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Integrating RF MEMS Switch on Array Antenna to Achieve Reconfigurability in Wideband Application

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Abstract

Reconfigurable multi-band antennas are highly used for commercial as well as military purposes as a single antenna could be reconfigured dynamically to send and the receive multiple signals of different frequency simultaneously. In this work an antenna array is designed and integrated with RF MEMS shunt capacitive switch over it, for the applications of S,C,X-band in the frequency range of 2-12GHz. A membrane that can move freely over a coplanar waveguide serves as the MEMS switch. Here, a double meander tuned dual beam arrangement is used to increase switch isolation. Electrostatic mechanisms are used for actuators due to their low power requirements, compact design, and quick switching. By the simulation result, The beam starts to bend from 0.60793mm to 0.4116mm at the voltage 1.78492mV to 57.7382mV and it provides capacitance at 1.435pF to 1.597nF. It was noticed that the insertion loss (S21) and the return loss (S11) of a MEMS switch are around -0.079 dB and 20.618 dB correspondingly, in order to have a good switching characteristic in the up state. The switch has an insertion loss (S21) of -31.307 dB and return loss (S11) of about -0.256 dB in the up state thus exhibiting good switch characteristics. The RF MEMS shunt capacitive switch is integrated on the predesigned antenna array the dynamically shifting of the switch from on state to off state helps achieving the reconfigurability in the antenna array. Such antennas are applicable in spaceborne radar, communication satellites, unmanned aerial

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vehicles, unmanned aircraft system and various other communication as well as sensing applications.

Keywords: MEMS, Pull-In-Voltage, Insertion Loss, Return-Loss, Isolation Loss.

1. Introduction

Due to its wideband operation and superior RF performance, radio-frequency micro-electromechanical systems (RF-MEMS) are currently at the forefront of technology. The design of RF components and systems, wireless sensor networks, biological sectors, defence, and satellite communication are just a few areas in which these devices are widely used. By including MEMS components in the design, devices based on RF-MEMS technology increase their performance and productivity. The unique capability of MEMS devices to conduct both mechanical and electrical operations. The RF-MEMS switch, one of many MEMS devices, is the fundamental part used in practically all wireless communication systems. Due to their distinct electromechanical functioning, RF-MEMS switches have largely superseded all of the current conventional switches, including PIN diodes, field-effect transistors (FETs), and tunnel field-effect transistors (TFETs). While RF-MEMS switches exhibit great RF performance, low power consumption, and tiny size, solid-state switches use more power. However, the reliability, high power handling capacity, and switching speed of RF-MEMS switches are poor [4]. To enhance the switches' electromagnetic and electromechanical performance in order to increase switching speed and RF power management. However, RF-MEMS switches have low reliability, high power handling capacity, and switching speed [4].to improve the electromagnetic and electromechanical performance of switches in order to speed up switching and manage RF power.

1.1 Introduction of MEMS Switch

Let RF switch be a two-port network applied in making and braking the switches. The high resistive losses, and the low power handling capability has limited the performance of the conventional RF switches in the components like transistors, rectifier etc. Because of their improved isolation, reduced loss, and capability to function at extreme frequencies that are high, MEMS switches have recently gained in popularity. However, it has have a low power handling capacity and reducible voltage. A thin membrane that can be electrostatically activated in the RF switches applying the direct current bias voltage makes up RF MEMS switches. The two fundamental switches utilised in the designing the circuit of RF are: The series and shunt switches. Switch in Up position with bias voltage ends in open circuit (transmission line). The switch in Down position with bias voltage, ends in short circuit (transmission line).

The bias voltage enables the switch to either connect/disconnect the transmission line to the ground. The switch in down position with bias voltage causes an infinite isolation, switch in up position with nil bias voltage results in insertion loss = 0. The switch uses electrostatic actuation, which uses less energy, to change its capacitance when a tuning voltage is supplied. In an electrostatic actuation system, the force produced causes one plate in a parallel plate configuration to move towards or away from another plate.

The movable plate of the RF MEMS switch swiftly descends to the bottom plate once the threshold bias voltage is reached, at which point the voltage given to it has no further effect on the position of the beam. The force produced by this movement is dispersed over the movable plate's length. Only for deflections of less than one-third of the original distance between the supports can the electrostatic attraction force and the support force remain in a stable equilibrium. RF MEMS switches are widely used in high-performance switching applications, especially in microwave and millimeter-wave frequencies. It is combined with more traditional elements, including as filters and antennas, to achieve frequency tuning. High performance Phase Shifters are also designed using RF MEMS shunt switches.

2. Designing Specification

Depending on the actuation mean and to maintain the specification integrity MEMS are classified as

(i) Acoustic-MEMS,

(ii) Optical-MEMS

(iii) Radio-Frequency MEMS (RF-MEMS).

RF MEMS operates in 3 kHz - 300 GHz (emf) range [7-8]. This frequency offers heightened circuitry efficiency and capacity to drift in the paths comprising insulating material, for e.g. dielectric insulators. The RF MEMS switches are high preferred in variety of application due to their, exceedingly high isolation, exceedingly low inter modulation products and insertion loss as described by Rebiez (2003). The RF switches also comes with certain disadvantages for e.g. low power management, and speed, high voltage etc. To produce a large electrostatic force and enjoy a reliable operation, RF switches requires very high voltage ranging from 20 to 80V to attain this the voltage up-converters are used, which in turn results in increased complexity and cost. The pull-in or actuator voltage of RF MEMS switches is higher than the 5V or lower typical voltages of CMOS. So to reduce the pull-in voltage of RF MEMS switch is a prerequisite for this the switches and the control circuits are made compatible.

3. Relation between Bending Beam and Potential Difference

By investigating stability of MEMS switch was based on applied potential voltage with respect to beam bend. Bending of beam depend on pull-in-voltage. From figure 1(a),Where pull-in-voltage is reference voltage at which at 2/3 of beam bend. Now if applied voltage $Vout$ and VPI = Voltage given at the input and the critical pull-in voltage of the micro-beams and the system respectively. electrostatic force across the two electrodes as depicted in figure 1(b) is increased to make the cantilever beam to deflect in the direction of the substrate. Figure 1(c), depicts how the electrical connection is established on the cases when the cantilever are unstable and the critical pull-in voltage pulls the tip of the flexible electrode towards the substrate.

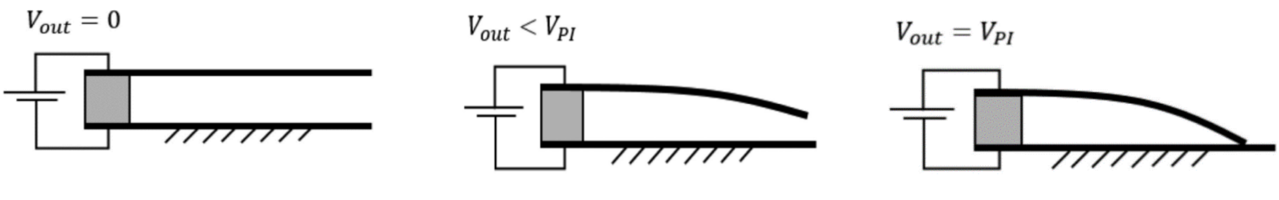

Figure 1(a) **Figure 1(b)** **Figure 1(c)**

The prime use of these components is to provide a very fast communications without compensation on the size and the efficiency.

4. Mechanical Modeling of MEMS Switch

In the proposed mems design we must consider following parameter they are,

- Length of the electrode(L)=4500um or 4.5mm
- Width of the electrode(W)=2000um or 2mm
- Thickness of the electrode(H)=35um or 0.035
- Air gap(y_0)=608um or 0.608mm
- Dielectric thickness(y_d)=250nm
- Electrode: gold(young's modulus=79GPa, poission's ratio=0.44,density=19320kg/m^3)
- Youngs modulus=200Gpa
- Poission's ratio:0.31
- Density:8900
- Dielectric material: silicon nitride (dielectric constant=7.5).

Let figure 4.1 show basic requirement of the design of the mems switch. The counter electrode is grounded in the substrate. The four rectangular flexures that are electrically isolated with the substrate found in the corners and are used in anchoring the suspended plate with the substrate. The initial potential = 0.001V used in measuring the devices DC capacitance is given to the Domain Terminal feature polysilicon. The initial potential is increased after few microseconds by 10 V and a step function with rise time = 10 µs. The applied voltage is higher than the structure's and the switch's pull-in and pull-down voltages onto the nitride. The device's capacitance changes significantly and abruptly as a result of this process. Only one quadrant of the structure may be modelled because of the device's symmetry. The mass, spring constant, and damping coefficient are computed for the spring mass model by

Area= electrode Area

Mass = density*thickness*Area

Spring constant (k)=$\frac{young'smodulus*height^3*Area}{(1-(poission'sratio^2))/lenght^4}$

Damping constant (b) = $b_o * Area$

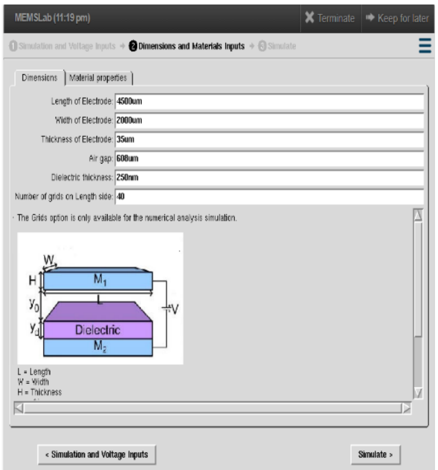

Figure 4.1. Dimension of Mems Switch

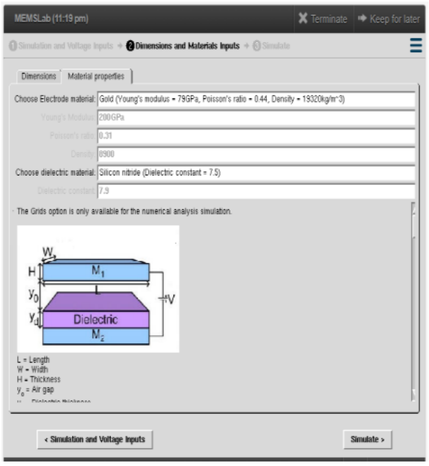

Figure 4.2. Material Properties

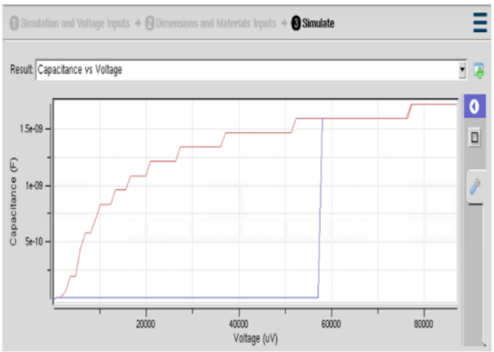

Figure 4.3. Capacitance Vs Voltage Plot

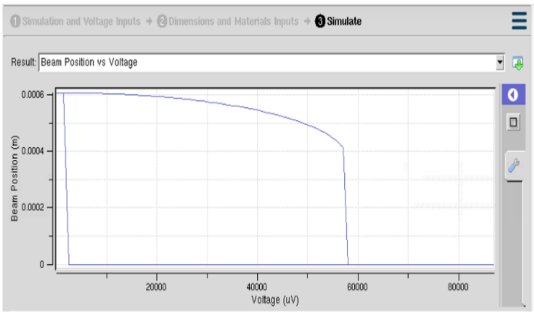

Figure 4.4. Beam Position Vs Voltage Plot

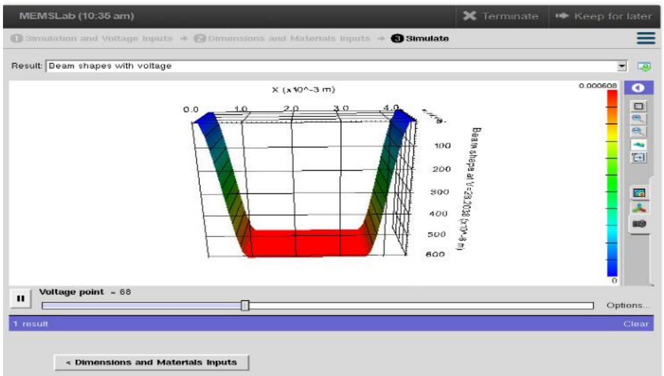

Figure 4.5. Beam Displacement with Respect to Applied Voltage

By the simulation result beam start bend from 0.60793um to 0.4116um at the voltage1.78492mV to 57.7382mV and it provide capacitance at 1.435pF to 1.597nF. So, the switch displacement happens with respect to time. The switch's inertia, which plays a major role, causes it to close much more slowly than the applied voltage variations deliver. Figure

4.5 shows device capacitance with respect to time. There is a gradual increase in the capacitance with respect to time in pF to nF. It is evident that the capacitance fluctuates on a time scale that is substantially less than the displacement.

5. Electrotechnical Modelling of Switch

The geometry of capacitive switches is extremely sensitive to the RF power on the transmission line, which is directly related to the type of switch contact. In for capacitive shunt switches, capacitance (up) is small and capacitance(down) is high. When the switch is actuated by RF voltage, it is resulted in a high ground $_{\text{capacitance}}$ and behaves as a short circuit the RF voltage of the switch = 0. The switch return to its normal position when the electrostatic force is low.

The MEMS switch is model includes (i) transmission_lines and (ii) lumped-CLR with bridge-capacitance that includes the down and up state values.

transmission line $_{\text{length}}$ = (w/2) + l, l = reference edge difference in MEMS bridge. “Inductance = 7 to 8 pH” , series resistance in the range of 0.2 to 0.3 ohms.

The switch shunt impedance is stated as

Zs= Rs + jωL + 1/jωC

C = Cu or Cd (depends on switch position)

The resonant frequency of LC series is

$$f_0 = \frac{1}{2\pi\sqrt{L * C}}$$

The shunt switch impedance is approximated as

$$Z_s = \begin{cases} {}^{1}/_{j\omega C} & for \quad f \ll f_0 \\ R_s & for \quad f == f_0 \\ j\omega L & for \quad f \gg f_0 \end{cases}$$

Above and below LC series resonant frequency the CLR model behaves as an inductor and capacitor correspondingly The “CLR model” resonance equates to the MEMS bridge series resistance. Cut-off frequency occurs when the on-off ratio of the impedance =1

Fc = $1/2\pi C_u R_s$

Up state:

Cup = 1.435 pF

Down State:

Cdown = 1.597 nf

Up Condition

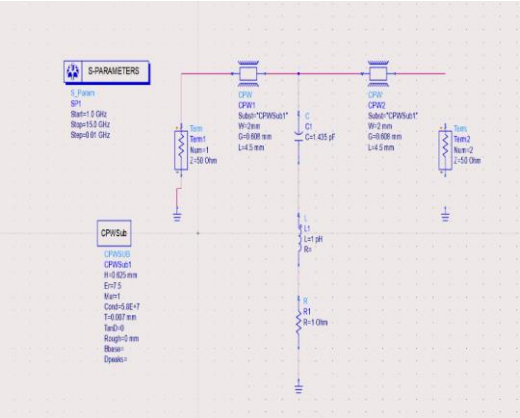

Figure 5.1. Proposed RF_MEMS up-Condition (Switch) using the CLR Model

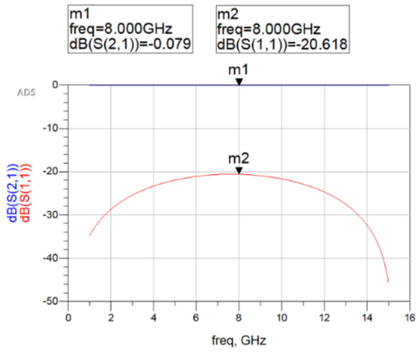

Figure 5.2. Proposed Up-Condition (Switch) Insertion and Return Loss

Down Condition

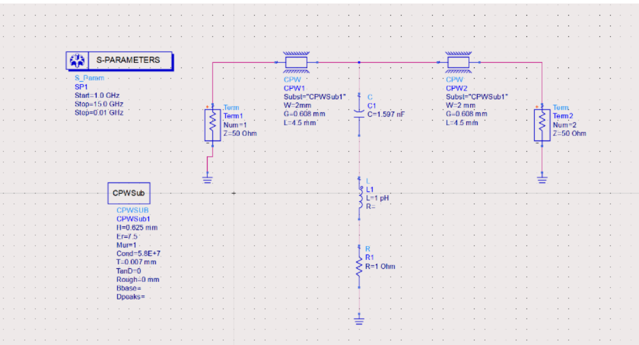

Figure 5.3. Proposed RF CLR Model MEMS Down-Condition (switch)

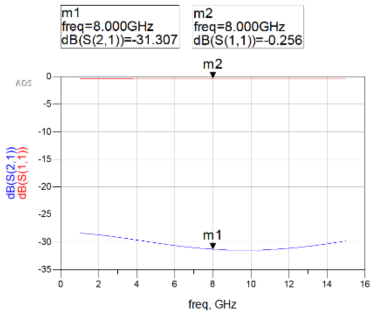

Figure 5.4. Proposed Down-Condition (Switch) Insertion and Return Loss

Fm the results attained for the upstate for MEMS switch : insertion and isolation loss of switch 21 = -0.079 dB and -31.307 dB correspondingly , return loss of switch 11 = -20.618 and -0.256 dB with a good switching characteristics.

Table 5.1. Comparison between Existing and Proposed Switch

RF MEMS Switch	**[23]** **Czaplewski, Nordquist**	**[24]** **Zhu, Han, L**	**[25]** **Girija Sravani1, D. Prathyusha1**	**Proposed work**
Voltage Control V	120	0.311-0.5544	12	1.7mV-57.7mV
“Insertion loss”, dB	3444	< 0.4555	0.59	0.079
“Isolation loss” ,dB	27.99	22.4555	27.84	31.307
Type of contact	resistive	Resistive	capacitive	Capacitive

The result in table 5.1 shows that the proposed switch can operate ar1.7mv to57mv and above 57mv may lead to damage. Moreover, switch can provide reduced insertion loss (on condition). And increased isolation loss (off condition) so it can be suitable for wideband application.

6. Antenna Array

In some cases, a single microstrip element might provide the essential antenna properties. “High gain, beam scanning, or steering capabilities”, however, are only achievable when discrete radiators are coupled to form a linear, planar, or volume array, much like in the case of traditional microwave antenna. A linear array is made up of pieces that are spaced finitely apart along a straight line. Similar to how a volume array has elements dispersed in three dimensions, a planar array has elements distributed across a plane. Depending on the intended use, the array type is typically used in practice.

6.1 Design Specification

The most important parameters include

- Operating frequency
- substrate Dielectric constant (εr) = 4.4 ,

- Substrate $_{\text{Dielectric constant}}$ = FR-4
- Substrate Dielectric height (h) =1.6 mm.

Table 6.1. Designing Parameters

S.No	PARAMETER	VALUE
1	Substrate_length	47mm
2	Substrate_width	29mm
3	Thickness of the substrate	1.6mm
4	Substrate_Type	Fr-4
5	substrate(ε_r)relative permittivity	4.4
6	Ground_length	47mm
7	Ground_width	29mm
8	thickness of the ground	0.035mm
9	Microstrip_length	40mm
10	Microstrip_width	1mm

Dimension of Single Element		
S.NO	**PARAMETER**	**VALUE**
1	Length of single patch	4mm
2	Width of single patch	4mm
3	Thickeness of single patch	0.035mm
4	Length of the microstrip	3.5mm
5	Width of the microstrip	0.5mm

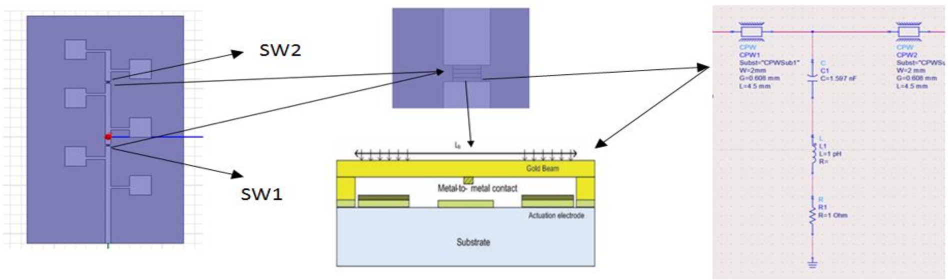

Figure 6.1. Proposed MEMs Switch Model(CLR) Integrated On The Antenna Array

Design parameters mentioned above helps in meeting the requirements of antenna

6.2 Simulation Result and Analysis

In this section discusses the proposed antenna integrated with MEMSswitch , then the variation in the design parameter, the return loss, VSWR, bandwidth, and radiation pattern are measured. From table6.2 antenna operating frequency with respect to various switching condition shown below.

Table 6.2. Summary of the Result

Switching Condition		**Operating Frequency Giga Hertz**	**"Frequency Band" Giga Hertz**	**"Gain" Decibel**	**Bandwidth Giga Hertz**	**No.Of Band**
SW1	SW2					
0	0	2.4	1 and 2.3	-1.89	0.132 , 0.102.	2
		5.9	2.7	-1.06	0.103.	1
		8	2.7	2.08	0.375.	1
		10	2.7	4.16	0.125.	1
		11	2.7	5.59	0.178.	1
0	1	2.4	2.21	-1.44	0.129.	1
		5.9	1.1 , 2.4 , 5.9	-1.89	0.298,0.047, 0.159.	3
		8	5.9 ,7 , 8	1.91	0.105,0.105, 0.457.	3
		10	2.4,5.9,9.5,10 .9	4.66	0.023,0.245, 0.124, 0.235.	4
		11	5.9	7.57	0.305.	1
1	1	2.4	1 and 2.4	2.06	0.425,0.354.	2
		5.9	1, 2.4, 5.9	5.42	0.203,0.301, 0.475.	3
		8	2.4, 5.9, 7, 8	4.51	0.475,0.267, 0.475, 0.532.	4

		10	2.3 ,5.9 ,7, 8, 9, 10	4.59	0.234,0.125, 0.351,0.172, 0.457, 0.277.	6
		11	1.4, 5.9, 7,8, 10. 9, 11.	9.62	0.125,0.751, 0.245,0.547, 0.452, 1173.	6

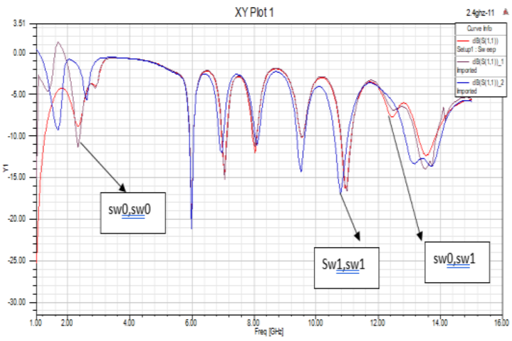

Figure 6.2. Return Loss at Various Switching Condition In 2.4GHz

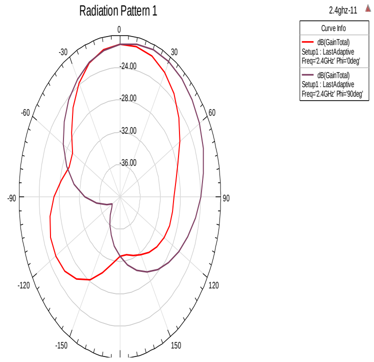

Figure 6.3. Radiation Pattern at 2.4GHz

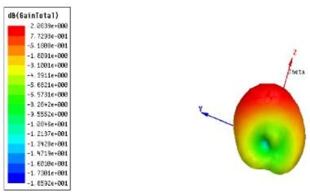

Figure 6.4. Maximum Gain at 2.4GHz

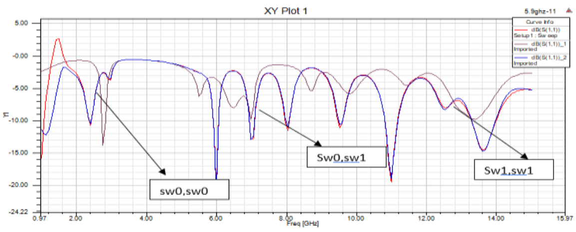

Figure 6.5. Return Loss at Various Switching Condition In

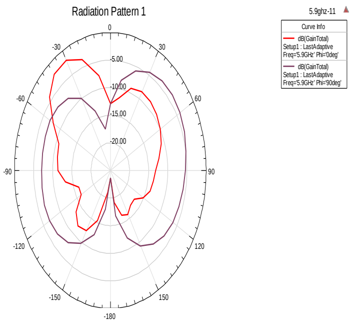

Figure 6.6. Radiation pattern at 5.9GHz

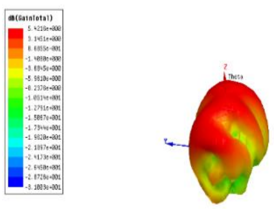

Figure 6.7. Maximum Gain at 5.9GHz

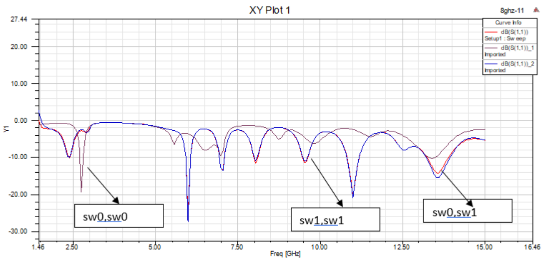

Figure 6.8. Return Loss at Various Switching Condition in 8GHz

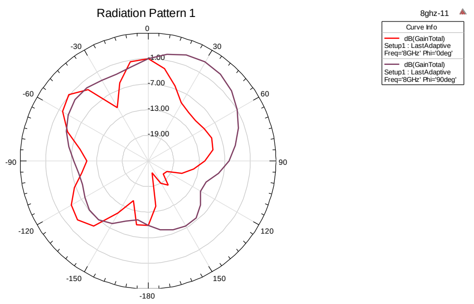

Figure 6.9. Maximum Radiation Pattern at 8GHz

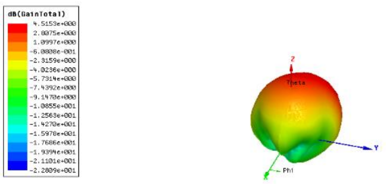

Figure 6.10. Maximum Gain in on-on Condition at 8GHz

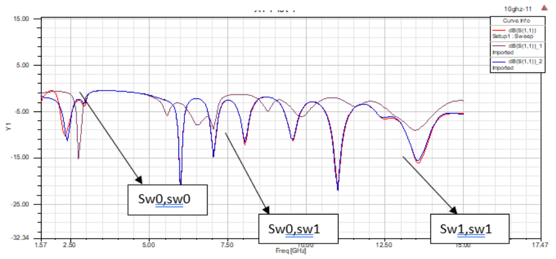

Figure 6.11. Return Loss at Various Switching Condition in 10GHz

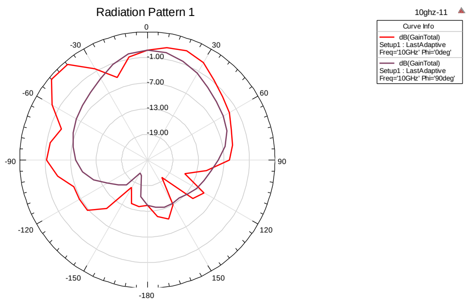

Figure 6.12. Maximum Radiation pattern at 10GHz

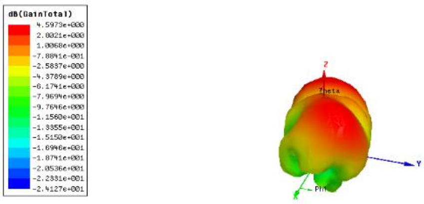

Figure 6.13. Maximum Gain at 10GHz

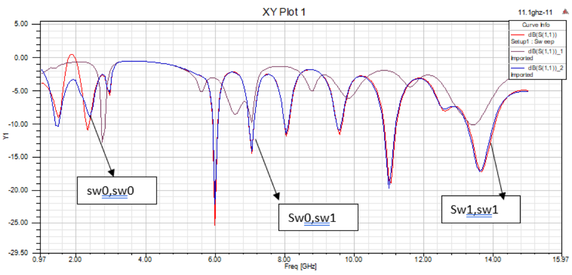

Figure 6.14. Return Loss at Various Switching Condition in 11.1GHz

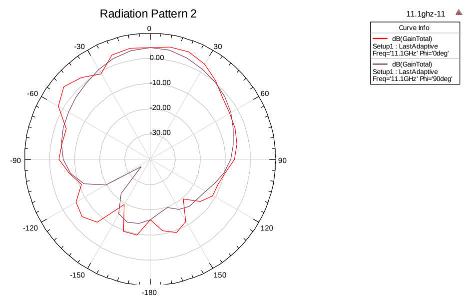

Figure 6.15. Maximum Radiation pattern at 11.1GHz

Figure 6.16. Maximum Gain at 11.1GHz

The proposed antenna integrated RF-MEMS switch shown in figure 6.1.In this antenna RFMEMS switch is integrated on the array antenna , so there are four possible combination, off-off(00),off-on(01),on-on(11) respectively. From the summary of table 6.2 the characteristics of antenna integrated with MEMS switch is understood. The table 6.3 depicts the comparison of the existing antenna with respect to proposed work is.

Table 6.3. Comparison between Existing Antenna with Proposed Antenna.

Reference / Parameters	[10] ShahSAA, KhanMF.	[11] UllahS, HayatS.	[12] M.Lakshmu Naidu, P.Jhansi	**Proposed work**
dimension	35x40	40x40	200x100	47x29
Thickness of substrate	1.6	1.6	1.6	1.6
“substrate”	“Fr-4”	“Fr-4”	“Fr-4”	“Fr-4”
“Resonant frequency”	2.45,3.45,5.4	2.45,3.50,5.20	3.7,8.1,9.3,11.79	2.4,5.9,8,10,11.1
Return loss	-15,-17.56,-23.87	-20,-12,-18	-19.8,-20.36,-20.1662	-16.35,-18.91, -11.53,-22.57,-27.71
VSWR	0.87-1.93	0.97-1.63	1.19-1.26	1.34,1.9,1.16,0.71
Gain	1.85-3.45	1.7-8.4	8-8.85	2.06,5.42,4.68,9.64
Bandwidth (MHz)	500-1250	147-1820	427.2-1066	480 -1173
No.of.band	3	3	3	5

7. Conclusion

In this work proposed work to design MEMs switch, at 4500um length,2000um width, thickness at 35um and air gap is 608um and gold used as electrode material as a result by applying a pull in voltage at 1.738492mV to 57.7382mV the beam start bend at 0.6793mm to 0.4116mm which lead to change capacitance for 1.435pF to 1.597nf .

The “insertion loss of the S21 = -31.307 dB and return loss of S11= -0.256 dB” in the up state with improved switching features. At the integrating part a wideband microstrip patch antennas array is designed. The parametric study was conducted to examine the proposed antenna characteristics. In this proposed array the MEMS switch is integrated on the patch lead for achieving various switching condition to get stable radiation patterns, good impedance matching, and high gain. This array covers a range of 2.4GHz,5.9GHz,10GHz,11.1 GHz frequency this was determined by employing the of structural analysis result for describing CLR model of MEMS switch. The results depict that the expected outcomes are provided by the MEMS switch to overcome the existing defects.

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