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DESIGN AND ANALYSIS OF MEMS CAPACITIVE SHUNT TYPE SWITCH FOR RF APPLICATIONS

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ABSTRACT

RF-MEMS is a promising technology that has the potential to revolutionize RF and microwave system implementation for next generation telecommunication applications [1]. In this paper, a MEMS capacitive shunt type switch is design and analyzed for RF applications. This new switch design focuses on the failure mechanisms restriction, the simplicity in fabrication, the power handling and consumption, as well as controllability with electromagnetic characteristics. The MEMS switch is designed in both ON and OFF states. 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 electrostatic and electromagnetic analyses of the designed RF-MEMS Switch have been performed using Ansoft High frequency structure simulator (HFSS) electromagnetic simulator tool.

KEYWORDS: RF MEMS, Microwave, MEMS Switch, Shunt Switch, Substrate, Electromagnetic, HFSS

INTRODUCTION

Micro-electro-mechanical system (MEMS) has been developed since the 1970's for pressure and temperature sensors, accelerometers, gas chromatographs and sensor devices. MEMS switches for low frequency applications have also been demonstrated in the early 1980s [2-4]. They are essentially miniature devices that use a mechanical movement to achieve a short circuit or, an open circuit in transmission line [5].

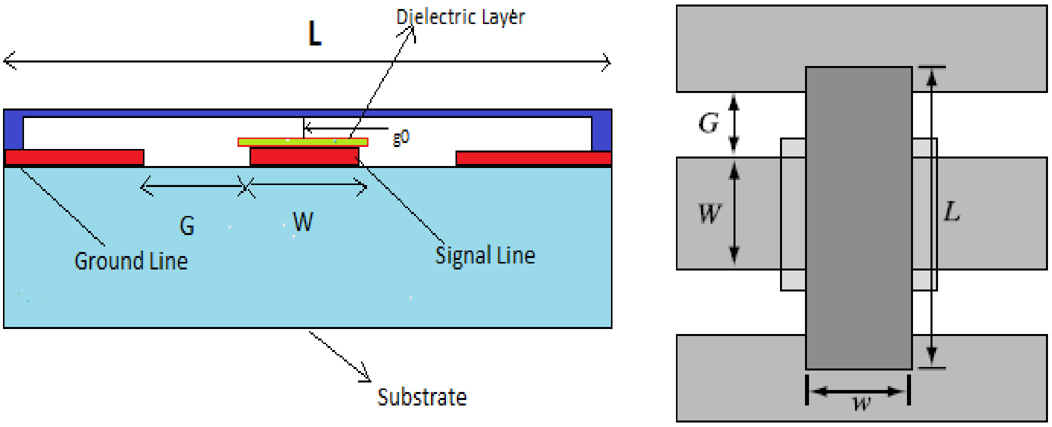
The MEMS switches have the capability to combine advantages of electro-mechanical and semiconductor technologies based switches. In particular, MEMS switches offer the high RF performance and low DC power consumption of electro-mechanical switches but with the size and cost features of semiconductor 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 [6]. This is due to their good linearity, low nose, low power consumption, high electrical isolation, and ultra wide frequency band.

RF MEMS SWITCH DESIGN

A MEMS switch can be made in several different configurations depending on the signal path (series or shunt), the actuation mechanism (electrostatic, magneto static, thermal etc.), the type of contact (Ohmic or capacitive) and the type of structure (cantilever or bridge). Capacitive RF MEMS switches use a thin layer of dielectric material to separate two conducting electrodes when actuated [7]. The dielectric layer prevents direct metal-to-metal contact. These switches generally operate in a shunt switch configuration where the RF signal is shorted to ground by a variable capacitor [8].

As shown in below fig (1), the switch is suspended at a height 'g' above the dielectric layer on the t-line, and the dielectric thickness 'td' with a dielectric constant ε_r. The switch is L µm long, w µm wide and t µm thick. The width of the t-line is 'W' µm. The substrate can be silicon, GaAs, Alumina, LTCC or, quartz dielectric [9-10].

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 SiO2 is deposited with thickness 0.5 µm. In the proposed design, it also consist of three identical CPW of equal dimension of 120 µm × 620 µm × 1 µm. The center CPW behaves as a conductor where the RF signal is given as an input to one terminal and it is transmitted through the other terminal and the other two CPW.



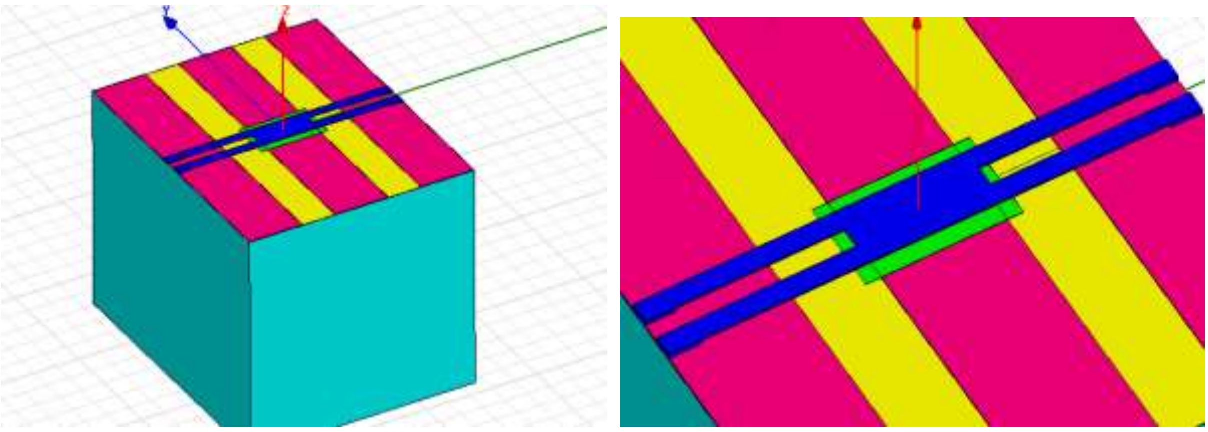
(a) **(b)**

Fig.1. Illustration of a typical MEMS shunt switches in (a) Cross section and (b) Top view

In the design, a RF MEMS capacitive shunt switch consisting of a movable metal bridge of gold material, suspended at a height 'g0' above the dielectric layer on the transmission line mechanically anchored and electrically connected to ground of the coplanar waveguide (CPW).The size of the bridge is 508 µm × 60 µm with thickness of 1 µm. The material used for CPW is also gold.

Switch Parameters	Dimension (µm)
L	508
G	74
g_0	2
W	120
Si_3N_4 Layer	0.15

Table 1: RF MEMS Switch parameters with their dimensions



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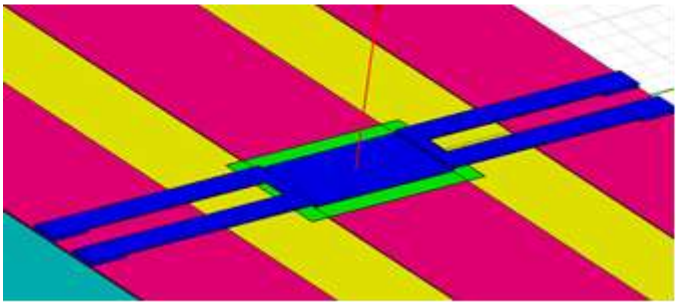


(c)

Fig.2. HFSS design of Proposed RF MEMS Capacitive Shunt Switch Views (a) General view (b) UP (ON)-State view and (c) DOWN (OFF)-State view

WORKING PRINCIPLE OF RF MEMS SWITCHES

A dielectric is deposited on the top of the bottom electrode as shown in figure.3. When the suspended beam is in the upstate, the capacitance is in the range of fF. 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 [11-12]. This will increase the capacitance in the range of pF, 20-100 times higher than the upstate capacitance. The upstate capacitance mainly depends on the initial gap. The down state capacitance depends on the dielectric thickness (td), dielectric constant etc. Sio2, Si3N4, Tio2 can be used as dielectric for RF MEMS switches. The capacitive contact switch is suitable for high frequency applications. At low frequency (DC), the impedance always is very high for a capacitive switch [13].

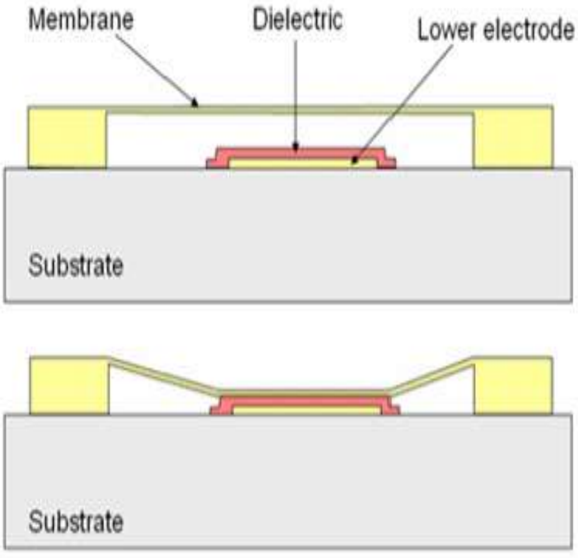


Fig.3. Schematic drawing, cross sectional view of the switch at a non- actuated state (top, on state), and an actuated state (bottom, off state)

CIRCUIT MODEL OF THE MEMS CAPACITIVE SHUNT SWITCH

MEMS shunt switch is modeled by two short sections of t-line and a lumped CLR model of the bridge with a capacitive having an up-state and a down-state value [14].

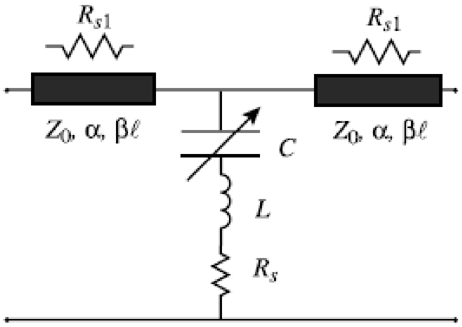


Fig.4. Equivalent circuit model of RF MEMS Capacitive shunt switch

The switch shunt impedance is given by

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

With C = C_u or, C_d depending on the switch position.

The LC series resonant frequency of the switch is given by

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

And the impedance of the shunt switch can be approximated by

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

The cut-off frequency is defined as the frequency where the ration of the off (up-state) and on (down-state) impedance degrades to unity and is

$$f_c = \frac{1}{2\pi C_u R_s}$$

RF MEMS SWITCH ANALYTICAL MODELING

UP-State Capacitance

The parallel plate capacitance of the MEMS shunt switch is

$$C_{PP} = \frac{\varepsilon_0 wW}{g + \frac{t_d}{\varepsilon_r}}$$

Down-State Capacitance

The MEMS switch capacitance in the down-state position can easily be calculated using,

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

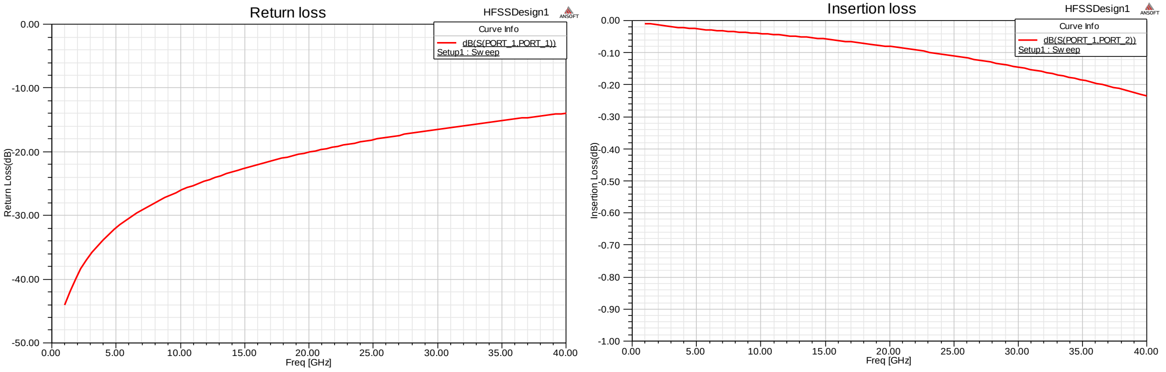
Capacitance Ratio

The Up-state/Down-state capacitance ratio **is**

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

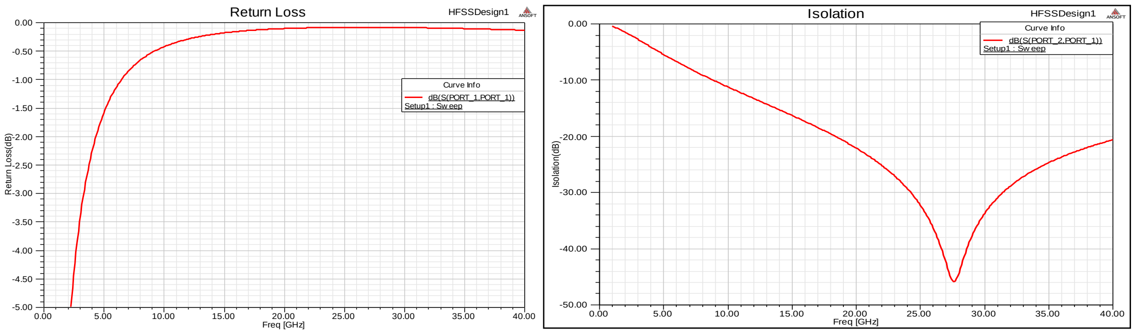
SIMULATION AND RESULT ANALYSIS

The designed MEMS switch is simulated and analyzed with the help of ANSOFT HFSS software.



(a) **(b)**

Fig.5. Simulated Result of RF MEMS Capacitive Shunt Switch in ON-state (a) Return Loss and (b) Insertion Loss



(a) ***(b)***

Fig.6. Simulated Result of RF MEMS Capacitive Shunt Switch in OFF-state (a) Return Loss and (b) Isolation

CONCLUSION

In this paper, the RF characteristics of proposed and designed capacitive shunt switch have been analyzed and studied such as return loss, insertion loss, isolation. From the obtained result, MEMS capacitive shunt switches of RF applications show low insertion losses in the OFF state and high isolation in the ON state. The designed switch is very suitable in applications where high isolation and low losses are required over 0 – 40 GHz frequency range.

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