ISSN 2347 - 3983
Volume 8. No. 9, September 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter195892020.pdf
https://doi.org/10.30534/ijeter/2020/195892020

Cantilever Based Series Metal Contact RF MEMS Switch with Reduced Pull-in voltage and RF losses

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ABSTRACT

In this paper, a cantilever-based series metal contact radio frequency micromechanical switch is designed with reduced pull-in voltage and RF losses. The paper also discusses the cantilever structural analysis. The analysis is extended with single and multiple contact regions. The switch RF losses are reduced by placing separate contact regions. The circular holes are placed to micromechanical structure which eventually helped to minimize the necessary pull-in voltage. The RF MEMS switch proposed in this paper is offering an pull-in voltage of 8.5V, insertion losses -0.62dB, isolation losses -62dB.

Key words: Cantilever, CPW Transmission Line, Pull-in voltage, RF Losses, Series Metal Contact Switch.

1. INTRODUCTION

The micromechanical RF MEMS switching circuits have major demand in millimeter and microwave communication applications. Generally, solid state switches like the PIN diodes and GaAs MOSFET are incorporated in the single pole single through switches in communication networks because of their extreme adaptability and low fabrication cost. But the solid-state switches proved their performance only at low operating frequency and the high frequency factor mitigating the performance of the electrical solid state switches [2]. The electrical switches are struggling with high insertion losses and low isolation losses at high operating frequency in GHz range[15].

Because of the non-linear behavior the electrical solid-state switches are not that much preferable for wide band communication applications [1]. So, the researchers are reluctant to opt electrical switches for future communication applications. Electromechanically switches are offering high linearity compared with electrical switches because of that the RF micromechanical switches are offering low insertion, best isolation, nominal power consumption. Crosstalk can be mitigate with the help of micromechanical switches at very high frequency range [1]. In the last decade period, many researchers are showing interest on RF MEMS switches and advanced the work and proposed many solutions to the research challenges on RF MEMS switches.

Growth in micro electro mechanical systems have demonstrated the design and micromachining of high frequency signal switching devices i.e. RF MEMS switches. The first RF MEMS switch was introduced in 1979, as electrostatically actuated cantilever structure micromechanical switches are developed to route low frequency electrical signals [3].

Because of the small size the micromechanical switches are offering best performance at high frequency range, and the RF MEMS switches are struggling to offer low ON resistance in metal contact switches similarly high ON capacitance in capacitive switches[4].In this paper, a 10GHz to 35GHz RF micromechanical switch is proposed with multiple contact regions. The switch proposed is very small size i.e. all dimensions are in micrometer range and the performance is analyzed up to V-band.

2. STRUCTURAL ANALYSIS

This paper explains the design of series metal contact RF MEMS switch with the aim of low pull-in voltage and high RF performance. In this aspect we have extended the analysis on the role of cantilever structure and the number of contact regions on the performance of series metal contact RF MEMS switches.

Overall, we have taken two micromechanical structures as shown in figure 1, one is cantilever with one contact region and the other one is cantilever with three contact regions. And both the structures are associated with the circular holes.

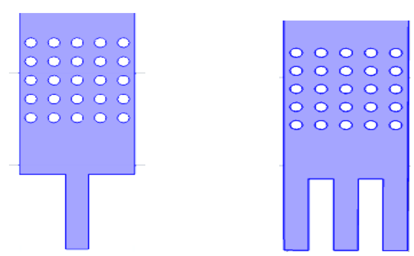
(a) (b)

Figure 1: Cantilever Structure with different contact regions, a) one contact, b) Three contacts.

In figure 2, we have presented the model structure of proposed series metal contact RF MEMS switch, the switch is design on CPW transmission line with best G-S-G dimensions what we have noticed in the literature i.e. 100μm-100μm -100μm.

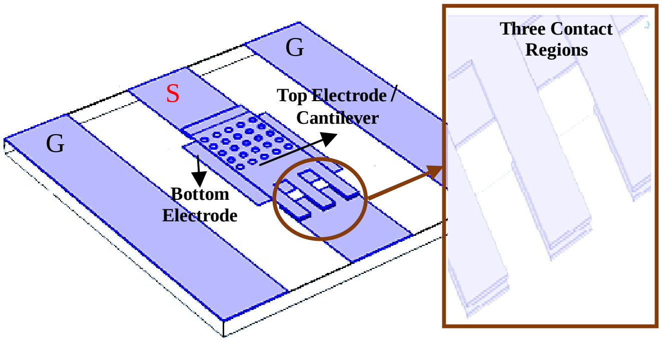

Figure 2: Proposed series metal contact RF MEMS switch model structure.

Table 1: Series metal contact RF MEMS switch parameters

Parameter	Dimensions (μm)
Silicon Substrate	500×500×60
Oxide Thickness	1
Thickness of CPW lines	0.1
Gap between cantilever and bottom electrode	1
Area under electrodes	150×250
Thickness of dielectric	0.1
Cantilever thickness	1

Table 2.:Proposed switch materials

Particular	Material	Thickness	Relative permittivity
Substrate	Silicon	1.5mm	9
CPW	Au	1	--
Dielectric	Si_3N_4	1μm	7.2
Cantilever	Au	1μm	--
Contact Material	Au	1μm	--

A. Actuation Voltage

Actuation voltage is a DC component which required to deform the micromechanical structure here it is cantilever. Not like in thermal, piezoelectric, electromagnetic, this DC voltage is required in electrostatic actuation technique.

The required DC voltage can be reduced by decrease air gap between bottom and top electrode, decrease cantilever stiffness and can increase actuation area. The actuation voltage is the voltage for which the cantilever deform,

$$Actuation\ Voltage = \sqrt{\frac{8kg_0^3}{27A\varepsilon_0}} \tag{1}$$

B. Spring Constant

The stiffness of the cantilever can be approximate from the spring constant of the micromechanical structure. The required actuation voltage is proportional to the stiffness of the cantilever, the actuation voltage can be predict from the spring constant (k). The spring constant can be written as,

$$Spring\ Constant = \frac{EWt^3}{l^3} \tag{2}$$

where, '*w*' is the width, '*E*' is the young's modules, '*t*' is the thickness, '*l*' is the length of the cantilever.

C. Switching Time

switching time of the switch nothing but, time required to toggle from up state to downstate. Switching time is one of the switch performance deciding. It directly proportional to pull-in voltage of the switch and inversely relate to the source voltage of the switch.

$$t_s = 3.67\frac{v_p}{v_s\omega_0} \tag{3}$$

Where V_P is pull in voltage, w_0 is resonant frequency of the cantilever and Vs is source voltage from electrodes.

$$\omega_0 = \sqrt{\frac{k}{m}} \tag{4}$$

3.RESULT ANALYSIS

The proposed RF MEMS switch is designed and simulated with the help of finite element method tools. The switch is designed on coplanar waveguide transmission line and silicon used as a substrate. The gold material is chosen for CPW lines, electrodes and cantilever. The circular holes are created to cantilever with radius is 5um. The CPW line G-S-G dimensions are 100-100-100. The structural analysis on the cantilever clearly show that one contact cantilever requiring actuation voltage when compared with three contact cantilever structure in terms of pull-in voltage as shown in figure 4 and figure 6. Eventually, the three-contact cantilever structure offering low pull-in voltage i.e. 8.5V because more cross-sectional actuation area(*W*w*). The theoretical measured spring constant is 1.8N/m for cantilever with dimension i.e. length is 260um, width is 100um, thickness is 1um and the cantilever is designed with gold and its elasticity is 70GPa. The theoretical pull-in voltage with *W*=50um and *w*=50um is 5V. The ε_o =8.85 x 10^{-12} is the free space relative permittivity.

Isolation losses of the RF MEMS switch indicates the OFF-state performance of the switch. Insertion loss of the RF MEMS switch indicates ON state performance of the switch. The isolation losses and insertion losses are measured by S_{21}

along the signal line with no applied voltage bias. The radio frequency performance of the switch is simulated in the range of 0 to 60GHz.

The simulated isolation loss (S_{21}) and insertion losses (S_{21}) of the three-contact cantilever RF MEMS switch are shown in figure 7 and figure 8. The radio frequency parameters like insertion losses offered by the switch is -62dB and the insertion loss is 0.62 dB at 60 GHz. Overall the three contact cantilever based switch offering a pull-in voltage of 8.5 V.

This wide parametric extraction from simulated graphs showcase that the proposed three contact cantilever series RF MEMS switch is suitable for Q & V-band applications. Especially in Surface movement radars and High attenuation radar applications we can prefer the proposed RF MEMS switch.

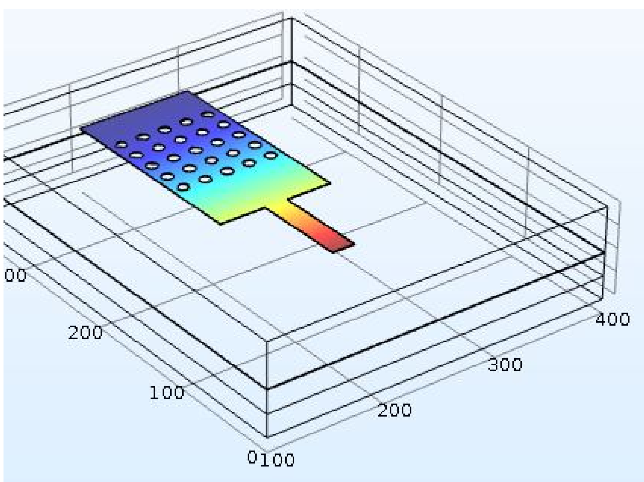
Figure 3: Single contact cantilever

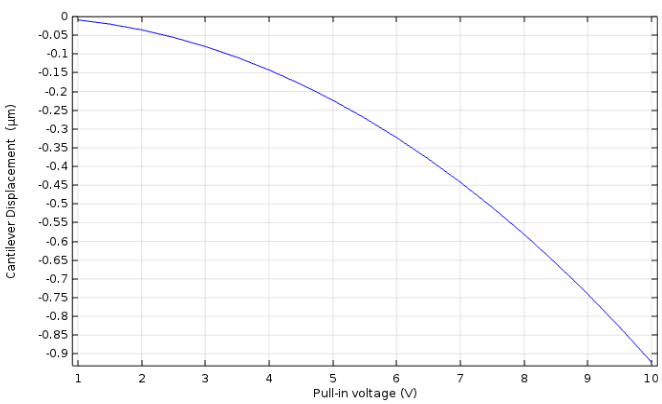

Figure 4:Single contact cantilever displacement

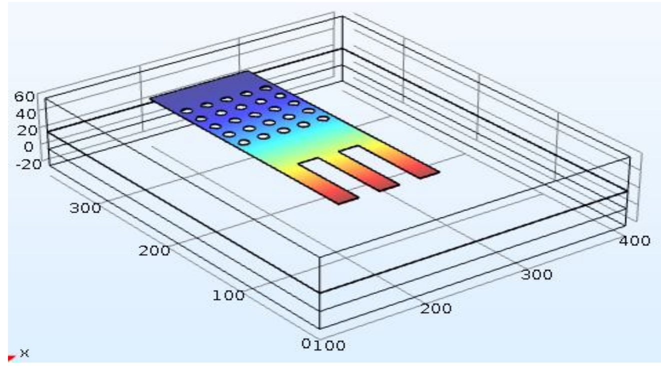
Figure 5: Three contact cantilever

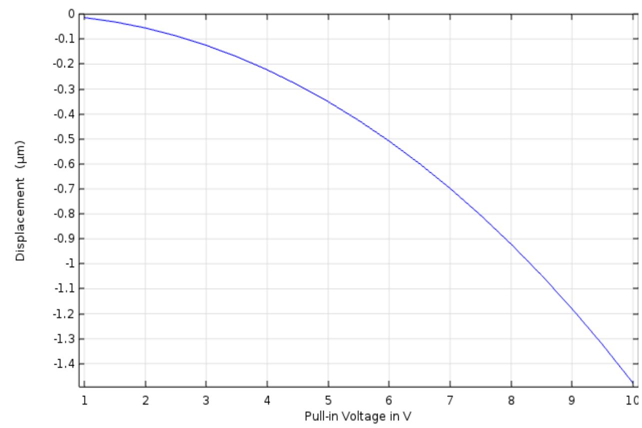

Figure 6: Three contact cantilever displacement

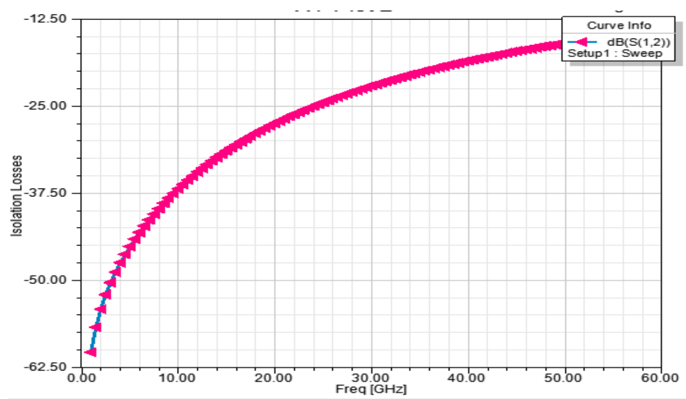

Figure 7: Isolation Losses of switch with three contacts cantilever.

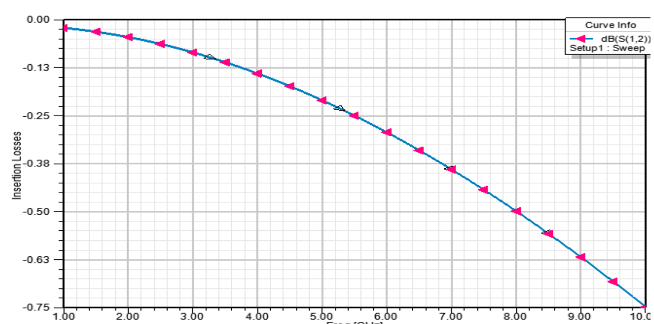

Figure 8: Insertion Losses of switch with three contacts cantilever.

Table 4: Proposed switch performance comparison with investigation

Parameters	Reference [1]	Reference [4]	Reference [9]	Proposed Switch
Substrate	Silicon	Silicon	Quartz	Silicon
Linear Elastic Structure	Cantilever	Bridge	Bridge	Cantilever
Pull-in Voltage(V)	20 V	25V	35V	8.5V
Holes to Linear Elastic structure	No	No	Yes	Yes
Hole Dimensions	-	-	-	Circle Radius=5 um
Insertion Losses (dB)	-0.7dB	-0.2dB at 40GHZ	-0.35dB	-0.62dB
Isolation Losses (dB)	-51dB	-40dB	-15dB	-62dB

4. CONCLUSION

A cantilever-based series metal contact radio frequency micromechanical switch is designed with reduced pull-in voltage and RF losses. The paper also discusses the cantilever structural analysis. The analysis is extended with single and multiple contact regions. The switch RF losses are reduced by placing separate contact regions. The circular holes are placed to micromechanical structure which helped to reduce the required pull-in voltage. The switch proposed in this paper is offering an pull-in voltage of 8.5V, insertion losses -0.62 dB, isolation losses -62dB.

ACKNOWLEDGMENT

The authors would like to thank Dr.V.R. Anitha, Professor, MEMS Design center, SVEC, Tirupati, India for providing simulation facility.

REFERENCES

1. Mengwei Li, Qiuhui Liu, Qiannan Wu, Yueping Han," Broadband radio frequency MEMS series contact switch with low insertion loss"microsystemTechnologies, https://doi.org/10.1007/s00542-018-4201-y,(October 2018.
2. Singh Tejinder, Kaur Navjot (2016) Layered axial force coupled membrane-based metal contact single-pole quad-throw RF MEMS switch: design, RF performance and mechanical modelling. Microsystem Technol 22:2117–2123
3. Xu Y, Tian Y, Zhang B et al (2018) A novel RF MEMS switch on frequency reconfigurable antenna application. Microsystem Technol 24(9):3833–3841
4. Younis S, Saleem MM, Zubair M et al (2018) Multiphysics design optimization of RF-MEMS switch using response surface methodology. Microelectron J 71:47–606. 78
5. Z. J. Yao, S. Chen, S. Eshelman, D. Denniston, and C. Goldsmith, "Micromachined low-loss microwave switches," Joumal of Microelectromechanical Systems, vol. 8, no. 2, pp. 129-134, 1999. 9
6. C. Goldsmith, T. H. Lin, B. Powers, W. R. Wu, and B. Norvell, "Micromechanical membrane switches for microwave applications," in IEEE Microwave Theory Tech. Symp., May 1995, pp. 91–94.
7. C. Goldsmith, J. Randall, S. Eshelman, T. H. Lin, D. Denniston, S. Chen, and B. T. H. Norvell, "Characteristics of micromachined switches at microwave frequencies," in IEEE Microwave Theory Tech. Symp., May 1996, pp. 1141–1144.
8. R. H. Caverly, "Distortion in off-state arsenide MESFET switches," IEEE Trans. Microwave Theory Tech., vol. 41, pp. 2295–2302, Dec. 1993.
9. Jae-Hyoung Park, Sanghyo Lee, Jug-Mu Kim, Youngwoo Kwon, and Yong-Kweon Kim," A 35-60 GHz Single-Pole Double-Throw(SPDT) Switching Circuit Using Direct Contact MEMS Switches and Double Resonance Technique ", International Conference on Salid State Sensonr, Actuators and Microsystems, Boston, June 8-12, 2003
10. K. W. Kobayashi, A. K. Oki, D. K. Umemoto, S. K. Z. Claxton, and D. C. Streit, "Monolithic GaAs HBT p-i-n diode variable gain amplifiers, attenuators, and switches," IEEE Trans. Microwave Theory Tech., vol. 41, pp. 1323–1328, Aug. 1993.
11. P. Osterberg, H. Yie, X. Cai, J. White, and S. Senturia, "Self-consistent simulation and modeling of electrostatically deformed diaphragms," in Proc. MEMS'94, Osio, Japan, Jan. 1994, pp. 28–32.
12. P.M.Osterberg,"Electrostaticallyactuatedmicroelectromechanical test structures for material property measurement," Ph.D. dissertation, Massachusetts Inst. Technol., Cambridge, MA, 1995.
13. Sree Kumar Reddy D.V., Ganesh G.V., Sri Harsha M., Avinash M., Venkateswarlu R., Siddaiah N. (2019), 'Design and performance analysis of meanders-based RF mems shunt configuration switch', International Journal of Emerging Trends in Engineering Research, 7(11), PP.700-703.
14. ABAQUS/Standard Version 5.7, Hibbitt, Karlsson, & Sorensen, Inc., 1080 Main Street, Pawtucket, RI 02860-4847.
15. K.Rajasekhar,Dr S.Sunithamani "Low settling time offering series capacitive RF MEMS switch for Wi-Fi applications "ES2079017519/19©BEIESP
16. .K. Vikas, S. Sunithamani, M. Yagnika , S. Siva Krishna, S. Avanthi "*Study and analysis of novel RF MEMS switched capacitor" I*nternational Journal of Engineering & Technology, 7 (2.31) (2018) 34-36.
17. Siddaiah N., Jayadev P., Prasad G.R.K., Siva Kumar K., Srinivasarao K. (2017),'Design and simulation of coupled cantilever sensors for pathogen detection', Journal of Advanced Research in Dynamical and Control Systems,9(Special Issue 17), PP.2025-

18. Lakshmi Narayana T., Girija Sravani K., Srinivasa Rao K. (2017),'Design and analysis of CPW based shunt capacitive RF MEMS switch', Cogent Engineering,4(1)
19. Jayavardhani K., Noureen Fathima S.K., Bhima Sankar K., Kavya Sri K., Sunithamani S. (2018) , 'Design and simulation of low actuation voltage RF MEMS shunt capacitive switch with serpentine flexures & rectangular perforations', International Journal of Engineering and Technology(UAE), 7 (2),PP. 4- 8
20. Siddaiah N., Prasad G.R.K., Sai Pravallika S.S., Sai Prasanna G.V.S., Raja Gopal R.R. (2018) , 'Performance of analysis crab leg based RF MEMS switch for defense and aerospace applications', International Journal of Engineering and Technology(UAE), 7 (1.5),PP. 71- 76
21. Girijaavani K., Guha K., Baishnab K.L., Shanti G., Srinivasa Rao K.S. (2018) , 'Design of Low Pull-In Voltage and High Isolation of Step Structure Capacitive RF MEMS Switch for Satellite Applications',Proceedings of International Conference on 2018 IEEE Electron Device Kolkata Conference, EDKCON 2018, (),PP. 312- 322.
22. Ramakrishna T.V., Ganesh G.V., Saikumar B.S.D., Chandana K., Lokesh D., Siddaiah N. (2019), 'Electromechanical and RF performance analysis of MEMS shunt configuration switch', International Journal of Emerging Trends in Engineering Research, 7(11), PP.563-568
23. Rao K.S., Mounika P.S., Pavan P., Guru V., Dinesh N., Kumar P.A., Vineetha K., Sravani K.G. (2019), 'Design, simulation and analysis of RF-MEMS shunt capacitive switch for 5G application', Microsystem Technologies, 25(11), PP.4197-4208