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RF MEMS in-line Series switch for S band Application

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ABSTRACT

This paper proposed an RF (Radio Frequency) MEMS (Micro Electro Mechanical systems) cantilever beam switch for S band application. The switch shows good RF parameters over the range of (2-6) GHz along with low actuation voltage. Although RF MEMS switches are very good counterpart for solid state switches but its high actuation voltage and high switching time is matter of concern. So in this paper, we generally concentrates on reducing the high actuation voltage for that a novel design of an RF MEMS in line series cantilever beam switch was proposed and designed using the software Intellisuite 8.7v for electromechanical analysis and by EM software for RF analysis. From simulation, we get actuation voltage of (2.5V) and insertion loss of -0.2683 dB at 2.55 GHz with return loss of -16.3720 dB at 2.20 GHz and isolation loss of -29.1203 dB at 2.40 GHz.

I. INTRODUCTION

Now-a-days Radio Frequency (RF) Microelectromechanical (MEMS) switches have gained lots of attention of researchers and scientist from the different parts of the world. The allurement of these switches is that it that it offers RF performance similar to that of relay based switches and miniaturized in size and cost as similar to FET based switches. These switches show low power consumption, good return loss, low insertion loss, wider temperature range, high isolation loss, very good linearity, etc [1]. But area of concern for these switches are its high actuation voltage, high switching time, reliability, lower power handling capacity and packaging. So lots of research is going out throughout the world that how to overcome these challenges and make these switches available for the commercial purposes. In 2001, Xiaodong, Lumtao, et al. designed a compact RF MEMS switch for S band application whose actuation voltage was 25 V with insertion loss of -0.5 dB and isolation loss of -21 dB at 3 GHz [2]. In 2012, Sinha, Bansal, and Rangra proposed compact T-type switch for space application whose actuation voltage was 7.5 V with insertion loss of -0.48 dB and isolation loss of -22.12 dB up to 25 GHz [3]. In 2014, Angira, Sundaram, and Rangra designed interdigitated shunt capacitive switch for X and K band application whose insertion loss is -0.11 dB at 25 GHz and isolation loss of -40.7 dB at 21.4 GHz with an actuation voltage of 12.25 V [4]. In 2015, Ziaei, Bansropun, Martins and Baillif designed a fast high power capacitive switch for X band application whose insertion loss is -0.1 dB and isolation loss of -30 dB at 10 GHz with a high pull in voltage of 60 V [5]. In 2016, El massry, Medhat and Mostafa proposed a mobile compatible switch whose actuation voltage is 3.3 V with insertion loss of -0.05 dB and isolation loss of -21 dB at 6 GHz [6]. So this paper emphasis on the analysis and simulation of a novel RF MEMS switch design to lower the actuation voltage along with good RF parameters.

II. PROPOSED DESIGN

An ultra low voltage switch is designed and simulated in FEM software Intellisuite 8.7v, where displacement and mises stress are calculated under the influence of electrostatic actuation. Table I shows the design dimensions of the switch and Figure 1 and Figure 2 shows the top view and side view of the switch. The material used for the switch is aluminium (Al).

TABLE I

Dimensions of parameters

Parameters	Proposed design
Length of beam(μm)	210
Breadth of beam(μm)	70
Thickness of beam (μm)	1
Air gap (μm)	1.5

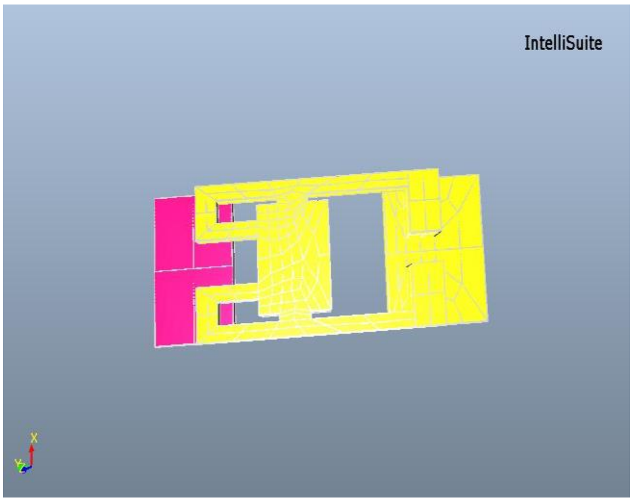

Figure 1. Top view of switch

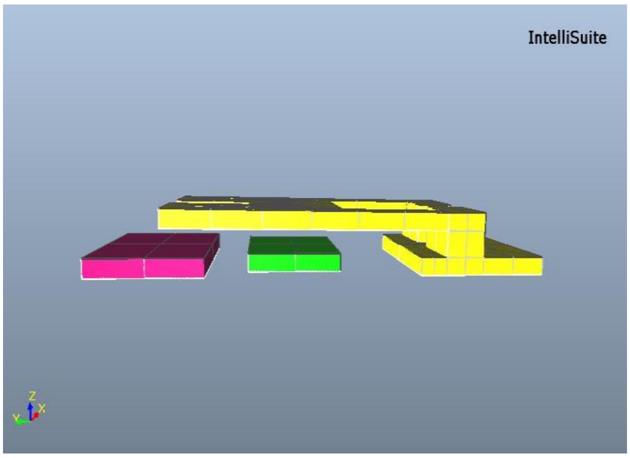

Figure 2. Side View Of Switch

The schematic representation of the switch on the Co Planar Waveguide (CPW) is shown in Figure 3

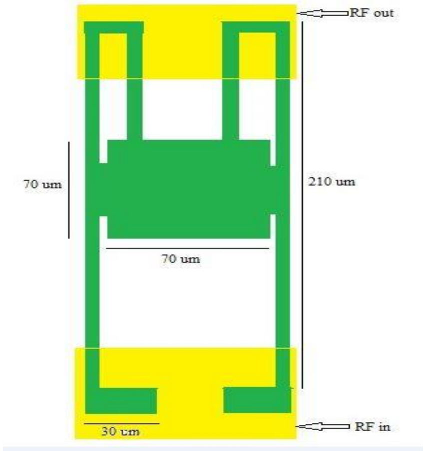

Figure 3. Schematic representation of the switch

III. MATHEMATICAL MODELING

The mathematical modelling of the RF MEMS switches has two categories: (1) Electromechanical analysis, (2) Electromagnetic analysis.

A. Electromechanical Analysis

In this analysis we generally focus on the mechanical parameters of the cantilever beam such as spring constant, Young's modulus, electrostatic force between the beam and lower electrode, actuation voltage, switching time etc,. Consider a cantilever whose one end is fixed and other is hanging freely over the t- line as shown below in Figure 4

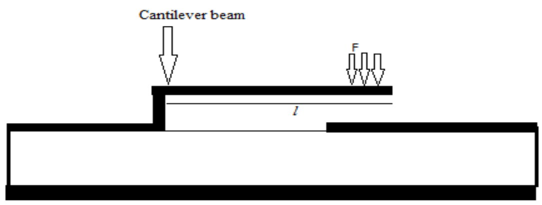

Figure 4. A simple cantilever beam

When a force F is applied at the free end of the beam it gets deflected by Δ x and is given by [7]

$$F = K \Delta x \tag{1}$$

Where K represents the spring constant of the beam and is given by [7]

$$K = 2\,Ew\left(\frac{t}{l}\right)^3 \frac{1-\frac{x}{l}}{3-4\left(\frac{x}{l}\right)^3+\left(\frac{x}{l}\right)^4} \tag{2}$$

where E represents beam Young's modulus. The critical stress of the beam is defined as the maximum amount of compressive stress before yielding or buckling beam occurs and is given by [7]

$$\sigma_{cr} = \frac{\pi^2 E t^2}{3l^2(1-v)} \tag{3}$$

Where l is beam length, t is beam thickness and v is material Poisson's ratio. The concept behind electrostatic actuation is same as the electrostatic force between the two parallel plates of capacitor. The capacitance between parallel plates is given by [8]

$$C = \frac{\varepsilon W w V^2}{g} \tag{4}$$

Where g represents beam height and ε represents the permittivity of the medium. The electrostatic force is given by [9]

$$F_e = -\frac{\varepsilon W w V^2}{2g} \tag{5}$$

Where V represents the applied bias voltage between the lower electrode and the beam and F_e is electrostatic force. So after equating linear spring force with square electrostatic force and solve for V we get actuation voltage or pull-in voltage [10]

$$V_p = V\left(\frac{2g_0}{3}\right) = \sqrt{\frac{8K\,g_0^3}{27\,\varepsilon W w}} \tag{6}$$

Where V_p represents "pull-in voltage" and g_0 is zero bias height above the electrode. The frequency of the beam is given by [11]

$$w_0 = \sqrt{\frac{K}{m}} \tag{7}$$

where m is mass of cantilever beam. The quality factor (Q) is very important parameter for determining the switching time of the switch. From experiments it is found that if $Q \le 0.5$, then switching time is slow and if $Q \ge 2$, then settling time is longer after release. So for better overall performance Q = 1, and switching time is given by [11]

$$t_s = 3.67\frac{V_p}{V_s w_0} \quad \text{for } V_s \ge 1.3\,V_p \tag{8}$$

B. Electromagnetic analysis

In this we generally focus on the S parameters of the switch such as insertion loss, return loss, isolation loss etc,. RF MEMS switches are highly linear and passive two port device. When switch is in upstate (or in OFF condition) S_{21} gives isolation of the switch from that we can find C_s (series capacitance between transmission line and beam) and C_p (parasitic capacitance), and C_u is given by [12]

$$C_u = C_s + C_p \tag{9}$$

When the switch is in downstate (or in ON condition) S_{21} gives insertion loss and S_{11} gives return loss of the switch. In down state it behaves as series resistance and is given by [12]

$$Rs = R_c + 2\,R_{sl} + R_l \qquad (10)$$

Where R_c is contact resistance, R_l is bridge resistance and R_{sl} is t-line resistance. The isolation loss of the switch is given by [12]

$$S_{21} = \frac{2\,jwC_u Z_0}{1 + 2\,jwC_u Z_0} \qquad (11)$$

IV. RESULTS AND DISCUSSION

A. Electromechanical Results

The switch is designed and simulated in Intellisuite 8.7v software. The displacement of the switch is 1.5822 μm shown in Figure 5 and mises stress of the switch is 7.05611 Mpa shown in Figure 6 which is less than the critical stress which is 8.2671 Mpa (3) and the vertical displacement of the switch with applied voltage gives pull-in voltage of ~ 2.5 V as shown below in Figure 7

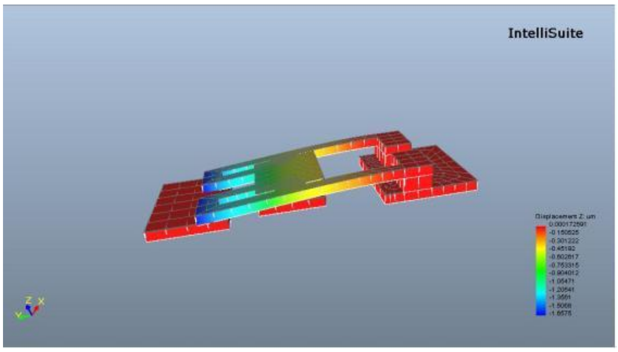

Figure 5. Switch Displacement

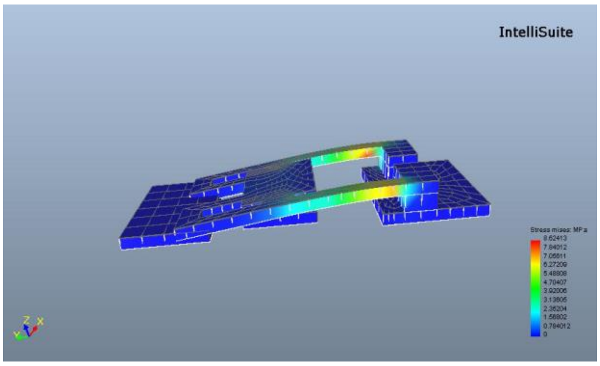

Figure 6. Switch Mises Stress

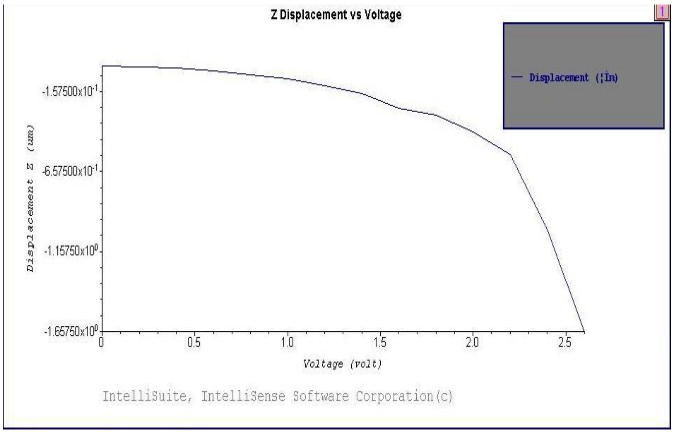

Figure 7. Voltage vs. beam vertical displacement

B. Electromagnetic results

For electromagnetic analysis the switch is designed and simulated in EM software. When the switch is in OFF condition (i.e., it will not allow power to transfer from port 1 to port 2) in that case S_{21} gives isolation loss and it is -29.1203 dB at 2.40 GHz as shown in Figure 8

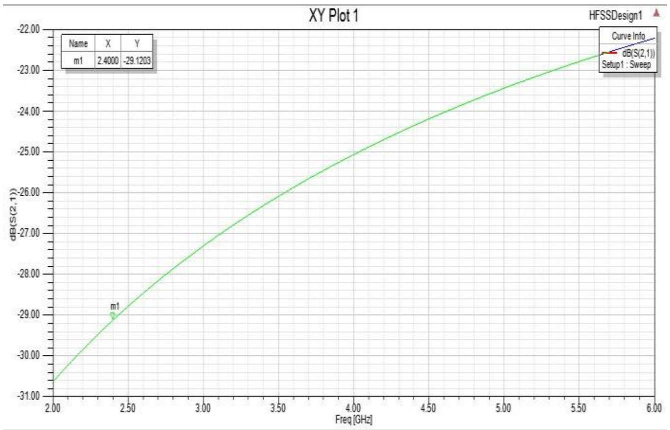

Figure 8. Isolation loss (S_{21}) in OFF condition

When the switch is in ON condition S_{21} gives insertion loss and it is -0.2683 dB at 2.55 GHz and S_{11} gives return loss of the switch and it is -16.3720 dB at 2.20 GHz as shown in Figure 9 and Figure 10.

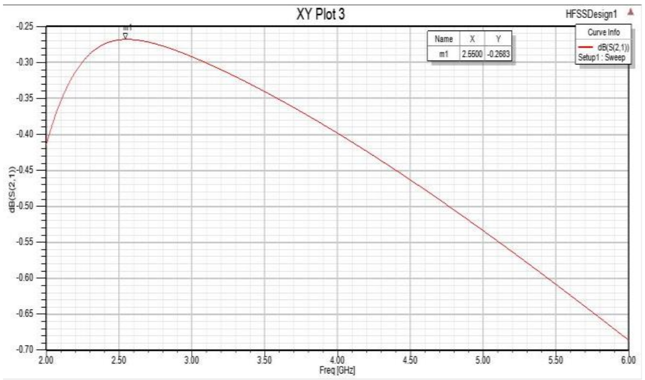

Figure 9. Insertion loss (S_{21}) in ON condition

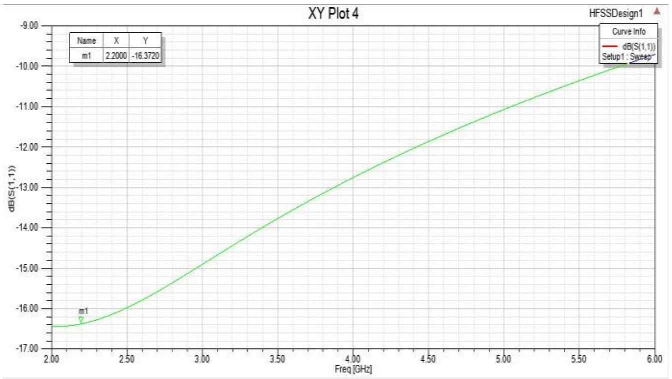

Figure 10. Return loss (S_{11}) in ON condition

TABLE II Results of proposed design

Parameters	Proposed design
Displacement (μm)	1.5822
Mises stress (MPa)	7.05611
Pull-in Voltage (V)	2.5
Isolation Loss (dB)	-29.1203 at 2.40 GHz
Insertion Loss (dB)	-0.2683 at 2.55 GHz
Return Loss (dB)	-16.3720 at 2.20 GHz

V. CONCLUSION

A novel switch was designed and simulated by software Intellisuite 8.7v which shows a low pull-in voltage of ~ 2.5 V which is well matched with today's IC technology and the electromagnetic analysis is done by EM software which shows good S-parameters such as insertion loss of -0.2683 dB at 2.55 GHz, return loss of -16.3720 dB at 2.20 GHz and isolation loss of -29.1203 dB at 2.40 GHz. In future we can work on some issues related to bandwidth, contact resistance and on the material analysis so as to get better overall performance of the switch.

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