Performance Evolution of Micro-Electro-Mechanical-Systems Switches for High Frequency Applications

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Abstract - Micro Electro Mechanical Systems (MEMS) are miniature (micro metric and mill metric in size), multifunction system consisting of sensors, actuators and electronics they bring mechanical structures to microelectronics. It is very promising way of building smart integrated transducers. This technology come from the integrated circuits micro fabrication technology and thus has access to large pool of technical and scientific resources. The applications are not only limited by our imagination. Right now ,application are found in many areas like domestic transportation, biotechnology biomedical engineering, etc .The most popular devices are the pressure sensors and accelerometers wildly used to control air bags in cars and other safety devices. One of the unique advantages of Micro Electro Mechanical System (MEMS) is the possibility of integrating micromechanical devices with electronics. The application of MEMS techniques to the fabrication of miniaturized mechanical relays can solve some of the inherent difficulties involved with transistor switches, not only that will have immediate impact on several important products in both aerospace and consumer electronics. One of the most exciting application areas for these micromechanical relays is in radar and microwave circuits and their systems.

Keywords - *Authenticity touch, Electron mechanical Consideration, MEMS Series Switch, MEMS Shunt Switch, Application, and Future scope*

1. Introduction

This paper presents the latest development in RF microelectromechanical systems (MEMS) switches and high isolation switch circuits RF MEMS switches offer a substantially higher performance than p-i-p or FET diode switches and have been extensively used in state-of-art MEMS phase shifter and switching network unto 120 GHz. RF MEMS technology is now at turning point, important issues ,such as long and short term reliability, packaging techniques and their effects on reliability, and production costs, are currently being addressed. MEMS application areas are in the phased arrays and reconfigurable apertures for defense and telecommunication systems, switching network for satellite communications and single-pole N-throw switches for wireless applications.

MEMS switches are devices that use mechanical movement to achieve short circuits or open circuits in RF transmission line. RF MEMS switches are micromechanical switches designed to operate at RF-to millimeter wave frequencies (0.1 to 100 GHz). The forces for the mechanical movement can be obtained using electrostatic, magneto static, piezoelectric, or thermal designs. To date only electrostatic-type switches have been demonstrated at 0.1-100GHz with high reliability (100 million to 10 billion cycles) and wafer-scale manufacturing techniques.

2. Authenticity Touch

The beauty of MEMS switches is their near ideal behavior and the relative ease of their circuit design

2.1 Advantages

i. Near-Zero power consumption: Electrostatic actuation requires 20-80 V but does not consume any current, leading to very low power dissipation.
ii. Very Low Insertion Loss: RF MEMS have insertion loss of – 0.1db upto 40 GHz.
iii. Very High Isolation: RF MEMS switches are fabricated with air gaps and therefore have low off-state capacitances (2-4 pf) leading in excellent isolation at 0.1-40 GHz.
iv. Very Low Cost: RF MEMS switches are fabricated using surface micromachining techniques and can be built on quartz, Pyrex, low temperature confined ceramic, mechanical grade high resistivity silicon, or GaAs substrates.
v. Intermodulation Products: MEMS switches are very linear devices and result in low intermodulation products.

2.2. Disadvantages

i. Relatively Low Speed: The switching speed of most MEMS switches is around 2-40 microsec. Certain communication and radar systems require faster switching circuits.
ii. Power Handling: Most MEMS switches cannot handle more than 20-50mw.
iii. High Voltage Drive: Electrostatics MEMS switches require 20-80 V for reliable operation and this necessitates a voltage up converter chip when used in portable telecommunication systems.
iv. Packaging: MEMS switches needs to be packaged in inert atmosphere and in a very low humidity, resulting in hermetic seals.
v. Cost: While MEMS switches have a potential a very low cost manufacturing one must add the cost of packaging and high voltage drive chip.

3. Electromechanical Considerations

The RF MEMS switches follow the basic mechanical laws. However the scale and relative importance of force acting on the switch is micro in nature much different from the micro world we experience daily. Surface forces and viscous air damping dominate over inertial and gravitational forces. The switches have very low. For a spring constant of 10 N/m and acceleration of 10g the movement is of the order of nanometers.

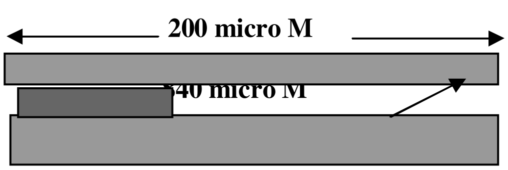

Fig 1 Side View MEMS Switch

3.1 Construction

The switches are either fabricated using a fixed -fixed membrane or floating cantilever and are modeled as mechanical spring constant *k*. The spring constant depends on the geometrical dimension.

3.2 Working

The actuation mechanism is achieved using an electrostatic force between the top and bottom electrodes and is given by

$$F = QE / 2 = CVE / 2$$
$$= CV*V / [2 (g + td/r)]$$
$$= \in AV*V / [2 (g + td/r)]^2$$

Where V, g and C are the voltage, gap distance and capacitances between the lower and upper electrodes respectively, and A is the area of the electrode The bottom electrode is covered by a dielectric of thickness (td) of 100-200 nm and relative dielectric constant $\in$ between 3 and 8 to prevent a short circuit between top and bottom plates.

When a voltage is applied to the electrode, electrostatic actuation results in a very low force and the switch is pulled down to bottom electrode, the gap is reduced, and the pull down force on the switch is increases. On the other hand there is a pull up force due to the spring constant of the switch. The equilibrium is achieved when both the force are same and

$$F = \in AV*V/ [2 (g + td/r)]^2$$
$$= k (g0 - g)$$

Where g0 is the initial height of the bridge

The solution of the above cubic equation in g results in stable position at g0/3 approx. and then a complete collapse of the switch occur to the down state position. The voltage which a use this collapse is called pull-down voltage and is

$$Vp = [8kg0^3 / 27 \in A]^{1/2}$$

Once the switch is pulled down g is reduced hence the electrostatic voltage can be reduced while still keeping the switch in the down -state position (this is done so as to reduce the electric field in the dielectric and the possibility of dielectric breakdown). Once bias voltage is removed the pull up force is approx. given by

$$F = k.g0$$

Where go is displacement constant of the bridge.

4. Mems Series Switch

The electrical model of a MEMS series switches has a series capacitances in the upstate position and small resistance in the down state position is given by

$$I\ Su\ I^2 = 4\ W^2\ Cu^2\ Zo^2$$

Where Cu is upstate capacitances and Zo is transmission line impedance. The insertion loss is
2

I Su I = 1 - (Rs/Zo)

Where Rs is contact resistance of switch. If it is seen that an upstate capacitances of 2-4fF and a contact resistance of 1 ohm results in isolation of -46 to -40 db at 4 Ghz and a -0.1 db loss up to 40 GHz .

This is a spectacular performance not attained by any solid – state device.

The figure of merit cutoff frequency is

Fc = 1/ (2*pi*Cu*Rs)

And is an indication of the low loss performance of the switch. The cutoff frequencies of MEMS series switches is 30 -80 THz while it is only 1-2 THz for GaAs p-i-n diodes and 0.2-0.5 THz for FET switches.

There are two types of MEMS switch:

1 The broadside series switch
2 The inline series switch

4.1 The Broadside Series Switch

Performance

The actuation of the broadside series switch occurs in a plane that is perpendicular to the transmission line. In this switch only the contact portion need to fabricate using metal layer and the actuation portion can be composed of dielectric / metal cantilever of fixed- fixed beam. The Rockwell Science Center MEMS series switches are there. It has two pull – down electrode on either side of contact area. The actuation voltage is typically 75 -80 V.

4.2 The Inline Series Switch

Performance

The actuation of the inline switch occurs in the same plane as the transmission line. The main difference between broadside and inline series switch is that the RF signal will pass by the entire inline switch. They are fabricated using a thick metal layer (Au, Al, Pt etc). The analog devices MEMS series inline switch is there. The measured insertion loss is -0.15db upto 20 GHz.

5. MEMS Capacitive Shunt Switches

The switch is based on fixed-fixed metal (Al or Au) beam design. The anchors are connected to the coplanar – waveguide ground plane and the membrane is therefore grounded. In micro strip implementation the switch anchor are connected to the ground plane using via holes or l λ / 4 redial stub. The electrode provides both the electrostatic actuation and the RF capacitances between the transmission line and the switch membrane .when the switch is in up-state position, it provides a low capacitances to ground, around 25 -75 fF and does not affect the signal on the t -line. When the switch is actuation in the down – state position , the capacitances to the ground become 1.2 – 3.6 pF and this results in the excellent short circuit and high isolation at microwave frequencies (10 GHz and above).

6. Application

1. Radar Systems for Defense Application:
   Phase shifters for satellite- based radars (20 billion cycles), long range radars.
2. Automotive Radar: 24, 60 and 77 GHz. (1-4 billion cycles and 10 years)
3. satellite communication system:
   Switching networks with 4 * 4 and 8 * 8 configuration and reconfigurable antenna application
4. wireless communication system:
   Switching filter banks for portable units, switched filter banks for based stations
5. Instumentation System:

These required high – performance switches, programmable attenuators, and SPNT network and phase shifters capable of at least 20 -40 billion cycles and 10 years of operation especially in industrial test benches.

7. Future scope

This paper presented and overview of MEMS switches. The development of MEMS switches has been progressing at a relatively rapid speed since the first practical dc-contact and capacitive switches. RF MEMS technology is currently quite mature at the wafer level, and the mechanics of switch actuation is well understood. It is seen that a variety of switches available today covering the 0.1 -120 GHz. range, and the performance of RF switches is truly spectacular when compared to p-i-n diode or FET switches

However there is currently no high power RF MEMS switches and this limits their use in many radar and telecommunication systems. Several problems relating to long term reliability, metal to metal contacts under low forces, packaging, and fabrication cost currently been addressed and it expected that practical solution will be available in 3 -5 years. Still it is not clear if RF MEMS switches at 0.1 – 6 GHz and may be first used in high –

performance defense and satellite systems.

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