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Methods For The Minimization Of Actuation Voltage In MEMS Switch

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Abstract

MEMS (Micro-Electro-Mechanical Systems) is the Combination of mechanical functions such as sensing, moving, heating and electrical functions such as switching on the same chip using micro fabrication technology. The term MEMS refers to a collection of microsensors and actuators which can sense its environment and have the ability to react to changes in that environment with the use of a microcircuit control. These micros witches have two major design groups: capacitive (Metal-Insulator-Metal) and resistive (Metal-To-Metal). In the capacitive design of a microswitch it refers the RF signal is shorted to ground by a variable capacitor. In the Resistive design switch operates by creating an open or short in the transmission line.

This paper reviews the progress in MEMS applications from a device perspective. It includes the designing of cantilever switch and will tell about the important device parameters that are highlighted, as they have significant contributions to the performance of the final products in which the devices are used. The challenges and statuses of these MEMS devices are discussed.

In this paper, a cantilever type of switch is proposed that could reduce the stress sensitivity of the switch as well as providing a low actuation voltage. The overall switch structure will be designed with size miniaturization. Here in this paper the main objective is to Design the cantilever switch and to measure its actuation voltage.

The main advantages of using the MEMS is to achieve the small size, lower power consumption, lower cost, increased reliability improved reproducibility and higher precision, Low insertion losses.

IndexTerms— RF MEMS switch, Low actuation voltage, RF parameters.

1.Introduction

MEMS are small integrated devices or system that Combine electrical and mechanical components. They range in size from the submicrometer level to the millimeter level. MEMS replace traditional mechanical and electronic devices such as actuators, transducers and gears with micrometer-scale equivalents that can transform whole industries. MEMS devices are currently used in telecommunications, wireless networking, global positioning systems, cellular, auto, and even toy industry.

MEMS can help in the miniaturization of various types of electronic systems. For example, a MEMS sensor can be 1 mm^3 in volume, including interface electronics. Sizereduction tends to result in decreased power consumption. Since there are essentially no moving parts the electronic system can be made very reliable. As a result, MEMS is revolutionizing the electronics. The most significant advantage of MEMS is their ability to communicate easily with electrical elements in semiconductor chips. There are also certain Advantages Of MEMS Switches such as

(1) Small size: Semiconductor manufacturing techniques used in the batch fabrication of micro systems, these systems process sizes ranging from micro meters to a few milli meters.
(2) Low Cost: MEMS technology allows complex electromechanical systems to be manufactured using batch fabrication techniques, allowing cost of switches to be put in party with that of integrated circuits. Much of labour involved in packing and assembly of such a system would simply disappear.
(3) Low power consumption: The MEMS switches are power efficient. The power losses in data transmission and also the time lag are eliminated because the switches are made next to controlMEMS circuitry in the same chip.
(4) High isolation: Isolation of MEMS switches in the range 1-40 GHz is very high than the other switches.
(5) Ability to be integrated with other electronic devices with excellent linearity.

The main Disadvantages in MEMS design are Complex design, Complex fabrication procedures, and it requires high actuation voltage, high switching time.

2.Internal Equivalent Circuit of MEMS Switch (SPST)

The internal equivalent circuit of this MEMS switch is the combination of the variable capacitor that is made between the movable electrode and fixed electrode and the internal resistance that the silicon actuator has. Those variable capacitor and internal resistance elements are series-connected. The capacitance value of the electrodes changes from several pF to 20pF according to the electrode gap at the time of operation. The internal resistance value of actuator is about 10K ohm.

The internal equivalent circuit after packaging is a SPDT structure which has a common terminal on input side and output side. Each GND terminal on input side and one half of the RF ports on output side are connected, as shown in the figure1.

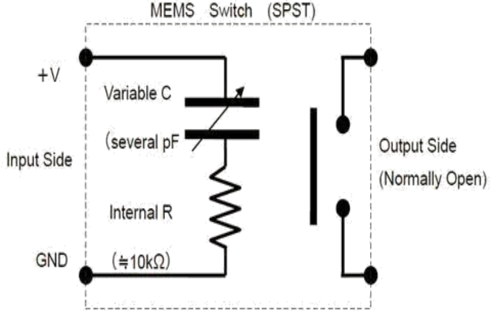

Fig 1: internal equivalent circuit

2.1 Basic Structure of MEMS Switch & Working Principle

The basic structure of MEMS switch consists of following three layers which are Glass-Silicon- Glass, as shown Figure2. It has a SPST i.e. Single Pole Single Throw contact configuration. The top Layer i.e. glass part is used for protecting the actuator . The middle silicon section contains the actuator and movable electrode. Here a capacitor is built up between the fixed electrode and movable electrode. The signal line and fixed electrode are made on a glass base. When voltage is applied between the Fixed Electrode and the Movable Electrode, an electrostatic force is generated and it pulls in the Movable Electrode (actuator). When the driving voltage becomes OFF that is in OFF condition , the electrostatic force will disappear, and then the actuator will go back to its original position because of self-restoring force.

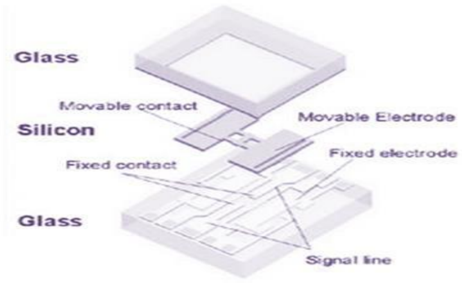

Fig 2 : Basic structure of MEMS switch

2.2 Operating Principle And Structure of Electrostatic Actuator

The electrostatic actuator's is the basic structure like a parallel plate type capacitor shown in figure3. The electrostatic force generated between the two electrodes is represented by the following equation.

$$F=\frac{\varepsilon_0\ \varepsilon_r\ s v^2}{2d^2} \qquad \text{…………(1)}$$

Where F is the electrostatic force, ε0 and εr are the dielectric coefficients , S is the area of the electrode, V is the applied voltage, and d is the average gap between the two electrodes. The MEMS switch can be operated by using this electrostatic force.

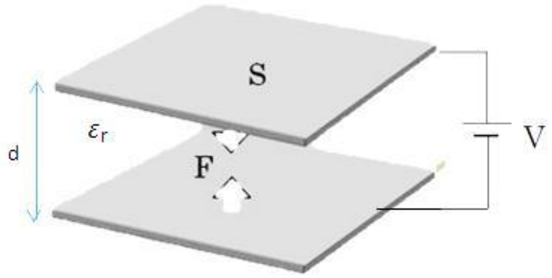

Fig 3: Structure of Electrostatic Actuator

3.Types of Switches

Basically RF MEMS switches are of two configurations-:

1. RF series contact switch
2. RF shunt capacitive switch

3.1 RF Series Contact Switch

An RF series switch operates by creating an open or short in the transmission line, as shown in Figure 4(a), 4(b) The basic structure of a MEMS contact series switch consists of a conductive beam suspended over a break in the transmission line. Application of dc bias induces an electrostatic force on the beam, which lowers the beam across the gap, shorting together the open ends of the transmission line1. Upon removal of the dc bias, the mechanical spring restoring force in the beam returns it to its suspended (up) position. Closed circuit losses are low and the open-circuit isolation is very high. Because there is direct contact of the switch, it can be used in low frequency applications without affecting the performance.

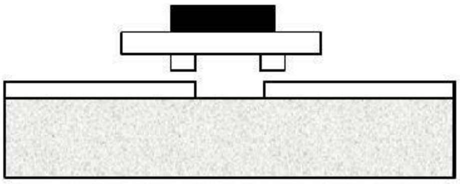

Fig 4(a) **Unbiased - off**

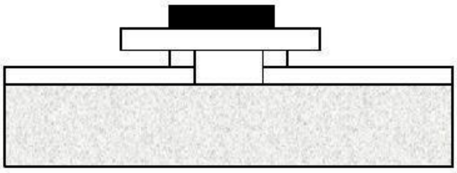

Fig 4(b) **Biased-on**

3.2 RF Shunt Capacitive Switch

A circuit representation of a capacitive shunt switch is shown in fig 5.

In this case, the RF signal is shorted to ground by a variable capacitor. Shunt switches is usually based on a fixed-fixed beam design. Specifically, for RF MEMS capacitive shunt switches, a grounded beam is suspended over a dielectric pad on the transmission line. When the beam is in the up position, the capacitance of the line-dielectric-air-beam configuration is on the order of ~50 fF, which actually translates to a high impedance path to ground through the beam. Here the anchors are connected to the CPW ground plane, and the membrane is grounded. The center electrode provides both the electrostatic actuation and the RF capacitance between the transmissionline and the ground. When the switch is in the up-state it provides the low capacitance to the ground, and it does not affect signal on the transmission line. When the switch is actuated in the down-state, the capacitance to the ground becomes higher and this results in short circuit and high isolation.

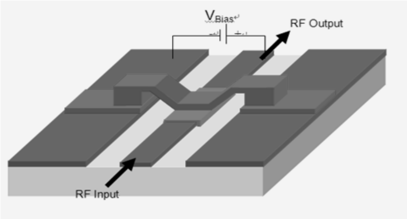

Fig 5: Schematic of shunt capacitive type RF MEMS switch

4.MEMS model

Analysing the RF MEMS switches requires extracting the mechanical as well as electrical models of the switches.

4.1 Mechanical model

Figure 6shows the basic mechanical model of MEMS switch. There are basically three types of forces involved in MEMS switches. First is the the Vander Waals force, which plays very important role when the gap between the two electrodes is in the range of a few nano meters. The second force is the electrostatic force, which relies on a voltage source and a capacitor between the transmission line and the membrane. The third force is due to the elastic force, which is modeled as a spring and depends on the shape, material and size of the beam or the membrane. Another important mechanical parameter of the MEMS switch is the switching time. The switching time of MEMS switches is limited by the mechanical structure. The pull in actuation voltage (Vpull-in) and switching time (ts) for vertical types of MEMS is as follows

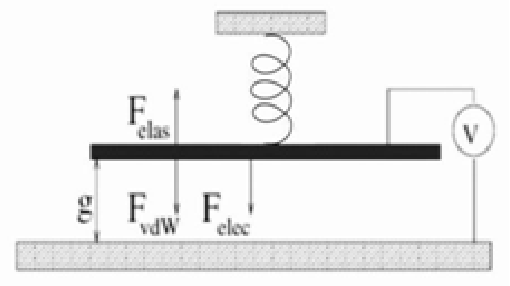

Fig 6: Mechanical Model of MEMS Switch

$$V_{pull\text{-}in} = \sqrt{\frac{8K g_0^3}{27A\varepsilon_0}} \qquad \text{........(2)}$$

$$t_s = 0.46 f^{-1} \qquad \text{.........(3)}$$

$$f = \sqrt{\frac{k}{m}} \qquad \text{.........(4)}$$

where k is the spring constant, g0 is the gap between electrodes without actuation voltage, A is the overlap area between the bridge and the transmission line or the electrode, f, m is the mass of beam and f is the first resonant frequency of the beam.

4.2 Electrical model

The switch has two states: On and Off.

Figure7shows the RF MEMS shunt and series switches, which are modelled by electrical circuits. The switch is modeled by R, L, and C components. Where L represents the inductance of the switch, R shows the insertion loss, and C represents the capacitance between the bridge and the transmission line. This capacitance has two extreme values at the up state and the down state and varies between them.

This capacitance has two extreme values at the up state and the down state and varies between them. Thevalues of S11 and S21 strongly depend on the capacitance of the bridge. For example, the amount of S11 and S21 for the shunt switches are given by According to equations. For example, reducing the gap between the signal line and the bridge (g) reduces the actuation voltage. However, this increases the up state capacitance (Cup) and diminishes the isolation (S21). Therefore, it reduces the bandwidth at up state(S21)

$$|S_{11}|^2 + |S_{21}|^2 = 1 \quad ..(5)$$

$$S_{11(upstate)} = \frac{-j\omega C_{up} z_0}{2 + j\omega Z_0} \quad ..(6)$$

$$S21(downstate) = \frac{2}{2 + j\omega C_{down} Z_0} \quad ..(7)$$

Moreover, although reduction of spring constant (K) reduces the actuation voltage but it reduces the resonant frequency or increases the switchingtime.

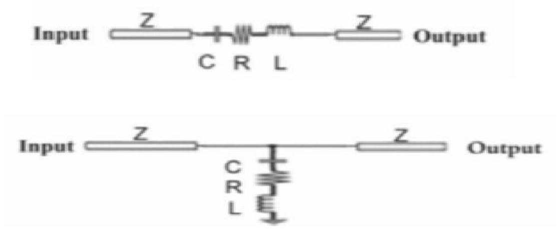

Figure 7: Series and shunt electrical model ofMEMSswitches

5.Different Actuation Schemes

RF MEMS switches can be categorized into four groups according to their types of actuation forces i.e. Piezoelectric, Electromagnetic, Electro- thermal & Electrostatic. The first type is the Piezoelectric RF MEMS switches. This type of switch uses piezoelectric materials such as AlN or PZT on top of the membrane or beam. These Piezoelectric materials deform under the application of an electric field, or conversely, develop an electric field under the action of an applied strain and make the beam deflect by applying the voltage. The amount of force depends on the piezoelectric coefficient. Therefore, the low actuation voltage can be achieved by chosen a high piezoelectric .The second type of MEMS switch is the electromagnetic RF MEMS switch. This type of switch uses coil on top of the membrane. Here the electromagnetic force is created when a DC current is applied to the coil and actuates the membrane . The third type is the electro-thermal RF MEMS switch. In this the bending of the structure depends on the thermal expansion coefficient of materials. Thermal actuators utilizes the property of thermal expansion to produce motion. When a current is applied across the actuator, it heats up and thermal expansions occur. Parameters such as member geometry, size, and overall configuration may be tuned to achieve optimal deflection. Itcould provide the desirable large force and large displacement when considered an appropriate design.

The last and more applicable type is the electrostatic RF MEMS switch. This type of switch operates only based on the amount of actuation voltage and the capacitance between the transmission line and the membrane. When an electric field is excited between two parallel plates, there will be an attractive force acting on both plates to bring them closer and minimize the electrical potential energy of the system. Electromagnetic actuation is based on the Lorentz force. By applying current through a long wire, which has been wound many times into a tightly packed coil, a magnetic field is established .

Table 1 compares the all types of the RF MEMS switch. It can be seen from the Table 1, electrostaticforce performs better in all parameters except for the actuation voltage, which is very high. Although the switching time and reliability of the electrostatic MEMS switches are better than those of other types, they not compare well with other RF switches, such as semiconductor and mechanical switches.

	Piezoelectric	Electrothermal	Electromagnetic	Electrostatic
Size	Medium	Medium	Large	Small
Actuation Voltage	Medium	Low	Low	High
Power consumption	Medium	High	High	Low
Switching speed	Fast	Slow	Medium	Fast
Reliability	Medium	Low	Medium	High

Table 1 : Comparison of different types of MEMS switch actuation

6.Various Approaches for low-actuation-voltage switches

The high-voltage actuation of MEMS switches makes them far beyond the compatibilityof standard IC technology . The pull-in voltage can be reduced by three different methods:

(a)Increasing the area of actuation: Here in this Increasing the area is not a practical solution because the compactness is the prevailing issue and adoption of MEMS technology is to achieve the miniaturization.

(b) Decreasing the gap between the switch and the bottom electrode: Here the return loss associated with the RF signal restricts the size of the gap.

Matching circuit: The amount of parasitic capacitance affects negatively on the insertion loss of the MEMS switches at up state position. One effective method for compensating this capacitance is by using a matching circuit accompaniedby a switch. In this way, the amount of gap can be reduced at any range.

(c) By designing the structure with a low spring constant: In this design the spring does not considerably impact the size, weight or RF performance.spring constant plays an important role on the actuation voltage of RF MEMS switches.The spring constant of MEMS switch is given by the following equation

$$K = K_{spring} + K_\sigma \quad .(8)$$

Therefore, reduction of the spring constant can be categorized into reduction of spring constant of beam or membrane and the residual stress (K_σ).

7.CONCLUSION

Here in this paper, different methods for the reduction of the actuation voltage of RF MEMS electrostatic switches have been studied. Reduction of gap and spring constant are mostly used for reducing the actuation voltage of RF MEMS switches based on metals. The fabrication of this type of switches is based on surface micromachining. They are a new generation of electro-mechanical switches, and the researchers are trying to improve their RF parameters. Thus the actuation voltage required to induce the switching action is lower than that required for membrane type RF MEMS switches, all other things being equal. For the same actuation voltage the down-state transition time must be reduced.

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