Laboratoire de l'Intégration du Matériau au Système CNRS UMR 5218

Report

on the PhD thesis elaborated by Mr. Vratislav MICHAL.
Submitted in the partial fulfillment of the requirements for the Degree of Doctor of Philosophy at Université Pierre et Marie Curie – Paris 6.
Report elaborated by Monsieur Pascal FOUILLAT, Professor at l'ENSEIRB.

Title of the thesis:

Design of CMOS analog integrated circuits as readout electronics for high-T_C superconductor and semiconductor terahertz bolometric sensors

The work of Mr. Vratislav MICHAL was realized in the frame of the European Union project Marie Curie *NANOTIME* (*NANostructures of Oxides for Terahertz IMaging Exploration*). The project deals with the detection and imagery in the domain of Terahertz electromagnetic waves. In the presented thesis, the author brings his contribution to the design of the readout electronics associated to the THz bolometric detectors. The electronics is to be implemented as the integrated circuit in the CMOS process. More precisely, the subjects treated in the thesis concern architecture of readout amplifiers for extreme temperature range, as well as active low-pass frequency filters, aiming at improvement of signal-to-noise ratio.

The document summarizing the doctoral thesis is written in English and organized in four parts. It is further complemented by a detailed French summary, bibliographic citations, and by three short summaries in Czech, English, and French. In the first part of the thesis, the author coherently presents the electrical characteristics of semiconductors and superconductors bolometric detectors and of transistors in the CMOS technology. This CMOS technology is to be used in order to integrate the readout electronics and the signal processing chain. The particularity of the electronics to be developed leads the author to present a detailed noise analysis of electrical components and to show the noise behaviour of electronic circuits with and without feedback. The fundamental aspects of thermal behaviour of the electronic components are presented in the following part. Nevertheless, these aspects concerning thermal behaviour and eligibility of the BSIM3 model for cryogenic environment should have already been introduced in this part. However, this well-documented and properly written part of the thesis highlights the interdisciplinary context of the work, in which the author was able to correctly extract the fundamental information, afterwards useful for the elaboration of his research work.

The second part analyzes the architecture of readout electronics as well as traditional approaches to instrumentation amplifier realisation, suitable for the bolometers read-out. In this analysis, the author reveals the possibility to obtain improved electrical performance by an original configuration, which he has specified himself. In this configuration, the author makes use of the current biased sensor, followed by the AC coupled differential amplifier in a feedback-free configuration. Here, he proves correctly his choice which, in fact, facilitates the integration of amplifier and pushes away the amplifiers' frequency limits. These improvements are obtained together with reducing the noise level and the power consummation, as compared with traditional closed-loop

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approaches. However, the major difficulty, presenting also the main objective of the thesis is to find solutions allowing to accurately control the gain of the feedback-free amplifier (40dB) in extreme temperatures ranging from 70K to 300K. Other specified parameters of the amplifiers are the bandwidth of several MHz and low noise level of several $nV/\sqrt{Hz}$. In this chapter, Mr. Vratislav MICHAL demonstrates a deep knowledge of the aspects linked to integration of amplifiers intended for instrumentation.

The third part presents the main contribution to the design and integration of readout amplifiers. The estimation of the thermal behaviour of the amplifiers is based on extraction of the fundamental MOS transistor parameters: carrier mobility and threshold voltage. These parameters are used in an analytical temperature model of transistor. Consecutively, the proposed structure of the amplifier is presented in a progressive and pedagogical way. The amplifier consists of a new element utilised as an active load: *low transconductance composite transistor*. This composite transistor is applied to *differential folded cascode transconductor*, in order to achieve the required voltage gain of 40dB in the wide bandwidth. The low transconductance composite load allows avoiding excessive transistor dimensions, of which the parameters are generally inaccurate. Thus, the gain of the feedback-free amplifier becomes independent of technological parameters, and is only controlled by adjusting the transistors' dimensions. The judicious choice of the transistor dimensions allows to reach the noise level, which, even if obtained with low-cost technology, is comparable to the state-of-the-art amplifiers, usually realised in bipolar technology. An improved topology of the *low-transconductance composite load* is also proposed. The objectives of the improvements are linearization of the transfer characteristics, decrease of the offset voltage, and finally provision of temperature compensation down to 70K. The implementation of this structure was provided in the CMOS AMS 0.35µm process. The rigorous electrical characterisation allows to highlight the excellent performances such as the gain which is very close to 40dB, reduced power consumption in order of 2mA, and the gain-bandwidth product reaching up to 1,7GHz at 77K. In the first amplifier version, the noise level is as low as $2nV/\sqrt{Hz}$, whereas the second amplifier type exhibits a very low distortion. The results presented in this part, being very competitive as compared to the state-of-the-art, are the fruit of the authors' consequent work and his rigorous scientific approach.

The last part of the thesis deals with optimization of active analog frequency filters, aiming mainly at improvement of attenuation above the pass-band. Even if these filters are utilizable for the processing of signals generated by the bolometric detectors, the topic is not fully presented in the context of the thesis. On the experimental background, the author brings a useful contribution with the realization of the instrument providing analog signal processing by cascading one 1^{st} order filter and up-to five filters of the 2^{nd} order. The parameters of these filters can be digitally controlled. In the part dealing with architecture of biquadratic filters, an improvement of classical structure Sallen-Key is shown, allowing to reduce the influences of real active components to the stopband attenuation. Design and implementation of the current conveyor in the technology CMOS AMS 0,35 µm is also presented. Advantages of the biquadratic structure containing no parasitic zeros degrading the high frequency performances are shown on the experimental results. This part of the thesis shows, once again, the scientific rigor and very good mastering of the topic acquired by the author in the domain of the conception of analog integrated circuits.

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The document submitted by Mr. Vratislav MICHAL is of a very high quality, both on the form and on the content. The results presented in this document are appreciable for the quality of the selected scientific approach, as well as for the quantity of the presented results. The architecture of readout amplifiers which operate in very large temperature range make use of innovative structures integrated in CMOS technology. This original work is reinforced by rigorous experimental methodology. Mr. Vratislav MICHAL is the principal author of one publication in an international peer-reviewed journal, and the main author and co-author of many oral communications, some presented at well-recognized international conferences. This is a matter of very high quality of scientific production. Therefore, I give my highest esteem with regards to the work presented in the thesis of Mr. Vratislav MICHAL.

Talence, 17th May 2009

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