

RF MEMS Based Tunable Circuit for Wireless Communication

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Abstract-Modern wireless systems have an increasing need for multiband and tunable microwave and millimeter wave components. The Wireless communication system has several tunable circuits, which reduces the number of the circuits, size, and cost of the front-end. The application of micro electromechanical systems (MEMS) technology to RF systems enables production of components with low power consumption, high linearity, low insertion loss and high isolation. RF MEMS components are particularly attractive due to their tunable properties. The recent dramatic developments of personal communication devices forced the market to acquire miniaturized efficient devices, which is possible only by the development of radio frequency (RF) MEMS.

Keywords- MEMS, Coplanar waveguide (CPW)

I. INTRODUCTION

During the past decade, several new fabrication techniques have evolved which helped popularize micro electro-mechanical systems (MEMS) [1] and numerous novel devices have been reported in diverse areas of engineering and science. One such area is microwave and millimeter wave systems. MEMS technology for microwave applications should solve many intriguing problems of high-frequency technology for wireless communications. The recent and dramatic developments of personal communication devices forced the market to acquire miniaturized efficient devices, which is possible only by the development of radio frequency (RF) MEMS. The term RF MEMS [7] refers to the design of MEMS for RF integrated circuits. It should not be interpreted as the traditional MEMS devices operating at RF frequencies. MEMS devices in RF MEMS are used for actuation or adjustment of a

separate RF device or component such as variable capacitors switches and filters.

II. MEMS AND RF MEMS SWITCH

RF switches [3] are the most common and basic circuit elements. Current solid state RF technologies (PIN diode- and FET- based) are utilized for their high switching speeds, commercial availability, low cost and ruggedness. This technology reached its maturity in areas such as device design, fabrication, packaging, applications/system insertion and consequently, high reliability and well-characterized performance. Some parameters such as isolation, insertion loss and power handling can be adjusted via device design to suit many application needs. In spite of this great design flexibility, there are two major bottlenecks with solid-state switches: breakdown of linearity and frequency bandwidth upper limits, and the degradation of insertion loss and isolation at signal frequencies above 1-2 GHz. By utilizing electromechanical architecture on a miniature- (or micro-) scale, RF MEMS switches [3] combine the advantages of traditional electromechanical switches (low insertion Loss, high isolation, extremely high linearity) with those of solid-state switches.

Table 2.1 Performance comparison between solid-state switches and MEMS switches for RF applications.

	Insertion Loss (dB)	Isolation (dB)	Linearity (dBm)	Peak power (W)	Power consumption	Speed (μ s)
SS Switch	~0.5	~-25	~-40	~2	~5 mW	<0.1
MEMS Switch	~0.1-0.2	~-35	~-65	~2	~10 μ W	<10

Parameters for the design of MEMS Switch

Table 2.2 Switch Parameters of MEMS switch

SWITCH PARAMETERS
Parameter
Length [μm]
Width [μm]
Thickness [μm]
k_{Beam} [N/m]
V_{PI} [V]
Switching Speed (ON) [μs]
Switching Speed (OFF) [ns]
Contact Force [μN]
Restoring Force [μN]

The pull in voltage (V_{PI}) required to defect the beam in the MEMS switch can be determined with the equation

$$V_{PI} = \sqrt{\frac{8k_{Beam}g^3}{27\epsilon_0 A}}$$

Where A is the actuation area, g is the gap between the beam and biasing structure in the neutral position, ϵ_0 is the permittivity constant of free space and K_{Beam} is the spring constant of the beam. Assuming a nearly uniform electrostatic force on the cantilever beam, the spring constant (K_{Beam}) is determines with equation

$$k_{Beam} = \frac{2Ew}{3} \left(\frac{t}{l}\right)^3$$

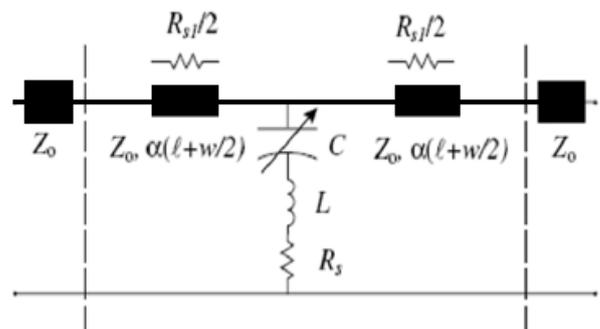
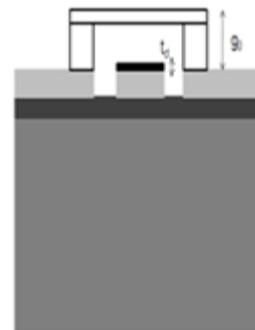
Where E is Young’s modulus of the material, w is the width, t is the thickness, l is the length of the beam. The restoring force and the contact force will vary depending on the application and design of the MEMS switch. The restoring force F_r is determined with equation

$$F_r = k(g - g_{on})$$

And contact force F_c is determined with the equation

$$F_c = \epsilon_0 A \left(\frac{V_{Actuation}}{2g_{on}}\right)^2$$

Where $V_{Actuation}$ is the applied switch bias and g_{on} is the separation between the MEMS device and the biasing pad in the ON state. The applied switch bias $V_{Actuation}$ may be higher than the pull in voltage V_{PI} to achieve the desired contact force value. The sacrificial layer thickness and the operating voltage can be varied as needed for the desired restoring force and the contact force of the specific application. RF MEMS devices mainly consist of four different designs viz. metal- contact switches, capacitive switches, switched capacitors and analog varactors. The metal contact switches utilize physical contact of metal with low contact resistance to achieve low insertion loss when actuated and can be operated from DC to RF frequency [4]. An RF MEMS switch with a capacitance ratio of 30-150 is commonly used for routing purposes (SPNT, DPDT, NxN matrices) and phase shifter designs. RF MEMS switches result in low- loss phase shifters with high linearity and provide 3-4dB improvement (6-8dB in two way telecommunication systems) over on- wafer designs using GaAs FET switches. An RF MEMS switched capacitor with a capacitance ratio of 2-6 is mostly used in tunable filters and reconfigurable networks. The analog varactors with a continuous tuning range of 1.5-8:1 can be used as tuning devices from 500MHz to 100GHz .Owing to the advantages of near-zero power consumption, very high isolation, very low insertion loss and low inter modulation products and very low cost.



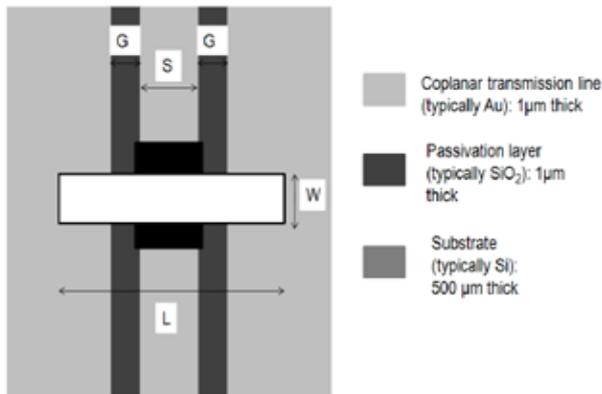


Fig 2.3 Cross-section and top view of a typical RF MEMS Capacitive shunt switch and CLR model

III PHYSICAL DESCRIPTION OF MEMS CAPACITIVE SWITCH

A MEMS shunt capacitive switch is shown in Fig 2.3. It consists of a substrate which can be silicon, GaAs, alumina, LTCC or a quartz dielectric, which houses a RF transmission line; typically a CPW t-line. The CPW t-line is typically made of gold owing to its low conductor losses and ease of plating. The CPW is so chosen that the values of $G/S/G$ correspond to 50ohm characteristic impedance. A shunt membrane is suspended at a height g_0 above the dielectric layer on the transmission line where the dielectric thickness is t_d , with a dielectric constant ϵ_r . The shunt membrane is $L\mu\text{m}$ long, $W\mu\text{m}$ wide, $T\mu\text{m}$ thick. Typical values of the switch geometry are a dielectric thickness of 1000-1500 Å, a relative dielectric constant of 5.0-7.6 depending on the nitride material used, a bridge height of 2.5-5µm, a length around 200- 300µm, and a width between 25 and 180µm depending on the switch capacitance required. The length is rarely shorter than 200µm due to the sharp increase of the actuation voltage with decreasing bridge length. The width is practically limited to 200µm so as to result in a flat contact area between the MEMS Bridge [13] and the t-line. The thickness of the shunt membrane is between 0.5-2µm depending on the length and width of the membrane geometry to obtain an acceptable value of spring constant of the membrane.

IV. A PARAMETRIC MODEL OF MEMS CAPACITIVE SWITCH

Published example of the electromagnetic model which shows shunt capacitive MEMS switch consists of a thin metal membrane bridge suspended over the center conductor of a coplanar waveguide (CPW) [5] and fixed on the ground conductor of the CPW. The parameters L and H indicate the length and the height of the membrane bridge.

The full wave electromagnetic simulation of the switch can be done using a soft High Freq Structure Simulator (HFSS). In the simulation a box size 1200 x 600 x 600 µm can be used and boundary radiation conditions can imposed on the six sides of the box. After the full wave analysis is performed, S -parameters can extract in the frequency range going from 1 GHz to 60 GHz for different heights of the switch. The substrate can assume to be lossless with relative dielectric constant of 9.8 (correspondent to Alumina). The thickness of the substrate is 600µm and the CPW conductors and MEMS switch can treat as perfect conductors. The central conductor of the CPW can assumed to be coated with silicon nitrate (Si_3N_4) having relative dielectric constant of 7 and thickness of 0.1 µm. Fig 4.1 (b) presents the first order equivalent circuit model obtained for the capacitive MEMS switch.

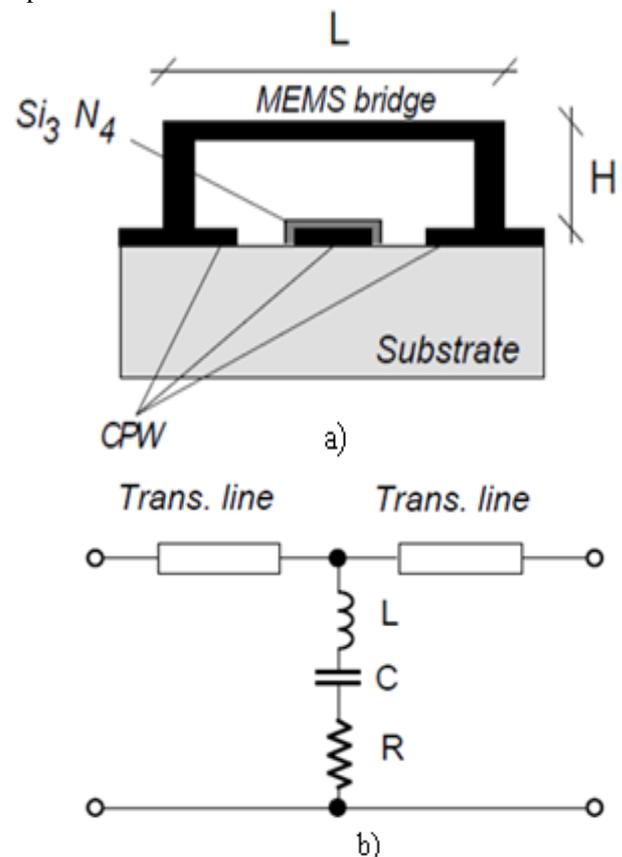


Fig 4.1 (a) Cross section of the capacitive MEMS switch over CPW line. (b) Equivalent circuit model of the capacitive MEMS switch

The parameters of the model can optimized to fit the S -parameter obtained from the full wave Electro-magnetic simulation. Fig 4.2 shows the EM simulated and circuit model S -parameters of a 300 µm by 200 µm membrane suspended 5 µm over a CPW transmission line having a center conductor width of 100µm and a gap of 50µm. Since the capacitance is very small and it dominates the shunt impedance, it is very difficult to determine the resistance

and inductance associated with the model in this state (*off-state*). The capacitance in the circuit model for this state is 0.0493pF.

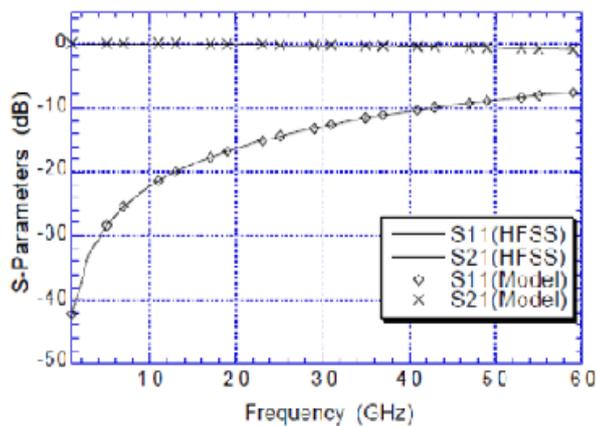


Fig 4.2 S-parameters of the EM simulated and circuit modeled for 300µm long, 5µm gap switch off-state

When the switch is in the *on-state*, similar procedure can be used and S-parameters can be obtained from the full wave analysis can compared with those obtained using model in Fig. 4.3

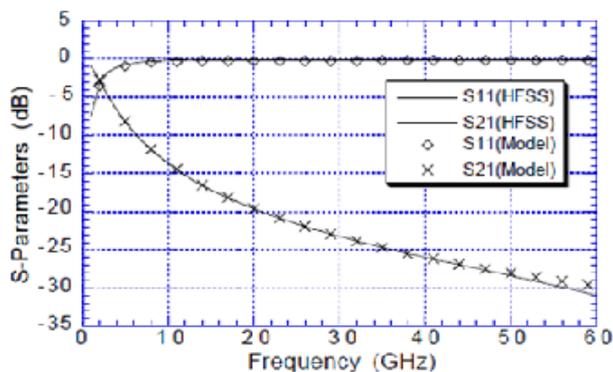


Fig 4.3 S-parameters of the EM simulated and circuit modeled for 300µm long 5µm height switch in the on state

V. CONCLUSIONS

Thus the RF MEMS switch can be use as a tunable circuit for various applications and the MEMS Switch can provide better performance over solid state switch. Thus the use of RF MEMS switches makes deliberate changes in wireless communication. A parametric model based on full wave analysis capable of predicting the performance in the *off state* of MEMS capacitive switches can be developed by this way.

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