Reinforcing RF MEMS Capacitive Switch To Reduce Stress For Radar Application

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***Abstract* – Radio frequency microelectromechanical systems (RFMEMS) shunt capacitive switches are used in microwave and millimeter wave systems. The presence of residual stress in these microstructures affects the static and dynamic behavior of the device. In this paper, we propose a RF MEMS capacitive switch to reduce stress by introducing perforations as well as reinforcement. The thickness of the reinforcement layer (hanging bridge) is optimized and the perforations are introduced on the plate to reduce deformation. The stiffness is enhanced by reducing buckling effect. The pull-in voltage of the switch is also reduced. The switching speed will be very high with high frequency isolation and low insertion loss.**

Keywords- Pull-in Voltage; Perforations; Reinforcement; Buckling; Upstate Capacitance; Downstate Capacitance

I. INTRODUCTION

RF MEMS shunt capacitive switch is used to get better insertion and isolation loss than series switch. Radio frequency micro-electro-mechanical-systems (RF MEMS) technology has already emerged as an enabling technology for a new generation of high-performance RF components such as RF MEMS switches, tunable capacitors, and inductors. Those RF MEMS components can be fully integrated with monolithic microwave integrated circuits and therefore can potentially lead to systems with small size, lighter weight, low power consumption, and mass production.

II. SHUNTCAPACITIVESWITCH DESCRIPTION

Among the mentioned RF MEMS devices, the MEMS switch is a key device due to its unique RF performance comparing to the current existing devices. These unique characteristics make MEMS switches ideal candidates for incorporation into passive circuits, such as phase shifters or tunable filters, for implementation in many terrestrial and space applications including portable telecommunication, wireless computer networks, reconfigurable antennas, and others.[3] Microelectromechanical system (MEMS) electrostatically actuated reflective switches for low-loss microwave and millimetre - wave applications. The development of highly miniaturized wireless communication systems requires full integration of circuits and radio-frequency components on a single chip. Microelectromechanical systems using existing semiconductor technology are promising to facilitate such integration. In a large variety of RF MEMS components, micromechanical switch has found many applications in controlling microwave signals. [2]

Accurate modelling of pull-in voltage is very challenging due to high nonlinearity and instability**.** Effects such as fringing field, residual stress and stress gradient induced curling have further complicated the modelling of such device. Numerical method based modelling, such as the finite element method is often used for the modelling of such phenomena, and it can be implemented in various commercial MEMS simulation software such as Coventorware, Intellisuite, Ansys and Femlab. [2]

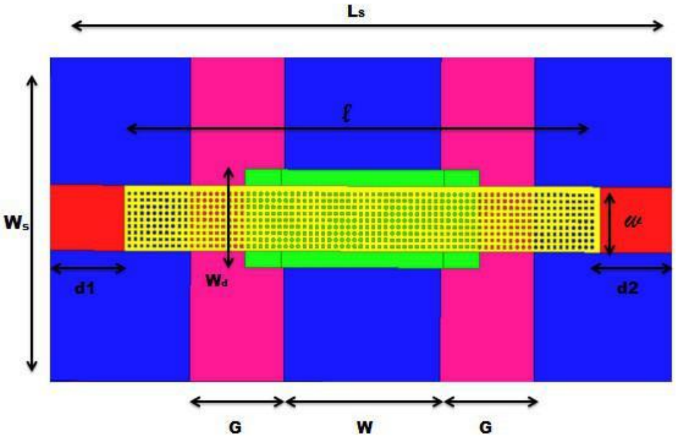

Figure 1: Proposed structure of RF MEMS capacitive switch.

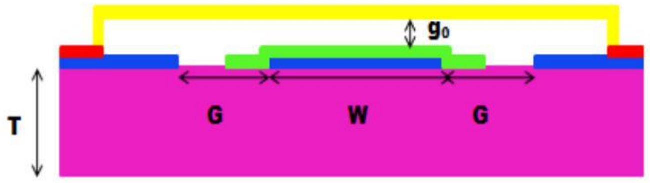

Figure 2: Side view of RF MEMS capacitive switch.

When the switch (membrane) is up, the switch presents a small shunt capacitance to ground. When the switch is pulled down to the centre conductor, the shunt capacitance increases by a factor of 20–100, presenting an RF short. MEMS shunt switches have several advantages over their p- i-n diode counterpart. The MEMS switch has very little dc power consumption (micro joule during the switching process), allows for large down- to up-state capacitance ratios (C_d/C_u=20-100), has very low inter-modulation products, and can be fabricated on almost any substrate. [1]

Low actuation voltage and high isolation of the switch were achieved by exploiting buckling and bending effects induced by well-controlled residual stress. Several disadvantages include slow switching speeds (2–10 s), high actuation voltages (15–80 V), and hot switching in high RF power applications (2 W). These disadvantages may be tolerated in many applications, such as low-loss high-isolation telecommunications switches and radars with relatively low scanning rates. [1]

Silicon micromachining has been a key factor for the vast progress of MEMS. Silicon micromachining refers to fashioning microscopic mechanical parts out of a silicon substrate or on a silicon substrate. Silicon micromachining comprises of two technologies: bulk micromachining, in which structures are etched into silicon substrate, and surface micromachining, in which the micromechanical layers are formed from layers and films deposited on the surface. [4]

This paper focuses on designing the RF MEMS capacitive switches. The disadvantages have been rectified by using this switch design as mentioned in the paper. The buckling effect is reduced by minimising the thickness of the hanging bridge which in turn enhances the stiffness. The switching speed is also increased as the perforations are included in the proposed structure.

III. STRUCTURE OF SHUNT CAPACITIVE SWITCH

There are two basic switches used in RF to millimetre wave circuit design: the shunt switch and the series switch. The shunt switch is placed in shunt between the t-line and ground; and depending on the applied bias voltage, it either leaves the t-line undisturbed or connects it to ground. Therefore, the ideal shunt switch results in zero insertion loss when no bias is applied (up-state position) and infinite isolation when bias is applied (down-state position). Shunt capacitive switches are more suited for higher frequencies (5–100 GHz). [5]

The MEMS shunt switch can be integrated in a coplanar-waveguide (CPW) or in a micro strip topology. In a CPW configuration, the anchors of the MEMS switch are connected to the CPW ground planes.

The substrate used here is made of silicon which is 400 µm long (Ls) , 200 µm wide (W_s) and 100 µm thick (T_s). It is coated with silicon- di-oxide as dielectric of thickness 1 µm. Co-planar waveguide (CPW) has a transmission line of width 100 µm along with a gap of 60 µm between the ground planes. A thin dielectric layer made up of silicon nitrate of thickness 1 µm (t_d) and length 150 µm (t_l) is placed in-between the transmission line and the bridge. The bridge is made of gold (Au) which is 2 µm thick (t), 300 µm long (l) and 40 µm wide

(w) is placed over the CPW with height of 1.5 µm (g_0). The anchor is placed 40 µm from the edge of the ground plane and it is of length 50 µm. The perforations in the bridge are of 4 µm in diameter and the gap between them is also 4 µm.

A DC voltage is applied between the MEMS Bridge and the microwave line. This results in an electrostatic force that causes the MEMS Bridge to collapse on the dielectric layer, largely increasing the bridge capacitance by a factor of 30–100. [5] This capacitance connects the t-line to the ground and acts a short circuit at microwave frequencies, resulting in a reflective switch. When the bias voltage is removed, the MEMS switch returns back to its original position due to the restoring spring forces of the bridge. This switch has a set of closely spaced holes in the bridge membrane. The holes are introduced in this design in order to reduce the buckling effect.

PARAMETER	**SYMBOL**	**MEASUREMENTS (in µm)**
Substrate Length	L_s	400
Substrate Width	W_s	200
Substrate Thickness	T_s	100
CPW	(G/W/G)	60/100/60
Dielectric Thickness	t_d	1
Dielectric Length	t_l	150
Bridge Length	l	300
Bridge Width	w	40
Bridge Thickness	t	2
Bridge height	g_0	1.5
Anchor	a	50
Hole Diameter	d_h	4

Table 1: Dimensions of the RF MEMS capacitive switch.

IV. MECHANISM

It is tempting to make the dielectric layer as thin as possible to increase the capacitance ratio. However, it is impractical to deposit a Si N layer, which is thinner than 1000Å due to pin-hole problems in thin dielectric layers. Also, this dielectric layer must be able to withstand the actuation voltage (20–50 V) without dielectric breakdown. It is for this reason that this layer is typically 1000–1500-Å thick in all switches built today. The down- state capacitance can be degraded if the MEMS bridge layer or dielectric layer is rough. This can be due to the deposition parameters of the nitride or the fabrication process of the MEMS bridge.[1]

A. *Pull-down voltage*

In order to actuate the switch, the center conductor of the CPW line is dc biased with respect to the ground. The resulting electrostatic forces pull the membrane toward the center conductor, with a pull-down voltage of,

$$v_{pp} \sqrt{\frac{8k}{27\,{}_{0}\,Ww}\, g_0^3}$$

where k is the effective spring constant of the membrane, W is the CPW center conductor width, w is the membrane width, ε_0 is the permittivity of free space, and g_o is the nominal gap height. Notice that the pull-down voltage is independent of the switch width.

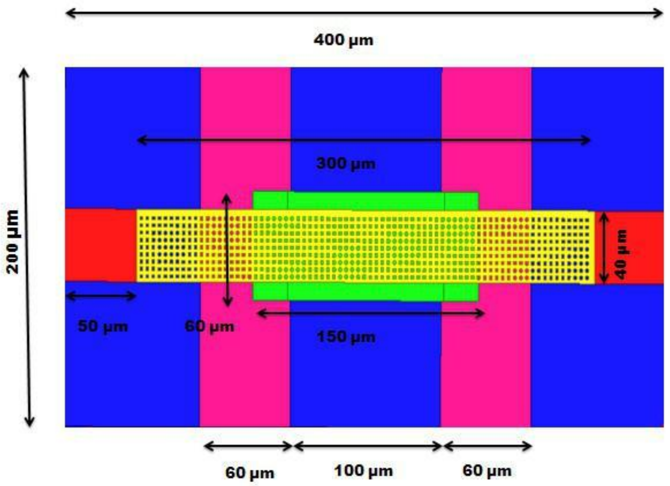

Figure 3: Design with measurements.

B. *Loss*

The loss of a MEMS shunt switch is sometimes taken to be $|S_{21}|^2$. The decrease in S_{21} does not necessarily indicate power loss in the switch, but can simply be due to an increase in the reflected power from the switch ($|S_{11}|^2$). The loss of a MEMS switch is better derived from the S-parameters as

$$Loss\,1 \quad |S_{11}|^2 \quad |S_{21}|^2$$

and this can be easily calculated using a microwave circuit simulator or using measured values. The MEMS shunt switch loss is composed of two parts: the transmission-line loss underneath the bridge, and the MEMS bridge loss.

C. *Up-state capacitance*

The -parameters are first measured in the up-state position and the measured data is fitted to get the up-state capacitance of the switch. The inductance and resistance are not fitted using this measurement since their effect is negligible in the up-state position.

The up-state capacitance of the shunt switch is given by

$$C_u \quad C_{pp} \quad C_f$$

where C_f is the fringing and parasitic capacitance and C_{pp}= $\varepsilon A/g_o$ is the parallel-plate capacitance. The up-state capacitance can also be measured by,

$$C_{pp} \quad \frac{{}_{0}\,wW}{g_0\; t_d / {}_{r}}$$

Still, it is evident that MEMS switches, with their extremely low up-state capacitance (series switches) and their very high capacitance ratio (capacitance contact switches), offer a far superior performance compared to solid-state switches for low to medium power applications.

D. *Down-state capacitance*

The MEMS switch capacitance in the down-state position can be easily calculated using,

$$C_d \quad \frac{{}_{0}\,{}_{r}A}{t_d}$$

In this case, the thickness of the dielectric is so small that the fringing capacitance can be neglected. At RF frequencies (f < 1 GHz), the down-state capacitance dominates the switch performance, and it results in a poor insertion loss (for Cd < 4 pF).

V. OBSERVATION AND RESULT

The return loss obtained for the designed RF MEMS capacitive switch is shown in the figure below,

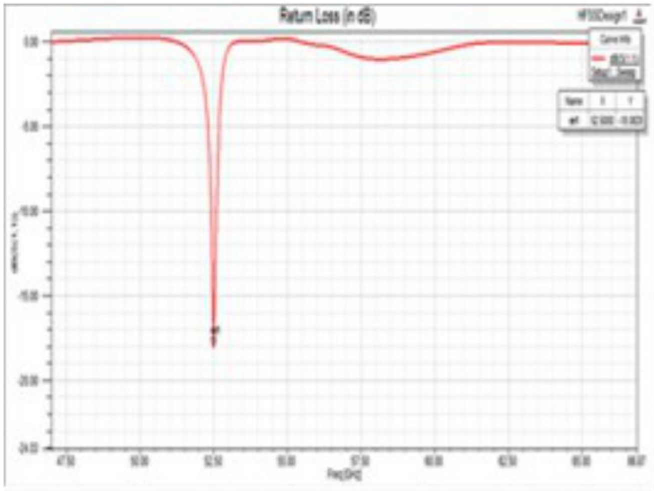

Figure 4: Return loss of the RF MEMS capacitive switch.

The operating frequency of the proposed RF MEMS capacitive switch is 52.5 GHz and this can be used for radar application. The return loss is obtained at -18.08 dB.

VI. CONCLUSION

By introducing perforations, a small increase in the pull-in-voltage is observed due to a reduction in the bridge overlap area. The stiffness is enhanced by reducing buckling effect. The pull-in voltage of the switch is also reduced. The switching speed will be very high with high frequency isolation and low insertion loss. A DC voltage is applied between the MEMS Bridge and the microwave line. This results in an electrostatic force that causes the MEMS Bridge to collapse on the dielectric layer. The S_{11} gained in the proposed structure is -18.08 dB.

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