Reconfigurable Antenna using Micromechanical Actuation Switches for K and Ku-Band Applications

Sathuluri Mallikharjuna Rao, G. Sasikala

Abstract- ***In this paper, we have proposed a reconfigurable antenna using micro mechanical actuation switches for K and Ku-band applications. Overall two identical cantilever micro mechanical switches (S_1 & S_2) are used to design reconfigurable patch antenna. The switches are working by electrostatic actuation mechanism. With the switches, overall the antenna is offering four resonant frequencies based on the switches ON/OFF condition. The Micro mechanical switches are offering an isolation loss of -18.5dB and an insertion loss of -1dB. The switch requires a DC actuation voltages of 6V. The Proposed reconfigurable antenna is resonating at four different frequencies based on the different switching conditions of RF MEMS switches. If S_1 & S_2 both are ON the antenna is resonating at 16.9GHZ, if S_1 -ON & S_2-OFF the antenna is resonating at 47.3GHZ & 59.1GHZ, if S_1 -OFF & S_2-ON the antenna is resonating at 28.4GHZ, if S_1 -OFF & S_2-OFF the antenna is resonating at 27.9GHZ***

Index Terms- ***Patch antenna, re-configurability, RF MEMS switch, PIN diode, FET, Polarization, bandwidth, gain, directivity.***

I INTRODUCTION

The latest communication applications require high speed data transmission with low power consumption, this is the significant research problem. Massive MIMO like systems require array of antennas but it eventually suffers with signal interference problems. To overcome these type of problems, we can use reconfigurable microstrip patch antennas other than the array of antennas. The re-configurability in patch antennas can be achieved with structure like E-shape, but the efficiency is not up to the level, so this approach is not preferable[1-4].

The alternative method to get re-configurability in microstrip patch antenna is by placing switches like PiN diodes or FET transistors and RF MEMS switches. In this RF MEMS switches offering best performance compared with PiN diode and FET transistors in terms of power consumption and offers better linearity[5-9].

Achieving the high isolation, low insertion and low pull-in voltage are the significant research challenges in micromechanical switches.

In this paper, we have designed and verified the performance of reconfigurable antenna using capacitive RF MEMS switches. The antenna is preferable in k-band and ka-band applications.

Revised Manuscript Received on December 15, 2019.

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The eventual reconfigurable microstrip antenna design is done in three steps, as an initial task we have designed an RF MEMS switch suitable in K-band and Ku-band frequency range, in the second level a microstrip patch antenna is designed and which is suitable to place RF MEMS switches, and in the final step the RF MEMS switches are placed in the proposed microstrip antenna structure as shown in figure 9.

II MICROMECHANICAL SWITCH

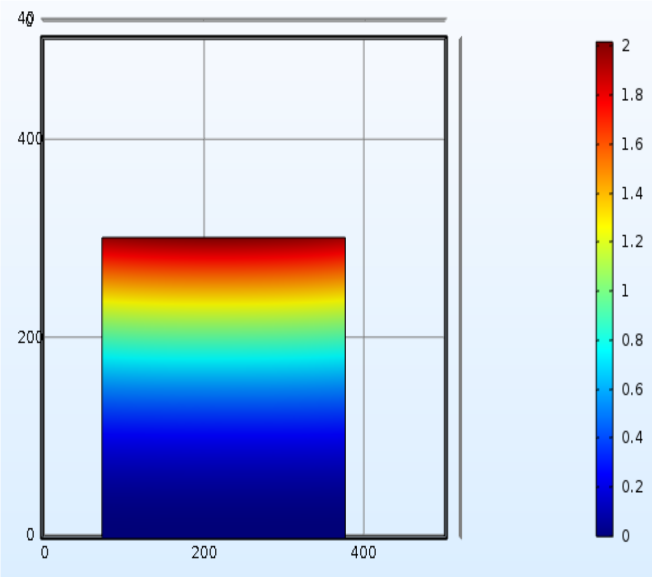

Figure 1: Micromechanical Cantilever shunt capacitve switch electromechanical analysis

The reconfigurable micro strip patch antenna design involves placing of two identical RF MEMS switches. An electrostatic shunt capacitive RF MEMS switches are used. CPW transmission line is used for switch design with dimension 100 µm x100 µm x100 µm.

The working principle of micro mechanical switch is, when the structure is in upstate(OFF), the input radio frequency signal is allowed to the output port with low insertion losses, and if the structure is in downstate(ON) the switch offers a capacitance in the range of pF and the input radio frequency signal is completely isolates and the output is zero. The electrostatic actuation model cantilever based shunt capacitive RF MEMS switch is shown in figure 1.

Table 1: RF MEMS switch materials and dimensions

Parameter	Material	Dimension in µm (Length x width x thickness)
Substrate	Silicon	500 x 500 x 1600
CPW	Gold	100 x 100 x 100
Cantilever	Gold	300 x 300 x 1
Dielectric	Silicon Nitrite (ε_r=7)	320 x 120 x 0.5

Silicon is used as a substrate for RF MEMS switch, CPW lines, cantilever is designed using gold material and silicon nitride (Si3N4) is used as a dielectric material. The shunt capacitive switch is actuated with electrostatic actuation.

The switch is designed and simulated using FEM tools. The cantilever with dimensions 300µm x 300 µm x 1 µm requires an actuation voltage of 6V to displace 2µm as shown in figure 1, is the simulation result.

The pull-in voltage of the cantilever based shunt capacitive RF MEMS switch can be calculate using following mathematical equation[10-12],

$$Pull - in\ \ Voltage = \sqrt{\frac{8kg_0^3}{27A\varepsilon_0}} \tag{1}$$

where, k is the cantilever spring constant, g0 is the switch air gap, A is the electrodes cross sectional area, and εo =8.85 x 10-12 is the free space relative permittivity.

The spring constant (k=(Ewt3)/l3) of gold cantilever structure with 300umx300umx1um dimension, E=70GPa, is theoretically value is 0.77 N/m, the required pull-in voltage for air gap of 2um with actuation electrodes cross sectional area 300umx300um is 4.5V.

The error in the pull-in voltage result is very low that is % of error=((Simulation-Theoretical)/Theoretical)X100 , the error in the pull-in voltage in terms of simulation (6V) and theoretical (4.5V) is approximately 0.33%. It is indicating that simulated one is very close to theoretical result.

The switch Radio frequency behavior is analyzed using HFSS tool. The switch overall performance is simulated in the frequency range 1GHZ to 60GHZ. The insertion losses of the switch is -1dB and the isolation losses of the switch is -18.5dB as shown in figure 3 and 4 respectively.

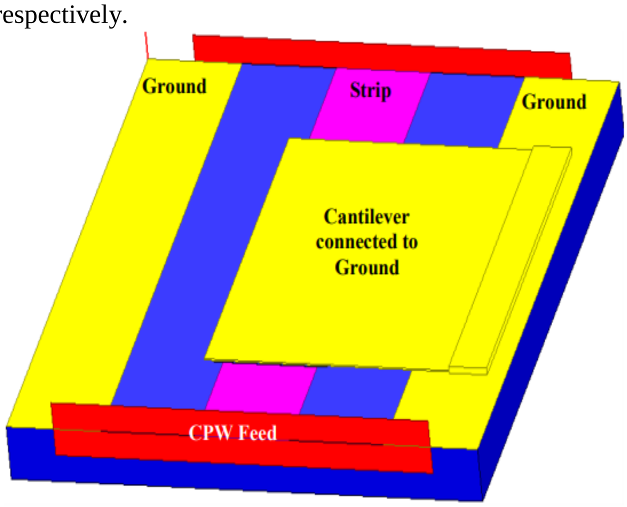

Figure 2: Micromechanical cantilever shunt capacitve switch Radio Frequency analysis.

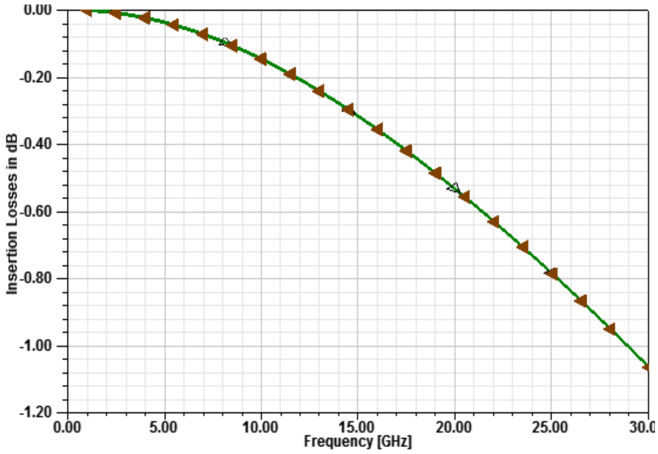

Figure 3: Insertion Losses in dB

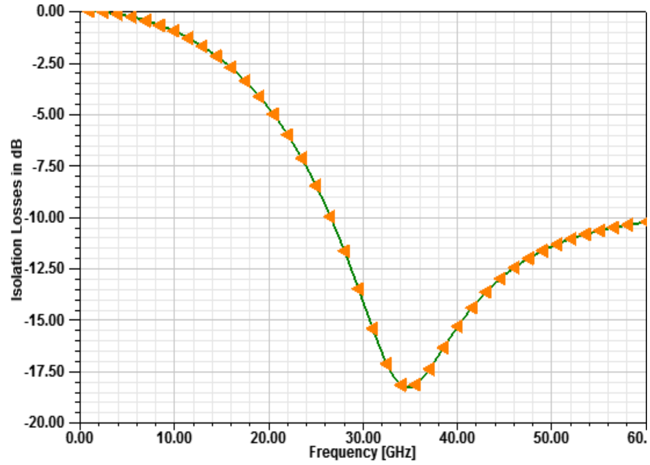

Figure 4: Isolation Losses Losses in dB

III MICROSTRIP PATCH ANTENNA

In this paper we have proposed a rectangular slotted microstrip patch antenna suitable to incorporate the RF MEMS switches as shown in figure 5. CPW feeding is used to feed microstrip antenna with input impedance of 50Ω.

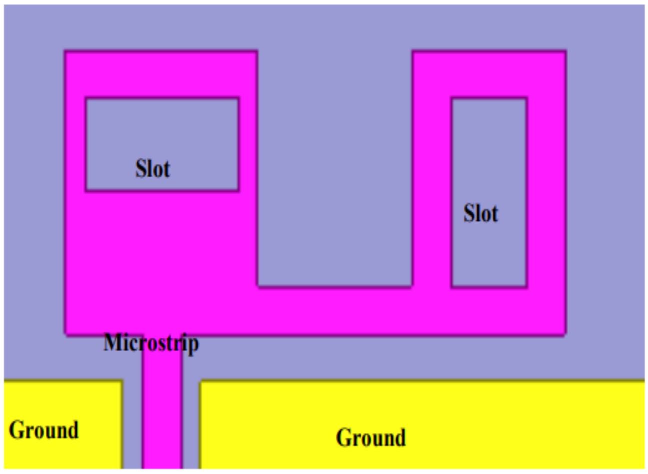

Figure 5: Proposed micro strip patch antenna suitable to incarporate RF MEMS swithes

The operating frequency of reconfigurable antenna is to be aimed in the range k-band and Ku-band, so the basic antenna is also designed in appropriately same band.

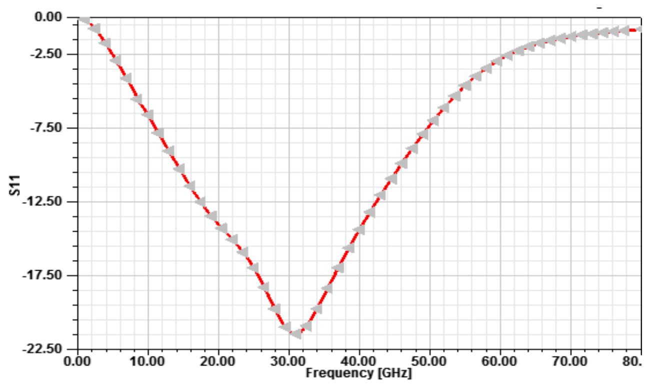

Figure 6: Micromechanical switche in microstrip patch antenna

The antenna without RF MEMS switches is resonating at 30GHZ as shown in figure 6. Here, we have extended out analysis on the performance of antenna with different substrate materials like FR4, Rogers RO3006, Glass and silicon. In this analysis we noticed that as silicon as the substrate antenna is offering best performance.

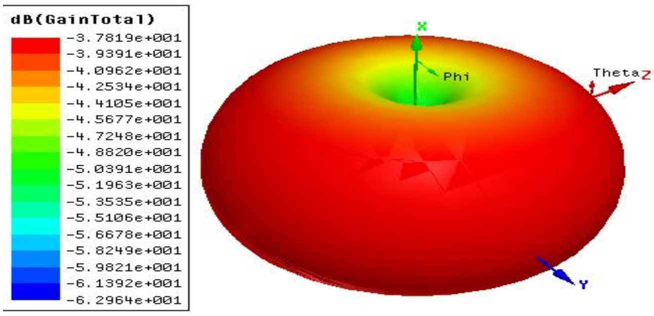

Figure 7: Polar plot of antenna with out RF MEMS switches.

IV PROPOSED RECONFIGURABLE ANTENNA

The eventual reconfigurable microstrip antenna using RF MEMS switches design is discussed in this section. Overall two RF MEMS switches are placed in the proposed microstrip antenna structure which is convenient to place RF MEMS switches. Silicon with 1.6mm thickness is used as a substrate material, microstrip, ground and RF MEMS switches design is done using gold material.

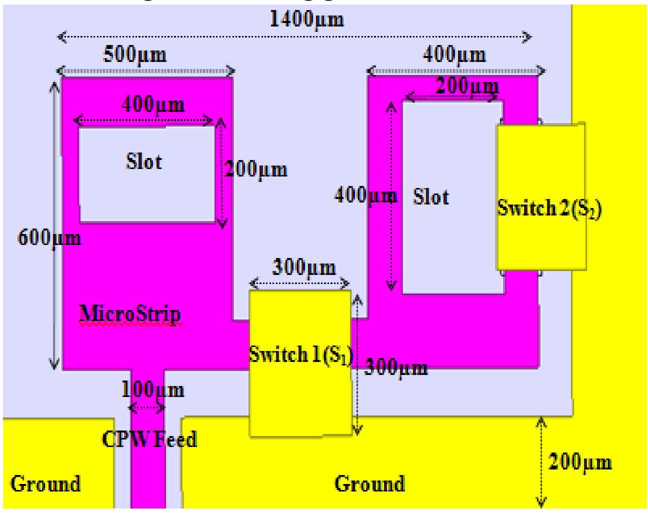

Figure 8: Proposed reconfigurable antenna model-top view

Under different switching condition of RF MEMS switches the antenna resonating in different frequencies. Overall proposed reconfigurable antenna is resonating at four different frequencies.

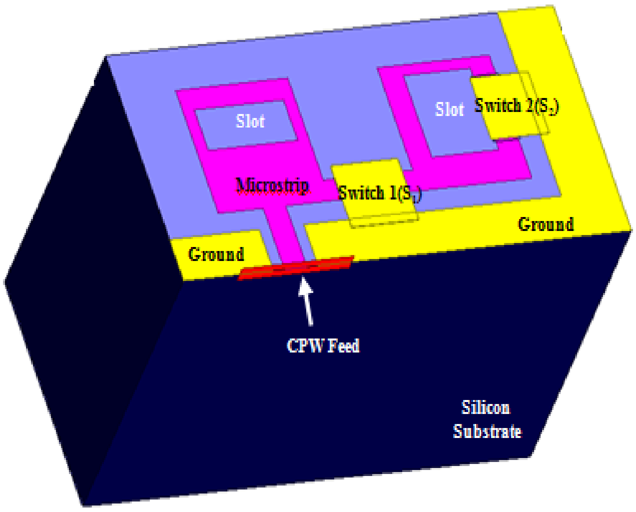

Figure 9: Proposed reconfigurable antenna model- side view

If S1 & S2 both are ON the antenna is resonating at 16.9GHZ, if S1 -ON & S2-OFF the antenna is resonating at 47.3GHZ & 59.1GHZ, if S1 -OFF & S2-ON the antenna is resonating at 28.4GHZ, if S1 -OFF & S2-OFF the antenna is resonating at 27.9GHZ.

The antenna performance is analyzed over the frequency range 1GHZ to 80GHZ using HFSS FEM tool. After observing the frequency response of the reconfigurable antenna we would like to refere the antenna in a wide range of applications in K-band and ka-band range. Other than polarization proposed antenna is switching the operating frequency from one frequency to other frequency.

Table 2: Antenna Resonant Frequencies for different switch conditions

Condition	Resonant Frequency
S_1=*ON*, S_2=*ON*	16.9GHZ
S_1=*ON*, S_2=*OFF*	47.3GHZ & 59.1GHZ
S_1=*OFF*, S_2=*ON*	28.4GHZ
S_1=*OFF*, S_2=*OFF*	27.9GHZ

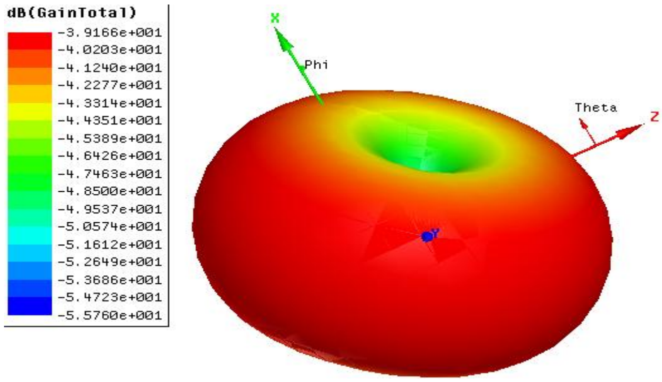

Figure 10: Polar plot of reconfigurable antenna at S_1-ON & S_2-ON

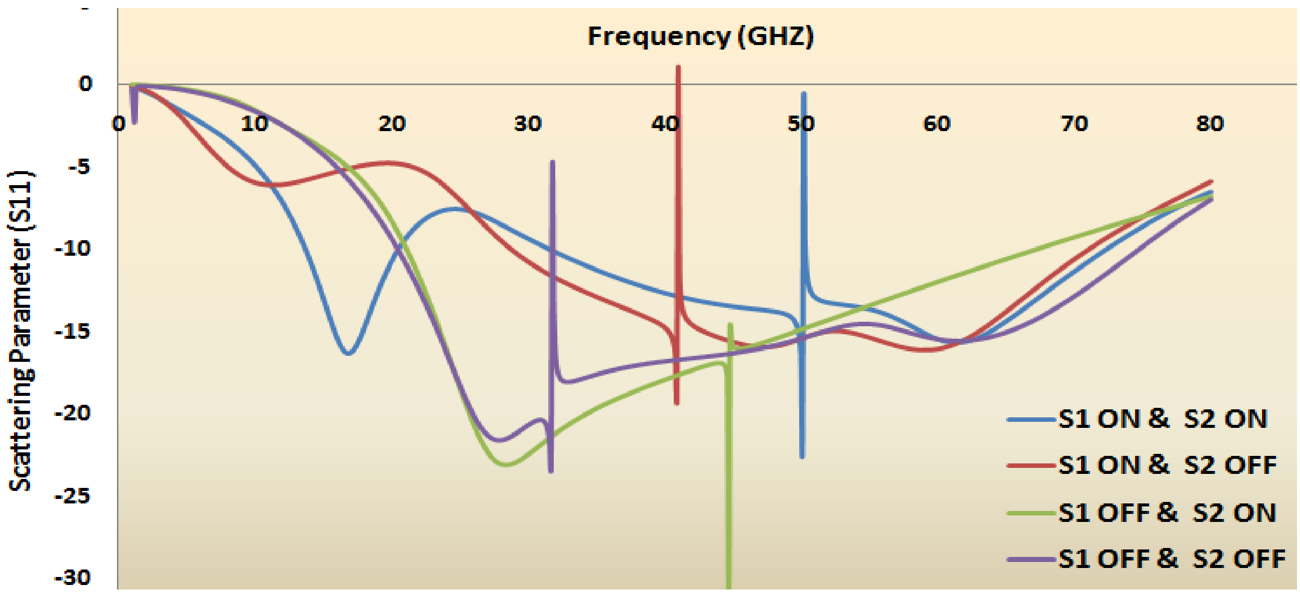

Figure 10: Scattering parameters for different switch states

Table 3:Comparison of the related work with the proposed reconfigurable antenna

Survey Paper	Antenna Shape	Number of switches	Switches	Switches State and Resonant Frequency	Antenna Application
Harish Rajagopalan et al. [13]	E-shape	2	RMSW100HP - SPST, High Power (10 W), DC-12 GHz	S1 & S2 : ON-2-2.6 GHz, S1 & S2 : OFF-2.6-3.2 GHz.	Cognitive Radio
Tony J. Jung et al. [14]	Circle	1	DC contact RF MEMS	S1 :OFF- Circular polarization(17.4 -21.9 GHz), S1 :ON- Linear polarization(16.9-22.5 GHz).	Satellite
Caner Guclu et al.[15]	Split rings	6	Series DC contact RF MEMS switch.	24.4 GHz and 35.5 GHz independently.	K-Band & Ka-Band.
Chih-Chieh Cheng et al. [16]	Programmable Lens-Array Antenna	5	Capacitive RF MEMS switches.	35 GHz	Ka-Band
Proposed	Slotted Rectangular	2	Shunt capacitive cantilever RF MEMS switches	S_1=ON, S_2=ON: 16.9GHZ S_1=ON, S_2=OFF:47.3GHZ & 59.1GHZ S_1=OFF, S_2=ON: 28.4GHZ S_1=OFF, S_2=OFF:27.9GHX	K-Band & Ku-Band

V CONCLUSION

The reconfigurable microstrip antenna design is done in three steps, as an initial task we have designed an RF MEMS switch suitable in K-band and Ku-band frequency range, in the second level a microstrip patch antenna is designed and which is suitable to place RF MEMS switches, and in the final step the RF MEMS switches are placed in the proposed microstrip antenna structure. The RF MEMS capacitive shunt switch is designed with cantilever structure with electrostatic actuation. The switch requires 6v actuation voltage and it offers 1dB insertion and 18.5dB isolation. The microstrip patch antenna suitable to place RF MEMS switches is resonate at 30GHZ frequency before placing RF MEMS switches. Overall two RF MEMS switches are place in the slotted rectangular patch antenna. Under different switching condition of RF MEMS switches the antenna resonating in different frequencies. Overall proposed reconfigurable antenna is resonating at four different frequencies.

ACKNOWLEDGMENT

We would like to thank Department of ECE, K L University, AP, India, for official use of FEM software for designing and simulation.

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