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

R. Raman[1] and T. Shanmuganantham[1]*
[1] *Department of Electronics Engineering, Pondicherry University, Puducherry*
[*] *shanmuga.dee@pondiuni.edu.in*

Abstract. In this paper, a reconfigurable microstrip patch antenna with RF MEMS switch providing frequency reconfiguration is presented. This paper gives a brief account on the methodology of designing an antenna changing its frequency using RF MEMS switches. By implementing RF MEMS switch in the slot of a patch antenna achieves to make a change in the frequency of the antenna by switch action. The proposed design is analyzed in the frequency from 2 to 20 GHz. RF MEMS switch with serpentine cantilever beam is implemented with the design to make a switching in the frequency response of the antenna. The switch is designed with an isolation of −67.9 dB at 12 GHz. The insertion loss of the switch is −0.094 dB at 12 GHz. The antenna is designed to resonate at three different frequencies. The frequency reconfiguration of the antenna is analyzed by changing the state of the switch implemented in the antenna.

Keywords: Reconfigurable antennas, RF MEMS switch, cantilever beam, isolation, frequency response.

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 the low profile on planar surfaces, they find their application in the field of aircraft and space applications [7, 9].

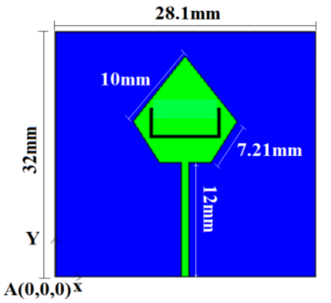
In this paper, the of reconfigurable patch antenna operating at three different frequencies is designed. The RF MEMS switch with serpentine cantilever beam is integrated between the slots in the patch antenna. The switch is operated at pull-in voltage of 4V and it produces excellent RF performance. The 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

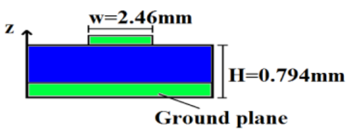
In the literature, various techniques were demonstrated for multiple frequencies antennas with the large width such as L-shaped patch, U-shaped patch, stacked patch, and E-shaped patch and also the use of fractals, parasitic elements, and genetic based antennas [10-13]. In this paper, an antenna with 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.



(a) Front View



(b) Side View

Fig.1. Schematics of the microstrip patch antenna.

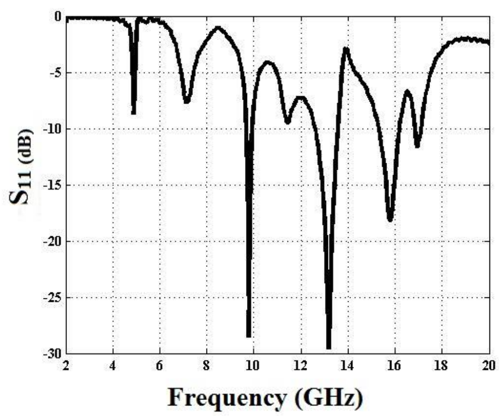
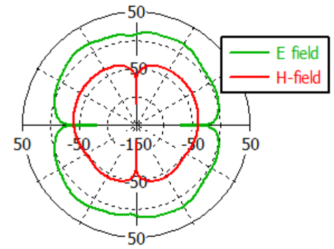


Fig.2. Reflection coefficeint of the proposed antenna design

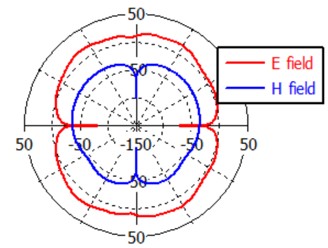
The gain and the total efficiency of the proposed antenna is given in the Figure 4. The antenna showed a gain of 4.6 dB at 9.2 GHz, 6.1 dB at 12.6 GHz and 6.3 dB at 15.6 GHz. The efficiency of the antenna is 80% at 9.2 GHz, 83% at 12.6 GHz and 83.5% at 15.6 GHz.

3. RF MEMS switch

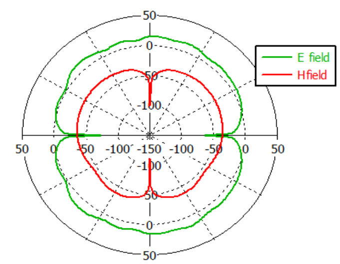
The structure of the proposed RF MEMS switch is shown in Figure 5. RF MEMS switches are mostly employed in the field of wireless communication and also in many portable devices because of compactness and high performance. The main disadvantage of the MEMS switches is the amount of voltage required for 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.



(a)



(b)



(c)

Fig.3. Radiation patterns of the proposed antenna
a) 9.2 GHz b) 12.6 GHz c) 15.6 GHz

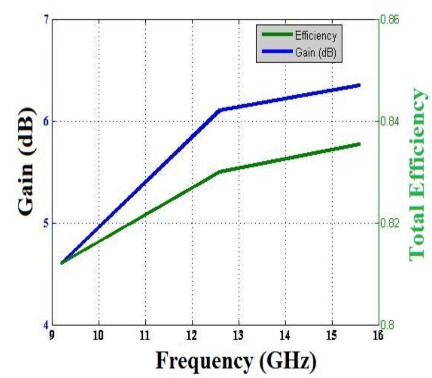
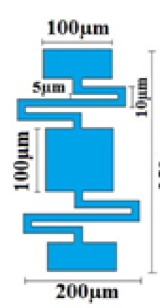
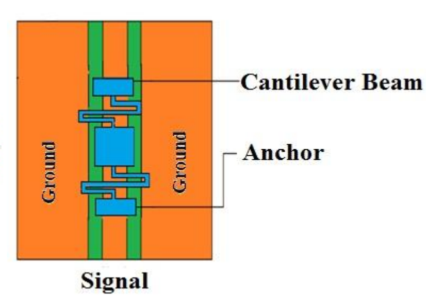


Fig.4. Gain and Efficiency of the proposed antenna





(a) (b)

Fig.5. Structure of proposed RF MEMS switch
a) Serpentine beam b) Switch on a CPW transmission line

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.

$$v_{pi} = v\left(\frac{2}{3}g_0\right) = \sqrt{\frac{8kg_0}{27e_0A}} \qquad (1)$$

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].

$$k_z = \left[\frac{(8N^3a^3)+2Nb^3}{3EI_x} + \frac{abN\,[3b+(2N+1)(4N+1)a]}{3GJ} - \frac{Na^2\left[\left(\frac{2Na}{EI_x}\right)+\frac{(2N+1)b}{GJ}\right]^2}{2\left(\frac{a}{EI_x}+\frac{b}{GJ}\right)} - \frac{Nb^3}{2}\left(\frac{a}{GJ}+\frac{b}{EI_x}\right)\right]^{-1} \qquad (2)$$

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.

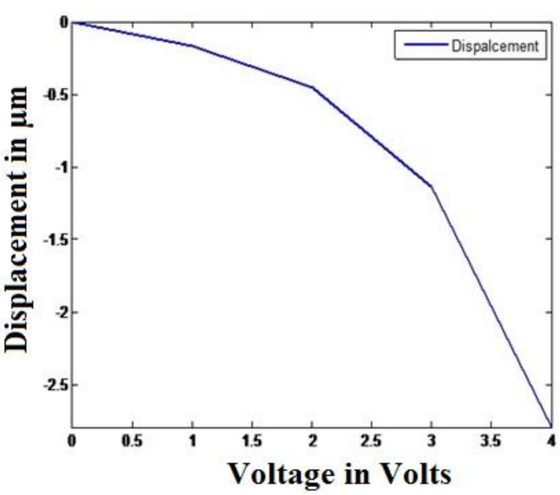


Fig.6. Pull-in analysis of the switch

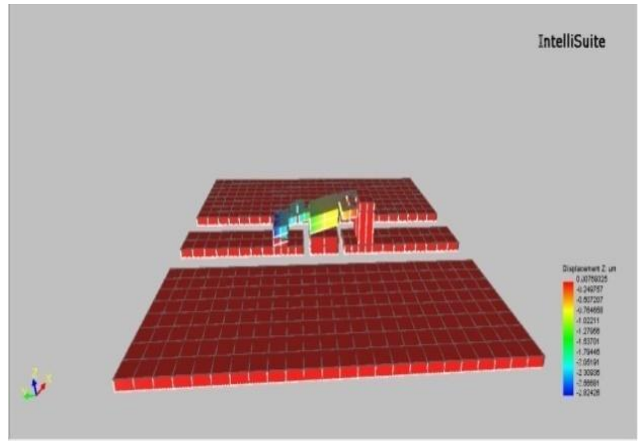


Fig.7. Displacement made by the switch

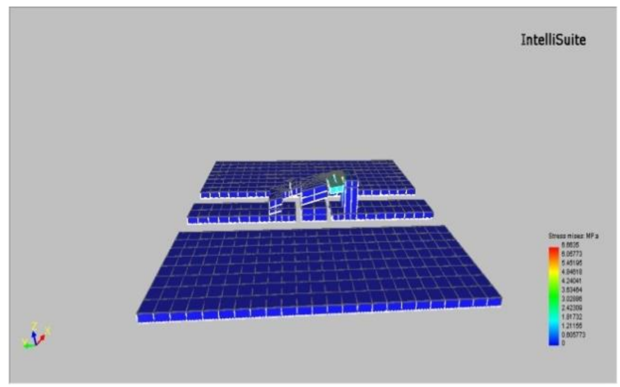


Fig.8. Analysis of the stress at the anchor.

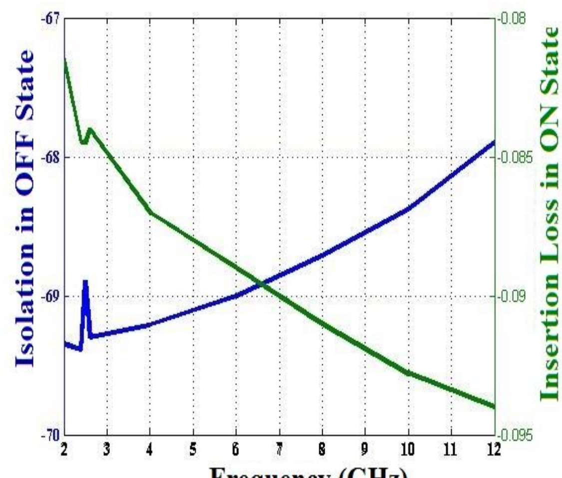


Fig.9. Isolation S_{21} and Insertion loss S_{21} when the switch is in OFF-state and ON-state, respectively

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.

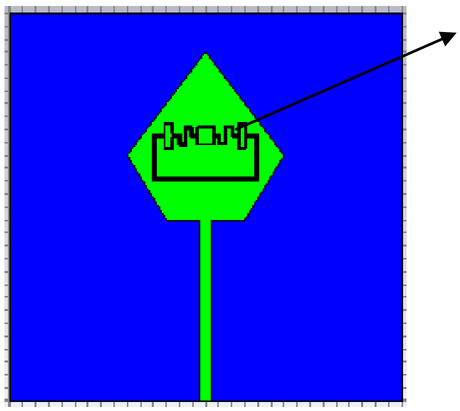


Fig.10. Antenna integrated with RF MEMS switch

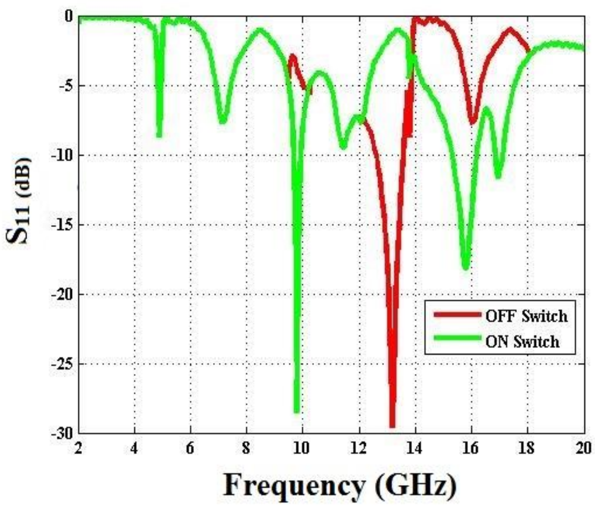


Fig.11. Reflection coefficient of the antenna when the switch is in OFF-state and ON state.

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

[1] R. Broawn, RF-MEMS switches for reconfigurable IC's, *IEEE Transactions on Microwave Theory and Techniques*, Vol. 46, No. 11, pp. 1868-1880, 1998.

[2] S. A. Syed, Reconfigurable broadband microstrip antenna fed by a coplanar waveguide, *Progress in Electromagnetic Research* ,55, pp. 227–239, 2005.

[3] I. Kim and Y. Rahmat-Samy, RF MEMS switchablity in slot patch antenna integrated with bias network, *IEEE Transaction on Antennas and Propagation*, vol. 59, no. 12, 2011.

[4] J. M. Kovitz, H. Raja, and Y. Rahmat-Samy, Practical and cost-effective bias line implementations for reconfigurable antennas, *IEEE Antennas and Wireless Propagation Letters*, vol. 11, 2012.

[5] T. J. Junk, I.-J. Hyeon, C. –W. Baek, and S. Lim, Circular and linear polarization in reconfigurable antenna on simplified RF-MEMS packaging in K-band, *IEEE Transaction on Antennas and Propagation*, vol. 60, no. 11, 2012.

[6] C.–Y. Chiu, J. Li, S. Song, and R.D. Murch, Frequency-reconfigurable pixelable slot antenna", *IEEE Transaction on Antennas and Propagation*, vol. 60, no. 10, 2012.

[7] A. Zohur, H. Mopidevi, , D. Rodrigo, M. Unlu, L. Jofre, and Bedri A. Cetiner, RF MEMS reconfigurable two-band antenna" *IEEE Antennas and Wireless Propagation Letters*, vol. 12, 2013.

[8] V. Kolte, P. M. Mahajan, Design and analysis of non-uniform shaped RF MEMS switch", *J Comput Electron 13:547–554 Springer Science Media* New York 2014.

[9] H. Zareie, and G. M. Rebeiz, Compact high-power SPST and SP4T RF MEMS metal-contact switches, *IEEE Transactions on Microwave Theory and Techniques*, vol. 62, No. 2, February 2014.

[10] C. Puente, J. Anguera, C. Borja, and J. Soler, Fractal-shaped antennas and their application to GSM 900/1800, *The Journal of the Institution of British Telecommunications Engineers*, vol.2, Part 3, July-Set. 2001.

[11] J. Anguera, C. Puente, and C. Borja, Dual frequency broadband microstrip antenna with a reactive loading and stacked elements, *Progress In Electromagnetics Research Letters*, vol. 10, pp. 1-10, 2009.

[12] J. Anguera, C. Puente, and C. Borja, A procedure to design wide-band electromagnetically-coupled stacked microstrip antennas based on a simple network model". *IEEE Antennas and Propagation Society*, 1999.

[13] J. M. J. W. Jayasinghe, J. Anguera, and D.N. Uduwawala, "A simple design of multi band microstrip patch antennas robust to fabrication tolerances for GSM, UMTS, LTE, and Bluetooth applications by using genetic algorithm optimization," Progress In Electromagnetics Research M, Vol. 27, pp. 255-269, 2012.

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.

T. Shanmuganantham received B.E. degree in Electronics and Communication Engineering from the University of Madras, M.E. degree in Communication Systems from Madurai Kamaraj University and Ph.D. (Gold Medal) in the area of Antennas from National Institute of Technology, Tiruchirappalli, India under the guidance of Dr.S.Raghavan. He has 19 years of teaching experience in various reputed Engineering colleges such as SSN College of Engineering, National Institute of Technology and Science. Presently he is working as Assistant Professor in the Department of Electronics Engineering, School of Engineering and Technology, Pondicherry University, Pondicherry. His research interest includes Microwave/Millimeter-Wave Circuits and Devices, Microwave Integrated Circuits, Antennas. He has published 210 research papers in various national and International level Journals and Conferences. He is a member of IEEE, Life Member of IETE, Institution of Engineers, CSI, Society of EMC, OSI, ILA, ISI, and ISTE.