Speedy Processing of Sparameters Behaviour for Switch Optimization

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ABSTRACT: *We are in a state for providing reliable and correct switch models for which we propose MEMS switch applications. We have used the artificial neural networks to develop the model where we have used the lateral dimensions of the switch bridge and the Sparameters. The proposed system permits the speedy processing of Sparameters behavior, for which a shorter time is needed and also to do operations. The goal of this work is to analyse the switch return loss changes with small the changes of the bridge dimensions. We have performed the experiments to analyse it and describe the suggestions for better switch optimization.*

Keywords: Artificial Neural Networks, Return Loss, Insertion Loss, RF MEMS Switch

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1. Introduction

RF MEMS switches are surface-micromachined devices which use mechanical movements to achieve a short circuit or an open circuit in the RF transmission-line [1]. These devices are extremely small and light and are applicable in many communication devices and systems. Also, they are highly linear and can operate up to higher frequency bands providing high isolation and low insertion loss in general. The dimensions of RF MEMS switch components have to be optimized carefully in order to fulfil the desired RF specifications. Generally, the optimization is performed by full-wave EM simulations [2]. However, simulations in standard simulators are time consuming and require considerable computing resources because the switch generally consists of several thin layers and vias with high complexity. Moreover, since the optimization process mostly involves a series of EM simulations with varying parameters, the computing load is further increased. The common method to improve simulation speed and efficiency is to use a lumped element circuit model in a circuit simulator. However, to derive an accurate circuit model is demanding, especially at high frequencies, because the circuit model should involve more parasitic components at higher frequencies, which increases the model complexity [3]. A solution to these needs can be the application of artificial neural networks (ANNs) for deriving proper models for different switch types and to relate different sets of input parameters to the desired output quantities. ANNs have been widely used as a fast and efficient tool for modeling of different electronic devices [4]-[5], among them RF MEMS devices [6]-[7]. Use of ANN based models has a great advantage in reducing the computational cost, especially when implemented within a circuit simulator that has integrated tuning and optimization options. Namely, ANNs are capable of modeling nonlinear mappings of multiple input/output parameters, providing models which enable an accurate device characterization and efficient prediction of unknown input-output relationships with low computational overhead.

ANN based modeling and optimization of an ohmic series RF MEMS switch is presented in [8]. On the base of several full-wave numerical simulations of the switch, ANNs are developed to directly relate the switch geometrical parameters to the scattering parameters over frequency. Besides the lateral dimensions of the bridge, the lateral dimensions of the gap surrounding the bridge are concerned as well. The gap size has to be adjusted in order to achieve a proper matching of the bridge section with input/output line impedance. It is reported that with the developed model an optimization of the structure can be done within seconds.

In the design of an RF MEMS switch one of the requirements to be met in the optimization is to keep return loss below a specified value in the frequency range of interest. In this paper the model presented in [8] is exploited for analysis of the switch return loss. In particular, special attention is put on analysis how the return loss deviates from the nominal values if the dimensions of the bridge membrane are changed due to their small changes caused by the fabrication tolerances. In addition, the corresponding insertion loss changes are reported in the paper.

The paper is organized as follows: After the introduction, in Section 2 the considered RF MEMS switch is described. The ANN model used in this work is presented in Section 3. The results of the analysis of the switch return and insertion losses and the corresponding discussion are given in Section 4. Finally, Section 5 contains the concluding remarks.

2. Modeled Device

The device considered in this work is a CPW (coplanar waveguide) based RF MEMS ohmic series switch, depicted in Figure 1a. The switch is fabricated at FBK in Trento on a 525μm thick silicon wafer by standard surface micromachining and CMOS technologies, which requires eight masks, [9]. A serious switch should have a low return loss in ON state. Therefore, not only the bridge length (L_b) and width (W_b), but also lateral (L_g) and longitudinal (W_g) gaps between a bridge anchor and CPW ground have to be adjusted. This means, during optimization, those dimensions are to be simultaneously swept and determined to the optimums.

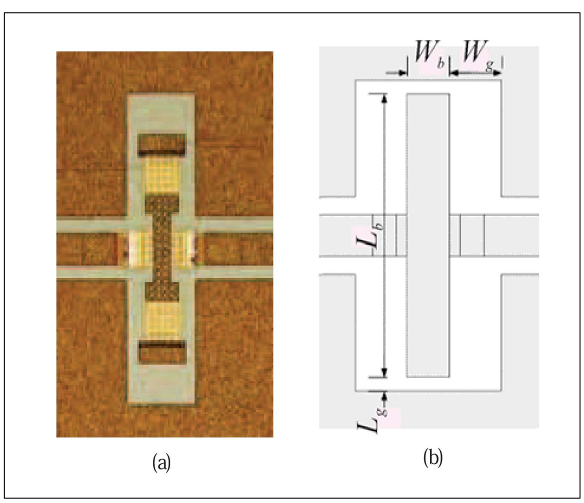

Figure 1. Fabricated ohmic series RF MEMS switch [9] (a) and the simplified configuration (b)

3. Exploited ANN model

The ANN model used to perform the analysis consists of four multilayer perceptron networks modeling magnitudes ($|S_{ij}|$) and for the phases ($\angle Sij$) of S_{11} and S_{21} scattering (S-) parameters against the switch lateral dimensions (L_b, W_b, L_g, W_g) and frequency f, as shown in Figure 2. As the switch is a symmetrical and reciprocal component, it follows that $S_{22} = S_{11}$ and $S_{12} = S_{21}$, therefore the presented model can be used to predict all four S-parameters. Each of the four ANNs has five input neurons corresponding to four mentioned lateral dimensions of the switch and the frequency. All the ANNs have only one neuron in the output layer corresponding to one of the modeled parameters ($|S_{11}|$ (dB), $\angle S$(deg), $S_{21}|$dB| and $\angle S_{21}$ (deg)).

The ANN model of the considered device was developed and validated with the S-parameters data obtained from fullwave simulations with CST Microwave Studio (CST MWS) [10]. Instead of the original device layout, a simplified layout as shown in Fig. 1(b) was used. The details about training and validation of the model can be found in [8]. Trained ANN models are capable to predict the S-parameters for the given bridge geometrical parameters and frequency, enabling fast and efficient further analyses related to the bridge size adjustment in order to fulfill the design requirements.

For the analysis of reported in this paper, the ANNs modeling magnitudes of S_{11} and S_{21} have been used, as magnitude of S_{11} represents return loss and the magnitude of S_{21} represents the insertion loss. As reported in [8], the both ANNs have two-hidden-layers: the ANN modeling $|S_{11}|$ (dB) has 17 hidden neurons in each of the two hidden layers, whereas the ANN modeling $|S_{21}|$ (dB) has 18 hidden neurons in the first hidden layer and 16 neurons in the second hidden layer.

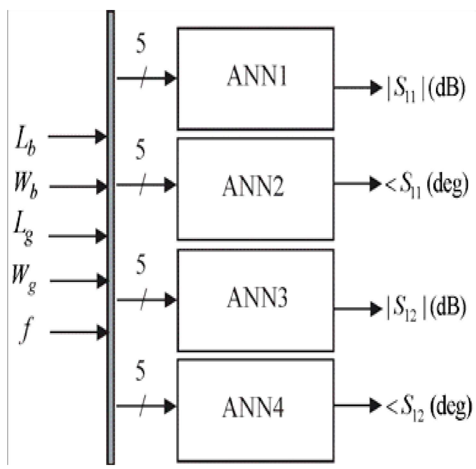

Figure 2. ANN model of ohmic series RF MEMS switch

4. Results and Discussion

The mentioned two ANNs have been used for further analysis of the behavior of the switch return loss and switch insertions loss with changes of the switch lateral dimensions. The analysis has been performed for the following range of the lateral dimensions: L_g - from 30 to 110 μm, L_b - from 200 to 1000 μm, W_b - from 70 to 150 μm, W_b - from 20 to 220 μm. The considered frequency range has been from 0 to 40 GHz. It should be mentioned that the above given ranges correspond to the validity range of the model, i.e. to the range of input parameters used for the model development. For the purpose of analysis, eight differently sized devices, i.e., eight combinations of the bridge lateral dimensions have been considered.

As mentioned in Introduction, the aim of work is to analyze changes of the switch return loss caused by small changes of the dimensions in fabrication of the bridge. The considered deviations have been in the range +/- 3 μm (taken with the step of 1 μm), as that can be considered as the range of bridge fabrication tolerances in the considered technology. Moreover, besides return loss, analyses of the insertion loss changes are given. Therefore, the analysis has been performed for the deviation of the bridge dimensions L_b and W_b. First, the return and insertion loss changes when one of the two considered bridge lateral dimensions has been changed, while the others have been kept constant have been calculated by the neural model and the corresponding deviations from the expected nominal values were calculated.

The calculated deviations, i.e. maximum deviation values (absolute values) in the considered frequency range are given

Lb [µm]	*Wb* [µm]	*Lg* [µm]	*Wg* [µm]	Max$\|\Delta S_{11}\|$ [dB]	Max$\|\Delta S_{21}\|$ [dB]
200	20	30	70	0.5	0.0026
400	20	50	70	0.29	0.0025
300	70	90	70	0.42	0.0038
800	70	70	90	0.27	0.0054
800	20	50	110	0.54	0.0075
400	20	30	150	0.73	0.0045
1000	220	30	20	0.08	0.012
600	120	70	110	0.58	0.0063

Table 1. Return And Insertion Loss Maximum Deviations - *Lb* Changes

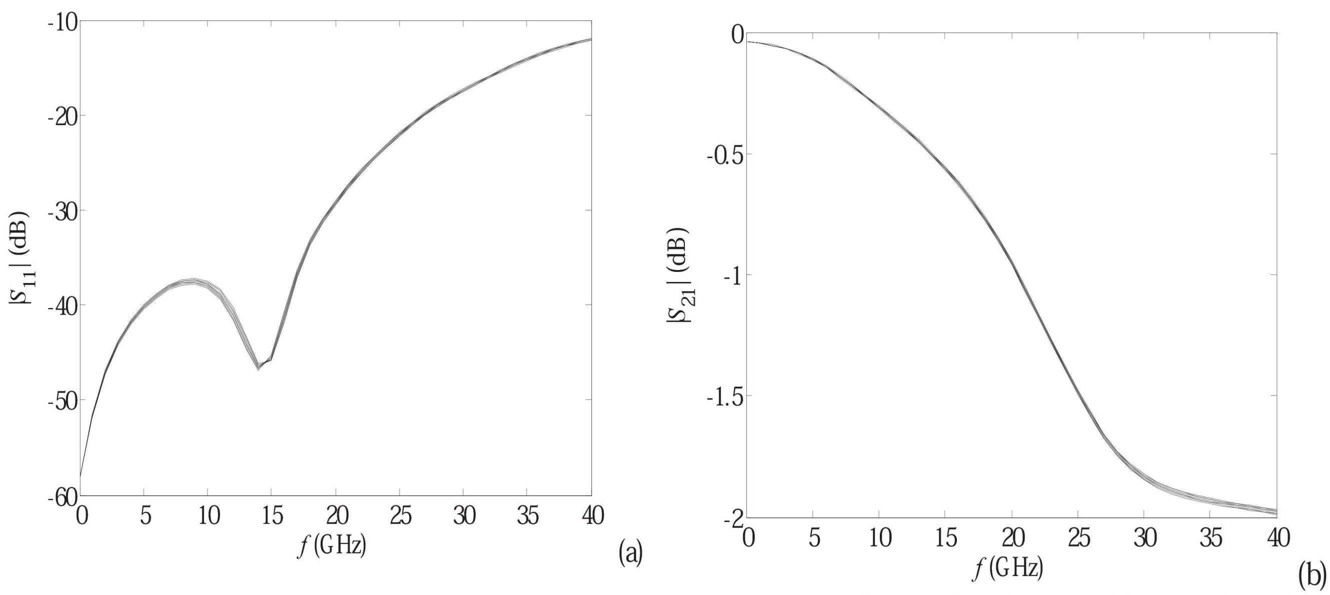

Figure 3. Maximum influence of L_b deviation: (a) Return loss: device (400, 20, 30, 150), (b) Insertion loss: device (1000, 220, 30, 20)

in Tables 1 and 2 for changes of L_b and W_b, respectively. The results show that the maximum deviation of the return loss is less than 0.73 dB for the L_b deviation and less than 2.4 dB for the W_b deviation. For the insertion loss, the deviations are less than 0.024 dB, which is significantly smaller comparing to the values of insertion loss. For illustration, in Figure 3 and 4, the plots corresponding to devices which exhibited the maximum deviations are given. Devices are denoted as (L_b, W_b, L_g, W_g), where dimensions are given in µm.

In order to examine what happens when both dimensions are changed simultaneously in the range +/- 3 µm, keeping the gap dimensions constant, the same eight sized bridges have been considered. The maximum deviations of the return and insertion losses are depicted in Table 3. The maximum deviation of the return loss is less than 3.1 dB and 0.032 dB for the insertion loss.

The frequency dependence of the return and insertion loss for the devices exhibiting max deviations is shown in Figure 5.

In all analysed cases, the insertion loss is most sensitive in frequency range from 25 to 40 GHz, where in the case of return loss the most sensitive frequency range varies with the bridge size. As expected, deviations are higher in the case of smaller sized devices.

Lb [μm]	*Wb* [μm]	*Lg* [μm]	*Wg* [μm]	Max$\lvert\Delta S_{11}\rvert$ [dB]	Max$\lvert\Delta S_{21}\rvert$ [dB]
200	20	30	70	1	0.0016
400	20	50	70	0.95	0.0092
300	70	90	70	0.83	0.0064
800	70	70	90	1.1	0.011
800	20	50	110	2.4	0.024
400	20	30	150	2.4	0.015
1000	220	30	20	0.24	0.017
600	120	70	110	1.3	0.0079

Table 2. Return and Insertion Loss Maximum Deviations -w_b Changes

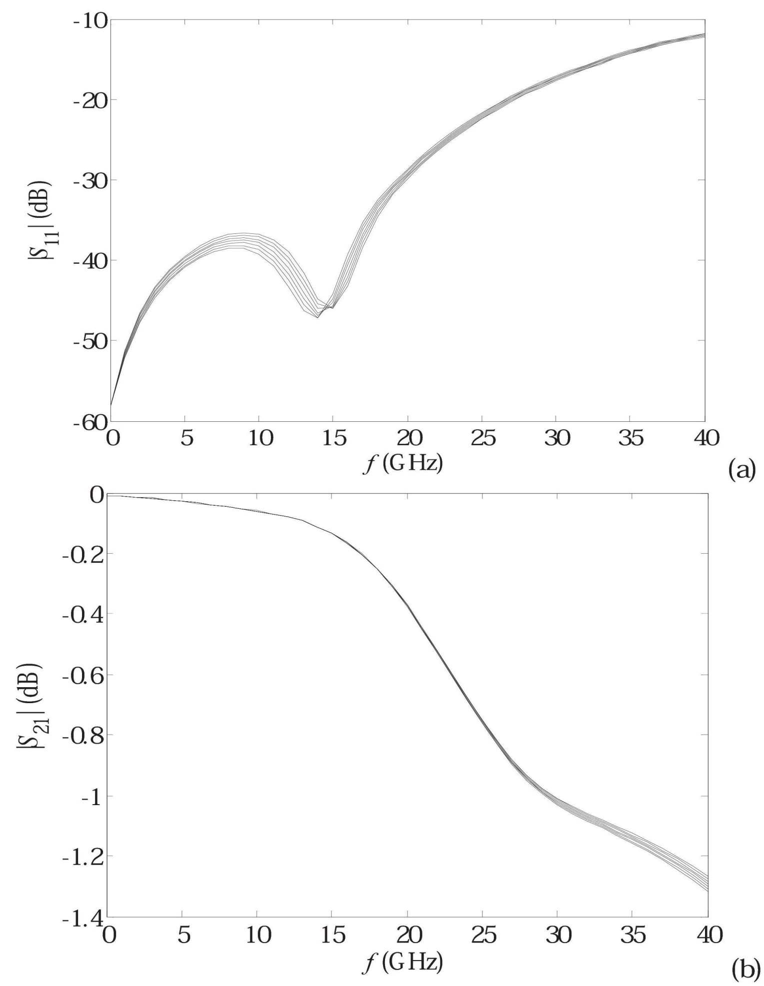

Figure 4. Maximum influence of W_b deviation: (a) Return loss: device (400, 20, 30, 150), (b) Insertion loss: device (800, 20, 50, 110).

Lb [μm]	Wb [μm]	Lg [μm]	Wg [μm]	Max$\lvert \Delta S_{11} \rvert$ [dB]	Max$\lvert \Delta S_{21} \rvert$ [dB]
200	20	30	70	1.5	0.0036
400	20	50	70	1.2	0.012
300	70	90	70	1.3	0.01
800	70	70	90	1.4	0.016
800	20	50	110	3	0.032
400	20	30	150	3.1	0.02
1000	220	30	20	0.31	0.029
600	120	70	110	1.9	0.014

Table 3. Return and Insertion Loss Maximum Deviations for Simultaneous Changes of the L_b and W_b Up To +/- 3 μM

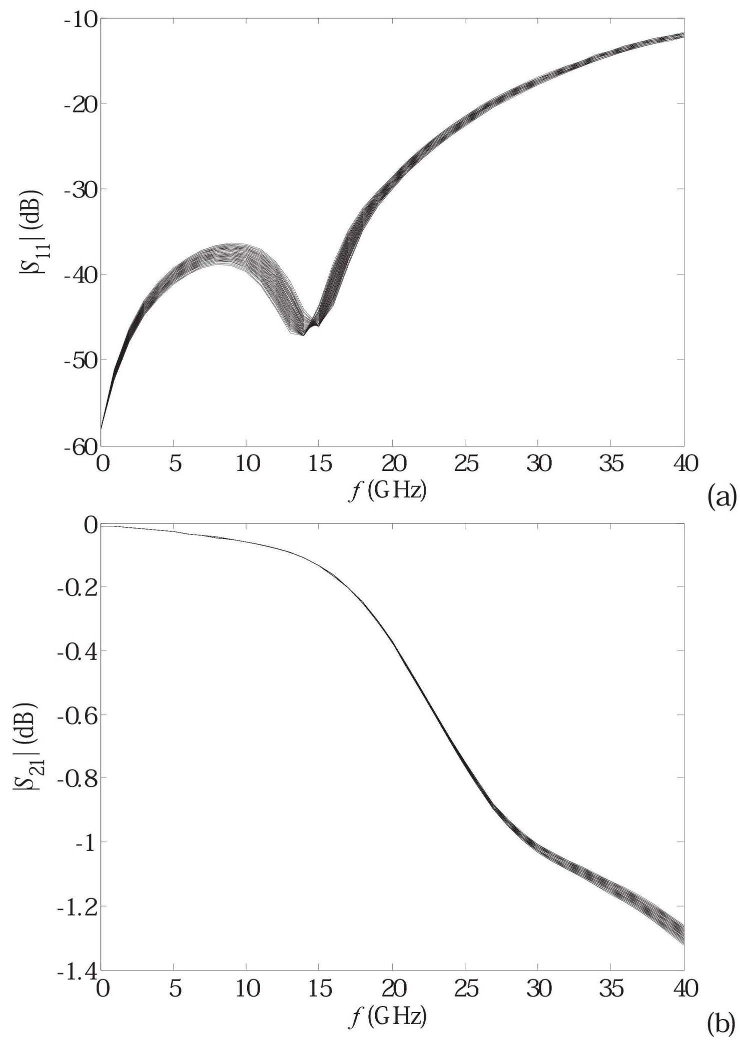

Figure 5. Maximum influence for simultaneously deviation of L_b and W_b: (a) Return loss - device (400, 20, 30, 150), (b) Insertion loss -device (800, 20, 50, 110)

5. Conclusion

In this paper an ANN model of ohmic series RF MEMS switch has been applied to obtain and analyze the switch return and insertion losses versus the switch bridge lateral dimensions. Since the model has very short response time, the analysis was performed in significantly shorter time that it would be needed in standard electromagnetic simulators. The influence of small changes of the bridge lateral dimensions caused by the fabrication process on the return and insertion losses has been studied. It is shown that the deviation of the switch lateral dimensions during fabrication process cause deviations of the return and insertion loss. However, in all considered case, the deviations of the insertion loss are almost negligible, while in the case of return loss the deviations can be up to around 3 dB. Therefore, taking care about the frequency range of interest, it is recommended to set the optimization goal for the return loss to be a few dB smaller that the requested value in order to ensure that, even with the deviation of the bridge dimensions during the fabrication, the return loss is below the desired value.

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References

[1] Rebeiz, G.M., Mems, R.F. (2003). Theory, Design, and Technology. Wiley: New York, USA.

[2] Vietzorreck, L. EM modeling of RF MEMS. Eurosime 7th International Conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro-Electronics and Micro- Systems. Como, Italy, pp. 1–4.

[3] Llamas, M.A., Girbau, D., Pausas, E., Pradell, L., Aouba, S., Villeneuve, C., Puyal, V., Pons, P., Plana, R., Colpo, S. & Giacomozzi, F. (2009) Capacitive and Resistive RF-MEMS switches 2.5D & 3D Electromagnetic and Circuit Modeling, Spanish Conference on Electron Devices, Vol. 2009. *California Department of Education*, p 451–454, 11-13 February 2009.

[4] Zhang, Q.J. & Gupta, K.C. (2000). Neural Networks for RF and Microwave Design. Artech House: Boston, USA.

[5] Kabir, H., Zhang, L., Yu, M., Aaen, P., Wood, J. & Zhang, Q.J. (2010) Smart modelling of microwave devices. IEEE Microwave Magazine, 11, 105–118 [DOI: 10.1109/MMM.2010.936079].

[6] Lee, Y., Filipovic, D.S. (2005). Combined Full-wave/ANN based Modelling of MEMS Switches for RF and Microwave Applications. Proceedings of the of IEEE Antennas and Propagation Society International Symposium, Vol. 1a. Washington, DC, USA, pp. 85–88.

[7] Gong, Y., Zhao, F., Xin, H., Lin, J., Bai, Q. (2009) Simulation and optimal design for RF MEMS cantilevered beam switch. Proceedings of the of International Conference on Future Computer and Communication (FCC '09). Wuhan, China, pp. 84–87.

[8] Milijic, M., Marinkovic, Z., Kim, T., Pronic-Rancic, O., Vietzorreck, L. & Markovic, V. Modeling and optimization of ohmic series RF MEMS switches by using neural networks 8th German Microwave Conference, GeMiC 2014, Aachen, March, Germany, 2014, pp. 1–4.

[9] DiNardo, S., Farinelli, P., Giacomozzi, F., Mannocchi, G., Marcelli, R., Margesin, B., Mezzanotte, P., Mulloni, V., Russer, P., Sorrentino, R., Vitulli, F. & Vietzorreck, L. (2006) Broadband RFMEMS based SPDT. Proceedings of the European Microwave Conference. Manchester, September 2006.

[10] CST Microwave STUDIO® (2012).