Wireless Personal Communications (2022) 123:709–725
https://doi.org/10.1007/s11277-021-09154-z

Comprehensive Analysis and Design of Capacitive RF MEMS Switches for Reconfigurable Microstrip Patch Antenna

Mallikharjuna Rao Sathuluri[1,2] · **G. Sasikala**[1]

Accepted: 16 September 2021 / Published online: 26 September 2021
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2021

Abstract
This paper presents design of a reconfigurable micro strip patch antenna by using RF MEMS. Primarily we have analyzed the performance of different shunt capacitive RF MEMS switches and eventually we have incorporated the switch on reconfigurable micro strip patch antenna. Analyzed two micromechanical flexures i.e., fixed–fixed and serpentine flexure. The performance analysis done in simulation level using FEM tool by extracting different parameters like pull-in voltage, capacitance, RF losses. Also analyzed the role of material and micromechanical structure on improving the pull-in voltage. Eventually a switch with improved performance is presented, the switch offering an actuation voltage of 4.5 V, insertion losses of -0.55 dB, isolation losses of-51 dB. Two identical switches are placed on the reconfigurable antenna, based on the switching the antenna is resonating in different frequency bands. The designed antenna is switching between X-band, K-band and Ka-band applications.

Keywords RF MEMS switches · Reconfigurable antenna · FEM tool · Material analysis · Micro structure analysis

1 Introduction

MEMS is the trending technology with great potential which offers high reliability and linearity. RF switches are very needy devices in future high frequency communication applications. Now MEMS technology based RF switches are offering best performance when compared with SST based RF switches. Not only RF switches, MEMS technology proved its ability in the design of filters, varactors which are essential devices in communication applications [1].

The high frequency communication applications need reconfigurable antenna elements which is capable to switch from one frequency band to another frequency band. To design such a reconfigurable antenna elements we can use high reliability offering switches. The

✉ Mallikharjuna Rao Sathuluri
smr.aliet@gmail.com

1 Department of ECE, Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology (Deemed To Be University), Chennai, Tamilnadu, India

2 Department of ECE, ALIET, Andhra Pradesh, Vijayawada 520008, India

primary challenges of MEMS technology in the design of RF switches using electrostatic actuation are offering low actuation voltage, maintaining good radio frequency properties, low upstate capacitance and high downstate capacitance. X, K and Ka-band frequency ranges are 8–12 GHz, 18–26.5 GHz and 26.5—40 GHz respectively, which have some potential millimeter wave range applications like vehicle speed detection, satellite communication, satellite television, radar astronomical observation and microwave communication [2].

Earlier so many researchers are proposed different switch with different verities of material and actuation techniques [3]. Switches can be configured different actuation techniques, i.e., piezoelectric, magneto static, electro thermal and electrostatic. The thin film material section, i.e., substrate, dielectric and membrane material is one of the RF MEMS switch performance deciding factor [4]. By considering potential applications in X, K and Ka-band, in this paper we have presented an performance analysis based design of reconfigurable microstrip patch antenna using shunt capacitive switches with electrostatic actuation for k-band applications Tables 1, 2, 3, 4, 5 and 6.

This paper is systematized as follows: in Sect. 2, we have presented RF MEMS switches literature survey. Section 3 reported the performance analysis of shunt capacitive switches. Performance improved switch for K-band applications is discussed in Sect. 4. Reconfigurable micrpstrip patch antenna using switches is discussed in Sect. 5 and the paper is concluded in Sect. 6.

2 Related Work

RF MEMS switch performance improving is really a potential research aspect, so many researchers are advance the research on MEMS switches. And eventually design of reconfigurable antenna by using performance improved RF MEMS switches is especially needy in the present high frequency communication applications. But because of the requirements of high frequency communication applications RF MEMS switches have few research

Table 1 Problem statement

Parameter	Research challange	Description
RF MEMS switch	Actuation voltage High Capaciatnce ratio High isolation	The high actuation voltage is the biggest research challange in switches. The selection high-K dielectric thin films is essential to get high capacitnace ratio. The isolation property primarily depends on the switch capacitance ratio
Antenna	Reconfigurability Frequency selectivity	RF switches plays a prominent role in design of reconfigurable antennas. RF MEMS technology proved its ability in offering reconfigurable communication modules. The frequency selectivity is the biggest challange in the design of antennas

Table 2 MEMS structure parametric extraction

Parameters	MEMS structures			
	Theory		Simulation	
	Clamped–Clamped	Serpentine with uniform meander	Clamped–Clamped	Serpentine with uniform meander
Mass (m)	800×10^{-12} kg	827×10^{-12} kg	800×10^{-12} kg	827×10^{-12} kg
Spring constant (k)	4.2 N/m	2.132 N/m	6.18 N/m	1.93 N/m
Resonant frequency (ω)	11,537 Hz	8085 Hz	14,000 Hz	7745
Pull in voltage (V_{pull_in})	1.14 V	0.81 V	1.134	0.78 V
Upstate capacitance(C_{up})	140.8 fF	140.8 fF	151.1 fF	151.1 Ff
Downstate capacitance(C_{down})	24.92 pF	24.92 pF	20.8 pF	20.8 pF

Table 3 Shunt capacitive RF MEMS switch dimensions and material

Parameter	Material	Dimension in μm
Substrate	Silicon	400 × 400 × 800
Insulator	Silicon Dioxide	400 × 400 × 1
CPW	Gold	100 × 80 × 100
Dielectric	Aluminum Nitrite ($\varepsilon_r = 8.8$)	220 × 80 × 0.05

Table 4 Performance improved shunt capacitive RF MEMS switch theory and simulation results

Parameters	Serpentine with non uniform meander	
	Theory	Simulation
Mass (m)	827×10^{-12} kg	827×10^{-12} kg
Spring constant (k)	2.132 N/m	1.93 N/m
Resonant frequency (f_r)	8085 Hz	7745 Hz
Pull in voltage (V_{pull_in})	0.81 V	0.78 V
Upstate capacitance(C_{up})	140.8 fF	151.1 fF
Downstate capacitance(C_{down})	24.92 pF	20.8 pF

Table 5 Comparison our work on shunt capacitive switch with literature

Parameter	Reference 9	Reference 10	Our work
Mass (m)	–	–	827×10^{-12} kg
Spring constant (k)	–	–	1.93 N/m
Resonant frequency (f_r)	–	–	7745 Hz
Actuation Voltage	19.3 V	25.2 V	4.5 V
Upstate capacitance(C_{up})	22 fF	–	151.1 fF
Downstate capacitance(C_{down})	2.21 pF	–	20.8 pF
Insertion Losses (dB)	− 0.05 dB	− 0.1 dB	− 0.55 dB
Isolation Losses (dB)	− 12 dB @ 61.5 GHz	− 40 dB @ 11 GHz	− 51 dB

Table 6 Comparison our work on reconfigurable microstrip patch antenna using RF MEMS switch with literature

Parameter		Reference [11]	Reference [12]	Present work
Shunt Capacitive RF MEMS switches	Number of switches	2	2	2
	Type	SPST	SPST	SPST
	Substrate	Silicon	Silicon	Silicon
	Dielectric material	–	Si_3N_4	SiO_2
	Membrane material (thickness)	–	Gold (1 µm)	Gold (0.5 µm)
	Perforation	No	Yes	Yes
Reconfigur-able antenna	Working Band	4.5–12.5	Up 40 GHz	Up to 40 GHz
	Number of modes	4	4	4
	switching conditions and operating frequencies	S1- OFF & S2-OFF 8.6 GHz & 12.5 GHz	S1- OFF & S2-OFF 16.4 GHz & 21 GHz	S1- OFF & S2-ON, 12 GHz & 25–37 GHz
		S1- ON & S2-OFF 9 GHz & 12.4 GHz	S1- ON & S2-ON 14.2 GHz & 16.8 GHz	S1- ON & S2-OFF, 27- 40 GHz
		S1- OFF & S2-ON 9 GHz & 12.4 GHz	S1- OFF & S2-ON 16.5 GHz & 21 GHz	S1- OFF & S2-OFF, 10 GHz
		S1- ON & S2-ON 4.5 GHz, 9 GHz & 12.3 GHz	S1- ON & S2-OFF 14.5 GHz & 19 GHz	S1- ON & S2-ON, 22 GHz & 33 GHz

challenges like low actuation voltage, high isolation, low insertion losses and high switching speed.

In paper [5], the authors primarily described the parameters influencing the reliability of the RF MEMS switches, like dielectric chagrining. Bridge type micromechanical structure is incorporated in the switch. Authors proposed switches for future 5G communication applications.

In paper [6], the authors mainly demonstrated the shunt capacitive switch with electrostatic actuation. Role of dielectric material on the performance of RF MEMS switches is analyzed. Si3N4 and AlN dielectric material are taken in to consideration in the performance analysis. The switch with AlN as a dielectric material offering upstate capacitance of 98.67 fF and the down state capacitance of 1.295 pF.

In the paper [7], the authors proposed a novel shunt capacitive switch with AlN as a High-k material. the switch is offering an actuation voltage of 5 V for 1 μm gap, insertion of −0.5 dB and isolation of −55 dB.

In paper [11], the authors proposed a reconfigurable microstrip patch antenna using switches. Overall two switches are incorporated for reconfigurability with four switching modes i.e., if S1- OFF & S2-OFF the antenna is resonating at 8.6 & 12.5 GHz, if S1- ON & S2-OFF the operating frequency is 9 & 12.4 GHz, if S1- OFF & S2-ON the operating frequency is 9 & 12.4 GHz, and if S1- ON & S2-ON the operating frequency is 4.5, 9 & 12.3 GHz.

In paper [12], the authors discussed about the design aspects of reconfigurable antenna using switches. The antenna range is up to 40 GHz. Especially the antenna is designed for K-band applications. Two shunt capacitive switches are used for the antenna design.

3 Problem Statement

The design of reconfigurable antennas with ferequency selectrivity for appropriate applications is the biggest reserch challange.The RF MEMS technology has proved its ability in the design of reconfigurable antennas. But the RF MEMS technology faces few challanges like high actuation voltage, low capacitance ratio and low isolation. In this paper, we presents a prominant solution for improving the performance of switches and design of Reconfigurable antennas with better frequency selectivity.

4 Performance Analysis

In this paper we have analyzed two structures one is clamped–clamped and second one is serpentine structure. The performance analysis is done on the role of structure, perforation, materials, perforation and type of meanders.

4.1 Theoretical Analysis

The overall mass (m) of the micromechanica structure can be measure with m = ρ*l*w*t, where, ρ—material density, l-length, w-width, t-thickness. Spring constant will vary from flexure to flexure, for the clamped–clamped flexure the spring constant (K) can be expressed as [8],

$$k = 4Ew\left(\frac{t}{l}\right)^3 \tag{1}$$

For the serpentine flexure with material young's modulus (E), the spring constant can be expressed as,

$$\frac{1}{K} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \frac{1}{K_4} \tag{2}$$

where,

$$K_{(1,2,3,4)} = \frac{Ewt^3}{l^3}$$

The switching time is one of the primary parameters which decides the switch performance, the switching time can be formulate with the help of resonant frequency. From the free body analysis, we can extract the expression for the resonant frequency i.e.,

From the Fig. 1,

$$\mathrm{m}\ddot{x} + \mathrm{k}(\mathrm{x} + \delta) - \mathrm{F} = 0 \tag{3}$$

$$\mathrm{m}\ddot{x} + \mathrm{kx} + \mathrm{k}\delta - \mathrm{k}\delta = 0$$

$$\mathrm{m}\ddot{x} + \mathrm{kx} = 0$$

$$\ddot{x} + (\mathrm{k}/\mathrm{m})\mathrm{x} = 0$$

by comparing above equation with simple harmonic motion i.e.,

$$\ddot{x} + \omega^2\mathrm{x} = 0 \tag{4}$$

Therefore,

$$\omega^2 = \mathrm{k}/\mathrm{m}$$

$$\omega = \sqrt{\frac{K}{m}}$$

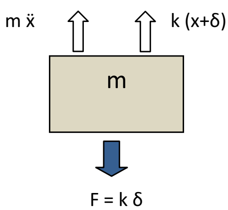


Fig. 1 Free body diagram

$$f_r = \frac{1}{2\pi}\sqrt{\frac{K}{m}} \tag{5}$$

The electrostatic ally actuated RF MEMS switch performance primarily depends on the pull-in voltage, it can be expressed as,

$$V_{pull-in} = \sqrt{\frac{8kg^3}{27A\varepsilon_0}} \tag{6}$$

Compared to series DC contact switches, shunt capacitive RF MEMS switches offer best performance at high frequency applications. The switch capacitance can be expressed as,

$$C_{up} = \frac{\varepsilon_0 A}{g + \frac{t_d}{\varepsilon_r}} \tag{7}$$

$$C_{down} = \frac{\varepsilon_0 \varepsilon_r A}{t_d} \tag{8}$$

where, g—is the gap between the membrane the bottom electrode, A—is the cross sectional area, $\varepsilon_o = 8.85*10^{-12}$, t_d—is the thickness of dielectric material Figs. 2, 3, 4, 5, 6, 7, 8, 9.

4.2 Structural Analysis

The performance of the switch primarily depends on the micro mechanical structure incorporated. Previously there are so many popular structures are proposed by different researchers, here we have taken clamped–clamped structure and serpentine structure for performance analysis. Gold material with E of 70 GPa, and density (ρ) of 19,300 kg/m^3. The thickness of the structure is taken as 1 µm.

The both the micro mechanical structures are designed with gold metal and actuated electrostatically. The structure with clamped–clamped flexure requires an actuation voltage of 7.5 V and the structure with serpentine flexure requires an actuation voltage of 5 V for one micro meter displacement.

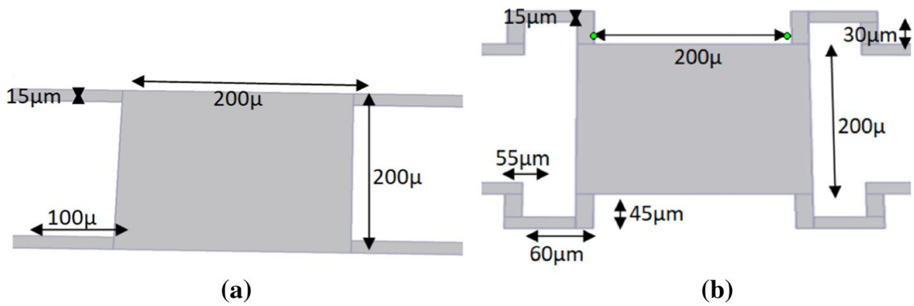


Fig. 2 Structural analysis, **a** clamped–clamped, **b** serpentine flexure with uniform meanders

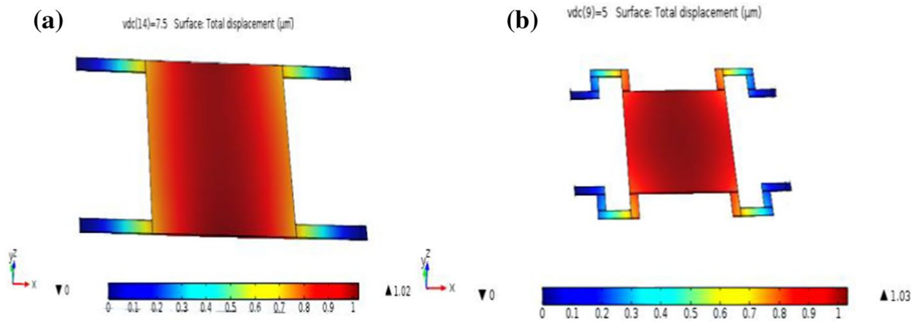


Fig. 3 Electrostatic actuation, **a** clamped–clamped, **b** serpentine structure

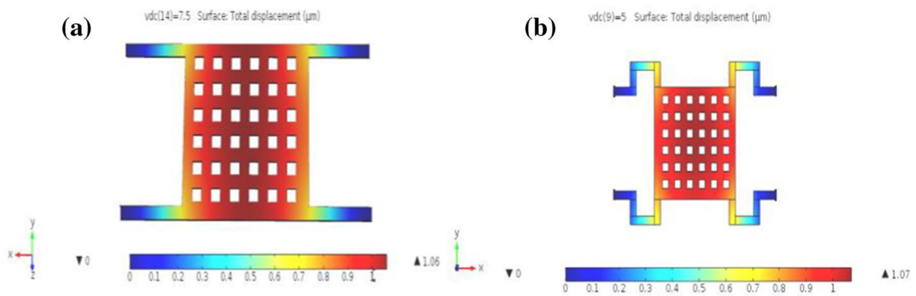
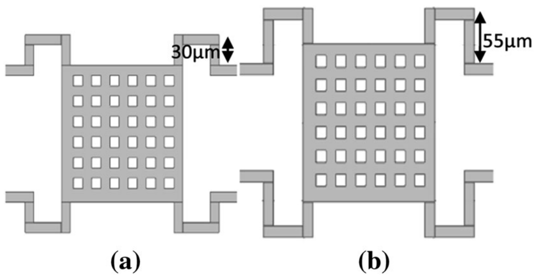


Fig. 4 Effect of perforation, **a** clamped–clamped flexure, **b** serpentine flexure with uniform meander

Fig. 5 Serpentine structure meander analysis, **a** uniform meanders, **b** non uniform meanders



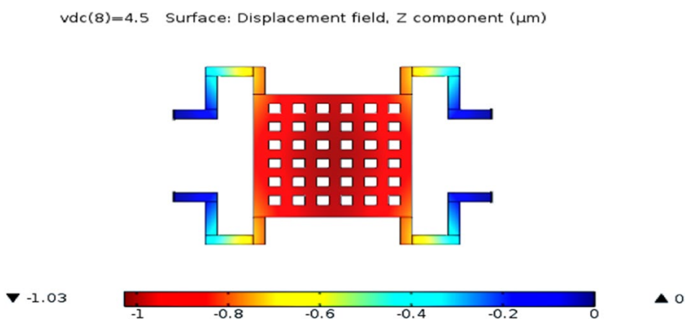


Fig. 6 Electrostatic actuation of serpentine flexure

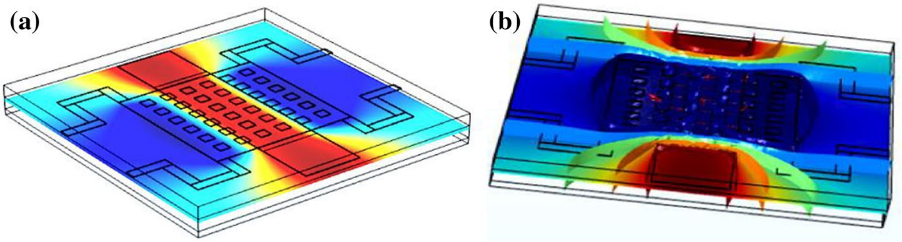


Fig. 7 RF MEMS switch capacitance analysis, **a** Electrostatic analysis, **b** fringing fields

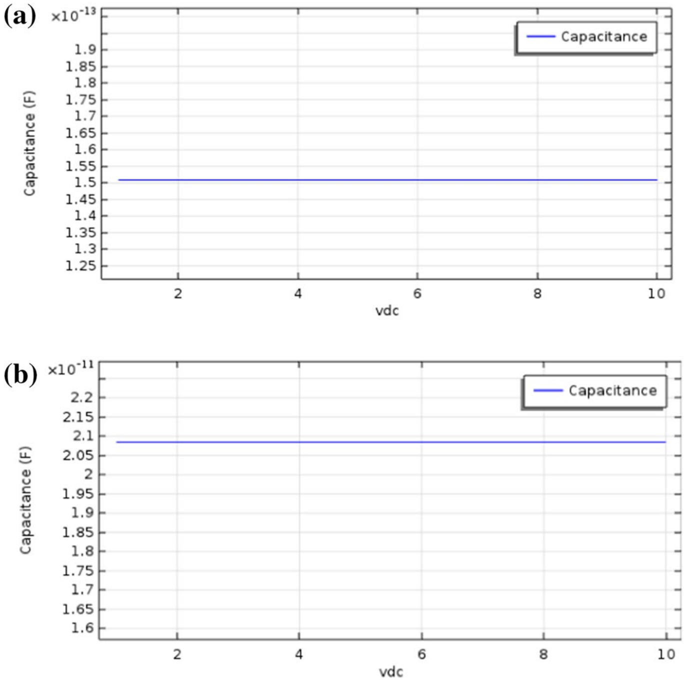
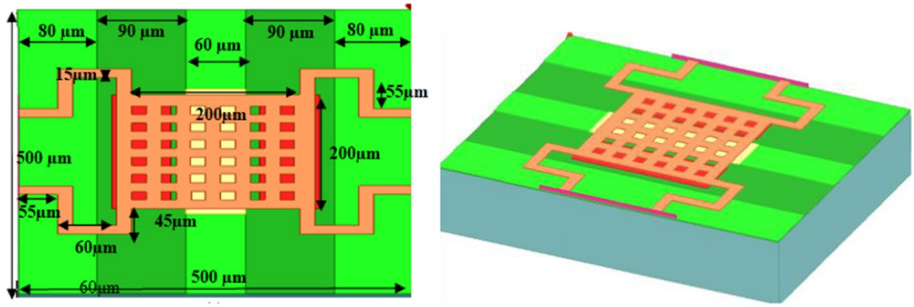


Fig. 8 Capacitance, **a** upstate capacitance, **b** downstate capacitance

4.3 Perforation Analysis

Perforation to the micromechanical structure helps in the process of load distribution and improves the switch reliability. Here we have perforated the micromechanical structure with holes of dimension 15 X 15 µm. The perforation the required actuation voltage is reduced for both the structures.

Because of the perforation the micromechanical structures displacement is increased an amount of 0.04 µm. And it is clear that compared to the clamped–clamped flexure serpentine flexure is offering low actuation voltage. So, further analysis id done on the serpentine structure.



(a) (b)

Fig. 9 Serpentine membrane based shunt, **a** top view, **b** side view

4.4 Meander Analysis

From the previous analysis it is clear that the serpentine structure with uniform meander is offering best performance compared with clamped—clamped structure. In this sub section, The role of type of meander i.e., uniform and non uniform meander of the serpentine structure on the actuation voltage.

After observing the electrostatic actuation, it is clear that compared to uniform meanders, the non uniform meander serpentine structure is offering a low actuation voltage. The structure is offering a displacement of 1 µm for 4.5 V. The above analysis is performed by considering the gold (Au) as the membrane material.

4.5 Capacitance Analysis

The shunt capacitive switch performance depends on the capacitance offered by the switch when membrane in up and down state. Here we have performed the capacitance analysis by choosing AlN. The thickness of the dielectric is 0.05 µm and the relative permittivity is 8.8.

When no actuation voltage applied, the micromechanical structure is in upstate, so the switch with serpentine structure with perforation is offering an upstate capacitance (C_{up}) of 151.1 fF.

When the micromechanical structure is actuated electro statically the structure deforms and the downstate capacitance (C_{down}) of the switch is 20.8 pF.

The micromechanical structures most of the parameters are extracted, which helps in the process of structure validation and the theory and simulated results are compared for better support. Finally it is clear that, the serpentine structure with non uniform meander is helping to reduce the actuation voltage, and AlN as a dielectric material the switch is offering good upstate and downstate capacitances.

5 Proposed Model

From the performance analysis in the Sect. 4, we have proposed an shunt capacitive RF MEMS switch with perforated serpentine structure with non-uniform meanders and AlN as a dielectric material. Completely the switch is micro machined on silicon substrate

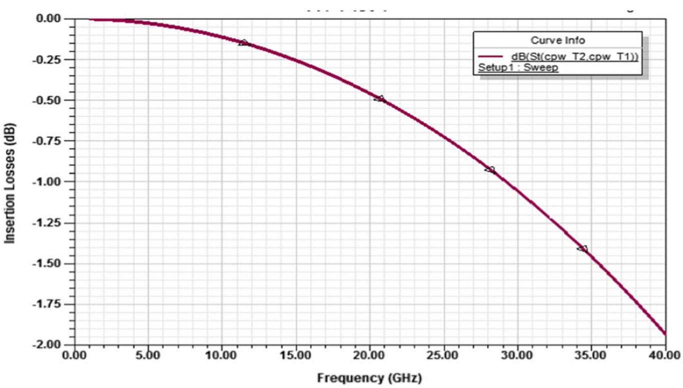
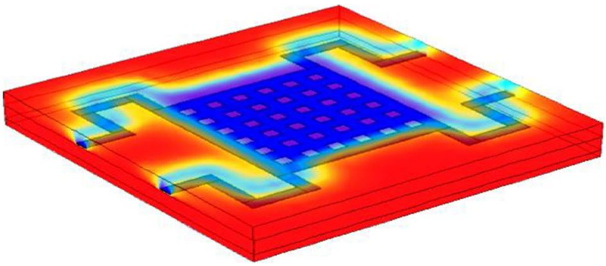


Fig. 10 Insertion Losses (dB)

Fig. 11 Load distribution in non uniform meander serpentine flexures



and 1 μm thickness SiO2 is place in between substrate and CPW lines as a insulating layer. The structure is perforated with 15 × 15 μm size square holes.

If the applied actuation voltage is below the pull-in voltage the micro mechanical structure is in upstate, the input RF signal is completely allowed to the output, so the switch is offering low insertion loss of −0.55 dB at 23 GHz as shown in Fig. 10.

The perforation to the membrane helps in uniform distribution of electrostatic force as shown in Fig. 10. When the actuation voltage is applied the micromechanical structure is much above the pull-in voltage, the structure will get deform and it will come to downstate as shown in Figs. 11 and 12.

When the micromechanical structure is in down state the switch will offer high isolation of −51 dB at 23 GHz. And the switch is offering an upstate capacitance of 151.1 fF and the down state capacitance of 20.8 pF.

Eventually, the most of the performance deciding parameters of the switch and try to compare the theoretical and simulated values. Here the simulated results are very close to the theoretical values. The roof mass of the serpentine structure is 827×10^{-12} kg, because of the serpentine structure with non uniform meanders the structure is offering low spring constant of 1.93 N/m.

The Eigen frequency (or) natural frequency (or) resonant frequency is 7.745 kHz. The upstate capacitance (C_{up}) is 151.1 fF and the downstate capacitance (C_{down}) of the switch is 20.8 pF Fig. 13.

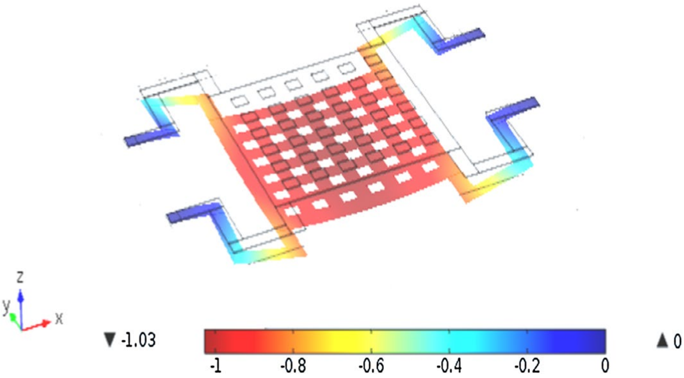


Fig. 12 Membrane is in downstate

6 Reconfigurable Antenna

In this section, we have discussed about the design of reconfigurable microstrip patch antenna using performance improved shunt capacitive RF MEMS switches discussed in section IV. Design calculation of the rectangular patch antenna is as follows

$$\text{Width}, w = \frac{C}{2f_{r\sqrt{\mu_{0\varepsilon_0}}}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{9}$$

$$\text{Where c } = \frac{1}{\sqrt{\mu_{0\varepsilon_0}}}\text{speed of the light} \tag{10}$$

Effective dielectric constant is,

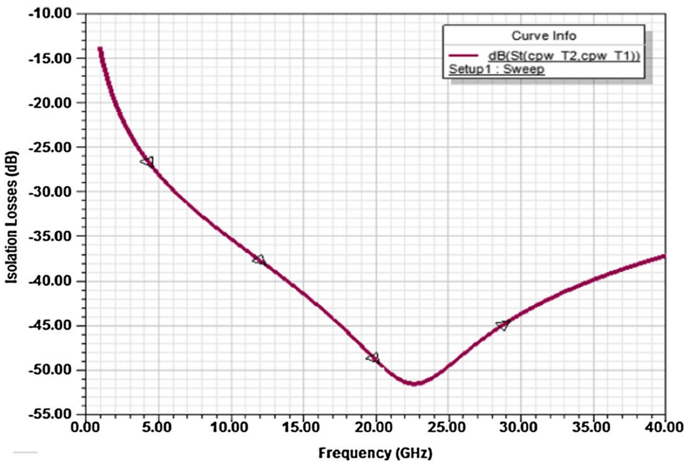


Fig. 13 Isolation Losses (dB)

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12h}{w}}}\right) \tag{11}$$

where h = thickness of the substrate.

Length of the antenna is,

$$\text{Length}, L = L_{eff} - 2\Delta L \tag{12}$$

where L_{eff} = effective length

$$L_{eff} = \frac{c}{2f_o}\left(\sqrt{\varepsilon_{eff}}\right) \tag{13}$$

İn proposed antenna,Three uniform size of 800 × 800 µm square type microstrip patch antennas (P_1, P_2& P_3) are connected CPW feed line through two identical RF MEMS switches (S_1 & S_2) as shown in Fig. 14. The antenna is micro machined on 3000 × 3000 µm size high resistance offering silicon substrate. 50/100/50 µm are the G/S/G values of the CPW feeding line.

SiO_2 thin film of 1 µm thickness is used as a insulating layer on the top of the silicon substrate. AlN is used as a dielectric material for the both the switches. Gold (Au) is used to micro machine the serpentine membrane with perforation of 1 µm thickness Figs. 15, 16.

The reconfigurable antenna designed in this section has two RF MEMS switches (S_1& S_2) with four operating modes. In mode-1, S_1 is OFF and S_2 is ON and the antenna is resonating at 12 GHz and 25–37 GHz. In mode-2, S_1 is ON and S_2 is OFF and the antenna resonating frequency is shifted to 27- 40 GHz. In mode-3, S_1 is OFF and S_2 is OFF the resonating frequency is 10 GHz. In mode-4, the S_1 is ON and S_2 is ON the resonating frequency is 22 GHz & 33 GHz. The designed antenna is preferable for X-band and Ka-band applications.

The radiation characteristics of the proposed antenna are demonstrated in the Fig. 17. The project radiation patterns are verified in both E-plane as well as H-plane it is noted that at E-plane the antenna gets dipole type of pattern and at H-plane the pattern is

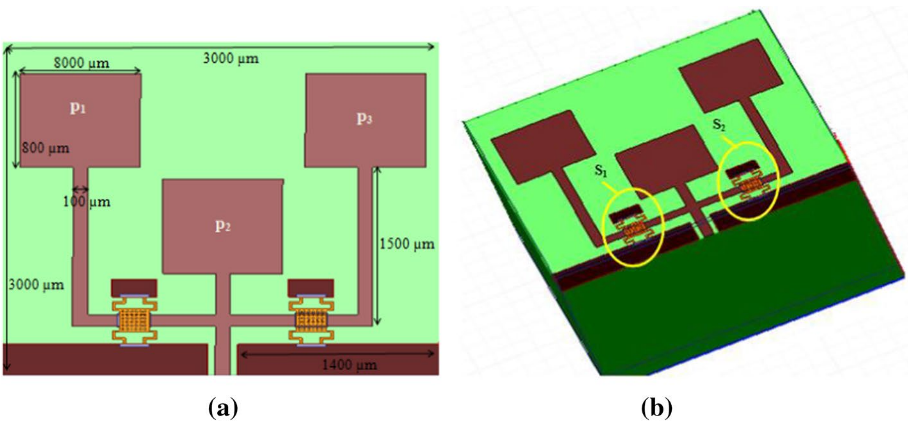


Fig. 14 Reconfigurable microstrip patch antenna using RF MEMS switches, **a** top view, **b** side view

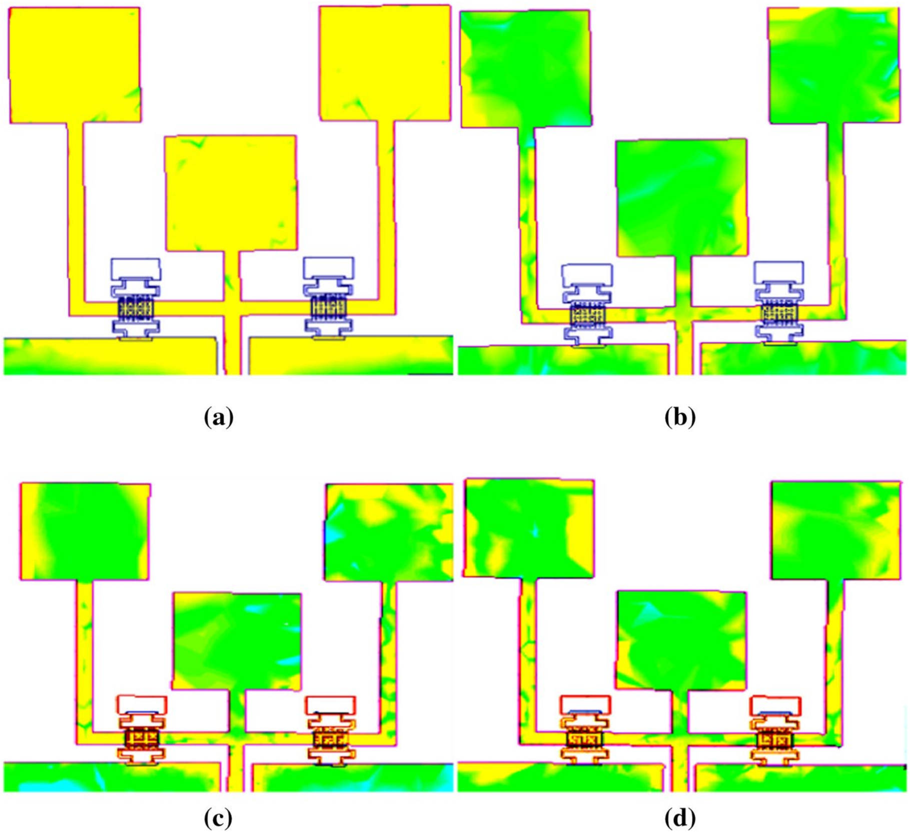


Fig. 15 Current distribution of reconfigurable antenna under different switching conditions, **a** S_1-OFF & S_2-OFF, **b** S_1-ON & S_2- ON, **c** S_1-ON & S_2- OFF, **d** S_1-OFF & S_2- ON

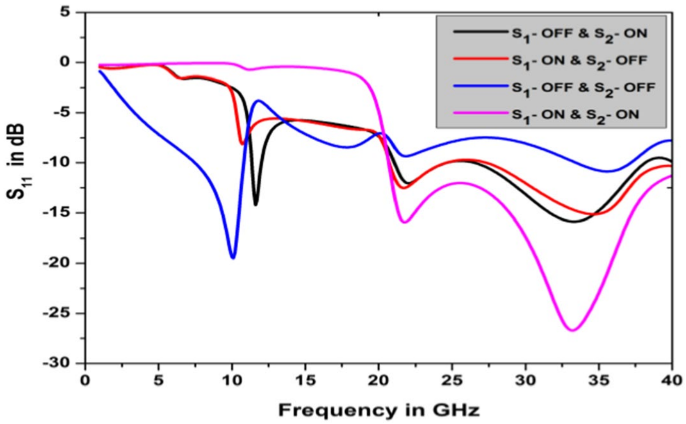


Fig. 16 S_{11} under different switching conditions

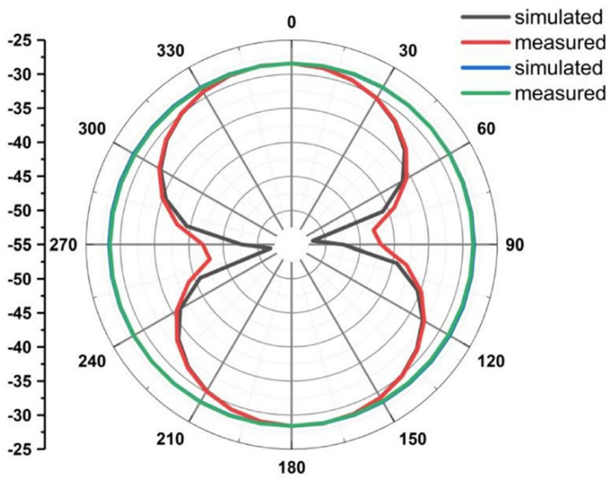


Fig. 17 Radiation characteristics at GHz

omnidirectional pattern. The radiation characteristics is verified, and good correlation can be seen in simulated and measured characteristics.

7 Conclusion

The role RF MEMS switches in the design reconfigurable microstrip patch antenna is presented. Analyzed two micromechanical flexures i.e., fixed–fixed and serpentine flexure. The roof mass of the serpentine structure is 827×10^{-12} kg, because of the serpentine structure with non uniform meanders the structure is offering low spring constant of 1.93 N/m. The Eigen frequency (or) natural frequency (or) resonant frequency is 7.745 kHz. The upstate capacitance (C_{up}) is 151.1 fF and the downstate capacitance (C_{down}) of the switch is 20.8 pF. The proposed switch is offering a low insertion loss of −0.55 dB and high isolation of −51 dB at 23 GHz. So, the switch offers best performance in k-band applications. Eventual, we have designed switches based reconfigurable microstrip patch antenna with four modes of operation. In mode-1, S_1 is OFF and S_2 is ON and the antenna is resonating at 12 GHz and 25–37 GHz. In mode-2, S_1 is ON and S_2 is OFF and the antenna resonating frequency is shifted to 27−40 GHz. In mode-3, S_1 is OFF and S_2 is OFF the resonating frequency is 10 GHz. In mode-4, the S_1 is ON and S_2 is ON the resonating frequency is 22 GHz & 33 GHz. The designed antenna is preferable for X-band and Ka-band applications.

Acknowledgements We confirm that we have read, understand, and agreed to the submission guidelines, policies, and submission declaration of the journal.

Declarations

Conflicts of interest The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

References

1. Nabet, M., Rack, M., Hashim, N. Z. I., de Groot, C. K., & Raskin, J. P. (2019). Behavior of gold-doped silicon substrate under small- and large-RF signal. *Solid-State Electronics*. https://doi.org/10.1016/j.sse.2019.107718
2. Chaudhary, R., & Mudimela, P. R. (2020). Pull-in response and eigen frequency analysis of graphene oxide-based NEMS switch. *Materials Today: Proceedings*, https://doi.org/10.1016/j.matpr.2020.01.560.
3. Angira, M., Bansal, D., Kumar, P., Mehta, K., & Rangra, K. (2019). A novel capacitive RF-MEMS switch for multi-frequency operation. *Superlattices and Microstructures*. https://doi.org/10.1016/j.spmi.2019.106204
4. Thalluri, L. N., Koushik Guha, K., Srinivasa Rao, G., Prasad, V. H., Girija Sravani, K., Sastry, K. S. R., Kanakala, A. R., & Bose Babu, P. (2020). Perforated serpentine membrane with AlN as dielectric material shunt capacitive RF MEMS switch fabrication and characterization. *Microsystem Technologies*. https://doi.org/10.1007/s00542-020-04755-3
5. Dubuc, D., & Grenier, K. (2018). Jacopo Iannacci," RF-MEMS for smart communication systems and future 5G applications ". *Smart Sensors and MEMS*. https://doi.org/10.1016/B978-0-08-102055-5.00018-8
6. Badía, M. F. B., Buitrago, E., & Ionescu, A. M. (2010). RF MEMS shunt capacitive switches using AlN compared to Si3N4 dielectric. *Journal Of Microelectromechanical Systems, 21*(5), 1229.
7. Laxma Reddya, B., & Shanmugananthamb, T. (2014). Design of novel capacitive RF MEMS shunt switch with aluminum nitride (AlN) dielectric. *Procedia Materials Science, 6*, 692–700.
8. Raman, R., Shanmuganantham, T., & Sindhanaiselvi, D. (2018). Analysis of RF MEMS series switch with serpentine spring shaped cantilever beam for wireless applications. *Materials Today: Proceedings*, *5*(2018), 1890–1896.
9. Pertin, O. (2018). Kurmendra," Pull-In-Voltage and Rf analysis of MEMS based high performance capacitive shunt switch ". *Microelectronics Journal*. https://doi.org/10.1016/j.mejo.2018.05.001
10. Younis, S., Saleem, M. M., Zubair, M., & Zaidi, S. M. T. (2018). Multiphysics design optimization of RF-MEMS switch using response surface methodology. *Microelectronics Journal*. https://doi.org/10.1016/j.mejo.2017.11.012
11. Goel, S., & Gupta, N. (2020). "Design, optimization and analysis of reconfigurable antenna using RF MEMS switch", Microsystem Technologies. *Doi.* https://doi.org/10.1007/s00542-020-04823-8
12. Lago, H., Zakaria, Z., Jamlos, M. F., & Soh, P. J. (2018). A wideband reconfigurable folded planar dipole using MEMS and hybrid polymeric substrates. *International Journal of Electronics and Communications*. https://doi.org/10.1016/j.aeue.2018.12.011

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Mallikharjuna Rao Sathuluri is a Research Scholar in the Department of ECE, Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology (Deemed to be University), Chennai . He has been working as a Assistant Professor in the Department of ECE, Andhra Loyola Institute of Engineering and Technology, Vijayawada, A.P., India. He has service of a decade. He has widely published research articles in various journals of high reputation and also in various national and international conferences. He is a life member of IETE. His research interests include Reconfigurable Antennas, RF MEMS and IoT.

Dr. G. Sasikala Working as Professor in Department of Electronics and Communication, Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology (Deemed to be University), Chennai since 2003 onwards. She has published more the 50 high reputation journals including 20 Scopus and 2 SCI journals and 10 more international and national conferences. She is a member of IETE. Her research interests include Embedded Systems, VLSI and Image Processing.