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Design and Analysis of RF MEMS Switch For High-Frequency Applications

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Abstract — *This communication describes the capacitive analysis and design aspects of Radio Frequency (RF) MEMS switch over 1-80 GHz frequency range. Especially capacitive RF MEMS switches are compatible for higher-order frequency applications like 5G taken into consideration. A new verity of MEMS structure is used in the RF MEMS switch design, which helped reduce the pull-in voltage. CPW transmission line is used for the switch design. Two separate bottom electrodes are used to reduce the required actuation voltage. Si3N4 dielectric material and its relative permittivity are 7.8 used. Complete design and simulation are done using FEM tools. The isolation loss is -30 dB, and the insertion loss is -1.22 dB.*

Keywords — *RF MEMS switches, Pull-in voltage, CPW transmission lines, FEM tool.*

I. INTRODUCTION

Recent connectivity applications include the high-speed transfer of data with low power consumption, a major research concern. Huge MIMO systems require several antennas, but they ultimately suffer from signal interference issues [1-2]. Reconfigurable patch antennas are preferable to the antenna array to resolve these kinds of problems. With designs such as E-shape, patch antennas' reconfigurability can be achieved, but the output is not up to the mark, so this solution is not preferable. The alternative way of making microstrip patch antenna reconfigurability is to position switches such as PiN, FET, and RF micro-electro-mechanical switches. The RF micro-electro-mechanical switches provide the highest performance in power consumption relative to PiN diode and FET transistors and provide improved linearity. In the design of today's multimedia and connectivity modules, the need for micromechanical structures encourages researchers to work on MEMS technology. Research on MEMS technologies has been advancing for a few decades, but researchers still have too many optimization problems. Accelerometers, gyroscopes, RF switches, RF sensors, RF phase shifters, and RF isolators are the primary MEMS technology applications [3-5].

Parameters such as spring constant, deformation rate, resonant frequency, system mass, structure fatigue nature, losses, actuation power, and environmental effects determine the MEMS technology-dependent systems' efficiency. The authors' core research is on RF MEMS switches, so our research on MEMS structures' role has been extended to create RF MEMS switches. The spring constant (K) is the primary factor that will evaluate the turn, pull voltage, and switching path Eigen values[5-7].

II. RELATED WORK

The key benefits of RF microelectromechanical switches, as opposed to alternative solid-state devices, are low power requirement, good electrical efficiency, and best linearity. In general, by altering the micro-beam and electrostatic air gap thickness, a switch configuration with a low pull-in voltage is obtained[8-10]. As a micro-beam material, the gold thin film is an outstanding alternative. It is commonly used for RF microelectromechanical systems because of its low sensitivity to mitigate degradation and chemical inertness to eliminate corrosion and pollution. But the power of gold gives way, and sneak properties are causes of strong left over stress and the spread of intermittent stress[11-14]. The mechanical components' temperature-based buckling is one of the research questions on the RF micro-electro-mechanical switches. The MEMS packaging temperature, in particular, may cause the microbridge to deform.

This deformation influences the RF and electro-mechanical output of the switch. Concerning its length, the MEMS bridge consists of a very thin single metal layer. The bridge's buckling or enduring bend is an undesired result since the shunt switch's RF output depends on the air distance.

By means of numerous bridge materials and well-made membrane structure, the MEMS membrane's temperature-based buckling can be reduced. As the temperature increases, most of the RF-MEMS designs to date display major differences in actuation voltage. While cantilever switches are less prone to fluctuations in temperature than fixed-fixed beams with one end free, no work has been undertaken to thoroughly investigate the difference in temperature observed and its consequences[14-15].

III. MATHEMATICAL ANALYSIS

The MEMS technology computer design depends primarily on micro-level mechanical systems that can be controlled electrostatically (or) thermally (or) piezoelectrically (or) magnetostatically. Micro electro-mechanical structures like cantilevers, bridges, crab legs, folded, etc., are trendy.

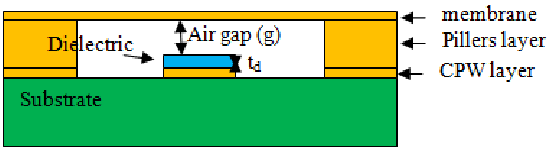


Figure 1 Parallel plate Capacitance model.

From Figure 1 and the parallel plate capacitance of RF micro-electro-mechanical switch, we can express the upstate and downstate capacitance as[16]

$$C_{up} = \frac{\varepsilon_0 A}{g + \frac{t_d}{\varepsilon_r}} \tag{1}$$

$$C_{down} = \frac{\varepsilon_0 \varepsilon_r A}{t_d} \tag{2}$$

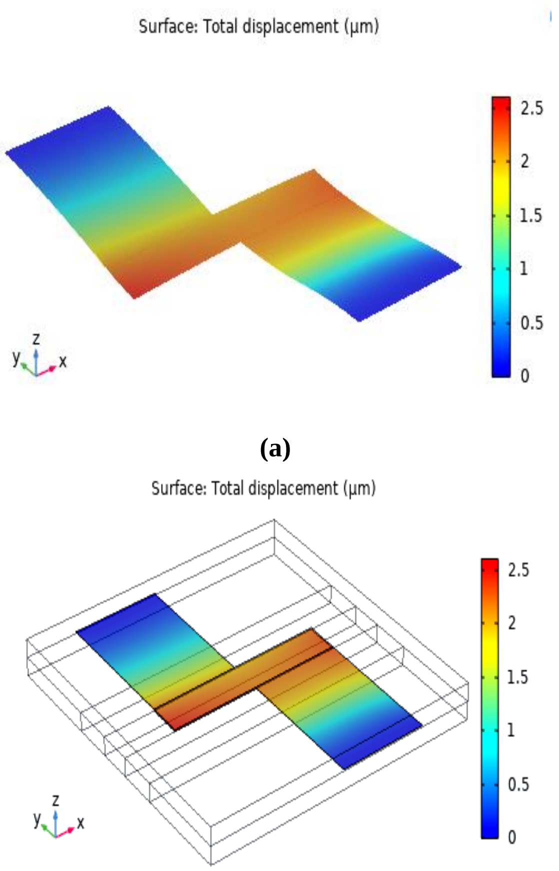
IV. PROPOSED METHODOLOGY

This paper has proposed a new micromechanical structure target to decrease the actuation voltage and improve the RF micro electro-mechanical switch's isolation. The proposed MEMS structure is validated at the simulation level by extracting the electrical, mechanical, and RF parameters. Using numerous membrane materials and well-made membrane structures, the temperature based buckling of the MEMS bridge can be minimized. As the temperature increases, most of the RF micro-electro-mechanical designs to date display major differences in actuation voltage. Eventually, the RF micro-electro-mechanical switch is intended by plasing the proposed membrane on the CPW transmission line. Parallel plate capacitance analysis is done using high dielectric constant thin films i.e., Al2O3, ZnO, and Si_3N_4.

V. DESIGN AND SIMULATION

A. Membrane analysis

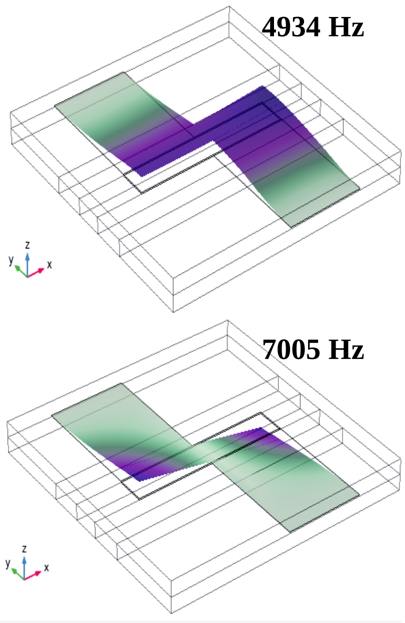
The era of high frequency reconfigurable mobile applications like 5G demands low power RF devices. MEMS technology RF switches are very vital in this low power consumption aspect. This communication clearly explains the design level critical performance indices of capacitive RF MEMS switches. Electrostatic actuation is used for deformation of MEMS structure which plays a major role in switching input RF signal. A new membrane structure (shown in Figure 1) is used for switch design, an air gap of 2.5 µm is maintained.



(a)

(b)

Figure 2 Proposed MEMS structure electrostatic actuation, (a) membrane, (b) membrane on the CPW line.



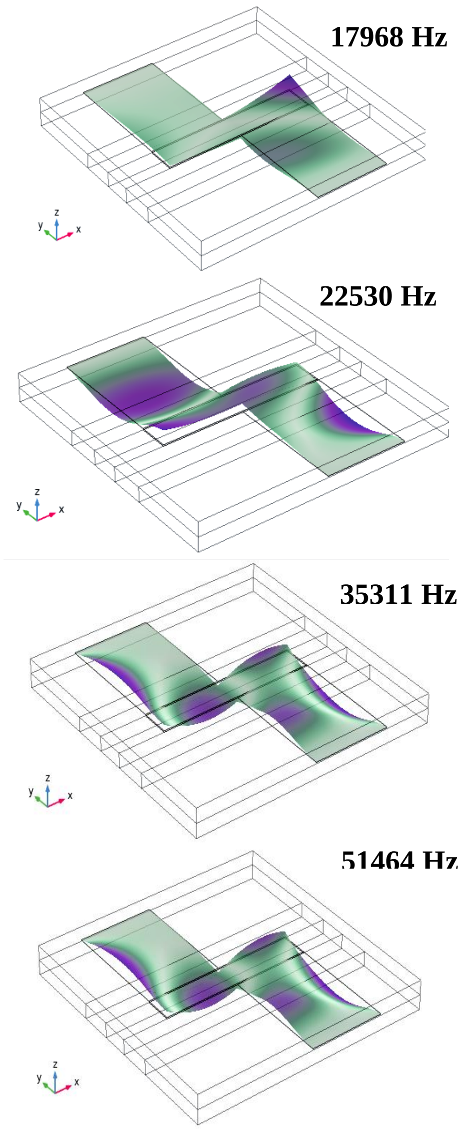
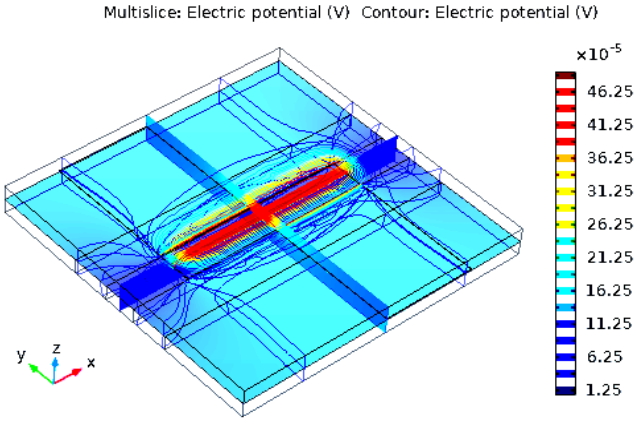
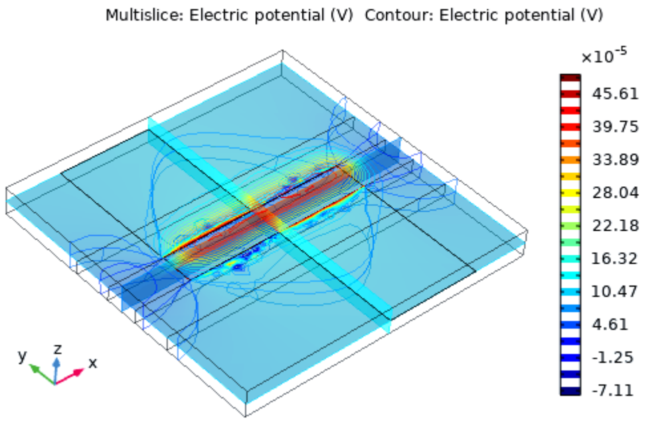


Figure 3 Eigen Frequencies.

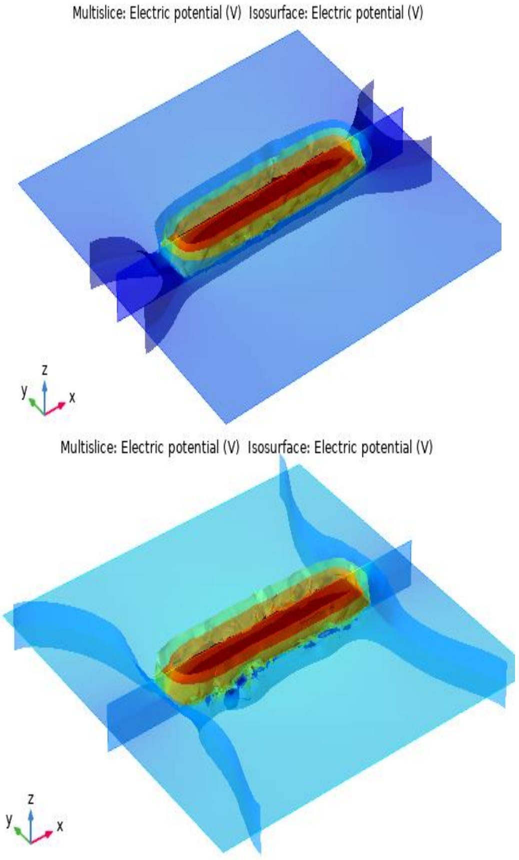

Multislice: Electric potential (V) Contour: Electric potential (V)

(a)


Multislice: Electric potential (V) Contour: Electric potential (V)

(b)

Figure 4 Capacitance fringing fields, (a) membrane upstate,(b) downstate.


Multislice: Electric potential (V) Isosurface: Electric potential (V)

Multislice: Electric potential (V) Isosurface: Electric potential (V)

Figure 5 Isosurface electric potentials.

Table 1. parallel plate capacitance analysis.

Material	Dielectric Constant (ε_r)	Cross-sectional area A=W x w	Dielectric thickness (t_d)	Parallel plate capacitance			
				Using Eq.		Using FEM tool simulation	
				$C_{up} = \frac{\varepsilon_0 A}{g + \frac{t_d}{\varepsilon_r}}$	$C_{down} = \frac{\varepsilon_0 \varepsilon_r A}{t_d}$	C_{up}	C_{down}
Al_2O_3	5.7	500 µm x 90 µm	0.05 µm	1.55×10^{-13}	4.59×10^{-11}	1.55×10^{-13}	4.59×10^{-11}
ZnO	8.3			1.552×10^{-13}	6.66×10^{-11}	1.552×10^{-13}	6.66×10^{-11}
Si_3N_4	9.7			1.557×10^{-13}	7.78×10^{-11}	1.557×10^{-13}	7.78×10^{-11}

The proposed membrane Eigen frequency analysis, capacitive analysis, and Is surface electric potentials. Results are shown in Figures 3,4 and 5, respectively.

B. RF MEMS switch

The projected switch is micromachined on an FR4 substrate whose dielectric constant is 4.4. And the high of the substrate is 0.8 µm. The eventual view of the switch is, as shown in Figure 6. CPW line is adopted to micro machine the switch. Si3N4 with εr= 9.7 dielectric material is placed for better isolation.

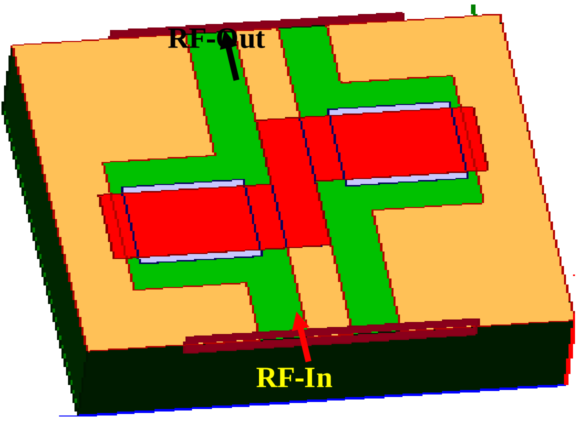


Figure 6 Capacitive RF Micro Mechanical Switch.

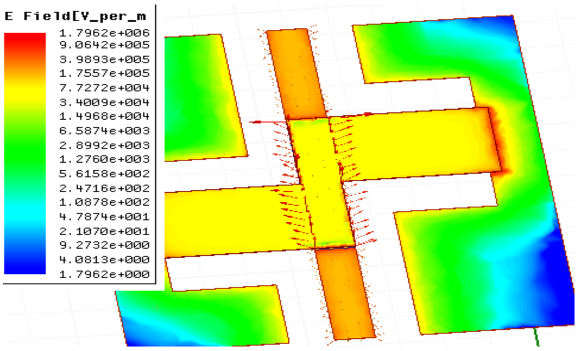


Figure 7 Membrane upstate, RF input permissible to output.

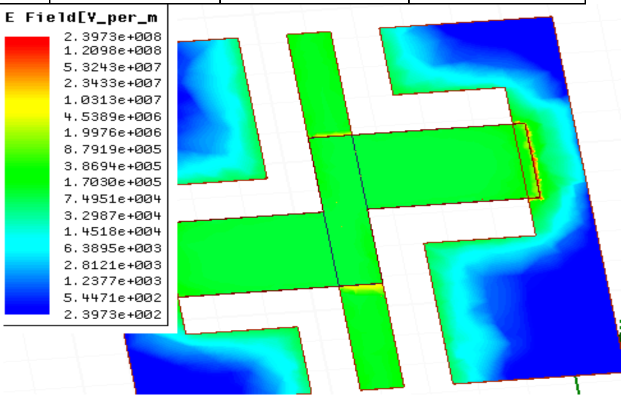


Figure 8 Membrane downstate, RF input not permissible to output.

The radiofrequency (RF) analysis is done using the FEM tool. Under two conditions, i.e., membrane upstate and downstate, the RF signal propagation is clearly shown in Figures 7 & 8.

The radiofrequency properties are analyzed in the radio frequency range of 1-80 GHz. The isolation loss is -30 dB, and the insertion loss is -1.22 dB, as shown in Figure 9.

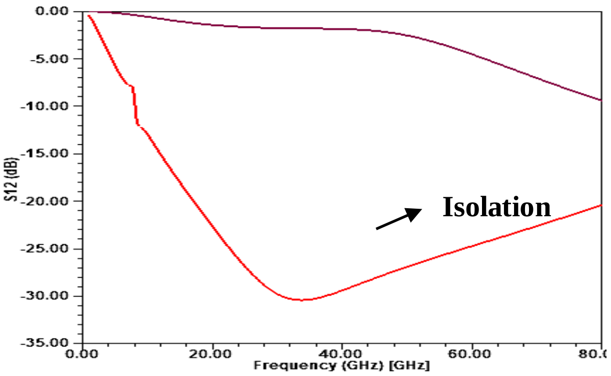


Figure 9 Insertion and Isolation Losses.

VI. CONCLUSION

Especially capacitive RF MEMS switches are compatible for higher-order frequency applications like 5G taken into consideration. A new verity of MEMS structure is used in the RF MEMS switch design, which helped reduce the pull-in voltage. CPW transmission line is used for the switch design. Two separate bottom electrodes are used to reduce the required actuation voltage. Si_3N_4 dielectric material and its relative permittivity are 7.8 used. Complete design and simulation are done using FEM tools. The radiofrequency properties are analyzed in the radio frequency range of 1-80 GHz. The isolation loss is -30 dB, and the insertion loss is -1.22 dB.

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