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Analysis of RF MEMS Series Switch with Serpentine Spring Shaped Cantilever Beam for Wireless Applications ☆

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Abstract

This paper analyses the design and simulation of a low voltage RF MEMS metal contact switch with its RF performance in the frequency range from 2 to 12 GHz. Low actuation voltage can be achieved by varying three parameters namely air gap, actuation area and spring constant. In this paper a serpentine structure is used to reduce the spring constant of the beam without affecting the performance of the switch. A very low pull-in voltage of about 4V very close to the analytical value is achieved by simulation using Intellisuite v8.8. The RF performance of the switch shows that the return loss in the ON state is -7.217 dB and -9.71dB in the OFF state at 12GHz. The isolation of about -67.97dB at 12 GHz and the insertion loss is -0.09 dB at 12 GHz.

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Keywords: RF MEMS, Actuation voltage, spring constant, serpentine structure.

1. Introduction

With the development in the MEMS technology miniaturized RF components with low power and low cost were invented and used for high frequency applications. With the advancement in RF MEMS technology it is possible to improve the performance of the devices that operates in the frequency range from millimeter wave to microwave

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ranges. RF MEMS switches are one of the conventional MEMS devices that are used for millimeter/microwave applications. For a given bandwidth the physical mechanical movement of the RF MEMS switch is used to control the impedance of the RF transmission line by making an open or short circuit in transmission line. These RF MEMS switches are used in low-loss microwave devices which do not require high switching rates.

RF MEMS switches are broadly classified as series or shunt and capacitive or ohmic contact type. Cantilever beam structure is mostly used for series switches and fixed-fixed type beam is used for shunt switches. Series switches are mostly designed for lower gigahertz range and shunt switches are suitable for 10-100 GHz applications [1].

To achieve a low actuation voltage several actuation mechanism has been used by these switches such as electrostatic, thermal, magnetic and piezoelectric. Low switching speed, increased power consumptions and the structural complexities were unavoidable in the design of these switches [2]. The main objective of the design of such switches is to reduce the actuation voltage by overcoming various difficulties such as low power handling capability, low isolation, insufficient reliability, , large transition time and high insertion loss [3, 4].

The most commonly used actuation mechanism is the electrostatic actuation due to its near zero power consumption, small size and less switching time. To decrease the actuation voltage of RF MEMS switches several methods were adopted such as decreasing the air gap and increasing the area of the electrostatic field [6]. Any change in these parameters may cause a loss on the other parameters of the switch. Increase in the area of the electrostatic field or decrease in the air gap leads to increase in the off state capacitance and leading to low switch isolation. Another way to reduce the actuation voltage is by reducing the equivalent spring constant by varying the structure and materials without affecting the performance of the switch [7]. But the RF performance of the switch is always affected while reducing the actuation voltage, mainly the isolation of the metal contact switches. By introducing serpentine spring folded suspensions in the beam structure, the actuation voltage can be reduced with maintaining sufficient isolation [5].

This paper deals with designing a metal contact switch with low actuation voltage by lowering the spring constant of the beam with serpentine spring in the structure and analyzing the scattering parameters at 0 to 12 GHz. The pull-in voltage is analyzed with commercial software Intellisuite. The RF performance is analyzed with software Ansoft HFSS in terms of scattering parameters.

2. Design and Working Principle

2.1. Design

A silicon substrate with 50μm thickness having a relative dielectric constant of 11.6 is used for the design. A 0.5μm thickness of silicon nitride is coated over the silicon substrate with a dielectric constant of 7.6 for electrical isolation. The cantilever beam has to withstand a major mechanical deflection being a perfect conductor. In this work aluminum is chosen as the metal for micro-fabrication due to its good electrical conductivity and easy manufacturability. The coplanar waveguide (CPW) is designed using 0.8 μm thickness of aluminium. At the ends of the CPW transmission line two test pads were designed for the input and output signals. In this design the electrostatic actuation mechanism with two actuation electrodes of size 100×100 μm^2 were used. A cantilever beam is chosen as the structure for the design of the series switch since it is suitable for metal contact switches and easy fabrication. The beam is made up of aluminium with a thickness of 1 μm. A serpentine spring is introduced in the cantilever beam structure in order to lower the spring constant without affecting the performance of the switch. The structure of the beam is shown in Fig.1.

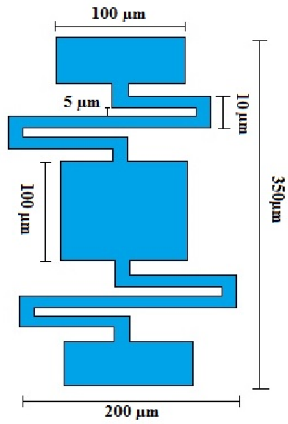

Fig. 1. Cantilever beam with serpentine spring.

2.2. Working Principle

In a series metal contact switch a cantilever beam is fixed to the anchor at one end and freely suspended at the other end over the coplanar waveguide. When actuation voltage is applied to the electrodes an electrostatic force is created which moves the beam down. At a threshold level mechanical force is not balance by the electrostatic force and the beam is bent down which results in a small up-state capacitance making the switch in 'on' state. When no actuation voltage is applied the switch capacitance becomes high making the switch in 'off' state. The pull-in voltage expressed as in equation (1) [6].

$$\boldsymbol{V}_{\boldsymbol{p}(\boldsymbol{V})} = \sqrt{\frac{8kg_0^3}{27\varepsilon_0 A}} \tag{1}$$

From the equation (1) it is evident that the pull-in voltage depends on the air gap g_0 actuation area A and the spring constant k. so the pull-in voltage can be reduced by reducing the air gap g_0, increasing the actuation area A and by lowering the spring constant k. Reducing the air gap leads to adverse effect at high frequency at off-state affecting the switch isolation. Increase in the actuation area causes practical issues mainly in the compactness of the design. The alternative way is to reduce the spring constant that provides flexibility in the design to achieve a low actuation voltage [7, 8].

This work aims at realizing a design with low actuation voltage by reducing the spring constant of the switch. To achieve this serpentine spring is introduced in the cantilever beam structure. Equation (2) gives the spring constant of the serpentine spring beam [9, 10].

$$k_z = \left[\frac{(8N^3a^3)+2Nb^3}{3EI_x} + \frac{abN[3b+(2N+1)(4N+1)a]}{3GJ} - \frac{Na^2\left[\left(\frac{2Na}{EI_x}\right)+\frac{(2N+1)b}{GJ}\right]^2}{2\left(\frac{a}{EI_x}+\frac{b}{GJ}\right)} - \frac{Nb^3}{2}\left(\frac{a}{GJ}+\frac{b}{EI_x}\right)\right]^{-1} \tag{2}$$

Where N represents the number of meanders, a is the primary meander length and b refers the secondary meander length. The torsion modulus G is given by equation (3)

$$G = E/2(1+v) \tag{3}$$

The axis moment of inertia is denoted by equation (4)

$$I_z = wt^3/12 \tag{4}$$

And Torsion constant J is given by equation (5) as

$$J = 0.413 \times I_p \quad (5)$$

Where I_p is the polar moment of inertia denoted as $I_p = I_x + I_z$

The total spring constant k of the switch is given by equation (6) as

$$k = mk_z \quad (6)$$

Where m is the number of serpentine arms.

The physical dimensions and the material constants used for the design of the switch is given in the table 1

Table 1. Physical Dimensions and Material constant of the switch

Parameters	Values
Primary meander length (a)	10 µm
Secondary meander length (b)	105 µm
Thickness of the switch (t)	1 µm
Width of the beam (w)	200 µm
Air gap (g_0)	1 µm
Young's modulus of aluminum (E)	70Gpa
Poisson's ratio of aluminum (v)	0.35
Torsion constant (J)	$0.413I_p$

3. Results and Discussion

3.1. Results of Actuation Voltage

The stimulated pull-in voltage of the proposed design is shown in the fig.2. The pull-in voltage of the switch is found to be 4V and the calculated value of the pull-in voltage was 3.84V. This shows that the stimulated result was very close to the calculated results. The result proves that a lower pull-in voltage can be obtained by using a serpentine spring structured beam which lowers the spring constant of the beam without affecting the performance of the switch.

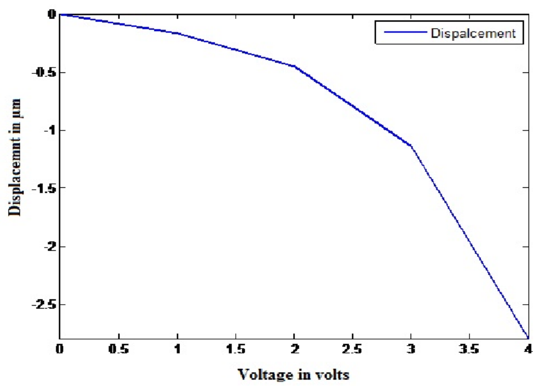

Fig. 2. Pull-in Voltage of the proposed design

The displacement of the proposed design is shown in fig.3. A maximum displacement of 0.007693 µm was obtained with an actuation voltage of 4 V.

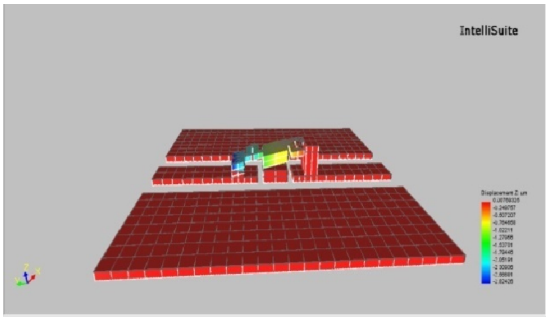

Fig.3. Displacement of the switch

Fig.4 shows the mises stress with the given load voltage of about 4V. The mises stress is performed to check whether the design withstands to the given load conditions. The stimulated result show a mises stress to be 6.6635 MPa and can withstand to the given load conditions.

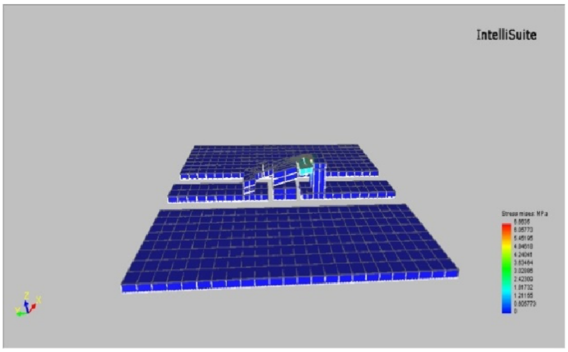

Fig.4 Mises stress analysis of the switch

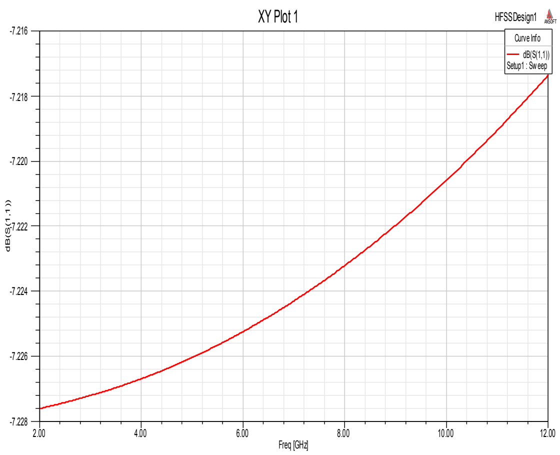

Fig.5. Return loss (S_{11}) in OFF state

3.2. RF response of the switch

The RF analysis is done in ansoft HFSS software. The s-parameters of the switch are observed in the frequency range from 2 to 12 GHz which is suitable for most of the wireless applications. The return loss $S_{11}$of the switch in the off state is -7.217 at 12 GHz as shown in the fig.5. In ON state the return loss was found to be -9.71dB at 12 GHz as shown in fig.6.

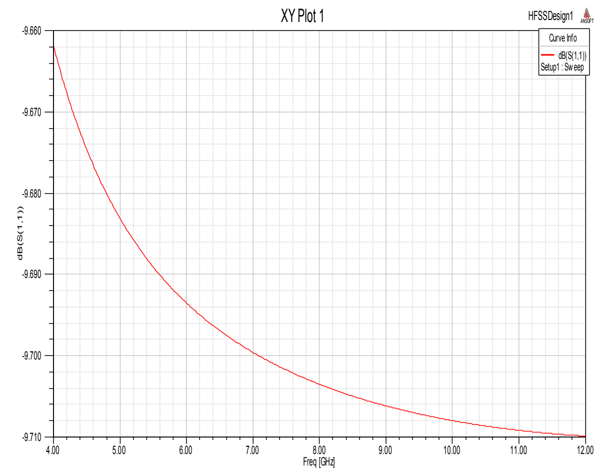

Fig.6 Return loss (S_{11}) in ON state.

The isolation S_{21} is analyzed when the switch is in OFF state and it was found to be -67.9714 dB as shown in the fig.7.The change in the structural parameter of the beam always affects the isolation but with the proposed structured a high isolation is obtained as the off state capacitance was lowered with the serpentine spring.

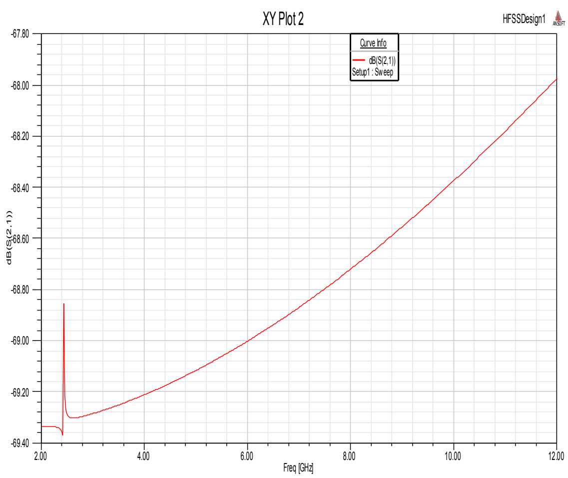

Fig.7 Isolation (S_{21}) in OFF state

The insertion loss S_{21} of the switch is analyzed to be -0.094 dB at 12 GHz which shows very negligible losses in the design structure. The simulated insertion loss in the ON state is shown in the fig.8.

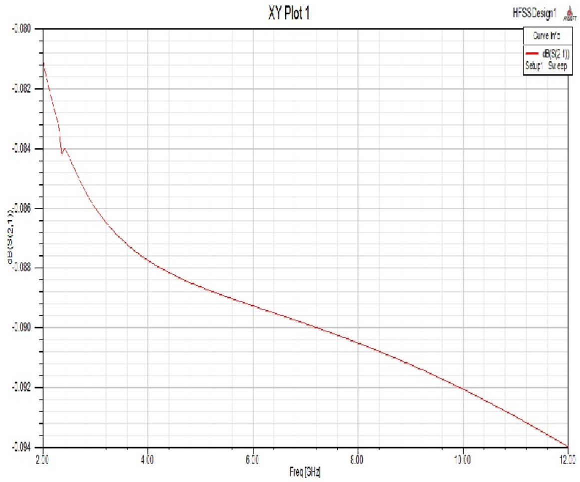

Fig.8. Insertion loss (S_{21}) in ON state

4. Conclusion

A low actuation voltage metal contact series switch for wireless communication was analyzed in this paper. A serpentine spring shaped cantilever beam was designed to reduce the spring constant sufficiently. With reduction in the spring constant a low pull-in voltage of about 4V was achieved. The structure was optimized without affection the RF performance of the switch. RF analysis shows that the return loss was about -7.217 dB at 12GHz in the OFF state and -9.71 dB at 12 GHz in the ON state. A high isolation of -67.97 dB was achieved in the OFF state and a low insertion loss of -0.094 dB was obtained. The results show that the switch is suitable for wireless applications operating in the frequency range from 2 to 12GHz.

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References

[1] Rebeiz, G.M, RF MEMS Switch: Status of the technology, 12th international conference on solid state sensors, actuator and microsystems pp. 1726-1729, June 8-12, 2003, Boston:IEEE.
[2] Rebeiz.G.M. and Muldavin.J.B., Rf MEMS switches and switch circuits, IEEE microwave magazine, pp.59-71, 2001.
[3] Rebeiz.G.M., RF MEMS: Theory, design and technology, Colorado:Wiley, 2003.
[4] Varadan.V.K., Vinoy.K.J and Jose.K.A., RF MEMS and their applications, Colorado: Wiley, 2003.
[5] Pacheco.S., Nguyen.C.T., andKatehi.L.P.B., Design of low actuation voltage RF MEMS switch, Baltimore: IEEE MIT-S International Microwave Symposium Digest, pp. 165-168, 2000.
[6] Peroulis.D., and Pacheco.S.P, Electromechanical considerations in developing low-voltage RF MEMS Switches, IEEE Transactions on Microwave Theory and Techniques, 51, 259-270, 2003.
[7] Abbaspour-Sani.E., and Afrang.S., A low voltage MEMS structure for RF capacitive switches, Progress in Electromagnetic Research, 65, 157-167, 2006.
[8] Song.M., Yin.J., and He.X.et al., Design and analysis of a novel low actuation voltage capacitive RF MEMS switches, Proceeding of the 3rd IEEE international conference on nano/micro engineered and molecular system, 2008.
[9] Jaafar.H. Sidek.O., and Miskam.A., Design and simulation of Microelectromechanical system capacitive shunt switches, American Journal of engineering and applied sciences, 2(4), 655-660, 2009
[10] Maher Bakri-Kassem and Raafat R. Mansour, High Power Latching RF MEMS Switches, IEEE Transactions on Microwave Theory and Techniques, vol. 63, no. 1, January 2015.