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ANALYSIS OF COMPLEMENTARY BEAM STRUCTURED RF MEMS SWITCH FOR WIRELESS APPLICATIONS

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Abstract

This paper analysis the performance of a RF MEMS switch having a complementary beam structure operating at frequency ranging from 0 to 12GHz, which facilitates its application in the field of wireless mobile communication. This design is a modified cantilever beam forming a complementary structure with an easy fabrication process to implement. The switch is designed in form of a meander beam spring type in order to lower the spring constant there by achieving a relatively less pull-in voltage for actuation. The simulated results show a pull-in voltage of about 4V with the complementary cantilever beam structure. RF analysis shows a negligible insertion loss of -0.113dB and -7.181dB in the up-state of the switch from 0 to 12GHz. The isolation in the up-state was -57.62dB at 12GHz.

Keywords:

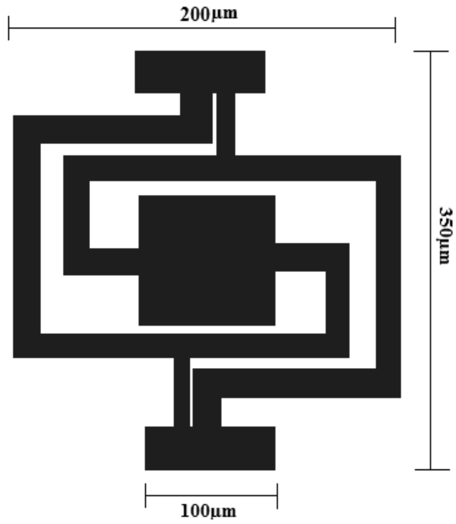
RF MEMS, Switch, Cantilever Beam, Pull-in Voltage, Electrostatic Actuation, Coplanar Waveguide

1. INTRODUCTION

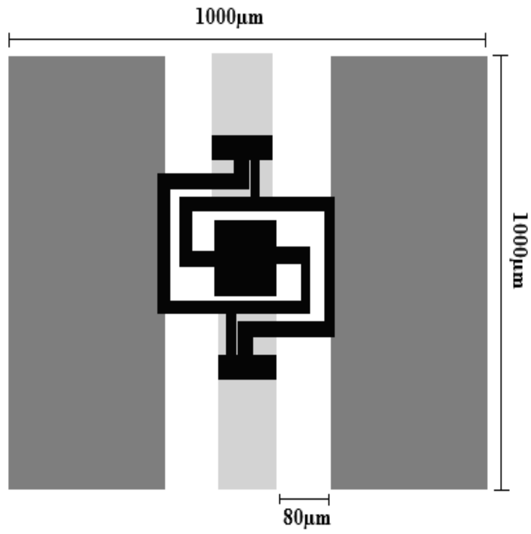
For consumers and aerospace applications at radio frequencies, wireless communication have grown to a great extend in recent years. The future needs for such system would be a device with reduced size, weight and cost which can be highly integrated in RF-front ends. These devices are expected to operate in a wide range of frequencies from 0 to 12GHz. At this frequency range there is a high possibility of interference due to environmental effects. These issues were managed by using tunable filters that operate by selecting narrow band of frequencies from the entire band. But these tunable filters make the circuit more complex, bulky and power consuming. With the advancement in the MEMS technology the existing passive devices can be replaced to provide a better performance. MEMS switches can be integrated with MEMS tunable filters to construct the whole reconfigurable receiver circuit on a single chip that reduces the weight size and cost of the receiver circuit employed in wireless communication technology [1].

In the future MEMS Switches plays an important role in switching operation at high frequencies as it has many advantages like less power consumption, good isolation and very negligible insertion loss than the existing switches like PIN diode and FET switches [2, 3]. Many actuation methods are used for the actuation of the RF MEMS switches, the most widely used actuation method is the electrostatic actuation method, which consumes low power and it is easy to implement. The disadvantage of using electrostatic actuation method is that they require high voltage and also gives a low mechanical stability. With a high driving voltage the life time of the MEMS switch degrades and often causes malfunction of the switch due to charge tapping problem. The better solution to achieve a less voltage for actuation is by using a meander spring type witch. The meander spring-type approach is compatible between the spring constant and the switching speed [7, 8].

The performance of the DC switch with metal contact having a complementary beam structure where one end of the switch is attached to the anchor with a complementary meander beam from one side and another end is suspended over the coplanar wave guide (CPW). The objective of having a complementary cantilever beam structure is that it minimizes the spring constant with a simple fabrication steps and with less material requirement. The design resembles a spring attached to the anchor so that its actuation is made easy with a very less voltage to drive the switch.



(a) Complementary Beam structure



(b) Front View

Fig.1. Geometry of the proposed switch

2. DESCRIPTION OF THE PROPOSED SWITCH

The switch is attached to the anchor with a meander beam from one side and the free end is suspended over the coplanar waveguide with another meander beam from the other side. This forms a complementary structure as shown in Fig.1. The dimensions of the proposed switch are tabulate in table.1.

Table 1.Dimension of the proposed switch having a Complementary beam structure

Parameters	**Dimensions(μm)**
Beam Thickness	1μm
Beam Length	350μm
Beam Width	200μm
Gap Height	1μm
CPW	100/80/100μm
Area of Actuation	100μm
Electrode Thickness	1μm

A lower spring constant is provided by the complementary beam structure without increasing the size and weight of the device. By combining the spring constant of each and every section of the beam the total spring constant can be determined. The spring constant of the beam with meander spring is given by Eq.(1) [4].

$$K = \left[\begin{array}{l} \dfrac{8S^3 + 2LS^3}{3EI_x} + \dfrac{sL(3l + 15S)}{3GJ} \\ -\dfrac{S^2\left(\dfrac{2S}{EI} + \dfrac{3L}{GJ}\right)^2}{2\left[\dfrac{S}{EI_X} + \dfrac{L}{GJ}\right]} - \dfrac{L^2}{2}\left(\dfrac{S}{GJ} + \dfrac{L}{EI_X}\right) \end{array} \right]^{-1} \tag{1}$$

where, L is the secondary meander length, S is the primary meander length; E denotes the young's modulus of the material. G is the sheer modulus and is given by $G = E/2(1+v)$, where V is the Poisson's ratio of the material of switch, I_x represents the moment of inertia along X-axis and is given by $I_x = wt^3/12$, where W is denotes the thickness of the beam, t is the switch thickness. J represents the torsion constant and is given by $J = 0.413I_p$, where $I_p = I_x + I_z$ and $I_z = tw^3/12$. Non-meander spring constant is given by Eq.(2) [5][6].

$$k = 32Ew\,(t/l)^3 \tag{2}$$

The total spring constant can be calculated by combining these spring constant equations.

3. VIRTUAL FABRICATION PROCESS

The switch was designed on a 50μm thick relatively more resistive silicon substrate with 0.1μm thick oxide layer. This layer connects the DC pad to the pull-down electrode using a path that is cut in the ground plane of the CPW, which is later connected using a bridge in a subsequent process. There are totally four mask needed during the fabrication process. One is to obtain the CPW transmission line, second is to deposit the electrodes, third is to realize the anchor, and the fourth is used to produce the membrane and the beams.

Masking is done by spin coating using 3μm thickness of PR-1800. CPW with 1μm thickness of aluminum was patterned over the substrate by E-beam evaporation process. A 0.1μm thickness of Si_3N_4 (silicon nitride) was deposited over the actuation electrode to avoid direct metal contacts with PECVD process. An opening in the sacrificial layer was used to realize the anchor. RF sputter deposition of 1μm thickness of aluminum was done to realize the beam structure. Plasma etching was used to completely etch the sacrificial layer [9].

4. RESULTS AND DISCUSSION

4.1 PULL-IN VOLTAGE

The driving voltage was analyzed using intellisuite software using electrostatic actuation method. Mathematically the pull-in voltage of the switch was analyzed using the Eq.(2) and Eq.(3) as:

$$V_{pull\text{-}in} = \sqrt{\frac{v((8Kg_0^3)}{27\varepsilon_0 A_{DC}}} \tag{3}$$

where, $V_{pull\text{-}in}$ is the minimum voltage required to collapse the beam to the down-state position. A_{DC} is the area of actuation. ε_0 denotes the permittivity of air. K represents the spring constant and g_0 is the bridge height. The switch sustains a down-state position until the electrostatic force is exceeds the mechanical restoring force and this $V_{Hold\text{-}Down\text{-}DC}$ is given by Eq.(4).

$$V_{Hold\text{-}Down\text{-}DC} = \sqrt{\frac{2kg_0}{\varepsilon_0 A_{DC}}}\left(\frac{t_d}{\varepsilon_r}\right)^2 \tag{4}$$

where, t_d denotes the dielectric thickness and ε_r represents the dielectric permittivity. The pull-in voltage was analyzed by the graph with displacement vs. voltage as given in the Fig.2. For the proposed design with an air gap of 1μm resulted in pull-in voltage of 4V.

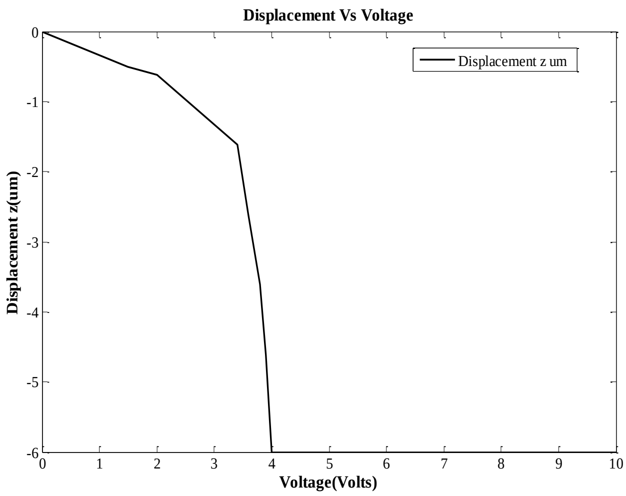


Fig.2. Displacement vs. Voltage Plot

4.2 RF SIMULATION

RF simulation was done from 0 to 12GHz frequency ranges by using High Frequency Simulator software (HFSS). Both open and closed position of the switch was analyzed. The beam makes or breaks the two ports of the transmission line while the switch is closed or open position respectively.

No actuation occurs when the switch is in off state as there is a break in the RF signal line. The return loss (S_{11}) and isolation (S_{21}) are represented in the Fig.3 and Fig.4, with a return loss of -7.181dB and isolation of -57.62dB at 12GHz.

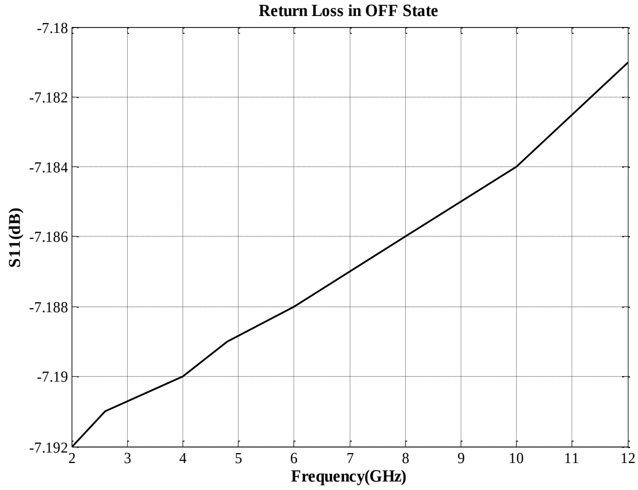


Fig.3. Return loss S_{11} in OFF State

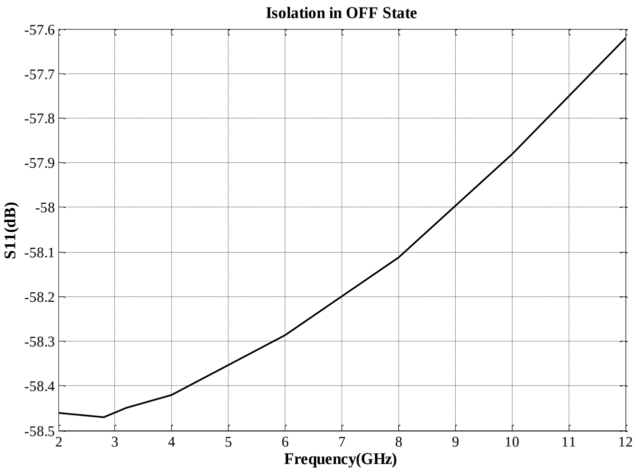


Fig.4. Isolation S_{21} in OFF state

Actuation occurs when the switch is in the down state as the contact is made between the transmission line and the beam. During this state the return loss (S_{11}) is -6.757dB and the insertion loss (S_{21}) is -0.131dB at 12GHz as shown in the Fig.5 and Fig.6.

A comparison of the proposed work with that of the existing switches is given in Table.2. The tabulated values shows that the proposed switch exhibits a very low pull-in voltage with good RF performance than the existing switch.

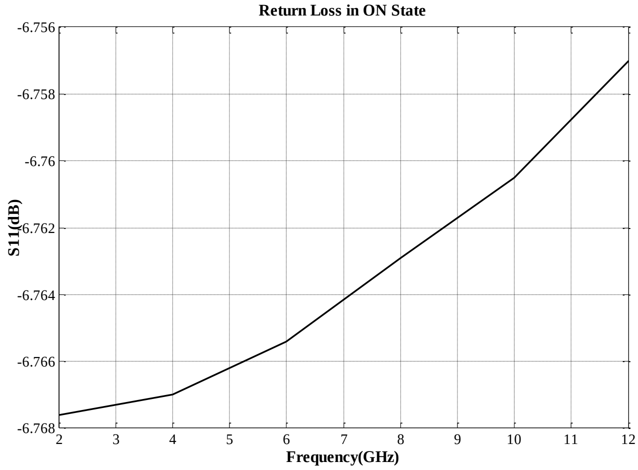


Fig.5. Return loss S_{11} in ON state

Fig.6. Insertion loss S_{21} in ON state

Table.2. Comparison response results of various cantilever structure at temperature as 30°C

Structure	Pull-in voltage (Volts)	Isolation (dB)	Insertion Loss (dB)
Compact High-Power SPST and SP4T RF MEMS Metal-Contact Switches [10]	45V	36–20dB at 1-2GHz	0.8dB at 12GHz
High Power Latching RF MEMS Switches [11]	12V	20dB	0.8dB upto 40GHz 1.2dB upto 40GHz 1.5dB and 18GHz
Complementary Beam Structure (Proposed)	4V	-57.62dB at 12GHz	-0.131 at 12GHz

5. CONCLUSION

A complementary beam structure for RF MEMS switch was designed and analyzed for its performance in the frequencies from 0 to 12GHz. The design was successful in achieving a low pull-in voltage of about 4V with stable operation. This complementary structure reduces the spring constant of the switch and exhibits a good RF performance showing a negligible insertion loss of -0.131dB and return loss of -7.181dB in the off state. In the ON state it had a very high isolation of about -57.62dB and return loss of about -6.757 at 12GHz. The design opens up the possibilities of using the switch in wireless application and in reconfigurable circuits.

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