Active Capacitive-Sensing Circuit Technique for Image Quality Improvement on Fingerprint Sensor

Seung-Min Jung

School of Information and Telecommunication, Hanshin University, Osan, Korea, jasmin@hs.ac.kr

Abstract

This paper proposes an active capacitive sensing circuit for fingerprint sensors, which includes a pixel level charge-sharing and charge pump to replace an ADC. This paper also proposes the operating algorithm for 16-level gray scale image. The active capacitive technology is more flexible and can be adjusted to adapt to a wide range of different skin types and environments. The proposed novel circuit is composed with unit gain buffer, 6-stage charge pump and analog comparator. The proper operation is validated by the HSPICE simulation of one pixel with condition of 0.35µm typical CMOS parameter and 3.3V power.

Keywords: Biometrics, Active Capacitive, Fingerprint, ADC, Charge pump

1. Introduction

Biometrics, which uses the physical features of the human body, makes user identification convenient and secure. Biometrics using the fingerprint has a long history as a tool for criminal investigations. Fingerprint identification is based on the invariance of a fingerprint over a lifetime. For a decade, CMOS processes have been used to produce fingerprint sensor prototypes. Most of them rely on capacitive coupling between the finger and a matrix of small metal plates to detect ridges and valleys on the finger surface. The finger is modeled as the upper electrode of the capacitor, and the metal plate in the sensor cell as the lower electrode. When the finger is placed on the sensor, the electrical charge is extremely weak building a pattern between the finger's ridges or valleys and the sensor's plates. Using these charges the sensor measures the capacitance pattern across the surface. The measured values are digitized by the sensor then sent to the microprocessor. The surface of a capacitive sensor is a neat array of plates, able to measure the capacitance between these plates and the fingerprint contour. This can be done directly by applying an electrical charge to the sensor electrode. This is direct capacitive (DC) measurement [1-3]. On the other hand, the active capacitive (AC) measurement can be done by applying an electrical charge to the finger skin directly [3-4]. The latter method is sometime referred as reflective or inductive capacitive measurement, and it brings several advantages. A sensor for biometrics will be used by various users that have different conditions for sensing[12-13]. The quality of images captured by a capacitive fingerprint senor LSI depends on the finger-surface condition. The image quality for a dry, wet, corrupted and dirty finger is poor compared to that for a normal finger. AC technology is more flexible and can be automatically adjusted to adapt to a wide range of different skin types and environments [5-7].

In general, a fingerprint sensing circuit uses ADC(analog-to-digital converter) with large layout area for digital image processing of an identification algorithm and also needs high performance gain controlled amplifier and filter for internal calibration as shown in Figure 1[8-10]. This paper describes the novel active capacitive sensing circuit techniques without ADC that meet these requirements using the charge pump.
2. Proposed Capacitive-Sensing Circuit

Figure 2 shows the proposed active capacitive charge-sharing sensing scheme and Figure 3 is timing diagram. The capacitance of \( C_f \) is at its maximum value when a ridge has contact with the passivation layer. As the distance between the chip surface and the finger’s skin increases, the capacitance becomes smaller. In Figure 2, BUFFER is a unit-gain buffer and PCH means precharge signal. When PCH is high, the operation is in the precharge phase. The node N1 and M3 of Cp3 are precharged to VDD, and node Cp2 is discharged to GND. In this phase, no charge is accumulated in Cp3 because the two electrodes have the same potential. In Cp1 and Cf, the amount of charge stored is \( C_p1 \cdot VDD \) and \( C_f \cdot VDD \). At the beginning of the evaluation phase, the charges are redistributed between the nodes. The BUFFER is enabled as a unit-gain buffer in this phase. The BUFFER tracks the voltage change of the node N1, which makes the potential of Cp3 to zero. Usually, because Cp1 and Cp2 are the parasitic metal routing capacitances, they are much smaller than Cp3. Therefore, the adoption of BUFFER is an effective method to remove the influence of Cp3. The BUFFER is composed of only five MOSFETs for the restricted pixel area below the sensor plate. In the evaluation phase, the VAC is driving pulse for applying an electrical charge to the finger skin directly. The charge is collected in Cf between finger skin and sensor electrode (M4) by VAC. The amount of charge is various between ridge and valley. Therefore, \( V(N1)_{p-p} \) which is peak to peak voltage of node N1, is larger at ridge than valley as shown in Fig 3. This paper applies a charge pump circuit for reference voltage generation of comparator as shown in Figure 2. In general, a charge pump circuit is applied as a voltage multiplier for a nonvolatile memory [11]. As shown in Figure 4, the output voltage of a charge-pump circuit gradually increases due to non-overlapping two clock signals. One stage is comprised of one diode and actual coupling capacitor. As an effect of diode, the voltage is transferred to only one direction, to show an overall gradual output voltage increase effect. This increased voltage is applied as a comparator’s reference voltage. The comparator compares the reference and the sensor voltage then, decides whether the image is a ridge or valley.
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Figure 2. Proposed active capacitive sensing circuit

Figure 3. Timing diagram

Figure 4. Principle of a charge pump circuit
This paper proposes the operating algorithm for 16-level gray scale image without ADC using the charge pump. At the beginning of VAC rising, the charge pump circuit receives clock CLK from microcontroller to increase comparator’s reference voltage. The comparator compares the fingerprint sensing voltage of node N1 and reference voltage of charge pump circuit. It then saves the number of clock, at the changing point, where logic is changed from 0 to 1, in a memory. The number of clock is C1 at high driving pulse as shown in Figure 3. The charge pump is reset at the beginning of VAC falling. The comparator compares a fingerprint detection voltage created by the sensor and charge pump circuit output, reference voltage again. It also saves the number of clock, at the point where logic is changed from 0 to 1. The number of clock is C2 at low driving pulse as shown in Figure 3. Finally, microcontroller subtracts each pixel’s value of C2 from C1, which is a corrected image. The final clock count value is 16-level gray scale image and it also is saved in a memory.

3. Circuit Implementation and Evaluation

Fig 5 shows the implementation of the proposed active capacitive-sensing circuit on Cadence environment and Fig 6 shows 6-stage charge pump circuit. The proper operation can be seen by the HSPICE simulation of one pixel with condition of 0.35μm typical CMOS model parameter and 3.3V power supply in Fig 7, 8 and 9. By effective removing of parasitic capacitance Cp3 using unit gain buffer, the peak to peak voltage of ridge is 1381mV and the value of valley is 80mV. The peak to peak swing time is larger at ridge than valley as shown in Fig 8 and 9. Thereby, the comparator easily discriminates a ridge and valley and microcontroller subtracts each pixel’s value of C1 from C2, which is gray image value. The final number of clock count is a 16-level gray scale image, and it also is saved in a memory.
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Figure 6. 6-stage charge pump circuit

Figure 7. Peak to peak voltage of sensing output at ridge and valley

Figure 8. Comparator output at ridge
4. Conclusions

This paper proposes the active capacitive sensing circuit for fingerprint sensors, which includes a pixel level charge-sharing and charge pump to replace an ADC. The active capacitive measurement can be done by applying an electrical charge to the finger skin directly. The method is sometime referred as reflective or inductive capacitive measurement, and it brings several advantages. A sensor for biometrics will be used by various users that have different conditions for sensing. The active capacitive technology is more flexible and can be adjusted to adapt to a wide range of different skin types and environments. A fingerprint sensing circuit uses ADC with large layout area for digital image processing of an identification algorithm. This paper also describes the novel active capacitive sensing circuit techniques without ADC that meet these requirements using the charge pump and proposes the operating algorithm for 16-level gray scale image. The proposed novel circuit is composed and implemented with unit gain buffer, 6-stage charge pump, comparator and precharge unit. The proper operation can be seen by the HSPICE simulation of one pixel with condition of 0.35µm typical CMOS parameter and 3.3V power. The result shows possibility of the active capacitive sensing technique for a low-power, high-accuracy and small size fingerprint sensor chip.

5. Acknowledgments

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6. References


