

# CANTILEVER TYPE SWITCH DESIGN

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## Abstract

This paper deals with the RF (Radio Frequency)-MEMS (Micro-Electro-Mechanical-System) switch design using the coventorware software and its superiority over the existing technologies like PIN Diodes and Field-Effect-Transistors regarding size, power, Isolation and Insertion loss, and graphically how Pull-in voltage affects on the deflection of the switch. Also this paper deals with the fabrication process of the cantilever switch.

**Keywords:** Etching, Sacrificial Layer, Actuation Voltage, Electrostatic Force, RF Switch, PIN Diodes, Stiction, Isolation and Insertion loss.

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## 1. INTRODUCTION

RF MEMS Switches are used for make and break contact between the transmission lines, and operates in the frequency range 0.1 GHz to 40 GHz. In the last two decades MEMS provided very strong and effective solution in the various passive circuits applications like varactors, switches and in various complex networks like filters.

As per recent generation requirements in terms device should be small in size, should be effective in performance such as low loss, less DC power consumption, less insertion loss and high isolation between the plates and for high frequency applications device should have high Q-factor. These all requirements full filled by the MEMS technology and practically implemented as effective technology for Military applications, mobile, wireless and satellite communications. The RF MEMS technology dominates over the existing technologies based devices like PIN diodes and FET. As per following characteristics mentioned in the Table 1.

MEMS Switches combines the advantages of Mechanical and Semiconductor Switches together and yields the advanced switches which will fulfill all the requirements like small in size, low DC power consumption, lower insertion loss, high off-state isolation [1]. Because of electromechanical isolation, without any losses RF circuit coupled significantly to the actuation circuit. Electromechanical coupling is done through electro statically through air less power required because power consumes only when actuation occurs.

Based on MEMS actuation, MEMS switches can be classified by following three characteristics;

- i. RF circuit configuration,
- ii. Mechanical structure,
- iii. Form of contact.

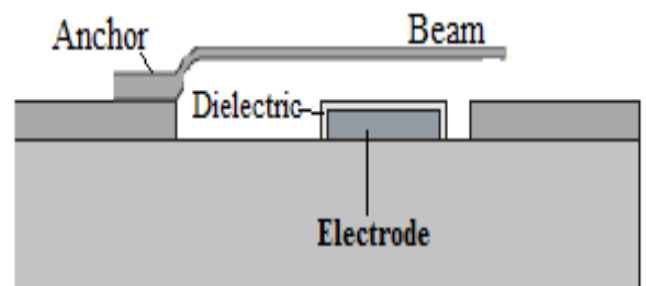
**Table -1:** Comparison between various RF Switches

Switch Type	Isolation	Insertion Loss	Power Consumption	Switching Time	Linearity
PIN Diode	Medium	Good	More	Good	Poor
FET's	Low	Good	Medium	Excellent	Poor
RF MEMS	Large	Excellent	Less	Poor	Excellent

Basically from a switch contact perspective, there are two types of switches based on the MEMS technology Application point of view- Series Contact Switches and Shunt Capacitive Switches.

### 1.1 Series Contact Switches

The basic structure of a MEMS contact series switch is its conductive beam suspended over the transmission line. Application of dc bias exerts an electrostatic force on the beam, which lowers the beam across the gap and shorts the open ends of the transmission line. After removing the dc bias, the spring restoring force in the beam returns it to its suspended (up) position.



**Fig -1:** Series Contact Switch

## 1.2 Shunt Capacitive Switches

In such switches grounded beam is suspended over a dielectric pad on the transmission line. When the beam is in up position, the capacitance of the line dielectric air beam is of the order of  $\sim 50$  pF, which translates to a high impedance path to ground through the beam. However when a dc voltage is applied between the transmission line and the electrode, the induced electrostatic force pulls down the beam which is to be coplanar with the dielectric pad results in lowering the capacitance to pF levels, impedance of the path through the beam for high frequency (RF) signal and shorting the RF to ground.

The capacitive switch insertion loss is lower than 1.2 dB up to 40 GHz, extracted up-state capacitance is 30 pF and isolation is 1.3dB at 1GHz, 26dB at 20GHz, and 27dB at 40GHz. Due to one end is free in cantilever type switch, it requires lower actuation voltage compared to Air bridge MEMS switch [9]. The capacitive MEMS switch is as shown in Figure 2.

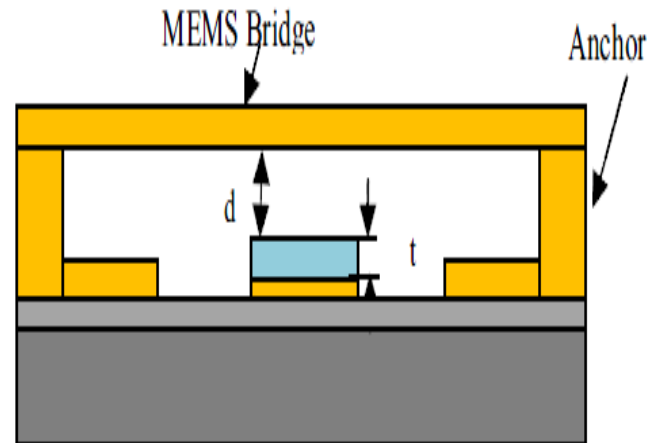


Fig -2: Shunt Capacitive Switch

## 2. RF PERFORMANCE

For designing cantilever beam as an actuator we must know the pull-in voltage, hold down voltage, spring constant required for cantilever and the resonant frequency for cantilever. Also needs to consider switching lifetime and switching time. The Solid structure of RF MEMS Cantilever Switch looks as shown in Figure 3(a) and its side view is shown in the Figure 3(b).

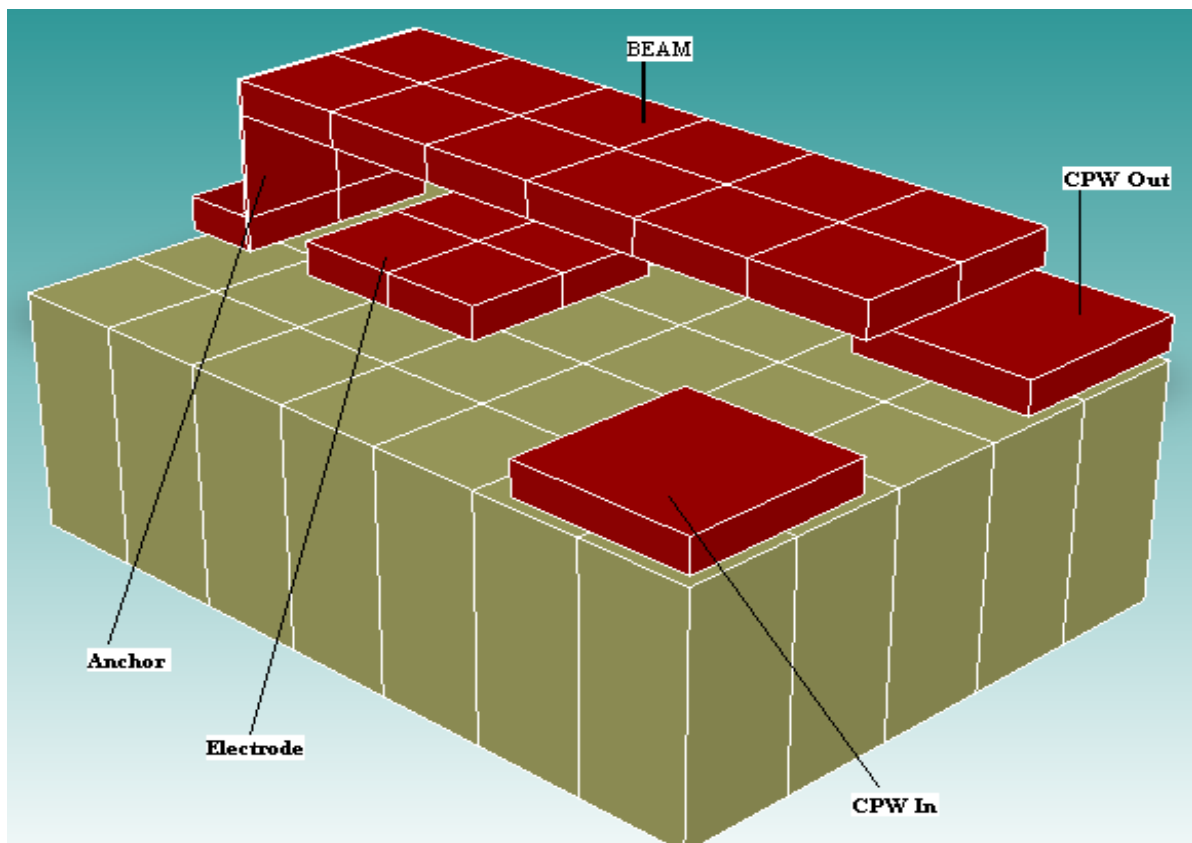


Fig -3(a): Solid Cantilever switch

### 2.1 Actuation Voltage

The working of the cantilever switch is mainly depends on the applied electric field to the electrode V, because of this applied field the electrostatic force F is exerted on the beam, this electrostatic force is measured as in equation (1),

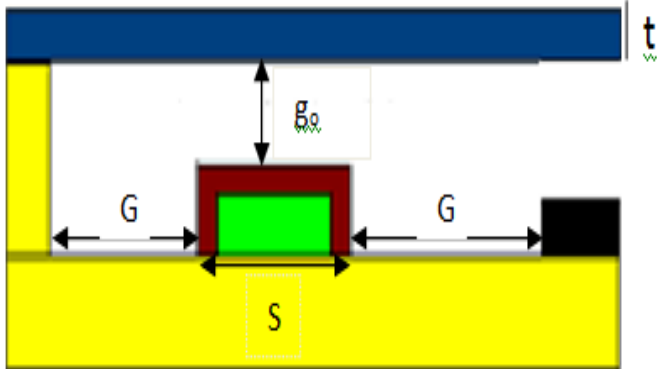


Fig -3(b): Side view of Cantilever switch

$$F = \frac{\epsilon_0 AV^2}{2g^2}, F_r \propto K_t \Delta x \tag{1}$$

Where, V is applied voltage, A is contact area between electrode and beam & g is the deflected gap between electrode and the beam, and K<sub>t</sub> is the spring constant. When the applied voltage goes on increasing the electrostatic force exerted on the cantilever beam is goes on increasing which will tends to beam pull down towards the electrode tends to decreases the gap present between the beam and the electrode.

When this applied voltage goes on increases the time comes at certain value of applied voltage beyond that voltage the electrostatic force F is greater in magnitude than the restoring force which is exerted by the anchor because of the spring constant of the material. At applied voltage the electrostatic force dominates over the restoring force which pulls down beam towards the electrode as shown in Figure.7, which completes the path causes the signal to move from input to output. This makes the switch on. Here we designed the Cantilever switch having beam length 150 μm, width of beam (W) 40 μm, g<sub>0</sub> is 2.2 μm and 0.7 μm thickness of the beam. Values of Pull in voltages by theoretical & Coventorware simulation are 38.8 V & 40 V respectively as shown in the Figure 5. This voltage at which the beam pulled down towards the electrode is called as the pull-in voltage V<sub>p</sub> and is given by [4], [5] the equation (2) as,

$$V_p = \sqrt{\frac{8K_t g_0^3}{27 \epsilon_0 A}} \tag{2}$$

Where K<sub>t</sub> is the spring constant of the beam material, g<sub>0</sub> is the original gap between the beam and the electrode and ε<sub>0</sub> is the permittivity of the material. The spring constant is calculated by the equation (3) as,

$$K_t = \frac{EWt^3}{4l_m^3} \tag{3}$$

Where, E is the young's modulus of the material, t is the thickness of the beam and l<sub>m</sub> is the enforced length of the beam is given by the equation (4) as,

$$l_m = l - W - l_s \tag{4}$$

Where l the length of the beam, W is the width and l<sub>s</sub> is the isolation length of the beam.

Due to the applied voltage movement of the cantilever beam switch is as shown in the Figure 4.

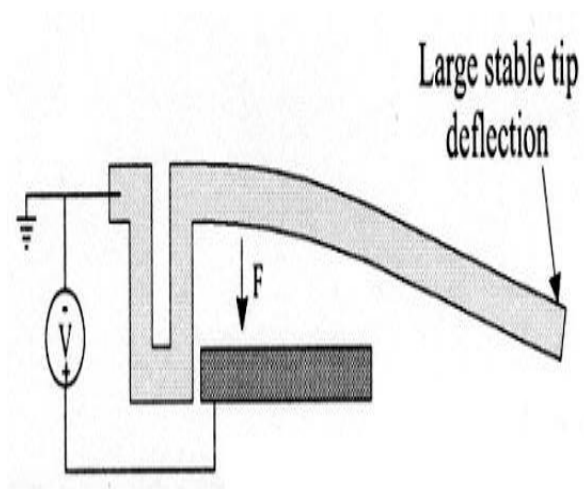


Fig -4: Movement of cantilever switch verses applied voltage

Initially as the applied voltage goes on increases the gap between the beam and ground electrode slowly reduces, as the gap becomes 2/3 of original gap the beam suddenly pull downs. And the figure 5 represents the voltage required to pull down the cantilever beam to make switch as an on. The figure 6 shows the electrostatic force exerted by the applied voltage to the electrode.

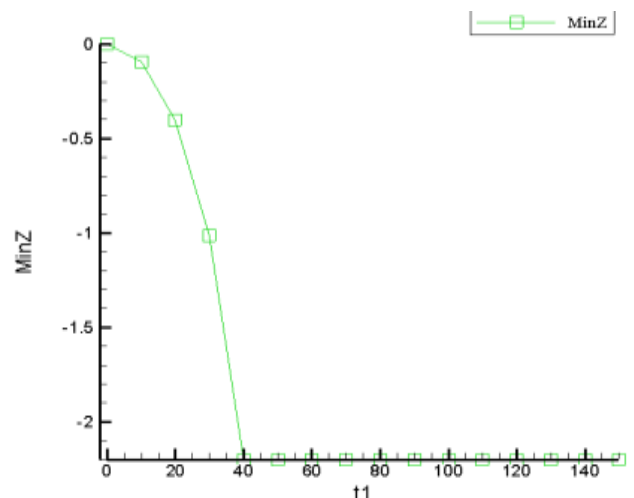


Fig -5: Graph of Voltage verses Displacement of beam

Also from the different analysis on the structure it is observed that the actuation voltage required pulling the beam downward

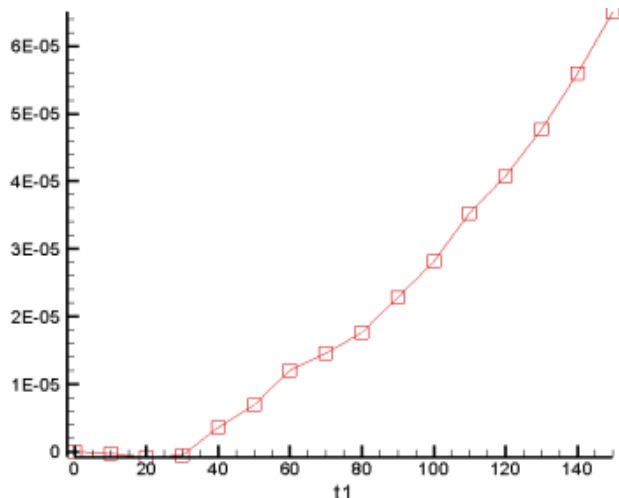


Fig -6: Graph of Applied Voltage versus electrostatic force on the beam

To make switch on is varies according to the length of the beam and also by Varying area of the actuated electrode. This is shown in the Table 2.

Table -2: Shows Different Lengths Beam and the Required Pull in Voltage

Length of Beam	Pull in Voltage $V_p$
150 $\mu\text{m}$	40 V
180 $\mu\text{m}$	16 V
200 $\mu\text{m}$	11 V
250 $\mu\text{m}$	7 V
280 $\mu\text{m}$	5 V

### 2.2 Switching Times

Using 4-point resistance measurement and the laser vibrometer the electrical resistance and mechanical displacement of the switch is measured as a function of time. The closing time depends on actuation voltage whereas opening time depends on the mechanical properties of the switch by proper scaling the MEMS devices the switching time can be scale downs, as

$$t_s \approx 3.67 \frac{V_p}{V_s \omega_0}, \quad f_0 = \sqrt{\frac{K}{m}} \quad (5)$$

Where  $(\omega_0, f_0)$  is resonant frequency,  $V_p$  is pull-in voltage and  $V_s$  is applied voltage.

## 3. FABRICATION PROCESS

In the fabrication process of the cantilever switch is explained roughly step by step and Figure 3.1 Through 3.6 Explains Fabrication Process of Cantilever Type Switch, as bellow

### 3.1 Substrate Creation

To form the cantilever type structure we require the platform is called the substrate, silicon dioxide ( $\text{SiO}_2$ ) material used as the substrate. In this design the substrate of 150  $\mu\text{m}$  length, 110  $\mu\text{m}$  width and 5  $\mu\text{m}$  thickness is used.



Fig -3.1: Substrate

### 3.2 Electrode Formation

Electrode is formed with the help of generic plasma enhanced chemical vapor deposition (PECVD) and generic dry etching process by exposing the part of the deposited electrode material through the openings in the masking layers and removes the unnecessary material. In this design Aluminum material is used for the electrode purpose, as shown in figure 3.2



Fig -3.2: Actuated Electrode Formation

### 3.3 Deposition of Silicon Nitride Layer

To avoid the stiction problem, arises in the metal to metal contact occurs which affects on the smooth switching operation without this layer. In this design 0.2  $\mu\text{m}$  thick  $\text{SiN}_3$  layer is deposited over the electrode by PECVD process, as shown in figure 3.3.

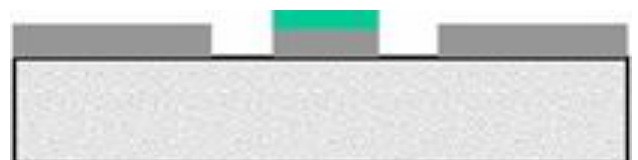


Fig -3.3: Deposition of  $\text{SiN}_3$

### 3.4 Sacrificial Layer Formation

To make the cantilever beam over the free space and separation between the CPW lines, BPSG material of 2.2  $\mu\text{m}$  in height is used as shown in the figure 3.4



Fig -3.4: Deposition of Sacrificial Layer

### 3.5 Forming Cantilever Beam

By using low chemical vapor deposition (LPCVD) 0.7  $\mu\text{m}$  thickness and 2.2  $\mu\text{m}$  high Aluminum cantilever beam is formed, as shown in the figure 3.5



Fig -3.5: Deposition of metal

### 3.6 Removing the Sacrificial Layer

After cantilever beam structure formation the BPSG material is deleted to make the beam free in the air by using plasma etching process, as shown in figure 3.6



Fig -3.6: Deleting Sacrificial Layer

## 4. CONCLUSION

In this Paper we have seen how cantilever switch is designed and the different observations have been studied like varying the length of the beam we can reduce the pull in voltage required to make the switch on and off, also how can voltage relates with the electrode contact area and gap between the electrode and the actuating beam is seen in this paper. Also in this paper how fabrication can be done to prepare the RF switch is presented.

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