Microsystem Modeling – from Macromodels to Microsystem Design

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ABSTRACT

The paper presents ideas about possible approaches to development of microsystem models. From general point of view, microsystem (MST) is considered as a system dealing with non-electrical quantities from all energy domains of real environment. System modeling of properties of the whole system is required for complex approach to MST design. System modeling is described on higher and lower level. For design optimization it is necessary to use modeling on structural and material levels, further it is necessary to consider influence of technological process and modeling on physical level. Frequently design can be simplified utilizing equivalent models realized by equivalence of discrete elements between various energy domains. It is possible to demonstrate MST operation using, micromodels (SOFT) or macromodels (HARD). Micromodels are developed from macromodels according to the rules for design of integrated MST.

Keywords: Microsystems, sensors, actuators, system, model, equivalence.

1 INTRODUCTION

Modeling and simulation of MST on various system levels are methods that are in standard use at present. For them there have been gradually developed software tools that satisfy needs connected with development of new types of MST based on new principles (e.g. biosystems). In addition, their properties are being improved so that they may be used for more precise modeling of real system properties. In simple approximation static or dynamic models of systems and behaviour of their internal functions can be used.

MST reprezent an interdisciplinary area (typically interconnection of mechanical and electrical domains). Therefore analogy between quantities from various energy domains is implacable in models. Using analogy, non-electrical quantities can be converted to electrical ones. Solutions of electrical models are well elaborated and very good tools for modeling and simulation of their properties are developed.

Developing "macromodels" of MST enables to explain students functions of a concrete MST. The main topic is search for connections between individual energy domains, or search for equivalent models for analysis utilizing known means applied in electronic systems.

2 COMPLEX ACCESS TO MST DESIGN

From general point of view MST is produced using hybrid, monolithic or special MST technologies. MST links various functions, combines in its operation various energy domains from surrounding real environment (thermal, mechanical, electrical, magnetic, chemical, radiant). MST system function can be very complex. The complexity depends on required MST functions.

In general, MST system function ensures system operation. Above all, the system ensures three basic functions: information sensing (converting non-electrical quantities to electrical ones), information processing (a system of electric converters), and action on the output (converting electrical quantities to non-electrical ones).

Problems of exact data acquisition from sensors and data transmission to control elements or actuators are very topical in many areas of non-electrical quantities processing. Successive integration of designed systems on one or more chips improves reliability and usability, and decreases consumption of electric energy for system feeding. A system aimed at use in control circuits, having sensor inputs, actuator outputs and exploiting software algorithms, can reach very good parameters. Systems used in interdisciplinary areas are known as MST nowadays. Example of an intelligent MST is presented in Figure 1. The structure can be modified for other energy spaces. MST structure complexity can vary depending on requirements on function. On one side MST may be complex systems with very sophisticated inner structure and high demands on their functions. On the other side MST may be very simple (e.g. integrating only electrical and mechanical energy domains). Then requirements laid on design, modeling of these systems are relatively low. If we want to get complex view on behaviour of designed MST, several levels have to be considered.

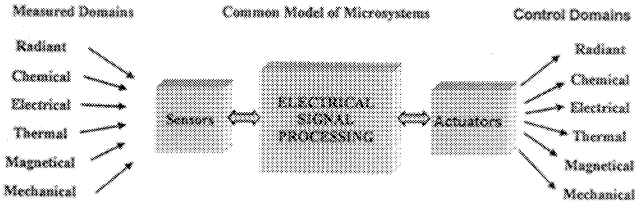

Figure 1: Conceptual structure of an intelligent MST.

2.1 Approach to MST models development

When designing MST it is necessary to consider several different views on different levels. For complex modeling of MST properties it is necessary to use various approaches to model development. It is possible to optimize MST during design process by interconnecting outputs of these models. Approaches to complex problem solving may differ and depend on nature of solved MST [1]. Example of one possible approach to system model solving is illustrated in Figure 2.

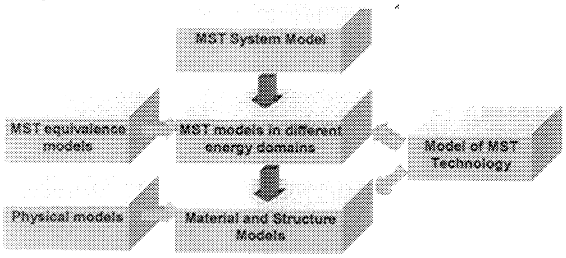

Figure 2: MST design from system model perspective.

a) System model (model realizing system function). System model may have several levels that are placed in different MST levels. System model on higher level ensures logical connection of basic functions of individual MST parts. Model ensures logical function in its connection with energy domains of surrounding environment. System model on lower level ensures logical function inside individual MST parts (connection of electric converters with sensor and actuator parts including function inside these parts). Possible view on such model is illustrated in Figure 3. In modeling hierarchy, the system model of higher level lies on the highest level. All other model types must respect its logical functions. System model can be viewed as space in which a number of functions and logical relations must be satisfied. In this space there must be ensured correct function and links to models of further MST parts that approximate real behaviour of MST. Example of one possible solution of such a space is shown in Figure 4. The space is simplified to several basic necessary parts important for MST design.

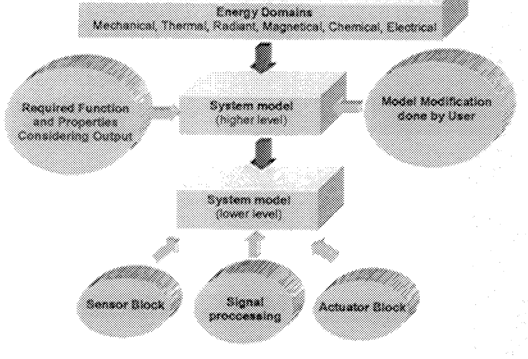

Figure 3: System model on higher and lower levels.

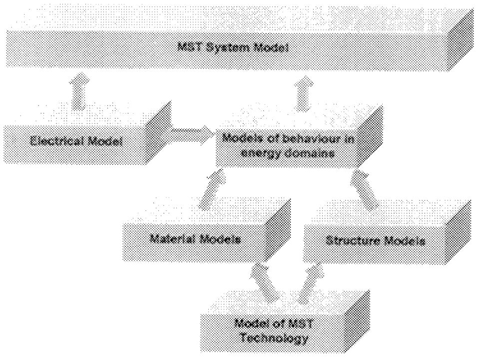

Figure 4: System model as a space for MST design.

b) Model on the level of energy domain. For correct functioning it is necessary to consider MST operation in different energy domains. Domains have their specific properties that are frequently very different. Thus for correct functioning of MST it is necessary to model correctly system behaviour in individual MST parts, including energy domains. Models depend on function nature in the given domain. Various types of models can be used for this modeling. The difference is given, above all, by environment and nature of energy domain and tools that are available for modeling of the domain. Output information of these models serves as input for system modeling.

c) Equivalent models between energy domains. For many applications, it is possible to utilize equivalent models. Models are based on equivalence of discrete elements and their behaviour described by mathematic expressions in various energy domains. The best-known equivalence is utilized between electrical, mechanical and thermal domains. In these domains individual equivalences are elaborated well.

d) Material and structure models. When realizing MST, properties of intelligent materials and structures are utilized. Then modeling their properties as input parameters for higher-level models is necessary.

e) Physical models. For development of new qualitatively different MST structures, it is necessary to utilize new materials and new structure properties. However, for this development it is necessary to utilize knowledge resulting from understanding physical behaviour of materials and structures and their mutual relations during operation.

2.2 Equivalent models between energy domains

Behaviour of a sensor or sensor block can be described by differential equations whose form is dependent on physical nature of corresponding sensor or sensor block activity. Three basic function types exist for description of this behaviour. Functions describe relation between input and output (zero-order, first-order, second-order). Mathematical modeling of a sensor is a powerful tool in assessing its performance.

Mathematical models are utilized for equivalence generation. Physical laws are applied to these models. Results are models with simple lumped parameters. Mechanical and thermal elements can be converted in this way to equivalent electric connection. For solving this electric model well-known and elaborated methods for electric circuits can be used.

For the mechanical components, Newton's second law is used and for thermal components Newton's law of cooling is applied. Table 1 shows the various lumped parameters [2]. F denotes power, Q is heat, V is voltage and i is electric current.

Mechanical	Thermal	Electrical	
Mass M $F' = M\frac{d(v)}{dt}$	Capacitance C $Q' = C\frac{dT}{dt}$	Inductor L $V' = L\frac{d(i)}{dt}$	Capacitor C $i' = C\frac{d(V)}{dt}$
Spring k $F' = k\int v \cdot dt$	Capacitance C $T' = \frac{1}{C}\int Q \cdot dt$	Capacitor C $V' = \frac{1}{C}\int i \cdot dt$	Inductor L $i' = \frac{1}{L}\int V \cdot dt$
Damper b $F' = bv$	Resistance R $Q' = \frac{1}{R}(T_2 - T_1)$	Resistor R $V' = Ri$	Resistor R $i' = \frac{1}{R}V$

Table 1: Mechanical, thermal, and electrical analogies.

3 MACRO MODELS AND PROCESS OF MODEL REALIZATION

During design and modeling of properties of simpler MST, the system of models can be simplified when considering concrete properties and purpose of MST. This approach is suitable for MST education at university as well. The design of MST can be realized in several forms with corresponding time series.

Ideative model. At first the student creates an ideative model of a MST with input information, output functions, and inner logical functions.

Soft model. Further step is realization of the SOFT model of MST using PC and libraries of electronic components and blocks. For special MST blocks it is necessary to use either existing blocks or to define these special blocks. In this model it is possible to simulate simple functions using means for analysis of electronic circuits and systems. Realization of micromechanical elements in this model is based on electrical and mechanical, or possibly further analogies. For realization of the SOFT model in this phase simplified electrical and non/electrical functions are considered so that it is possible to realize them in a simple way.

HARD model. Realization of HARD model is a successive step and is used for verification of basic functions of the designed SOFT model. It is possible to use available elements for realization of the HARD model. This model illustrates characteristics and behaviour of the designed MST model. It is instructive for education, it is possible to demonstrate its behaviour and basic characteristics. There are close connections between SOFT and HARD models. The students can develop a real functional model.

Design of a MST. Design of MST is the most difficult part and follows after previous steps. Micro-models are developed from these macro-models according to the rules for design of integrated MST (technology, materials, software, etc.). Macro-model properties are compared with simulated and modeled properties of real MST. For these purposes, suitable tools are utilized (MEMCAD, CADENCE, HSPICE, etc.) [3]. In the paper there are presented examples of realized HARD macro-models. The students usually design very simple MST; more complex models are realized in the frame of Master or PhD theses. Individual models and their interconnections are illustrated in Figure 5.

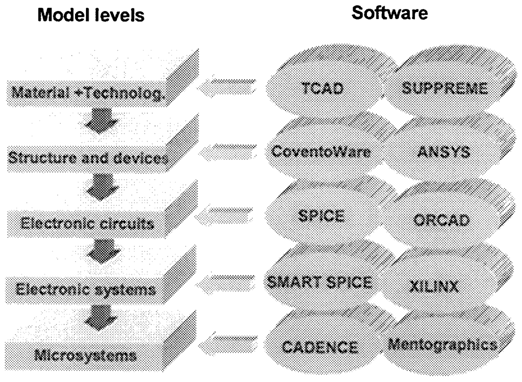

Figure 5: Flow of model levels.

3.1 Application of „macro" models

When developing a system for pressure measurement, wireless information transmission and information processing, interconnection scheme (see Figure 5) can be used. Structure of integrated one-chip LC circuit realized on Si substrate is shown in Figure 6. In the middle part of the structure there is a capacitor with flexible membrane. The capacitor measures external pressure. Integrated inductor is a part of integrated LC circuit. Inductor is produced by evaporation of metal spiral around capacitor. Besides L and C parameters, the structure displays a number of parasitic parameters caused by construction. Model on material and structural level can be used for modeling of basic properties of the structure as well.

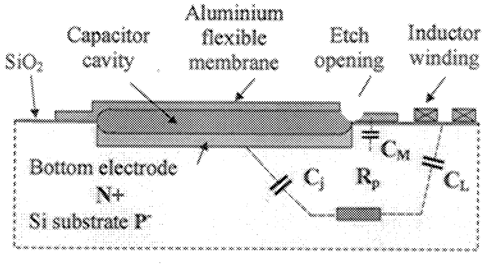

Figure 6: Structure of integrated LC circuit with dominant circuit elements.

For modeling structure properties from the point of electric behaviour model on the level of electric circuits can be used. The equivalent scheme of the sensor with parasitic elements is shown in Figure 7. That diagram enables modeling of properties using standard simulators, e.g. SPICE.

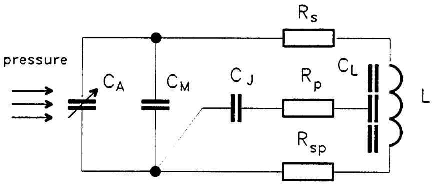

Figure 7: Equivalent electrical model of the integrated resonance circuit.

When designing and modeling properties of the whole designed measuring system it is necessary to use model on the level of electronic circuits. The model solves logical functions of the system, defines signal interfaces, data volume and flow, etc. Example of a model of the whole electronic system is shown in Figure 8.

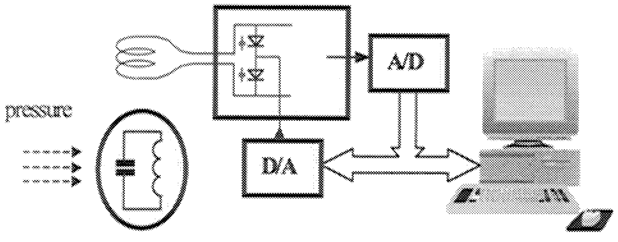

Figure 8: Model of electrical system.

Presented functional structure must be realized using MST design tools. This step represents the last block in the presented "flow of model levels" denoted as MST model. Design tools, as for example CADENCE, are used in design process.

Presented models can be used for design of integrated matrix of micromirrors. For the mechanical simulation of micromirror, ANSYS program for finite element analysis and design can be used. The mirror is a moveable plate, while the access line underneath is a fixed plate. The capacitor electrodes is movable – see Figure. 9. The standard mechanical model with the Newton equations can be used for the design of the mechanical properties of the electrostatically actuated micromirror. Electrical equivalent network model can be created and solved.

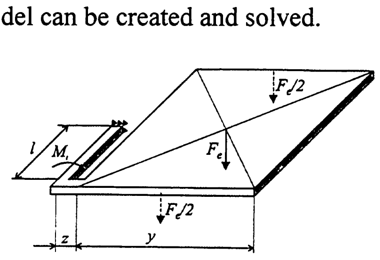

Figure 9: Micromirror plate with torsion springs.

Building the equivalent network consists of the sub-dividing the complete device structure into lumped elements. Each element is then described on the basis of analogies between relevant physical parameters of the dominating phenomenon and electrical parameters. Each lumped element has a mechanical impedance, which is defined as the pressure drop to flow-rate ratio. A complex mechanical device can then be modeled with an equivalent network by linking lumped elements in accordance to Kirschoff's laws adapted to mechanical system, the total mechanical moment taken around any closed loop is zero. An equivalent electrical model of electrostatically actuated micromirror is depicted in Figure 10.

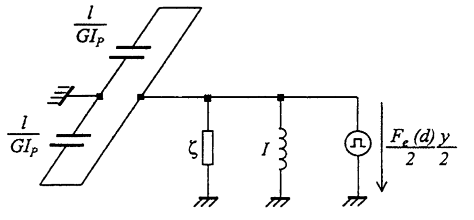

Figure 10: Equivalent circuit of an electrostatically actuated micromirror.

4 CONCLUSIONS

Modeling and simulation on various MST levels are utilizes for optima MST design. It is necessary to use models on system level for correct complex functioning of the designed MST. On lower levels, further types of models can be used: models on the level of individual energy domains, physical models, etc.. In design process, there can be used equivalent models that operate with quantities from various energy domains. A number of design tools (ANSYS, CoventorWare, MEMCAP, etc.) exist for modeling of structures and further elements of MST. Presented principle of development of macromodels of MST enables to bring this topic closer to educational process. Contribution of this approach is: Development of illustrative functional models of MST, simulation and modelling of real MST, comparison of properties of macro and micro models, utilization of tools for design and simulation of integrated circuits and MST, development of macromodels for electrical, mechanical, thermal and chemical energy domains, real function of macromodel and its application.

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