Design of RF-MEMS Switch Integration with Circular Microstrip Patch Antenna

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Abstract

This paper presents the design and analysis of a microstrip circular patch antenna, integrated with the RF-MEMS capacitive type switch. Here, two different types of RF-MEMS (Radio frequency Micro-electromechanical systems) switches are proposed, one is a bridge-type and the other is a single-beam type switch. These two switches are designed and simulated by using FEM (Finite Element Model) tool, the pull-in voltages of the two switches are obtained as 1.9 V, 4.9 V. Both switches are integrated with the circular patch antenna and measure the device characteristics and analysed in HFSS (High Frequency Structure Simulator) tool. The work is focused on analysing the performance of circular micro strip patch antenna such as return loss, radiation pattern, gain, VSWR (voltage standing wave ratio) and bandwidth and compared the performances of both switches are in ON and OFF condition. The circular microstrip patch antenna with RF-MEMS switches are designed to achieve antenna re-configurability at low frequencies up to 15 GHz.

1 Introduction

Present days antennas are playing a crucial role in wireless communications because antennas convert electrical signals into electromagnetic waves and vice versa. The antenna improves the characteristics of its radiation, polarization, and frequency by changing its mechanical structure. Reconfigurable antennas are needed in radars and modern communication systems with the ability to emit more than one radiation pattern at different frequencies. Most reconfigurable antennas focus on changing the operating frequency while at the same time maintaining the characteristics of radiation. Antennas capable of operating on multiple wireless bands will be required later in radio and satellite communications systems [1]. Reconfigurable multiband antennas are a huge requirement in wireless applications because they operate at multiple frequencies. The research on circular microstrip patch antennas have seen great progress in recent years. Wireless antennas are often manufactured to meet current requirements in the field of communication technology, so there is an immense need for CPW power. Circular patch antennas with multiband functions, in reducing the design. Moreover, circular patch antennas are suitable for monolithic microwave integrated circuits and optoelectronic integrated circuits for their lightweight and low manufacturing and product quality [2]. Circular microstrip patch antennas are certainly appreciated for their design, performance of manufacture and growth of experience. The advantages of patch antennas must overcome their shortcomings, such as lightweight design applications in various fields like medical applications, satellites, and of course, even in military systems as well as in missiles, aircraft missiles, etc.

Circular patch antennas are widely attractive in all areas, now they are grown commercially due to cheap materials and cheap manufacturing [3–5], the use of patch antennas is also expected to increase. The ability to improve radiation patterns while sustaining operating frequency can

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significantly improve system performance. Antenna model manipulation can be used to avoid sources of noise or loose blocking, improve safety by sending signals to intend users only, use diversity as a switching system, and enhance beam steering capabilities with large cascade arrays. Reconfigurable antennas have been executed utilizing three major technologies, namely MEMS antennas, optical antennas, and holographic antennas, the latter two are similar, using light or some field damage to create the desired shape of the emitting structure. MEMS devices are ideal for reconfigurable antennas and network subsystems. [6–8]. The RF MEMS switch provides high isolation, low insertion, low power consumption, small footprint, and very low intermodulation distortion. MEMS antennas are more widespread due to their higher linearity and less signal distortion compared to semiconductor devices. MEMS devices give very low switching times and can be driven with resistive lines. It is assumed that any offset network for RF-MEMS switches will not interfere with and degrade antenna patterns [9–12]. The fact that the bias network does not consume power is an important advantage for large antenna arrays.

RF-MEMS switches are still moving towards extremely secure devices as they can replace more and more semiconductor devices for their improved performance in terms of low loss, high linearity, low power consumption, and compatibility between embedded designs. [13–16].

The paper is constructed as follows, Sect. 2 specifies the design of Circular microstrip patch antenna and RF- MEMS switches, and its specifications, dimensions of the proposed device. Section 3 illustrates results and discussions such as return loss, radiation pattern, 3-D plot, VSWR, gain, and bandwidth of the proposed device. Finally, Sect. 4 concludes the paper.

2 Proposed Device

2.1 Structure of Circular Micro-strip Patch Antenna

The CPW (coplanar waveguide) feed consists of both radiation patch and ground in the same plane, which makes integration with the electronic circuit components easy. The antenna is designed by using a transmission feeding technique. The proposed structure consists of a substrate 30 mm long and a circular patch loaded with a CPW. Here "S" is the distance between the stream and CPW, and "W" is the width of the transmission stream, as shown in Fig. 1. The substrate material is very important to improve the quality and performance of the antenna. The strip is used to feed the antenna and is attached to the edge of the patch. Antenna functionality depends on impedance matching, between the patch and the CPW feed, this method is easy to fabricate.
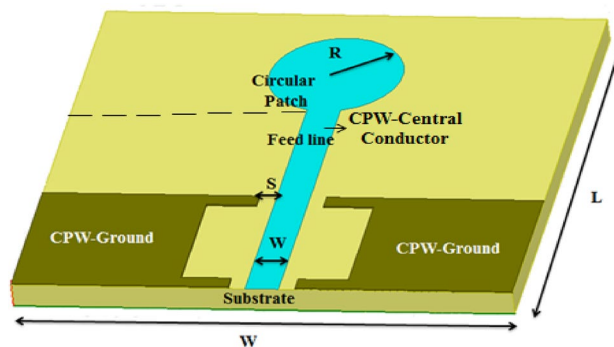

Fig. 1 The schematic view of Circular microstrip patch antenna

In this paper, we have designed the CPW feed, as it has low radiation losses, less dispersion, and uni-planar configuration. This also helps to increase the efficiency of the antenna and better front-to-back ratio.

Antenna miniaturization and bandwidth improvement can be achieved by cutting a slot in the ground and a patch of the CPW feeder antenna to a proper length, width, and by changing the antenna configuration. The analysis of the proposed device is based on the transmission of a circular patch antenna signal. They are attractive for low-profile applications above 100 MHz. The configuration of the variable antenna is based on the concept of coupling or splitting a resonant structure.

The length of the radiating element is calculated by using below formula,

$$L_{fr} = \frac{C}{4fr\sqrt{\in_{eff}}} \tag{1}$$

Here, the $\in_{eff}$ is written as

$$\in_{eff} \approx \frac{\in_r + 1}{2} + \frac{\in_r - 1}{2}\left(1 + 12\left(\frac{w}{h}\right)\right) - 0.5 \tag{2}$$

Here, 'w' and 'h' are the width, height of the substrate, '$\in_{eff}$' is the effective dielectric constant.

A circular strip is connected to the ground plane to observe the antenna reflectance response for all switching states. When the stub is connected to the ground the antenna will resonate with good impedance matching.

2.2 RF-MEMS Capacitive Type Switches

2.2.1 Model-1(Bridge Type Switch)

RF-MEMS switches are best suited for reconfigurable antenna selection due to their low power consumption and wideband response. Here, re-configurability is achieved through the use of RF-MEMS switches, and these switches either stimulate or disable circular patches using DC bias.

Here, the proposed antenna is simulated with RF-MEMS switches that have ON and OFF conditions [17–20].

Here the RF-MEMS switch consists of a substrate, CPW which means ground and signal or transmission line as shown in Fig. 2. The beam is fixed between anchors, the meanders and perforations on the beam help reduce the pull-in voltage and also increase the isolation of the switch, finally the actuation voltage of the proposed switch is 1.9 V.

2.2.2 Model-2 (Single Beam Type Switch)

Here, we have proposed a single beam-type RF-MEMS switch, it consists of meanders and perforations is shown in Fig. 3, by compared with a FET's and PIN diodes, RF-MEMS switches have better performance such as low power consumption, high linearity, good isolation, and low pull-in voltage. The operation of the shunt type switch is, by means of DC voltage control, it can be applied directly to the CPW central conductor. When voltage is applied, the electrostatic force pulls down the beam as it collapses on the dielectric, which creates a high capacitance between the ground and signal, and it will be a short circuit. When a continuous bias is not applied, the RF-MEMS switch is in UP state position, the antenna receives an RF signal for radiation, and exhibits the different radiation behavior from the previous condition. The pull-in voltage of the proposed switch is 4.9 V.

The pull-in voltage is calculated by using formula,

$$V_P = \sqrt{\frac{8Kg_0^3}{27\varepsilon_0 A}} \tag{3}$$

where 'ε_0' is permittivity of free space, 'K' is the spring constant, 'A' is actuated area and 'g_0' is the air gap between beam and signal dielectric [21].
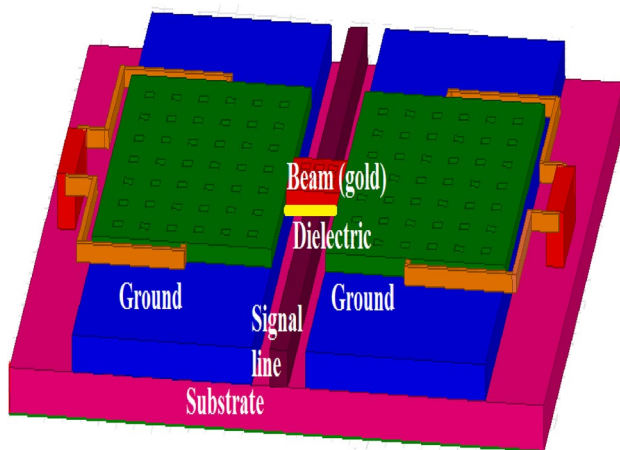
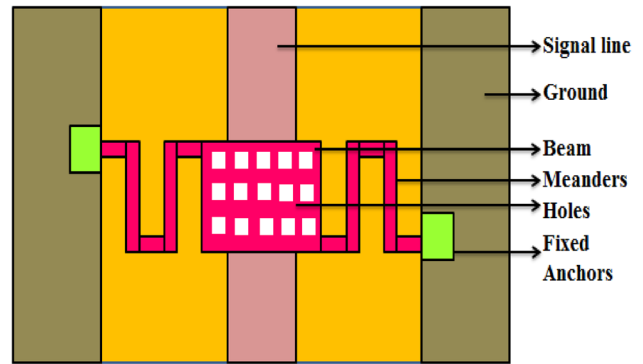The spring constant is calculated by

Fig. 3 The schematic view of RF-MEMS Single beam switch

$$K = \frac{Ewt^3}{l^3} \tag{4}$$

Here, 'E'—young's modulus, 'W'—width,' t'—thickness, and 'l'—the length of the beam.

Here, Fig. 4 shows the pull-in voltage simulations of the proposed capacitive type switches-1 and 2, by using the FEM Tool. Here the capacitive shunt type RF-MEMS switches are taken, as these switches have low power consumption, high linearity, and good isolation by comparing the PIN, FETs.

The capacitance analysis is a critical part for working of the switch, It is developed between the beam and signal dielectric.

The up state capacitance is calculated and simulated by the help of FEM tool, it is given as, [22]

$$c_u = \frac{\varepsilon_0 A}{g_0 + \frac{t_d}{\varepsilon_r}} \tag{5}$$

The beam and dielectric materials are taken as gold and silicon nitrite.

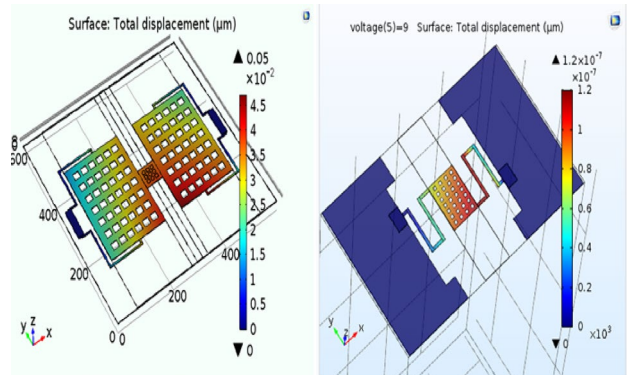**Fig. 2** 3D view of RF-MEMS bridge type switch

Fig. 4 Pull-in voltage simulations (voltage versus displacement) of proposed capacitive type switches-1 and 2

Theoretically the down state capacitance is calculated by

$$C_d = \frac{\varepsilon_0 \varepsilon_r A}{t_d} \qquad (6)$$

where, t_d is dielectric thickness, ε_0 is permittivity, 'A'- area, 'ε_r' is Relative permitivity of beam material, 'g_0'—gap.

The up and down state capacitance of two switches are 2.7 fF,4.47 pF and 1.27fF,6.72 pF respectively as shown in Fig. 5.

2.2.3 The Proposed RF MEMS Capacitive Shut Type Switches Integrated with Antenna

The characteristics of the antenna in the frequency adjustment phases verified when integrated with RF-MEMS switches. These two switches are integrated with the patch antenna and we have observed the characteristics such as gain, radiation pattern, bandwidth, and surface current distribution. The main principle of the device is by applying some DC voltage between the connecting antenna and transmission line, in that time the RF-MEMS switches are actuated, which leads to electrostatic performance moving on the beam. The proposed structure consists of a circular patch antenna with coplanar waveguide (CPW) having a silicon substrate.

Here, we have designed two types of RF-MEMS switches, one is a bridge-type switch, and another one is a single beam type switch as shown in below Figs. 6 and 7. These switches have meanders and perforations, to reduce the pull-in voltage and obtained good reconfigurability of the proposed antenna.

The RF-MEMS shunt type switches are incorporated at the center of the CPW feed, the gap between the CPW and transmission line is 0.1 mm. The switch-1 has a length of 10 mm and a width of 8 mm and switch-2 has the length and width of 8 mm, 5 mm with a thickness of 0.1 mm, by considering gold material which has a high thermal conductivity and Euler-young's modulus of 77 GPa due to which better performance is obtained.
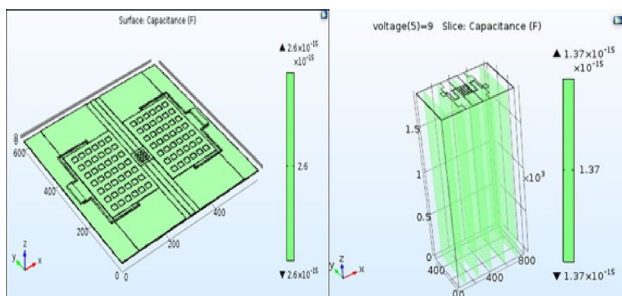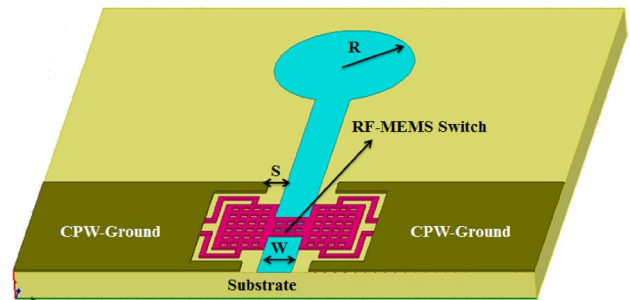

Fig. 6 3D view of bridge type (switch-1) is integrated with micro strip circular patch antenna

RF-MEMS switches have low miniaturization, less weight, low pull-in voltages. These two switches are integrated with the patch antenna and antenna characteristics such as gain, radiation pattern, bandwidth, and surface current distribution are observed. The operating frequency of the proposed device is obtained at 6–15 GHz. By comparing two RF-MEMS switches integrated with antenna, we have observed the performance, characteristics, and reconfigurability of the antenna [23–27]. Here, one of the main problems happens, if the integration of any semiconductor switch with integrating the reconfigurable antenna, the radiation characteristics are also changed. To overcome this problem, RF-MEMS switches can be used for switching operations because they do not require continuous polarization lines for operation.

2.2.4 The Dimensions of Proposed Antenna with RF-MEMS Switches

The device consists of CPW feed and a Circular microstrip patch. The RF-MEMS switch is integrated into the patch antenna by using the HFSS 15.0 tool. The dimensions of the proposed device are listed in the below Table 1.
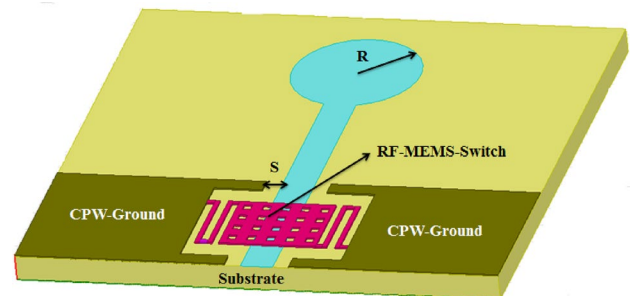

Fig. 5 Capacitance analysis of both switches

Fig. 7 3D view of single beam (switch-2) is integrated with patch antenna

Table 1 Specifications of the Proposed device

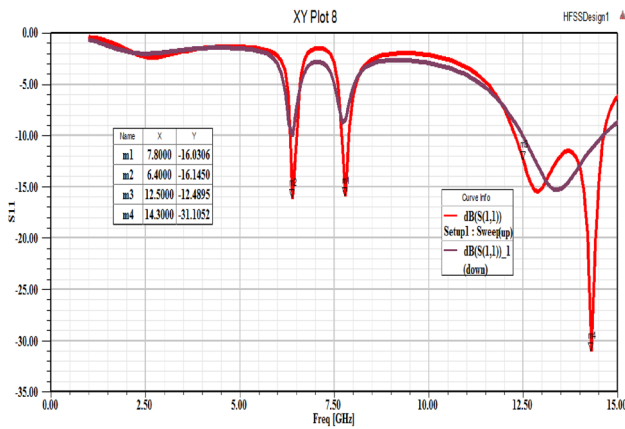| Sl. No.	Structural component	Length (mm)	Breadth (mm)	Height (mm)	Material
1	Substrate	30	30	1	Silicon
2	CPW	15	10	0.1	Gold
3	Switch-1	10	8	0.1	Gold
4	Switch-2	8	5	0.1	Gold
5	Transmission feed	20	2	1.5	Gold
6	Circular patch radius (R)	4	0.2	1.5	Gold
7	CPW gap (S)	0.1	–	–	–

Fig. 8 Return loss of antenna with bridge type switch is in up and down state (switch-1)
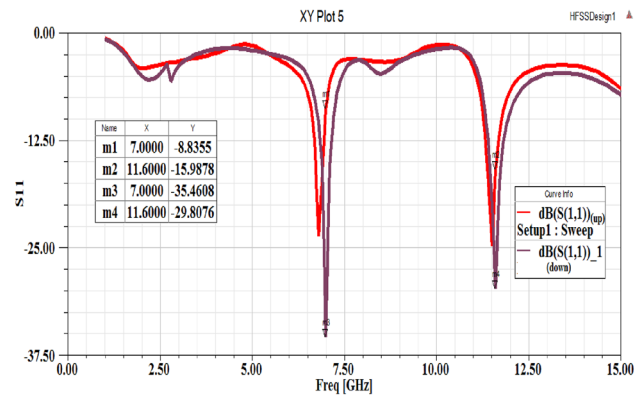

Fig. 9 Return loss of antenna with single beam switch is in up and down state (switch-2)

3 Results and Discussions

3.1 Return Loss of Proposed Antenna with RF-MEMS Capacitive Switches

The loss of power in the signal returned or reflected by a discontinuity in a transmission line, is normally expressed in decibels. It is indicated that as decibels (dB) [28].

The reflection coefficient (S_{11}) of the designed antenna in the ON and OFF states of switch 1 and 2 is shown in the below Figs. 8, 9. The figures shows the frequency versus reflection losses with and with-out switches, in this we have observed the shifting of the band shifted at low frequency up to 14 GHz. With an increase in the value of the length, the resonant frequency of the second band moves towards a lower frequency, while the impact on the primary resonance band is insignificant.

It is a measure frequently used in RF-circuits where impedance matching is necessary. It is the proportion of a signal that is displayed as an effect of an impedance mismatch.

The switches are in UP state position until there is no voltage applied in this direction, the RF power is transmitted through the patch. Figures 8, 9, 10 show the return
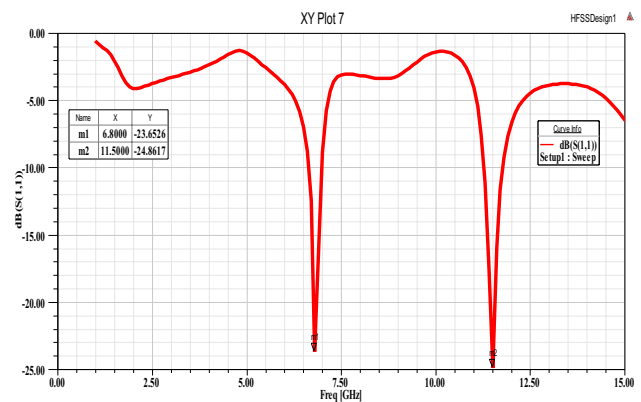

Fig. 10 Return loss of antenna without RF-MEMS switches

loss of the proposed antenna with RF-MEMS switches as 31.10 dB, 35.46 dB, and without switches the circular patch antenna measured the return as 23.65 dB from 6 to 14 GHz.

3.2 Radiation Pattern of Antenna with RF MEMS Switch-1 and Switch-2

The radiation pattern is the graphical design of the radiation characteristics of the antenna as a function of space.
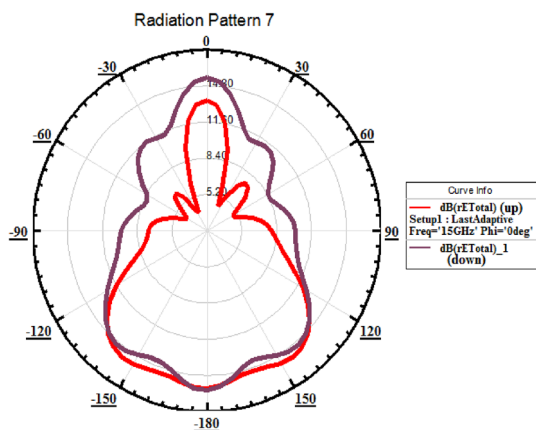
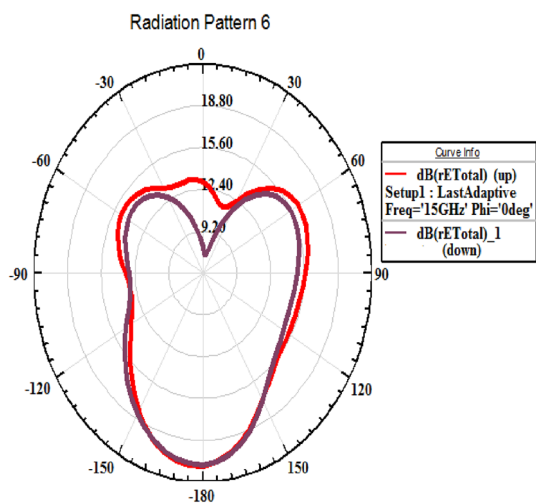**Fig. 11** Radiation pattern of Antenna with RF-MEMS switch-1 in up and down states

Fig. 13 Frequency verses VSWR plot of proposed antenna with RF-MEMS switch-1

Fig. 12 Radiation pattern of antenna with RF-MEMS switch-2 in up and down states

Fig. 14 Frequency verses VSWR of antenna with RF-MEMS switch-2

Which measures the antenna's pattern illustrates how the antenna radiates energy out into space. It refers to the directional dependence of the strength of the radio wave from antenna [29–31]. When both switches are actuated, the antenna shows a different radiation pattern as shown in below Figs. 11, 12. The proposed antenna with switch-2 is simulated and we have observed how the radiation pattern is shifted at the frequency, as shown in Fig. 11, it depends on the operating frequency of the antenna.

The radiation pattern was modelled and measured at phi 0° to 180° with three different cases. The main current content is present on switch-1, resulting in beam amplification in one direction by 90–180°. The time-varying ground plane current, the size and structure of the ground plane is an important factor in determining the impedance and radiation characteristics of an antenna.
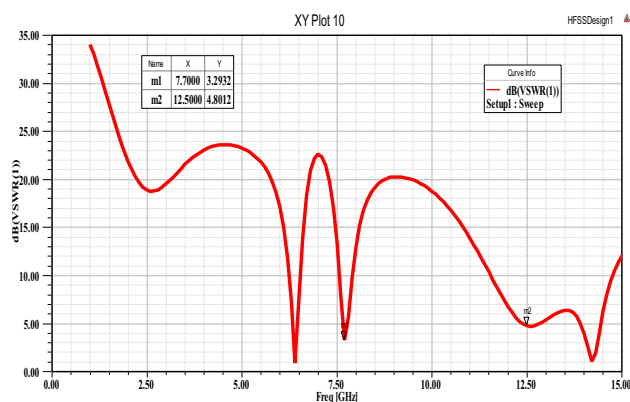
3.3 Band Width and VSWR of Antenna with RF-MEMS Switches

The antenna performance depends on the band width, it is defined as the variation of the input impedance of the antenna and the frequency range [28, 32–35]. The frequency bandwidth and the percentage bandwidth are calculated using the equation below.

$$f_H - f_L \tag{7}$$

$$\frac{f_H - f_L}{f_C} \times 100 \tag{8}$$

where 'f_H' and 'f_L' are higher and lower cut off frequency points on the curve of the return loss, f_C is the center frequency, which we have observed that peak of the resonance [20–23].

The VSWR is a measure of the impedance matching of the antenna with the transmission line, the below graphs Figs. 13, 14 shows the frequency versus VSWR. It describes

the power reflected by the antenna and we have measured the reflection coefficient is given as "Γ". It is nothing but return loss. The VSWR is defined as,

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \qquad (9)$$

3.4 Gain of Proposed Antenna with RF-MEMS Switches

It is described as, the ratio of energy transferred in the radiation peak region to that of an isotropic radiation source. The gain of the antenna is indicated above the directionality in the antenna specification because it offers initial losses [36–38]. The gain depends on the signals, which located wherever the signals come from the destination.

The simulation of proposed antenna gain while a function of frequency and under different states of two RF-MEMS switches as shown in below Fig. 15. From the different simulation results, we have observed the proposed antenna with RF-MEMS switches exhibit the maximum gain of 3.45 dB and 4.10 dB.

3.5 Directivity of the Proposed Antenna with RF-MEMS Switches-1 and 2

Directivity is one of the characteristics of the antenna radiation and the way of antenna radiation in a particular direction of the radiation pattern, it measures increasing the power density at a fixed distance from the transmitting antenna. Figure 16 shows the directivity of the proposed antenna with RF-MEMS switches at certain frequencies [24].

3.6 Surface Current Distribution of the Proposed Antenna with RF-MEMS Switches

The characteristics of a certain resonant frequency can be easily predicted from the surface current distribution. The
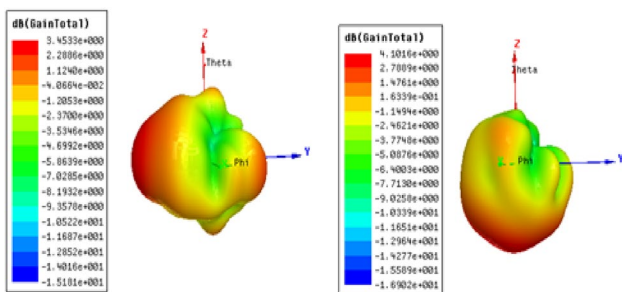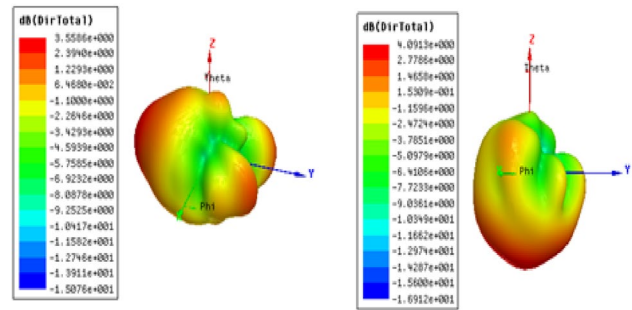

Fig. 16 Directivity of the antenna with both RF-MEMS shunt switches

electric current is applied and accelerates the charge around the antenna while the current distribution is generated.

Moreover it describes the performance of the proposed antenna, the surface current distributions at 8.0 GHz and 7.7 GHz are shown in the Fig. 17.

When the current distribution is high, the antenna gives a high gain and a high resistance of the magnetic field [39, 40]. It depends on the height of the substrate and the size of the antenna.

The Table 2 shows that simulation results such as return loss, gain, directivity, current directivity, a bandwidth of the proposed device.

4 Conclusion

In this paper we have presented design and simulation of a microstrip circular patch antenna, integrated with two RF-MEMS capacitive type switches. The main purpose of this paper is to measure the characteristics of the antenna with the RF-MEMS switch. Here, the pull-in voltages of two RF-MEMS switches are 1.9, 4.9 V, obtained through simulation using the FEM Tool. The return loss of the
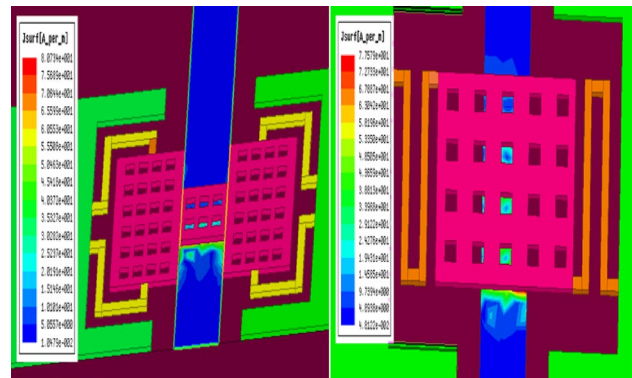

Fig. 15 Gain of proposed antenna with both RF-MEMS switches

Fig. 17 Current distribution of antenna with RF MEMS switch-1 and switch-2

Table 2 Comparison results of the proposed device with existing work

Propose device and reference work	Return loss (dB)	Gain (dB)	Directivity (dB)	Current directivity (GHz)	Bandwidth (GHz)	VSWR (dB)
Antenna with Bridge type switch-1	31.10	3.45	3.55	8.073	10	3.29
Antenna with Single beam type switch-2	35.46	4.10	4.09	7.757	15	1.36
Ref-[38]	24.6	6.3	–	–	30	1.12
Ref-[39]	–	2.50	–	–	–	–
Ref-[40]	–	2.63	–	–	–	–

proposed antenna with switch-1 and switch-2 is obtained as 31.10 dB, 35.46 dB, and without RF-MEMS switches, the return loss is measured as 23.86 dB. The gain of the circular patch antenna with switches is measured as 3.45 dB, 4.10 dB respectively, and the percentage of bandwidth obtained at 10 GHz, 15 GHz, and VSWR is 3.29 dB and 1.36 dB maintained at a 7 GHz frequency and the current distribution is radiated to 14 GHz. However, we have improved the characteristics of the antenna using different technologies known, by increasing the applicability of this patch antenna. Finally, in this paper, we used the CPW feed and two RF-MEMS switches are incorporated with a circular patch antenna and we have observed the different results. By comparing two RF-MEMS switches, the switch-2 (Single beam) integrated with the antenna was obtained the best results. Therefore, the proposed microstrip circular patch antenna is used for low-frequency applications (6–15 GHz) and wireless communications applications.

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