

A low power CMOS readout IC design for bolometer applications

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Abstract

A prototype of a readout IC (ROIC) designed for use in high temperature coefficient of resistance (TCR) SiGe microbolometers is presented. The prototype ROIC architecture implemented is based on a bridge with active and blind bolometer pixels with a capacitive transimpedance amplifier (CTIA) input stage and column parallel integration with serial readout. The ROIC is designed for use in high (≥ 4 %/K) TCR and high detector resistance Si/SiGe microbolometers with $17 \times 17 \mu\text{m}^2$ pixel sizes in development. The prototype has been designed and fabricated in 0.25- μm SiGe:C BiCMOS process.

Keywords: microbolometer, infrared imaging, focal plane array (FPA), Si/SiGe quantum well, readout integrated circuit (ROIC), capacitive transimpedance amplifier (CTIA), column parallel.

1. INTRODUCTION

Infrared ray (IR) imaging systems find use in many commercial and military applications ranging from biomedical imaging, traffic monitoring, automotive applications, night vision and surveillance. Specifically, thermal infrared imaging and uncooled resistive type microbolometer thermal detectors has been the subject of heavy research in recent times. While the choice of the detector material is highly application specific, depending on a myriad of factors such as intended absorption bandwidth, detector noise, detector thermal time constant, pixel size, cooling requirements, and uniformity expectations. Uncooled microbolometers are receiving attention as they can be operated at room temperature and have lower cost, wider spectral response, compared to their cooled photon detector counterparts which add a significant cost in cooling requirements.

The operation of a microbolometer IR imager starts with the absorption of IR energy radiated on it which heats up the bolometer and causes a change in resistance in its thermistor material accordingly. As such, for higher performance imagers, the microbolometers should be kept thermally isolated from their surroundings, exhibit a larger resistance change with respect to temperature as well as efficient absorption of the incident IR radiation with low thermal capacity. The readout electronics of the imager are tasked with converting the resistance change to an electrical signal, such as a voltage or a current depending on the readout architecture. The signal from the detector is then amplified ready to be converted by an analog-to-digital converter for processing the digitized video information.

In this paper, a 4×4 ROIC infrared focal plane array (IRFPA) intended for high TCR Si/SiGe microbolometers with pixel pitch of $17 \mu\text{m}$ and fabricated in 0.25- μm SiGe:C BiCMOS process is presented. The design is aimed towards high bolometer detector resistances intended for use in high TCR (≥ 4 %/K) MQW Si/SiGe microbolometers with $17 \mu\text{m}$ pitch which is currently in development. The ROIC prototype is functionally tested with FETs emulating bolometer resistances and resistance changes.

2. BOLOMETER EMULATION

The MQW Si/SiGe microbolometers have been shown to be superior in terms of TCR to conventional thin film materials used in bolometers such as vanadium oxide and amorphous silicon, with TCR increases thanks to higher Ge content in SiGe layers [1-5]. The on-wafer IV measurements of the triple stack bolometer devices for various Ge content were carried out in a probe station with thermal control with 5 K steps. The TCR is found to be increasing as the bolometer devices' Ge content increases. However, the detector resistance also increases considerably as the increase in Ge content causes more valence band offset [3][5]. While resistance increase results in lower Joule power dissipation for a constant voltage bias and consequently lower self-heating in the bolometers, high resistance is not ideal in terms of detector noise and responsivity. As the overall goal is in ultimately achieving a detector noise limited NETD (noise equivalent temperature difference) for the IR imager system, the bolometers are still currently in development.

In order to ensure and test for the functional correctness of the designed ROIC, n-channel and p-channel FETs are used instead of microbolometers which are biased to keep the same DC detector resistance with measured on wafer resistances (~1M Ω for the %40 Ge content case). These FETs are used to emulate the detector resistance change due to IR absorption and heating in the implemented IRFPA by changing bias during testing to test the sensitivity and dynamic range of the ROIC. The amount of resistance change emulated is taken as proportional to their measured and extracted TCR. This corresponds to approximately 4.5 %/K TCR and a resistance change of 45k Ω for a 1 K temperature change of the bolometer for the %40 Ge content case.

3. READOUT ARCHITECTURE

The IRFPA architecture is illustrated in Fig. 1. Every pixel in a column shares an optically isolated reference blind bolometer and an integrator to facilitate column parallel readout. The bolometer bias signals are shared in a row. Blind bolometer is used as a reference bolometer in bridge type readout pixel as shown in Fig. 2. The readout is implemented in a column parallel fashion which is a good compromise between pixel parallel and serial readout in terms of circuit footprint and thermal imager operation speed. The columns are integrated in parallel and then serially readout in a rolling line manner using the column multiplexer.

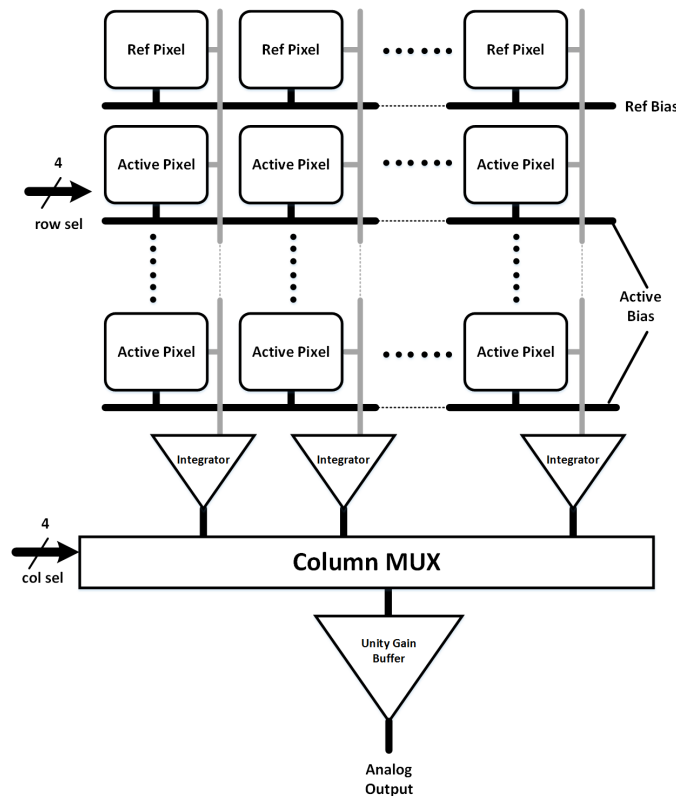


Figure 1. Readout architecture.

The readout circuitry is based on the commonly used capacitive transimpedance amplifier where the detector is biased by a constant voltage and the current difference between the active and blind bolometers is summed with an integrator. The CTIA configuration with bridged reference and active bolometers is suitable for highly resistive bolometer detectors because of the high output resistance of the direct injection biasing circuit. If we neglect the effect of bulk-to-source transconductance in the direct injection transistors, the output resistance of the direct injection biasing circuit is

$$r_{out} = \frac{1 + (g_m + g_d)R_{bolo}}{2g_d} \cong \frac{g_m R_{bolo}}{2g_d} \quad (1)$$

where, g_m and g_d are the input and output transconductance values of the p-channel and n-channel direct injection biasing transistors which are taken to be identical for simplicity and R_{bolo} is the nominal resistance of the identical active and reference detectors. The term $g_m R_{bolo}$ is much larger than unity; the output resistance of the direct injection biasing circuit is much higher than the detector resistance of the transistor. The high output resistance reduces the contribution of op-amp/integrator input noise current to the detector input noise current which makes CTIA favorable. However, the current responsivity of the detectors biased with the direct injection transistors is decreased as a result of negative feedback; a small decrease in the detector resistance upon incident radiation increases the detector current which, in turn, increases the gate overdrive voltage of the direct inject transistor and causing a small signal voltage drop in the actual detector bias voltage. This drop in detector bias tends to lessen the current increase, decreasing responsivity of the detector. It should be noted that maximum responsivity does not necessarily result in minimum NETD which is the hallmark of maximum detector performance.

The readout operation is controlled by INT and RS switches implemented as transmission gates enabling pulsed bias operation as seen in Fig. 2. The active and blind detector biases are set by the V_{bias1} and V_{bias2} signals using the direct injection transistors, respectively. The small signal current resulting from the resistance change of the active pixel due to IR heating is emulated by changing the V_{bolo} signal.

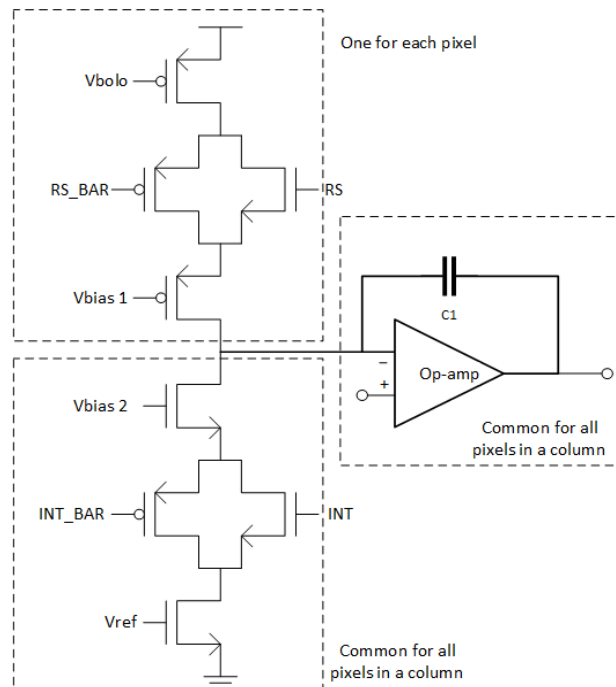


Figure 2. The readout circuit implementation.

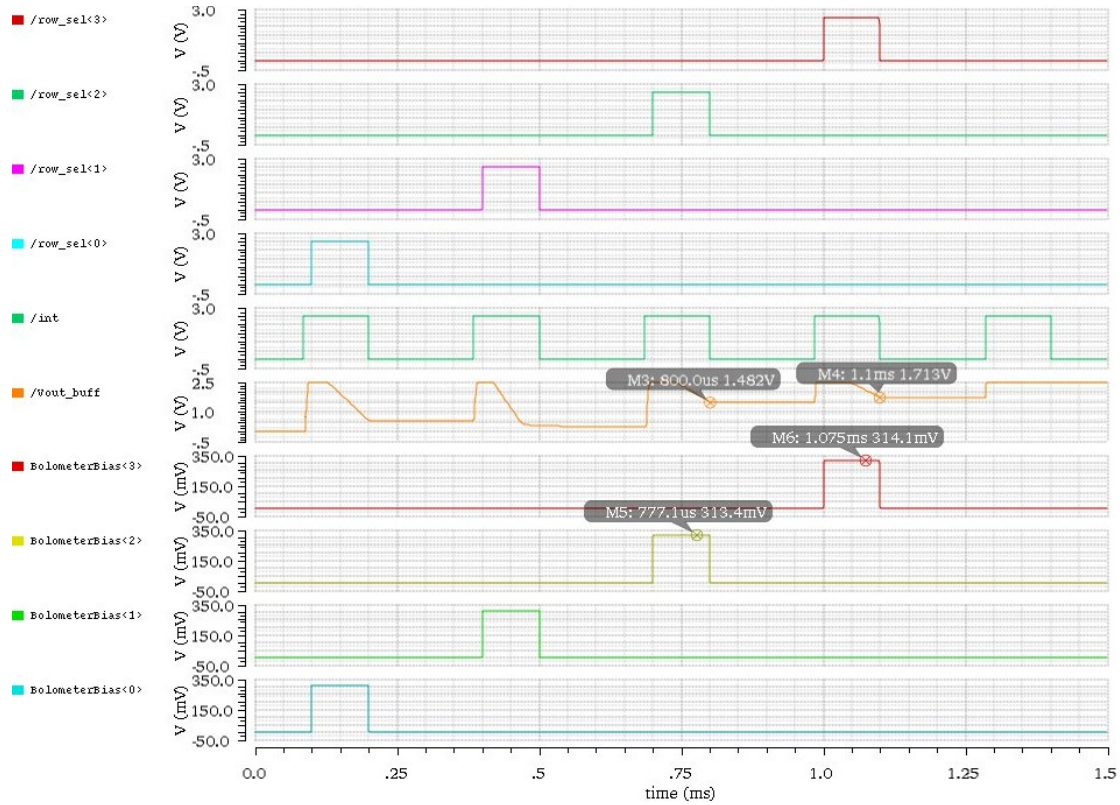


Figure 3. Simulation result of 4x4 prototype ROIC with row selecting and different V_{bolo} values.

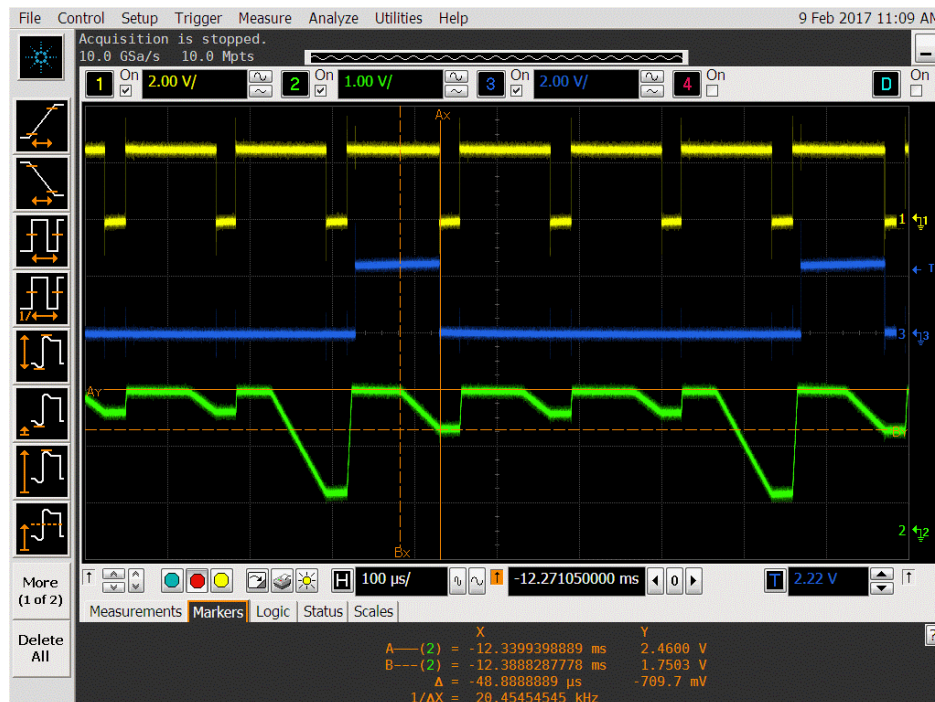


Figure 4. Measurement result of 4x4 prototype ROIC with row select and different V_{bolo} values.

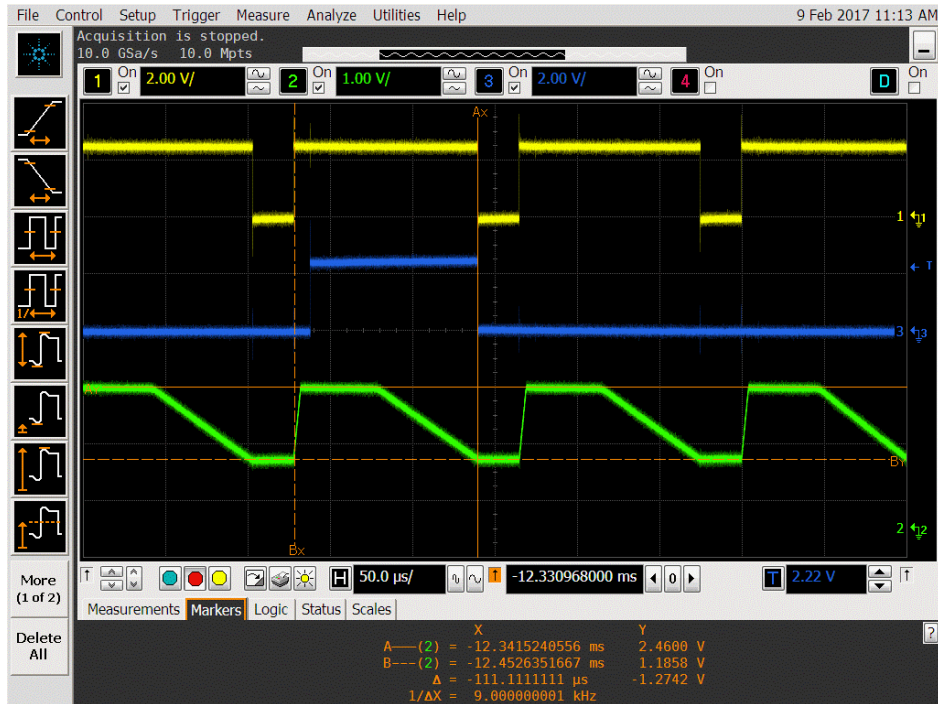


Figure 5. Measurement result of 4x4 prototype ROIC with same V_{bolo} biases across rows.

4. SIMULATION AND MEASUREMENT RESULTS

In this section, simulation and measurement results of the 4x4 IRFPA prototype is presented. Simulation results for a fixed integration time of 100 μ s and different bolometer biases across the rows are shown in Fig. 3. The first four signals are row select signals and the fifth signal is the INT (shown in green) signal controlling the pulsed bias operation of the bolometers. The INT pulse biasing signal is set high before the row selection signal to reset the integration node back to V_{dd} . The integration results for four different bolometer biases are shown in the analog output signal, V_{out_buff} . The different bolometer biases are 310.6 mV, 306.7 mV, 313.4mV, and 314.1mV corresponding to pixels 0, 1, 2 and 3. A larger resistance decrease change corresponds to a lower bolometer bias and V_{out_buff} provided that the integration times are the same. The integration can go from 2.5V to 0V corresponding to a dynamic range of 2.5 V- 0 V.

The measurement results for different V_{bolo} biases across rows for 111 μ s integration time are shown in Fig. 4. The analog output signal corresponds to four different levels at the end of same integration periods for four different V_{bolo} biases, as expected. Measurement results for the same V_{bolo} biases applied across different rows for 111 μ s integration time can be seen in Fig. 5. As expected, for the same bias, the integration ends at the same voltage level for a fixed integration time.

5. CONCLUSION

A 4x4 ROIC prototype intended for highly resistive triple stack, %40 Ge content Si/SiGe MQW bolometers was designed and presented in this work. ROIC was functionally tested with bolometer structures emulated by FETs biased accordingly. Future work will target the development and optimization of reduced noise Si/SiGe MQW bolometers of various Ge content and suspension leg parameters and hybrid integration of ROIC to larger array formats of 80x60 and 320x240 for determining the NETD of the overall system.

ACKNOWLEDGEMENTS

The authors would like to thank TUBITAK, The Scientific and Technological Research Council of Turkey, for funding this project. The work was carried out under grant 115E098.

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