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An Analytic Approach for the Synthesis of RF MEMS Capacitive Switches

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***Abstract-* This paper is an extension of a previously published work concerning a novel approach for the design of RF MEMS switches in coplanar waveguide (CPW) configuration. The peculiarity of the method is to allow imposing the matching condition directly in analytic form. This result is obtained using the image parameter representation for the modeling of the device. Standard commercial simulators are used to develop a comparison among different switch configurations designed by means of the proposed modified approach. The numerical results confirm the validity of the method.**

I. INTRODUCTION

The modeling of RF MEMS switches has to be considered a powerful tool for obtaining equivalent circuits of building blocks to be used in complicated structures, where a full electromagnetic simulation is time consuming for the prediction of the electric performances of the MEMS configuration. In this framework, several results are available in literature about lumped or frequency scalable models of the single switch [1][2][3]. In a recent paper an innovative procedure for the synthesis of RF MEMS capacitive CPW switches has been proposed [4]. The basic idea was to use the image parameter representation of two port networks for the development of an analytic model for the switch in the "up" state. As discussed in [4], the "up" configuration is in many cases the most critical one from the point of view of the matching. Thus, to improve the performance of the component two uniform transmission lines with suitable values for the characteristic impedance and for the electric length are added at the input and output ports of the MEMS metallic membrane [5]. For the design of the so obtained structure the matching condition has been directly imposed on the image impedance [4]. In this paper this condition will be replaced by another one on the image phase. The goal is to extend the previously presented approach, obtaining a more general tool for the synthesis of RF MEMS switches. In order to demonstrate the effectiveness of the proposed method several devices, each of them employs two CPW bridges, will be designed. The circuital simulation of these structures, performed by means of a commercial software package, shows very good values for the reflection losses.

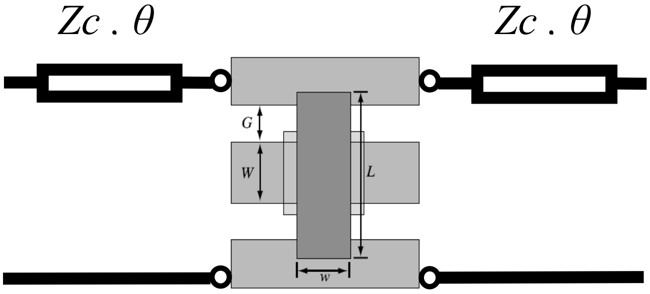

Fig. 1. The basic configuration of the MEMS CPW switch.

II. DESCRIPTION OF THE ANALYTIC APPROACH

The considered structure, composed by a thin suspended metallic CPW membrane and two matching uniform transmission lines [5], is shown in fig. 1. According with [4] and neglecting losses the CPW bridge can be accurately modeled by means of a T-network with two equal series connected X_s and a shunt connected X_p reactances. It is worth noting that in X_s and X_p are included all the geometrical, physical and technological data concerning the metallic membrane. The values of these reactances, that are frequency dependent, are provided by experimental measurements or by electromagnetic simulations of the bridge. Replacing the membrane with the T-model a symmetric equivalent circuit for the structure is obtained. To simplify the analysis only half of this circuit can be considered, obtaining the lossless network in fig. 2. According with [6] its image phase φ_{i1} is defined as:

$$e^{j\phi_{i1}} = \sqrt{AD} + \sqrt{BC} = \sqrt{AD} + j\sqrt{B'C'} \qquad (1)$$

where $jB' = B$, $jC' = C$ and A, B, C, D are the elements of the transmission matrix. Equation (1) gives:

$$\cos\phi_{i1} + j\sin\phi_{i1} = \sqrt{AD} + j\sqrt{B'C'} \qquad (2)$$

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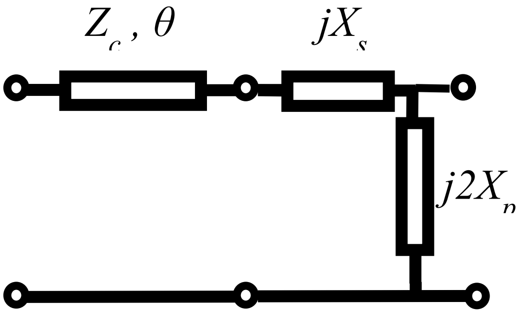

Fig. 2. Half network for the circuital model of the MEMS CPW bridge.

Defining a new variable U = $Z_c tg\theta$ the four real parameters A, B', C' and D can be easily computed as function of U, Z_c, X_s and X_p. Inserting the obtained A, B', C' and D in equation (2) we have:

$$tg\varphi_{i1} = \sqrt{\frac{B^{'}C^{'}}{AD}} = \sqrt{\frac{\left(X_S + U\right)\left(\frac{U}{Z_c^{\ 2}}\left(1+\frac{X_S}{2X_P}\right) - \frac{1}{2X_P}\right)}{\left(1+\frac{X_S}{2X_P}+\frac{U}{2X_P}\right)\left(1-\frac{X_S U}{Z_c^{\ 2}}\right)}} \qquad (3)$$

It can be demonstrated that if the image phase φ_i of a two port network verifies the following condition:

$$\varphi_i = \pi + k\pi \quad , \quad k = 0, 1, 2, ... \qquad (4)$$

the network is matched. It is well known [7] that the image phase of a device composed by N equal cascaded basic cells is $N\varphi_{i1}$, being φ_{i1} the image phase of the elementary cell. Therefore for the whole CPW bridge the image phase is $2\varphi_{i1}$. Sometimes it may not be practical to impose $\varphi_{i1} = \pi/2$ and for this reason it is not always possible to fulfill (4) with a single membrane component. In this case it is necessary to have, at least, a structure obtained by the series connection of two equal shunt connected MEMS capacitances. With this hypothesis the solution of (4) with k = 0 corresponds to a phase $\varphi_{i1} = \pi/4$. Inserting this φ_{i1} value in (3) a second degree equation in the unknown U is obtained. It is convenient to choose for the characteristic impedance Z_c a quite high value, suitable with CPW realization, in order to reduce the length of the transmission line sections, and therefore of the whole component.

III. DESIGN CONSIDERATIONS AND NUMERICAL SIMULATIONS

In this section numerical results for MEMS switches in the "up" state designed by means of the image phase approach are presented. As previously discussed the adopted topology is with two MEMS CPW bridges, thus assuming for φ_{i1} the value $\varphi_{i1} = \pi/4$.

In this case from (3) we have the following second degree equation:

$$-\frac{U^2}{Z_c^{\ 2}}\left[\left(1+\frac{Xs}{Xp}\right)\right]+U\left[\frac{1}{Xp}-\frac{2Xs}{Z_c^{\ 2}}\left(1+\frac{Xs}{2Xp}\right)\right]+\frac{Xs}{Xp}+1=0 \qquad (5)$$

It is obvious that this equation is different from that one discussed in [4] (eq. (7)) obtained imposing the matching condition on the image impedance. It is worth noting that for the physical feasibility of the structure the variable U must be real and positive. If this condition cannot be fulfilled using the design procedure presented in [4], the method here proposed provides an alternative solution for the design of the switch.

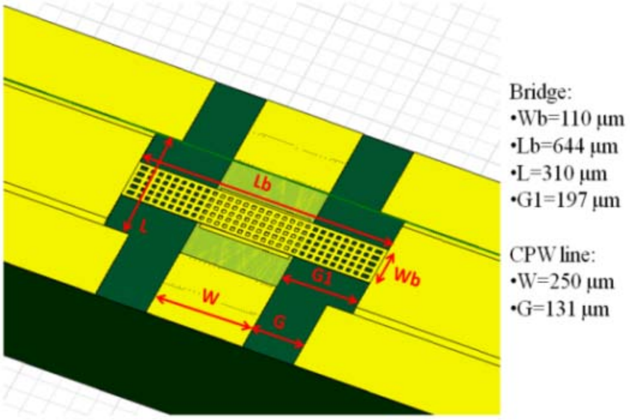

Fig. 3. The single RF MEMS CPW switch, with dimensions of the metallic membrane, simulated for validating the proposed design procedure.

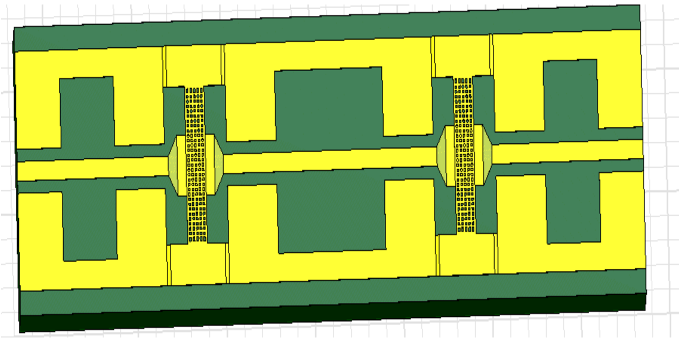

Fig. 4. The layout of the MEMS CPW configuration with two switches.

The first step to solve (5) is to have the X_s and X_p reactances characterizing the equivalent circuit of the metallic CPW membrane shown in Fig. 3. To this end electromagnetic simulations of the bridge have been performed by means of the commercial 3D software package HFSS. A working frequency of 30 GHz has been chosen. Three different values for the characteristic impedance Z_c have been considered (Z_c =

40Ω, 50Ω, 90Ω). The associated electric lengths θ are respectively θ = 34.9°, 33.1° and 26.7°. The layout of the switch is shown in Fig. 4. The behaviors of the return loss and of the insertion loss as function of the frequency are plotted in Fig. 5 and 6. More in detail, the black curve (double triangle) is for a single basic coplanar bridge, the red one (triangle) is for a component with Z_c = 40Ω, the blue one (square) is for Z_c = 50Ω and the green one (diamond) is for Z_c = 90Ω. The numerical results confirm the validity of the novel design method.

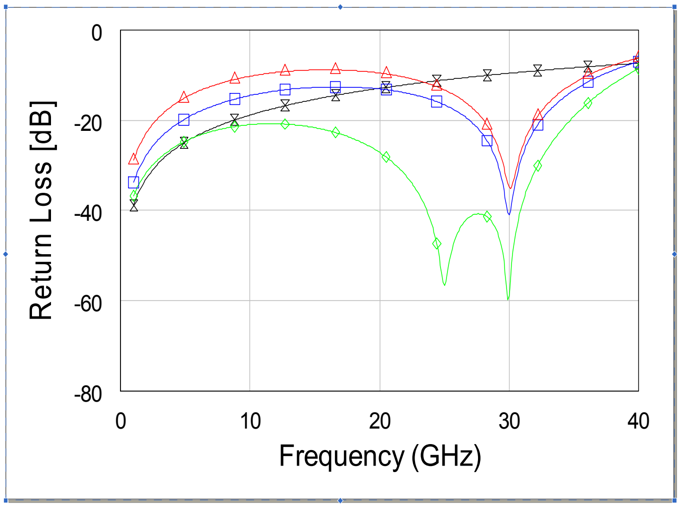

Fig. 5. Behavior of the Return Loss as function of the frequency for a single basic coplanar bridge (black curve, double triangle) and for three switches having different values of the characteristic impedance for the transmission line sections (red (triangle) 40Ω, blue (square) 50Ω, green (diamond) 90Ω).

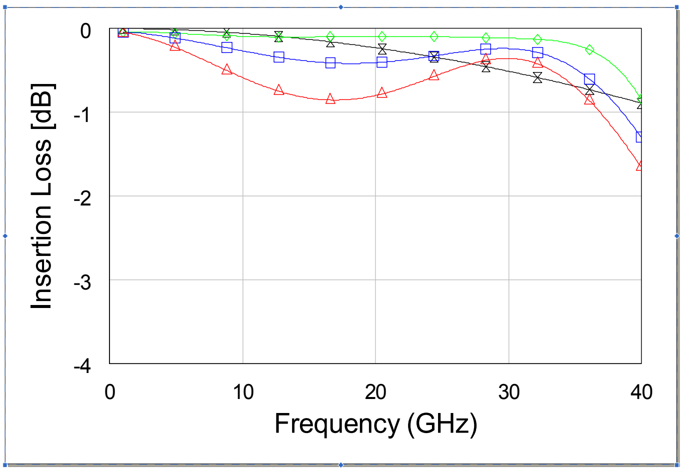

Fig. 6. Behavior of the Insertion Loss as function of the frequency for a single basic coplanar bridge (black curve, double triangle) and for three switches having different values of the characteristic impedance for the transmission line sections (red (triangle) 40Ω, blue (square) 50Ω, green (diamond) 90Ω).

Moreover the simulations show that increasing the characteristic impedance a remarkable improvement of the electric performance of the switch can be obtained. In particular, the component with Z_c = 90Ω exhibits a very wideband matched behavior.

It is worth noting that two-bridge MEMS switches were firstly presented in [8] and [9]. In comparison with those previous works, in this paper a different design approach is proposed and a more general electric model for the CPW membrane device is adopted.

IV. CONLUSIONS

This paper has provided a theory, based on the image parameter characterization of two port networks, for the synthesis of RF MEMS shunt connected capacitive switches. The image phase concept has been used to impose the matching condition in the "up" state of the device, extending the results previously published in [4]. As described, the method has been employed for the design of switches composed by two MEMS CPW bridges. No technological complication in the manufacturing process has to be considered for the proposed structure, as standard RF MEMS technology is involved. The structures exhibit very good electric performance, in particular in terms of reflection loss. It is also worth noting the value of the insertion loss, which renders the simple configuration designed with the proposed method suitable of very wideband performances, exhibiting predicted losses lower with respect to the structure made by one switch only, thus confirming the good electrical matching of the full structure.

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