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Reconfigurable Antenna Using Ohmic RF MEMS Switch

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***Abstract*—In the present work, reconfigurable antenna using MEMS switch is designed and fabricated. Simulation is done using the HFSS software and standard surface micromachining is used for the fabrication of the reconfigurable antenna. Two type of reconfigurable antenna has been designed, first is CPW feed based and second is microstrip line based. The presented reconfigurable antennas are frequency reconfigurable and operate within Ku band.**

Keywords—MEMS, Reconfigurable Antenna, SPST

I. INTRODUCTION

Reconfigurable antenna play vital role in the present market of wireless communication. Today, there exists different types of wireless communication systems e.g. GSM, CDMA, 3G, 4G, Bluetooth, Wi-Fi, LTE. All these types of communication system work in different operating frequencies [1-3]. From the user point of view, we want to integrate all these protocols in a single hand held device. If we use separate antenna for every set of protocols, the hand held device become too bulky and also difficult to fabricate.

The solution of such type of problem is to use a single antenna which is able to reconfigure in terms of operating frequency, polarization or radiation pattern. This can be achieved by simply doing changes in the size or geometry of patch, due to which there will be change in surface current and voltage distribution of the effective aperture of the antenna. Table 1 lists the dependence of operating frequency on substrate material and dimensions of patch.

There are various techniques available to change the size of the patch like using RF-MEMS switch, PIN diode, photoconductive elements or by changing the material properties and physically alter the size of patch. Table 2 shows the comparison of the characteristics of PIN diode, RF-MEMS and optical switch (photo conductive cell) when used for the reconfiguration of the antenna [3].

TABLE I. Operating frequency variation with dimension of patch and substrate material [4-9]

Sr. No.	Dimension of Patch	Material/ Permittivity	Operating Frequency
1	20 mm × 20 mm	ε_r =4.0	All band b/w 640 MHz & 5.85 GHz.
2	6 mm × 6 mm, 6 mm × 1.5mm	ε_r =2.1	12.5 GHz, 20.1 GHz
3	17 mm×17mm (8 Patches)	FR-4 ε_r =4.4	7.77 GHz, 4.91, 5.81, 9.79 GHz
4	3 mm × 3 mm	Silicon ε_r = 11.9	20.4695 to 23.1156 GHz
5	23.5mm × 9.8 mm	RO 4003 ε_r = 3.38	718 MHz & 4960 MHz
6	6.7 mm × 6 mm	Rogers4003C ε_r = 3.55	12.5 GHz 12.34 GHz
7	3 mm × 3 mm	Silicon ε_r = 11.9	22.1912, 22.0710, 21.8566 GHz
8	5 mm × 7 mm	Silicon ε_r = 11.9	16 GHz (Approx.)
9	1.6 mm ×1.3 mm	Silicon ε_r = 11.9	77 & 94 GHz
10	4.8 mm x 6.6 mm	Silicon ε_r = 11.9	17 to 19 GHz
11	1 cm × 1 cm	Quartz ε_r = 3.78	18 to 21 GHz

RF-MEMS Switch is one of the best alternatives over the conventional PIN diode. The main advantage of the RF-MEMS switches are the direct integration with the substrate. It also offers very high isolation and low insertion loss and also consume less power in comparison with PIN diode or Optical switch. These characteristics make it suitable candidate for use in reconfigurable antenna.

TABLE II. Comparison of Characteristics of PIN Diode, RF-MEMS Switch & Optical Switch

Properties	**RF MEMS**	**PIN Diode**	**Optical Switch (Si)**
Voltage (V)	20-100	3-5	1.8-1.9
Current (mA)	0	3-20	0-87
Power Consumption (mW)	0.05-0.1	5-100	0-50
Switching Speed	1-200 µs	1-100 ns	3-9 µs
Isolation (1-10GHz)	Very High	High	High
Loss (1-10GHz)	0.05-0.2	0.3-1.2	0.5-1.5

The size of the patch is the function of dielectric constant and thickness of the substrate material [7]. If we use high dielectric constant and low thickness substrate material the size of the patch reduces drastically. Silicon offers very high dielectric constant around ε_r = 11.9 and the thickness of the substrate is around 275 to 280 µm. By using silicon, the patch size reduced drastically and it makes antenna suitable for hand held devices. Another advantage of using silicon as substrate is, its easy integration with the RF-MEMS Switch.

II. Proposed Design

In this work we designed a frequency reconfigurable antenna which is able to reconfigure within K band. Length and width of the patch antenna is the function of frequency of operation and the permittivity of the substrate material. To reduce the size of the patch, high permittivity silicon is selected as a substrate material for the reconfigurable patch antenna design. A schematic of the microstrip patch antenna is shown in the Fig. 1. Governing equations for the calculation of the dimensions of patch antenna are given in Eq. 1 and 2 [10].

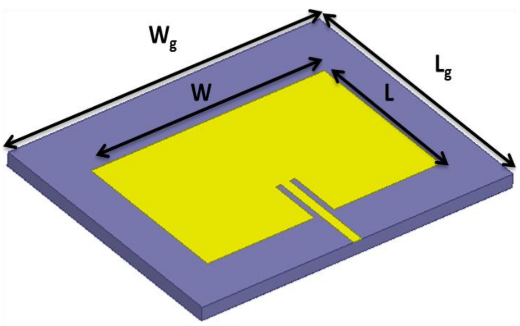

Fig.1. Schematic of microstrip patch antenna

Width and length of the patch is calculated by the following equations:

$$W = \frac{c}{2f_o\sqrt{\varepsilon_r+1}} \quad (1)$$

$$L = L_{eff} - 2\Delta L \quad (2)$$

where effective length (L_{eff}) and length extension (ΔL) is calculated by following equation

$$L_{eff} = \frac{c}{2 f_o \sqrt{\varepsilon_{reff}}}$$

$$\Delta L = 0.412h \frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

here, c is the speed of light, h is the height of the substrate, f_o is the frequency of operation, ε_r is the permittivity of the substrate and ε_{reff} is the effective permittivity of the substrate.

Length and width of the ground plain are given by the eq. 3 and 4.

$$L_g = 6h + L \quad (3)$$

$$W_g = 6h + W \quad (4)$$

where, L is the length of patch, W is the width of patch and h is the height of the substrate.

HFSS tool is used for the designing of the reconfigurable patch antenna. Optimized dimensions of the RPA are listed in the Table 3. High resistive silicon wafer is selected as a substrate material. Patch is made by gold with thickness of 2 µm. Two type of RPA are simulated first is with CPW feed and other is with microstrip feed line.

TABLE III. Dimensions of RPA

Microstrip feed RPA		
	Length (mm)	***Width(mm)***
Patch 1	3.60	6.00
Patch 2	0.80	6.00
MEMS Switch	0.40	0.20
Microstrip Line	2.24	0.22
CPW feed RPA		
Patch 1	3.52	4.80
Patch 2	0.80	4.80
MEMS Switch	0.40	0.20
CPW Line (Gap- 0.058 mm)	3.20	0.10

In the presented design equivalent of ohmic RF-MEMS switch is used to simulate and fabricate antenna. Fig. 2 shows the RF MEMS ohmic contact switch fabricated separately.

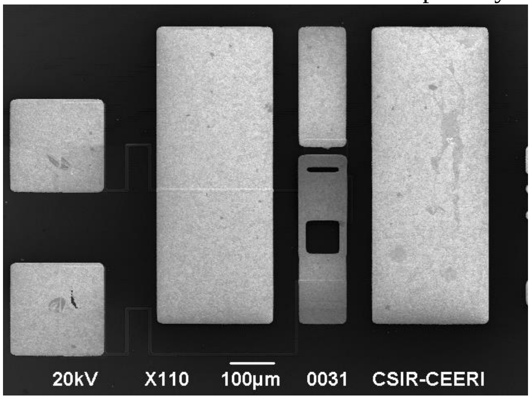

Fig.2. Schematic of microstrip patch antenna

III. FABRICATION OF RECONFIGURABLE ANTENNA

Surface micromachining is used for the fabrication of reconfigurable antenna. The fabrication process flow is shown in Fig. 3. High resistive (>5KΩ-cm) silicon wafer with orientation <100> and thickness of 275 µm is selected as a substrate material. Process starts with Radio Corporation of America (RCA) cleaning of the silicon substrate followed by growth of 1µm thick thermal oxide layer. Ti/Au seed layer of thickness 10/30 nm is deposited using dc sputtering. Ti is used as adhesion promoter. 2 µm thick gold patch is made by using a LIGA-like UV process. Thick electroplating compatible photoresist (AZ9260) is used for the patterning. A short plasma ashing (2 min at 300 watts RF Power) is carried out to make the gold surface electrophilic. Electroplating of the patch is done by using a transene electrolyte (TSG-250) gold plating solution. After gold electroplating, unwanted Au/Ti layer is removed by etching process by using selective chemical etchant.

IV. RESULTS AND DISCUSSION

SEM micrograph of fabricated microstrip and CPW fed reconfigurable antenna in ON and OFF state are shown in Fig. 4.

Frequency response of the CPW feed RPA antenna is measured with the help of Vector Network Analyzer (VNA) of Agilent Technologies shown in Fig. 5. Simulated response of CPW fed RPA is shown in Fig. 6. Resonating frequency in OFF and ON state are 12.80 GHz and 12.0 GHz and return loss are -17.86 dB and -14.15dB respectively. Measured frequency response for the same is shown in Fig. 7. A frequency shift is observed in the measured result because of impedance mismatch during measurement. Radiation pattern of simulated CPW feed RPA in OFF and ON state is shown in Fig. 8. In both ON and OFF state no major change is observed in the radiation pattern of the RPA.

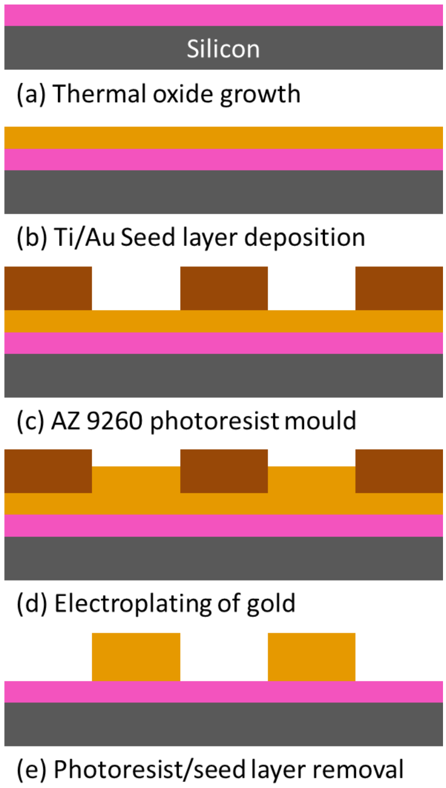

Fig.3. Fabrication process flow

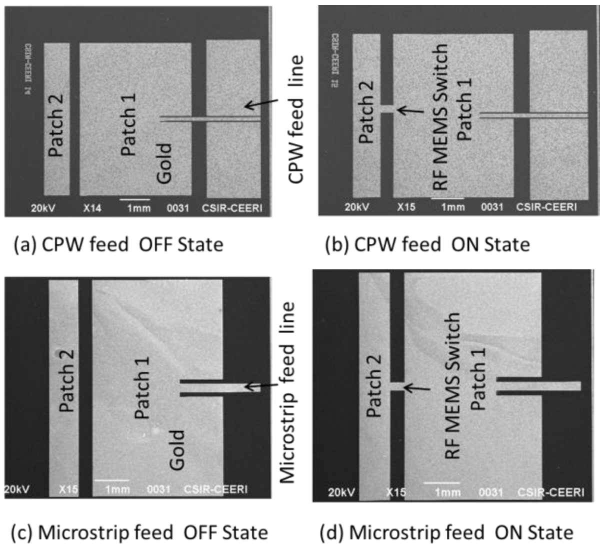

Fig.4. SEM micrograph of fabricated RPA

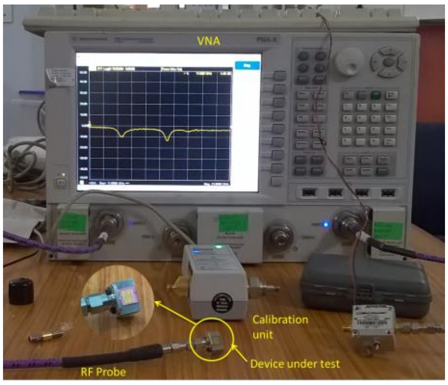

Fig.5. S11 response measurement through VNA

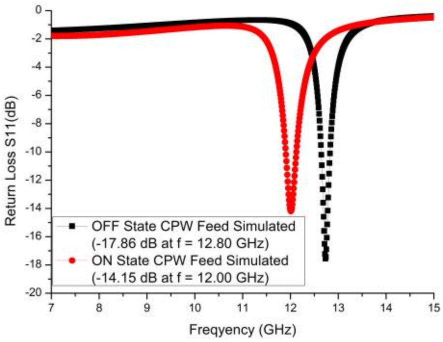

Fig.6. Simulated S11 parameter for CPW feed RPA

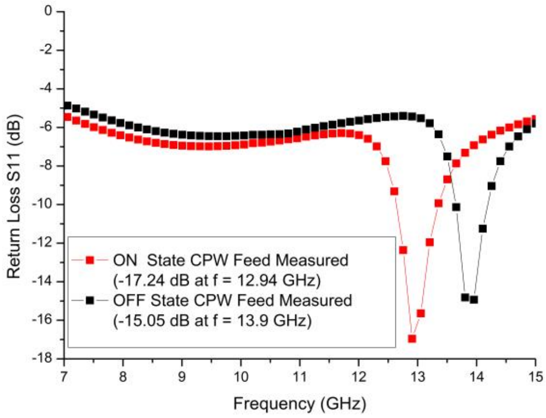

Fig.7. Measured S11 parameter for CPW feed RPA

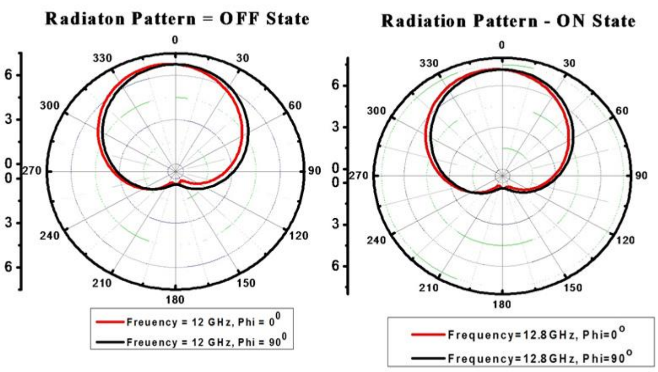

Fig.8. Radiation pattern of CPW feed antenna in ON and OFF state

Frequency response of the simulated microstrip feed RPA is shown in Fig. 9. Resonating frequencies in OFF and ON state are 12.50 GHz and 12.0 GHz

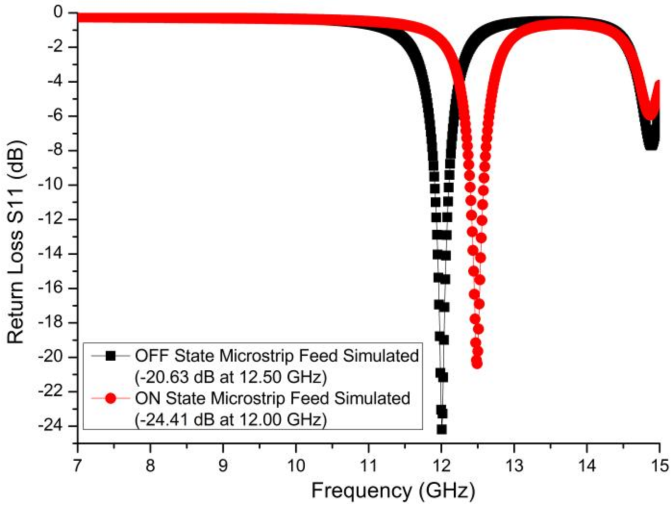

Fig.9. Simulated S11 parameter for microstrip feed RPA

V. CONCLUSION

In this paper two types of RPA are simulated and fabricated, first one is CPW feed line based and other is microstrip feed line based. A conductor line is used as an equivalent of ohmic RF MEMS switch to connect the two patches. Microstrip antenna is operating between 12 GHz and 12.5 GHz in OFF and ON state respectively. CPW fed antenna is operating between 12GHz and 12.8 GHz ON and OFF state respectively. Impedance mismatching during the measurement leads in shift in the measured response form simulated response.

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