

Radio Frequency - Micro-Electro Mechanical System Switches for Wireless Communication

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Abstract: This paper deals with the RF-MEMS switches importance in the wireless communication system. Also explains the dominance of RF-Switch over existing devices like PIN Diodes and Field-Effect-Transistors with power, isolation, size, insertion loss, and how Pull-in voltage affects on the tip deflection of the switch; and how they can be effectively used for future Smart technology Applications.

Keywords: Insertion loss, Isolation, PIN Diodes, Pull-in voltage, RF-MEMS, RF Switch.

Introduction

RF (Radio frequency) MEMS (Micro-electro-mechanical-system) Switches are most important based on their Performance and various researchers have done a great amount of research on this topic .The radio frequency micro-electro-mechanical system (RF MEMS) refers to electronic components of which moving sub-millimeter-sized parts provide RF functionality. Besides RF-MEMS technology, compound semiconductors (GaAs, GaN, InP, InSb), ferrite or Ferro-electric, silicon-based semiconductors like (RF CMOS, SiC and SiGe), and vacuum tube technology are available to the RF designer. Each of the RF technologies offers a distinctive trade-off between power consumption , reliability, ruggedness, cost, frequency, gain, large-scale integration, lifetime ,linearity, noise figure , packaging , power handling , size, supply voltage, switching time and weight.

Electromechanical isolation prevents RF circuit from leakage or from coupling significantly with actuation circuit. Electromechanical coupling is done electro statically through air because less power is required and is consumed only

At the time of actuation MEMS (Micro-Electro-Mechanical-Switch) actuation classifies MEMS switches In following three characteristics:

1. Configuration of RF circuit.
2. Mechanical Structure.
3. Contact form.

RF MEMS Switching

Radio frequency signals are used for wireless communication in a range of 9 KHz to 300 MHz. As RF signals exhibits electromagnetic field for this purpose micro machined devices such as filters, oscillators and switches are required. For wireless communication applications RF switches are designed at high frequency (1MHz to 60 GHz).RF MEMS circuit leaves huge impact on communication.

Prevalent RF MEMS mechanical structures are the:

1. Cantilever beam.
2. Air bridge structures

A. Advantages

MEMS switches are better than the existing semiconductor devices: Field-effect-transistors, PIN Diodes, less power consumption, Small size, low insertion loss and high OFF-state isolation.

Fabrication process is compatible with CMOS technology providing ease of interfacing with rest of the circuitry.

B. Disadvantages

Low switching time, High actuation voltage, commonly series or parallel connected circuit configurations are used.

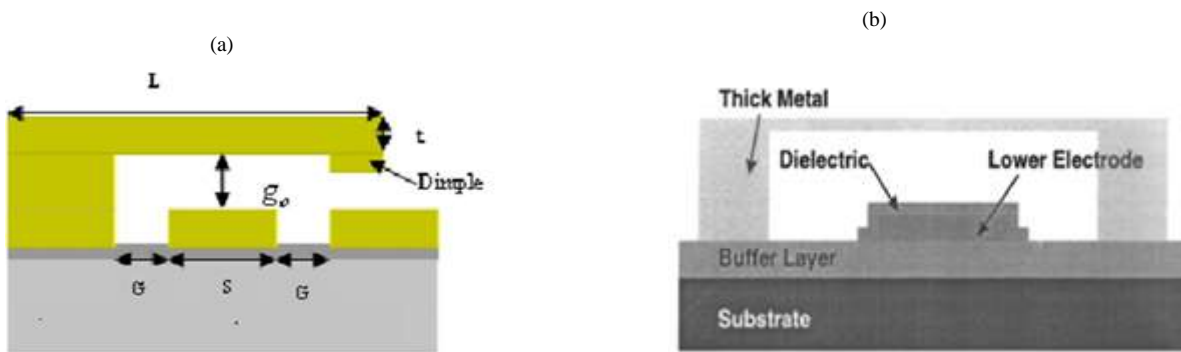


Figure 1: The functional diagram of (a) Cantilever MEMS switch and (b) Air bridge MEMS switch

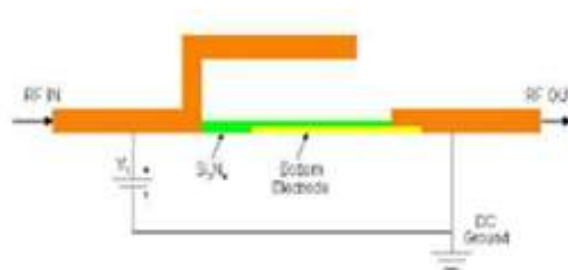


Figure 2. The cross section of cantilever beam capacitive MEMS switch

Prevalent RF MEMS mechanical structures are the:

- 1.) Cantilever beam.
- 2.) Air bridge structures.

1) Cantilever Type MEMS Switch: In this one beam end is fixed and other is free as shown in figure below. Now when voltage is applied across the electrode i.e. the free end of beam, there appears charge causing electrostatic force flow on the beam which pulls it downward. Stress in the beam increases due to decreasing gap. When the voltage source is removed an equal and opposite restoring force brings the beam back to its original position. Fig.1 shows the schematic of cantilever type MEMS switch.

Latest Application:

1. Ultra-Short Cantilevers (USC) are used in High-Speed Atomic Force Microscopy (HS-AFM).
2. Reliability and Fatigue Analysis.

The Cantilever switches are further divided into two types:

a) **Capacitive contact switches:** Metal-insulator-metal type contact is used. Fabrication is done using surface micro machining process. The figure of merit (FOM) of RF MEMS capacitive switch is calculated below:

$$FOM = \frac{\text{Down State Capacitance (Cd)}}{\text{Up State Capacitance (Cu)}} \quad (1)$$

Figure of merit also depends on the Q factor of the design switch. Performance of the switch is directly proportional to Q factor; that is if Q factor is greater, performance of switch is good and if Q factor value is small then the performance of the switch is poor. The insertion loss of the capacitive switch is lower than 1.2 dB up to 40 GHz, the extracted up-state capacitance is 30 PF and isolation is 1.3dB, 26dB, and 27dB at 1GHz, 20GHz, and 40GHz respectively. Lower actuation voltage compared to Air Bridge MEMS switch is required due to a free end [2]. The capacitive MEMS switch is as shown in Fig.2.

b) **Resistive contact switches:** Metal to metal Ohmic contact between signal line and contact beam is used. Fabrication is done using bulk micro machining or surface micro machining process. The dc bias is between ground and the cantilever beam, electrostatic force pushes the cantilever beam to move laterally and contact with signal line.

Such type of switch is used for an X-band reconfigurable impedance tuner development [3]. The Resistive MEMS switch is in Fig.3.

Depending on where and how MEMS actuation is carried out in RF circuit, MEMS switches are classified in following three classes:

- a) RF extrinsic: Outside MEMS structure that controls other devices in the circuit.
- b) RF intrinsic: Inside MEMS structure to perform dual role in the circuit but decoupled with actuation.
- c) RF reactive: MEMS structure is located inside the circuit and coupled to the actuation function.

2) Air Bridge Type MEMS Switch: Both beam ends are fixed. When voltage is applied in middle region to let the beam touch substrate, displacement is maximum in the middle region. The Air bridge MEMS switch is as shown in Fig.1 (b)

Latest Application:

- 1. Low voltage RF MEMS switch at 35 GHz.
- 2. RF-MEMS switchable CPW air-bridge.

RF Performance

For cantilever beam design as an actuator we should be aware of pull-in voltage, hold down voltage, spring constant and the resonant frequency. Switching lifetime and switching times are also considered.

A. Actuation Voltage

The actuation voltage or applied voltage or pull in voltage is the maximum voltage at which the electrostatic force becomes superior over mechanical restoring force, causes MEMS device pull down towards the ground plane. At equilibrium as the applied voltage increases the plate moves lower and the gap decreases corresponds to increases the electric field, causes increase in the electrostatic force which pushes plate further lower. At certain value that is pull-in voltage the plate or actuator beam suddenly collapses and allows signal to pass [6].

Due to the small actuation area and low spring constant MEMS switches have low contact and release forces [5]. As the applied voltage to the RF MEMS switch is varies the respective displacement of membrane changes for different dimensions of switch [4], is shown in Fig.4.

Initially as the applied voltage goes on increases the gap between the beam and ground electrode gradually reduces, after the gap becomes 1/3 of original gap cause the beam suddenly pull downs, is shown in Fig. 5.

B. 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 the actuation voltage and the opening time depends on the mechanical properties of the switch. By scaling the MEMS devices the switching time is also scale down.

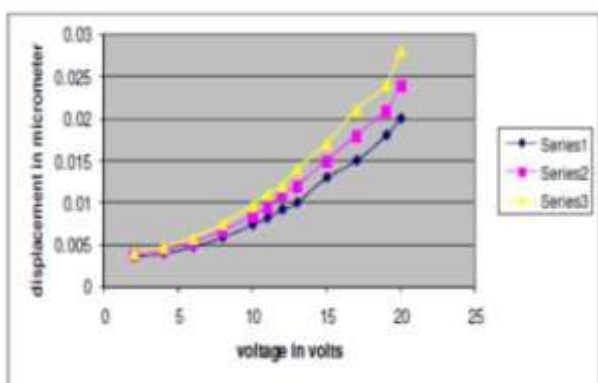


Figure 4. Graph of displacement verses voltage

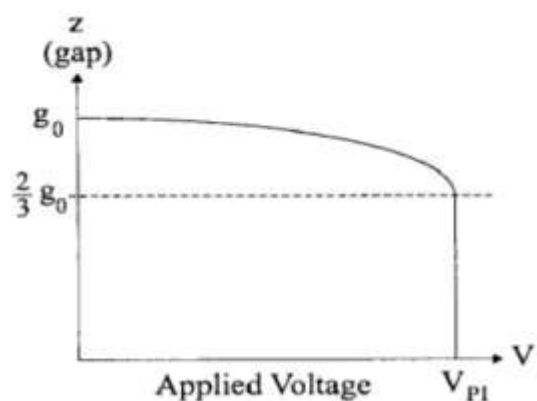


Fig 5: Graph between actuator deflection and applied voltage

Future Possibilities

A technology commonly used in satellite and defense applications - RF MEMS or Radio Frequency Micro-Electro-Mechanical Systems is now poised to improve smart-phone performance and wireless communications in the near future by way of higher antenna efficiency.

Conclusion

In this paper we have seen the different types of RF MEMS switches with its structure. Further how the RF MEMS switch is superior to other existing devices In comparison with size, required power, isolation and insertion loss. Also seen how applied voltage effects the actuator deflection with different sizes of cantilever beam.

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