Design and Analysis of Capacitive RFMEMS Switch with Ladder Beam Structure

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***Abstract*— In this paper a low pull-in voltage capacitive switch with ladder shaped beam structure is designed and stimulated. The switch is a freely moving cantilever beam over a coplanar waveguide (CPW). The Ladder shaped beam structure is used here to improve the isolation, insertion loss and to achieve a low pull-in voltage. Actuation is achieved by using electrostatic mechanism because of its low power consumption, small size and less switching time. Simulation using intellisuite software shows that the pull-in voltage of the switch is 7.5V and the stress mises is about 11.33 MPa. HFSS stimulation reveals that the insertion loss is in the range of -0.63 dB and the up-state return loss is better than -15 dB in the frequency range 10 to 50 GHz. The Switch offers a down-state isolation of -42.66 dB at 40 GHZ.**

Keywords—RF-MEMS; Switch; pull-in voltage; electrostatic actuation; Coplanar Waveguide.

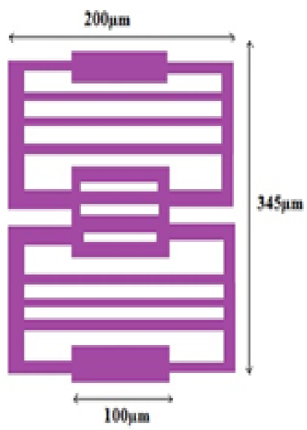
I. INTRODUCTION

RF MEMS switches have become an important part of switching devices operating at high frequencies because of low power consumption, very high isolation, very low insertion loss than PIN diode or FET switches as described by [1] But the disadvantage of these RF MEMS switches is that they require a high actuation voltage and has a low power handling capability with low operating speed. The design is proposed to achieve a low actuation voltage with increased power handling capability. It also gives a very high isolation with low insertion loss.

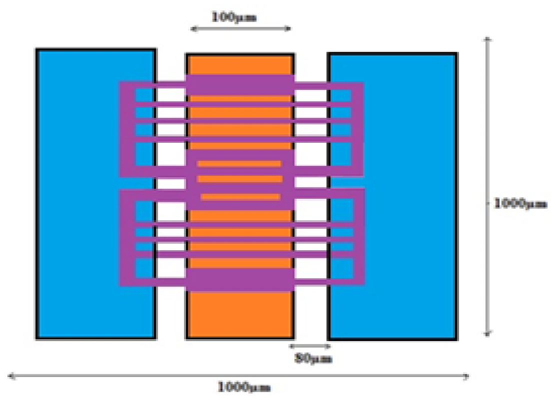
In this paper the performance of the capacitive switch with splitted beam structure is analyzed and its simulation results have been discussed. The design of the switch was done using a splitted beam structure where both end of the switch is fixed to the anchor. The advantage of having a splitted beam structure is that it reduces the spring constant without increasing the size and weight of the switch. In section II the design of the proposed switch and its specifications is given in detail. Section III illustrates the fabrication process involved in the design of the proposed switch. Section IV discusses the stimulated results.

II. DESCRIPTIPON OF THE RF MEMS SWITCH

The switch is fixed to the anchor with a meander beam on both sides over the coplanar waveguide. The proposed beam structure is shown in Fig.1. This ladder shaped beam structure provides a lower spring constant without increasing the size and weight of the device. The spring constant K can be determined by combining the spring constant of each part of the beam. Spring constant of the meandered beam is given by equation (1) and described by [2]



. (i) Geometry of the ladder Beam



(ii) Front view

Fig.1 Proposed Structure of the Switch with Ladder beam

$$k = \left[\frac{8S^3 + 2LS^3}{3EI_x} + \frac{sL(3l+15S)}{3GJ} - \frac{S^2\left(\frac{2S}{EI}+\frac{3L}{GJ}\right)^2}{2\left[\frac{S}{EI_x}+\frac{L}{GJ}\right]} - \frac{L^2}{2}\left(\frac{S}{GJ}+\frac{L}{EI_x}\right)\right] \quad (1)$$

Where L is the secondary meander length, S is the primary meander length; E is the young's modulus of the material, G is the sheer modulus and is given by G=E/2(1+v) where V is the Poisson's ratio of the material of switch, I_x is the moment of inertia along X-axis and is given by $I_x = wt^3/12$, were W is the thickness of the beam, t is the switch thickness. J is torsion constant and is given by $J=0.413I_p$, where $I_p=I_x+I_z$ and $I_z = tw^3/12$.

Non-meander spring constant as explained by [5] is given by equation (2).

The total spring constant can be calculated by combining these spring constant equations. The dimensions of the proposed switch are given in table 1. The switch is made on high resistive silicon substrate. CPW and the beam are made of highly conductive metal aluminium.

The switch is actuated when a voltage is applied between the beam and the signal line Pull-in voltage can be reduced by minimizing spring constant K, air gap and increasing the actuation area The pull-in voltage can be calculated using the equation (2).

$$V_p = \sqrt{\frac{8kz_0^3}{27A\varepsilon_0}} \quad (2)$$

Where k is the spring constant of the beam, z_0 is the initial gap height between the beam and the signal line, $\varepsilon_0$is the permittivity of air, 8.854×10^{-12} F/m and A is the area of the beam namely the width (*w*) and the length (*l*) *w* × *l*.

Table 1: Parameters and Dimensions of the proposed switch

Sl.No.	*Parameters*	*Dimensions*
1	Beam Thickness	1
2	Beam Length	345
3	Beam Width	200
4	Beam Height	350
5	Gap Height	1
6	Area	100
7	Electrode Thickness	1
8	Dielectric Thickness	0.5
9	CPW	100/80/100

III. SIMULATED RESULTS AND DISCUSSIONS

A. *DC simulations*

DC simulation is done using intellisuite software. Pull-in voltage, charge, capacitance, electrostatic force for the switch is studied under DC simulations.

Fig.2 shows the simulated results of the pull-in voltage with displacement and the applied voltage. The actuation voltage was applied in the range of 0 to 12V. Simulated result shows that the switch was actuated at a pull-in voltage of about 7.5 V. The displacement and the stress analysis of the switch with the applied voltage are shown in fig.3 and fig.4. The switch had a displacement of 0.24µm and the maximum stress was 11.33 MPa.

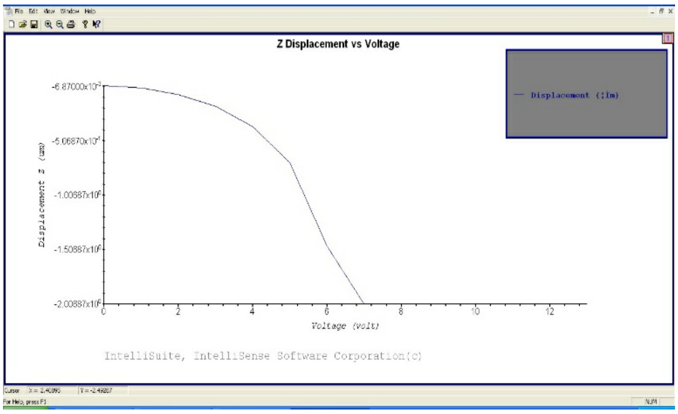


Fig.2 Proposed Structure of the Switch with Ladder beam

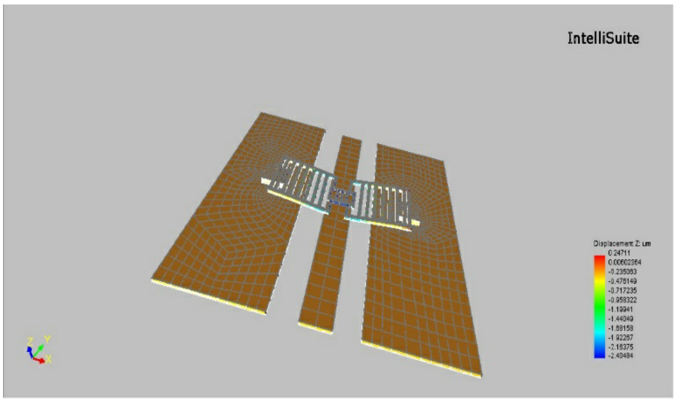


Fig.3 Displacement analysis

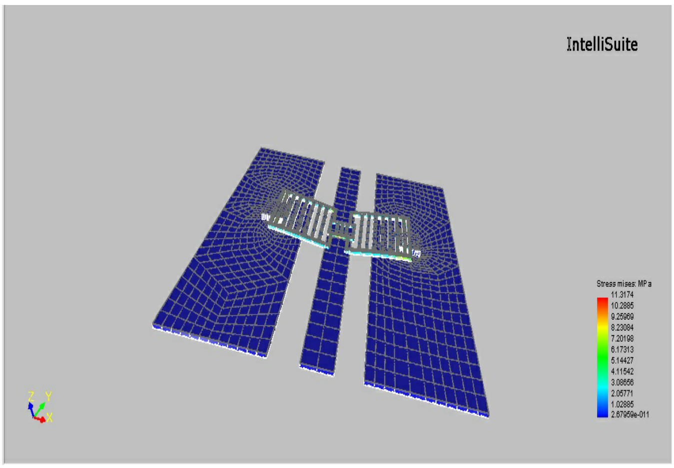


Fig.4 Stress analysis

B. *RF simulations*

RF simulations are done using HFSS software.

Insertion loss S_{11} and isolation S_{21} are two most important parameters that signify performance of switch. Figure 3 shows the design of switch in HFSS. Up-state capacitance and down-state capacitance solely determines the value of S_{11} and S_{21}. Fig.6 shows the insertion loss S_{21} in the ON state which is observed to be -0.63 dB, at a frequency range from 10 to 50 GHz. The isolation (S_{21}) is measured when the switch is in OFF state and is observed to be -42.66 dB from 5 to 40 GHz. The reflection co-efficient (S_{11}) parameter is observed to be -15.44 dB from 10 to 50 GHz.

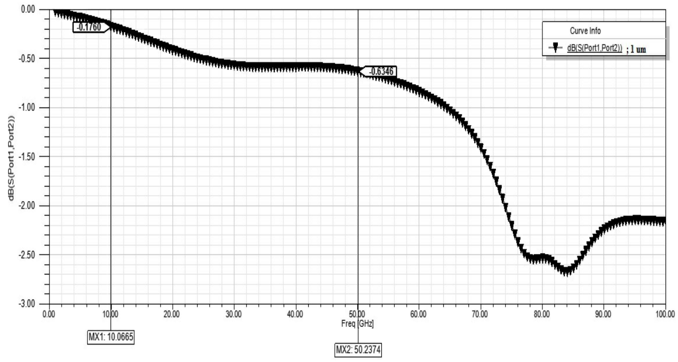


Fig.5 Insertion Loss

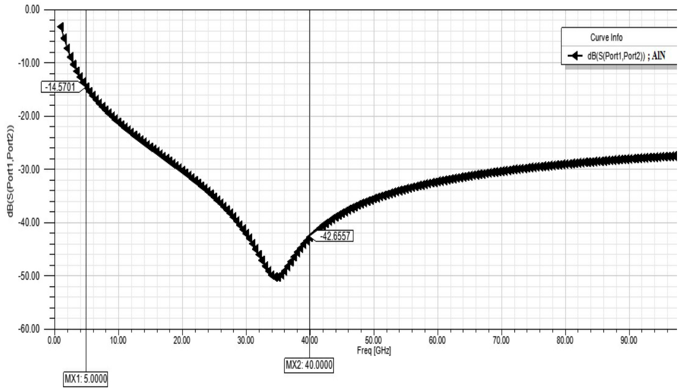


Fig.6 Isolation

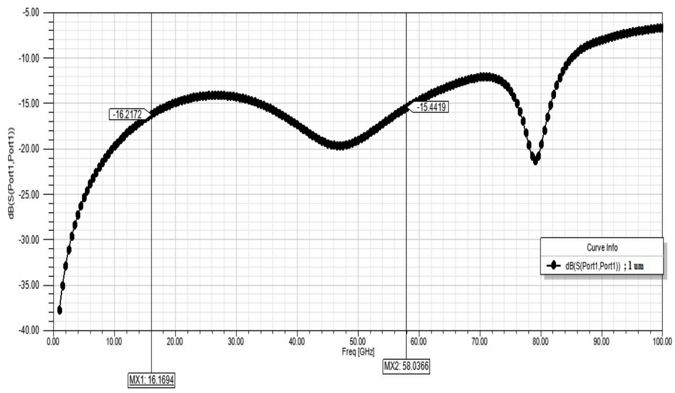


Fig.7 Reflection Coefficient

IV. CONCLUSION

A capacitive RF MEMS switch with split beam structure has been designed, virtually fabricated and simulated. Split beam structure was successful for achieving low stress and high spring constant. The switch exhibited an insertion loss of -0.63 from 10 to 50 GHz. The isolation of the switch was found to be -42.66 from 5 to 40 GHz. The pull-in voltage of the switch was less than 7.5V. The maximum stress Misses under actuation condition was 11.33 MPa, with a maximum displacement of 0.24µm. The results of this proposed switch makes it suitable for wireless applications.

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