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APPLICATION OF „MULTI ARCHITECTURE MODELING“ DESIGN METHOD TO SYSTEM LEVEL MEMS SIMULATION

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ABSTRACT

The paper is focussing on high abstraction level CAD modeling of MEMS using a new methodical approach called „Multi Architecture Modeling“ which makes it possible to simulate models at different abstraction levels together. The paper presents the MAM method and its application to the design of the experimental prototype „vibration sensor array“. This system consists of a micromechanical sensor (array of laterally moving mass-spring systems, fabricated by SCREAM technology, intended for low cost applications in wear state recognition [1]), an environmental model for the sensor, analog and digital signal processing.

1. INTRODUCTION

Before constructing a prototype, a simulation of the whole system is necessary to check the functionality of the individual components and their interaction. If the system contains non-electrical components then a simulation environment is needed which allows simulation of this non-electrical e. g. thermal or mechanical components together with analog electrical and digital components. VHDL-AMS allows the simulation of such systems. Additionally, with VHDL-AMS it is possible to describe and simulate the system at different levels of abstraction.

High level modeling and simulation become more and more important in MEMS design due to the increasing complexity. But high level models have the disadvantage that they often cause a to large error in simulation. More accurate models may become to slow for system simulation. A new approach filling this gap in the design flow is parameter reduction of FEM models [2], [3]. Behavioral models which are generated by such a method provide high accuracy and simulation speed but may not fit into the system simulation environment when a high level system description already exists. So a new approach called „Multi Architecture Modeling“ (MAM) was developed. It allows an easy exchange of models at different abstraction levels by unification of their interfaces using the hardware description language VHDL-AMS.

2. THE EXPERIMENTAL PROTOTYPE „VIBRATION SENSOR ARRAY“

The sensor system consists of a sensor array containing eight individual mass-spring resonators with an electrically tunable natural frequency each, an analog signal processing unit and a high voltage amplifier. The system is controlled by a micro controller. The system also includes a fuzzy pattern classification system (Figure 1).

An environmental model called „virtual machine tool“ provides the stimuli for simulation. It reproduces measured data in time or frequency domain or generates fictitious data. The vibration sensor converts this mechanical stimulation frequency-selectively into an electrical signal. Analog signal processing amplifies this signal and extracts the magnitude at a specific frequency. The individual resonators in the sensor can be activated separately, in groups or all together by a cell activation unit. The high voltage amplifier generates voltages up to 40 V for the natural frequency tuning of the sensor. A micro controller starts or stops the measurement, activates or deactivates resonators and starts self-calibration. It tunes the natural frequency of the resonators and transmits measured data to the classification unit. The classifier decides whether the data are produced by e. g. an sharp or worn out tool using a fuzzy pattern classification algorithm.

The function of the sensor was simulated by FEM simulation during the development of the sensor array. For system simulation an FEM simulation takes too much time. Therefore a model at high abstraction level was developed using analytical relations of the mass-spring resonators [4]. Additional a behavioral model was generated from the FEM simulation data [2].

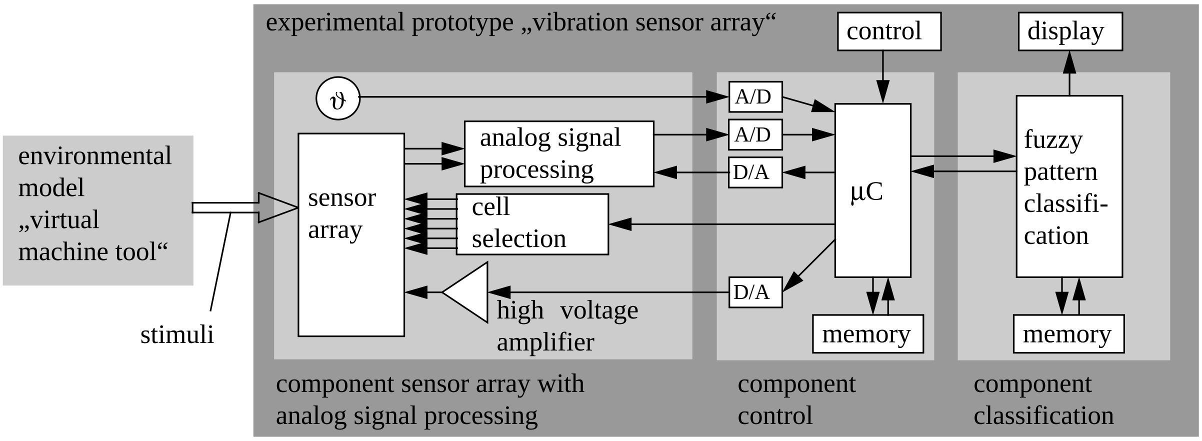

Figure 1: Block diagram of the experimental prototype „vibration sensor array“

The environment of the sensor was modeled with vibration sources which may produce a certain spectrum of vibration and with a model which can replay recorded vibration noise. The analog signal processing is modeled as electrical circuit and as abstract signal flow. The digital signal processing consists of a microcontroller, described as abstract behavior and, a fuzzy pattern classification, described as an abstract and a clock-true VHDL model.

The „Multi Architecture Modeling“ combines all these models, so the system can be simulated more or less accurate and more or less fast regarding to the aim of the simulation.

3. THE „MAM“ METHOD

If MEMS are designed by a Top Down based method or MEMS component models are generated by automated methods then digital, analog electrical and non-electrical models at different abstraction levels may appear during the design process. A possible resulting problem of this is shown in Figure 2.

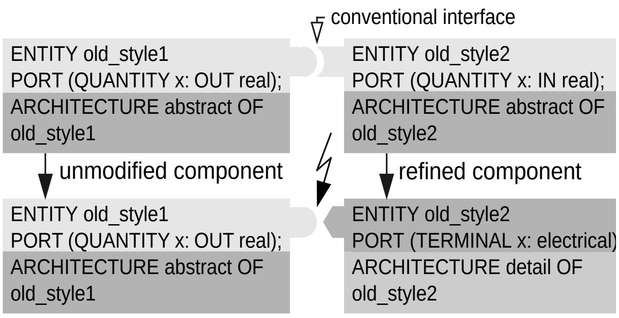

Figure 2: Possible problem during conventionally Top Down design process due to different interface objects

On high abstraction level the interface of analog components may use non-conservative nodes (`QUANTITY`) as it is common in signal flow models. During the design process one or more of these abstract models may be refined to an conservative system (network, energy flow model) either manually or automatically. This new refined model must use conservative nodes (`TERMINAL`) in its interface. Due to the fact, a `QUANTITY` cannot be connected directly to a `TERMINAL`, it is necessary until now to modify the interfaces of the system and component models at every design step of a component model.

One solution of this problem is the „Multi Architecture Modeling“ - MAM [5]. The main idea of this approach is to use the interface, which will be necessary at low abstraction level, already at a high abstraction level. In relation to Figure 2 this means: Because the refined model at low abstraction level will need `TERMINALS` as interface the model at high abstraction level also has to use `TERMINALS` instead of `QUANTITIES` (Figure 3).

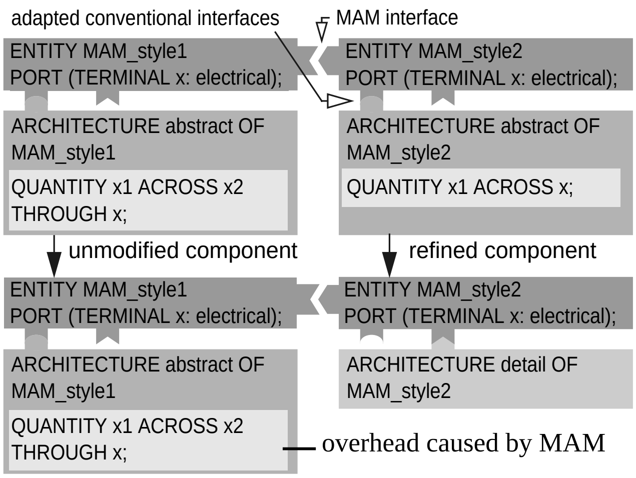

Figure 3: Unified interface for analog models using MAM

The behavior inside the abstract model is the same as it would be without using the MAM method. In the case of an analog interface the connection between the interface and the behavior is done simply by the definition of branch `QUANTITIES` between the `TERMINAL` and ground. In case of a digital port the connection is done by special functions which are implemented in a MAM supporting library. Additionally this library provides special A/D and D/A converters which make it possible even to connect analog and digital representations of the same model (e. g. an inverter described as logic function or modeled with two MOSFETs) with its environment.

The MAM not only contains some models in a library, it also includes a modification of the Top Down design process of MEMS. This modified design flow using MAM method is shown in Figure 4.

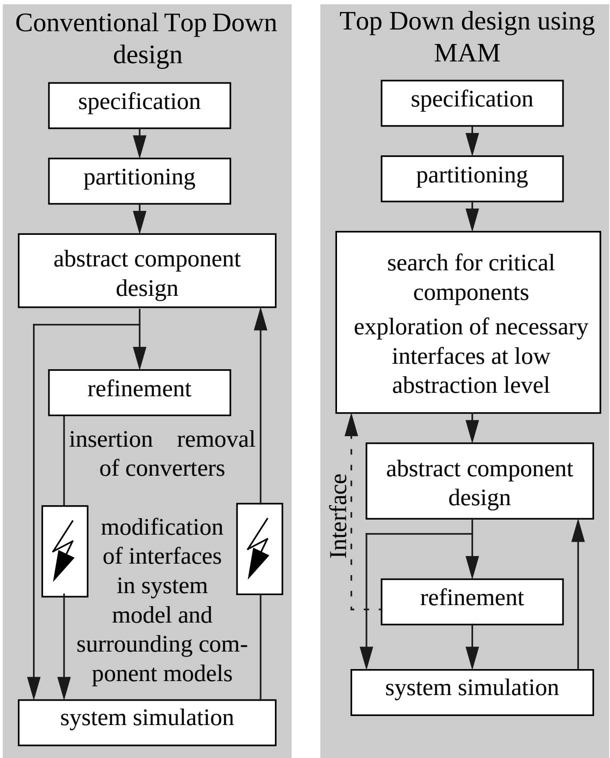

Figure 4: Simplified Top Down design Flow without and with using MAM

It can be seen that the MAM method simplifies Top Down design process, especially when design cycles between abstract and refined components are necessary. Using the MAM helps to avoid a lot of work because abstract models of a component can now be replaced by detailed models or vice versa without any modification to the interface or the surrounding models.

4. APPLICATION OF „MULTI ARCHITECTURE MODELING" DESIGN METHOD TO SYSTEM LEVEL MEMS SIMULATION

The MAM-Method was tested while modeling and simulating the experimental prototype „vibration sensor array" which is described above.

First, the system was modeled at high abstraction level (Figure 5, ■ blocks). Without using MAM the models of the system have the following properties:

- environmental model:
  - model contains two architectures, one replays a recorded waveform the other one consists of simple mechanical sources
  - output data are transferred by `QUANTITIES`
- sensor array:
  - model uses simplified analytic differential algebraic equations
  - input and output data are transferred by `QUANTITIES`
- analog signal processing:
  - modeled by functional blocks
  - input and output is done by `QUANTITIES`
- micro controller with A/D converter:
  - modeled as abstract behavior
  - input by `QUANTITIES` output by a `SIGNAL` of type real
- fuzzy pattern classifier:
  - model contains the fuzzy-pattern algorithm as an non-synthesizeable behavior
  - input is a `SIGNAL` of type real

In opposition to this the use of MAM method causes the following modification to the model and modeling overhead:

- environmental model, sensor array and analog signal processing:
  - behavior of the models is the same as without using MAM, but the input and output data are transferred by `TERMINALS` instead of `QUANTITIES`
  - additionally the definition of a set of branch `QUANTITIES` is necessary
- micro controller with A/D converter and fuzzy pattern classifier:
  - behavior of the models is the same as without using MAM, but the input of the A/D converter is now a `TERMINAL` and the micro controller and the fuzzy pattern classifier communicate by two `SIGNALS` with an RS 232 serial protocol

- additionally the definition of a set of branch `QUANTITIES` at the A/D converter input and a RS 232 UART model at the output of the micro controller and at the input of the fuzzy pattern classifier is necessary

As this list shows, the only real modeling overhead is the use of an RS 232 UART model instead of a data transfer by a simple `SIGNAL`. But this UART model can be stored in a library and can be reused in the next design. So this overhead occurs only when implementing a digital protocol for the first time.

To check the general function of the system the abstract models are sufficient but for more accurate results more detailed models are necessary (Figure 5, ◆ blocks). The following overview displays some properties of these refined models and shows the work which is spared using MAM when a component model is exchanged separately:

- environmental model:
  - an architecture was added which is generated from an FEM model of a chisel by order reduction
  - without using MAM:
    - an adaptation of the interface of the system model and of the sensor array model would be necessary
    - the sensor array model must be expanded by a mechanical input resistance
- sensor array:
  - for the sensor model a more accurate model was generated from an FEM model by order reduction (macro model)
  - without using MAM:
    - an adaptation of the interface of the system model, of the environmental and of the analog signal processing model would be necessary
    - mechanical sources in the environmental model and an electrical resistance at the A/D converter input in the analog signal processing model must be added
- analog signal processing:
  - this model was refined to an electrical circuit which partly contains simplified elements
  - without using MAM:
    - an adaptation of the interface of the system model, of the A/D converter and of the sensor array model would be necessary
    - electrical sources in the sensor array and an resistance at the A/D converter input are needed
- A/D converter and micro controller:
  - kept unchanged
- fuzzy pattern classifier:
  - this model was refined to a synthesizeable, clock true model
  - without using MAM:
    - an adaptation of the interface of the system model and of the micro controller model would be necessary
    - an RS 232 UART model must be added to the micro controller model

This list shows clearly how much work can be spared using the MAM method.

Figure 5 displays an overview over available component models at different abstraction levels which can be combined together to configure the system simulation between speed an accuracy.

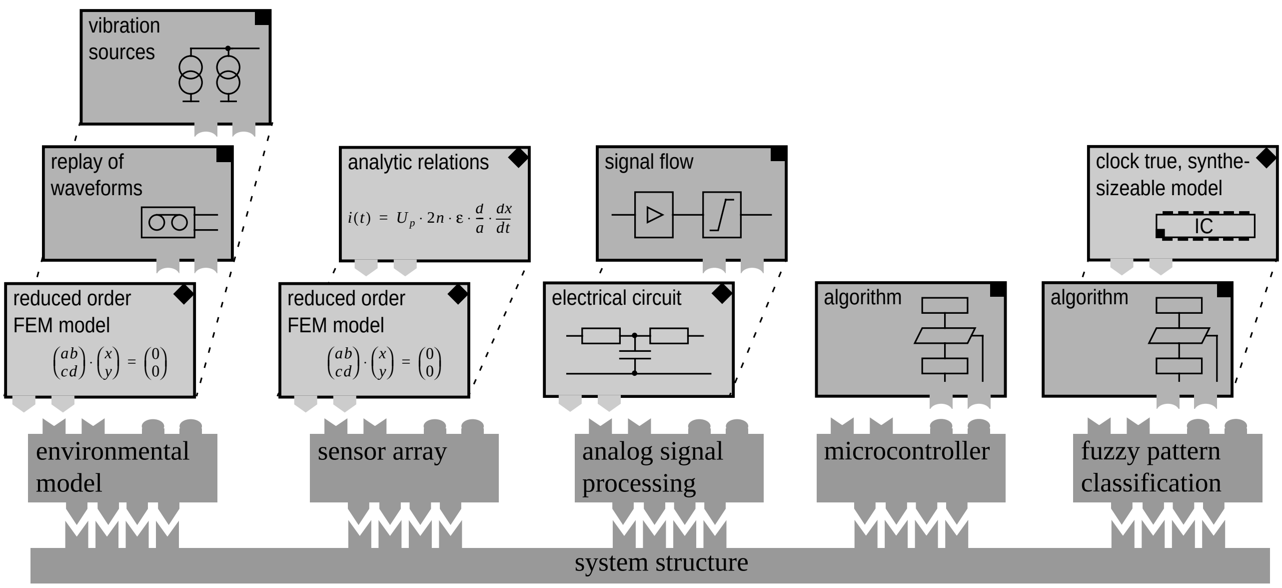

Figure 5: Application of MAM to system design of the experimental prototype „Vibration Sensor Array“

5. RESULTS

Although it seems that the MAM causes an overhead at high abstraction level, the really design overhead is limited. Using of `TERMINAL` interfaces instead of `QUANTITY` interfaces requires only one additional line of VHDL-AMS code per port. Using the RS 232 protocol at high abstraction level instead of a simple `SIGNAL` port e. g. of datatype integer or real causes more work at high abstraction level. But these necessary converters can be stored in a library and can be reused in the next project so there is no real overhead the next time.

By using the MAM method no significant disadvantages are caused and also modeling overhead is limited. But now refined component models may be inserted into the system environment without any problems.

With MAM it is possible to configure the system model in a way so that the model is as fast as possible and as accurate as necessary. This means: If the behavior of the signal processing is of interest then for the analog signal processing the accurate model and for the sensor the abstract, fast model is used. If the behavior of the sensor should be examined then the analog signal processing uses its abstract model and the sensor uses its more detailed model.

The system was simulated by Mentor Graphics' AdvanceMS on a SUN ULTRA60 workstation with UltraSPARC-II 296 MHz CPU. The simulation of measuring the magnitude of one frequency takes about 15 minutes time using the abstract models. The error is about 20 %. The use of the refined model (macro model) for the sensor lowers the error to 1 % compared with the FEM simulation and it also lowers the simulation time to 7 minutes. By using the MAM it tooks only 5 seconds to reconfigure the system from abstract sensor model to the sensor macro model.

For the analog signal processing a low pass filter is required. The original version of this filter has a very long settling time which results in simulation time of about 10 minutes. By using MAM, an abstract replacement model with the same corner frequency but other behavior can be used to reach the 7 minutes simulation time. If the accurate behavior of the analog signal processing is required then the original version can be re-insert in a few seconds.

The MAM method can also be used inside component models and not only at system level. The refined model for analog signal processing is an electrical circuit. But some of the components are simplified to increase simulation speed. But if the accurate electrical behavior should be simulated then the detailed models can be inserted.

For system simulation of the experimental prototype the abstract model of the fuzzy pattern classifier is used. By application of the MAM the system model can be used as testbench for the clock true, synthesizeable model of the fuzzy pattern classifier without any modification to a model.

6. CONCLUSION AND OUTLOOK

With the design of the experimental prototype „vibration sensor array“ it could be shown that it is of advantage to use a detailed interface already at high abstraction level. The application of the „Multi-Architecture-Modelling“ method saves a lot of time and reduces error-prone adapting steps. Furthermore the MAM will help to exchange models between groups of designers because the interfaces of the models must be fixed in a wide range before generating or writing the models.

The fundamentals of this method are implemented. The MAM method has shown its efficiency in a first application and will be evaluated in further designs.

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