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Electromagnetic Analysis of RF MEMS Switch

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***Abstract*—Micro Electro Mechanical Systems (MEMS) is a integration of sensors, actuators, microstructures and microelectronics. Components of MEMS that comprises of moving sub millimeter sized parts, capable of providing RF functionality are collectively referred as RF MEMS. In this work, electromagnetic analysis of RF MEMS series switch and shunt switch is presented. Using electromagnetic analysis, insertion loss (S12), reflection loss (S11), and isolation loss (S21) are calculated. Electromagnetic model of the system is extracted from measured S-parameter. MEMS switches are modelled in MEMS FAB tool COVENTORWARE 2012 and analyzed in the electromagnetic analysis software ANSOFT HFSS. The analysis results are presented by varying geometry of the switches.**

Keywords*—*Radio Frequency (RF), microelectromechanical systems, insertion loss, return loss, isolation loss.

I. INTRODUCTION

Advancement of micro fabrication techniques aided the development of MEMS in various engineering fields [1]. MEMS technology plays an important role in fabrication of RF components such as switches, variable capacitor, variable inductors. These RF components proved to be much more reliable and feasible than electrical counterparts for communication applications [2-3]. RF MEMS switch constitute a major part of RF MEMS components fabricated through batch fabrication process.

RF MEMS switches has a thin metal membrane which would be actuated using electrostatic, piezoelectric, magnetostatic, and thermal designs [4-8]. For electrostatic actuation, we apply a dc voltage between membrane and the electrodes [9]. The membrane deflects due to electrostatic force and based on switch used, it either short circuits or open circuits transmission line. RF MEMS has many advantage like high linearity, low dc power consumption, low insertion loss, and high isolation loss over conventional components [10-14].

Electromagnetic analysis calculates electric field, the magnetic field and their interactions at all points in space, which gives S-parameter. S-parameter is expressed in terms of the power relation between input and output terminals. In other words, S-parameter describes relation between incident and reflected power of the two port network. S11 is forward reflection coefficient which represents reflection or return loss of the system. S12 is the forward transmission coefficient which gives insertion loss of the system. S21 is the reverse transmission coefficient which represents isolation loss of the sytem[15]. Due to size constraints in MEMS, normal approach of using spectrum analyzer or network analyzer has its practical limitations. To overcome this limitation of hardware systems, electromagnetic analysis is carried out on simulation environment before fabrication.

MEMS Fab tool generally specializes on fabrication and electromechanical analysis. Focus of MEMS Fab tool like Coventorware on electromagnetic analysis is minimal. Therefore a full fledge electromagnetic analyzer tool are required for electromagnetic analysis of the MEMS systems. Generally two types of numerical technique is used for electromagnetic analysis, Finite Element Method (FEM) and Finite Difference Method (FDM). These techniques enables us to find approximate solutions of the boundary value problems. When compared to FDM , FEM provides better results when solving complicated geometry and boundary problems.

In this work, integrate Coventorware and electromagnetic analysis tool ANSOFT HFSS for analysis. MEMS series switch and shunt switch are modelled in Coventorware and export it into ANSOFT HFSS. In ANSOFT HFSS, Plotted the scattering parameter for various dimensions such as width, thickness of dielectric and beam of the switch and calculating insertion loss, return loss, isolation loss, Upstate and downstate capacitance of the systems.

II. RF MEMS SWITCH

Switches are fundamental part of the system. All RF MEMS switches that are developed, are bound to follow some basic mechanical laws. In MEMS Switch, surface forces and viscous air damping dominates over inertial and gravitational forces. Switches are fabricated using fixed-fixed beam or cantilever beam and modelled as a mechanical spring. RF MEMS switches are classified as shown in fig 1.

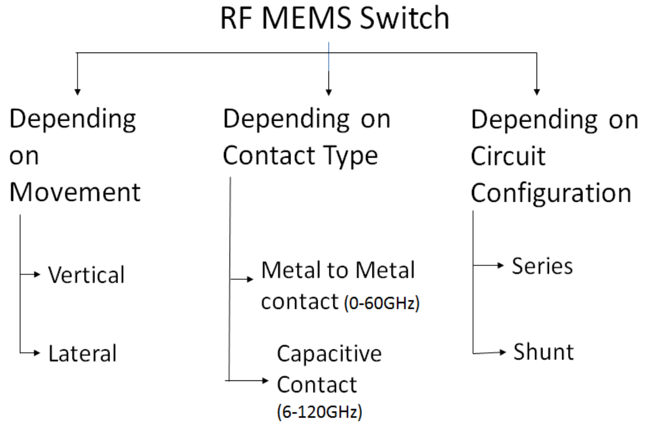

Figure 1. Classification of RF MEMS Switch

A. RF MEMS SERIES SWITCH

RF MEMS switch consists of two distinct parts: Mechanical and Electrical part. The mechanical part is operated using different mechanisms like electromagnetic, electrostatic, and piezoelectric actuations. Fig 2. Shows cross sectional view of RF MEMS series switch.

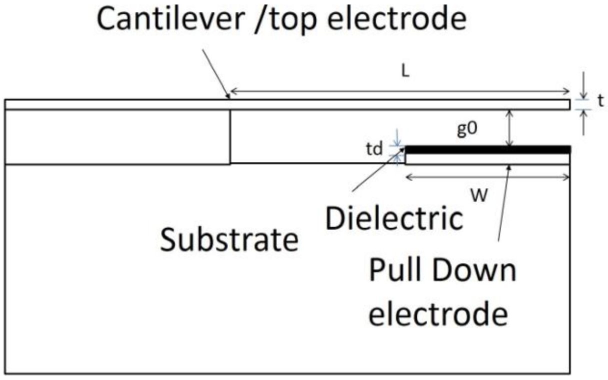

Figure 2. Cross sectional View of RF MEMS Series Switch

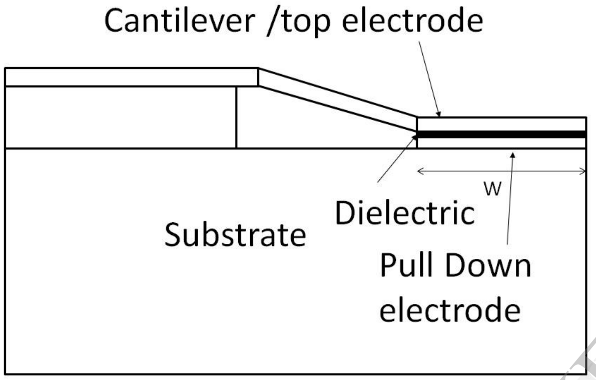

Figure3. Cross sectional view of Actuated RF Series Switch

When a dc voltage is applied between the bottom electrode and cantilever, an electrostatic force is generated which pulls down the cantilever from anchor as shown in figure 3.This will complete the RF signal path at downstate. Short circuit between the t- lines comes to RF signal to pass through and get transmitted. When voltage is removed, cantilever is back to original position by restoring force of cantilever.

Electrical model of MEMS series switch consists of series capacitance in upstate and resistance in the down state for dc contact switches. Upstate capacitance is composed of series capacitance between t-line and switch metal and parasitic capacitance between open ends of t-line. Contact resistance depends on size of contact area, mechanical force applied and quality of metal to metal contact. Isolation loss is calculated from upstate capacitance and is given by

$$S21 = 2j\omega C_{up}Z0 / 1 + 2j\omega C_{up}Z0 \qquad (1)$$

Where Cup is upstate capacitance and Z0 is the transmission line impedance.

1) RESULTS

In this section, electromagnetic analysis of the series switch is done by varying width, thickness of dielectric and thickness of beam. Series switch have air gap height 2µm, length of the cantilever 300 µm, length of the actuation pad is 100 µm, and thickness of the dielectric is 0.1 µm. Gold is used as cantilever and bottom electrode, SiO2 as dielectric material and Si substrate as shown in fig4.

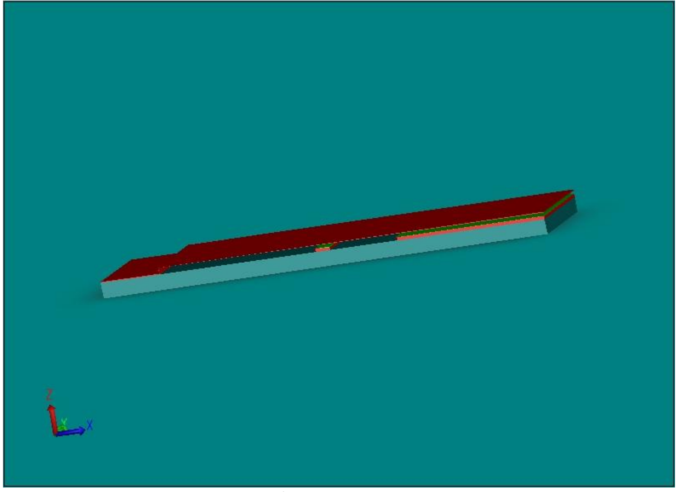

Figure 4. Model of RF Series switch in Coventorware

In HFSS , Width of the series switch is varied from 70 µm to 120 µm, then insertion loss, return loss, and isolation loss is plotted and analyzed.

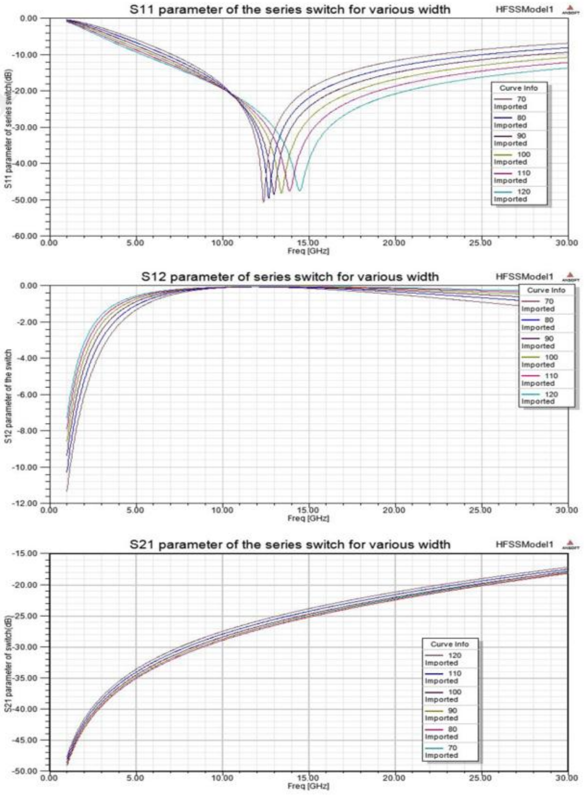

Figure5. S-Parameter of the series switch for various width

Fig 5 shows that as width of membrane increases, isolation loss and return loss also increases. Insertion loss increases at low frequency (< 10 GHz) and becomes approximately equal in high frequencies.

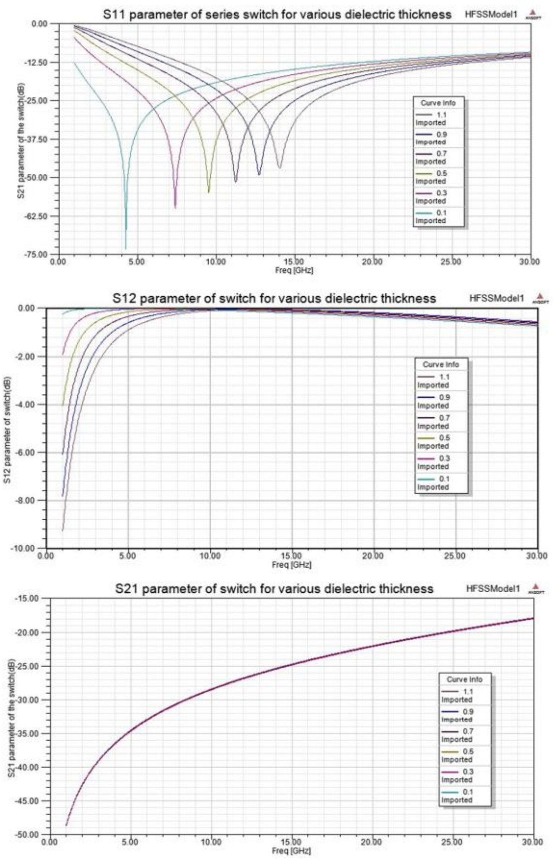

Figure 6. S-parameter for various dielectric thickness.

Thickness of the dielectric is varied from 0.1 µm to 1.1µm, then insertion loss, return loss, and isolation loss is plotted and analyzed. Fig 6 shows that resonant frequency and return loss increases when thickness of dielectric increases. Insertion loss is approximately equal in higher frequencies.

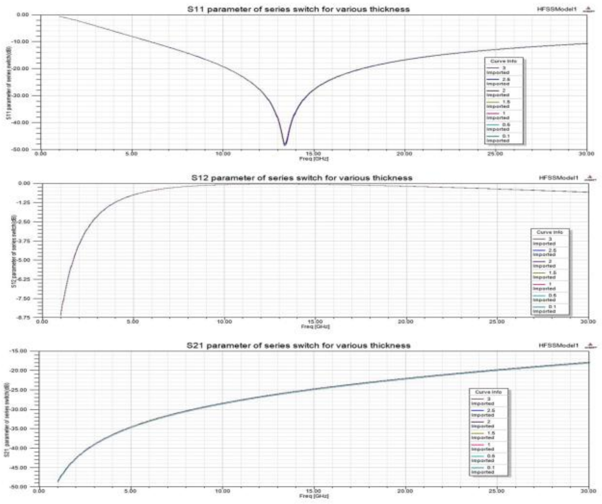

Figure 7. S-parameter for various thickness of the beam

Fig 7 shows that as thickness of the beam increasesfrom 0.1µm to 3 µm, there is no change in return loss, insertion loss and isolation loss. As thickness of the beam increases, the actuation voltage increases due to increase in spring constant of the beam. It requires more force to pull down the electrode if thickness of beam increases.

B. *RF MEMS SHUNT SWITCH*

RF MEMS shunt switch consists of coplanar waveguide fixed fixed beam metal bridge and a dielectric layer fabricated on the substrate Si as shown in fig 9.

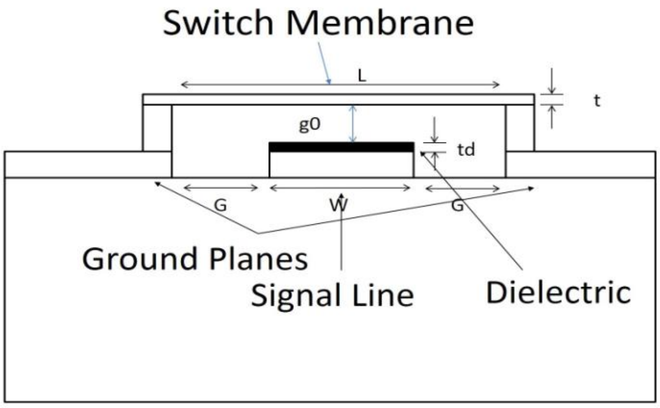

Figure 9. Cross sectional view of RF MEMS Shunt Switch

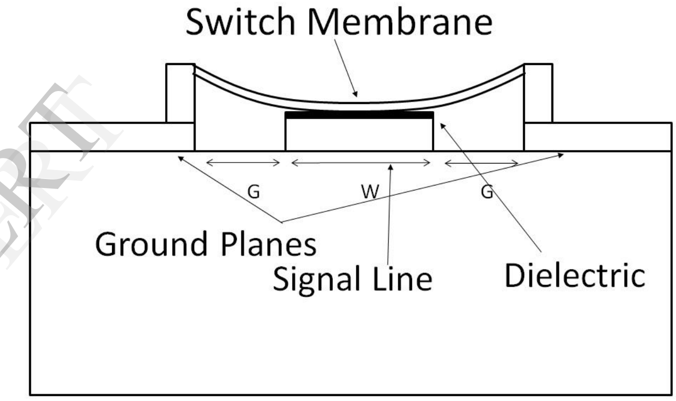

Figure 10.Cross sectional view of actuated MEMS shunt switch.

Normally RF signal is passed through the switch and transmit signal. When a dc voltage is applied, electrostatic force is produced between the beam and center conductor. This force pull down the membrane over dielectric layer on signal line as shown in fig10. It results in the formation of an open circuit between transmission lines and RF signal which prohibits the transmission of the signal. A dielectric layer is used to isolate metal membrane and center conductor.

Electric model of the MEMS Shunt switch is CLR model in which capacitance have an upstate and a downstate value. Upstate capacitance is the sum of parallel plate capacitance and fringing capacitance [3]. Fringing capacitance is 20– 40 % of the parallel plate capacitance. Capacitance ratio is the ratio between downstate capacitance to upstate capacitance. Capacitance ratio is in the range of 40 – 100. Reflection loss and isolation loss are depends on frequency, characteristic impedance of transmission line, and capacitance value as given below.

$$S11 = -j\,\omega\, Cup\, Z0 /\;\; 2 + j\,\omega\, Cup\, Z0 \qquad (2)$$

$$S21 = 1\;\; / \; 1 + j\,\omega\;\; Cd\;\; Zo / 2 \qquad (3)$$

1) *RESULTS*

MEMS Shunt switch is fabricated on a CPW line with dimensions G/W/G as 100 µm /120 µm /100µm for 1- 30 GHz measurements on the Si substrate. Membrane length is 320 µm, width of the membrane is varied from 70 – 120 µm to achieve different capacitance, air gap between membrane and dielectric is 2 µm, thickness of membrane is 1 µm and thickness of dielectric is 0.1 µm. MEMS shunt switch is modelled in following dimension as above and fig11 shows model of shunt switch in coventorware.

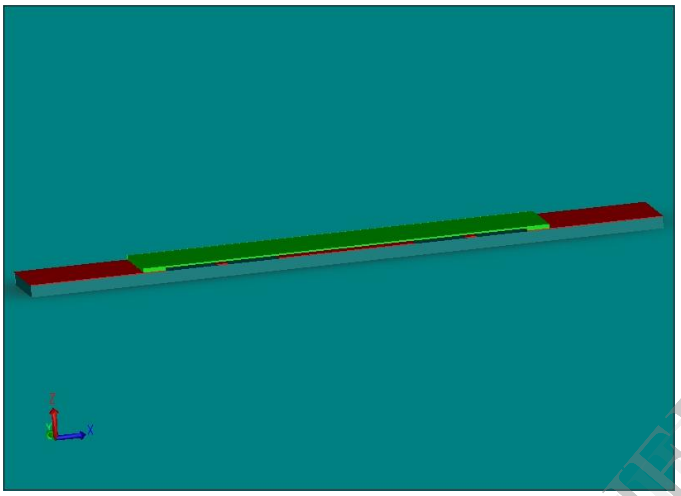

Figure11. Model of MEMS Shunt switch in Coventorware.

In HFSS , width of the shunt switch is varied from 70 – 120µm , then S11, S12, S21, S11actuated, Cup, Cd parameters of the switch is plotted and analyzed. For Shunt switch, return loss is calculated in downstate position and insertion loss is calculated in upstate position. Fig 12 shows that insertion loss and return loss increases in upstate position and isolation loss decreases when the width of the membrane increases from 70 to 120 µm.

Fig13 shows that as the width of the membrane increases, area of the actuation of switch increases. As a result capacitance value increases from 2.5fF to 20fF in upstate position and 5.5pF to 10pF in downstate position. Fig 14 shows that as the thickness of the dielectric increases from 0.1µm to 0.5µm , reflection loss and isolation loss increases and insertion loss decreases.

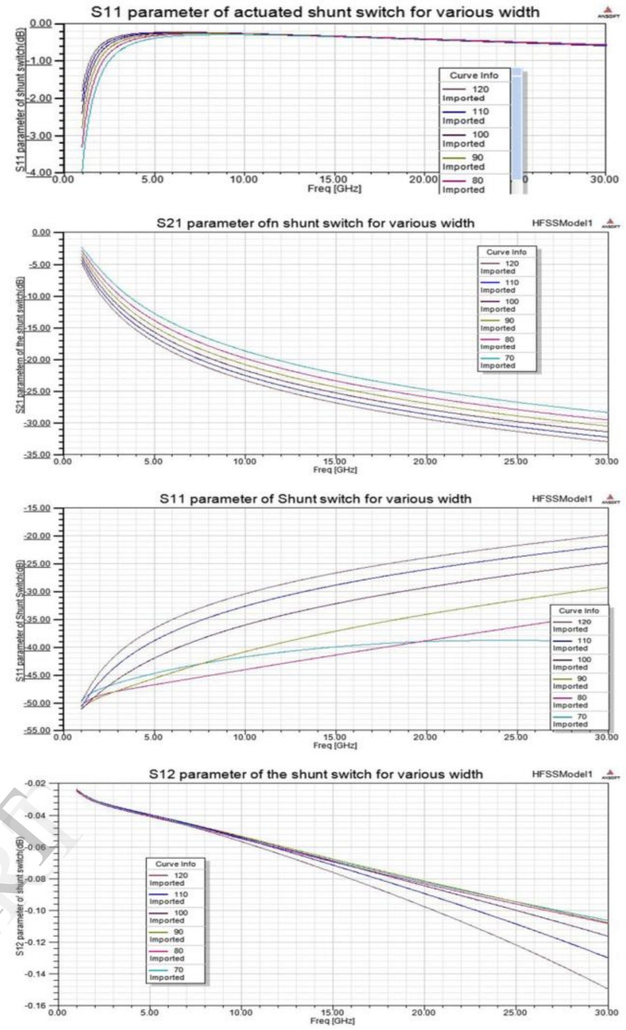

Figure12. S-parameter for various width of membrane

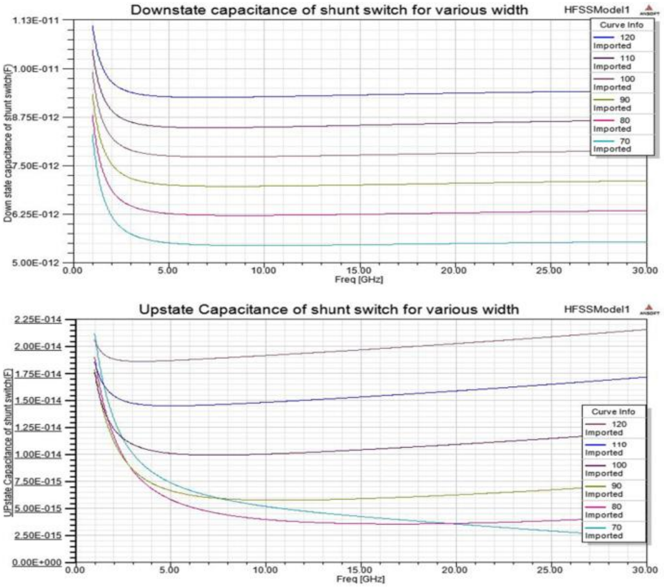

Figure13.Capacitance of shunt switch for various width

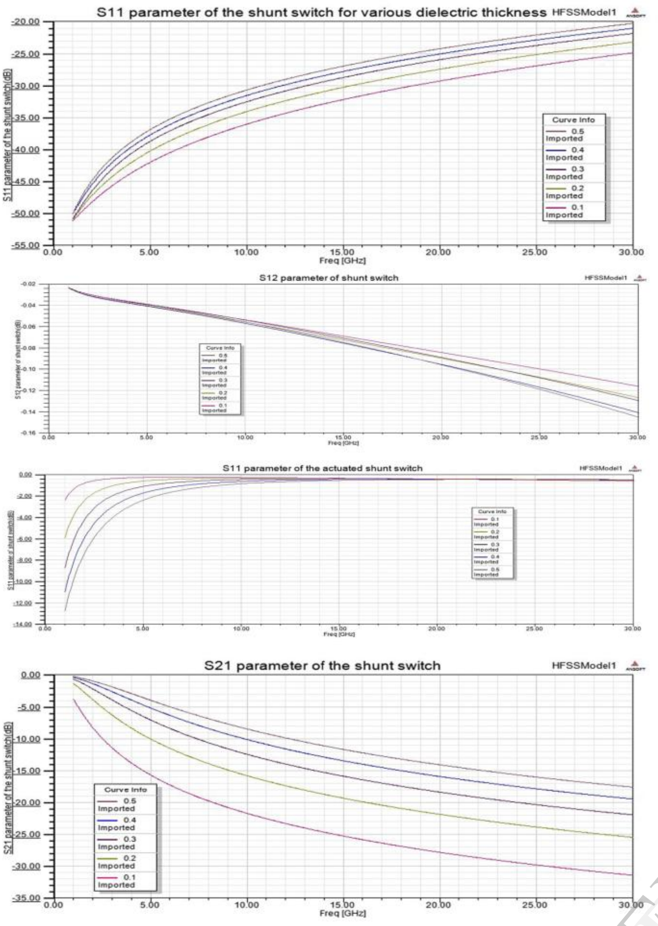

Figure14. S-parameter for various dielectric thickness

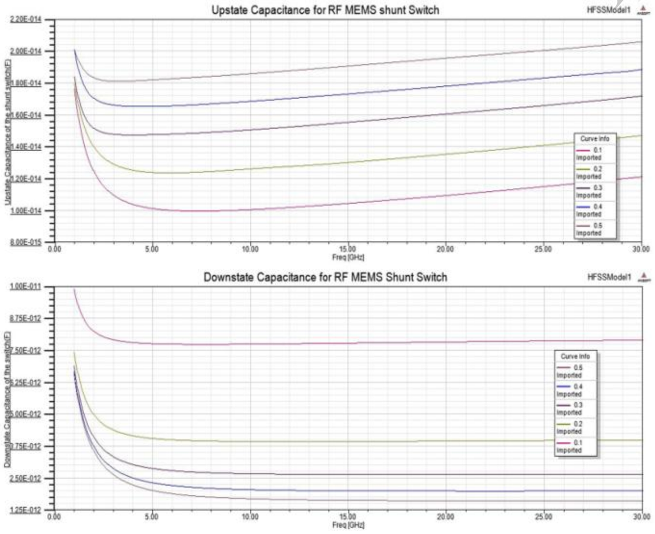

Fig15. Capacitance of switch for various dielectric

Fig 15 shows that upstate and downstate capacitance decreases when thickness of dielectric increases .

III. CONCLUSION

In this work, a novel hybrid approach was introduced to integrate Coventorware and HFSS for electromagnetic analysis of RF MEMS systems. Using HFSS, RF MEMS series switch and shunt switch are analyzed, insertion loss, return loss, and isolation loss are studied. Electromagnetic model is extracted from the measured S-parameter. It is seen that insertion loss of series switch is less than -0.3dB where for shunt switch is less than -0.2dB with acceptable isolation greater than -20dB upto 30 GHz.

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