Frequency Reconfiguration of Microstrip Patch Antenna with Serpentine Spring Shaped RF MEMS Switch

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1. Introduction

The growth in the field of wireless communication drives the requirement of the reconfigurable antenna. The antennas are used in the receiver front ends to improve its performance at different operating frequencies [1]. Reconfigurable antennas have the capability of changing their radiation characteristics in an adaptive manner. This reconfigurability is widely used in wireless communication systems and in satellite applications to cover wide patterns which are suitable for the traffic change which is called as frequency tuning [2]. The existing current systems are not able to overcome these problems faced in the exponential increase in traffic. Antennas with MEMS switch exhibits multi-functionality such that each frequency bands are assigned to particular applications. The design of reconfigurable antennas started with the design of RF MEMS phase shifters. A simple wire type antenna can be used for multifunctional applications by making a change in the length of the antenna [3].

Several design approaches were established to design reconfigurable antennas. In a dipole antenna, the adjustments in the frequency of resonance can be achieved by making a change in the length of the antenna or by adding and subtracting t-lines through RF switches [4]. In slot antennas the RF switches are used in the slot gaps to make a change in the response and pattern of radiation for the antenna. The tuning of an antenna is done by varying the electrical length with the RF switches along the slot. In microstrip antennas, RF MEMS switches are placed at the radiation edge to produce reconfiguration in the antennas [5]. The RF switches in microstrip antennas make a connection with extra t-lines by lowering its resonant frequency. In aperture antenna, the patches in the metals are combined using RF MEMS switches. Reflection of antenna arrays is designed as reconfigurable antennas by introducing a phase shift at each point or by changing the length of each antenna element using RF MEMS switches. MEMS switches can be used with phase shifters with the combination of arrays to make different frequency systems and polarization MEMS switches can be used to make the antenna reconfigurable for low power applications by connecting them to antenna segments [6].

The microstrip antenna is implemented using printed circuit technology. Because of low profile on planar surfaces, they find their application in the field of aircraft and space applications [7, 9].

In this paper, the of reconfigurable patch antenna operating at three different frequencies is designed. The RF MEMS switch with serpentine cantilever beam is integrated between the slots in the patch antenna. The switch is operated at pull-in voltage of 4V and it produces excellent RF performance. The frequency reconfiguration of the antenna is carried out by varying the dimensions and position of the slot in the patch by making the switch to change between the OFF condition and ON condition.

2. Design of the proposed microstrip patch antenna

In the literature, various techniques were demonstrated for multiple frequencies antennas with the large width such as L-shaped patch, U-shaped patch, stacked patch, and E-shaped patch and also the use of fractals, parasitic elements, and genetic based antennas [10-13]. In this paper, an antenna with the hexagonal patch is given. The antenna is designed to resonate at four different frequencies. A U-shaped slot is made in the middle of the patch which produces multiple resonances in the frequency of the antenna.

The antenna is designed over an FR-4 substrate with the dimensions given in Fig.1. The thickness of the feed line is about 0.05mm. The hexagonal patch is designed on the substrate with a thickness of 0.05mm. The length and width of the patch is 10mm and 2.46mm respectively. A U-shaped slot is made at the centre of the patch. The ground plane is designed at the bottom of the substrate with 0.05mm thickness.

The reflection coefficient of the proposed patch antenna is given in Fig.2. It is observed that the antenna resonates at three different frequencies i.e., 9.2 GHz, 12.6 GHz and at 15.6 GHz. The radiation patterns of the proposed antenna at 9.2 GHz, 12.6 GHz and 15.6 GHz are given in Fig.3.
The gain and the total efficiency of the proposed antenna is given in the Figure 4. The antenna showed a gain of 4.6 dB at 9.2 GHz, 6.1 dB at 12.6 GHz and 6.3 dB at 15.6 GHz. The efficiency of the antenna is 80% at 9.2 GHz, 83% at 12.6 GHz and 83.5% at 15.6 GHz.

3. RF MEMS switch

The structure of the proposed RF MEMS switch is shown in Figure 5. RF MEMS switches are mostly employed in the field of wireless communication and also in many portable devices because of compactness and high performance. The main disadvantage of the MEMS switches is the amount of voltage required for its actuation and reliability. These issues are overcome by optimizing the design of the proposed switch by changing the structural designs of the switch. In this paper, a cantilever based RF MEMS switch which is modified in the shape of a serpentine spring is proposed. The switch optimized in terms of dimensions and structure. The proposed switch is a metal contact series switch with a cantilever beam as the membrane. The cantilever beam is modified in the form of a serpentine spring shaped beam. The folded suspension makes the switch to reduce the stress required at the anchor. The spring-shaped suspension of the switch produces good low spring constant reducing the amount of voltage. The switch is designed to operate in the frequency ranging from DC-12 GHz.
The variations in dimension of the cantilever beam with serpentine spring are described in the Figure 5. The switch is designed on the silicon substrate. The material used for making the cantilever beam is aluminium. The beam length of the switch is 350µm and the width of the switch is 200µm. The switch is mounted on coplanar waveguide (CPW) transmission line. The pull-in voltage is analyzed using the equation 1.

\[ v_{pi} = v \left( \frac{2}{5} g_0 \right) = \frac{8k g_0}{27 \varepsilon_0 A} \quad (1) \]

where \( v \) is the applied voltage, \( k \) denotes the spring constant, \( g_0 \) is the initial gap height made and \( A \) is the area of actuation.

The pull-in voltage is proportional to the spring constant of the switch. The spring constant of the beam is calculated at each bends in the serpentine structure. The number of bends in the cantilever beam reduces the spring constant ‘\( k \)’ of the switch. The total value of the spring constant considering the all the bends in the beam is calculated by the equation 2 [8].

\[ k_z = \left( \frac{8N^3 a^3 + 2Nb^3}{3E_1} \right) + \frac{2bN \left( 3b + (2N+1)(4N+1)a \right)}{3E_1} \]

\[ - \frac{Na^2 \left( \frac{2Nh}{E_1} \right) \left( \frac{nh}{E_1} \right) - \frac{Nh^3}{2E_1} \left( \frac{a}{E_1} + \frac{b}{E_1} \right) \right]^{-1} \quad (2) \]

where the number of bends in the beam is considered as \( N \) and \( a \) and \( b \) are the length and width of the bends in the beam.

The switches are designed using the Intellisuite software. The simulated results of the designed switch showing its pull-in analysis are given in Figure 6. The graphical variations in the displacement of the switch with the applied voltage are analyzed to calculate the pull-in voltage. It can be seen that the pull-in voltage is about 4 V. The switch was displaced to 0.0076 µm with the applied voltage as shown in Figure 7. The stress appeared at the anchor junction of the switch is 6.66MPa as in Figure 8.

The electromagnetic parameter of the switch shows a maximum isolation of -67.9dB at 12 GHz and insertion loss \( S_{21} \) of -0.094 dB at 12 GHz as shown in Figure 9.

4. Implementation of RF MEMS switch in Patch antenna

The designed patch antenna with the RF MEMS switch between the slots is shown in the Figure 10. The switch is placed between U-shaped-slot of the antenna. The switch is operated by a bias voltage between the ON state and OFF state. When the switch goes to the OFF state, the frequency of the antenna is switched to 12.6 GHz. When the switch is toggled OFF state the frequency of operation is switched to 9.2 GHz and 15.6 GHz as shown in the Figure 11.
Fig.10. Antenna integrated with RF MEMS switch

Fig.11. Reflection coefficient of the antenna when the switch is in OFF state and ON state.

5. Conclusion

A microstrip patch antenna was modeled to operate at three frequencies. RF switch with serpentine spring shape cantilever beam was designed to operate with 4V of pull-in voltage providing an isolation of -67.9 dB at 12 GHz with insertion loss of -0.094 dB at 12 GHz. The designed switch was implemented between gaps in the slot of the patch antenna. The toggling of the switch to OFF state made a frequency of resonant at 12.6 GHz. In ON state the frequency of operation was shifted to 9.2 GHz and 15.6 GHz.

References


Biography of the authors

R. Raman received B.E. degree in Electronics and Communication Engineering from Anna University, M.Tech degree in Electronics and Communication Engineering from Pondicherry University. He is pursuing his Ph.D. in the area of RF MEMS under the guidance of Dr.T.Shanmuganantham. He has 4 years of teaching experience at CK College of Engineering and Technology. His research interest includes RF MEMS and Antennas. He is a life member of ISTE.

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