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Low settling Time offering Series Capacitive RF MEMS Switch for Wi-Fi Applications

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Abstract*: In this paper, a novel cantilever series capacitance based RF MEMS switch proposed for Wi-Fi applications. We have extended the analysis on the effect of quality factor on the switch on settling time. The holes in the cantilever help the switch to reduce the settling time. The quality factor of the switch designed with Al cantilever is 0.49. Low quality factor indicated damping effect is reduced. Si3N4 is used as dielectric material, with this the switch is offering high capacitance ratio. The series switch is offering high isolation at 2.4 GHz, so the proposed switch can be used in Wi-Fi applications as an isolator. The isolation losses of the switch is -30 dB, insertion loss is -0.34 dB and pull-in voltage required for the switching is 20 V.

Index Terms : Series Switches, Dielectric Losses, Cantilever, CPW Transmission Line.

I. INTRODUCTION

The MEMS technology based switches offering tremendous performance when compared with solid state devices. The actuation in micromechanical devices may be thermal, electrostatic, magneto static, piezoelectric [10]. The micro system RF switches have demonstrated high potential performance in RF losses, power aspects and reliability [1], [2]. The solid state switches are offering good performance at low frequency only, but the present day communication applications require high operating frequencies. In radio frequency t-lines, the RF MEMS switches created ON and OFF activity by a mechanical movement. In series RF MEMS switches damping, improving of contact resistance and micro welding has the significance for research extinction.

The paper [1] discusses about modelling of low damping MEMS device, the switch which is an electrostatic based laterally deflective type. The quality factor of the presented switch is 128. The actuation voltage is 40 V. Switch settling time is 3.5ms. The paper [2] presents three different electrostatic switches, the quality factor of the switches are Sw-1 (Q-20), Sw-2 (Q-17), Sw-3 (Q-15). The analysis id done at stress 60MPa.overall all the switches are requiring 300 µs settling time. The paper [3] proposes an electrostatic actuated DC contact RF MEMS switch and analysed settling time of the switch with low damping actuation signal. The switch settling time is 20 µs. The paper [10] presents dynamic bounce behaviour of the MEMS RF switch. Overall three models are presented, all the switches are maintaining uniform length of 240 µs. The settling time of the switches are in the range 40-80 µs. Settling time of the switch can be improved using holes to the structures. The holes will not affect the switching time, but it will help to improve the quality factor. If the quality factor of the switch is reduced the settling time of the switch will also reduce [10].

II. PERFORATION EFFECT ON QUALITY FACTOR AND SETTLING TIME

A series capacitive RF micromechanical switch is presented. The proposed switch actuation mechanism is created using electrostatic actuation technique in coplanar waveguide t-line. The cantilever structure is used as a micromechanical membrane. The entire switch is designed on quartz substrate. Proposed series capacitive RF switch model structure upper and side view is shown in figure 1.

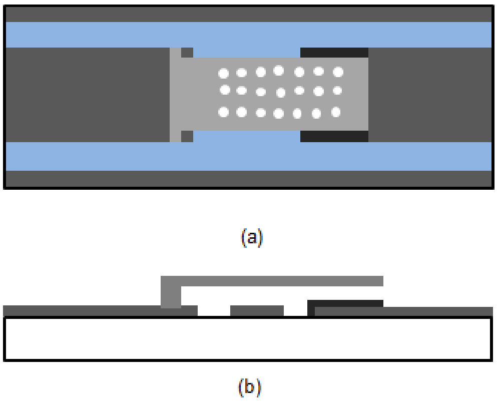

Figure 1. Perforated cantilever series capacitive RF micro mechanical switch, (a)Upper view, (b)Side view.

Series capacitive RF MEMS switch is ON when we apply the voltage, if the switch is ON input signal will go to output. If the voltage is not applied the switch is in OFF state, the input radio frequency signal is not able to reach output. After applying external biasing voltage the cantilever deforms to down state (switch ON), otherwise the cantilever is in upstate (switch OFF).

A. Holes to the structure

The most of the MEMS structures are incorporated with holes with the diameter in the range 3-8 µm. These holes will boost the switch performance in terms of reducing the squeeze film damping and improves the switching speed. But the holes area would not be more than 60% of overall area. The holes pattern is characterized using ligament efficiency, and it can be written as [10]

$$\text{Ligament efficiency} = l/\text{pitch} \qquad \text{Eq.1.}$$

Where l is the distance between two holes, pitch is nothing but the distance between two holes origins as shown in Fig. 2.

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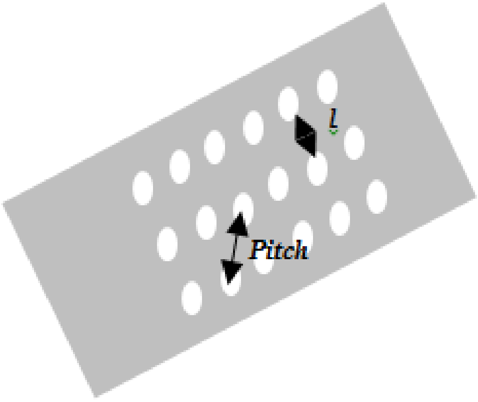

Figure 2. Holes to the MEMS structure

B. Quality factor

By using pressure, intrinsic material dissipation, and temperature variables we can determine the quality factor. The quality factor (Q) of micro mechanical switch helps to analyse the squeeze film damping behaviour, because most of the RF MEMS switches operate at atmospheric pressure.

$$Q_{cantilever} = \frac{\sqrt{E\rho}t^2}{\mu(wl)^2} g_0^3 \qquad \text{Eq.2.}$$

Where, ‘E’ young’s modulus, ‘ρ’ density,‘t’ thickness, ‘w’ width, ‘l’ length, ‘go’ gap of the membrane, ‘μ’ is the coefficient of viscosity.

The relation between the quality factor and the time constant can be written as

$$T=1/(\boldsymbol{\omega}_0 b) \qquad \text{Eq.3.}$$

Where, ‘b’ damping factor, ‘$\boldsymbol{\omega}0$‘ natural resonant frequency. In terms of damping factor and the resonant frequency the quality factor can be defined as

$$Q=k/\boldsymbol{\omega}_0 b \qquad \text{Eq.4.}$$

Therefore, we can relate the settling time and the quality factor i.e.

$$Q \propto k\,T \qquad \text{Eq.5.}$$

Where, ‘k’ spring constant of the cantilever. From Eq.5. we can conclude that the switch quality factor (Q) is low the cantilever settling time is also low.

III. DESIGN AND RESULTS DISCUSSION

The proposed switch design part is done using finite element analysis software, i.e., COMSOL Multiphysics tool. The switch is designed on 300**µ**mx300**µ**m quartz die. Series mechanism switching is created using cantilever structure. CPW transmission line with G/S/G ration is 30**µ**m/90**µ**m/30**µ**m. The switch is a vertically deflective electrostatic switch. We have analysed the switching properties of the switch using different materials like W, Cu, Au, Al metals.

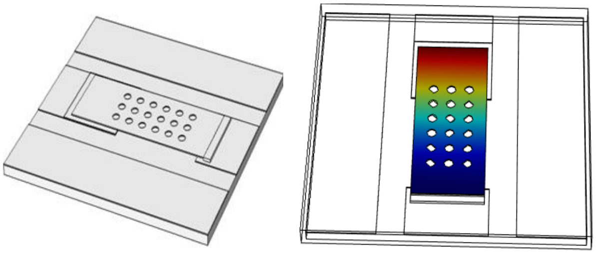
(a) (b)

Figure 3. Electrostatic Actuation, (a) before actuation, (b) After actuation.

The quality factor of the switch is analysed with different cantilever materials. Quality factor results are listed in the Table 1. The switch is offering the low quality factor i.e. below 0.5 when we use Al cantilever material. The damping behaviour of the switch for different materials are shown in figure 4.

Table 1. Quality factor of the proposed switch with different materials

Material	Young’s Modulus (E) in GPa	Density (ρ) in Kg/m^3	Quality Factor(Q)
W-Tungsten	411	19350	3.19
Cu- Copper	120	8960	1.175
Au-Gold	70	19300	1.31
Al-Aluminium	70	2700	0.49

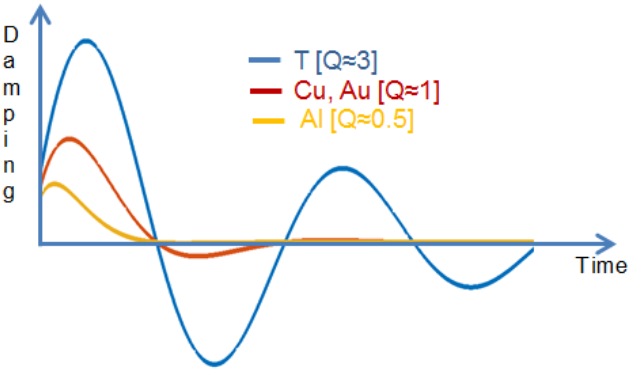

Figure 4. Different materials quality factor analysis with damping effect

From the above analysis, we can conclude that if the quality factor is high the switch mechanically actuated structure will take more time to settle. Here we did the analysis on the cantilever structure damping effect with different materials like tungsten (T), copper (Cu), gold (Au) and aluminium (Al). In that aluminium material offering the best performance compared to other metals.

Table 2. Proposed switch materials

Particular	Material	Thickness	Relative permittivity
Substrate	Quartz	1.5mm	3.8
CPW	Ti	2m	--
Dielectric	Si_3N_4	1**µ**m	7.2
Cantilever	Al	1**µ**m	--

The gap between the cantilever and the actuation electrodes is 1 **µ**m. The area of the actuation electrode is 200 **µ**m x 60 **µ**m.

Table 3. Proposed series capacitive micro mechanical switch dimensions

Parameters	Value(µm)
Substrate dimensions (*l – w – t*)	300 – 300 – 500
Cantilever dimensions (*l – w – t*)	200 – 80 – 1
Holes in membrane	Yes
Cantilever circular holes radius	5
Gap between the holes	10
Pitch of the holes	20
Cantilever height	1
Dielectric material dimensions (*l - w - t*)	90 - 80 - 1
Actuation area(*l-w*) [µm^2]	60 - 200

The switch is designed with electrostatic actuation. An analysis is carried out on, role of cantilever material properties on the pull-in

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voltage. Actuation voltage will minimized, if we use Al as a cantilever material when compared with Cu, T, Au. Al metal density is very low compared with other materials. The proposed switch pull-in voltage is 20V. The actuation results are as shown in Fig.5.

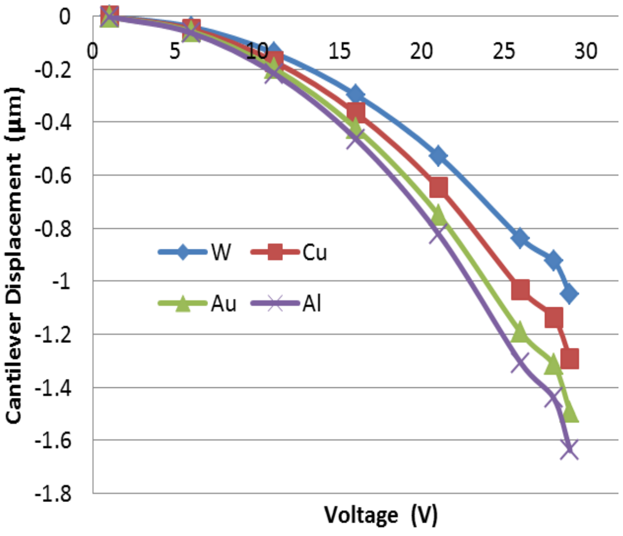

Figure 5. Cantilever displacement for applied voltage

The series capacitive switch radio frequency behaviour is analysed in with lower frequency limit is 10 MHz and upper frequency limit is 4 GHz. The switch is offering high isolation losses of -30 dB at 2.4 GHz. The return losses are below -10dB, insertion losses of the switch are also good i.e. in the range -0.05 dB to -0.35 dB over the frequency range 10 MHz to 4 GHz.

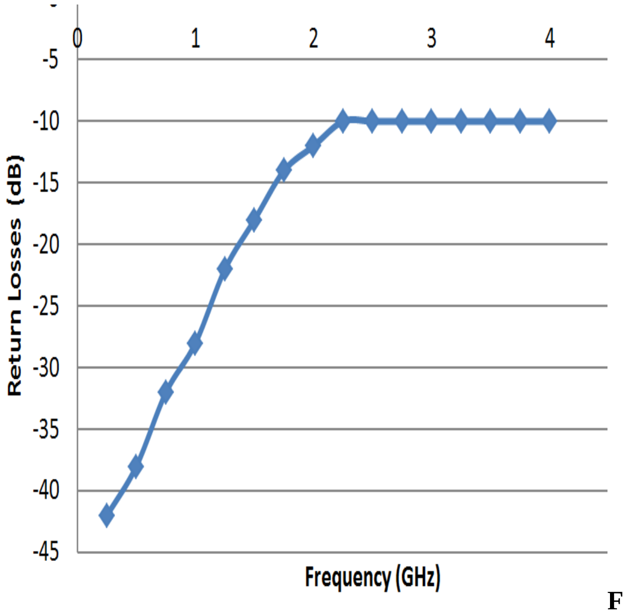

Figure 6. Return Losses

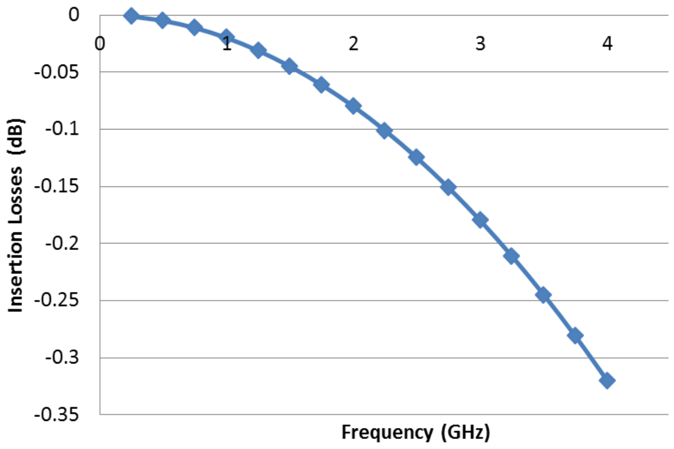

Figure 7. Insertion Losses

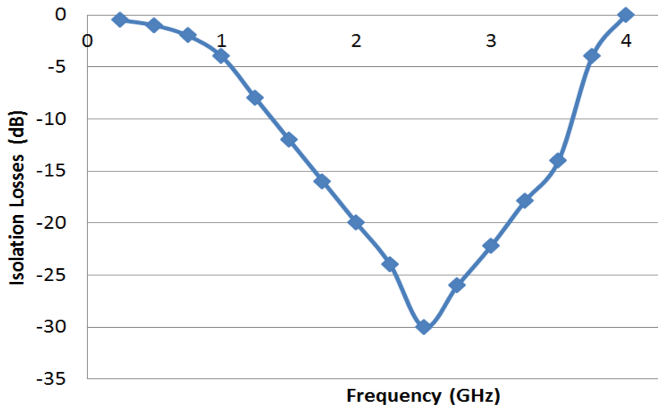

Figure 8. Isolation Losses

Table 4. Proposed switch comparison with literature

Parameters	**Ref. [13]**	**Ref. [14]**	**Ref. [15]**	**Proposed Switch**
Substrate	GaAs	---	Silicon	Quartz
Dielectric Material	Si_3N_4	Si_3N_4	---	Si_3N_4
Pull-in Voltage(V)	35	22V	10.4	20V
Holes to membrane	Yes	Yes	No	Yes
Hole Dimensions	Diameter-10μm (Circular Holes)	5μm x 5μm (Rectangular Holes)	---	5μm x 5μm (Rectangular Holes)
Insertion Losses (dB)	-0.5	-0.65	-0.7	-0.35
Isolation Losses (dB)	-22	-20	-23	-30

IV. CONCLUSION

Proposed switch can be used as an isolator in Wi-Fi applications. Low density Al is used as membrane material. Circular holes in the membrane push up the performance of the switch. Low quality factor is indicating that, the damping effect of the switch is minimized and switch settling time is reduced. The quality factor of the switch is 0.49, with this we can say the switch settling time is reduced. The switch is offering a very high isolation of -30dB at 2.4GHz, the insertion loss is -0.35dB.

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