A Readout IC Design for the FPN Reduction of the Bolometer in an IR Image Sensor

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In this paper, we propose and discuss the design using a simple method that reduces the fixed pattern noise (FPN) generated on the amorphous Si (α–Si) bolometer. This method is applicable to an IR image sensor. This method can also minimize the size of the reference resistor in the readout integrated circuit (ROIC) which processes the signal of an IR image sensor. By connecting four bolometer cells in parallel and averaging the resistances of the bolometer cells, the fixed pattern noise generated in the bolometer cell due to process variations is remarkably reduced. Moreover an α–Si bolometer cell, which is made by a MEMS process, has a large resistance value to guarantee an accurate resistance value. This makes the reference resistor be large. In the proposed cell structure, because the bolometer cells connected in parallel have a quarter of the original bolometer's resistance, a reference resistor, which is made by poly–Si in a CMOS process chip, is implemented to be the size of a quarter. We designed a ROIC with the proposed cell structure and implemented the circuit using a 0.35 um CMOS process.

Keywords : ROIC, Fixed pattern noise, Micro bolometer, IR image sensor, MEMS

1. INTODUCTION

Bolometers are thermal detectors that change their electrical resistance as a function of temperature. Infrared ray (IR) image sensors implemented by means of these bolometers are used in many applications such as in industrial, military, and medical tools. However, bolometers made by an α–Si and micro electro mechanical systems (MEMS) process have some serious problems[1]. The resistance of the bolometers in the IR sensor is different because of process variations. A variation of bolometer rèsistance from process variations is fixed pattern noise (FPN). This noise is one of the critical sections in IR image sensors. Another serious problem concerned the bolometer as an IR image sensor is large resistance value of the bolometer. A large bolometer resistance needs a large reference resistor which is implemented by a poly–Si resistor on a readout integrated circuit (ROIC) chip. In order to resolve these problems, extensive studies have been carried out on these problems[2,3]. In this paper, we applied a bolometer which had 1 MΩ resistance to our ROIC. The resistance variation of the bolometer was within 5 % [Fig. 1]. To correct for the FPN, we proposed a new bolometer cell structure and designed a ROIC with the proposed circuit structure.

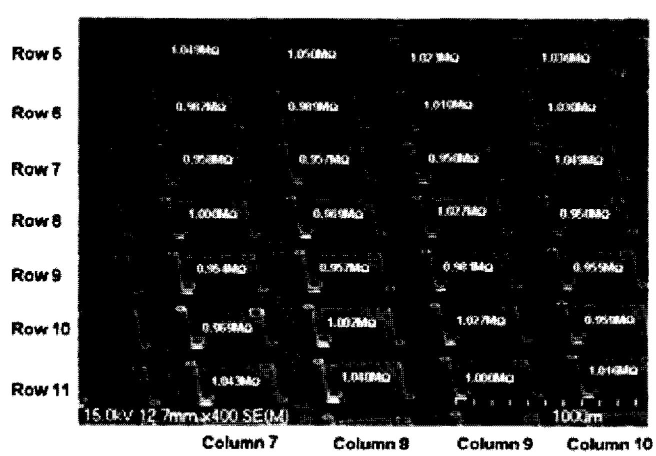


Fig. 1. The resistances of the bolometer cell array under condition of non IR energy state.

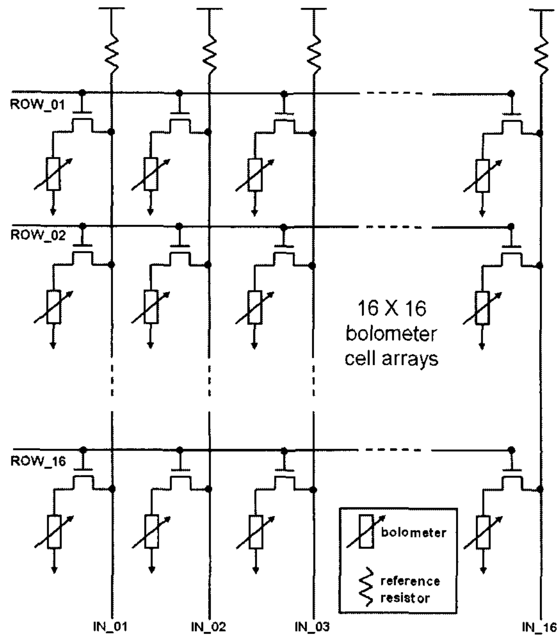


Fig. 2. The conventional bolometer cell structure.

2. THE BASIC CONCEPT AND CIRCUIT STRUCTURE

Figure 2 shows a conventional bolometer cell structure for the IR image sensor[4,5]. Each bolometer appears with 1 MΩ resistance at no incidence IR energy. The ΔR_T is equal to the resistance variation response to the incidence IR energy and the ΔR_P response to process variation. Therefore, the total resistance value of a bolometer at the condition of the existence of FPN and incident IR is equal to eq. (1).

$$R_{bol} = 1M\Omega + \Delta R_T + \Delta R_P \quad (1)$$

We assume that the reference resistor has an accurate resistance of 1 MΩ. In the case of a conventional cell structure, the input voltage is expressed in eq. (2).

$$V_{input} = V_{DD} \times \frac{1M\Omega + \Delta R_T + \Delta R_P}{1M\Omega + 1M\Omega + \Delta R_T + \Delta R_P} \quad (2)$$

In this case, the resistance variation by process variation at an arbitrary bolometer cell directly influences the input voltage. Moreover, the effects of the temperature variation and process variation on the input voltage variation are equal such as equation 3, if we assumed that ΔR_T and ΔR_P are very smaller than 1 MΩ.

$$\frac{\partial V_{input}}{\partial \Delta R_T} = \frac{\partial V_{input}}{\partial \Delta R_P} \approx \frac{1}{2} \times \frac{V_{DD}}{1 \times 10^6} (V/\Omega) \quad (3)$$

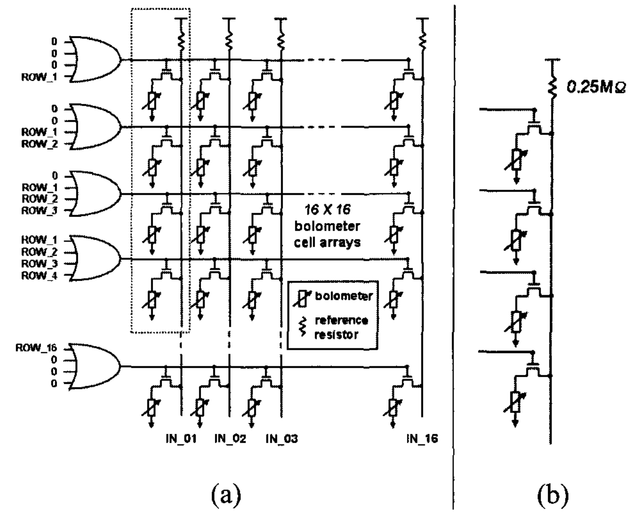


Fig. 3. Proposed bolometer cell structure(a) and activated bolometer cells by row decoder(b).

Therefore, the FPN of the bolometer cell is not reduced and the distorted signal is transmitted to the input of the ROIC.

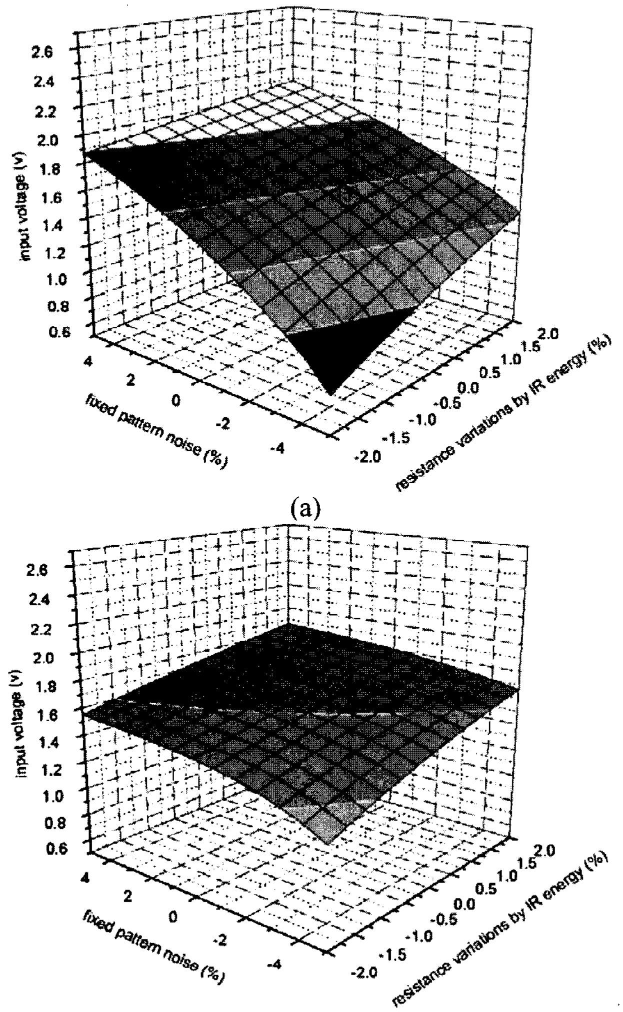
In order to reduce the FPN of a bolometer cell, we connected four bolometer cells in parallel using an OR gate at the output stage of the ROW decoder [Fig. 3]. Figure 3(b) shows the activated cells of the first column when the "ROW_1" signal is turned on. In this case, the reference resistor had a resistance of 0.25 MΩ that was equal to a quarter of the reference resistor in the conventional cell structure. We assumed that only one arbitrary bolometer cell, among the four connected bolometer cells, which were incident with the same IR energy had a resistance variation ΔR_P from process variations. Under this condition we calculated the input voltage (eq. (4)).

$$V_{input} = V_{DD} \times \frac{1M\Omega + \Delta R_T + \Delta R_P}{1M\Omega\left(1 + \frac{(3/4)\Delta R_P}{1M\Omega + \Delta R_T}\right) + 1M\Omega + \Delta R_T + \Delta R_P} \quad (4)$$

In this case, input voltage variation due to IR thermal incident is as same as the conventional case (eq. (5)). However, input voltage variation by non-uniformity of the bolometers is very smaller than the conventional case (eq. (6)).

$$\frac{\partial V_{input}}{\partial \Delta R_T} \approx \frac{1}{2} \times \frac{V_{DD}}{1 \times 10^6} (V/\Omega) \quad (5)$$

$$\frac{\partial V_{input}}{\partial \Delta R_P} \approx \frac{1}{16} \times \frac{V_{DD}}{1 \times 10^6} (V/\Omega) \quad (6)$$



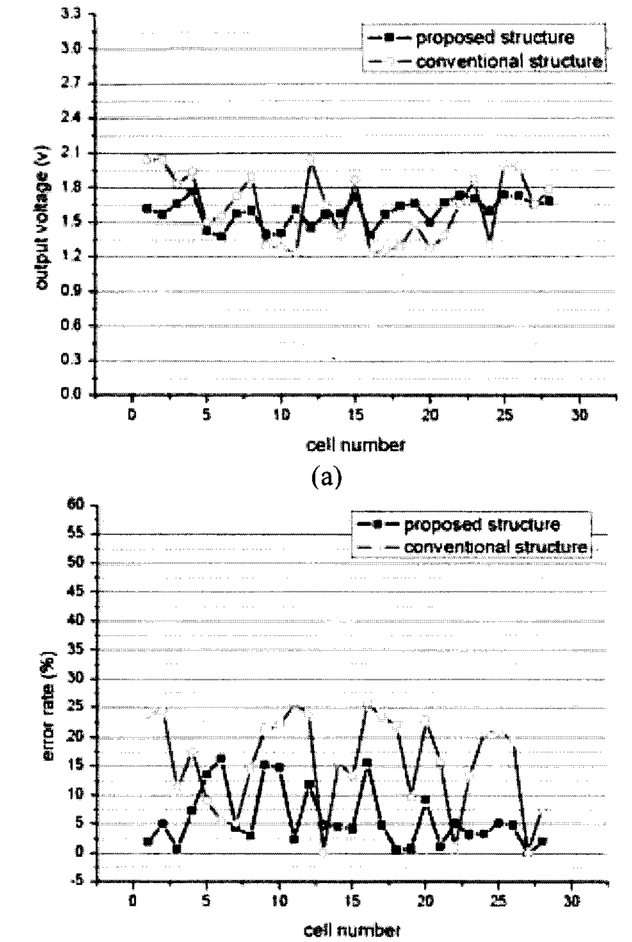
(a)

(b)

Fig. 4. The calculation results of the eqs. (2) and (4) according to resistance variations due to FPN and IR energy in conventional(a) and proposed(b) bolometer cell structure.

3. AN ANALYSIS OF THE CHARACTERISTICS

In order to analyze the effect of the resistance error caused by process variations on the input signal, we calculated eqs. (2) and (4) according to the variations of ΔR_T and ΔR_P. The results are indicated in Fig. 4. Each figure shows the input voltage value with resistance variations due to errors caused by process variations and the IR incident energy. In the conventional bolometer cell structure, resistance error due to process variations was from –5 % to 5 % and made a voltage difference of 0.084 V; but, the voltage difference was 0.021 V in the proposed bolometer cell structure under the condition of constant IR incident energy. This indicated that an extreme FPN noise correction effect was realized in the proposed bolometer cell structure.



(a)

(b)

Fig. 5. The simulation output results(a) and error rate(b) of the bolometer cell array under condition of Fig. 1 in conventional and proposed cell structure.

Based on the above results, we investigated the simulation results under the bolometer resistance condition of Fig. 1. Figure 1 shows the resistance values of 28 bolometers which were made by a MEMS process. The resistance values were measured under a non IR energy incident condition. Therefore, resistance variations due to the IR energy, ΔR_T, was zero. Figure 5(a) shows the resultant voltages at the output node and Fig. 5(b) shows the error rate of the output voltages in the conventional and proposed bolometer cell structures. The average error rate of the conventional structure was 15.6 % and that of the proposed structure was 5.9 %. These results showed that the ROIC with the proposed bolometer cell structure had a high FPN immunity even thought the bolometer cells randomly had FPN.

4. FULL CHIP DESIGN AND TEST

We designed an ROIC for investigating the new bolometer cell structure. Figure 6 shows the ROIC that

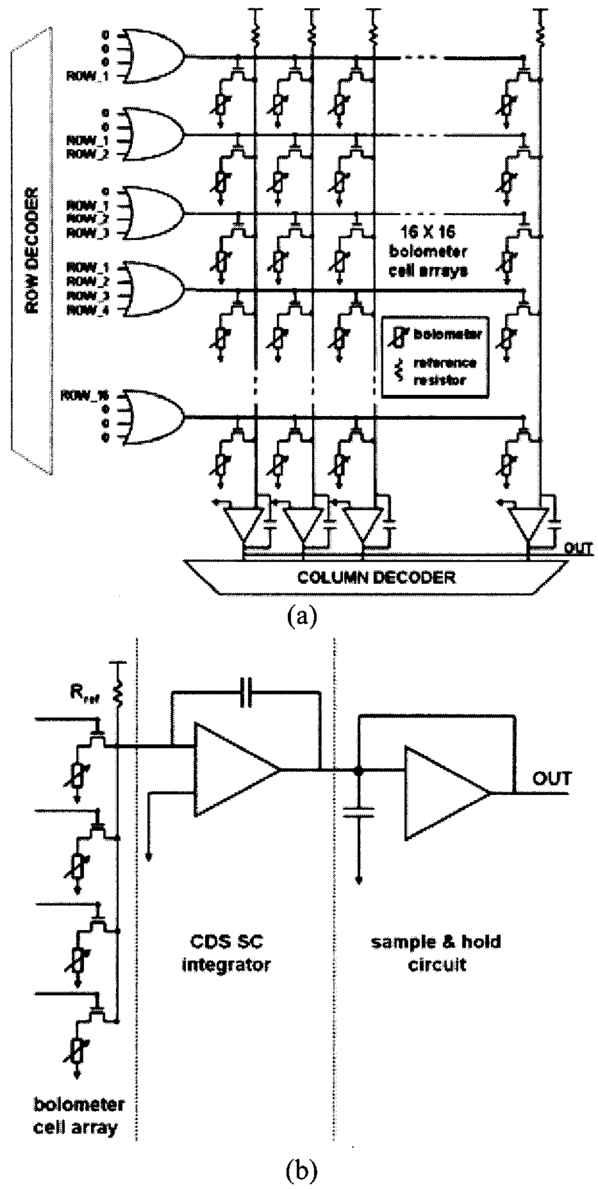


Fig. 6. Designed ROIC architecture(a) and single readout scheme(b).

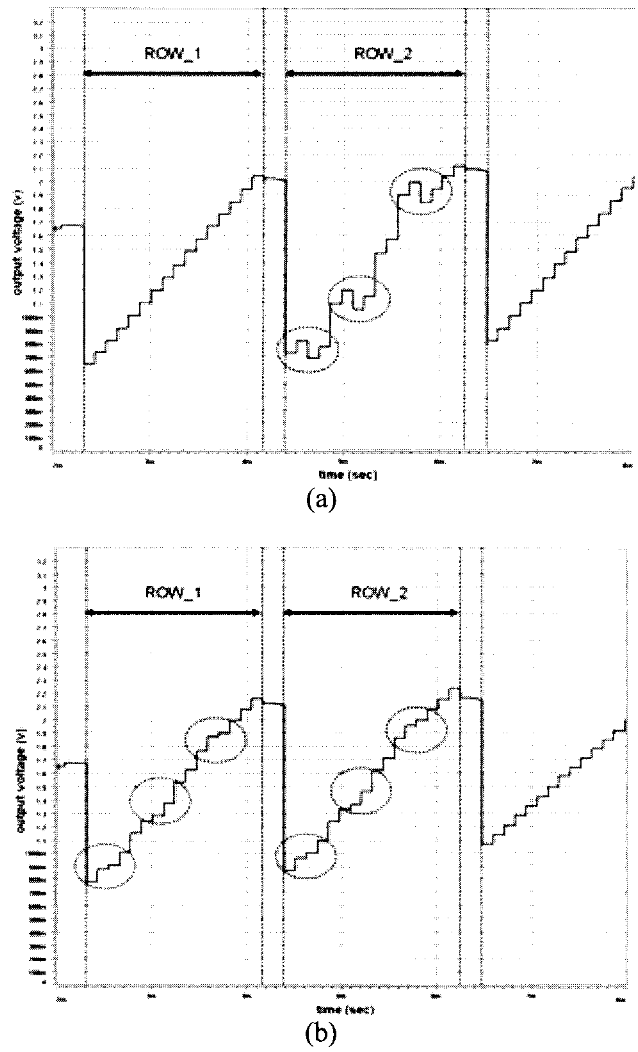


Fig. 7. Full chip simulation results of conventional(a) and proposed(b) cell structure.

integrated the one input signal. In order to reduce the FPN due to the integrator's mismatch a correlated double sampling (CDS) switched capacitor (SC) integrator was used[6,7].

In order to investigate the FPN reduction effect of the new bolometer cell structure, we compared the simulation results of the conventional and proposed cell structures. In the simulation, we assumed that the IR energy was linearly applied to the cell from the left top to the right bottom and the cells at the (2, 4), (2, 8) and (2, 12) had a 1 % resistance error due to process variations. Figures 7 (a) and (b) show the simulation results of the conventional and proposed bolometer cell structure, respectively. Moreover, both circuits were consisted by a differential input mode to obtain high gain. As we can see in Fig. 7(a), the at conventional cell structure the FPN directly responded to the output voltages as indicated by the circle. However, with the proposed cell structure the effect of the FPN was extremely reduced and distributed to the output at ROW_1 because of the parallel cell structure.

We implemented the ROIC chip by a 0.35 um 1 poly 4 metal CMOS process. Figure 8(a) shows the layout of the ROIC and Fig. 8(b) shows the test board for testing the characteristics of the ROIC by using variable resistors instead of a bolometer sensor. We obtained a smaller size of reference resistors in this chip than the chip which used the conventional cell structure. By testing the characteristics using the test board, we could obtain good characteristics as same as the simulation results.

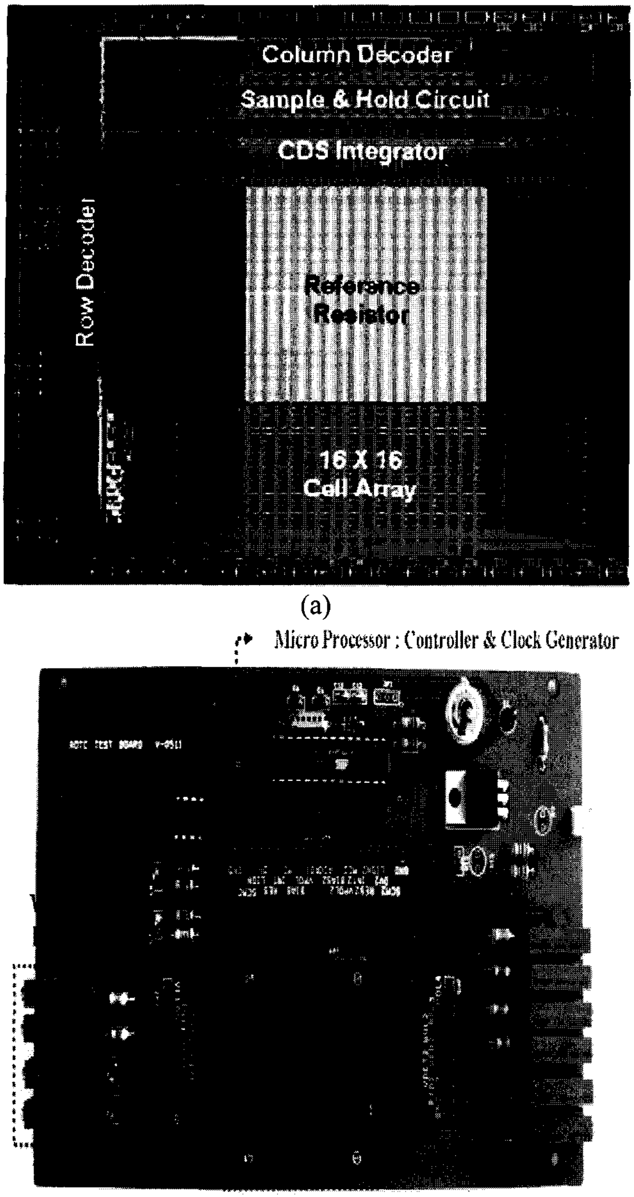


Fig. 8. Chip layout(a) and test board(b).

5. CONCLUSION

We proposed and discussed the design of a ROIC with a new bolometer cell structure for FPN reduction and the achievement of a small reference resistor size. By connecting the four cells in parallel, we were able to smooth out the resistance of the bolometers with FPN resulting from process variations. If one cell out of 4 cells had a 5 % FPN, the correction effect of FPN was increased four times. Moreover, when the bolometer cells randomly had FPN, the effect of FPN on the output of ROIC was decreased from 15.6 % to 5.9 %. By connecting the cells in parallel, we reduced the size of the reference resistor which occupied a large portion of the ROIC chip.

ACKNOWLEDGMENTS

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