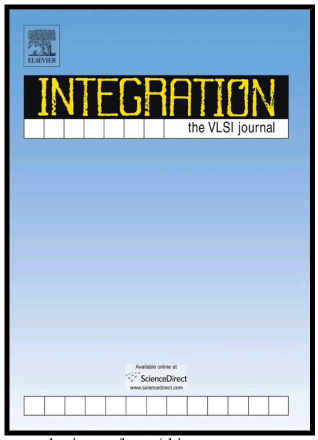

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A contribution towards model-based design of application-specific MEMS

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Abstract

The design process of heterogeneous systems containing electro-mechanical components and electronic circuits involves expert knowledge, methods, and tools from different engineering domains. Cost-efficient research and development of such heterogeneous systems requires a systematic design flow without gaps. A contribution towards this global goal is presented in this article. A development and synthesis tool for one-dimensional accelerometer MEMS has been implemented, calculating sensor solutions and generating the models and layouts required for a hierarchical design flow in an automatic, module-based approach. Utilizing this flow, different accelerometers have been designed, manufactured and characterized. A dedicated readout ASIC was developed to validate their dynamic behaviour.

Keywords model-based MEMS design, readout ASIC, 1D accelerometer, measurements

I. Introduction

Microelectromechanical Systems (MEMS) are important drivers of future product development in many market segments with quantities and revenue in billions. They consist of mechanical components like sensors and actuators in combination with readout and control electronics on just a few square millimetres of silicon. Due to their small sizes and low costs, MEMS are key components for the Internet of Things, where they form a basis of the interface between the virtual and the real world . MEMS development entails a growing demand for support by design methods and models. These should enable handling the ever-growing complexity of system design and the incorporation of its multi-physical character. The overall aim is to tightly interleave, systemize, and partially automate the design methodology of electro-mechanical and electronic components in order to enable access to application-specific MEMS development, not least for small and medium enterprises.

The goal of this work is to introduce the showcase implementation of a LEGO principle of the kind that is available in application-specific integrated circuit (ASIC) development to enable the fabless design of multi-physical systems. Such a principle yields lower development time and complexity as well as reduction in costs, compared with full-custom system design. At the same time it enables higher flexibility and more variety of products, meaning that designing for small numbers of pieces becomes more profitable, which opens market opportunities and possibilities of new applications. Thus our design method gets its bearings from modern ASIC development that combines analogue with digital circuit design and decouples circuit design from the development of semiconductor technology.

In ASIC design, a model-based top-down strategy with different hierarchy levels is used, starting with a specification and generating models that are iteratively refined towards the layout level. The right-hand side of Figure 1 illustrates this approach. Simulations on both system and device level are performed to adapt the functionality of a design to the specification. A kernel principle of this process is the usage of primitive devices provided by the foundry along with accurate, mostly lumped models in a process design kit (PDK).

For a model-based design strategy of the overall system co-simulations of electromechanics and electronics are required. Hence the ability to embed mechanics in a typical IC design environment is beneficial. The benefit, not only from the automation aspect, is that mechanics and electronics can be simultaneously considered, which may include shifting functionality from the electronics to mechanics and vice versa. As an example, a mechanical performance may be relaxed which might be compensated by a higher performance or different specification of the electronic part.

Commonly used tools for the design of the electro-mechanical parts of a sensor are FEM simulators like ANSYS. New system-based design methods (, , ,) were developed in the late 90s, which led to the publication of commercial tools like MEMS+ (Coventor), MEMS Pro (SoftMEMS) and SYNPLE (IntelliSense). These tools and methodologies can be utilized to design the electro-mechanical layout of MEMS, but they can as well be used in an integrated design flow of electromechanics and electronics, enabling interactions at different hierarchical levels and thus allowing system simulations of the whole MEMS sensor.

Although the idea of embedding mechanics in typical IC design environment is fairly old, this topic is still subject to intensive research and development activity. Recent contributions within the scientific community include the investiga-