Capacitive and Resistive RF-MEMS switches 2.5D & 3D Electromagnetic and Circuit Modelling

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***Abstract*— this paper proposes different strategies for the electrical modelling of capacitive and resistive RF-MEMS switches which take into account the dependence of the electrical performance on the mechanical properties and technological processes. The EM modelling of MEMS switches is addressed with 2.5D and 3D full wave EM softwares. More specifically, ADS-Momentum™ (2.5D) and EMDS™ (3D) from Agilent Technologies are used. Capacitive RF-MEMS switches were fabricated with the LAAS-CNRS 6-mask RF-MEMS process in Toulouse, France, and resistive RF-MEMS switches were fabricated with the FBK-irst 8-mask RF-MEMS process in Trento, Italy. It is shown that, by applying the proposed strategies, 2.5D and 3D simulations are in good agreement with characterization results.**

I. INTRODUCTION

The electrical modelling of RF-MEMS (Micro-Electro-Mechanical system) switches poses new challenges. Indeed, the switch electrical performance is coupled to the mechanical properties of the structures and materials involved in its implementation and also to the fabrication process technology [1]. Usually, these dependences are not taken into account in full wave EM (Electromagnetic) simulation. There are some works dealing with multidomain modelling of RF-MEMS switches [2-5] where in-house simulation tools or a combination of commercial simulation tools are used for taking into account the dependence of the electrical performance on the mechanical or thermal properties. Furthermore, although RF-MEMS switches are 3D structures, they can also be seen as 2.5D structures because of their very high aspect ratio. Electrical modelling can then be addressed by a great variety of 3D or 2.5D EM simulation tools [6].

The objective of this work is to compare these two different approaches. The EM modelling of MEMS switches is addressed with 2.5D and 3D full wave EM softwares. More specifically, ADS-Momentum™ (2.5D) and EMDS™ (3D) from Agilent Technologies are used. Using these EM tools, this work proposes different strategies for the electrical modelling of capacitive and resistive RF-MEMS switches which take into account the dependence of the electrical performance on the mechanical properties and technological processes.

II. 2.5D AND 3D MODELLING OF CAPACITIVE RF-MEMS SWITCHES IN DOWN-STATE

A. Device description and characterization

Fig. 1 (a) shows a photograph of the capacitive RF-MEMS switch to be modelled. It was fabricated with the LAAS-CNRS 6-mask RF-MEMS process [7]. This switch topology was designed to be integrated into a circuit where RF lines are DC-grounded, and then, the membrane cannot be directly anchored (resistive contact) to the CPW ground planes but a capacitive anchor is used for DC isolation [8]. Fig. 1 (c) shows the RF-MEMS switch down-state characterization with isolation better than 30 dB at the design frequency. Fig. 1 (c) also shows the isolation obtained using the proposed equivalent circuit model for the down-state, where lumped elements values have been selected to fit the measured isolation curve. The equivalent circuit model in Fig. 1 (b) is derived from the circuit models proposed in [9] for other topologies. It can be observed that the capacitive anchor of the membrane to the CPW ground planes has been modelled with two shunt capacitors, one for each anchor.

B. Capacitive contact roughness modelling

Fig. 2 (a) shows the 2.5D Momentum™ and 3D EMDS™ models of the capacitive RF-MEMS switch presented in Section II.A. Fig. 2 (c) shows a comparison between simulated (2.5D Momentum™ and 3D EMDS™) and measured isolation. Fig. 2 (b) presents down-state equivalent circuit model where lumped element values have been selected to fit the simulated isolation curve. The values in top and bottom boxes correspond to Momentum™ and EMDS™ simulations, respectively.

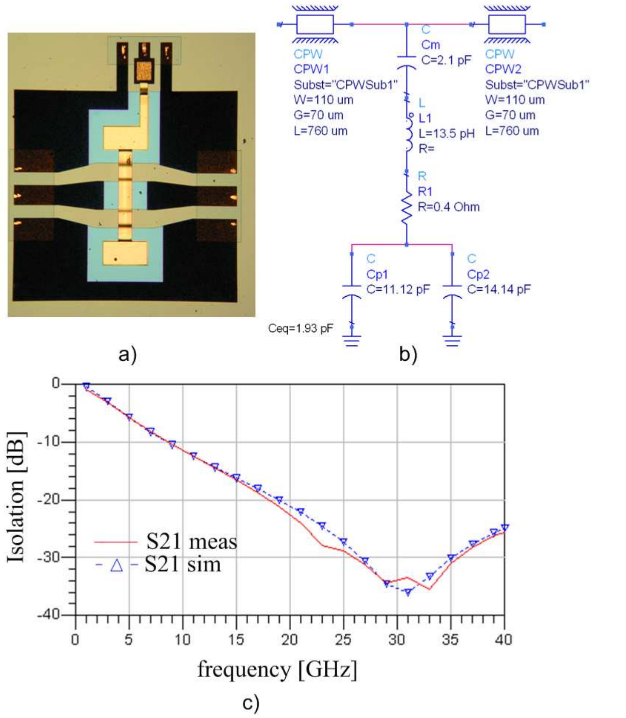


Fig. 1. a) Photograph of the capacitive RF-MEMS switch, b) down-state equivalent circuit model and c) characterization and equivalent circuit model isolation curves.

If a perfect contact between the membrane and the CPW central conductor is assumed, a deviation is observed between the contact capacitance in the down-state equivalent circuit model derived from measurement (Fig. 1 (b)) and that derived from EM simulation. This is due to the roughness of the materials on the capacitive contact area which effectively reduces the down-state capacitance and pushes up the resonant frequency of the DUT. The roughness of materials is a technological issue which cannot be directly modelled by EM software tools. However, the contact area can be reduced in the EM model in order to compensate the down-state capacity deviation as can be seen in the models presented in Fig. 2 (a).

With this technique, material roughness can be indirectly modelled. Then, EM modelling of the device results in more accurate prediction of the down-state behaviour of the capacitive RF-MEMS switch as can be seen comparing lumped element values in Fig. 1 b) and Fig. 2 b). From the results of Fig. 2 c) it can be observed a deviation between measured and simulated maximum isolation. Maximum isolation is related to switch membrane and anchor vias conductivity. Modelling of switch membrane and anchor vias conductivity will be discussed in the next subsection.

C. Switch membrane and anchor vias conductivity

In order to predict the capacitive switch maximum isolation at the design frequency the switch membrane and anchor vias conductivity plays an important role. In the previous simulations the conductivities of the switch membrane and anchor vias (both implemented with gold) were the same as the conductivity of the main metal layer (which implements the CPW). However, the effective conductivity of the switch membrane and anchor vias depends upon the conductivity of the membrane and vias materials, the deposition process, the thickness of the membrane and the vias interconnect resistance (mainly due to adhesion layers). As can be observed in the down-state equivalent circuit models (see Fig.1(c) and Fig.2(c)), the values of the resistances obtained from measurement and simulation are in disagreement.

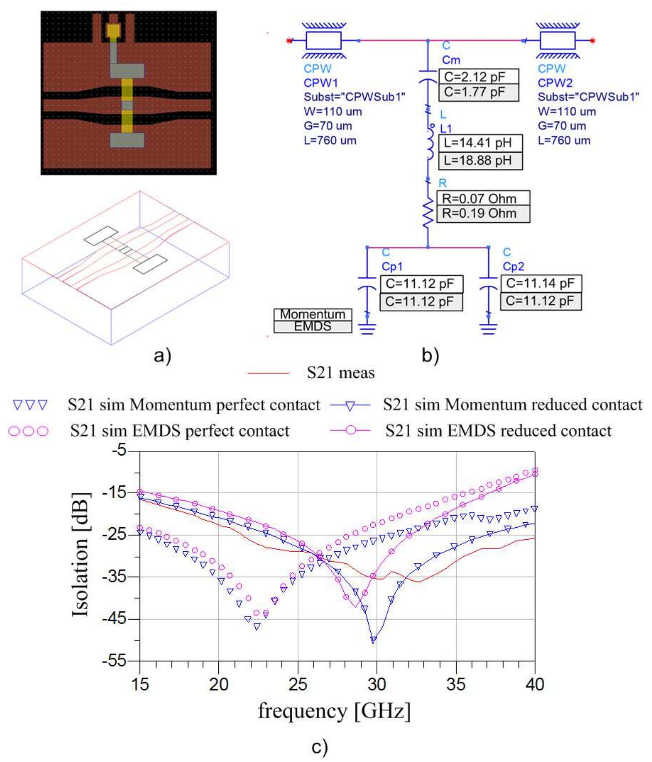


Fig. 2. a) Momentum™ 2.5D (up) and EMDS™ (down) models of the capacitive RF-MEMS switch with reduced capacitive contact area, b) down-state equivalent circuit model for EM simulation with reduced contact area and c) simulation (with and without reduced contact area) and characterization isolation results.

Fig.3 (b) shows the results obtained from EM simulation of the capacitive switch down-state isolation where the membrane and anchor vias conductivity have been selected in order to fit the measured maximum isolation. This new effective conductivity takes into account parameters such as the vias interconnect resistance determined by the fabrication process, which cannot be directly modelled during the EM simulation. As can be observed from the down-state equivalent circuit models of the capacitive RF-MEMS switch extracted from measurement (Fig. 1 (c)) and EM simulation with this new effective conductivity (Fig. 3 (a)), values of the resistances are now in agreement.

From previous results it can be concluded that 2.5D and 3D simulations results, by applying the proposed simulation strategies, are in agreement with characterization results.

However, the 2.5D simulation based on the method of moments (ADS-Momentum™) is faster than the 3D simulation based on the finite element method (EMDS™), as can be expected.

III. 2.5D MODELLING OF RESISTIVE RF-MEMS SWITCHES IN DOWN STATE

A. Device description and characterization

Fig. 4 (a) shows a photograph of the resistive RF-MEMS switch to be modelled. It was fabricated with the FBK-irst 8-mask RF-MEMS process [10]. The equivalent circuit model in Fig. 4 (b) corresponds to the circuit model proposed in [9] for resistive switch topologies, where *R* is the contact resistance for each contact area and *L* is the inductance introduced by the short section of the membrane between contact areas. A parasitic resistance is added to the inductance in order to take into account the membrane losses.

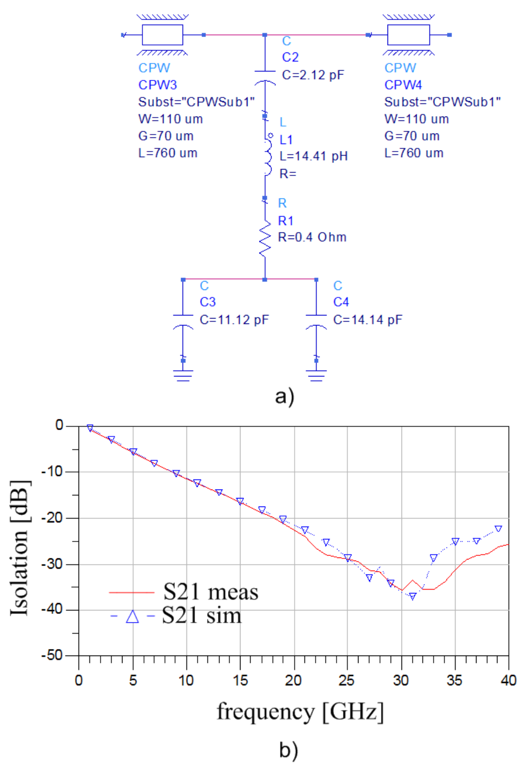


Fig. 3. a) Down-state equivalent circuit model extracted from the EM simulation with an effective conductivity value for switch membrane and anchor vias and b) Isolation curves for characterization and EM simulation with an effective conductivity value for switch membrane and anchor vias.

Fig. 4 (c) shows the RF-MEMS switch down-state characterization with insertion loss better than 0.8 dB in the frequency range 5–25 GHz. Fig. 4 (c) shows also return and insertion loss obtained using the equivalent circuit model for the down-state proposed in Fig. 4 (b), where lumped elements values have been selected to fit the measured return and insertion loss curves.

B. Contact resistance

A key parameter of the resistive RF-MEMS switch is the contact resistance, which determines the device down-state insertion loss. The contact resistance is influenced by the combination of a number of elements such as material properties (electrical resistivity, roughness and plasticity), contact area, contact force, adherence force, and temperature due to the current flow through the contact [11-13]. Mechanical parameters such as roughness, plasticity, contact force and contact temperature cannot be directly modelled with EM simulation tools. However, for a specific technology, contact area and contact force (related to the actuation force), the value of the contact resistance can be supposed in a certain range.

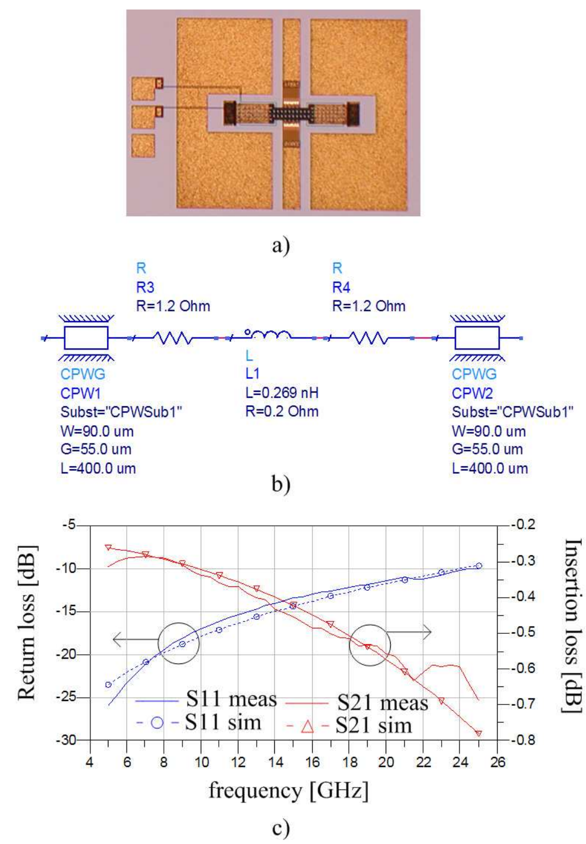
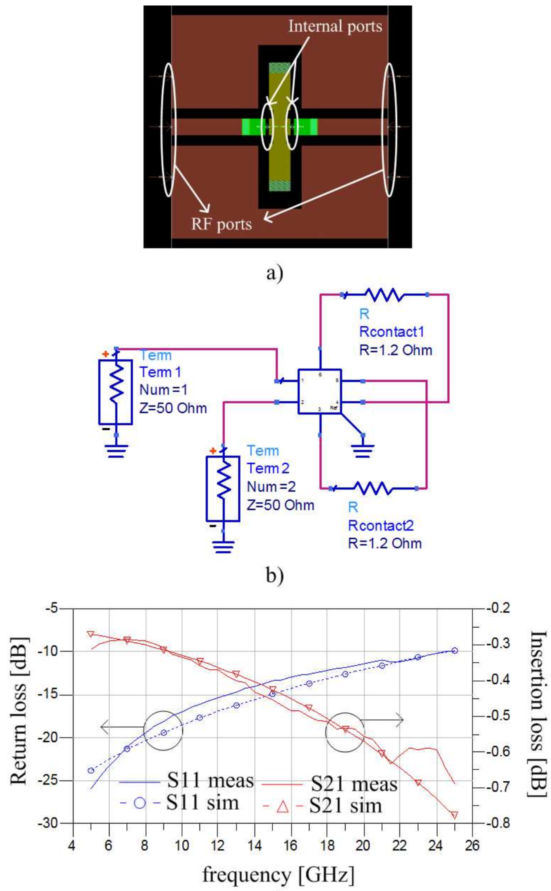


Fig. 4. a) Photograph of the resistive RF-MEMS switch, b) down-state equivalent circuit model and c) characterization and equivalent circuit model return and insertion loss curves.

We propose to integrate the contact resistance in a co-simulation environment where the contact resistance is added to the EM simulation with lumped elements. For this purpose, internal ports are used during the EM simulation with ADS-Momentum™ (see Fig. 5 (a)). Fig. 5 (b) shows the ADS schematic where the data item contains the 6-port EM simulation: two RF ports and four internal ports to connect the external lumped resistances (two ports for each resistive contact area) and the two contact resistances. The results of the co-simulation compared to measurement results are presented in Fig. 5 (c).

As can be observed from results of Fig. 5 (c) the proposed technique overcomes mechanical contact issues during the down-state EM simulation showing good agreement between simulation and characterization. This technique also permits a sensitivity study of device insertion loss respect to the contact resistance.



c)

Fig. 5. a) Momentum™ 2.5D (down) model of the resistive RF-MEMS switch with internal ports, b) ADS co-simulation model and c) co-simulation and characterization return and insertion loss curves.

IV. CONCLUSION

Different strategies to take into account mechanical issues during capacitive and resistive RF-MEMS switches EM modelling have been proposed. More specifically, strategies to take into account reduced contact area and maximum isolation in capacitive switches have been proposed. For resistive RF-MEMS switches a co-simulation strategy has been proposed to take into account the mechanical dependence of the contact resistance on the mechanical and technological aspects. These strategies are based on a previous knowledge of the RF-MEMS process and technology. Simulation results applying proposed strategies have shown good agreement with characterization results. Moreover, these strategies can accelerate the design process and allows for sensitivity studies of electrical performance with respect to mechanical parameters, which usually cannot be directly modeled during the EM simulation.

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