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An Advanced Real Time Lead RF-MEMS Based Switch Design for AI Applications

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Abstract: The artificial intelligence-based MEMS switch designs have been led technology in present micro-electronic applications. The 4G and 5G communication hardware networks have working been through RF-MEMS switches. The earlier MEMS deigns are outdated in terms of functionality and compatibility, so that a realistic RF-MEMS based advanced configurations are compulsory for future electronic applications. In this research work 2 different shunt-capacitive type configurations have been implemented and those are verified on COMSOL Multi-physics toolbox as well as functionality been verified on HFSS software tool. The electromechanical properties of proposed shunt type RF-MEMS switch attained more perfection in functionality compared to past configurations. The implemented switching model has uniform meandering and derives pull-in-voltage of 18.5v along with 1.2xs switching time. The 2nd type shunt RF-MEMS model has been generated pull-in-voltage of 25.5v and isolation loss of 37.20. The performance metrics like Length 25.34 µm, Width 28.92 µm and Thickness 34.42 µm had been improved compared to previous models. The deigned shunt-capacitive type RF-MEMS models are most prominent in operation and offering advanced microelectronics applications.

Keywords: COMSOL, MEMS switch, anchors, meanders, HFSS

1. Introduction

Theoretical concept of miniaturization refers to the process of making smaller, more energy-efficient structures. This concept has been widely used in the field of electronic engineering. Most frequently, RF MEMS switches employed in the field of various applications similar to temperature sensors, pressure measuring equipment, and many more. They are very small and are made to work on a single semiconductor [1]. This product is mainly used in the space communication and wireless communication markets. Due to their comfortable and constrained design, they are usually used in space applications. These RF MEMS switches have higher performance and are also more flexible than the traditional switches. The following designs are also more energy-efficient. To match RF MEMS switching performance, it is fed to subject the testing of electrical and mechanical properties. Moreover, outcomes of these tests allowed to develop the most cost-effective and smallest possible versions [2]. This product is mainly used for high-frequency RF switches. It has a good lifetime and low resistance losses. It can also be widely used in multiband frequencies.

MEMS are frequently employed in radio frequency circuits and have a variety of uses. Metal to metal contact and capacitive contact are two forms of RF MEMS switches. The most prevalent kind of connection switch is one that connects metals to metals [3]. These RF MEMS switches have shown to outperform solid state switches due to their low power consumption and high RF power handling capabilities (such as p-i-n diodes and field effect transistors). When compared to cantilever-based switches, RF MEMS switches based on capacitive fixed-fixed technology have exhibited greater isolation and less insertion loss at higher frequencies. The behaviour of a fixed-fixed RF MEMS

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switch operating at microwave frequencies has been reported by a number of researchers. MEMS have distinguished themselves from their component components in a variety of applications such as optical, mechanical, and fluidic systems due to their downsizing, dependability, and simplicity of assembly. Among other things, they have a high tuning ratio, minimum resistive losses, and a high self-resonant frequency. Despite worries regarding issues like as RF power management and electrostatic stresses, substantial research is being done to lower the actuation voltage of RF MEMS switches [4].

RF MEMS switches may be broadly characterised as either shunt or series contact types, or as ohmic contacts, depending on their use. In the case of cantilever beams, series switches are used, while fixed–fixed beams are used in the case of shunt switches [5]. Although there are many alternative actuation techniques available, none of them is capable of avoiding structural complications, poor switching speeds, and higher power consumption. By utilizing an electric actuation mechanism, we can achieve low actuation voltage and negligible power consumption. For RF MEMS switches, there are numerous ways to reduce the pull-in voltage, including adjusting the beam diameter and/or dielectric air gap. It is suggested to use a capacitive form of shunt switch for millimetre wave applications. The dependability of metal-to-dielectric contacts was found to be superior than that of metal-to-metal ohmic contact switches when comparing the two types of contacts [6].

Switches for high-frequency transmission using MEMS technology are becoming more common. For solid-state technology switches, MEMS technology has a tough fight on its hands, but in the high-frequency region, MEMS RF switches are showing remarkable promise [7]. They are being utilized to make devices for 5G networks because of their low power consumption. There are two key hurdles in designing and manufacturing capacitive MEMS switches: low pull-in voltage and high isolation. The switch's pull-in voltage is reduced by the serpentine structure's meandering. Devices with semi-circular arc-shaped curves on each side of the switch with varying flexures such as uniform & non-uniform meandering are chosen in order to address the issues in the literature stated above. The beam is etched with etching holes [8][9]. With the bottom-up approach, the suggested capacitive dimple type novel switch is optimized for Ka band applications [10].

The RF MEMS based micro-electronic switches has been used in different wireless communication applications, more overs recent technologies like IoT, phase shifting and tunning filters with AI operations has been deepening on MEMS switches. The designs like shunt capacitive, series capacitive, series contact type and shunt contact type models are most useful in AI based microelectronic application [11]. The organisation of paper as follows in section 1 brief discussion of MEMS designs have been discussed. Section 2 clearly explains about literature survey of RF-MEMS configuration and differentiated limitations compared to earlier techniques. Section 3 has been explained about proposed shunt type RF-MEMS modelling. Section 4 discussing about results and discussion as well as section 5 depicts conclusion of research work.

2. Literature Survey

Fundamental aspect under the structures of MEMS is to overall performance of the system. It represents the substrate that is used in the single chip. Silicon wafers are very flexible and are very much suitable for various microstructures. In addition to this, Silicon nitride is also used for high frequency components [12]. This material has many properties that make it more stable over different temperature conditions. It does not get affected by oxidation and provides a better electric constant [13]. The meanders factor can also be used to estimate the spring constant. This factor helps in estimating the stiffness factor of a design [14] [15]. The fixed-fixed beam capacitive shunt switch is the most common of all the RF MEMS switch types. The most often used transmission lines for RF MEMS devices are micro strip and coplanar waveguide (CPW) [16][17]. Micro strip lines, on the other hand, do not have the potential to integrate a lumped component in both series and shunt topologies, but CPW transmission lines can estimates more accurately [18][19]. The MEMS switch with a CPW transmission is seen in figure 1.

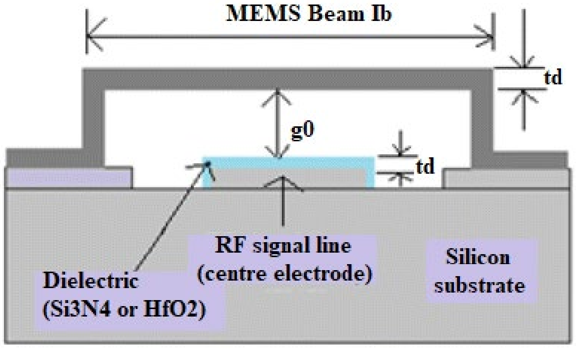

Fig. 1 - Switch with Si3N4/HfO2 dielectric

Switch-beam capacitance rises when a DC voltage is placed between the MEMS Bridge to the CPW, resulting in an electric forces causing switch beam collapsing on the dielectric substrate [20][21]. CPW transmission line is connected to the ground through this capacitor [22][23]. There are tiny holes designed on the beam to decrease damping and speed up switching when the switch is being pushed down [24][25].

Table 1 - literature survey

S No	Technique	keynote	Limitation	Advanced model
1	RF MEMS fabrication method [26]	The RF MEMS switch fabrication has been implemented through HFFS software tool. The performance measures are not that much improved compared to available MEMS switch.	Measures like switching time and pull in voltage are less accurate.	Electromagnetic model for MEMS design
2	RF-MEMS capacitive shunt switch [27]	The 5G application purpose a capacitive shunt-based MEMS switch design.	The energy consumption as well as area of design is more for this capacitive type.	CNN model-based MEMS design
3	RF-MEMS switch with EMF design [28]	A 5G design for RF MEMS	The shunt capacitive based MEMS design cannot handle	Micro-electronic MEMS design
4	Design of KA-band based RF-MEMS [29]	This RF design is most suitable for automatic robotic applications	Less sensitivity of operation	RF-MEMS with Electromagnetic
5	Micro and nano system for RF-MEMS system [30]	RF MEMS capacitive based switch for future electric application	Capacitive RF-MEMS design can be restricted at less frequency of operation	Nono electronic MEMS design

The above table 1 clearly explains about brief survey on RF-MEMS design analysis, here many models are facing limitations those are cross over by proposed design.

1. 2.1 RF MEMS Switch

Benefits for switching of RF MEMS are many, such as smaller size, better reliability, and higher performance. They can also reduce the overall power consumption. RF MEMS dimensions under switch have minimal value and it has a good capacitive mechanism. It is mainly used for controlling the transmission of radio frequency signals. Basically, these two types of switches are known as series switch and shunt switch. The former has the maximum isolation capacity, and the latter has the minimum. This switch has configuration of beam surface incorporated at flexible electrode zone. Switch starts working, and then instant the signal transmission appears.

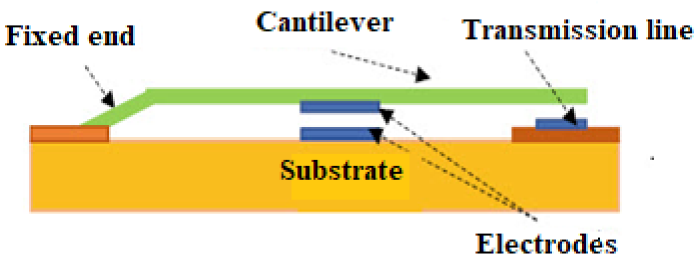

Fig. 2 - Cantilever beam type RF-MEMS switch

It is possible to do RF switching utilizing a variety of methods. Electro-mechanical RF switches and solid-state RF switches are the two primary kinds of RF switches competing with RF MEMS switches. For example, silicon or PIN diodes, FETs (field effect transistors), and hybrid technologies integrate PINS and FETs into a single device, which is constructed on silicon substrates. As RF-SOI (Silicon on Insulator) based switches continue to improve, RF MEMS switches compete with them. RF-SOI switches are now the most popular option. RF MEMS switches come in a wide variety of shapes and sizes and may be operated in a variety of ways. MEMS switch designs often use electrostatic actuation because of its low power consumption and tiny size. In addition to inertial, electromagnetic, electrothermal, and piezoelectric force, MEMS switches may also be opened or closed. A "cantilever beam" RF MEMS switch is seen in Figures 2. A fixed beam is suspended above a substrate in this arrangement. By forcing the beam to touch the substrate, an electrode on the beam activates the switch, completing the circuit.

3. Proposed Methodology

In this section shunt type RF-MEMS designs have been explained and verified at outstanding conditions. The proposed 2-type RF-MEMS shunt switches with capacitive nature is stimulated together and further development initiated through uniform and non-uniform meanders. The process is initiated with best suitable choice of materials, like instance silicon (substrate material with 450µm length), correlated under the switches holding CPW, within the sequential system of Ground and Signal line. The capacitance is further improved through portioning the surface of beam with signal dielectric. The Beam is fixed between two ends with the support of anchors. Beam with Perforations and meanders benefits to diminish the pull in voltage level. Proposed shunt-based RF MEMS switch representation is depicted normal functionality under typical conditions. Also, shunt RF-MEMS model requirements have been charted in below table 1 and 2.

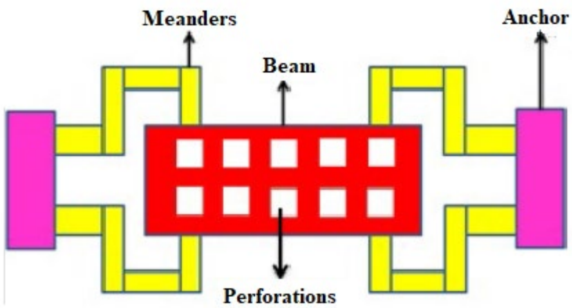

Fig. 3 - Proposed switch 1

Figure 3 is clearly explaining about proposed MEMS switch design, in this Meanders, beam Anchor and perforations are giving good functionality. The capacitive nature can balance switching time as well as performance accuracy. The air beam has been stimulating electric and mechanical properties, moreover substrate, oxidation layer, CPW signal line, Anchors and beam elements metrics are improved.

Table 1 - Design specifications of proposed switch 1

Parameters	Length (µm)	Width (µm)	Thickness (µm)	Materials
Substrate	440.0	400.0	4543.0	Si
Oxide layer	450.0	400.0	100.0	Sio2
CPW ground	143.5	400.0	100.0	Gold
CPW signal line	69.0	400.0	100.0	Gold
Dielectric layers	67.0	67.0	0.1	Si3N4
Anchors	30.0	80.0	0.1	Au
Beam	120.0	44.0	5.0	Au, Cu, Ni
Meander d	10.0	25.0	5.0	Au, Cu, Ni
C	30.0	10.0	5.0	-
B	10.0	35.0	5.0	-
A	25.0	12.0	5.0	-

The above table 1 explains about different elements discussion with various materials, length, width and area. It is noticed that proposed design is attained good improvement in terms of performance \measures like switching time.

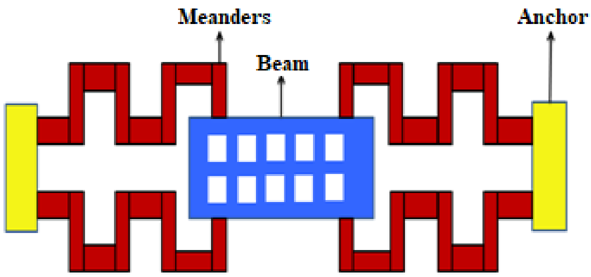

Fig. 4 - Switch 2 projected

Figure 4 is clearly explaining about projected switch 2 design, in this materials length and width is adjusted. The projected switch with design metrics is improved with respect to switching assignment. The air beam gap between plates have been adjusted with shunt capacitive property, so that RF-MEMS is self-trained in complex functionality condition.

Table 2 - Model requirements of switch 2 projected

Parameters	Length (µm)	Width (µm)	Thickness (µm)	Materials
Substrate	440.0	400.0	4543	Si
Oxide layer	450.0	400.0	100.0	Sio3N4
CPW ground	150.0	400.0	100.0	Gold
CPW signal line	65.0	400.0	100.0	Gold
Dielectric layers	65.0	65.0	00.5	Si3N4
Anchors	30.0	80.0	0.5	Au
Beam	120.0	44.0	01.5	Au
Meander 1	10.0	30.0	01.5	Au
Meander 2	30.0	10.0	01.5	Au

The above table 2 is clearly explains about various materials substrates design, here SI, Gold, AU and Si3N4 are verified. The above elements of length, width, thickness and materials metrics are verified on HFSS software tool and noticed that RF-MEMS design perseverance. The meander 1 of length 30.0 (µm), width 10 (µm), thickness 1.5 (µm) and Au material have been selected for design. The following parameters are most prominent to technology and verified on COMSOL software tool & HFSS Simulator tool. The performance of RF-MEMS conduction as well as electro-mechanical properties are clearly analysed in simulations. Moreover, this investigated MEMS proposed switch is a beam structured model.

RF-MEMS capacitive shunt design

Step :1 estimate material types
Materials = {Substrate Oxide layer, CPW ground, CPW signal line, Dielectric layers Anchors Beam Meander 1 Meander 2}
Step:2 parameters training
If K>1;
Noted as spring constant is valid
Else
K==0;
Step :3 Interpretation of Capacitance
If $C_u \sim C_d$
Assign surface capacitance== (increase)
Else
Load capacitance = C_d
Step :4 switching period t_s and stress {< T_h}
While ts, S < T_h

RF-MEMS == $V_P = \sqrt{\frac{8kg_0^3}{27\varepsilon_0 A}}$
Else S, ts == 0;
End if
End if
End while

End
Step: 5 processes for HFSS and COMSOL design fabrication

3.1 Spring Constant (K):

Fundamental parameter K analyse the behaviour under mechanical aspect of switched functioning, in this l^3 is improved by spring constant shown in equation 1. Theoretically, it is relying on stiffness of beams.

$$k = \frac{Ewt^3}{l^3} \qquad (1)$$

3.1.1 Pull in Voltage (Vp):

The actuation of switch is generated in an electrostatic way through pull-in voltage. Pre-requisite voltage is energized through triggering voltage integrated towards the spring constant (K); this analysis is shown in equation 2. The transition periods of switching are employed for the purpose of minimal range in voltage levels under DC, later supporting with the beam-oriented contact for layer development of dielectric signal.

Formulated equation for pull-in voltage (Vp) can be given as

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

The spring constant and pull in voltage are major parameters in MEMS switch design, in this formulated switching time is continually altering with connectivity as well as pull-in -voltage. The following elements has been balanced through K and Vp elements. The type-1 and type-2 RF-MEMS switch total displacement is get improved with proposed capacitive shunt design.

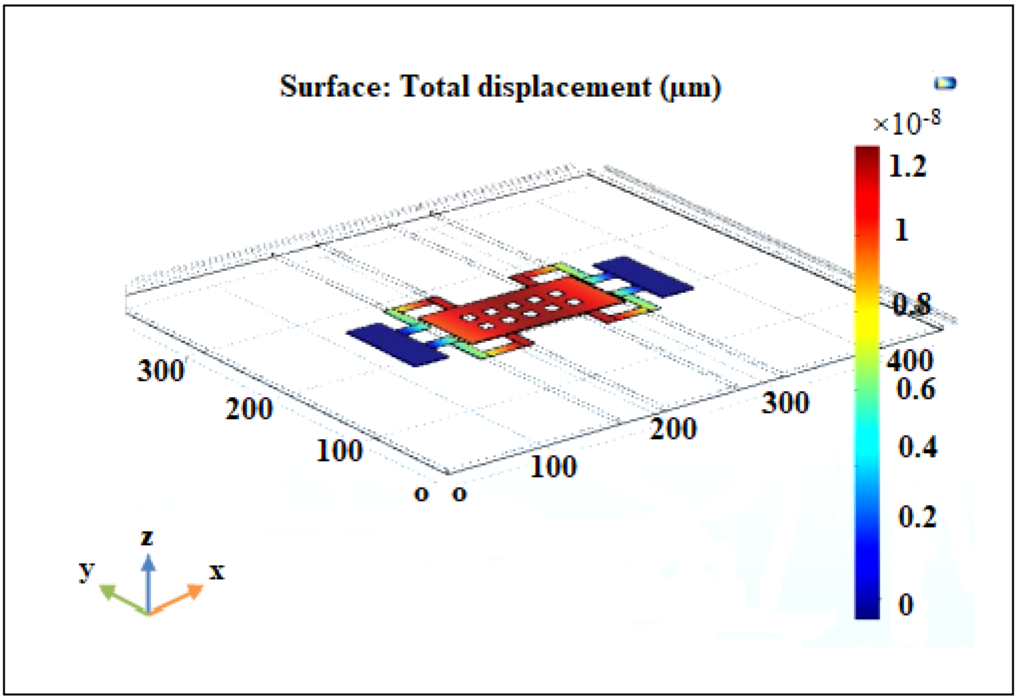

Fig. 5 - Proposed switch 1 case with electromechanical analysis

The above figure 5 is clearly explains about electromechanical analysis of proposed switch 1, in which total displacement is fixed at 25.34 µm, which is good improvement. The X, Y and Z axis are representing area of RF-MEMS design, such that beam, anchor and meander have been perfectly onboarded on MEMS chip.

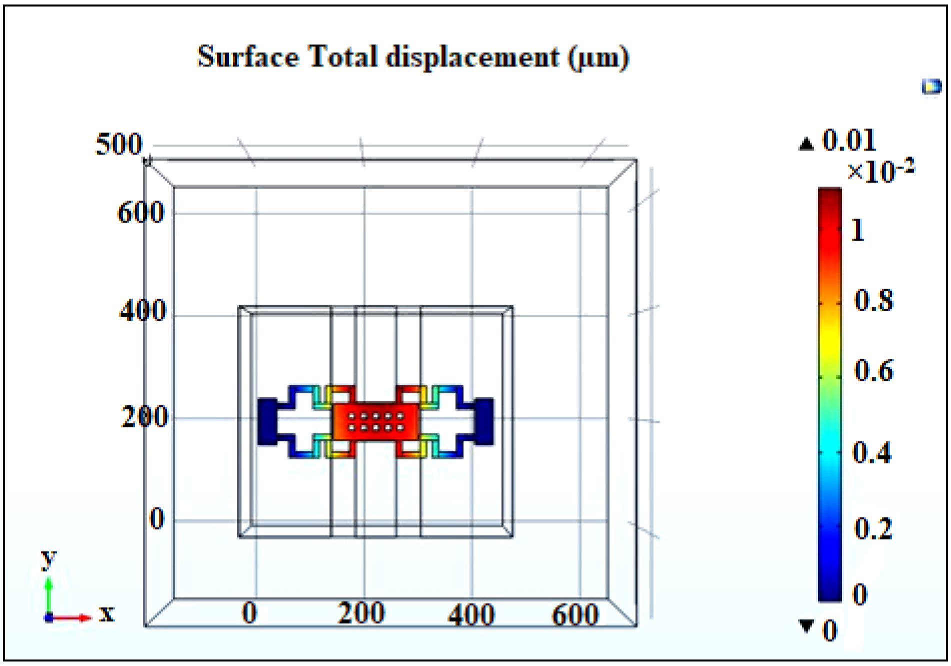

Fig. 6 - Electromechanical study of the proposed switch 2

For the case of switching displacement value, the electromechanical analysis demonstrated the voltage actuated shown in figure 6. The designed switch 2 with capacitive shunt configuration has been decrease the load of switching time along with performance efficiency.

3.1.2 Interpretation of Capacitance:

Fundamental aspect of switching RF-MEMS considered to be an investigation of Capacitive Evaluation. The performance of switch under the characteristics will be obtained within the state of capacitance, it is up and down the state of response. The beam material and signal dielectric have been balanced through beam gap established, based on capacitance at up state case, rather within no existence of air gap can signifies the capacitance state which is shown in Equation 3. The developed interpretation of capacitance has been followed below elements relationship.

$$C_u = \frac{\varepsilon_0 A}{g_0 + \frac{t_d}{\varepsilon_r}} \qquad (3)$$

Induced electrostatic force with voltage that has been utilised for the province of beam creates collapse towards down [20]. The capacitance which resulted due to collapse of beam is termed as downstate capacitance, which represents OFF state position of the switch. Equation 4 developed under the capacitance case for downstate (Cd) is stated.

$$C_d = \frac{\varepsilon_0 \varepsilon_r A}{t_d} \qquad (4)$$

Here, thickness d, signal dielectric will be td, beam relative permittivity denoted with '$\mathscr{E}$r' , '$\mathscr{E}$0' indicates air relative permittivity, and area is 'A' are elements involved in the down state capacitance.

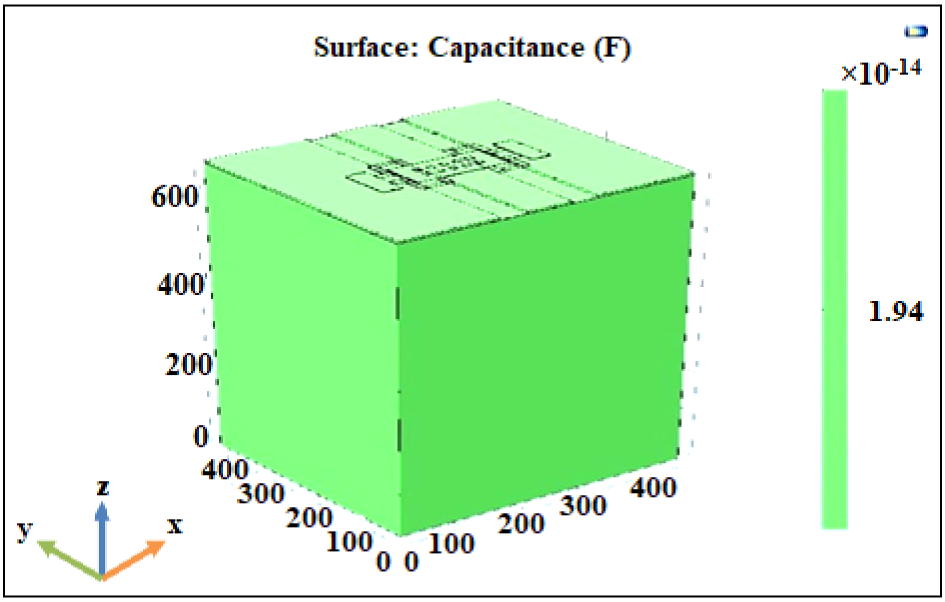

Fig. 7 - Interpretation of Shunt Capacitance under the switch 1 of RFMEMS

The above figure 7 is clearly explains about shunt-based capacitance, switch 1 configuration in which surface elements like width, length, anchor and beam have been improved compared to earlier RF-MEMS switches.

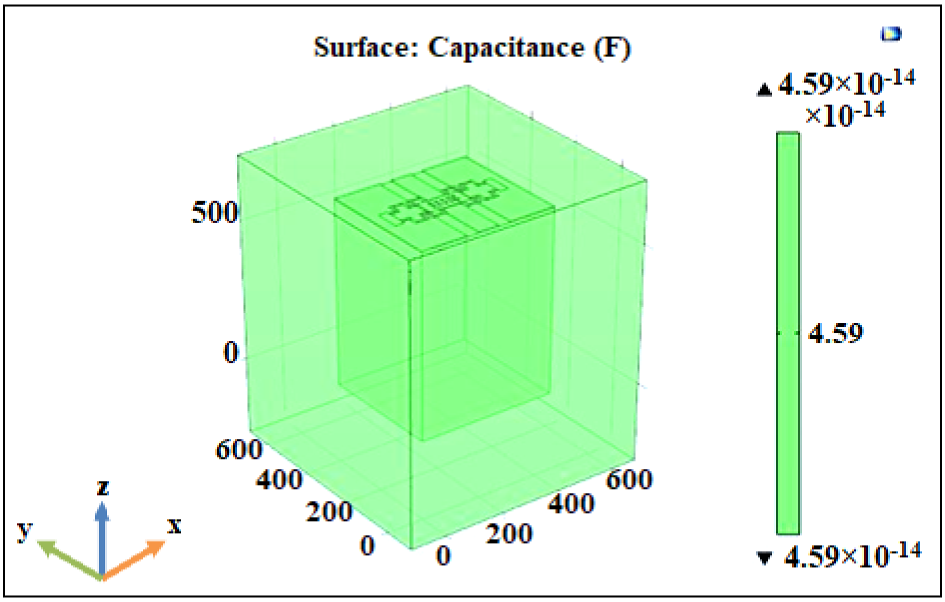

Fig. 8 - Interpretation of Shunt Capacitance under the switch 2 of RFMEMS

Figure 8 is clearly explaining about surface capacitance of RF-MEMS, in this switch 1 and 2 are giving X, Y and Z scale surface design. The shunt capacitance switches are most superior in switching time and operated at less area under the curve. This design is most useful for future AI based RF-MEMS applications.

3.1.3 Investigation of Switching Period

Depending on switching period, the speed can be transitioned. Mostly correlation property is developed among pull-in voltage (Vp), angular frequency, as well as supply voltage (Vs). Mathematically, the switching time is stated as follows at Vp and Vs, which has been shown in equation 5.

$$t_s = \frac{3.67V_P}{V_s w_0} \qquad (5)$$

3.1.4 Investigation of Stress

However, switch contortion is relative with beam enforced operations, which propagate uniformly those relation is shown in equation 6. Equivalent to stress, contra is attained within the proportional relation under the cross sections and dimensional criteria of straight enforcement.

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} \qquad (6)$$

Mathematically, force is stated as follows which is shown in equation 7,

$$\text{Force(f)} = \frac{\varepsilon_0 \varepsilon_r V^2}{2d^2} \qquad (7)$$

Here, beams relative permittivity is given as '$\mathscr{E}$r', '$\mathscr{E}$0' indicates relative permittivity of air, beam length symbolises 'l', beam width generalised with 'w', d suggests among signal line and beam for air gap, along with V denoting the suggested switch pull-in voltage (Vp).

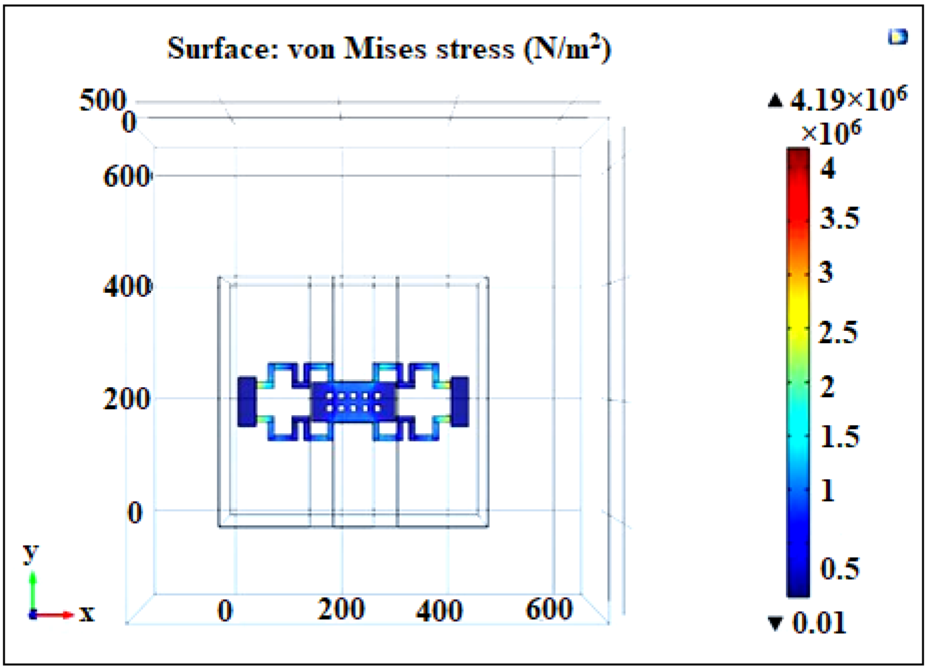

Fig. 9 - Switch 1 undergoing the investigation of stress for shunt-based RF MEMS

$$b = \frac{3}{2\pi} \frac{\mu A^2}{g^3} = 0.033 \times 10^{-3} \qquad (8)$$

The above equation 8 and figure 9 explains about shunt-based RF MEMS design according to beam value. In this analysis 'μ' representing that viscosity of air, A denotes that area electrode beam portioning.

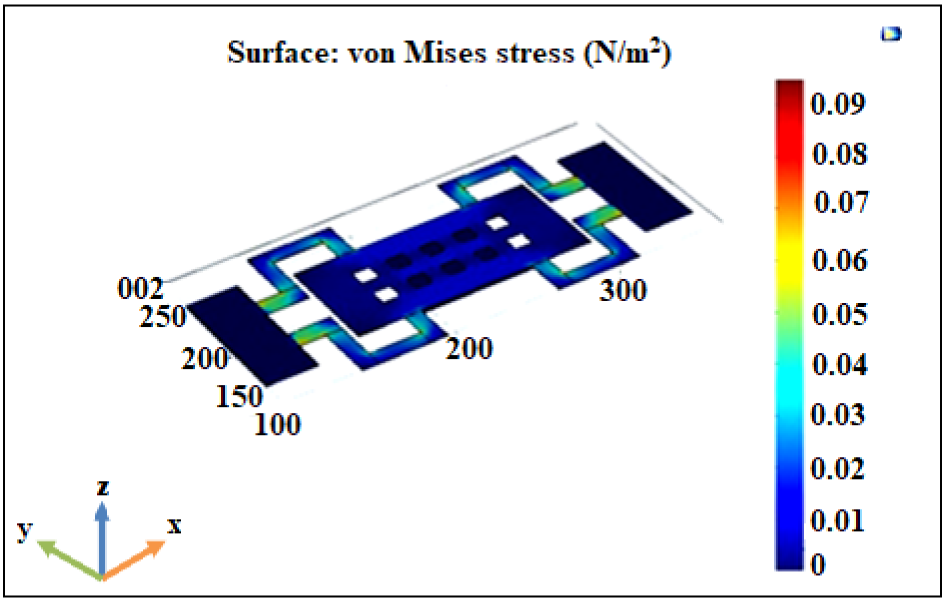

Fig. 10 - Switch 2 undergoing the investigation of stress for shunt-based RF MEMS

$$Q = \frac{K}{2\pi f_0 b} \quad (9)$$

The above figure 10 and equation 9 clearly explains about surface and stress on RF MEMS, in this proposed design is mostly concentrate on area and stress reduction point of view. The Q representing that impact of quality factor. At any instantaneous Q factor must be selected amongst the range of 0.6 and 2.

4. Results and Discussion

The proposed method switching action is analysed on HFSS toolbox with COMSOL software tool. The return Loss, and insertion loss has to be determined with switching conditions, although isolation will be computed upon evaluation under the condition at downstate region as well as feature fusion technique is imported from [25].

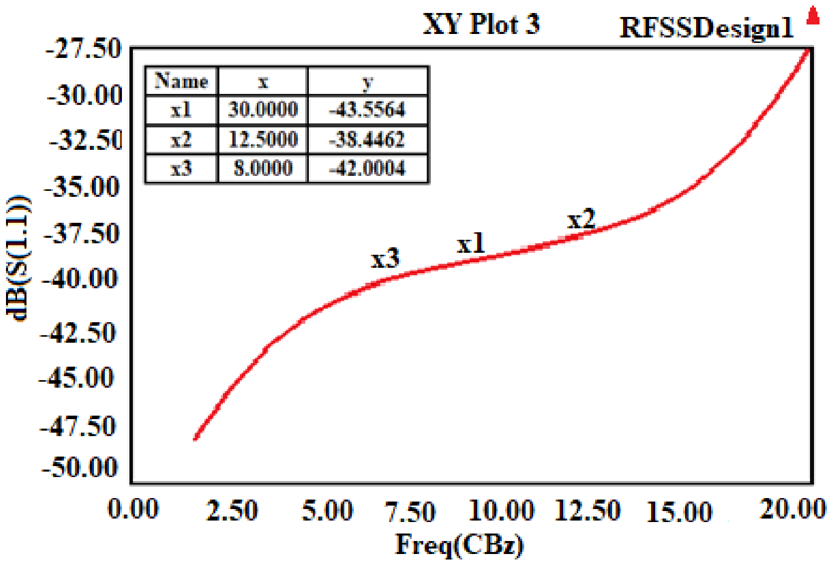

Fig. 11 - Analysis of return loss for switch 1 employing HFFS toolbox functions for investigation with simulation outcomes

The above figure 11 is clearly explains about HFSS based RF MEMS return loss analysis in this compared to earlier models proposed design attains more improvement. The frequency vs dB graph is mostly balanced at x1, x2 and x3 points. The above graphical analysis is linear at -32.00 dB to -45.00dB conditions.

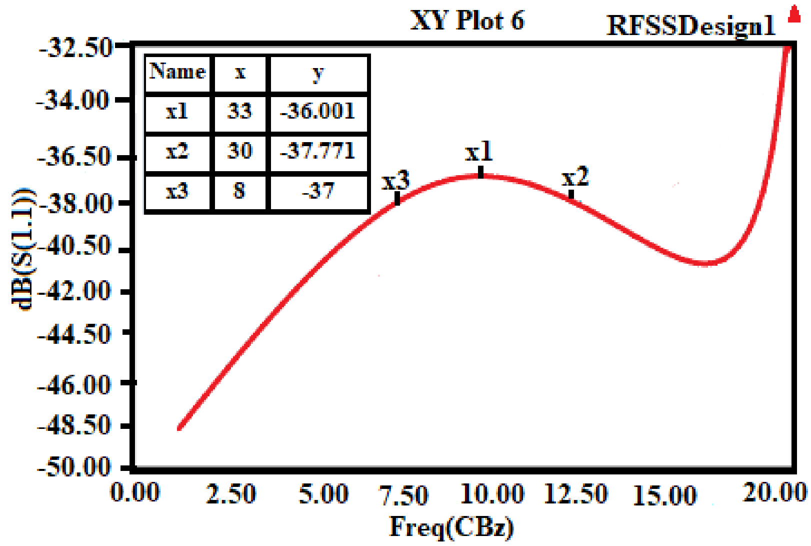

Fig. 12 - Analysis of return loss for switch 2 employing HFFS toolbox functions for investigation with simulation outcomes

The above figure 12 is clearly explains about switch 2 analysis which is identified on HFSS tool, in this return loss is more improved compared switch 1. The micro-electronic system with RF-MEMS magnetic properties have been altered at -40.50 to -42.00 dB as well as DC parameters is varying from 50 to 120 volts at DC-to-DC fed varied by 0 to 5 volts.

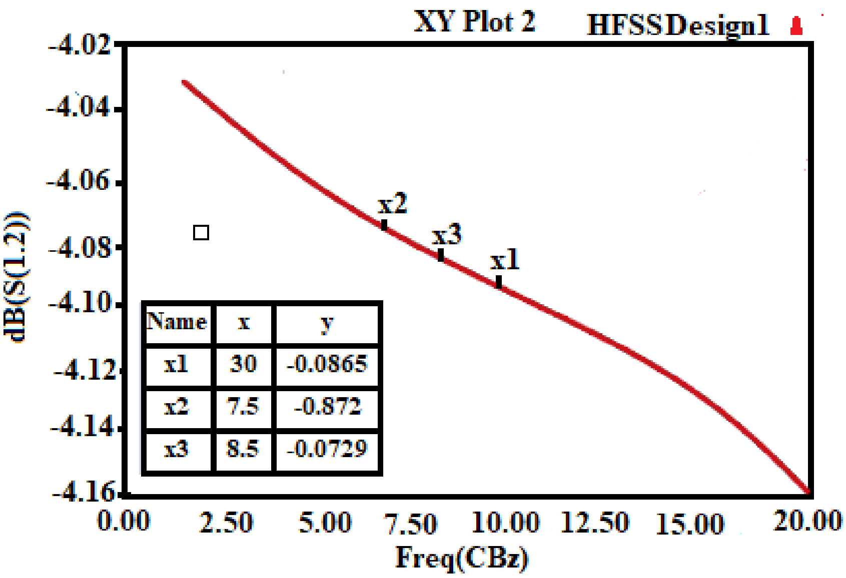

Fig. 13 - Analysis of insertion loss for switch 1 employing HFFS toolbox functions for investigation with simulation outcomes

The above figure 13 is clearly explains about Frequency vs loss analysis which is observed on HFSS tool. In this insertion loss has been locked at -4.06 (dB) and closed at -4.10 (dB) where frequency is varied among 0 to 20

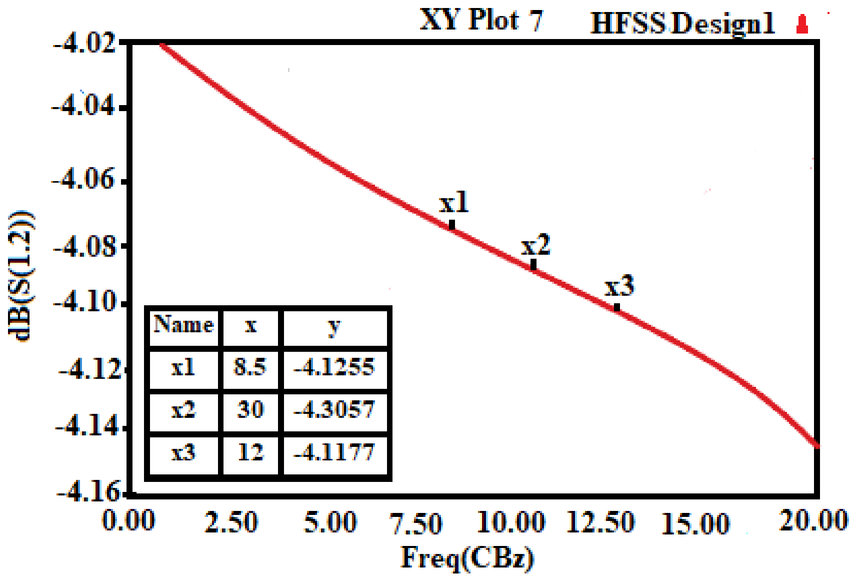

Fig. 14 - Analysis of insertion loss for switch 2 employing HFFS toolbox functions for investigation with simulation outcomes

The above figure 14 is clearly explains about insertion loss analysis with HFSS tool, in this various simulation outcomes are supporting proposed RF MESM design. The implemented design is operating with Self adapting property. The antenna design is useful for intelligence applications; the scale is more improved compared RF MEMS switch 1 design.

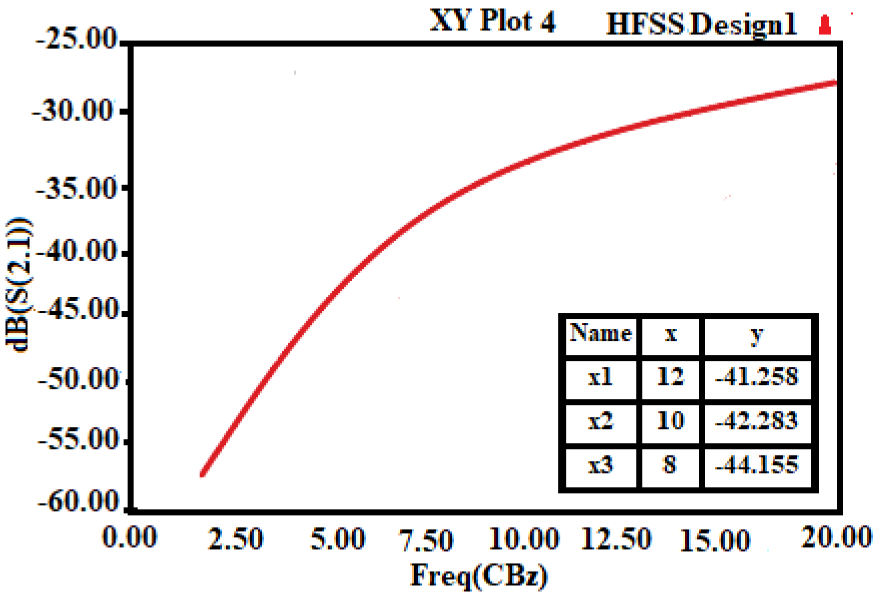

Fig. 15 - Analysis of isolation loss for switch 1 employing HFFS toolbox functions for investigation with simulation outcomes

The above figure 15 is clearly explains about isolation loss of Switch analysis, the HFSS tool is investigating simulation parameters.

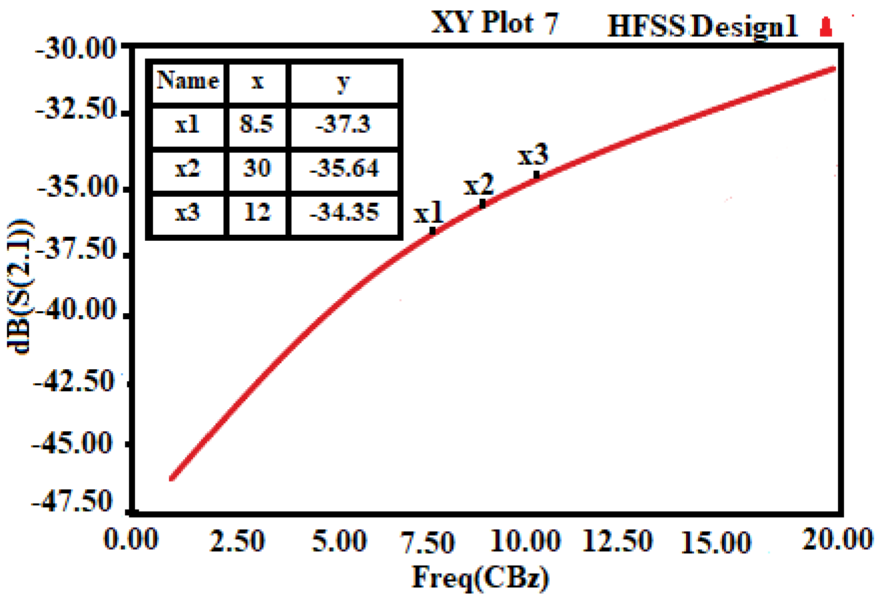

Fig. 16 - Analysis of isolation loss for switch 2 employing HFFS toolbox functions for investigation with simulation outcomes

The above figure 16 is clearly explains about switch 2 isolation loss of RF MEM, in this simulation outcomes are providing accurate improvement.

Table 3 - Comparisons of results

Parameters	M.Giridhar	Mafinejad and Kouzani	M. Tang	Proposed Switch 1	Proposed Switch 2
Pull-in (Vp) voltage	50V	20V	21.6V	16.9V	18.5V
Stress analysis	-----	-----	-----	1.286 MPa	6 Mpa
Switching time (ts)	-----	-----	25 µs	1.2 µs	2.5 µs
Upstate	-----	-----	137 fF	7.46 fF	5.12 fF
Capacitance (Cu)	-----	4.26 pF	3.9pF	1.25 pF	3.27 pF
Capacitance ratio	-----	-----	-----	16.75	1.46
Retum Loss (S11)	-----	25. dB	-----	-41.55 dB	-38.60 dB
Insertion Loss (S12)	-1.5 dB	1.5 dB	-1.46 dB	-1.0865 dB	-1.1177 dB
Isolation Loss (S21)	-32 dB	16 dB	-24 dB	-47.70 dB	-37.20 dB

The above table 3 is clearly explains about comparison of results, here return loss, insertion loss and isolation loss are mostly improved. The measures like Pull-in (Vp) voltage 16.9V, Insertion Loss (S12) -1.0865 dB, Isolation Loss (S21) -47.70 dB and Switching time (ts) 1.2 µs has been attained which are most prominent so that it is suggested that RF-MEMS switch is useful for future AI application.

5. Conclusion

In this research work, two various capacitive shunt type RF-MEMS switches design and its performance has been verified on COMSOL software tool. The pull-in voltage and switching characteristics have been employed on HFSS frequency analyser tool. It is identified that proposed 2-shunt capacitive RF-MEMS switches are prominent at electro mechanical properties. Both switches are designed with 18.5V pull-in-voltage and 1.2 Sec switching periods. The results of this investigation illustrate that proposed switches have great isolation and low insertion loss. The switching time between closed and open states of RF MEMS switches is made possible by their mechanical nature, which have numerous benefits over other technologies. Minimal power consumption, quick switching, low signal loss, strong off-state isolation and circuit-scale integration are only some of the benefits of RF-MEMS switches. Along with these benefits, proposed RF-MEMS switches have been offered future telecommunication, such as 4G and 5G mobile cellular communication, will make extensive use of RF-MEMS switches operating at GHz frequencies, therefore modern manufacturing devices and materials become more easily accessible. The proposed capacitive shunt type RF-MEMS switch design is more stable in operation compared to capacitive, inductive and all other available MEMS switch configurations.

References

[1] Ai Qun Liu., "RF MEMS Switches and Integrated Switching Circuits Design, Fabrication, and Test", Springer, 2010.

[2] J. J. Yao and M. F. Chang, "A surface micromachined miniature switch for telecommunications applications with signal frequencies from DC up to 4 GHz", in International Conference on Solid-State Sensors and Actuators Digest, Stockholm, Sweden, pp. 384–387,1995.

[3] J. B. Muldavin and G. M. Rebeiz, "Inline capacitive and DC-contact MEMS shunt switches", IEEE Microwave sWireless Comp. Letters, Vol. 11, No. 8, pp. 334–336, 2001.

[4] D. Hyman and M. Mehregany, "Contact physics of gold microcontacts for MEMS switches",IEEE Trans. Comp. Packaging Technology, Vol. 22, No. 3, pp. 357–364, September 1999.

[5] W.-B. Zheng, Q.-A. Huang, X.-P. Liao, and F.-X. Li, ``RF MEMS membrane switches on GaAs substrates for X-band applications," J. Microelec- tromech. Syst., vol. 14, no. 3, pp. 464_471, Jun. 2005.

[6] J. Y. Park, G. H. Kim, K. W. Chung, and J. U. Bu, ``Monolithically integrated micromachined RF MEMS capacitive switches," Sens. Actuators A, Phys., vol. 89, pp. 88_94, Mar. 2001.

[7] K. S. Rao, L. N. Thalluri, K. Guha, and K. G. Sravani, ``Fabrication and characterization of capacitive RFMEMSperforated switch," IEEE Access, vol. 6, pp. 77519_77528, 2018.

[8] K. Maninder, K. J. Rangra, D. Kumar, and S. Singh, ``Parametric optimization of symmetric toggle RF MEMS switch for X-band applications," Int. J. Recent Trends Eng., vol. 2, p. 95, Nov. 2009.

[9] H. Jaafar, K. S. Beh, N. A. M. Yunus, W. Z. W. Hasan, S. Sha_e, and O. Sidek, ``A comprehensive study on RF MEMS switch," Microsyst. Technol, vol. 20, no. 2, pp. 2109_2121, Dec. 2014.

[10] Hee-Chul Lee, Jae-Yeong Park and Jong-Uk Bu, "Piezo electrically Actuated RF MEMS DC Contact Switches with Low Voltage Operation", IEEE Microwave and wireless components letters; Vol: 15; pp: 202-204; (2005).

[11] Gustavo P. Rehder, Salvador Mir, Libor Rufer, Emmanuel Simeu, Hoang N. Nguyen, "Low Frequency Test for RF MEMS Switches", IEEE,vol:1, pp:350-354, (2010).

[12] Mahesh Angira ,Kamaljit Rangra, "Design and investigation of a low insertion loss, broadband, enhanced self and hold down power RF-MEMS switch" Microsystem Technol, vol. 21, pp: 1173-1178, (2015).

[13] J.Y. Park, G.H. Kim, K.W. Chung, J.U. Bu, Monolithically integrated micromachined RF MEMS capacitive switches, Sens. Actuators A vol. 89 pp: 88–94, (2001)

[14] S.Girish Gandhi, I.Govardhani, Sarat kumar K, "Improve the performance of a novel capacitive shunt RF MEMS switch by beam and dielectric material," IEEE Transactions on Electrical and Electronic Materials, Springer, Online ISSN 2092-7592, Oct. (2019).

[15] Giridhar MS, Jambhalikar A, John J, Islam R, Nagendra CL, Alex TK, "An X band RF MEMS switch based on silicon-on-glass architecture", Sadhana, vol:34(4),pp: 625-628,(2009).

[16] Mafinejad Y, Kouzani A, Mafinezhad K, Hosseinnezhad R, "Low insertion loss and high isolation capacitive RF MEMS switch with low pull-in voltage", The International Journal of Advanced Manufacturing Technology, vol. 93, pp: 661-670, (2017).

[17] M Tang, A.B Yu, A.Q Liu, A. Agarwal, S. Aditya, Z.S Liu, "High Isolation X-band MEMS Capacitive Switches", Elsevier, vol. 120, pp. 95-98, (2005).

[18] Jong-Man Kim, Jae-Hyoung Park, "The SIOG-Based Single-Crystalline Silicon (SCS) RF MEMS Switch with Uniform Characteristics", Journal of Micro Electro Mechanical Systems" vol. 13, pp. 1036-1042, (2004).

[19] Ganesh G.V., Srinivasa Rao K. (2019), 'Design and analysis of shunt configuration-based RF MEMS switch', International Journal of Innovative Technology and Exploring Engineering, 8(9), PP.2034-2039.

[20] Srinivasa Rao K., Sravya S., Varma G.S.K., Girija Sravani K. (2018) , 'Design of low actuation voltage RF MEMS capacitive switch using serpentine flexure and rectangular perforations',Journal of Advanced Research in Dynamical and Control Systems, 10 (2),PP. 523- 528.

[21] Mohan, C.L., Kavya, K.C.S. & Kotamraju, S.K. Design, and Analysis of Capacitive Shunt RF MEMS Switch for Reconfigurable Antenna. Trans. Electr. Electron. Mater. (2020). https://doi.org/10.1007/s42341-020-00212-0

[22] S. Girish Gandhi, I. Govardhani, M. Venkata Narayana, K. Sarat Kumar. "Design and performance analysis of novel bridge type RFMEMS switch for X-band", Materials Today:Proceedings, 2021
[23] Sailaja, B. V. S., & Naik, K. K. (2020). Design and analysis of serpentine meander asymmetric cantilever RF-MEMS shunt capacitive switch. Analog Integrated Circuits and Signal Processing, 102(3), 593-603.
[24] Sravani, K. G., Guha, K., Aditya, M., Balaji, B., & Rao, K. S. (2021). Design, simulation and analysis of uniform and non-uniform serpentine step structure RF MEMS switch. Microsystem Technologies, 1-11.
[25] Saikumar, K., Rajesh, V., & Babu, B. S. (2022). Heart Disease Detection Based on Feature Fusion Technique with Augmented Classification Using Deep Learning Technology. Traitement du Signal, 39(1).
[26] Kumar, R. (2021). Materials selection approaches and fabrication methods in RF MEMS switches. Journal of Electronic Materials, 50(6), 3149-3168.
[27] Chand, C., Maity, R., Srinivasarao, K., Maity, N. P., & Sravani, K. G. (2022). Design and analysis of novel RF-MEMS capacitive type shunt switch for 5G applications. Transactions on Electrical and Electronic Materials, 23(1), 30-44.
[28] Chand, C. G., Maity, R., & Maity, N. P. (2021). Electromagnetic modelling and analysis of RF MEMS capacitive shunt switch for 5G applications. Microelectronics Journal, 117, 105262.
[29] Srinivasa Rao, K., Girija Sravani, K., Akhil Chowdary, Y., Naveena, P., Vedha Vyasa, K., Raina, H., & Deepa Sunanda, B. (2021). Design, Analysis and Simulation of RF MEMS Capacitive Shunt Switch with Perforations for Ka-Band Applications. Transactions on Electrical and Electronic Materials, 1-6.
[30] Karumuri, S. R., Chand, C., Guha, K., Maity, N. P., Maity, R., Maity, S., ... & Kondavitee, G. S. (2021). Design, Simulation and Analysis of Perforated RF MEMS Capacitive Shunt Switch. Micro and Nanosystems, 13(4), 448-457.