

Design and Simulation of Capacitive RF MEMS Switches using Tuned Dual Beam

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Abstract

A low actuation voltage RF MEMS shunt capacitive switch has been designed and simulated for use in X-band (8-12GHz) applications. The MEMS switch is a freely moving membrane over coplanar waveguide. Double meander structure of tuned dual beam is used here to improve the isolation of switch. Actuation is achieved by using electrostatic mechanism because of its low power consumption, small size and less switching time. Simulation using CoventorWare shows that the actuation voltage for switch is 4.8V to 5.2V and up-state and down-state capacitance of 38fF and 3pF respectively. Spring constant for beam is 3.57N/m. HFSS simulation reveals that insertion loss is in the range of 0.01-0.02dB and up-state return loss better than -15dB in X-band. The switch offers a down-state isolation of 50dB at 10GHz.

Keywords: RF Switch; Spring constant; Actuation voltage; Coplanar waveguide; Down-state capacitance.

1. Introduction

From last few decades, RF MEMS switches have become an important part of switching devices operating at radio frequency to millimeter wave frequency because of their enormous advantages over PIN diode or FET switches like low or near zero power consumption, very high isolation, very low insertion loss and very low inter modulation products as described by Rebiez (2003). In spite of all these advantages, RF switches do have some disadvantages such as low speed, low power handling, high voltage etc. For reliable operation, a very high voltage of 20 to 80V is required to

produce large electrostatic force. So telecommunication systems require voltage up-converters to obtain such a high voltage, which increases the cost as well as complexity of systems. Actuation voltage or pull-in voltage of RF MEMS switches is higher than standard voltages of CMOS which is 5V or less. So an important task is to reduce pull-in voltage of RF MEMS switch to make switches compatible with control circuits. The purpose of paper is to design and analyze RF MEMS switch to achieve low actuation voltage of about 5V, high isolation as high as 50dB. The objective is achieved by using tuned beam with double meander spring with spring constant 3.57N/m.

2. Description of Switch

2.1 Actuation Voltage

Required actuation voltage dictates the mechanical design of electrostatically actuated switch. When designing switch with low actuation voltage, the choice of membrane material and beam design is very critical. The formula for calculating pull-in voltage (V_p) for fixed-fixed beam is shown in eq. 1.

$$V_p = \sqrt{\frac{8K_z g^3}{27\epsilon_0 A}} \quad (1)$$

The pull-in voltage depends upon spring constant (K_z) of membrane, air gap (g) between beam and pull-in electrode and actuation area A of switch. Pull-in voltage can be reduced by minimizing spring constant (K_z), air gap (g) and increasing the actuation area (A). Air gap cannot be reduced to a great extent because of the possibility of charge migration and dielectric breakdown. Because of the compactness of switch, actuation area cannot be increased. So, the possibility left is to reduce the spring constant, as beam design does not impact the size, weight and RF performance of circuit.

2.2 Beam Structure

Switch is connected to anchor with two meanders on each side as shown in figure 1. Double meander structure of beam provides lower spring constant without increasing the size and weight of the device. Spring constant K_z can be determined by combining spring constant of each part of beam. Spring constant for meandered beam is given by eq. 2 and described by K.J.Rangra (2005).

$$k = \left(\frac{8s^3 + 2L_s^3}{3EI_x} + \frac{sL_s(3L_s + 15s)}{3GJ} - \frac{s^2 \left(\frac{2s}{EI_x} + \frac{3L_s}{GJ} \right)^2}{2 \left(\frac{s}{EI_x} + \frac{L_s}{GJ} \right)} - \frac{L_s^2 \left(\frac{s}{GJ} + \frac{L_s}{EI_x} \right)}{2} \right)^{-1} \quad (2)$$

Where L_s is secondary meander length, s is primary meander length, E is young's modulus of material, G is sheer modulus and is given by $G=E/2(1+\nu)$ where ν is Poisson's ratio of material of switch, I_x is the moment of inertia along X-axis and is given by $I_x=wt^3/12$ where w is the thickness of 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 Jaibir Sharma (2012) is given by

$$k = 32Ew\left(\frac{t}{L}\right)^3 \quad (3)$$

Total spring constant can be calculated by combining these spring constant equations. All the necessary dimensions and material constants for the design are given in table 1. Spring constant for beam comes out to be 3.57N/m. The switch is made on high resistivity silicon substrate. CPW and bridge are made of highly conductive metal Gold. Silicon nitride is used as the dielectric material.

Table 1: Parameters and Dimensions of Switch.

Dimensions of Switch	
Beam Thickness	1.5 μm
Beam Length	420 μm
Beam Width	100 μm
Gap Height	2.5 μm
Area	100 $\times$ 100 μm^2
Electrode Thickness	1 μm
Oxide Thickness	1 μm
Dielectric Thickness	0.1 μm
Secondary Meander Length	90 μm
Primary Meander Length	40 μm
CPW	60/100/60
Young's Modulus of Gold	79GPa
Poisson's ratio of Gold	0.44
Dielectric constant of silicon nitride	7.6

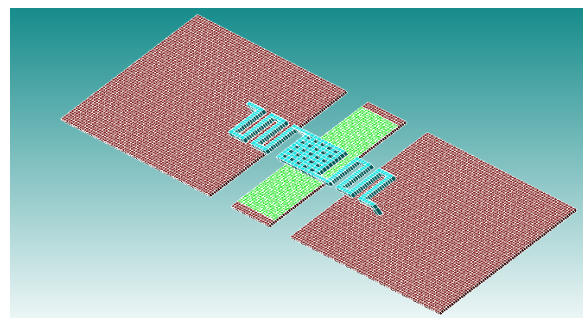


Figure 1: 3D Model of switch.

3. Simulation Results

3.1 DC Simulation

DC Simulations are done using CoventorWare software. 3D model of switch made using this software is shown in figure 1. Pull-in voltage, charge, capacitance, electrostatic force for switch is studied under DC simulation. Table 2 shows the calculated value and simulated value for switch. Pull-in voltage comes out to be 4.8 to 5.2V. Figure 2 shows the position of switch at pull-in voltage and displacement of membrane at pull-in voltage. Figure 4 shows the plot between for voltage and displacement. Up-state capacitance of switch comes out to be 6.72pF and downstate capacitance is 35.41fF. So the capacitance ratio for switch is 189.74 which are as high as desired.

Table 2: Calculated and Simulated Results.

$K_z(\text{N/m})$	Calculated $V_p(\text{V})$	Simulated $V_p(\text{V})$
3.57	8.9	4.8

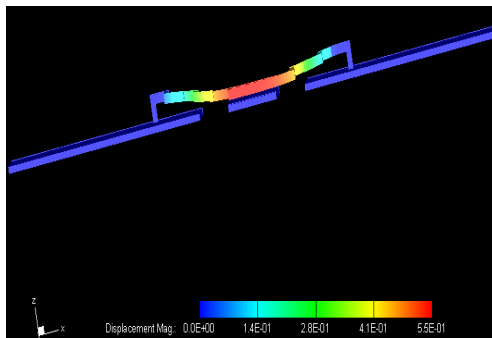


Figure 2. Displacement of Membrane at Pull-in Voltage

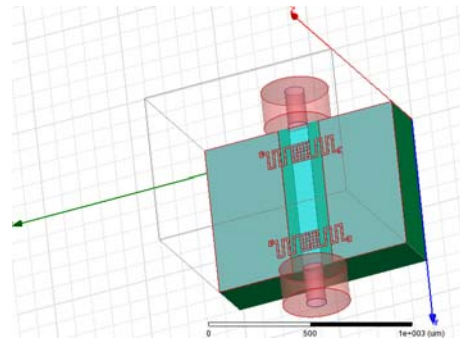


Figure 3. Design of Switch in HFSS

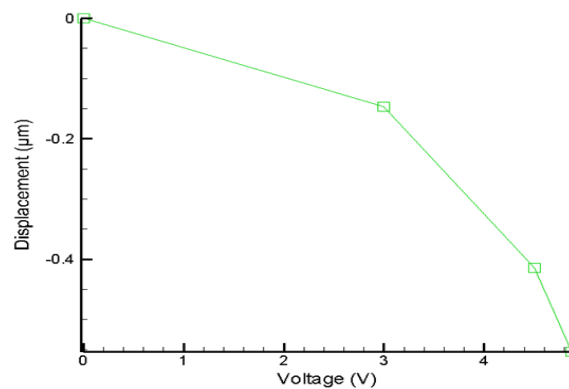


Figure 4: Displacement versus Voltage Plot.

3.2 RF Simulation

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} . S_{11} and S_{21} parameters are given as

$$|S_{11}|^2 \approx \frac{\omega^2 C_u^2 Z_0^2}{4} \quad (4)$$

$$|S_{21}|^2 \approx \frac{4}{\omega^2 C_d^2 Z_0^2} \quad (5)$$

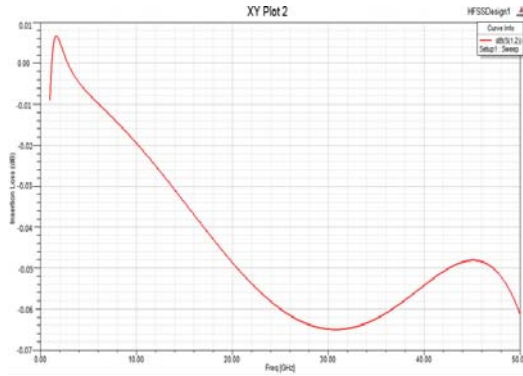


Figure 5. Insertion Loss versus Frequency Plot

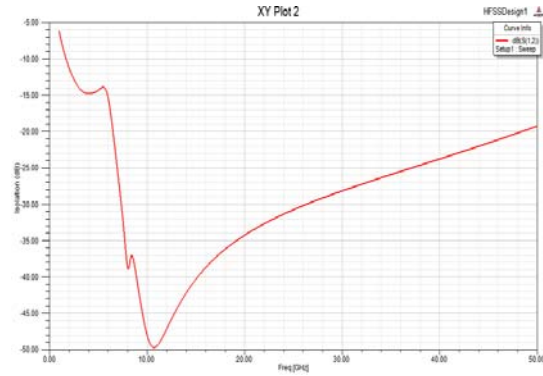


Figure 6. Isolation versus Frequency Plot

Insertion loss for the dual beam switch is (0.01-0.02) dB and isolation comes out to be 50dB at 10GHz frequency. So we can employ this switch in X-band applications. And dimensions for the switch are also verified from fabrication point of view from CEERI, Pilani.

4. Conclusion

A low voltage, low loss tuned dual beam RF MEMS capacitive switch has been designed suitable for X-band (8-12GHz) applications. Meandered spring supported beam is used to lower the actuation voltage as it reduces spring constant. Thus actuation voltage of 4.5V is achieved with an air gap of 2.5μm between CPW conductor and membrane. RF simulation shows that switch offers high isolation in down-state and low insertion loss in up-state. These characteristics make the switch a perfect choice to be used in X-band applications such as radars, phase shifters, satellites etc.

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