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Capacitive Fingerprint Sensor Circuit using Pseudo-Direct Scheme for Mobile Applications

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Abstract

This paper proposes a fingerprint sensor cell and its structure using pseudo-direct scheme. The fingerprint sensor cell uses an internal transmitted (Tx) plate instead of using an external bezel as a contact for direct signal driving to finger. It uses an active output voltage feedback (AOVF) integrator and multiple integration scheme to maximize the sensitivity and improve signal-to-noise ratio (SNR) as well. The circuit models of combined fingerprint and Tx electrode were analyzed and simulated using MATLAB. And the proposed fingerprint sensor were designed and simulated with standard 0.35μm CMOS technology. Simulations verified that the proposed fingerprint sensor using pseudo-direct scheme can be effectively used as a personal authentication method especially in mobile applications.

Keywords: *fingerprint sensor, pseudo-direct method, capacitive sensor, AOVF integrator, signal integration scheme*

1. Introduction

The demand for a biometric sensor, especially a fingerprint sensor is rapidly increased as a biometric recognition system for personal verification recently [1, 2]. Moreover, mobile systems start to use a fingerprint sensor as a personal identification method in payment service [3]. Therefore, it requires a low cost and a small volume integrated fingerprint device which can be implemented with a capacitive sensing scheme. It senses the variation of the capacitance formed between a sensor plate and a finger. So, the capacitance of the fingerprint sensor decreases as the passivation of the sensor increases. To achieve the maximum performance in a fingerprint recognition system, a method which drives a signal to a finger directly has been proposed and used in a mobile system, recently. It usually uses a bezel in order to drive a signal to a finger and senses the signal returned back to the sensor [4, 5].

This paper proposes a fingerprint sensor using pseudo-direct scheme which requires no bezel for direct signal driving. It adopts an AOVF integrator which is known that it has large output sensing range because it inherits that of a passive integrator. So, it is very suitable for low-voltage and low-power systems, such as mobile applications [6, 7]. The proposed fingerprint sensor uses a Tx electrode as an internal electrode which performs a similar function as a bezel does. This proposed scheme is named as a pseudo-direct scheme in this paper. The circuit model of the combined fingerprint and Tx electrode for this pseudo-direct fingerprint sensor has been analyzed and verified using MATLAB. And the fingerprint sensor units were designed and simulated using 0.35μm CMOS technology. The theoretical analysis and simulations of the proposed fingerprint sensor for pseudo-direct scheme were described in this paper and Spectre simulation results were compared with those of the theoretical analyses using MATLAB.

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2. Fingerprint Sensor Circuit with Pseudo-direct Scheme

Because the advantages of low-cost and high sensitive sensing, capacitive sensing fingerprint sensors have been introduced already [8-10]. This paper proposes a fingerprint sensor based on an AOVF integrator using pseudo-direct scheme which requires no bezel used as a contact for direct signal driving to a finger.

Figure 1(a) shows the to a fingerprint sensor based on the AOVF integrator [11]. Note that the sensor plate is shielded by a metal plate to prevent the noise from the circuit under the sensor plate and AOVF is applied to the shield capacitor to remove the parasitic capacitance effectively [11]. This fingerprint sensor requires an external bezel in order to drive a signal into a finger, which returns back through the capacitor formed between fingerprint and the sensor plate, C_{finger}, as shown in Figure 1(c).

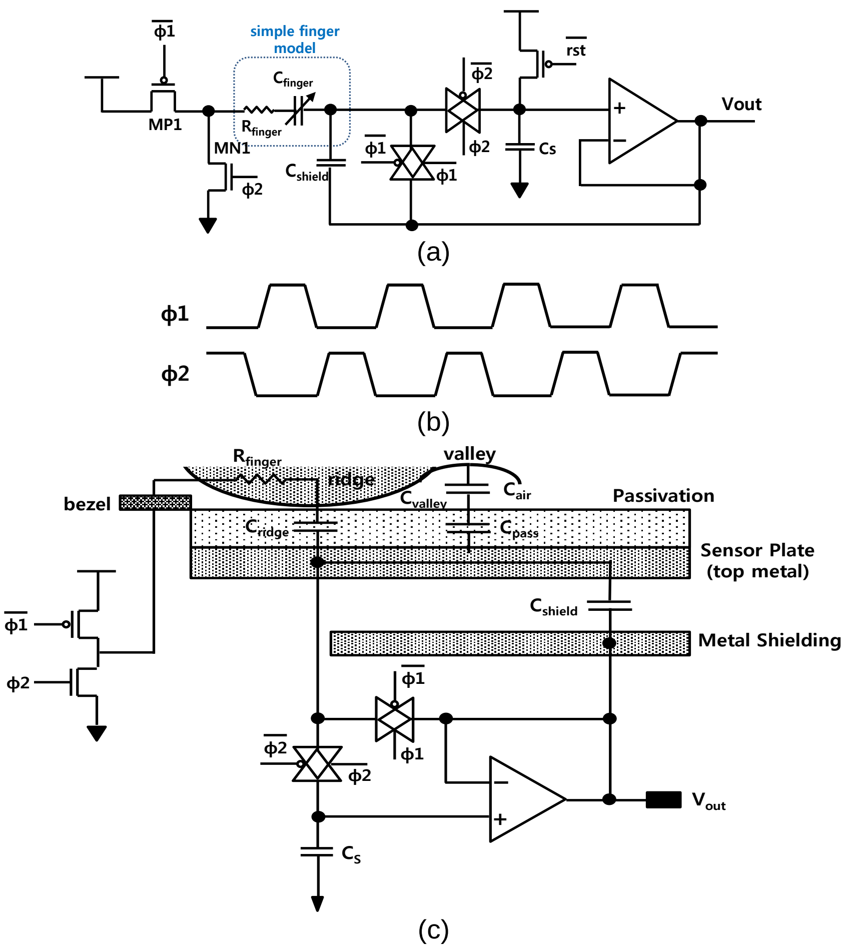
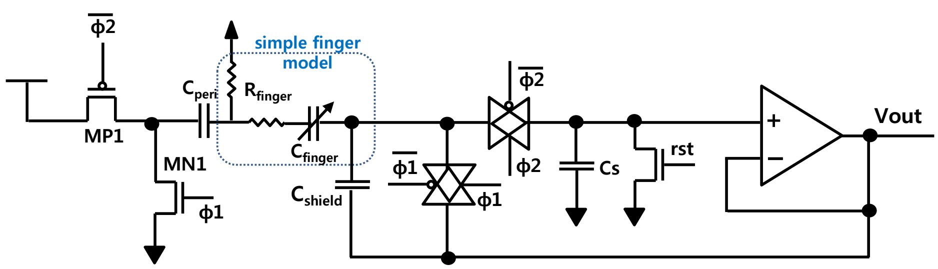


Figure 1. (a) AOVF Integrator for Fingerprint Sensor Cell with Direct Scheme, (b) Non-overlapping Two-phase Clock, (c) Vertical Layout Structure of an AOVF Integrator based Fingerprint Sensor unit Applied in MOS Technology [11]

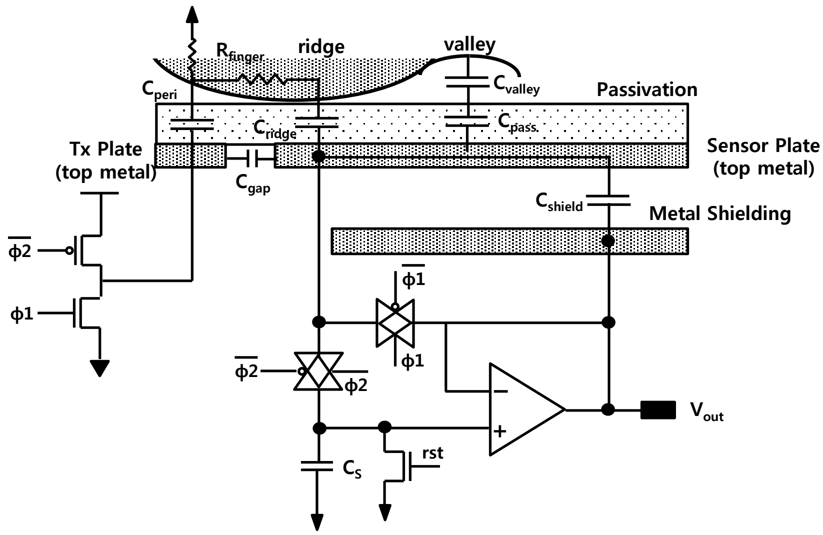
Figure 2(a) shows the proposed fingerprint sensor's circuit structure using a Tx electrode as a signal driving electrode, which is named as a pseudo-direct scheme. Instead of using a bezel in Figure 1(c), the proposed pseudo-direct scheme uses Tx electrode placed inside the integrated chip to drive a signal to a finger. Since the proposed fingerprint sensor using pseudo-direct scheme inherits the circuit structure of the fingerprint sensor with AOVF integrator, the proposed fingerprint sensor cell circuit structure is very similar to that of Figure 1(a). Therefore, the proposed fingerprint sensor inherits the maximum sensitivity with low-voltage by using full supply voltage and the improved SNR obtained by signal integration scheme. A finger combined with a Tx electrode are modeled in C_{peri}, R_P, R_S, and C_{finger} as shown in Figure 2(a). C_{peri} is a capacitor formed between the Tx electrode and a finger which is used as an electrode for signal driving to a finger. R_P is a parallel resistor at the point of C_{peri} and ground through the finger. R_S and C_{finger} are a series-connected resistor and a capacitor which are the same circuit models as shown in Figure 1(a).

The proposed fingerprint sensor includes the additional capacitance formed between the Tx electrode and a finger which is denoted as C_{peri} in Figure 2(b). Figure 2(b), (c) shows the vertical layout view of the fingerprint sensor cell which includes Tx electrode and the corresponding top layout view of the fingerprint sensor driver, respectively. As shown in Figure 2(c), the inside bezel which is placed at the perimeter of the whole chip or sensor cell array rather than each fingerprint sensor inside. Tx electrode as an inside bezel can be used as a port for signal drive to the finger through C_{peri}, which is named as pseudo-direct scheme in this paper. C_{gap} is the capacitance between the fingerprint sensor array and Tx electrode placed at the edge of the sensor array as shown in Figure 2(c). Since applied signals to Tx electrode can pass through to the sensor cell array via C_{gap}, C_{gap} should be small enough not to transmit the applied signal directly to the sensor array. Therefore, the gap must be large enough to be formed small C_{gap}. In this paper, it is assumed that the gap is large enough, two or more times than the thickness of the passivation, to ignore the electric field across between the Tx electrode and the sensor array.

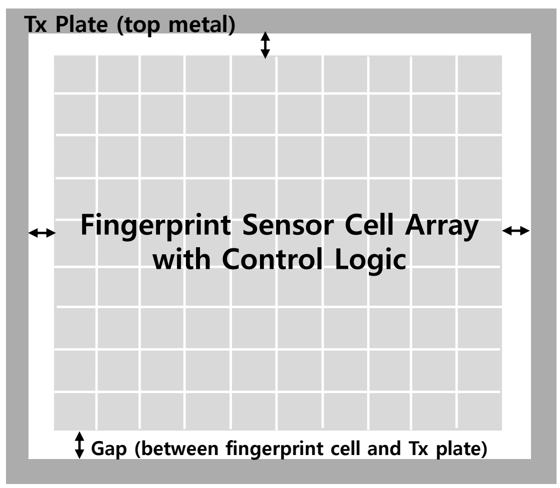
As mentioned, C_{finger} is composed of two series-connected capacitors which are a C_{pass} and C_{air}. The sensor plate is separated with metal shield to prevent the noises from the bottom of the sensor plate denoted as C_{shield}. Although, the fingerprint sensor direct scheme as shown in Figure 1 can drive C_{finger} directly with full voltage range, the signal driven to C_{finger} from Tx electrode is represented as a function of R_P, R_S, C_{peri}, and C_{finger} for the proposed fingerprint sensor using pseudo-direct scheme.



(a)



(b)



(c)

Figure 2. The Proposed Fingerprint Sensor Cell Circuit using Pseudo-direct Scheme (b) Vertical Layout Structure of the Fingerprint Sensor Cell unit Applied in MOS Technology (c) Top Layout view of the Proposed Fingerprint Sensor Array

As analyzed in [11], the capacitance of the fingerprint sensor are defined as (1)~(3).

$$C_{ridge} \approx C_{pass} \tag{1}$$

$$C_{valley} \approx \frac{C_{air} \cdot C_{pass}}{C_{air} + C_{pass}} \tag{2}$$

$$\Delta C_{finger} \approx C_{ridge} - C_{valley} \tag{3}$$

Different from the fingerprint using direct drive method, the variation of the output voltage for single charge transition is dependent on the voltage at V_A. However, the node V_A is isolated with C_{peri}, the node voltage is dynamically changed. If it is assume the voltage of node V_A can be considered as a dc, V_{diff} is roughly calculated as (4). However, it is estimated with simulation for more detail.

$$V_{diff} \approx \left(\frac{C_{ridge}}{C_{ridge} + C_S} - \frac{C_{valley}}{C_{valley} + C_S} \right) V_{peri} \quad (6)$$

V_{sense} after n-time integrations is derived as (7)~(9) using equation (6).

$$V_{sense} = n \cdot V_{diff} \quad (7)$$

Figure 3 shows the simplified circuit model of the proposed fingerprint unit using pseudo-direct scheme. A driver signal, V_1, is passed through C_{peri} to V_A. As a result, the node voltage of V_A would contribute the signal integration for fingerprint evaluation.

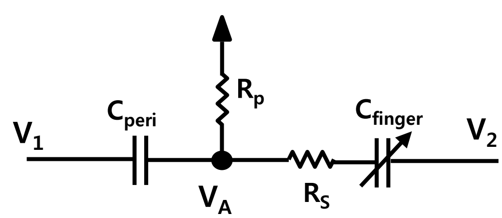


Figure 3. Simplified Circuit Model of Proposed Fingerprint Sensor Cell unit using Pseudo-direct Scheme

The frequency response of V_A is derived as (10). As analyzed in (10), V_A has a high-pass characteristics for V_1 or V_2 inputs.

$$V_A(S) = \frac{S^2 + S\left(\frac{C_{peri}V_1 + C_{finger}V_2}{C_{peri}C_{finger}R_S}\right)}{S^2 + S\frac{C_{peri} + \left(1 + R_S/R_P\right)C_{finger}}{C_{peri}C_{finger}R_S} + \frac{1}{C_{peri}C_{finger}R_PR_S}} \quad (10)$$

If it is assumed that V_2 is zero, then V_A is rewritten as (11).

$$V_A(S) = \frac{S^2 + S\left(\frac{V_1}{C_{finger}R_S}\right)}{S^2 + S\frac{C_{peri} + \left(1 + R_S/R_P\right)C_{finger}}{C_{peri}C_{finger}R_S} + \frac{1}{C_{peri}C_{finger}R_PR_S}} \quad (11)$$

Figure 4 shows the frequency response of the modeled circuit. R_P and R_S are fixed value of 500kΩ and C_{finger} is 1fF. As expected in analysis, the overall frequency responses are high-pass characteristics. As shown in Figure 4, the signal frequency of 3MHz or above will be transferred to V_A with less than 1dB loss. Hence this paper has chosen a 10MHz signal for the simulation which is a reasonable operating frequency for the fingerprint sensor. Signal losses more as C_{peri} decreases by simulation. Therefore, it is concluded that a sufficient C_{peri} is required for the proper operation of the proposed pseudo-direct fingerprint sensor.

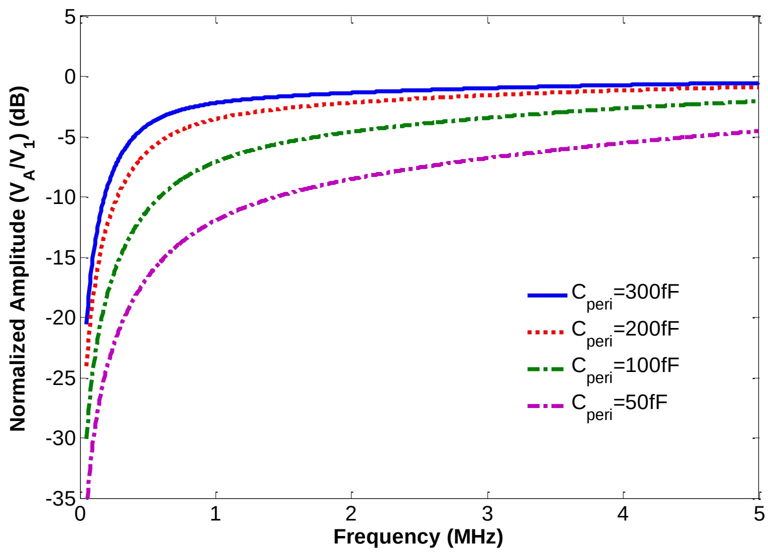
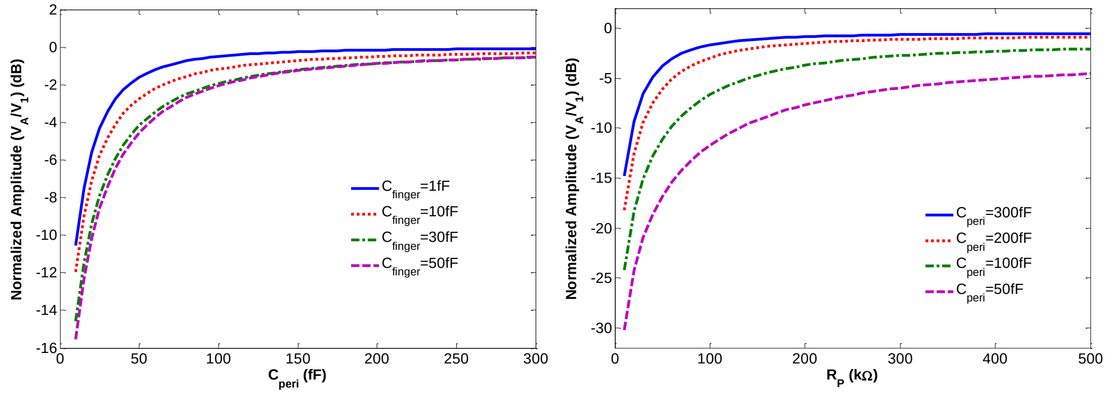


Figure 4. Frequency Responses of the Circuit Model of the Combined a Fingerprint and Tx Electrode of the Proposed Pseudo-direct Fingerprint Sensor

Figure 5(a) shows the normalized voltage amplitude of V_A with C_{peri}. R_P and R_S are fixed with 500kΩ. As shown in Figure 5(a), the signal loss is less than 1dB with C_{peri} of 150fF or above regardless of C_{finger}. The signal frequency is 10MHz as mentioned. Figure 5(b) shows the normalized voltage amplitude of V_A with R_P which models a finger resistance formed between the finger and the ground. R_S is fixed with 500kΩ because it does not much affect V_A characteristics with signal frequency of 10MHz. From the results, V_1 signal passes through V_A with less loss as R_P or C_{peri} increase. V_1 signal hardly passes to V_A with less than R_P of 50kΩ and also less than C_{peri} of 100fF. And the performance will be degraded less than 100kΩ even more than C_{peri} of 200fF. Therefore, C_{peri} of 200fF or more is required for desirable performance. Although, R_P cannot be adjustable because it is a resistance of a finger, it is considered that the resistance of a finger has more than 200kΩ normally. However, recent mobile systems often uses a metal case [12], which may possibly decrease the resistance of the finger to the ground because the metal case is often shielded with ground. In this case, it is advisable to increases the distance between fingerprint sensor and the metal case not to degrade the system performance.



(a) (b)

Figure 5. Normalized Transfer Characteristics of the Circuit Model of Combined a Fingerprint and Tx Electrode of the Proposed Pseudo-direct Fingerprint Sensor (a) with C_{peri}, (b) with R_P

Figure 6 shows the 3-dimenaional V_A characteristic to V_1 signal with various C_{peri} and R_P. According to the simulation results shown in Figure 6, the drive signal has high pass characteristic with respect to C_{peri} and R_P as expected. Therefore, it is advisable for the proposed fingerprint sensor using pseudo-direct scheme to have a larger C_{peri} (more than 200fF) and a larger R_P (more than 200kΩ).

3. Simulations

This paper simulates the proposed pseud-direct fingerprint sensor cell based on an AOVF integrator. Figure 7(a) shows of output voltage of the proposed pseudo-direct fingerprint sensor cell with C_{finger} and R_P. C_{peri} of 300fF has been chosen for the simulation, which is enough amount of capacitor value to transfer the Tx signal to C_S from MATLAB analysis.

C_{shield} of 80fF has been chosen, which is roughly calculated using 50μmX50μm plate area as mentioned. And also C_S of 30fF has been chosen for the simulations. C_{ridge} can be obtained as about 1fF which can be roughly calculated by choosing a 50μmX50μm sensor plate with 100μm-thickness passivation. C_{valley} is a series connected capacitor of C_{pass} and C_{air} in Figure 2(b). The capacitance value of 0.5fF is assumed for C_{valley}, which is obtained by assuming 20μm valley depth.

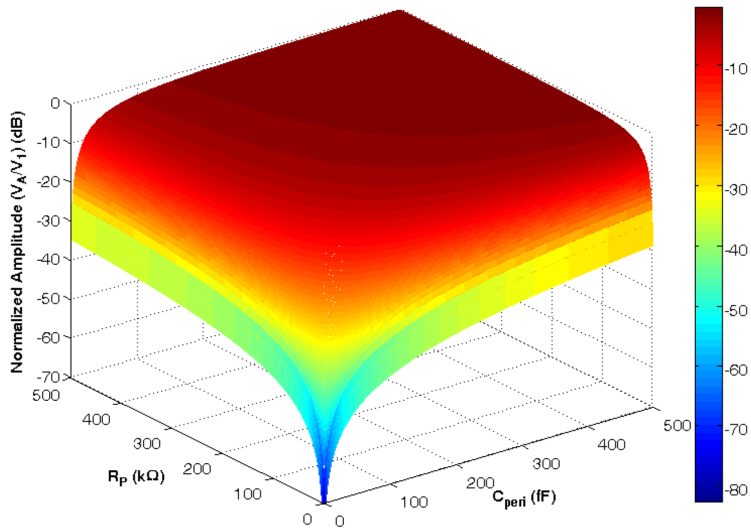


Figure 6. 3-Dimensional Normalized Transfer Characteristics of the Circuit Model of Combined a Fingerprint and Tx Electrode of the Proposed Pseudo-Direct Fingerprint Sensor with C_{peri} and R_P

Figure 7 shows that output voltage characteristic of the fingerprint sensor as the signal integration increases. The output voltage outputs are compared for ridge and valley which is modeled with a series connected capacitor of 1fF and 0.5fF, respectively. R_P and R_S of 500kΩ and C_{peri} of 300fF are used in the simulation. 10MHz two phase non-overlapping clock signals have been chosen to control the switches of the circuit for the simulation upon the MATLAB analysis. As shown in Figure 7, the output voltage goes up 636mV and 1.014V after 20-time integrations. V_{sense} defined as the voltage difference between ridge and valley is 378mV.

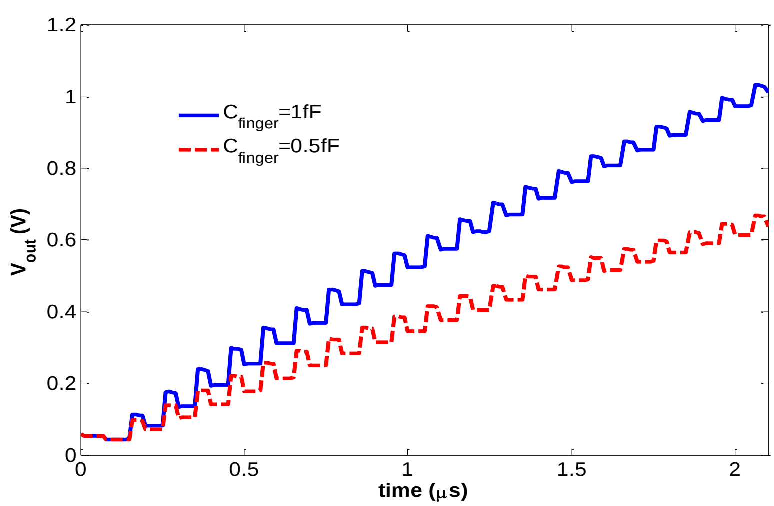


Figure 7. Time Domain Voltage Output Characteristics during Charge Transitions of the Proposed Fingerprint Sensor Cell Unit

Figure 8 shows the output voltage of 20-time signal integrations with C_{finger} and R_P increase. As shown in Figure 8, the output voltages of the proposed pseudo-direct fingerprint sensor cell increase linearly as the C_{finger} increases. The output voltage after 20-time integrations 1.884V and 432mV for Rp of 1MΩ and 50kΩ, respectively.

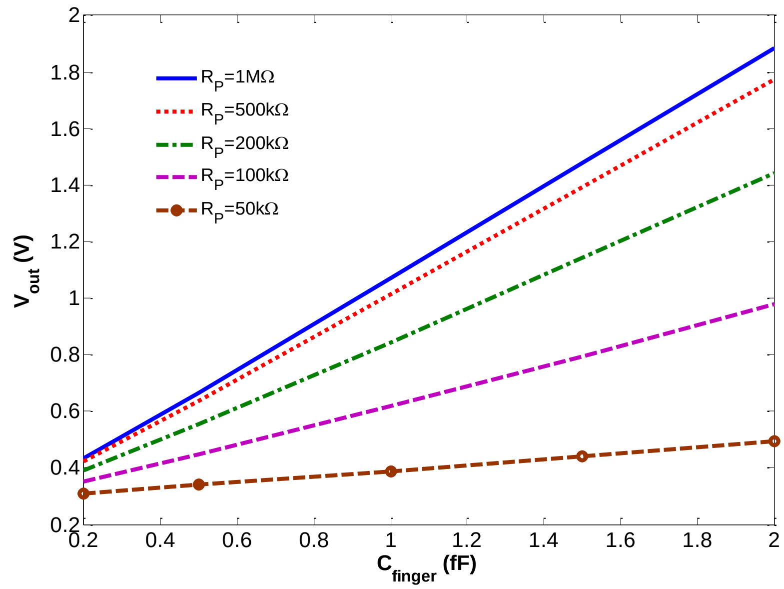


Figure 8. Output Voltage Characteristics of 20-time Signal Integrations with C_{finger} and R_P

Figure 9(a) shows the output voltage with 20-time signal integrations with C_{finger} of 1fF. As the R_P increases, the output voltage increases and then becomes saturated from 500kΩ as it can be predicted from the MATLAB analysis. The output voltage increases gradually as R_P increase and then the output voltage starts to saturate from R_P=200kΩ. The output voltage is almost saturated from 500kΩ, which means that most of the Tx signal passes through to V_A. The output voltages difference between ridge and valley, V_{sense}, were simulated. V_{sense} is defined as (7). As described, the fingerprint capacitances of 0.5fF, 1fF were chosen for C_{ridge} and C_{valley} to examine the performance of the proposed fingerprint sensor. Figure 9(b) shows V_{sense} for five R_P of the sensor for 20-time signal integrations. As shown in Figure 9(b), the simulated maximum V_{sense} is about 400mV with R_P of 1MΩ. V_{sense} is almost saturated with R_P of 500kΩ. V_{sense} falls rapidly with less than R_P of 200kΩ. Since the V_{sense} is defined as output voltage difference between the ridge and the valley, the characteristics of V_{sense} with R_P is similar to those of V_{out} as shown in Figure 9(b). As seen in Spectre simulations, results for the proposed fingerprint sensor with pseudo-direct scheme are well matched with those of MATLAB analyses. From the simulation results, the proposed fingerprint sensor using pseudo-direct scheme obtained hundreds of millivolt of V_{sense} after 20-time integrations with C_{peri} of 200fF or above for 10MHz driving signal. Although, the more parallel resistance of finger R_P is the better, R_P of 200kΩ or above, which is a common resistance value of the finger, is enough to get a reasonable V_{sense} performance of the proposed fingerprint sensor.

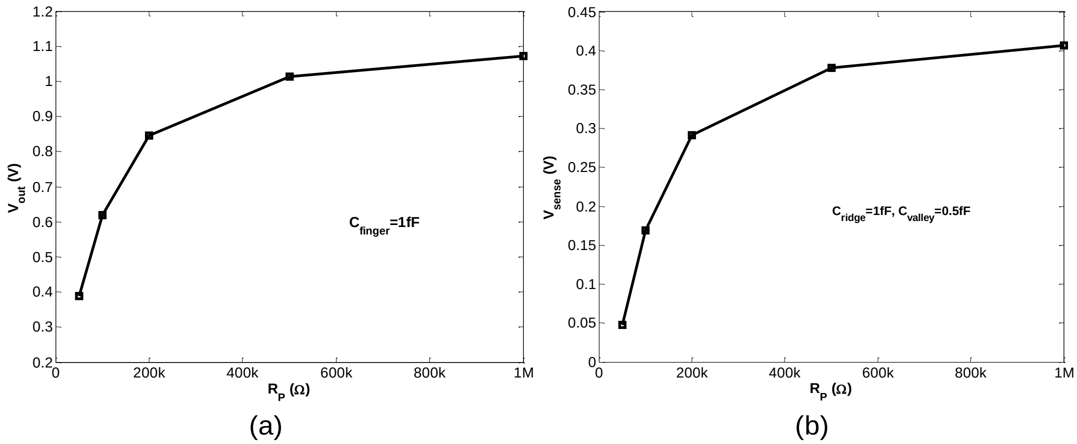


Figure 9. (a) Output Voltage with C_{finger} of 1fF and (b) Vsense Characteristics for 20-time Signal Integrations Versus R_P

4. Conclusion

This paper proposed an AOVF integrator based fingerprint sensor using Tx electrode as an internal bezel for signal driving to the finger, which is named as a pseudo-direct scheme. The proposed fingerprint sensor inherited the direct signal driving scheme using a bezel which maximizes the sensitivity of the sensor and also uses the signal integration scheme which improves SNR greatly. To verify the theoretical performances of the fingerprint sensor, a finger combined with Tx electrode has been modeled and analyzed using MATLAB. And the proposed fingerprint sensor with the modeled circuits was designed and simulated using standard 0.35μm CMOS technology. The simulation results of the proposed fingerprint sensor using pseudo-direct scheme is well matched with those of MATLAB analysis. From the simulation results, V_{sense} of hundreds millivolt is obtained with 20-time signal integrations for Tx electrode's capacitance of 200fF or above with the assumption that the parasitic resistance is 200kΩ or above,

In conclusion, the simulation results verified the proposed fingerprint sensor using pseudo-direct scheme can be effectively used as a fingerprint sensor without a bezel for direct signal driving to a finger. Moreover, it improves SNR of the fingerprint sensor by using signal integration scheme.

Acknowledgements

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