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A self-compensating system for fixed pattern noise reduction of focal plane arrays of infrared bolometer detectors

Pavel Neuzil[a,b]*, Jan Pekarek[a], Vojtech Svatos[a], Roman Prokop[a], Imrich Gablech[a], Michal Pavlik[a], Lukas Fujcik[a], Jaromir Hubalek[a]

[a]*Centre of Sensor, Information and Communication Systems, Brno University of Technology, Brno 616 00, Czech Republic*
[b]*Department of Microsystems, Northwestern Polytechnical University, Xi'an, P.R. China*

Abstract

This paper describes a self-compensating system for fixed pattern noise reduction (FPNR) of focal plane arrays (FPA) of infrared (IR) bolometer detectors. The proposed system used a ΔΣ modulator of first order which operates as non-saturating current integrator. The method also suppressed the self-heating effect as well as the effect of resistance non-uniformity across the FPA. The read-out circuit (ROIC) was designed in ONSemi I2T100 technology considering the matching and noise effects and fabricated using EUROPRACTICE service. Its verification was made on the test printed circuit board (PCB) with the variable resistors. These resistors were changed to emulate the real bolometer behavior due to IR radiation.

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Keywords: Bolometer; read-out integrated circuit; ΔΣ modulator; IR imaging;

1. Introduction

Uncooled infrared bolometer arrays are used in many applications, such as astronomy, thermal scanning to search for people or animals, and recently very popular preventive maintenance of electrical appliances and monitoring thermal isolation of buildings [1]. Bolometer is a device with thermally isolated membrane equipped with temperature sensor and their membrane warms up due to incident radiation. With advent of integrated circuit technology and micro

* Corresponding author. Tel.: +420-541-146-192; fax: +420-541-146-298.
E-mail address: pavel.neuzil@gmail.com

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electromechanical systems (MEMS), microbolometers were developed in format of focal plane arrays (FPA) for thermal imaging.

There are several reported methods of bolometer signal read-out circuits [2-5]. Some of them are able to compensate self-heating phenomenon either by injection of a current ramp [6] or by other compensating techniques. All of them suffer from the process variation and pixel to pixel variation. The read-out circuit described in [7] cannot integrate signal for unlimited time and it also needs digital to analog converter (DAC) with off-chip memory for pixels non-uniformity correction (fixed pattern noise reduction). The gain is typically corrected after the fixed pattern noise is subtracted and the bolometer is illuminated by IR source with known intensity. Digital processing unit (or analog circuit) introduces correction coefficients to get identical signals from all pixels [8].

In this paper, we propose using the ΔΣ modulator of first order in an unconventional way. Instead of typical oversampling for analog to digital conversion, we use it for suppression of fixed pattern noise from the bolometer focal plane array and thus dramatically increase its performance and ROIC simplicity as reported earlier [9]. Here we demonstrate performance of fabricated read-out integrated circuit (ROIC) chip on the test printed circuit board (PCB). The system neither needs DAC nor external memory as well as extra off-chip circuits for its operation. The self-heating correction technique can also be implemented to improve the performance of the proposed circuit. The proposed gain correction scheme does not require reference IR source and the correction is done when the shutter is closed.

1.1. Principle of sigma delta modulator-based FPNR

The proposed ΔΣ modulator ROIC was designed to measure bolometer sensors with nominal resistance higher than 4 kΩ as well as to evaluate sensor temperature changes in range of 1 – 256 mK using 1 MHz clock signal for modulator. The principal electrical schematic is shown in Fig. 1. The SWCTRL signal connects the sensors to the supply voltage over the transistors M_{SW1} and M_{SW2} at the beginning of the integration period. Electrical currents through both bolometers start to flow and the integrator integrates the bolometer and dummy resistor current difference in its capacitor. The transistor serving as reset switch is in "ON" stage by a CRES signal at the beginning to discharge the integrator capacitor. We chose 3 µs delay to release the integrator by CRES signal to ensure that the current mirror M_{M3} and M_{M4} are stabilized and we will not be integrating transient effects. The difference current of reference and measured sensors is then processed by the modulator for following chosen integration period such as 80 - 90 µs. The BV1OUT voltage is read by external circuits of the test PCB, then SWCTRL signal disconnects the sensors. After the integration period, CRES signal switch discharges the capacitor voltage to initialize integrator for the next measurement.

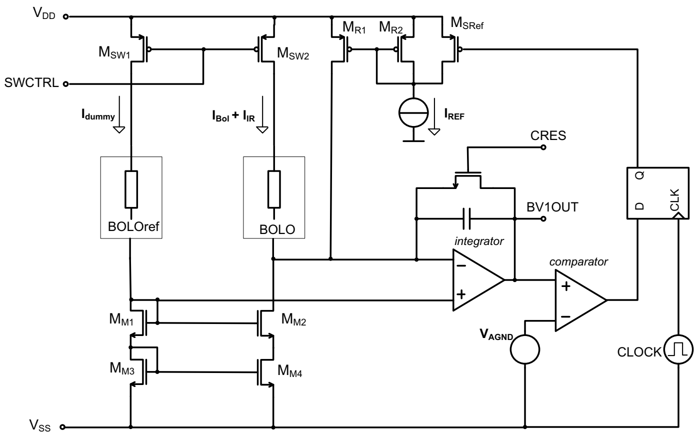

Fig. 1. The principal electrical schematic of the self-compensating system for FPNR of FPA of IR bolometer detectors.

2. Experimental

The ROIC was designed in ONSemi I2T100 technology (see Fig. 2a) considering the matching and noise effects. The chips were fabricated using EUROPRACTICE service and are shown in Fig. 2b.

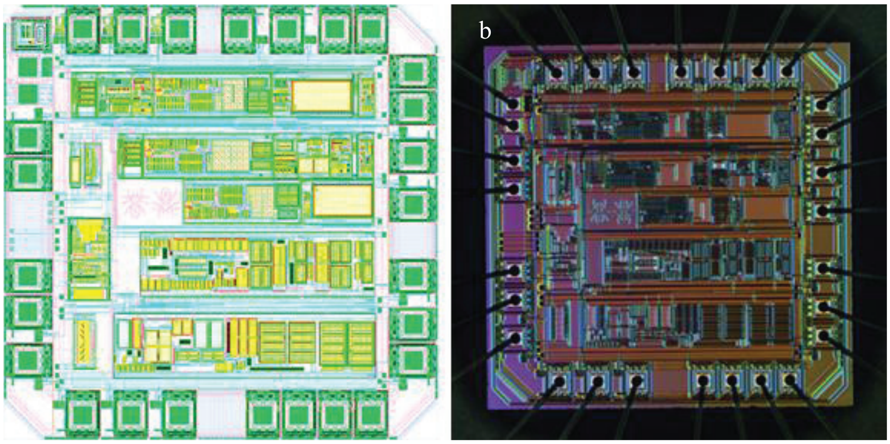

Fig. 2. (a) Design in ONSemi I2T00 technology; (b) Optical image of a fabricated ROIC by EUROPRACTICE service.

The test PCB was designed and fabricated to perform fundamental verification of the ROIC chip. The signals needed to control and setup of the ROIC chip (i.e. SWCTRL, CRES, CLK and AGND voltage) were generated with this test PCB. The test PCB consisted of microcontroller for driving the AD and the DA converters, low pass filters and circuits for galvanic separations. The ROIC core is powered by an external battery separated from ADC power supply as well as from the DAC's to reduce cross talk noise. A custom designed software with graphical user-friendly interface communicates with microcontroller through USB interface. The block diagram of the test PCB is shown in Fig. 3.

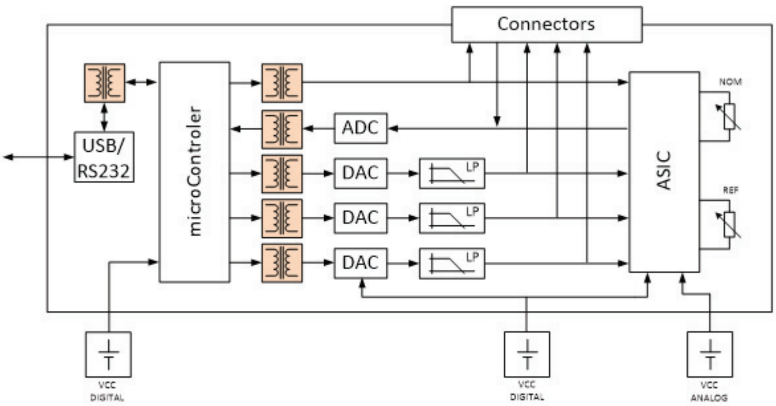

Fig. 3. The schematic of the test PCB for the verification of the ROIC chip.

We also placed variable resistors on this PCB to emulate the resistor change due to IR radiation adjustable from 0 Ω to 20 Ω. If the bolometer nominal resistor value is 10 kΩ and its temperature coefficient of resistance (TCR) is 0.3 $\%\cdot K^{-1}$, the temperature change of 10 mK will cause the bolometer resistance change of 0.3 Ω. The test PCB is also designed for measurement of the ROIC bonded with bolometer cell together into socket such as leadless carrier LCC68.

3. Results and discussion

The fabricated ROIC was tested with the variable resistors to demonstrate the functionality of proposed solution. The variable resistors emulated the resistivity change due to IR radiation. The time dependency of output voltage (BV1OUT) from ΔΣ modulator for different values of variable resistor for integration period 90 μs is shown in the Fig. 4a. The detail of output voltage in the end of the integration period is shown in Fig. 4b.

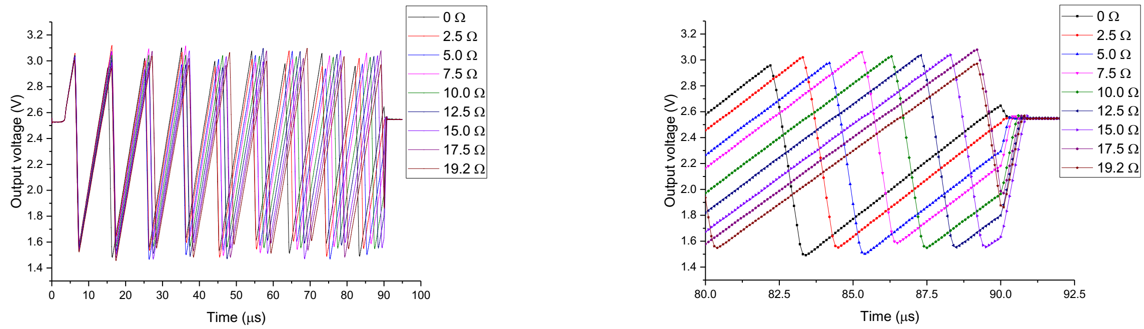

Fig. 4. (a) Time dependency of output voltage for different values of variable resistor; (b) The detail of output voltage in the end of the integration period.

The mean values of output voltage were recorded in the time of 89.5 μs. These values were plotted for the different variable resistor values as shown in Fig. 5. The output voltage values for the last two values of variable resistor can be recalculated to the straight line. The measured sensitivity is ≈70 mV/Ω and thus the ROIC can be used for read-out of small temperature (resistivity) changes in IR applications.

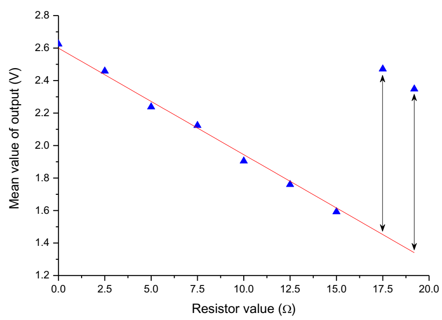

Fig. 5. Mean value of output for different values of variable resistor at 89.5 μs of integration.

4. Conclusion

A self-compensating system for fixed pattern noise reduction of focal plane arrays of IR bolometer detectors were described in this paper. The read-out circuit was designed in ONSemi I2T100 technology and fabricated using EUROPRACTICE service. The verification of the circuit was made on the test printed circuit board with the variable resistors. These resistors were changed to emulate the real bolometer behavior due to IR radiation. The measured sensitivity showed that the proposed solution could be used for small signal read-out in IR applications.

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