Inverse Electro-Mechanical ANN Model of RF MEMS Capacitive Switches - Applicability Evaluation

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***Abstract* – The aim of this paper is to analyze applicability of the inverse electro-mechanical models of capacitive RF MEMS switches based on artificial neural networks (ANN). The analyzed model, proposed earlier, is developed to predict length of the fingered part of the switch for fixed length of the solid part of the bridge, resonant frequency and actuation voltage, directly without any optimization. Here, it is analyzed in which parts of the input space the model is applicable, and how to choose a physically meaningful combination of input values. Moreover, application of this model to determine bridge dimensions for the requested total length of the bridge is investigated as well. Finally, recommendations related to the application of the model are given.**

Keywords –**Artificial neural networks, RF MEMS, capacitive switch, inverse modeling, actuation voltage, resonant frequency.**

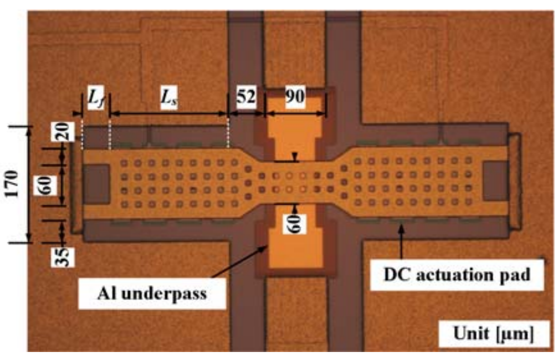
I. Introduction

In the recent years RF MEMS switches have become a competitive devices to their mechanical and electronic counterparts, as they have numerous advantages: they are very small, extremely linear, can be integrated and allow easy re-configurability or tunability of a system [1]. Due to the increasing application of RF MEMS switches in modern communication systems, there is also an increasing need for their accurate and efficient models. Standard simulations in commercial electromagnetic and mechanical simulators take a lot of time, making a design process time consuming [2]-[3]. To speed up the design process, alternative models based on artificial neural networks (ANNs) [4] can be used. Most of the developed neural models relate the switch electrical and mechanical characteristics and switch dimensions and operating conditions such as frequency and/or actuation voltage [5]-[10]. Since, the ANNs give response almost immediately, the simulation and optimization time is significantly reduced when these models are used. Moreover, inverse neural models aimed to determine the switch bridge dimensions for given requirements in electrical or mechanical domain were proposed [9]-[10]. Recently, authors of this paper proposed an inverse electro-mechanical model for determination of the switch dimensions for given electrical resonant frequency and actuation voltage [11]. It was shown that this model exhibits a very good accuracy of dimension determination. This paper deals with evaluation of the applicability of the mentioned model, with the main aim to determine the parts of the input space where physically meaningful output values are obtained.

The paper is organized as follows: after Introduction, in Section II the capacitive RF MEMS switch considered in this work is described. The analyzed inverse electro-mechanical ANN model is shortly described in Section III. The results of the analysis and discussion are presented in Section IV. Section V contains concluding remarks.

II. Modeled Device

The considered device is an RF MEMS capacitive coplanar shunt switch, depicted in Fig. 1, fabricated at FBK in Trento in an 8 layer Silicon micromachining process [12].



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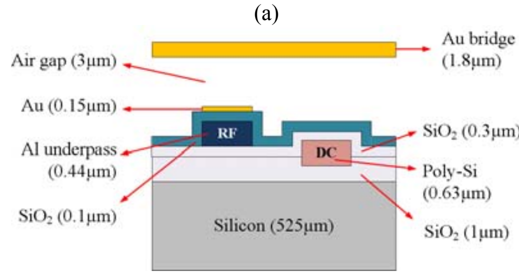

(b)

Fig. 1. a) Top-view of the realized switch; b) schematic of the cross-section with 8 layers in FBK technology [12]

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The actuation voltage is determined as the instant voltage applied to the DC pads when the bridge comes down and touches a coplanar waveguide centerline, which is a pull-in voltage (V_{PI}). This is strongly related to the switch features and mechanical/material properties, such as a DC pad size and location, a bridge spring constant and residual stress, bridge shapes or supports, etc. The finger parts (corresponding to L_f in Fig. 1) are to control V_{PI} . If finger parts are long compared to the other parts, the bridge becomes flexible and the switch is easily actuated by a low V_{PI} . But this increases the risk of a self-actuation or an RF hold-down when the switch delivers a high RF power. And opposite, with the short finger parts, the switch needs a high V_{PI} to be actuated. Moreover, the switch resonant frequency, determining the switch operating frequency, depends on the bridge dimensions as well. Therefore, the lengths of the bridge solid and fingered parts (L_s and L_f) should be carefully determined considering a delivering RF power and a feasible DC voltage supply [1].

III. Inverse Electro-mechanical ANN Model

In [11] an inverse electromechal model based on ANNs was poposed. It consists of an ANN traned to determine the length of the bridge fingered part (L_f) for given length of the bridge solid part (L_s) and desired resonant frequency (f_{res}) and actuation voltage (V_{PI}). ANNs are trained by using values of the resonant frequency and actuation voltage calculated in standard electromagnetic and mechanical simulators, or by using corresponding ANN models [10]. Once the ANN is trained properly, the length of the fingered part can be determined instantaneously, saving a lot of time comparing to the standard approach based on the optimizations in electromagnetic and mechanical simulators.

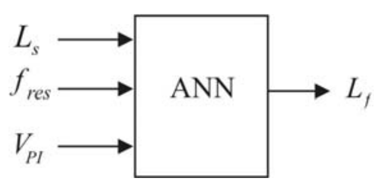


Fig. 2. RF MEMS ANN inverse electro-mechanical model.

IV. Results and Discussion

The inverse electromechanical model developed for the RF MEMS switch described in Section II is an ANN having two hidden layers, containing 10 and 20 neurons. The details on model development and validation can be found in [11].
The model was developed for the following ranges of the switch geometrical parameters: L_s from 100 µm to 500 µm, and L_f from 0 µm to 100 µm. The corresponding ranges of resonant frequency and actuation voltage are approximately

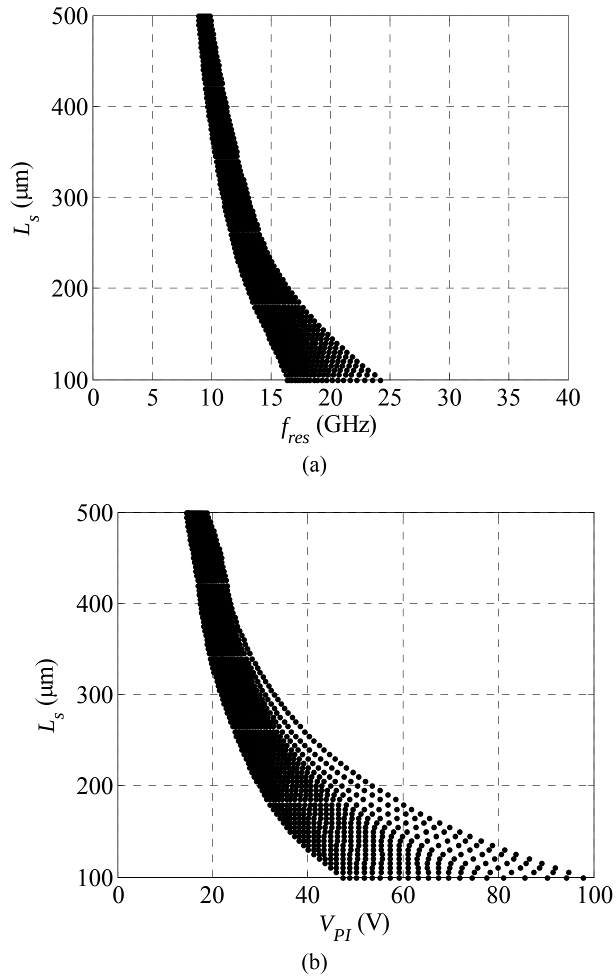


Fig. 3. Bridge solid part versus (a) resonant frequency; (b) actuation voltage.

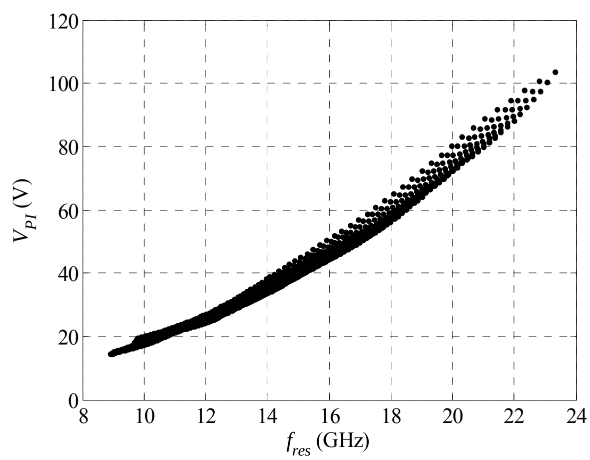


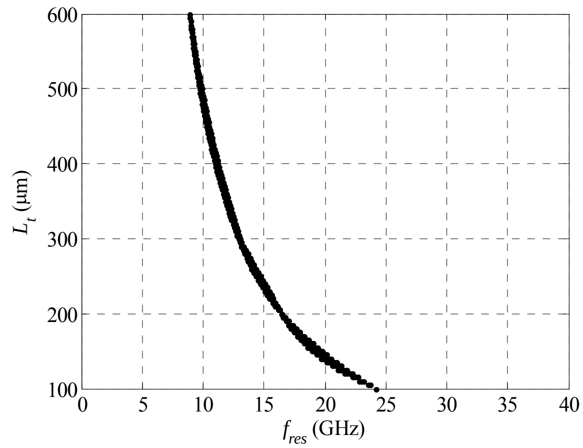
Fig. 4. Possible combinations of the actuation voltage and the resonant frequency for the considered range of bridge dimensions.

(8-24) GHz and (10-105) V, respectively. However, although the ANN model would give a response for every combination of values falling within the mentioned ranges, not every combination is physically meaningful, i.e. the model is not applicable in such cases. Therefore, here it will be analyzed in details which combinations of the input values are physically meaningful.

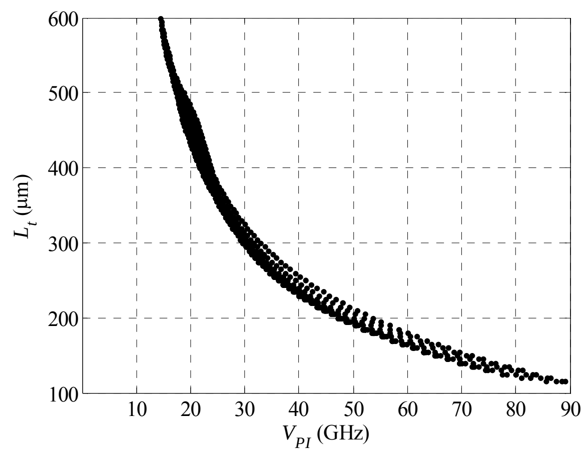
With that aim, the resonant frequency and actuation voltage have been calculated for different combinations of L_s and L_f in the above mentioned ranges by using the earlier developed neural models developed to determine resonant frequency [9] and actuation voltage [10] for the given bridge dimensions. Further, the bridge solid part is plotted versus the obtained f_{res} and V_{PI}, as shown in Fig. 3.

Moreover, in Fig. 4 there is a plot relating possible combinations of f_{res} and V_{PI} for the considered ranges of the bridge dimensions. In other words, these three plots represent parts of the input space referring to the physically meaningful input combinations. Therefore, the first step in determining the dimensions is to check if the input combinations are valid. This will be illustrated on the following example. Let the desired resonant frequency be 12 GHz. From Fig. 4, it can be seen that the corresponding actuation voltage values are from 24 to 28 V. The possible values of L_s for the resonant frequency of 12 GHz are from 250 μm to 350 μm, according to Fig. 3a. This range has to be compared to the range of possible values for a chosen V_{PI} values falling in the mentioned range from 24 to 28 V. Let the V_{PI} be 25 V. According to Fig. 3b, the corresponding L_s values are from 270 μm to 400 μm. Therefore, for the resonant frequency 12 GHz and actuation voltage 25 V, the possbile L_s values are in the range from 270 μm to 350 μm.

However, often the bridge part lengths should be determined for the fixed total length of the bridge ($L_t = L_s + L_f$). This model can be used to determine the dimensions also in such a case. As in the previous case, a desired resonant frequency can be achieved only for certain values of L_t, within the necessary range of the actuation voltage. By using the same data used for making plots shown in Fig. 3, the corresponding L_t is plotted versus f_{res} and V_{PI} and presented in Fig. 5. These plots are useful to estimate the possible values of L_t. As an example, with the total length of 300 μm it is possible to achieve only frequences between, approximately, 12 and 13 GHz, with the corresponding voltages in a range around 30 V. Also, the possible combinations of f_{res} and V_{PI}, plotted in Fig. 4, should be kept in mind. Once the total length is verified to be valid for the desired resonant frequency and the corresponding necessary actuation voltage, L_s and L_f can be easily found graphically, determined by the intercept point of the functions $L_f = f_{inv\_ANN}(L_s, f_{res}, V_{PI})$ obtained by the inverse electromechanical model and $L_f = L_t - L_s$, both for the L_s from 0 μm to L_t. This will be illustrated on the following example. Let the desired resonant frequency be 14 GHz, the actuation voltage 35V and the desired total lenght 260 μm. For L_s from 0 μm to 260 μm, L_f is calculated and plotted in Fig. 6a as a black line. $L_f = L_t - L_s$ is a linear function plotted as a blue line. There are two intercept points, one around L_s =110 μm and the other at L_s =200 μm. Considering the plot shown in Fig. 3a, values around 100 μm are not physically possible for the resonant freqeuncy of 14 GHz, therefore this intercept point is not a possible solution. The plot from Fig. 6a is zoomed around the second intercept point and shown in Fig. 6b, i.e., Fig. 6b shows the physically possible values which are represented in Fig. 6a as thicker parts of plotted lines. It can be clearly seen that the corresponding dimensions are L_s =200 μm and L_f =60 μm.



(a)



(b)

Fig. 5. Bridge total length versus (a) resonant frequency and (b) actuation voltage in the considered range of the bridge dimensions.

V. Conclusion

In this paper, an extensive analysis of the applicability of the earlier proposed electromechanical inverse model of RF MEMS switches aimed at calculation the length of the fingered part of the bridge has been done. Although the model is developed for a certain range of input space, not all combinations of the input variables result in physically possible and meaningful values. Therefore, by using the previously developed neural models for determining the resonant frequency and actuation voltage, the plots defining the possible input combinations have been made. On an appropriate example, it was illustrated how to chose a valid input combination. Moreover, as sometimes it is requested to determine the lengths of the bridge part for the total bridge length given, the similar analysis has been conducted. In addition, a graphical approach based on using the considered neural model for obtaining the lengths efficiently for the given total length has been developed. This study can serve as a useful guide in a design of RF MEMS switches based on the switch inverse electro-mechanical neural models.

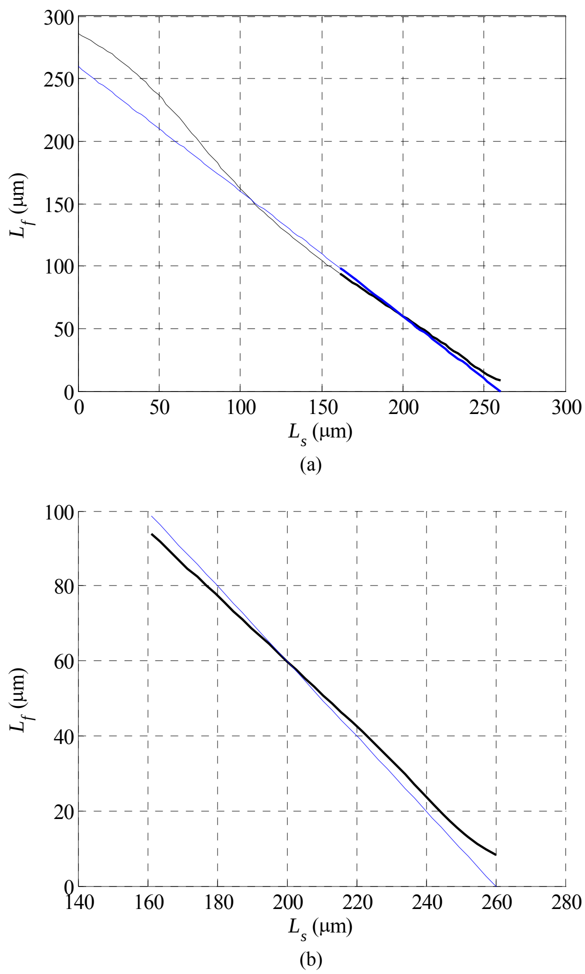


Fig. 6. L_s and L_f determination for the total length L_t =260 μm.

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