 ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

ISO 3297:2007 Certified ⁒ Impact Factor 8.102 ⁒ Peer-reviewed / Refereed journal ⁒ Vol. 12, Issue 5, May 2023

DOI: 10.17148/IJARCCE.2023.12592

ULTRA HIGH PERFORMANCE INLINE CONTACT RF MEMS SWITCH

MADHUKARA S[1] LAVANYA L[2]

Electronics and Communications, SJC Institute of Technology, Chikkaballapur, Karnataka[1]

Electronics and Communications, SJC Institute of Technology, Chikkaballapur, Karnataka[2]

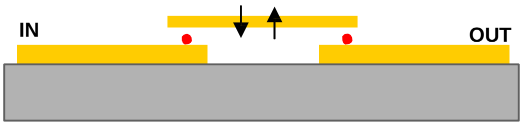
Abstract— The design of a capacitive RF MEMS switch and its mathematical analysis are presented in this study in order to achieve high isolation, minimal insertion loss, and minimal pull-in voltage. The fact that electrostatically actuated RF MEMS switches outperform state-of-the-art solid-state switches in terms of RF performance is what motivated the current work. RF-MEMS switches with metal contacts can have their hot-switching reliability increased with the use of a shunt protection approach. The RF-MEMS switch is triggered by electrostatic force and operates in a robust manner with a maximum von Mises stress of 13.208 MPa, which is lower than the yield stress of aluminum.

I. INTRODUCTION

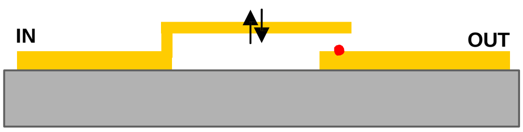
As new generation systems emerge, wireless mobile communication systems must incorporate multi-band services. Additionally, users want to have access to multi-functional services like video recording, MP3 playing, and global positioning system (GPS). Lack of research into how RF MEMS switches work in an electrical circuit is a significant flaw in MEMS switch design. It is crucial yet frequently overlooked in publications to predict how the MEMS switch will behave during actual usage (in the circuit).

The impact of passive components on the RF performance of switches has not yet been studied. Micro Electro Mechanical devices (RF MEMS) in the radio frequency regime have showed considerable potential for cutting-edge wireless devices. These gadgets provides not only offer more functionality and flexibility on a single platform with smaller footprints, but are also portable and power-efficient.

The performance of metal contact radio-frequency micro-electro-mechanical systems (RF-MEMS) switches in terms of isolation, linearity, insertion loss, bandwidth, and power consumption is superior. Several businesses have proven and are actively commercializing meta contact RF-MEMS switches. Because the primary contact and the protective contact are parallel, the overall OFF-state capacitance rises and the OFF-state isolation decreases.



a) Two contact point’s series switching



b) Single contact point series switching

Fig.1. Comparison of two contact point switching and in-line direct contact switching.

Because the riding pressure is concentrated on a single spot, this in-line MEMS transfer demonstrated extremely low insertion loss. It also demonstrated low actuation voltage by using an electrostatically actuated membrane.

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II. DESIGN AND FABRICATION

Since the introduction of the RF MEMS switch, a few switches have used in-line direct contact. However, due to the preceding switch's utilisation of the tiny electrode region beneath the signal line, these switches required a very high actuation voltage. High contact force and power switches were created, but the applied voltage was not satisfactory.

Due to the single contact point of the proposed MEMS RF switch, a portion of the RF input line is floating and moves up and down to connect the signal. A supporting membrane was used, and a single contact point was placed in the centre of the floating signal line, in order to reduce the actuation voltage of the MEMS switch. In Fig. 2, the suggested MEMS RF switch is shown schematically with parameters explained. An up-state reflection coefficient (S11) of less than -10dB can ensure a very good matching of the input with the switch at switch-on country [6]; a large capacitance ratio (>40) can promote an amazing RF overall performance. These are the design specifications for this capacitive shunt RF-MEMS switch, where the pull-in voltage of less than 3.3V is aimed for directly implementing with the majority CMOS IC designs.

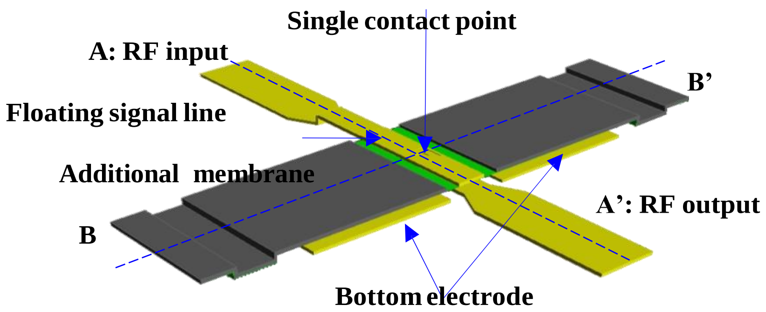
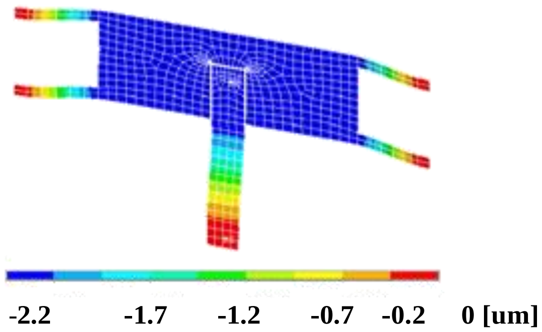
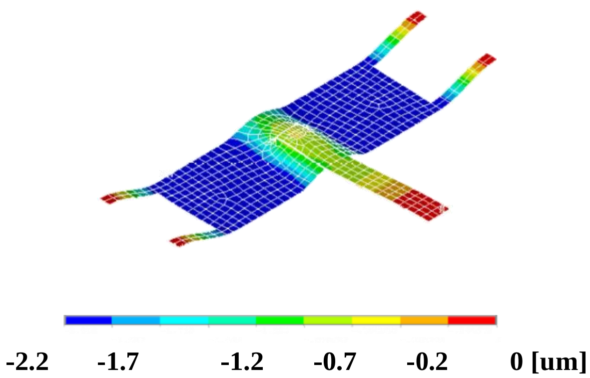


Fig.2. Schematic view of the in-line MEMS RF Switch



(a)



(b)

Fig. 3. (a) the approximate pull-in analysis and (b) the pull-in analysis including contact pairs (Displacement)

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W3Four springs have been used to secure the beam to the ground. Additionally, a number of holes have been employed to simplify the pull-up and pull-in motions. The usage of silicon substrates has some drawbacks, as was previously discussed. Glass has therefore been used as the substrate in the proposed device. Table 1 contains details about the proposed switch, such as the size of the bridge and the components it is made of. Calculating the spring stiffness constant in equation 3 is made easier with the aid of Table 2.

TABLE 1: The characteristics of the Micro-Electromechanical device.

Parameter	Material	Dimension(μm)	Thickness
CPW	Gold	15/80/15	0.5
Bridge	Gold	80x120	0.5
Substrate	Glass	600x400	200
Spring	Gold	-	0.5
Dielectric Layer	AlN	80x120	0.15
Hole	-	15x15	05
Gap	-	-	1.5

$$V_p=\sqrt{\frac{8K_{total}g_0^3}{27\varepsilon_0 A}} \quad \text{… (1)}$$

$$K=\frac{EWt^3}{L^3} \quad \text{… (2)}$$

TABLE 2: Calculating of the spring stiffness constant

Thickness	Spring-Stiffness (N/m)						
	K1	K2	K3	K4	K5	K6	K_{total}
0.5μm	148	4.74	345	1.54	197	1.14	4.57

$$\frac{1}{K_B}=\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}\ldots \quad \text{… (3)}$$

For the floating signal line and the solitary contact point in this system, a 1 m thick Au/Cr was sputtered. A thick floating metal line requires a larger actuation voltage than a thin one, hence they differ in thickness from coplanar waveguides (CPW). After the release process, Discern 4 displayed a scanning electron microscope image of the manufactured in-line RF MEMS switch.

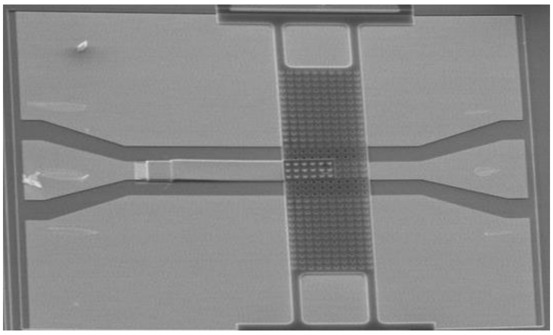

Fig.4. Scanning electron microscopy (SEM) image the fabricated in- line direct contact RF MEMS switch

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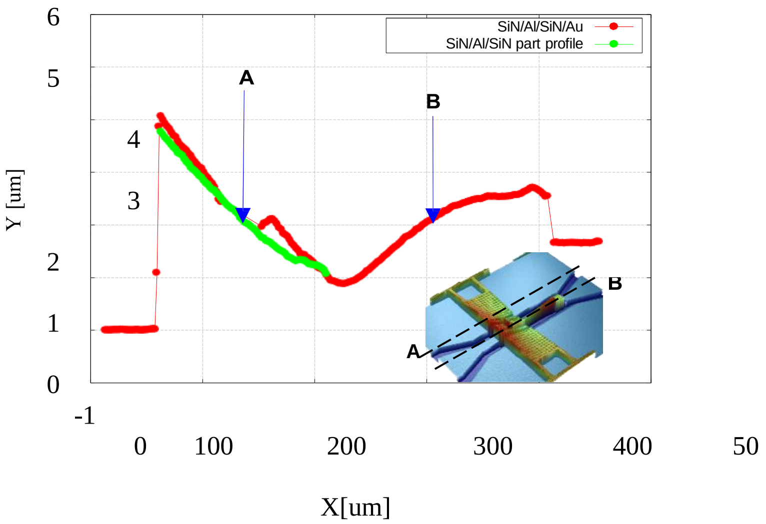
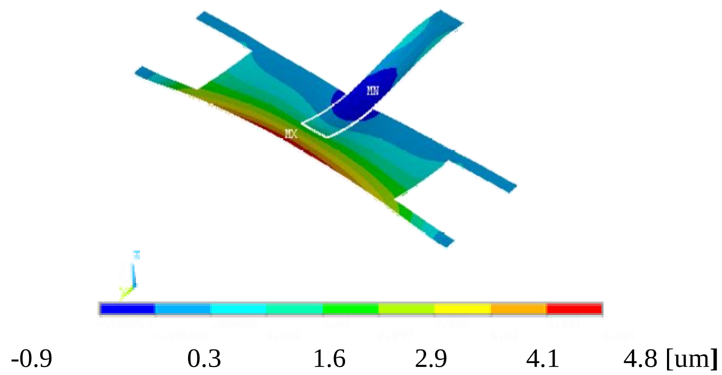


(a)



(b)

Fig.5. (a) 2-D profile data of the fabricated switch (b) thermal analysis including process temperature (Displacement)

As shown in Fig. 6(a), the stress of a supporting membrane was adequately adjusted. The extension of the gold-made floating signal line, however, caused the membrane to be sloped. It was confirmed by thermal analysis using the 570K maximal process temperature. The two figures in Fig. 6 that compared the measured surface profile to the computed thermal analysis coincided.

III. TEST AND EVALUATION

The pull-in voltage depends on the spring constant *K*, the gap between a top electrode and a bottom electrode *d*, and the electrode area *A* as given by (4).

$$V_p=\sqrt{\frac{8Kd^3}{27\varepsilon A}} \qquad \text{.....(4)}$$

The advanced RF-MEMS transfer model with two sections of excessive-impedance transmission line has been simulated by means of EM simulator.

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Parameter	Value	Unit	Comments
Au	19300	Kg/m^3	density
SIN	2700	Kg/m^3	density
Al	2300	Kg/m^3	density
m	$5.5x\ 10^{-10}$	Kg	Calculated mass
K	12	N/m	Simulated spring constant
f	23.3	KHz	Calculated (small damping)
V_p	8	V	Simulated pull-in voltage
V_s	15	V	Source voltage
T_{off}	25	µs	Measured switch OFF time
T_{on}	20	µs	Measured switch ON time
T_{cal}	14	µs	Calculated switch time

Table 3: Data for the switching time calculation

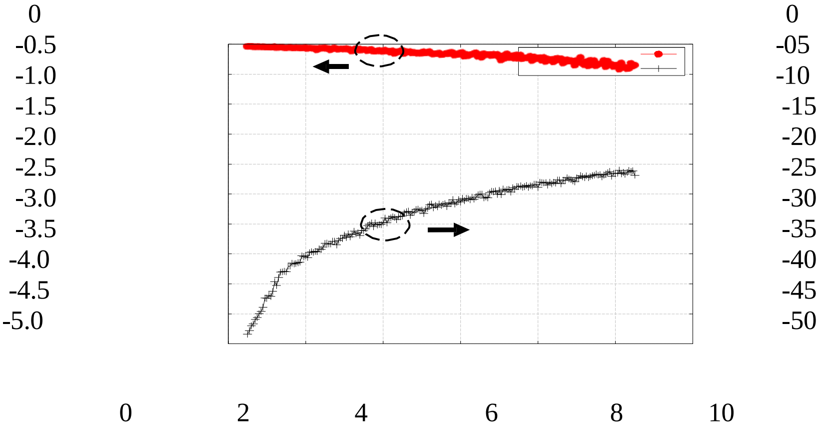

Fig.6. RF characteristics of the fabricated in-line RF MEMS Switch

This calculation is based on a crude approximation that a parallel plate capacitor's electrostatic force and the mechanical switch's electrostatic force are equivalent [8]. The manufactured in-line switch's observed actuation voltage was higher than the pull-in voltage that was simulated.

The spring constant was made stronger by the stiffening effect of the membrane structure, and equation (1) states that this is mostly because the initial gap is different due to the thermal stress of the floating signal line. Additionally, switching time was measured and computed. An oscilloscope's output port was linked to an input port, which received a sinusoidal wave with a frequency of 200 kHz and a peak-to-peak voltage of 4 V, as an input signal, to measure voltage of 4 V, as an input signal, to measure

IV. RESULTS AND DISCUSSION

The s-parameters of the switch can be obtained by using Equations (5) and (6).

$$S_{11} = -20\log\left|\frac{-Z_h}{2Z_h+Z_0}\right| \quad ..... (5)$$

$$S_{21} = -20\log\left|\frac{-Z_h}{2Z_h+Z_0}\right| \quad ...... (6)$$

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Where in $Z_0$the impedance of a CPW and Z_0h is the impedance of the beam. Additionally, the electrical section of the proposed switch has been simulated via HFSS software program, which may be seen in Figures 7.a and 7.b. Isolation and insertion loss were obtained -58 dB and -0.87 dB, respectively, which can be very perfect values. Further, as shown in figure 6.b, the return loss is identical to -12.64 dB. All of the above values were obtained at the frequency of 58 GHz.

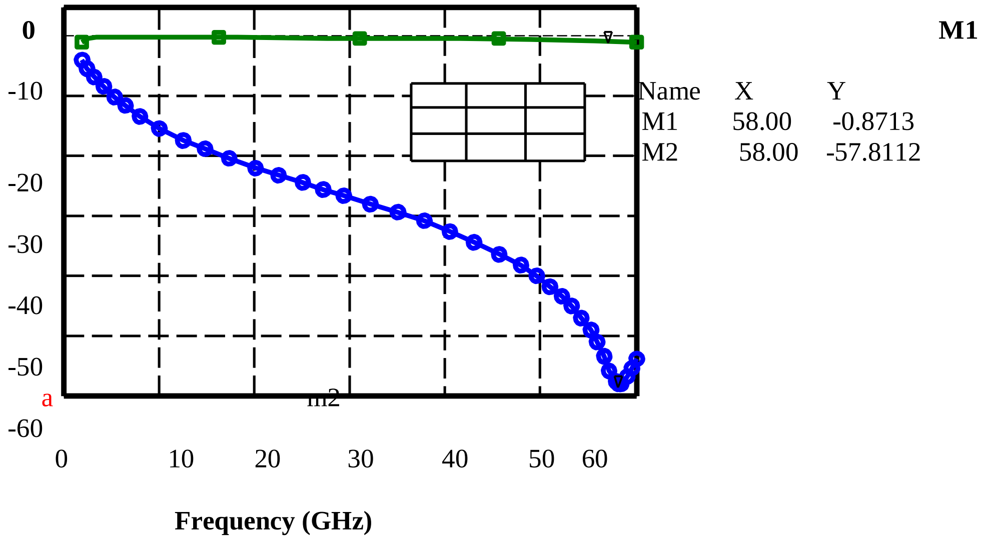

Fig.7. Insertion loss (green) and isolation (blue)

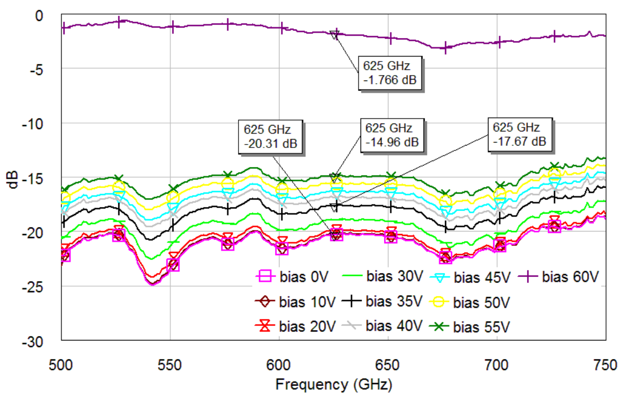

Fig.8. S21 performance measured under bias voltage change from 0 to 60 Air gap caused insertion loss is decreased when increasing bias voltage.

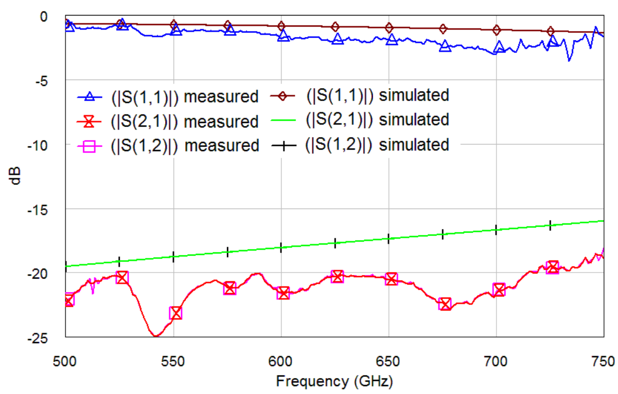

Fig.9. Switch's performance simulated and measured in "OFF" state. Isolation in most of the band is better than 20dB. After 700 GHz, it gradually decreases to around 17 dB at 750 GHz.

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The results of designing an RF MEMS switch have been analysed without putting the switch in an electrical circuit. This is contrary to reality. RF MEMS switches are widely used in the military, electronics and aerospace industries and thus must be tested in an electrical circuit in the presence of many passive and active elements. The presence of these elements might considerably affect the switch RF performance.

Measured and simulated "ON" state performance is pre- sented in Fig. 9. The insertion loss is smaller than 1.3dB from 500 to 600 GHz and increases to a range of 2 to 2.65 dB in the band of 600 to 750 GHz. Around 675 GHz, higher insertion loss is measured. The Switch's electrical length is approximately 90° at this frequency, so it is likely that the switch is radiating more significantly than at lower frequencies.

VI.CONCLUSION

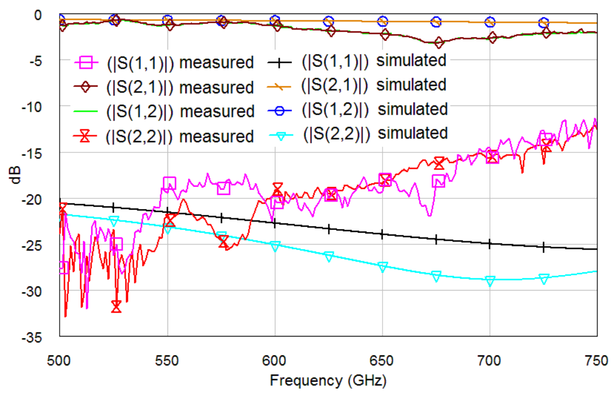

Fig.10. Switch's performance simulated and measured in "ON" state. The insertion loss is below 1.3 dB in band of 500 GHz to 600 GHz.

An RF MEMS shunt capacitive transfer with excessive isolation and occasional actuation voltage become designed that's desirable for use at 60 GHz. similarly, 3 ideas had been used to improve the traits of the switch and the clinical richness of the paper. Within the first step, the switch substrate changed from silicon to glass, which decreased value and made the fabricating procedure easier. Inside the 2nd step, the switch changed into pinned to the CPW unlike previous works where the switch were fixed. This reduced the strain within the interface between spring and anchor. Ultimately, with inside the third step, the amount of isolation versions because of the presence of the inductor and the capacitor.

The in-line contact RF MEMS switch turned into proposed, fabricated, and tested. The proposed switch has best unmarried contact factor on the give up of the floating signal line and it's far connected to the center of the membrane. The switch has a supportive membrane and is actuated by way of electrostatic pressure. The actuation voltage is 13V, and the measured insertion loss and isolation are -0.06 dB and -35.four dB at 2 GHz, respectively. it is believed that overall performance can be progressed with optimization of layout and fabrication: thickness of CPW, dimension of spring, and configuration of electrodes.

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