MEMS SWITCH DESIGN AND ANALYSIS BASED ON ELECTROMAGNETIC SIMULATOR

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Abstract: The paper presents a design procedure for a distributed switch consisting of an array of MEMSs (Micro-Electro-Mechanical-Systems) loading a CPW (CoPlanar Waveguide). The MEMS equivalent circuit is developed from the scattering parameters obtained by using an electromagnetic simulator and then this equivalent circuit is used to design the switch. The designed switch consisting of 1, 2 and 3 MEMSs are finally analyzed using again the electromagnetic simulator. The insertion losses in the all cases are smaller than 0.11 dB up to the maximum operating frequency of 35 GHz.

Keywords: MEMS, microwave switch, electromagnetic simulation

1. INTRODUCTION

In the last years, MEMS (Micro-Electro-Mechanical-System) devices behave as a very attractive solution to realize low losses switches, phase shifters and tunable filters, monolithically integrated on high resistivity semiconductor substrate [1], [2], [3], [4]. The lossless characteristic of these circuits is due to the very low MEMS series resistance (x 0.1 Ω), compare to the PIN or Schottky diode series resistances. Usually, the MEMS switches consist of a number of MEMSs loading a CPW (CoPlanar Waveguide). The distributed character of these circuits leads to a very large operating frequency bandwidth. If the switch analysis is performed by using an electromagnetic simulator, it may be possible to take into consideration a realistic structure, including the finite material resistivity, but the circuit must be design firstly on its equivalent circuit.

In this paper, a straightforward design procedure, using very simple formulas developed from the switch lumped equivalent circuit and an electromagnetic simulator (IE3D Zeland) for the MEMS analysis, is applied to design the switch. An equivalent circuit for the MEMS devices is developed from the electromagnetic analysis of a geometrical configuration which approaches the MEMS technological aspects. Then the switch performances are obtained by the circuit analysis using again the IE3D simulator.

2. MEMS SWITCH DESIGN

The switch is a distributed circuit having a number of MEMS, periodically loading a CPW transmission line. Therefore, the circuit consists of a number n of identical cells, each one having the schematically representation given in Fig. 1. In this figure, l_{CPW} is the half length of the CPW which connect two consecutive MEMSs, R_s, L_s and C_s are the MEMS equivalent series resistance, inductance and capacitance, respectively. Also, R_{sb} and L_{sb} are the equivalent resistance and inductance from the T – MEMS equivalent circuit.

In this paper, the circuit is designed for a silicon substrate having the resistivity equal to 6 KΩcm, covered by a deposited SiO_2 layer of thickness equal to 1 μm. For this substrate, the characteristic impedance of the CPW transmission lines must be chosen such as to minimize the attenuation constant, α (so, the insertion loss of the switch will be also minimized), as well as the electrical length, θ. The dependence of $\alpha\theta$, versus the CPW characteristic impedance, Z_c, assuming that the distance between the CPW ground planes is equal to 300 μm, shows that a CPW characteristic impedance, $Z_{c,CPW}$ of 80 Ω is a very good compromise for a very low insertion loss as well as for a short CPW length.

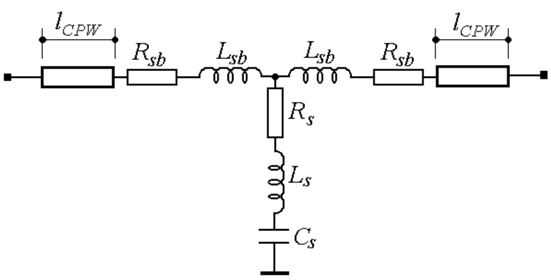

Fig. 1:

A switch cell schematically representation.

The circuit is designed when the MEMSs operate into the *off* – state, imposing the Bragg frequency, f_B and the input/output impedance, Z_c = 50 Ω, by using the following formulas (written for the lossless case and L_s = 0):

$$f_B = \frac{1}{\pi\sqrt{2(L_{sb}+L_{CPW})(C_s+2C_{CPW})}} \;;\; Z_c = \sqrt{\frac{2(L_{sb}+L_{CPW})}{C_s+2C_{CPW}}} \;;\; Z_{c,CPW} = \sqrt{\frac{L_{CPW}}{C_{CPW}}} \qquad (1)$$

where: L_{CPW} and C_{CPW} are the CPW equivalent inductance and capacitance having the length l_{CPW}` (see Fig. 1). Also, it is taking into account that the CPW electrical length (corresponding to l_{CPW}) is $\theta = 2\pi f_{\max}\sqrt{L_{CPW}C_{CPW}}$, where $f_{\max}$ is the maximum operating frequency of the switch. If $f_{\max}$ = 35 GHz, for $f_b = 3f_{\max}$ (the switch must be also less dispersive up to the maximum operating frequency), neglecting L_{sb} at this step, they are obtained the MEMS capacitance in the *off* – state of 37.04 fF and θ=12 deg. (l_{CPW}=110 μm).

The MEMS cross section and the MEMS top view are shown in Fig. 2. For W=150 μm, w= 60 μm, g= 2.5 μm, l_p= 100 μm, t= 1 μm (gold), t_d = 0.3 μm (Si_3N_4), Δl = 5 μm, w_{CPW} = 50 μm and s_{CPW} = 125 μm, this structure has been numerically analyzed by using the IE3D simulator. The [S] parameters obtained after the analysis have been used to find the elements values for the T – MEMS equivalent circuit: R_{sb}=0.03-0.07Ω, L_{sb} = 15.5pH, R_s = 0.2-0.3Ω and C_s=38fF – including the effect of L_s, for frequencies between 6 GHz and 25GHz. These results for C_s and L_{sb} have been used to compute again L_{CPW} and C_{CPW} using (1) and finally l_{CPW} = 76 μm has been obtained. For these values, f_B = 117 GHz $> 3 f_{\max}$.

3. RESULTS OF MEMS SWITCH ANALYSIS

Using l_{CPW} = 76 μm, the MEMS geometry and the substrate date mentioned above, the circuit has been analyzed by using the IE3D simulator, for a number of cells, n, equals to 1, 2 and 3. In Fig. 3, they are shown the dependence of the insertion loss ($IL[\text{dB}] = -20\lg(S_{21})$) and the return loss, ($RL[\text{dB}] = -20\lg(S_{11})$), versus the frequency. As it was expected, IL increases as the frequency increases, as well as the number of cells increases. At the maximum operating frequency, $f_{\max}$ = 35 GHz, IL is less than 0.11 dB, this meaning that the switches realized by using MEMSs are lossless compared to that realized by using PIN diodes. Also, RL has a very good value at $f_{\max}$, RL ~20 dB for n=3. It has been also seen that when the MEMSs operate in the *on* – state (the equivalent capacitance is ~2pF), the switch isolation is higher than 30 dB, at $f_{\max}$.

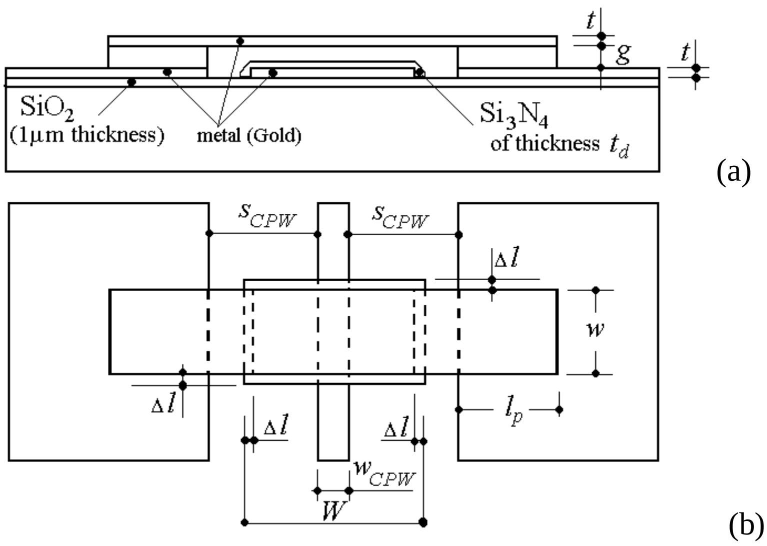

Fig. 2: The cross section (a) and the top view (b) for the MEMS used in this paper.

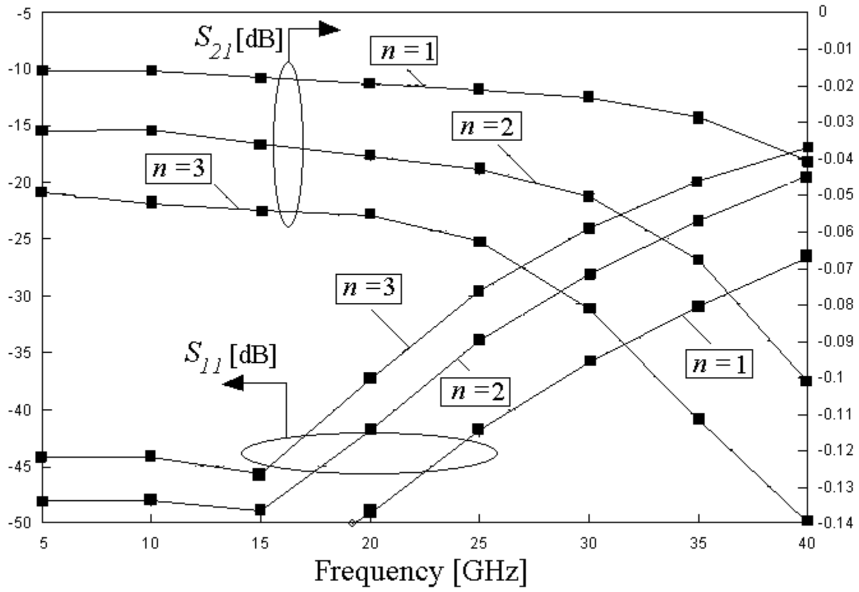

Fig. 3: S_{21} and S_{11} versus the frequency, for the MEMS switch designed in this paper.

In Fig. 4 it is shown the variation of bridge position versus the time, for different values of voltages applied on the bridge, obtained by using non-commercial software [5]. When no voltage is applied on the bridge, then the bridge high is 2.8 μm above the CPW central line (MEMSs are in the *off* – state). If the applied voltage is high enough, the bridge is in contact with the dielectric layer deposited on the CPW central line of width W, then the bridge high is 0.3 μm above the CPW central line (in this case the MEMSs are in the *on* – state). As it observed from Fig. 4, the switching time between the two states decreases as the voltage increases (see the curves for 40-70 V), while for 30 V, the *on* – state could be never attained. For applied voltage of 70V, a switching time of about 8 μs could be obtained.

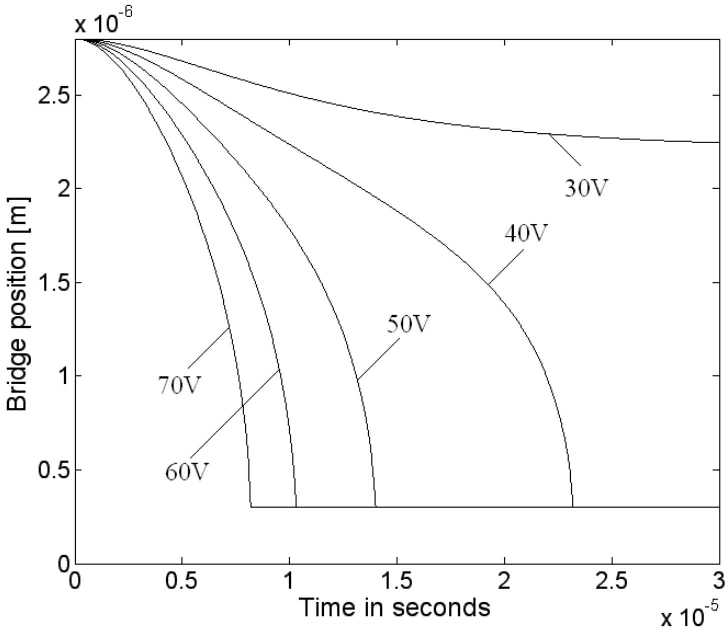

Fig. 4:

The bridge position versus the time, for different voltages applied on the bridge.

4. CONCLUSIONS

In this paper a microwave switch based on MEMS devices has been designed and analyzed by using an electromagnetic simulator (IE3D Zeeland). The design procedure take into consideration the MEMS equivalent circuit, which has been developed applying a parameters extraction method from the scattering parameters obtained by MEMS analysis using IE3D simulator. The MEMS configuration analyzed in this paper is a more realistic one, taking into account the technological flow aspects. The switch has been numerically analyzed for 1, 2 and 3 cells. The insertion and return losses in the all cases are smaller than 0.11 dB and higher than ~20 dB, respectively. These performances recommend the MEMS as a more attractive solution to realize microwave switch, especially in the millimeter-wave frequency bandwidth. For the designed switch, the switching time is ~8 μs, when the applied voltage on the bridge is 70V.

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