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Study of RF-MEMS Capacitive Shunt Switch for Microwave Backhaul Applications

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Abstract: *In this research paper, we have proposed a new type of capacitive shunt RF-MEMS switch. Micro-Electro-Mechanical System (MEMS) is a combination of mechanical and electromagnetics properties at micro level unit. This MEMS switch can be used for switching purpose at RF and microwave frequencies, called RF-MEMS switch. The RF-MEMS switch has a potential characteristics and superior performances at radio frequency. The MEMS switch has excellent advantages such as zero power consumption, high power handling capacity, high performance, and low inter-modulation distortion. In this proposed design, a new type of capacitive shunt switch is designed and analyzed for RF applications. The switch is designed both in UP and DOWN-states. The proposed switch design consists of substrate, co-planar waveguide (CPW), dielectric material and suspended metallic bridge. The proposed MEMS switch has dimension of 508 µm × 620 µm with a height of 500 µm and implemented on GaAs as a substrate material with relative permittivity of 12.9. The geometry and results of the proposed switch is designed using Ansoft HFSS electromagnetic simulator based on finite element method (FEM). The electrostatic and electromagnetic result showed better performances such as return loss, insertion loss and isolation. The switch has also excellent isolation property of -48 dB at 26 GHz.*

Keywords: *Capacitive shunt, RF-MEMS, Substrate, CPW, Dielectric, FEM, Return loss, Insertion loss, Isolation*

I. Introduction

MEMS refer to the Micro-Electro-Mechanical System and arrangement of electromagnetics and mechanical systems. The MEMS switches have the capability to combine advantages of electro-mechanical and semiconductor technologies based switches. In particular, MEMS switches offer the high RF performance and low DC power consumption of electro-mechanical switches but with the size and cost features of semiconductor switches. MEMS switch can be employed in radio frequency RF circuits, and their performances could be made better than those of other standard switches such as FET, and PIN diodes [1-2]. In recent years, a large number of research have been done on MEMS switch to use as switching application at radio frequency due to the larger number of advantages such as low speed, zero power consumption, low insertion loss, high isolation and very low intermodulation over the convention switching devices [3-5]. In 1970's , MEMS has been used for pressure and temperature sensors, accelerometers, gas chromatographs and sensor devices and MEMS switches for low frequency applications have also been established [6-9]. Over the available conventional solid state switching devices like PIN diode and FET, the RF-MEMS switch has numerous potential advantages for switching function and performs better performance including high bandwidth and good linearity [10]. On the other hand, the RF-MEMS switch has also some limitations during designing and operation such as low power handling, switching speed, low switching lifetime, high actuation voltage and electrostatic discharge [11-14]. To overcome the challenges faced in RF-MEMS switch, many of researchers have designed and analyzed different types of switches in which different techniques and switching parameters are considered like actuation voltage of switch and switching speed of switch. Piezoelectric actuation and spring constant parameters are responsible for actuation voltage whereas switching speed performance is improved by using different types of shape in bridges like meander, creating rectangular slot in bridge [15-20].

In this paper, a capacitive shunt type MEMS switch is designed and analyzed for RF applications. The objective of designing this switch is to improve the electromagnetics and mechanical characteristics such as return loss, isolation and actuation voltage. In this design, the bridge length is reduced to half as compare to old design to improve the spring constant and actuation voltage properties and the bridge has also five identical cylindrical slots above the actuation pad to minimize the stickiness between bridge and electrode during actuation time.

II. RF-MEMS Switch Design Geomerty

According to applications, the designing structures of RF-MEMS switches are different like Ohmic, capacitive, series, shunt etc. In the proposed design, the switch is capacitive and shunts type in nature. The switch consists of several layers such as substrate, silicon dioxide layer, CPW, silicon nitride dielectric layer and a metallic bridge. The material used for bridge and CPW is gold.

Fig.1. shows the HFSS design structure of the proposed MEMS switch.

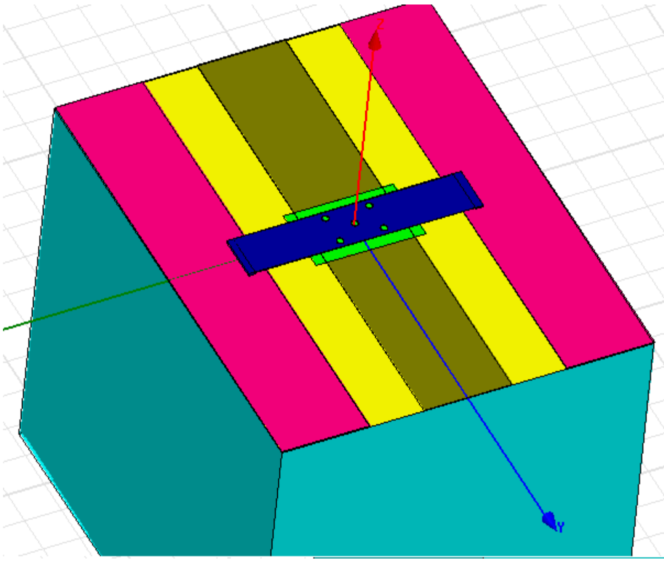


Fig.1. HFSS Design of proposed MEMS switch

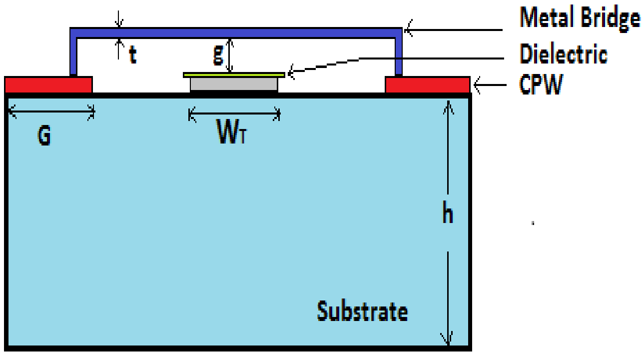


Fig.2. General View of proposed MEMS switch

In the above fig.2, a general view of the proposed MEMS switch is presented. The MEMS switch with different structures of substrate, silicon dioxide, dielectric material, and suspended bridge. The substrate is GaAs material having dimension of 508 µm × 620 µm × 500 µm with permittivity of 12.9. On the top surface of substrate, a thin layer of silicon dioxide layer is deposited of thickness 0.5 µm. In the proposed design, the MEMS switch consists of three identical CPW of each dimension of 120 µm × 620 µm × 1 µm. The middle CPW behaves as a transmission line where the RF signal is given as an input and the other two CPWs acts as ground. In capacitive shunt switch, a thin layer of dielectric material is used to separate two conduction electrodes bridge and CPW during actuation and it prevents the direct metal to metal contact. The material used for dielectric is silicon nitride (Si_3N_4) and its dimension is 150 µm × 90 µm × 0.15 µm is deposited on the top surface of middle CPW and the dielectric thickness 't_d' with a dielectric constant ε_r. As shown in fig.2 the capacitive shunt switch consists of a movable metal bridge of gold material, suspended at a height 'g' above the dielectric layer on the transmission line mechanically anchored and electrically connected to ground of the coplanar waveguide (CPW). The bridge is L_B µm long, W_B µm wide and t µm thick. The dimension of rectangular bridge is 320 µm × 60 µm and thickness is 1 µm.

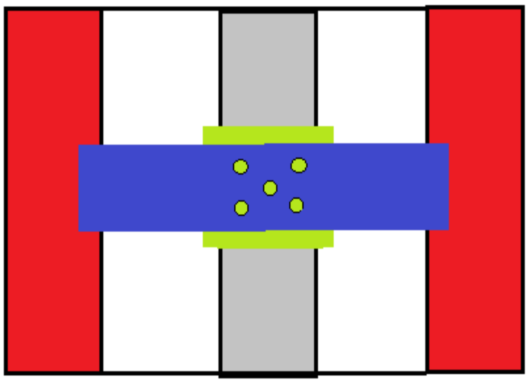


Fig.3. Top view of proposed MEMS switch

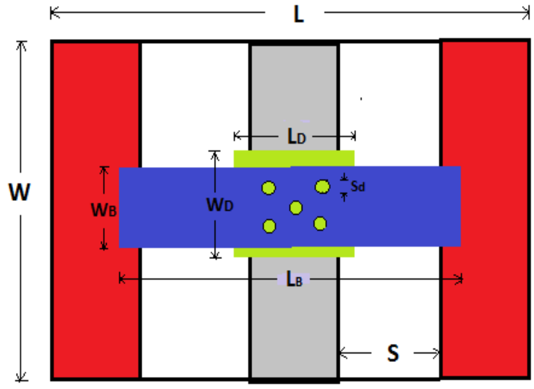
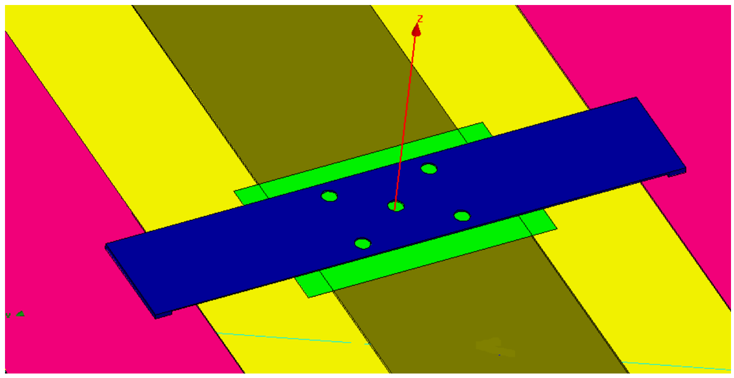


Fig.4. Design parameters of proposed MEMS switch

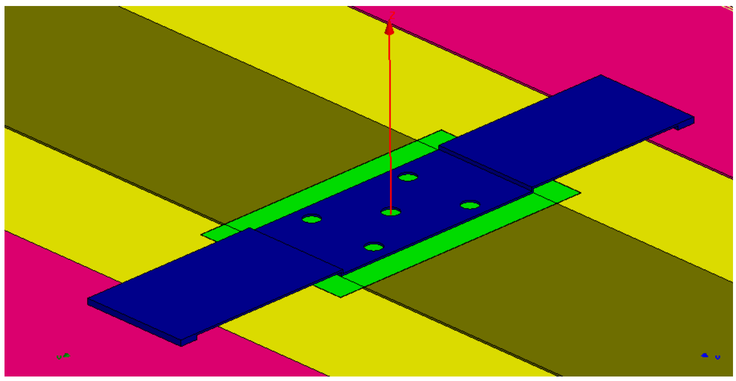
The RF-MEMS switch is mechanically designed in such a way that the metallic gold bridge is suspended 2 µm above the dielectric electrode. In the design technique, the length of bridge is reducing to minimize the actuation voltage and spring constant. Similarly the proposed switch has also five identical cylindrical slots above the transmission line due to this the stickiness between electrode and metallic bridge is minimized during actuation period. The dimension of each cylindrical slot is of radius 4.5 µm with height of 1 µm.

Table1. MEMS Switch Design Parameters and Dimensions

Switch Parameters	Dimension (µm)	Switch Parameters	Dimension (µm)
L	**508**	**W_D**	**90**
W	**620**	**S**	**74**
G	**120**	**G**	**2**
W_T	**120**	**T**	**1**
L_B	**320**	**S_d**	**9**
W_B	**60**	**H**	**500**
L_D	**150**	**t_d**	**0.15**

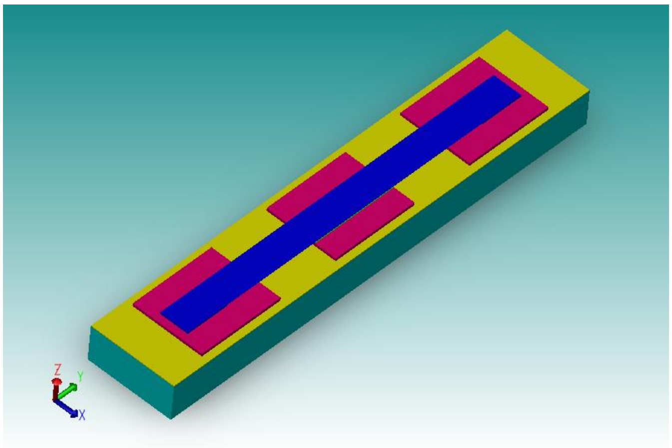


(a) MEMS switch in UP-state

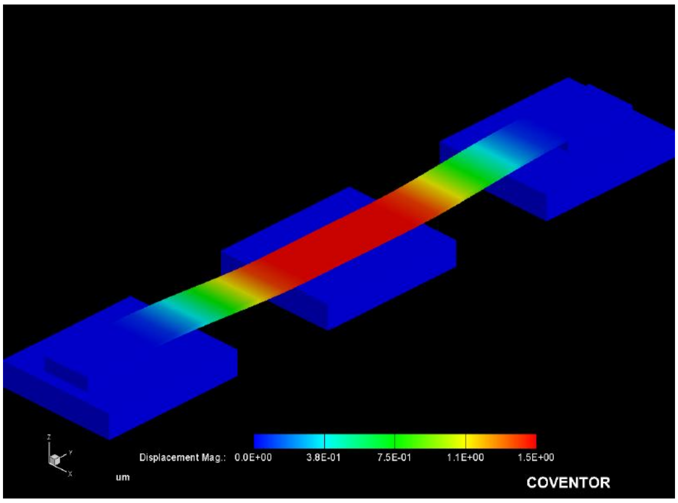


(b) MEMS switch in DOWN-state

Fig.5. HFSS Design of proposed RF-MEMS capacitive shunt switch (a) UP-state (b) DOWN-state



(a) MEMS switch in UP-state



(b) MEMS switch in DOWN-state

Fig.6. COVENTORWARE Design of proposed RF-MEMS capacitive shunt switch without cylindrical slot (a) UP-state (b) DOWN-state

III. Working Principle Of RF-MEMS Switch

The MEMS switch can be operate in two states: UP and DOWN states. In UP-state the switch is "on" and RF signal applied the center CPW is transmitted to the output port. In DOWN state the switch is normally "off" condition hence the applied RF signal to the transmission line is given to the ground CPW by shorting the bridge with center transmission pad. When an actuation voltage is applied between the actuation electrode and the suspended beam, the suspended beam will move downward and collapse on the bottom electrode.

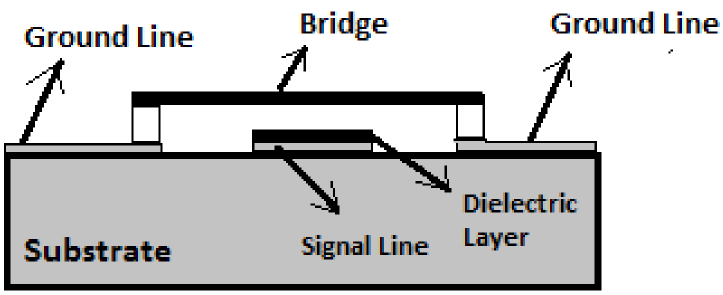


Fig.7. RF-MEMS shunt switch in UP-state

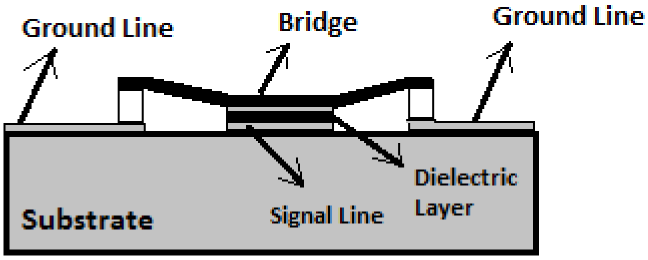


Fig.8. RF-MEMS shunt switch in DOWN-state

During the actuation, the force due to which the bridge moves towards the electrode is electrostatic force and this is due to charge accumulated between the bridge and electrode. The electrostatic force is given by

$$F_e = \frac{\varepsilon_0 A V^2}{2\left(g + \frac{t_d}{\varepsilon_r}\right)}$$

Where A is the area of actuation electrode, V is applied actuation voltage, g is the air gap between bridge and dielectric material, t_d is dielectric thickness and is relative permittivity. From above eq, it observed that force depends upon area, actuation voltage and air gap between bridge and electrode.

IV. Electromagnetic Modeling of RF-MEMS Switch

The modeling analysis of RF-MEMS switch can be performed in two domain i.e. electrical and mechanical domain. In electrical modeling, the switch is modeled with respect to their electrical or electromagnetic parameters like resonance frequency, electrical equivalent impedance, return loss, insertion loss and isolation.

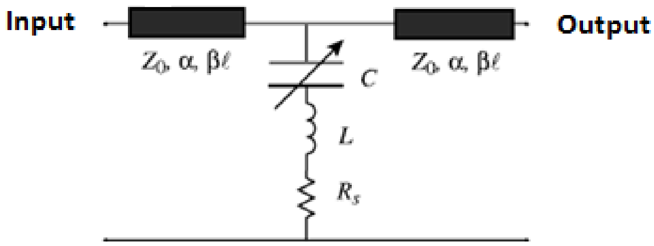


Fig.9. Electrical equivalent circuit of RF-MEMS shunt switch

The switch shunt impedance is given by

$$Z_s = R_s + j\omega L + \frac{1}{j\omega C}$$

Where R is the resistance of the switch and it depends upon the resistance of bridge and transmission line.

The impedance of the RF switch is given by

$$Z_s = \begin{cases} \frac{1}{j\omega C}, f \ll f_0 \\ R_s, f = f_0 \\ j\omega L, f \gg f_0 \end{cases}$$

Where f_0 is the resonance frequency of the LC switch and it is given by

$$f_0 = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$$

The return loss and insertion loss of RF-MEMS switch is given by

$$S_{11} = \frac{-j\omega C_u Z_0}{2 + j\omega C_u Z_0}$$

$$S_{21} = \frac{1}{1 + j\omega C_d Z_0/2}$$

Where C_u and C_d are the up-state and down-state capacitances and are given by

$$C_u = \frac{\varepsilon_0 A}{g_0 + \frac{t_d}{\varepsilon_r}}$$

$$C_d = \frac{\varepsilon_0 \varepsilon_r A}{t_d}$$

The Up-state/Down-state capacitance ratio is

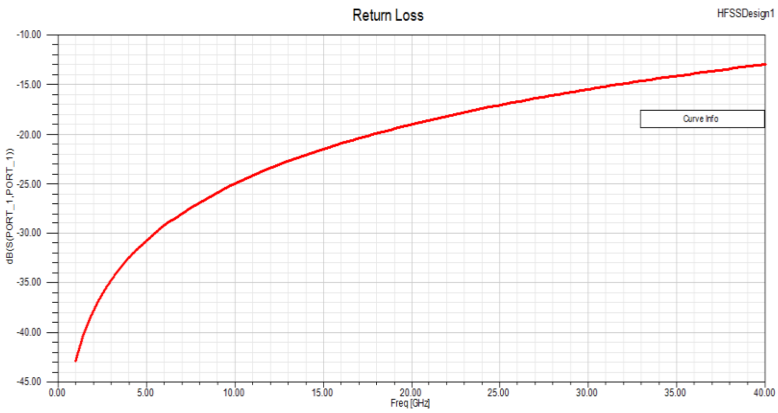
$$\frac{C_d}{C_u} = \frac{\frac{\varepsilon_0 \varepsilon_r A}{t_d}}{\frac{\varepsilon_0 A}{g + \frac{t_d}{\varepsilon_r}} + C_f}$$

In mechanical modelling, the switch is designed in such a way that the mechanical parameters like switching speed, spring constant and actuation voltage can be improved. The actuation voltage of switch is given by

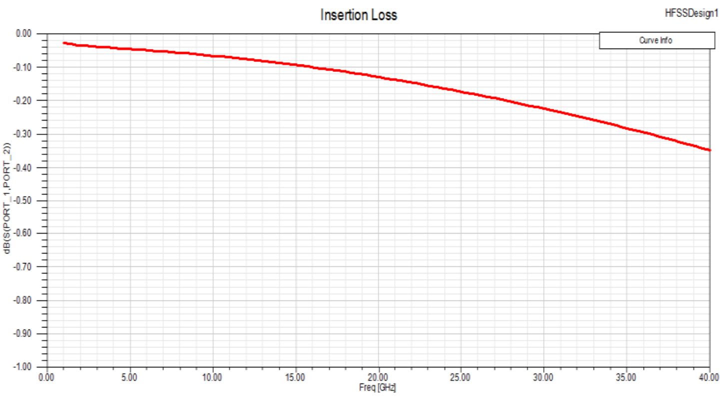
$$V_p = \sqrt{\frac{8k}{27A\varepsilon_0} g_0{}^3}$$

V. Simulation Result And Analysis

The simulated results of the proposed RF-MEMS switch are illustrated in following fig. The simulation of switch is done with the help of HFSS simulation tool [21].

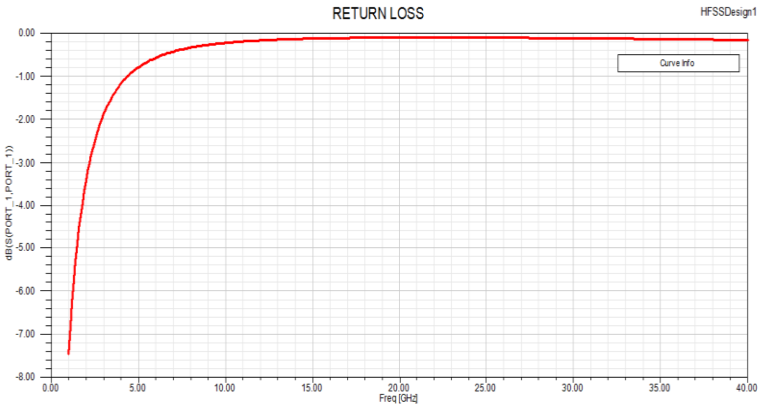


(a) Return loss

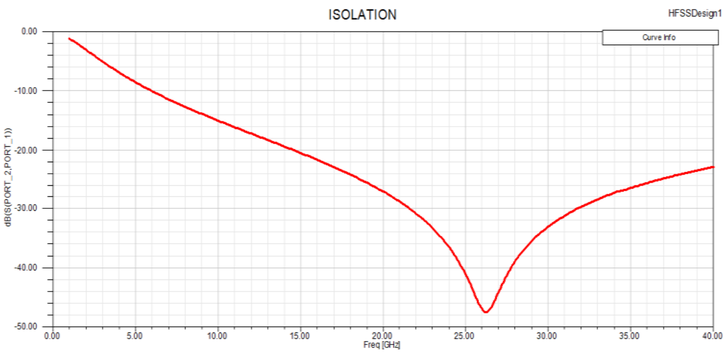


(b) Insertion loss

Fig.10. Simulated results of proposed RF-MEMS shunt switch in UP-state



(a) Return loss



(b) Isolation

Fig.11. Simulated results of proposed RF-MEMS shunt switch in DOWN-state

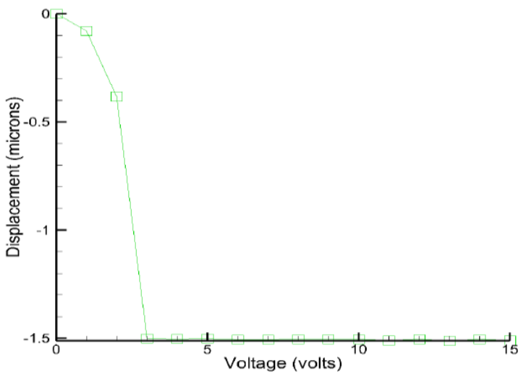


Fig.12. Simulated actuation voltage vs. displacement of proposed RF-MEMS shunt switch using CoventorWare simulation tool

VI. Conclusion

We have designed and simulated RF-MEMS capacitive shunt type switch. From the simulated result, characteristics of proposed and designed capacitive shunt switch have been analyzed and studied. Both in UP and DOWN-states, electromagnetic parameters are excellent such as return loss, insertion loss and isolation. Therefore, the proposed switch offers very low losses and has very high isolation property over the frequency range from 0 – 40 GHz. Similarly the proposed switch has also low actuation voltage i.e. 3 Volt due to reduction in length and it minimizes the stickiness between bridge electrode. Therefore, the proposed RF-MEMS switch is very suitable for satellite, radar and microwave applications where high isolation and low losses are required over 0 – 40 GHz frequency range.

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