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Design and Analysis of Series Configuration-Based Mems Switch

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Abstract: ***This paper reports the design and analysis of series type MEMS switch. This switch can be used for tunable filter applications from DC-10GHz frequency range. The study briefly explains the design of switch and analysis of various switching parameters. Through electrostatic actuation mechanism the switch is optimized in terms of various parameters like beam thickness, beam width, airgap, conductor and dielectric materials. Study of proposed design with COMSOL for electromechanical analysis and HFSS for electromagnetic analysis. The switch has theoretical and simulated actuation voltages of 22.81V and 38V respectively. It has the switching time of 33.36μs. The upstate and down state capacitances of 0.286pF, 3.93fF respectively. When the switch is in ON state an insertion loss of less than -0.1dB and return loss of -15dB is achieved. When the switch is in OFF state an isolation loss of -0.1dB and return loss of -21dB is achieved at 3GHz.***

Index Terms: ***Series type, MEMS switch, tunable filter, actuation voltage, switching time, return loss, Insertion loss, Isolation loss.***

I. INTRODUCTION

Micro Electromechanical systems (MEMS) devices are used in many Radio frequency applications like inductors, switches, filters, variable capacitors [1-4]. RF switches are commonly used in the communication applications due to their great isolation, less nonlinearity, less insertion loss and power consumption at microwave frequencies. Compared to PIN diode and GaAs FET, RF MEMS switches shows excellent performance. Switches are used in the applications like phase shifters, reconfigurable filters and antennas, switching networks, attenuator etc. [4]. MEMS switches generate open or short circuit in the transmission line. Switches are of two types one is either capacitive or direct contact type (ohmic or resistive contact). For low frequencies direct contact type switches are used. Capacitive switches are preferred for high frequency applications. Another category is either shunt or series type. A fixed-fixed beam is used in shunt and a cantilever beam is used in series type switches [5]. The switch is actuated by using thermal, piezoelectric, magnetic, electrostatic mechanisms [5-8]. Out of different actuation methods electrostatic actuation is mostly preferred because of less switching time, lesser size and power consumption. In addition to advantages, some draw backs like higher actuation voltage and lower switching speed, switch lifetime, fractures beyond some switching cycles, low power handling ability and generation of residual stress during fabrication results in low yield. [9-11].

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A cantilever switch with 0.37dB insertion loss, less than 22dB, and an isolation of 23.5dB with an actuation voltage of 6.39V is designed [12]. A DC contact switch was designed with an actuation voltage of 6.4V and insertion loss of -0.08dB and isolation loss of -22dB [13]. A RF MEMS series switch with an actuation voltage of 4.2V and an insertion loss of 0.067dB and an isolation loss of 16dB is designed [14]. Several RF MEMS series type switches are proposed in the literature [15-18].

Here we demonstrated an Electromechanical analysis of a Proposed RF MEMS Capacitive Series Switch. We plot the electromechanical behavior of the switch for different materials, widths and thickness of beam, and for different air gaps and different dielectric materials. Based on this behavior optimized geometrical parameters are finalized for the switch. After that we analyze the RF Performance using HFSS. The organization of the paper is as follows: Section-II, explains the design and theoretical analysis of the proposed switch. Section-III deals about the results and discussions of the switches. Section-IV concludes the paper.

II. THE PROPOSED SWITCH DESIGN AND THEORIATICAL ANALYSIS

In series switch, the beam is fixed at one end and other end of the beam is actuated by applying a voltage. The displacement will reach its maximum value when the applied voltage is maximum. When there is no applied voltage between top electrode and actuation electrode the switch is in OFF state and the capacitance between beam and signal line is low so that the output is disconnected from the input. When we apply a voltage, the Switch is actuated so that the beam is pulled down to 2/3 of the initial gap. In this condition the capacitance between bema and signal line is high so that the output is connected to the input.

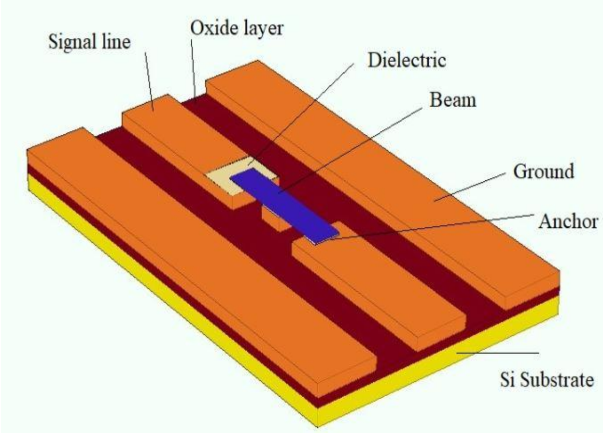

FIGURE 1. **Schematic of proposed RF MEMS switch.**

The schematic of the proposed series switch is as seen in fig 1. Substrate is silicon (dielectric constant 11.68) with thickness 20 µm. An oxide layer of SiO2 (dielectric constant 3.9) with thickness 15 µm is placed on top of the substrate. A metallic membrane placed over signal line of CPW (coplanar waveguide) and one side is fixed on the anchor placed on the ground line . A dielectric layer Si3N4 (dielectric constant 7) of thickness 220nm is placed on the signal line.

Typical dimensions of the proposed switch is as shown in TABLE I.

TABLE I
DIMENSIONS OF THE PROPOSED SWITCH

S. No	Structural Element	Dimension, µm
1	Substrate thickness	20
2	Ground and Signal line thickness	15
3	Dielectric layer thickness	0.22
4	Oxide layer thickness	10
5	Bridge Length	145
6	Bridge Width	30
7	Bridge Thickness	1
8	Airgap	2

Various parameters of the switch are explained below.

A. Spring constant

The spring constant of a cantilever beam is given by [5]

$$k = \frac{2}{3} Ew(\frac{t}{l})^3 \qquad (1)$$

where w =beam width

W= width of the signal line under the beam

B. Actuation Voltage

It is calculated [5] by using below equation [2].

$$V_p = \sqrt{\frac{8kg_0^{\ 3}}{27\varepsilon_0 Ww}} \qquad (2)$$

Here g_0= Air gap, ε0 = free space permittivity

Mechanical resonant frequency

The frequency of resonance of a mechanical spring is given by [5]

$$\omega_0 = \sqrt{\frac{K}{m}} \qquad (3)$$

C. Switching time

The time taken to switch from On to OFF is switching time and inverse is its speed. The switching time is given by [5]

$$T_s = \frac{3.67V_p}{V_s\omega_0} \qquad (4)$$

Where V_P =pull-in voltage

V_S=supply voltage, $V_s = 1.4V_P$

D. Up-state capacitance (C_{on})

The Upstate Capacitance Con is calculated as [5]

$$C_{on} = \frac{\varepsilon_o Ww}{g + \frac{t_d}{\varepsilon_r}} \qquad (5)$$

E. Down-state capacitance (C_{off})

The downstate capacitance can be calculated as [5]

$$C_{off} = \frac{\varepsilon_o \varepsilon_r Ww}{t_d} \qquad (6)$$

F. Capacitance Ratio (C_{ratio})

The ratio of two capacitances is given by. [5]

$$C_{ratio} = \frac{C_{off}}{C_{on}} \qquad (7)$$

Table II

TABLE II shows the theoretical parameter values of the proposed switch.

RF MEMS SERIES SWITCH THEORETICAL VALUES

Switch parameter	Shunt switch
Spring constant	0.518 N/m
Pull-in-voltage	22.81V
Switching time	33.36µs
Upstate capacitance	0.286pF
Downstate capacitance	3.93fF
Downstate to upstate capacitance	72.8

III. RESULTS AND DISCUSSIONS

1. Electromechanical analysis of capacitive series switch

A. Effect of beam width

Fig. 2 presents the variation of pull-in voltage for change in beam widths. Here we simulated for three beam widths of 20,30 and 40 µm with fixed airgap of 2µm. Observed pull-in voltage of 40,38 and 35V for three beam widths respectively, for a displacement of 2/3 of initial height (1.3 µm). A beam with higher width has a lesser pull-down voltage compared to with smaller width. For our design we have taken beam width of 30µm.

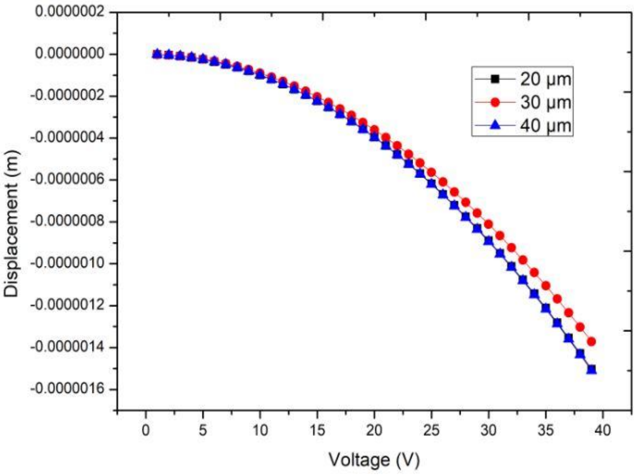

FIGURE 2. Simulated displacement graphs for various beam width values.

B. Effect of airgap

Actuation voltage is presented in equation (2). Pull down voltage is directly proportional to $g_0^{3/2}$. As gap increases actuation voltage increases. Series switch designed to test with different airgap heights 1µm,2µm and 3µm as shown in fig. 3. Here beam width of 30 µm is fixed for all airgaps. Observed the pull-down voltages of 35,38 and 55 respectively for a displacement of 2/3 of initial height (1.3 µm). At 1µm airgap lesser pull-down voltage is observed. For our design we have taken an airgap of 2µm as it is the best for fabrication point of view.

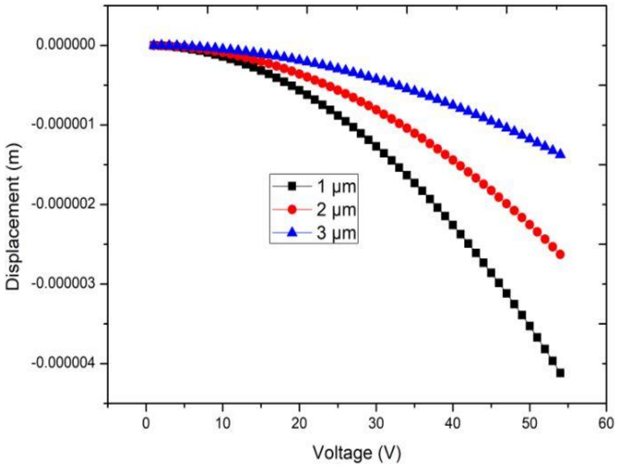

FIGURE 3. Simulated displacement graphs for various airgap values.

C. Effect of beam thickness

Fig. 4 presents the variation of pull-in voltage for change in beam thickness values. Here we simulated for three beam thicknesses of 0.5,1 and 1.5 µm with fixed airgap of 2µm and beam width of 30 µm. Pull-in voltage of 22.5,38 and 40V for three beam thickness values respectively for a displacement of 2/3 of initial height (1.3 µm). A beam with lesser thickness has a lesser pull-down voltage compared to with larger thickness values. For our design we have taken beam thickness of 1µm.

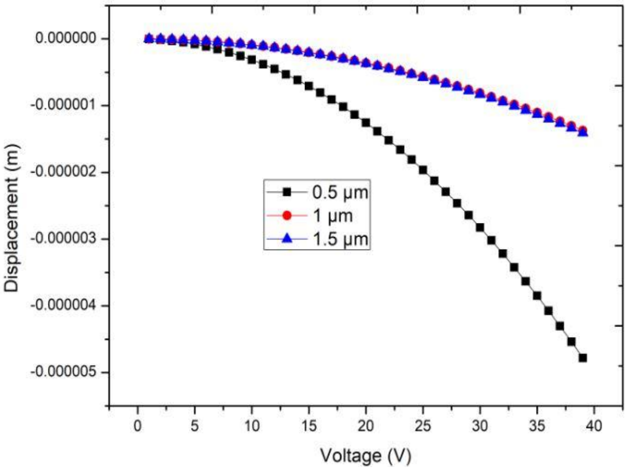

FIGURE 4. Simulated displacement graphs for various beam thickness values.

D. Effect of beam and dielectric materials

Fig. 5 presents the variation of pull-in voltage for change in conductors. Here we simulated for three conductors with fixed airgap of 2µm and beam width of 30 µm and beam thickness of 1µm. Observed the pull-in voltage of 38,45 and 55V for three conductors Gold, Copper and Chromium respectively for a displacement of 2/3 of initial height (1.3 µm). Gold is the best option for fabrication point of view.

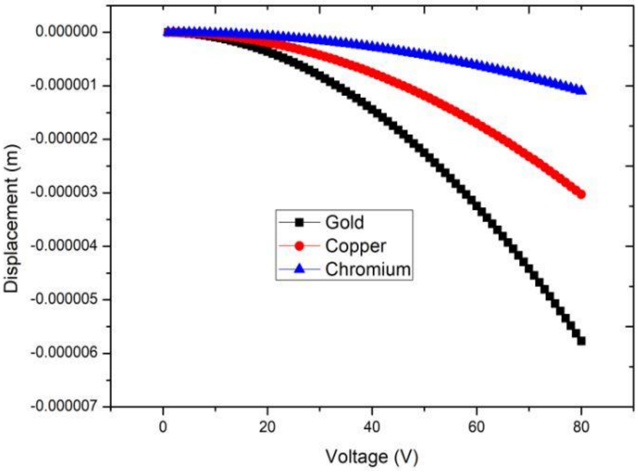

FIGURE 5. Simulated displacement graphs for various conductor materials.

Fig. 6 presents the variation of pull-in voltage for change in dielectrics. Here we simulated for three dielectrics with fixed airgap of 2µm and beam width of 30 µm and beam thickness of 1µm and Gold as conductor material. Observed the pull-in voltage of 30,30 and 38V for three dielectrics HfO_2, Al_2O_3, Si_3N_4, respectively for a displacement of 2/3 of initial height (1.3 µm).

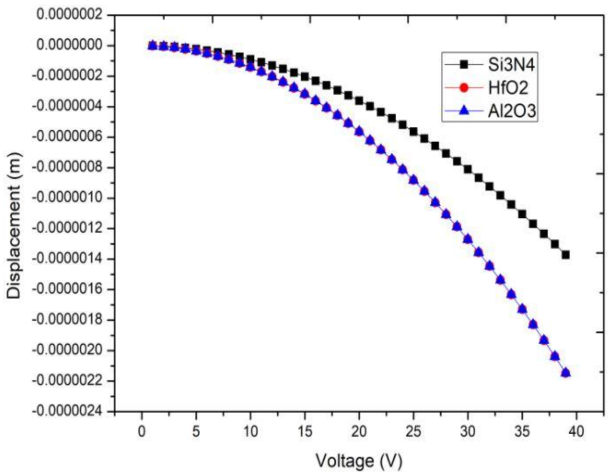

FIGURE 6. Simulated displacement graphs for various dielectric materials.

E. Switching time analysis

Switching time is a function of V_p, V_s and w_0 of the switch taken from equation (4). The plot of source voltage vs switching time is as shown in fig 7. At pull-in voltage i.e. 22.81, the switching time is observed to be 33.36µs.

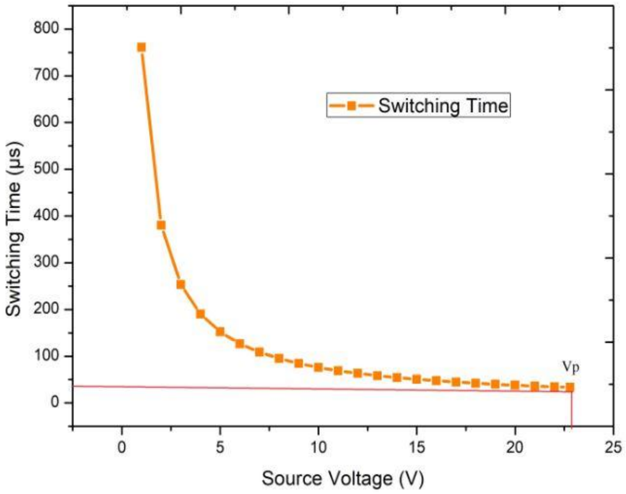

FIGURE 7. Switching time vs source voltage.

F. Up and downstate capacitive analysis

Capacitance ratio is a measure of the capacitance difference between two states of the switch. Up state capacitance is relying on the dielectric thickness and relative permittivity, beam area. From the fig. 8 the upstate capacitance of 0.286pF and down state capacitance of 3.93fF is obtained. So that the capacitance ratio obtained is 72.8.

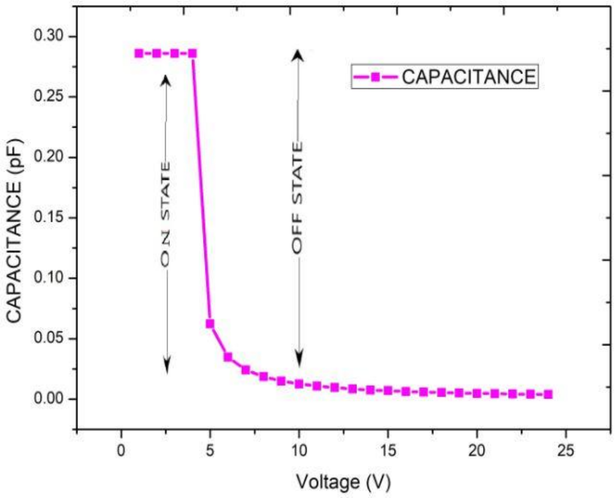

FIGURE 8. Series switch capacitance vs voltage curve.

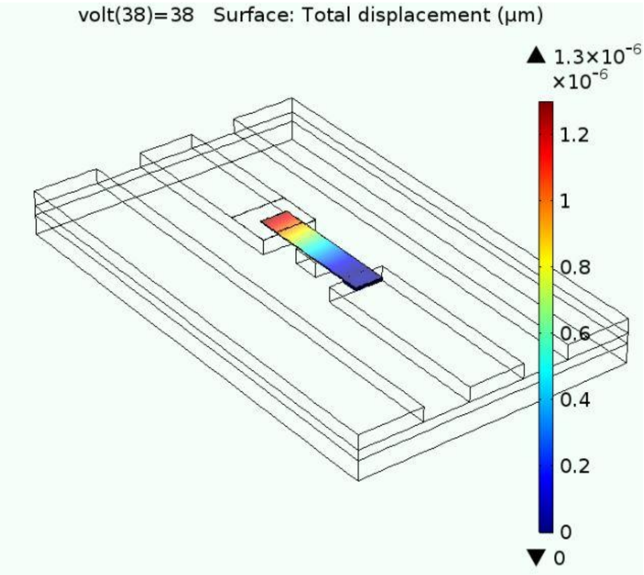

FIGURE 9. Beam deflection.

2. Electromagnetic analysis of capacitive series switch

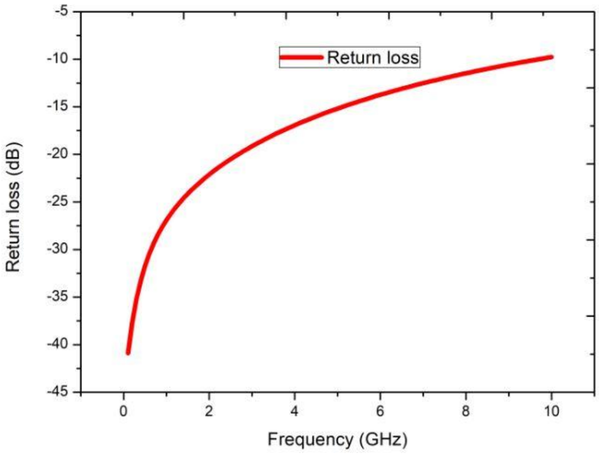

FIGURE 10. Return loss (s_{11}) of series switch in its ON state.

By using full electromagnetic wave analysis the switch S-parameter analysis has been done. The input and output impedance was takenas 50Ω. The return loss (S_{11}) is equal to input reflection coefficient. In the downstate (ON state) insertion loss and return loss will be calculated. The amount of incident power penetrate through the switch is called insertion loss. For RF MEMS switches insertion loss will be low. Figure. 10 & 11 presents the return loss and insertion loss in the ON state from DC-10GHz. At 3GHz, the return loass and insertion losses are -15dB and -0.1dB respectivley.

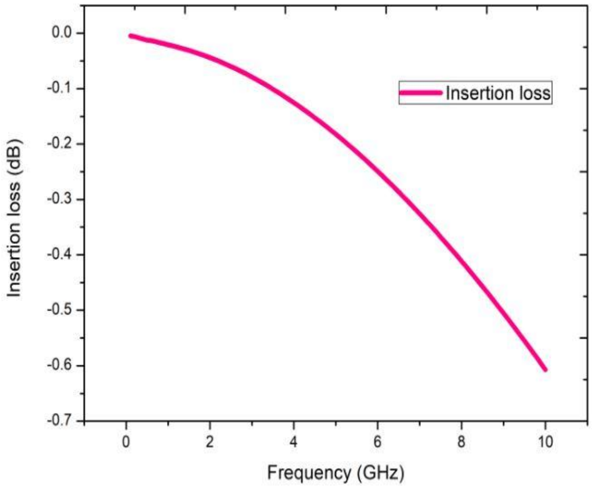

FIGURE 11. Insertion loss (s_{12}) of series switch in its ON state.

In the OFF state (upstate) the return loss and isolation loss will be calulated. The amount of power that leaks through the switch is isolation loss (S_{21}). For RF MEMS switches isolation loss will be high. Figure. 12 &13 presents the return loss and isolation loss in the OFF state from DC-10GHz. The simulation results are satisfactory as return loss and isolation loss values are-21dB and -0.1dB at 3GHz.

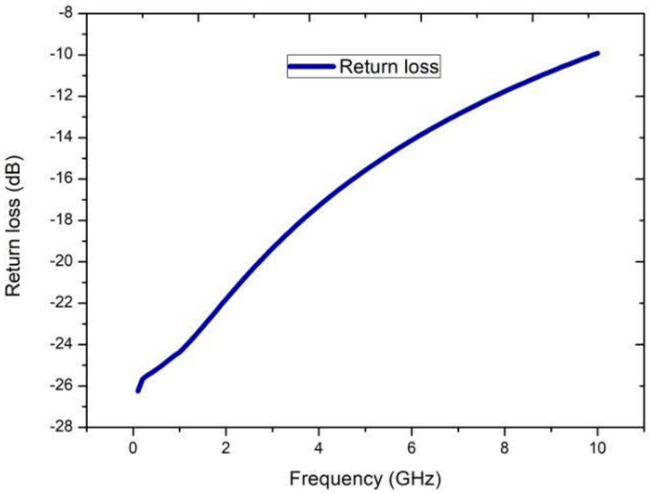

FIGURE 12. Return loss (s11) of series switch in its OFF state.

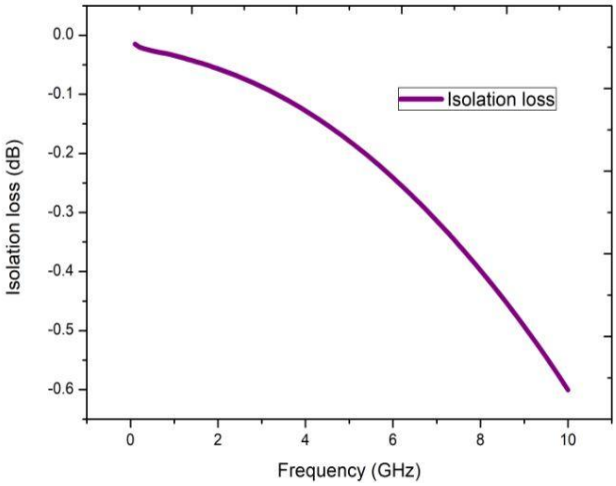

FIGURE 13. Series switch Isolation loss (s21) in its OFF state.

IV. CONCLUSION

In this paper, RF MEMS series capacitive switch is presented and investigated for tunable filter applications. RF performance in terms of S-parameters using HFSS and electromechanical performance in terms of actuation voltage using COMSOL is analyzed. Optimization is done based on different switch parameters. This paper gives a solution for better design and optimization of series switch. While optimizing the switch few conclusions are presented. Higher value of airgap will increase the actuation voltage. Beam width is inversely proportional to pull-in voltage. Beam thickness decreases the pull-in voltage decreases. The designed switch is having less insertion loss and high isolation loss from DC-10GHz.

REFERENCES

1. Attar SS et al.," Low-Temperature Superconducting DC-Contact RF MEMS Switch for Cryogenic Reconfigurable RF Front-Ends," IEEE Transactions on Microwave Theory Tech, vol.62, pp.1437–1447,2014.
2. Rajagopalan H et al.," MEMS Reconfigurable Optimized E-Shaped Patch Antenna Design for Cognitive Radio," IEEE Transactions on Antennas and Propagation, vol.62, pp.1056–1064,2014.
3. Daneshmand M et al.," Multi-Port RF MEMS Switches and Switch Matrices," Dissertation, University of Waterloo,2006.
4. Rebeiz, G. M.," RF MEMS Switches: Status of the technology," In The 12th IEEE international conference on solid state sensors, actuators and microsystems, pp. 1726–1729, June 8–12,2003, Boston.
5. G.M. Rebeiz, RF MEMS Theory, Design and Technology, Wiley, New Jersey, 2003.
6. Rebeiz, G. M., & Muldavin, J. B," RF MEMS switches and switch circuits," IEEE Microwave Magazine, vol.2, no.4, pp.59–71,2001.
7. Lahiri, SK., Saha, H., & Kundu, A," RF MEMS switch: An overview at-a glance," In International conference on computers and devices for communication,2009.
8. Varadan et al., RF MEMS and Their Applications, Colorado, Wiley.
9. Lee SD et al.," An RF-MEMS switch with low-actuation voltage and high reliability," Journal of Microelectromechanical System, vol.15, no.6, pp.1605–1611,2006.
10. Pacheco S et al.," Micromechanical electrostatic k-band switches," In Proceedings of the IEEE MTT-S international microwave symposium digest, vol.3, pp 1569–1572, Baltimore.
11. Shen SC et al.," Broadband low actuation voltage RF MEMS switches," In 22nd annual GaAs IC symposium, pp 161–164, Seatle.

12. Hamood Ur Rahman et al.,” Low Actuation Voltage RF MEMS Series Switch with Novel Beam Design,” 2008 International Conference on Emerging Technologies IEEE-ICET, Rawalpindi, Pakistan, 18-19 October 2008.
13. George Rahul Paull et al.,” Low Actuation Voltage: RF MEMS Series Switch,” IEEE WiSPNET 2016 conference, PP. 2383-2385, Chennai,23-25 Mar 2016.
14. Khadeijeh Khodadady et al.,” Design and modeling of a novel RF MEMS series switch with low actuation voltage,” Microsystem Technol, vol.22, pp.921–2929,2016.
15. Sharma AK et al.,” Electromagnetic modeling and parameter extraction of RF-MEMS switch,” Microsyst Technologies, vol.21, pp.181–185,2015.
16. Paul GR et al.,” Low actuation voltage RF MEMS series switch,” In International conference on wireless communications, signal processing and NETWORKING,2016.
17. Shen H et al.,” DC contact RF MEMS switches using thin-film cantilevers,” In IEEE European Microwave integrated circuit conference (EuMIC 2008), pp. 382–385,2008.
18. Molaei S, Ganji BA,” Design and simulation of a novel RF MEMS shunt capacitive switch with low actuation voltage and high isolation,” Microsyst Technology, vol.23, no.6, pp.1907–1912,2017.