Design of MEMS and Microsystems - Models and Simulation

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Abstract: - Various model systems are utilized in the process of design of integrated circuits, microsystems, microactuators, and microsensors. The models have their hierarchical levels that are mutually connected. The connection creates so-called "flow of models" system. It defines a system of simulation approaches to design of microsystems and microsensors. Models on different hierarchical levels and their mutual relations are discussed. Examples of utilization of equivalent models between different energy domains are presented. Analytical mathematical methods, numeric methods, or their hybrid combinations can be used for solution. Mutual interconnection represents design "flow". However, the "flow" solutions are not universal. For educational purposes, certain steps of the design (models) may be verified by realization of these models (subpart of the design). The principles are illustrated by the examples of design of an integrated strain gauge sensor and a wireless sensor system for pressure measurement. Presented examples are completed with reached results.

Key-Words: - Models, Simulation, Microsystems, Microsensor, Integration, Strain Gauge, Pressure, Hierarchical levels, Energy domains

1 Introduction

Present state of the art in the area of engineering is directed to interdisciplinary domains. New elements and systems are designed using specificity of various areas (electronics, mechanics, chemistry, etc.). In that way, essentially new elements having new properties are developed. The elements allow discover the world in new dimensions. When designing these elements it is necessary to apply extensive interdisciplinary knowledge.

For design of integrated circuits, there has been well developed a system of models on various hierarchical levels. The principles of model development can be applied to the area of design of microsystems (MST). However, MST is interdisciplinary. When designing MST it is necessary to consider characteristic properties of other areas as well. A number of tools are used for design.

MST represents 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 in addition, very good tools for modelling and simulation of their properties are developed.

Modelling 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. [1].

2 MST modelling

The concept of MST covers very broad area. It is impossible to create a universal scheme for MST design. MST design is closely linked to applied technologies. Some MST manufacturing technologies are derived from microelectronic technologies. In that case, MST simulation tools are usually adopted from microelectronic domain. Modelling and simulation of MST follows the flow [2] – Fig. 1.

There exist many software tools at various levels of simulation [3], [4], [5]. Individual simulation levels are not defined "sharply". There exist many ways of their mutual connection. Various 3D models for MEMS are developed.

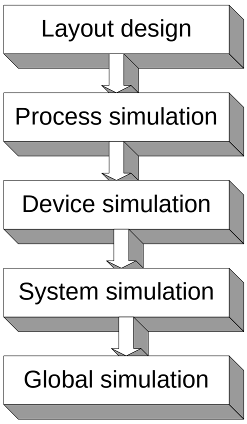

Fig.1 MST modelling and simulation flow

Challenges include geometric construction, 3D simulation, and construction of lumped macro models and computer processing of those models [6]. Analytical and numerical simulation methods are used [7]. The suitable tools were developed to improve sensor design [8], [2]. CoventorWare (before MEMCAD), SENSIM, SENSOR, CAPSIM can serve as examples. Device specific simulation tools have been created, for example PUSI (dynamic behaviour of micro pumps).

For electrical simulations of analogue electronic circuits, the SPICE tool is used. The VHDL tool is used for electrical simulations of digital electronic circuits.

Expression „Multilevel simulation“ is used for application of simulation models on different abstraction levels. Expression „Mixed Nature Simulation“ is used, when processing signals have different nature (electrical, mechanical, temperature, etc.). Expression „Mixed Mode simulation“ is used, when analogue models and digital models are used together [2].

Design of special sensor and MST structures requires very frequently application of individual approaches. At the university we use various models and tools for design of sensors and MST. In general, we use “multi-level flow” models. Models at individual levels are supported by various flows of software tools and some of them are suitable for integration into education.

3 Multilevel Models [1]

In the process of MST design, it is important to consider corresponding area of modelling in its complexity. Physical properties, material, structure, properties of energy domains and their interconnection, system functions of MST, etc. are considered. For this purpose models on different system levels are created.

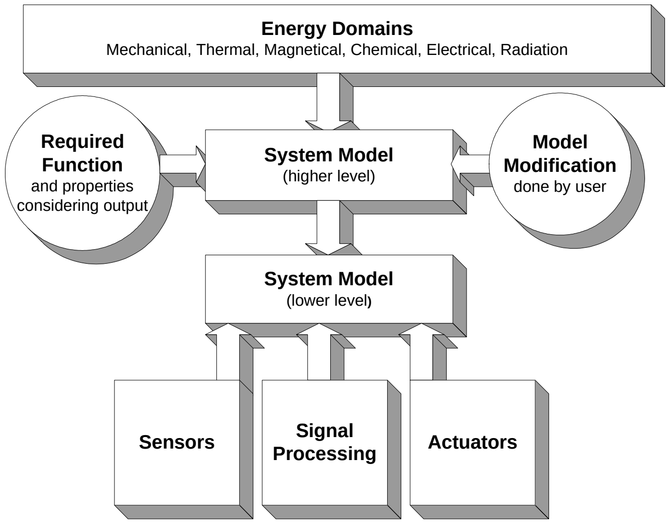

Fig.2 System model on higher and lower levels

System model
A system model may have several levels that are placed in different MST levels. The system model on higher level ensures logical connection of basic functions of individual MST parts; one ensures the logical function in its connection with energy domains of surrounding environment. The system model on lower level ensures the logical function inside individual MST parts. Possible view on such model is illustrated in Fig.2. Example of one possible solution of such a space is shown in Fig. 3.

Model on the level of energy domains
For correct functioning it is necessary to consider MST operation in different energy domains. Various types of models can be used for this modelling. The environment and the nature of energy domain and tools that are available for modelling of the domain give the difference, above all.

Equivalent models between energy domains The 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.

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

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.

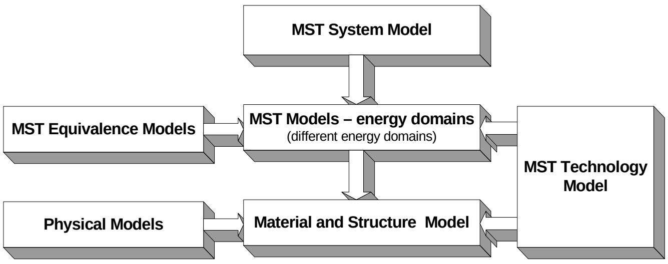

Fig.3 System model as a space for MST design

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. The functions describe the relation between input and output (zero-order, first-order, second-order). Mathematical modelling of a sensor is a powerful tool in assessing its performance.

The mathematical models are utilized for equivalence generation. Physical laws are applied to these models. Results are the models with simple lumped parameters. Mechanical and thermal elements can be converted in this way to equivalent electric connection. For solving the electric model, well-known and elaborated methods for electric circuits can be used. For the mechanical components, Newton's second law is used. We can create mechanical model of the system - Figure 4.

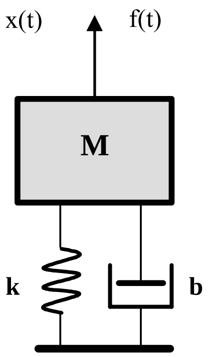

Fig.4 Mechanical system

From the Hook's law it follows for the spring

$$F' = k \cdot x \qquad (1)$$

where k is rigidity of the spring. The damp expresses loss in the system, it acts against the force. The damp prevents change of velocity. The damp can be expressed by the formula

$$F' = b\frac{dx}{dt} \qquad (2)$$

where b is the coefficient of damp [Ns/m]. Mass m is a solid element without elastic and damping properties. According to the second Newton's law it holds

$$F' = M\frac{d^2x}{dt^2} \qquad (3)$$

For the system in Fig.3. it holds

$$M\frac{d^2x}{dt^2} + b\frac{dx}{dt} + k \cdot x = F'(t) \qquad (4)$$

where *F'(t)* is excitation force. The equation (4) can be modified. It is possible to find known equivalence between the differential equation describing behaviour of serial or parallel resonance circuits and differential equation describing behaviour of mechanical structure. Serial resonance RLC circuit can be described by the equation

$$L\frac{di}{dt} + R \cdot i + \frac{1}{C}\int i \cdot dt = u(t) \qquad (5)$$

We introduce the substitution $\frac{dx}{dt} = i$ into the equation (4) and we get the equation

$$M\frac{di}{dt} + b \cdot i + k\int i \cdot dt = F'(t) \qquad (6)$$

Comparing both equations we get equivalence of mechanical and electrical parameters – see Table 1. For parallel resonance RLC circuit, the equation holds

$$C\frac{du}{dt} + \frac{1}{R} \cdot u + \frac{1}{L}\int u \cdot dt = u(t) \qquad (7)$$

Introducing substitution $\frac{dx}{dt} = u$ into the equation (4) we get

$$M\frac{du}{dt} + b \cdot u + k\int u \cdot dt = F'(t) \qquad (8)$$

Comparing parameters of both equations we get equivalence presented in Table 1.

Table 1. Mechanical and electrical analogies

Mechanical	Analogies	Electrical	
Mass M $F' = M\frac{d(v)}{dt}$	M ≡ L, M ≡ C	Inductor L $V' = L\frac{d(i)}{dt}$	Capacitor C $i' = C\frac{d(V)}{dt}$
Spring k $F' = k\int v \cdot dt$	k ≡ 1/C, k ≡ 1/L	Capacitor C $V' = \frac{1}{C}\int i \cdot dt$	Inductor L $i' = \frac{1}{L}\int V \cdot dt$
Damper b $F' = bv$	b ≡ R, b ≡ 1/R	Resistor R $V' = Ri$	Resistor R $i' = \frac{1}{R}V$

3.1 Models for Education Process [9]

During design and modelling of properties of designed structure, 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 of MST can be created. The model has input information, output functions, and inner logical functions.

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 [1].

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.

4 Design Flow in the Design of the Integrated Si Strain Gauge [10], [11]

Designed Si integrated sensor is placed on a flexible cantilever. "Flow design" from Fig. 5 was used for its design.

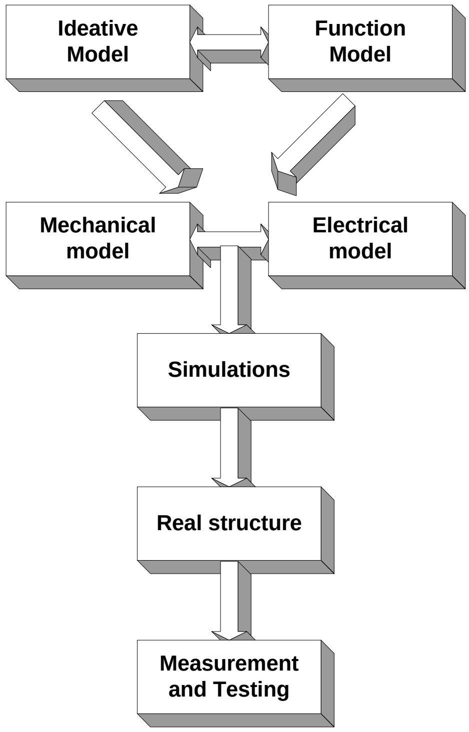

Fig.5 Design flow

When designing the strain gauge sensor, it is possible to take advantage of the equivalence between different energy levels [10].

The base of sensor is cantilever beam with piezoresistive layer as a strain gauge. Cantilever with geometric layout can be equivalently replaced with a system with spring, load, and damp of the system. Example of designed strain gauge geometry with long fibre for connection to full bridge is shown in Fig.6.

Measured force is effective on the free end of the cantilever perpendicularly to its axis and causes its deformation. Strain gauges are located in the place where the maximum mechanical tension is. Due to piezoresistive phenomenon the maximum mechanical tension causes the greatest change of resistance.

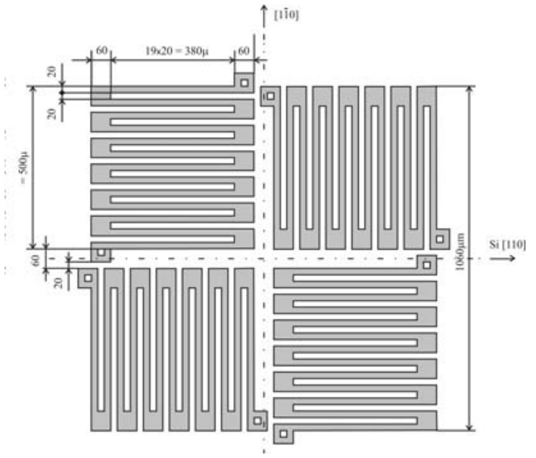

Fig.6 Geometry of strain gauge with long fibre

Construction of cantilever fixed at one side has been chosen for maximum simplicity of production. Geometry of Si cantilever with piezoresistors and fixation on kovar base is shown in Fig.7.

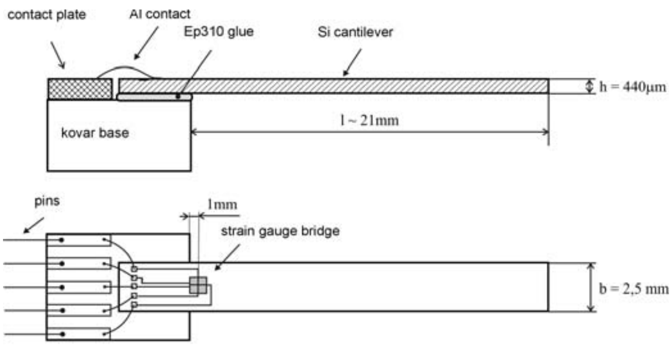

Fig.7 Geometry of Si cantilever with piezoresistors

Length of the cantilever (to the point of fixation) is *l=21 mm*, width *b=2.5 mm* and thickness *h=440 μm*. Mechanical tension in place of implanted strain gauges is calculated from the equation [12]

$$\sigma_x = \frac{3E \cdot y_0 \cdot h \cdot x}{2l^3} = \frac{6F \cdot x}{b \cdot h^2} \tag{9}$$

where E is module of Si elasticity $E=1.69.10^{11}\mathrm{Nm}^{-2}$, y_0 is cantilever bend, h is cantilever thickness, l is cantilever length and F is force effective on the free end of the cantilever. Maximum load and bend of the cantilever results from maximum allowed mechanical tension of Si σ_{DOV}. The value of σ_{DOV} has been found experimentally, σ_{DOV}=200 MPa. The equation can be written as [12]

$$y_{\max} = \frac{2 \cdot \sigma_{DOV} \cdot l^2}{3 \cdot E \cdot h} \tag{10}$$

$$F_{\max} = \frac{\sigma_{DOV} \cdot b \cdot h^2}{6l} \tag{11}$$

$$m_{\max} = \frac{F_{\max}}{g} \tag{12}$$

where g is gravitational acceleration. Simple comparison of sensitivity of strain gauges with different concentrations of impurities can be done using coefficient of deformation sensitivity K_i. If the end of cantilever is loaded with weight m, the coefficient K can be written as

$$K_i = \frac{\Delta R_i}{R_i} \cdot \frac{E \cdot b \cdot h^2}{58{,}8 \cdot x} \cdot \frac{1}{m} \tag{13}$$

where R_i is resistance of strain gauge in undeformed state, ΔR_i is change of resistance caused by deformation. At simplified design of Si cantilever we assume ideal fixation of Si cantilever to the base. We assume further that the coefficients of thermal expansibility of Si and material of the base are identical [13]. However in reality this assumption does not hold, therefore we have to consider dilatation of the base to Si by value

$$\Delta l = l\left(\lambda_{\mathrm{kovar}} - \lambda_{Si}\right)\Delta T \tag{14}$$

where λ_{kovar} is thermal coefficient of longitudinal extension of kovar (material of the base), λ_{Si} is thermal coefficient of longitudinal extension of Si. The coefficient λ_{kovar} has been determined experimentally from measured values.

For successful simulation, it is necessary to input all material constants correctly. There have been realised following simulations.

Mechanical simulation. The simulation calculates bend of the cantilever and value of mechanical strain on the surface of the cantilever caused by this bend. The input values are coordinates and magnitude of the vector of effective force.

Piezoresistive simulation. The simulation calculates magnitude of voltage on meander at constant current in dependence on cantilever deformation caused by effective force. The resistance of meander can be calculated from the voltage and known current. The resistance is proportional to surface tension. The surface tension has been acquired as a result of mechanical simulation. Inputs are piezoresistive coefficients and output files of mechanical simulation.

Thermal simulation. Results of this simulation are data on mechanical strain arising in connection of cantilever with base due to different thermal expansibility of material of base and Si at temperature changes. Input values are coefficients of thermal expansibility and environment temperature. For simulation it is assumed that the thickness of connecting layer is negligible in comparison with the thickness of Si cantilever.

Results acquired from performed simulations show distribution of mechanical tension along x axis of the cantilever with acting force on the end of the cantilever as parameter – see Fig.8. The graph shows that the strain gauge bridge is located in the place of the greatest mechanical strain of the bridge.

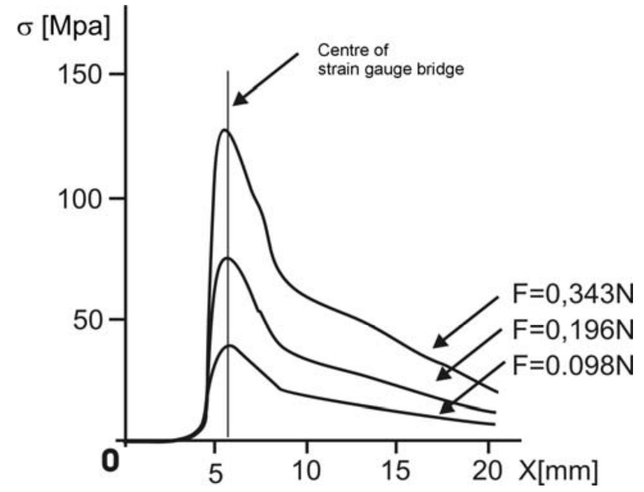

Fig.8 Simulation of distribution of mechanical tension in dependence on distance of fixation to base and acting force as parameter

Piezorezistive simulation enables to calculate dependence of resistance for different concentrations of impurities.

For *thermal simulation* it is assumed that thickness of glue layer is negligible in comparison to thickness of Si cantilever. Further it is assumed that at room temperature (~25°C) there is no mechanical strain in the fixation place. Fig.9 result of simulation of dependence of mechanical tension on distance in x axis with temperature as parameter (-30°C and 150°C) is shown.

According to the measurement, the coefficient of temperature dilatation of kovar is $\lambda_{kovar}=17.8\cdot10^{-6}$ °C^{-1} and that of silicon $\lambda_{Si}=2.5\cdot10^{-6}$ °C^{-1}.

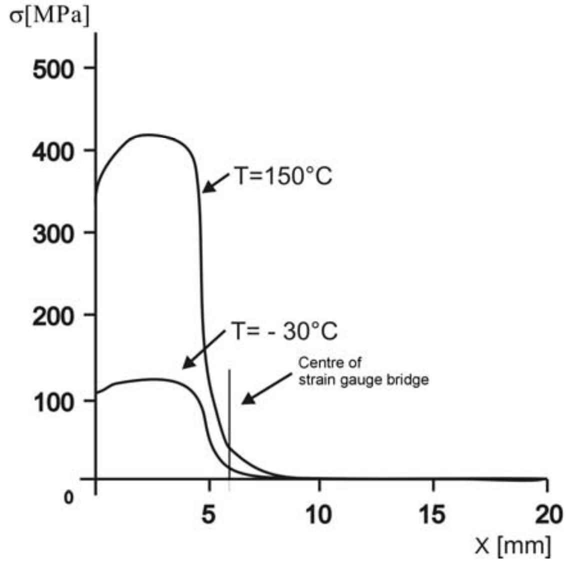

Fig.9 Simulation of distribution of mechanical tension in dependence on distance of fixation to base and temperature as parameter

5 Design Flow in the Design of the Pressure Wireless Sensor [14], [10]

The core of the designed structure is composed of a capacitor with flexible membrane. The capacity is modulated by pressure. Outside the capacity structure there are placed the coils of the inductance. The capacitor together with the inductance forms the resonance circuit. The resonance frequency is modulated by external pressure.

For design and realization of one-chip passive microsensor composed of capacitive pressure sensor and firm integrated planar inductance, we have started from basic properties of these elements in integrated version. For presented measuring principle, an integrated one-chip passive microsensor as resonance circuit has been designed and realised. A capacitive pressure sensor is a part of the resonance circuit. Structure design starts with the component dimension choice, calculation of active and passive capacitances, inductance and LC circuit parameters calculation. The intended application defines the maximum dimensions of the whole integrated circuit. The maximum size can be 3x3 mm. The capacitor area of 1x1 mm is chosen.

5.1 Structure Design and Mechanical Behaviour

Membrane design makes use of the mathematical models presented in [15], [16], and [17]. The maximum allowable pressure acting to the membrane and the maximum size of the edge length of the membrane must be calculated. Thickness of the membrane depends on the technology used. Value of the capacitance can be calculated from the chosen distance S of the electrodes for a reference pressure and ratio of the electrode and membrane area. Finally the capacity value and an approximate value of pressure sensitivity of the sensor are calculated - see Fig.10.

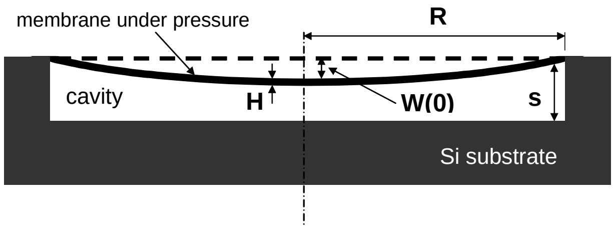

Fig.10 The principle of capacity computing

A formula for a circular membrane design can be adapted for a square membrane if the edge length is equal to 2R. The maximum tensile stress on the membrane [15] is

$$\sigma_{\max} = \frac{1.25\,pR^2}{H^2} \qquad (15)$$

where σ_{max} is the elasticity; its value is in interval (7.10^7 - 19.10^7 Pa) for aluminium. The thickness H of the membrane can be calculated when substituting chosen value of the elasticity $\sigma_{max} = 13.10^7$ Pa into equation (1)

$$H = R\sqrt{\frac{p_{\max}}{10.4x10^7}} \qquad (16)$$

where p_{max} is the maximum pressure on the membrane.

The membrane has been made of aluminium, two values of thickness have been used - 1.2 µm and 3.6 µm. Edge length of the membrane can be calculated for these membrane thickness values and various admissible maximum pressures on the membrane $p_{max.}$ The membrane deflection W in distance r from the centre is

$$W(r) = \frac{p}{49.6D}(R^2 - r^2)^2 \qquad (17)$$

The deflection in the centre of the membrane is

$$W(0) = \frac{R^4}{49.6D}p \qquad (18)$$

$$D = \frac{EH^3}{12(1-\mu_p^{\,2})} \qquad (19)$$

where $E=0.67.10^{11}$ Pa is the Young's modulus for aluminium, $\mu_p=0.33$ is the Poisson's ratio for aluminium.

5.2 Electrical Design and Behaviour

The total capacitance C can be determined by integration over the total capacitor area. S is the distance between the electrodes at the reference pressure.

$$C = \int_0^R \varepsilon \frac{2\pi r}{S - W(r)} dr \qquad (20)$$

An "effective deflection of the membrane" [15] can be defined as

$$d = \frac{1}{A}\int_0^R W(r)2\pi r dr \qquad (21)$$

where A is the membrane area. The value of pressure sensitivity of the sensor for small values of measured pressure can be calculated from the simplified formulas presented in [15]. For pressure sensitivity we can write

$$S_A = \frac{dC}{dp} = \frac{\varepsilon 12(1-\mu_p^2)}{49.6E}\frac{R^6}{S^2H^3} \qquad (22)$$

Pressure sensitivity depends on the membrane thickness H, electrode distance S at reference pressure and edge length 2R. Maximum dimensions of aluminium membrane for defined maximum pressure p_{max} at two different values of membrane thickness can be calculated from presented equations. Further, theoretical capacitor parameters can be calculated from the above mentioned equations.

A planar inductor has been chosen for the design. The empirical rule can be used to calculate its inductance L

$$L = 0.0241\,an^{\frac{5}{3}}\log\frac{8a}{c} \qquad (23)$$

where L (µH) is inductance, n (-) is the number of windings, c (mm) is the wire width, a (cm) is the mean winding length. The inductor L is required to provide high value of inductance, the higher number of winding is required. Because the coil area is limited, the windings of the coil must be thinner. Thinner and longer conductor of the coil has higher resistance R and because of this the quality factor Q decreases. Integrated LC circuits have Q much smaller with respect to the normal coil. The series resistance R_s of the coil can be approximately calculated from the sheet resistance of the aluminium layer and the number of squares of the coil. Exact value of the resistance in the inductor corners must be calculated in another way. However, for approximate calculation, this fact may be neglected.

To calculate the total resistance value of the whole LC circuit, we add the series resistance of the coil and resistance of the doped region, which makes connection between external winding of the coil to the back electrode of the capacitor. Calculation of the resistance is analogous to the $R_{\square}$ calculation. The value shows to be about 2.5 Ω/□ for a heavily doped connecting material. Depth of the doped region has been 11 µm. The aluminium connecting conductor has the resistance value presented when calculating the coil series resistance. The circuit resonance frequency is

$$f_r = \frac{1}{2\pi\sqrt{L(C_A + C_M)}} \tag{24}$$

where C_M is parasitic inductor winding/substrate capacitance and C_A represents the active capacitance.

5.3 Electrical Model of Structure

The dominant part of the parasitic capacitance is located in those areas where the aluminium membrane is attached to the silicon dioxide layer. There is only slightly conducting substrate under the most of the joint areas. The back electrode is only under the cavities and in places where the back electrodes of the small capacitors are interconnected.

Another essential part of parasitic capacitance is created by the back electrode-substrate-inductor winding structure. It can be described by a series combination of two capacitors and a resistor. The first capacitor is formed by the p-n junction, the other one is the inductor winding-local oxide-substrate structure. Since the capacitor back electrode is formed by the diffusion layer, a large area p-n junction with large capacitance is connected [15]. The parasitic resistor is located between the two capacitors. On Fig.11, there are illustrated dominant parasitic elements of the designed structure that have been considered during design phase.

C_j is capacity of p-n junction between bottom electrode N^+ and substrate SiP, C_M is capacity Si-SiO_2-Al, i.e. fixing of aluminium membrane to SiO_2 and metal connection; C_L is capacity between substrate and inductor, i.e. capacity is formed by windings of inductor- SiO_2-substrate P; R_P is parasitic volume resistance between capacities C_P and C_L.

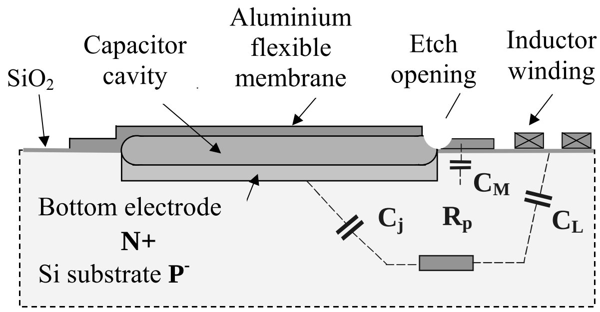

Fig.11 Dominant components of parasitic circuit elements of the designed structure

For R_P it holds

$$R_P = \rho\frac{l}{A} \tag{25}$$

where l is distance between N^+ area and inductor, A is the area of capacitor. Capacity C_M can be expressed from the equation

$$C_M = \varepsilon_o \varepsilon_r \frac{A_M}{b} \tag{26}$$

where A_M is the total area of parasitic capacitors, b is thickness of SiO_2 dielectric (standard value 1 µm). For total capacity of the sensor it holds

$$C_C = C_A + C_M \tag{27}$$

Resulting sensor sensitivity decreases according to the equation

$$S_C = S_A \frac{C_A}{C_A + C_M} \tag{28}$$

where S_A is theoretical sensitivity without influence of parasitic capacities, C_A is active capacity and C_M is total parasitic membrane capacity. Regarding dominant parasitic circuit elements, we can set up equivalent circuit diagram. This diagram enables modelling of properties using standard simulators, e.g. SPICE. The equivalent scheme of the sensor with parasitic elements is shown in Fig.12.

C_A designates the active capacitance, C_M is the parasitic inductor winding-substrate capacitance, L is inductance of the inductor and R_s its parasitic series resistance, R_p is the parasitic resistance of the substrate between the p-n junction and the inductor, R_{sp} is the parasitic series contact resistance.

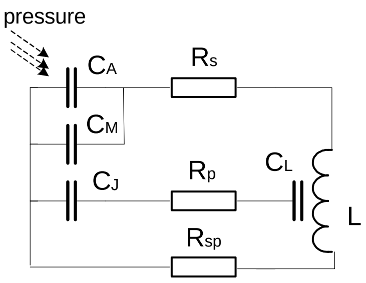

Fig.12 Equivalent electrical model of the integrated resonance circuit

5.4 Design of System Arrangement

When designing and modelling 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. [10]. Example of a model of the whole electronic system is shown in Fig.13.

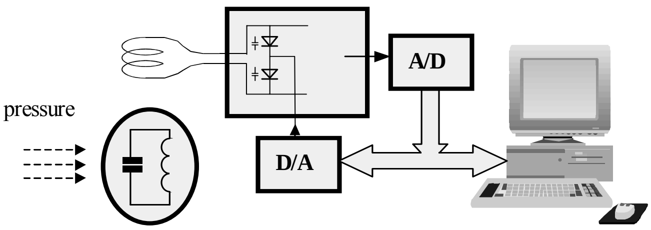

Fig.13 Design of measure system

The basic circuit is a Colpitt's oscillator. In the design it has been necessary to adhere to the general principles of high frequency design rules. The suggested interface provides communication through a converter and I/O circuits of the computer. It takes care of the A/D conversion for the evaluation of the oscillator amplitude variation, the D/A conversion for the oscillator tuning control signal, sufficient A/D and D/A speed with a minimum sampling frequency 80 kHz, sufficient A/D converter levels resolution (minimum 100).

When installing it into the PC the only hardware setting necessary is setup of the base card address, choice of the voltage range of the D/A converter (unipolar or bipolar logic), determination of the digital ports transfer direction or the mode of its software control. All other functions are software-controlled. Its physical dimensions permit its installation even in a notebook. The transfer characteristics for wireless measuring system are presented in Fig.14.

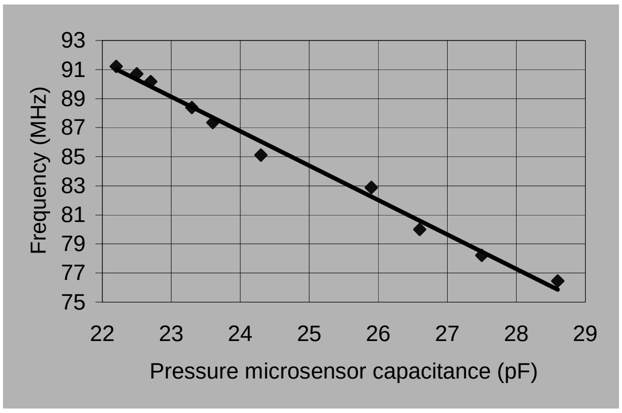

Fig.14 The transfer characteristic of the complete wireless measuring system

6 Conclusions

Utilization of system of models is an inseparable part of the process of design of integrated microelectronic applications. Models on different hierarchical levels are developed. Suitable simulators are developed for model solving. Measured parameters serve as input to these simulators. In this way, it is possible to make the simulation results more precise. The simulation results are then closer to real behaviour of realised structures. Different solution alternatives of designed structures can be simulated using more precise models. Based on the simulation results, layout with optimal required parameters can be selected for realisation.

Models on individual hierarchical levels are interconnected. Logical connection creates so-called “design flow”. There does not exist any universal scheme for development of individual parts of the design flow. The models are set up according to demands on the designed structure. When modelling MST structures, equivalence between energy domains is used very frequently. Equivalence often allows utilize means of analytical mathematics. It is possible to design equivalent electric circuit with equivalent elements. Tools for solving electronic circuits can be used for solving these equivalences. The tools are very well-developed. They allow analyze design structures and systems in both static and dynamic models of operation. Many simplified models can be used illustratively in education. Real models can be realised, it is possible to measure their characteristics and identify real parameters.

Various software tools are used for simulation and modelling. “Design flow” emerges by mutual connection of simulation levels. Various modified models and tools can be used in the process of design and simulation. These models serve for verification of basic functions of simple blocks. World software standards are used for final design of integrated structures. At the university, tools as Matlab, Mathematica, TCAD, ORCAD, XILINK, are widely used. Simulation and modelling of electronic connections are done using SPICE tool.

Models and simulations, supported by tools as for example CoventorWare of ANSYS, can be utilized for design of integrated MEMS structures, modelling and simulation of mechanical properties and thermal distribution. The software package CADENCE is used for design of structures of integrated electronic circuits.

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