-0.47	-0.30
-0.23	-0.40	-0.37	-0.56	-0.63	-0.61	-0.33	-0.65	-0.37	-0.33	-0.14	0.05	-0.37	-0.33

(a) Finger touch



$N_{BASE} = 18$

1.10	1.00	1.07	0.58	0.54	0.63	0.47	0.40	0.16	0.42	0.28	0.02	0.07	0.07
1.82	1.93	1.93	1.77	1.44	0.91	0.84	0.37	-0.09	0.33	0.05	0.33	0.30	0.30
3.12	3.80	3.73	3.57	2.52	1.65	1.05	0.28	0.00	-0.12	0.21	0.37	-0.02	0.26
4.19	6.43	8.16	10.07	7.04	3.77	2.24	0.72	-0.40	-0.35	0.19	0.63	0.30	0.40
3.36	7.43	15.89	27.50	19.32	9.69	4.78	1.56	-1.56	-1.61	-0.23	0.23	-0.07	0.23
-1.17	5.06	32.95	104.46	67.69	24.89	10.37	2.54	-5.29	-6.06	-2.24	-0.14	-0.21	-0.37
-2.75	-2.24	-8.90	6.83	67.50	66.57	49.84	34.21	14.35	1.28	0.05	0.09	-0.77	-0.30
-3.75	-8.92	-33.86	-102.81	-53.08	63.10	103.81	120.65	106.37	41.62	3.15	1.47	0.00	-0.28
-4.92	-8.44	-14.26	-40.29	-58.44	0.82	17.78	19.22	52.50	78.22	14.21	2.66	0.28	0.40
-2.38	-4.80	-4.43	-7.50	-34.95	-99.08	-59.02	-15.22	17.17	-6.43	13.07	3.26	1.44	0.77
-0.98	-1.68	-2.14	-4.36	-15.89	-61.47	-108.47	-64.27	-0.68	41.94	14.80	2.17	1.44	1.03
-0.98	-1.86	-2.33	-3.26	-5.38	-11.49	-18.78	-47.88	-9.39	44.58	42.62	0.79	0.21	0.07
-0.86	-1.14	-1.37	-1.56	-1.82	-2.12	-1.28	28.80	19.53	1.56	-6.24	-1.79	-0.37	0.21
-0.21	-0.19	0.23	0.51	1.17	2.96	10.44	7.06	-4.19	-30.97	-42.99	-3.80	-0.51	-0.16
0.79	1.47	1.75	2.49	2.94	2.59	-1.40	-11.02	-50.00	-97.26	-26.42	-2.26	0.33	0.42
0.93	1.12	2.19	3.75	3.73	3.19	-3.17	-57.83	-110.71	-50.33	-5.80	-0.65	0.09	0.26
0.19	0.07	0.14	-0.12	-0.49	-0.93	-2.98	-9.83	-16.31	-9.37	-2.61	-0.84	-0.47	-0.12
-0.26	-0.19	-0.21	-0.19	-0.16	-0.61	-1.07	-2.96	-4.40	-2.61	-1.10	-0.68	-0.44	-0.26

(b) Palm touch

Fig. 6. The distribution of capacitance changes and palm detection

the alternating drive operation in every frame reporting cycle, the SNR recovers over 33 dB in either A-mode or B-mode, as long as the stylus is outside the rectangular area surrounding the palm.

Fig. 10 shows the micrograph of the mutual capacitance touch sensing IC. The die size is 8.63×4.20 mm² including 0.16 mm scribe line. It is assembled in a 13.0×5.8 mm² ball grid array (BGA) package with 360 balls.

V. Conclusions

Alternating drive method and palm detection filter are introduced to realize a mutual capacitance touch sensing system with palm rejection. The techniques enable handwriting with a small tip stylus while placing one's palm on the surface of a touch sensor under external noise injection. They are implemented in a 136 channels IC with an 85 nm CMOS technology and 33 dB SNR for a 0.5 mm-diameter stylus is achieved while a 10 Vp-p noise of 50 kHz is being injected through a palm.

Acknowledgment

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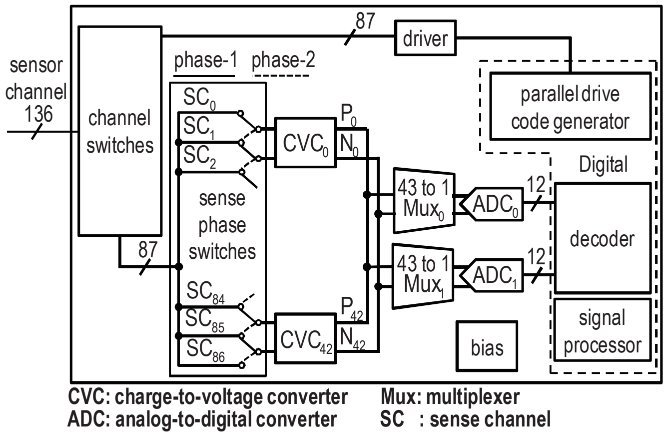

Fig. 8. Block diagram of the mutual capacitance touch sensing IC.

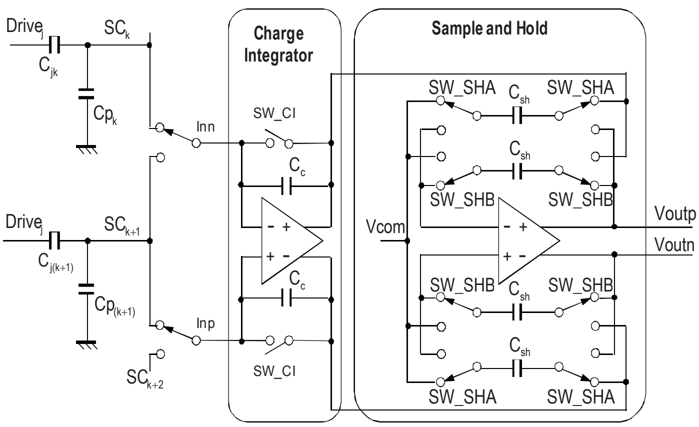

Fig. 9. Schematic of the CVC.

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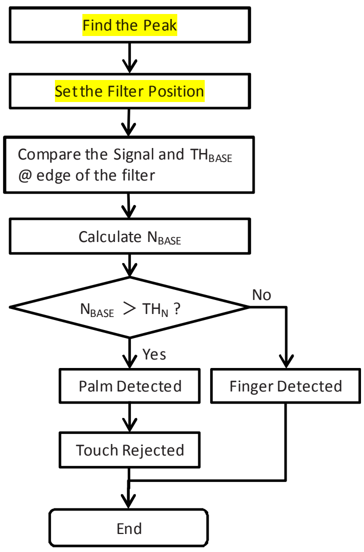

Fig. 7. Flow of the proposed palm detection filter.

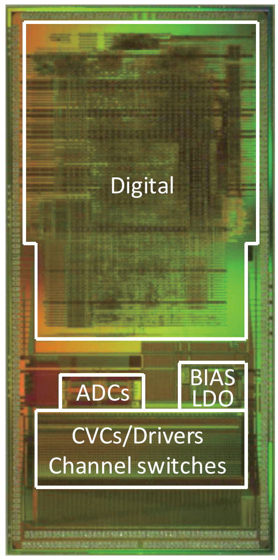

Fig. 10. Die micrograph of the touch controller IC.

TABLE I. Measured SNRs for 0.5 mm passive stylus with and without noise injection.

	[1]	[4]	This work A-mode	This work B-mode
Size[inch]	5	32	15.6	
Number of channels (Drive × Sense)	30 × 24	78 × 138	35 × 61	61 × 35
SNR[dB] (without noise)	35.0 @1.0 mm diameter	37.4 @1.0 mm diameter	40.1/ 36.5 (*2) @0.5 mm diameter	40.1 / 35.5(*2) @0.5 mm diameter
SNR[dB] (with noise) (*1)	Not described	Not described	37.7 / -3.9 (*2) @0.5 mm diameter	1.2 / 33.8 (*2) @0.5 mm diameter
Technology	2P6M 0.18 µm CMOS EEPROM	1P5M 0.18 µm CMOS	1P6M 85 nm CMOS	
Total Power [nW/(node・Hz)] (*3)	305.6	216.7	234.0	268.3
unit CVC Power [mW]	Not described	3.7	2.0	
Supply voltage[V]	3.3	3.3, 1.8	3.3, 1.2	
Die size	4.06 × 3.66 mm²	7.55 × 9.43 mm²	8.63 × 4.20 mm²	

(*1) 10 Vp-p 50 kHz sinusoidal noise is injected to the 100×100 mm² artificial palm and the stylus

(*2) Place1 / Place2 : shown in Fig. 4

(*3) Power/((Number of sense channels)*(Number of drive channels)*(reporting rate))