International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Frequency Reconfigurable Microstrip Patch Antenna for Multiband Applications with RF MEMS Shunt Capacitor Switch

J. Navarajan*[1], Dr. M. R. Ebenezar Jebarani[2], Dr. V. Gokula Krishnan[3]

Submitted: 01/11/2022 **Revised**: 10/01/2023 **Accepted:** 03/02/2023

Abstract: The wireless communication systems are playing a significant role in the communication system. The requirement of wireless communication system is increased based on the day-by-day usage. The antenna is the most important device for the wireless communication and the necessity of designing the good antenna for the wireless communication system is increased. Therefore, the proposed work is developed a ultrawideband antenna with reconfiguring the frequency to enhance the performance of the antenna. Here, the frequency reconfigurable microstrip patch antenna is proposed and the frequency is tuned by utilizing RF MEMS shunt capacitor switch. The proposed antenna is designed with two reconfigurable switches and the antenna design is validated by three switching conditions such as ON-ON, ON-OFF, and OFF-OFF. The evaluation of the proposed frequency reconfigurable antenna is executed on the basis of antenna performance metrics such as Return loss, Bandwidth, Gain, Radiation pattern, and VSWR. The simulation results are demonstrating that the proposed frequency reconfigurable microstrip patch antenna with RF MEMS shunt capacitor switch is performed efficiently and this antenna is most suitable for the wireless communication system.

Keywords: *Frequency Reconfigurable Antenna, Micro-Strip Patch Antenna, RF MEMS, Shunt Capacitor, Ultra Wideband, Wireless Communication System.*

1. Introduction

The communication system has gradually developed from wired to wireless communication system which was designed by G. Marconi at the year of 1901 that was effectively received and sent the radio frequencies. This wireless communication system is more advanced and has made a radical transform in the day life of humans with the utilization of wireless equipment [1].
This wireless technology contains the daily life devices such as global positioning system (GPS), laptops, mobile phones, FM radios, radio-frequency identification (RFID) systems, satellite phones and receivers, etc. The wireless communication system contains receiver, medium and transmitter. In here, the antennas are playing a significant role as equipment for transmitting and receiving the radio frequencies in an efficient way [2]. Therefore, the design of antenna is most important for attaining good antenna with effective performance. The antennas are designed by utilizing the maxwell equations which was developed by J.C. Maxwell who integrated the magnetism and electricity. If the design of the antenna is not appropriate, the designed antenna won't perform well and the efficiency of the antenna is also collapse [3]. There are several types of antennas are existed in the past few decades. Due to the simple of design and low-profile nature, the printed antennas are widely utilized for the wireless communication system and it is also easily adopted with the corresponding electronics. These printed antennas are basically manufacturing by utilizing the printed circuit technology [4]. There are some printed type antennas are commonly preferred for the wireless communication system and they are named as slot antennas, planar inverted F-shaped antennas (PIFA), loop antennas, printed dipoles and monopoles, and microstrip patch antennas (MPAs).

Generally, the microstrip patch antennas utilized for the wireless communication because of it is easy for manufacturing and designing. The theory of the microstrip patch antenna is also developed in the recent years. In this antenna three main parts are playing a significant role and they are Patch, substrate, and ground plane [5]. Patch and ground planes are made by the similar materials like copper and the substrate materials are selecting by their application and requirement of dielectric constant value. The arrangement of the microstrip patch antenna is placed the patch over the substrate and the ground plane is placed under the substrate. Furthermore, this antenna can able to design in different shapes such as rectangular and circular which are the commonly utilized shapes for the wireless communication due to its simplicity in design [6]. The microstrip patch antenna has some advantages compare to other antennas and they are, (i) the theory of microstrip patch antennas is well known that is making the design part to simple and they are widely utilized, (ii) Due to its simple design, they can manufacture in easier and they easily connect with the electronic equipment, (iii) For manufacturing the microstrip patch antenna, the low-cost substrate can also utilize to reduce the cost, and (iv) These

1 Research Scholar, School of Electrical and Electronics Engineering, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India.
2 Associate Professor, School of Electricaal and Electronics Engineering, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India.
3 Professor, Department of CSE, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Thandalam, Chennai, Tamil Nadu, India.
ORCID ID : 0000-0002-3913-3156
** Corresponding Author Email: navarajansathphd@gmail.com*

antennas have low-profile and rugged in appearance, therefore they are widely utilized for the real-time devices such as personal digital assistance (PDAs), GPS receivers, etc. [7]. For the wireless communication system, one of the best preferable antennas is Ultra-wideband or multi band antennas.

The economical process of ultra-wideband antenna was approved by Federal communication commission (FCC) at the year of 2002. The ultra-wideband antenna designs are commonly maintained between 3.1 to 10.6 GHz and it has been frequently developed [8]. These antennas are effectively performed for the low profile, manufacturing in low cost, and impedance matching which are mostly attracted by the industries of telecom. Furthermore, these antennas can able to afford efficient communication system in short-range with high-speed. Still, the ultra-wideband antenna contains bands with the current standard licensed for the wireless communication system [9]. Here, the potential malfunction or unwanted interferences are caused by these sub bands because the electromagnetic interference (EMI) is reached over the ultra-wideband system. Therefore, several band notch characteristics such as quadric, triple, dual, and single are implemented to rectify the electromagnetic interference (EMI) problems. Single band antennas are widely utilized for the ultra-wideband antennas where the design is simple and it consume minimum cost for the manufacturing [10]. Normally, the performance of the antennas is validated by utilizing the evaluation parameters such as Return loss, VSWR, Gain, Radiation pattern, Bandwidth, etc. These evaluation parameters are enhanced by utilizing the reconfigurable techniques which are focusing on controlling and enhancing the output of the antennas. Reconfigurable techniques have several types and they are named as frequency reconfiguration, Radiation pattern reconfiguration, polarization reconfiguration, and compound reconfiguration [11]. From these techniques, the frequency reconfigurable technique is performed effectively on antennas and the complexity of the process is very low compare to the other reconfigurable techniques.

In the new communication era, the demand of frequency reconfigurable antennas is increased in the platform of wireless communication because it can able to provide multifunctional and flexible for sensing the frequencies for wireless communication system. The frequency reconfigurable antenna contains frequently switchable, tunable or bouncing the resonance frequency [12]. Here, the frequency bouncing technology is mostly helpful for the anti-interference in the wireless communication system, for instance the military communication systems are utilizing this frequency bouncing technology for the security purpose. In the past decades, there are several switch types are utilized for reconfiguration the frequencies and they are MEMS switch, semiconductor diodes, liquid metals and other materials. Generally, the RF MEMS switch or PIN diodes are utilized for the reconfiguration of frequency by redirect the surface current of the antenna [13]. Mostly, the large frequency signals are controlled with the help of PIN diode by utilizing the low DC voltage. Still, they require high power for the process and obtaining low RF characteristics. Compare to the PIN diodes, the RF MEMS switches are performed well and they can able to attain high isolation and very low insertion loss with low power consumed. Furthermore, they are light weight and very compact compare to the PIN diodes [14]. To enhance the power factors of the RF MEMS switch, the shunt capacitor is playing an important role in the wireless communication systems. The requirement of high-performance antennas is increased in the recent years. Therefore, the presented work concentrating to provide novel frequency reconfigurable microstrip patch antenna by utilizing MEMS shunt capacitor switch.

2. Proposed Design and Configurations

The basic of the proposed antenna design is based on the microstrip patch antenna and here the frequency is reconfigured by utilizing the MEMS shunt capacitor switch. The basic microstrip patch antenna contains some main parts such as patch, substrate, ground plane, and feed line. These parts are designed by utilizing the Maxwell equations. The proposed work utilizing the substrate material as FR4-epoxy which has the dielectric constant value of 4.4 and the thickness of the substrate is taken as 1.6 mm. The input frequency which is also known as resonance frequency is taken as 3.5 GHz that is most preferable for the ultra-wideband antennas. The basic equations which are utilizing for calculating the designing parameters for the microstrip patch antenna is given below,

Patch Width

The patch width is estimated by implementing the below equation,

$$Wp = \frac{c}{2f_{rs}\sqrt{\frac{(\varepsilon_{rs}+1)}{2}}} \tag{1}$$

Here, the patch width is represented by Wp, the resonance frequency of the proposed antennas is represented by f_{rs}, the dielectric constant value is represented by ε_{rs}, and the c is representing the light's speed which has the constant value of 3×10^8.

Patch length

The actual patch length is estimated by applying the following equation,

$$Lp = LP_{eff} - 2\Delta Lp \tag{2}$$

Here, Lp is denoting the actual patch length, LP_{eff} denotes the effective patch length, and ΔLp is denoting the extension of patch length. The equations for estimating the effective patch length LP_{eff} and extension patch length ΔLp are given below,

$$Lp_{eff} = \frac{c}{2f_{rs}\sqrt{\varepsilon_{rseff}}} \tag{3}$$

$$\Delta Lp = 0.412h\frac{(\varepsilon_{rseff}+0.3)\left(\frac{Wp}{h}+0.264\right)}{(\varepsilon_{rseff}-0.258)\left(\frac{Wp}{h}+0.8\right)} \tag{4}$$

Here, the thickness of the patch is represented by h and the effective dielectric constant is denoted as ε_{rseff} which is estimated by utilizing the below equation,

$$\varepsilon_{rseff} = \frac{\varepsilon_{rs}+1}{2} + \frac{\varepsilon_{rs}-1}{2}\left[1+12\frac{h}{Wp}\right]^{-1/2} \tag{5}$$

Feed line length and width

The feed line length and width are depending on the impedance value and here the impedance value is taken as 50 **Ω**. The following equation is utilized to estimate the feed line length,

$$Lf = \frac{1}{4}\lambda_g \tag{6}$$

Here, the feed line length is denoted by Lf and λ_g is denoting the guided wavelength which is estimating by utilizing the following equation,

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{rseff}}} \tag{7}$$

Here, the wavelength of the frequency is denoted by λ which is estimated by utilizing the following equation,

$$\lambda = \frac{c}{f_{rs}} \tag{8}$$

The following equation is utilizing to estimate the feed line width,

$$Wf = \frac{7.48 \times h}{e^{\left(Z_0 \frac{\sqrt{\varepsilon_{rs}+1.41}}{87}\right)}} - 1.25 \times t \tag{9}$$

Here, the feed line width is represented by Wf, the impedance value is represented by Z_0, and the trace thickness is denoted as t which is taken as 0.0175 mm for the proposed work.

Substrate length and width

The following equation is utilizing for estimating the substrate length,

$$Ls = 6h + Lp \tag{10}$$

Here, the substrate length is represented by Ls and the substrate width is estimated by implementing the below equation,

$$Ws = 6h + Wp \tag{11}$$

Here, the substrate width is denoted by Ws. The ground plane length and width are taken as the values which are obtained from the Substrate length and width respectively. The obtained values are not applied directly to the designing process, because the direct parameters are not able to attain effective results. Therefore, the design parameters are optimized as per the requirement to enhance the performance of the proposed antenna design. The optimized designing parameters which are utilized for the designing process are given in the Table 1.

Table 1. The Optimized Designing Dimensions for the Proposed Antenna Design

Variables	Description	Optimized value (mm)
Wp	Width of the patch	26.06
Lp	Length of the patch	20.02
Wf	Width of the feed line	1.3
Lf	Length of the feed line	16.4
Ws	Width of the substrate	45
Ls	Length of the substrate	40
Wt	Width of the slot	3
Lt	Length of the slot	12

From the Table 1, the value for width of the patch Wp is optimized to 26.06 mm and the length of the patch Lp is optimized to 20.02 mm. The Length of the substrate Ls and feed line Lf are optimized to 40 mm and 16.4 mm respectively. Similarly, the width of the substrate Ws and feed line Wf are optimized to 45 mm and 1.3 mm respectively. Furthermore, there is two slots are added in the patch for the alignment of RF MEMS shunt capacitor switch. The length Lt and width Wt of the slots are taken as 12 mm and 3 mm respectively. The design of the proposed frequency reconfigurable microstrip patch antenna with RF MEMS shunt capacitor switch is shown in figure 1.

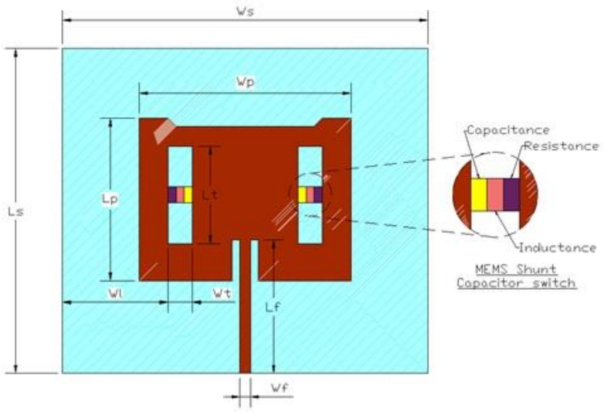

Fig. 1. Design of the proposed antenna

The above figure (figure 1) clearly illustrates the design of proposed frequency reconfigurable microstrip patch antenna with RF MEMS shunt capacitor switch. Here, the switches are placed in the middle of the slots. This switch contains one capacitance, one resistance and one inductance. When increasing the values of resistance, the switch is become OFF condition and when decreasing the values of resistance, the switch is become ON condition.

3. Design Procedure and Simulation

The proposed antenna is designed with the help of High-Frequency Structure Simulation (HFSS) software by utilizing the optimized values. The platform of HFSS software is based on ANSYS which is widely utilized for the design, simulation, and analysis. The proposed frequency reconfigurable microstrip patch antenna with RF MEMS shunt capacitor switch is designed as per the figure 1 with the help of HFSS software. The design and simulation process are performed in the system configuration of i3 9th gen Intel core processor with 8 GB RAM and the CPU speed at 3.60 GHz.

3.1 Procedure

This section explains the procedures for designing the proposed antenna in HFSS software. First, the substrate of the proposed antenna is designed by implementing the optimized values and the material of the substrate is selected as FR4-epoxy. Over the substrate, the patch and feed line are designed as per the optimized values and placed in the center of the substrate. In other side of the substrate, ground plane is designed which fully cover the length and width of the substrate. After that the port is designed in the side of the substrate which connecting the feed line and ground plane. Then two slots are drawn and cut from the patch to place the RF MEMS shunt capacitor switch. The switches are designed in the middle of the slot horizontally in the order of capacitance, inductance, and resistance and these switches are connecting the two edges of the slots. At last, the radiation box is designed with the dimensions which are required for the proposed antenna. After that, for the simulation process, the boundaries are assigned. Here, perfect E is assigned for Patch, feed line, and ground plane and the radiation boundary is assigned to the radiation box. Then lumped port excitation is assigned to the port by connecting the ground plane and feed line with the help of drawing the line from ground plane to feed line and the port impedance value is considered as 50 **Ω**. After that the boundary for the RF MEMS shunt capacitor switch is assigned by using the lumped RLC boundary. Here, first block is assigned as resistance and the value is set to 1 µohm. Second block is assigned as inductance and the value is set to 0.4 nH. Finally, the third block is assigned as capacitance and the value is set to 1 µF. These values are set for the RF switch in ON condition. After completion of assigning process, the simulation analysis setup is formulated and sweep of graph range is set to 1 GHz to 8 GHz for the resonance frequency 3.5 GHz. Then the simulation process is running with three switching conditions and they are ON-ON, OFF-ON, and OFF-OFF. The simulations results are taken based on Return loss, Gain, bandwidth, and VSWR and the obtained results are discussed in the following sections.

3.2 Simulation Results and Analysis

This section clearly analyses the obtained simulation results based on ON-ON, ON-OFF, and OFF-OFF conditions. The switch contains three components resistance, inductance, and capacitance and they are placed in series order. For ON-ON condition, the resistance, inductance, and capacitance values of two switches are set as 1 µohm, 0.4 nH, and 1 µF respectively. For ON-OFF condition, one switch is set as similar to the ON condition and another switch's resistance, inductance, and capacitance are set to as 1 Gohm, 0.4 nH, and 0.5 pF. Finally, in OFF-OFF condition, both switches are set to as similar to the OFF condition. The results are taken on the basis of Return loss, Bandwidth, Gain, and VSWR. The obtained results are discussed in the following sections.

3.2.1 Return Loss and Bandwidth

The ratio of reflected frequency to the resonance frequency is known as Return loss and the value of return loss should be attained lower as much as possible for the better antenna design. The range of frequencies is known as Bandwidth and it is measured to validate the efficiency of frequency transmitting and receiving in antenna.

3.2.1.1 ON-ON Condition

The obtained return loss for the proposed antenna in ON-ON condition is plotted by using HFSS software and it is demonstrated in figure 2.

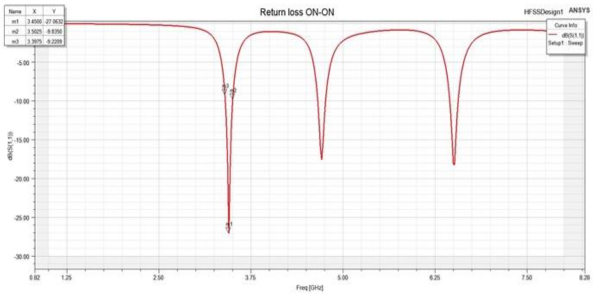

Fig. 2. Return loss of proposed antenna in ON-ON condition

The above graph (in figure 2) clearly shows that the proposed antenna is a multiband antenna by attaining three frequency bands. The obtained return loss for the nearest to resonance frequency is -27.06 dB and the Band width is measured as 0.11 GHz.

3.2.1.2 ON-OFF condition

The return loss for the proposed antenna in ON-OFF condition is plotted and illustrated in figure 3.

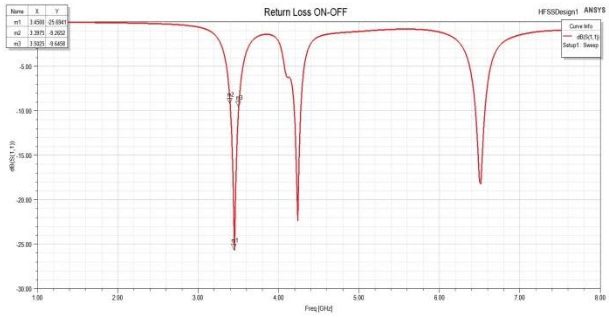

Fig. 3. Return loss of proposed antenna in ON-OFF condition

From the above graph (in figure 3), the return loss for the nearest resonance frequency is obtained as -25.69 dB and the bandwidth is obtained as 0.11 GHz.

3.2.1.3 OFF-OFF condition

The return loss for the OFF-OFF condition is plotted and shown in figure 4.

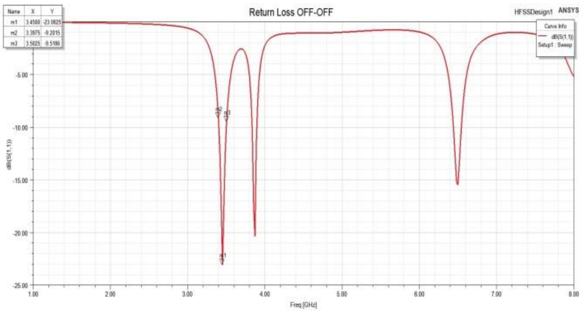

Fig. 4. Return loss of proposed antenna in OFF-OFF condition

From the above graph (in figure 4), the return loss of OFF-OFF condition for the nearest resonance frequency is obtained as -23.08 dB and the bandwidth is obtained as 0.11 GHz.

3.2.2 Gain

The strength of received or sent the frequency for the antenna is measured by Gain and it is playing an important role in the performance of antenna.

3.2.2.1 ON-ON condition

The obtained gain for the proposed antenna in ON-ON condition is plotted as 3D polar view and shown in figure 5.

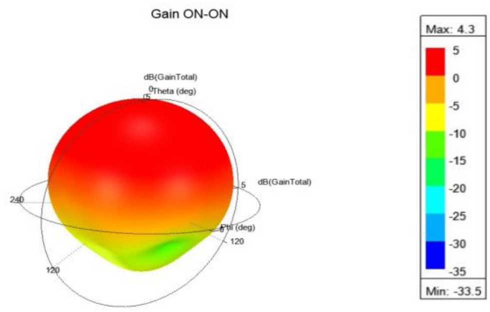

Fig. 5. Gain 3D polar view of proposed antenna in ON-ON condition

The above 3D polar view (in figure 5) is showing the gain of proposed antenna in ON-ON condition and the obtained Gain value for the proposed antenna is 4.3 dB.

3.2.2.2 ON-OFF condition

The gain in ON-OFF condition for the proposed antenna is plotted as 3D polar view and it is demonstrated in figure 6.

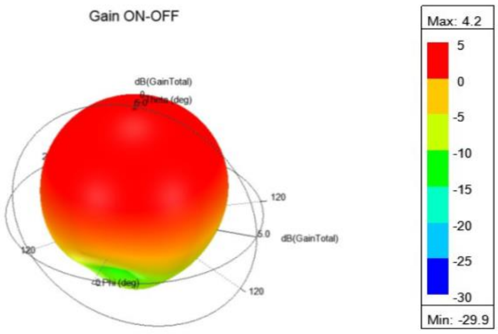

Fig. 6. Gain 3D polar view of proposed antenna in ON-OFF condition

From the above 3D polar view (in figure 6), the gain for the proposed antenna in ON-OFF condition is illustrated and the obtained gain value ON-OFF condition is 4.2 dB.

3.2.2.3 OFF-OFF condition

The 3D polar view of obtained gain for the proposed antenna in OFF-OFF condition is shown in figure 7.

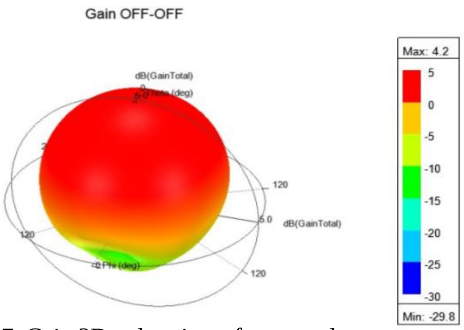

Fig. 7. Gain 3D polar view of proposed antenna in OFF-OFF condition

For OFF-OFF condition, the gain for the proposed antenna is obtained as 4.2 dB.

3.2.3 Radiation pattern

The energy which are radiated from the antenna is represented by radiation pattern and it shows the pattern of the radiation formed over the antenna.

3.2.3.1 ON-ON condition

The obtained radiation pattern for the proposed frequency reconfigurable antenna in ON-ON condition is plotted by using HFSS software and it is plotted in figure 8.

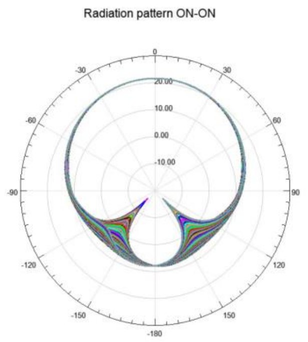

Fig. 8. Radiation pattern of proposed antenna in ON-ON condition

The above graph (in figure 8) explains that the radiation pattern for the proposed antenna in ON-ON condition is achieved approximately 21.6 dB.

3.2.3.2 ON-OFF condition

The obtained radiation pattern for the proposed antenna in ON-OFF condition is plotted in figure 9.

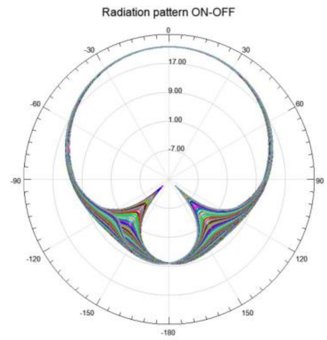

Fig. 9. Radiation pattern of proposed antenna in ON-OFF condition

The obtained radiation pattern for the proposed frequency reconfigurable antenna is 21.6 dB which is illustrated in the above graph (figure 9).

3.2.3.3 OFF-OFF condition

The radiation pattern for the proposed frequency reconfigurable antenna in OFF-OFF condition is attained and plotted in the figure 10.

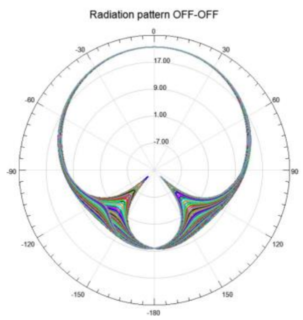

Fig. 10. Radiation pattern of proposed antenna in OFF-OFF condition

The above graph (in figure 10) is showing the obtained radiation pattern for the proposed antenna in OFF-OFF condition and the obtained value is 21.5 dB.

3.2.4 VSWR

The transmitted frequency power of the antenna is measure by Voltage standing wave ratio (VSWR) and the value of VSWR should be maintain between 1 to 2 for the good antenna design.

3.2.4.1 ON-ON condition

The obtained VSWR for the proposed frequency reconfigurable antenna in ON-ON condition is plotted in figure 11.

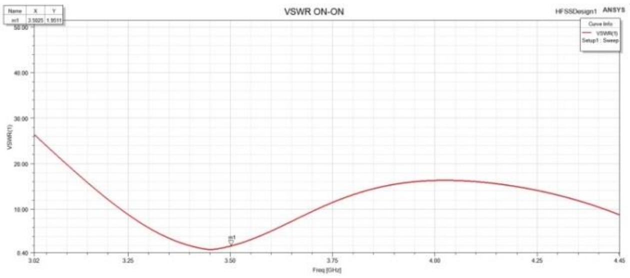

Fig. 11. VSWR of proposed antenna in ON-ON condition

The above graph (in figure 11) shows the obtained value for the proposed antenna in ON-ON condition and the obtained value is 1.95 in the resonance frequency. The obtained value is clearly proved that the proposed antenna design is good.

3.2.4.2 ON-OFF condition

The VSWR for the proposed antenna in ON-OFF condition is attained and plotted in figure 12.

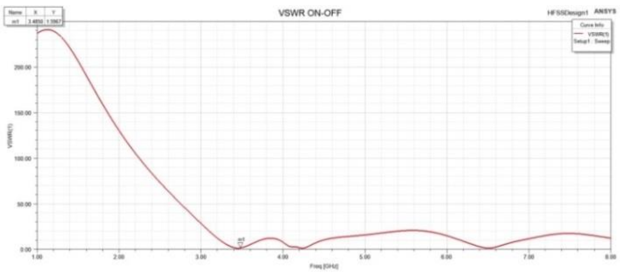

Fig. 12. VSWR of proposed antenna in ON-OFF condition

The VSWR for the proposed frequency reconfigurable antenna is 1.59 in ON-OFF condition and this proved that the proposed antenna design is good in ON-OFF condition also.

3.2.4.3 OFF-OFF condition

The obtained VSWR for the proposed frequency reconfigurable antenna in OFF-OFF condition is plotted in figure 13.

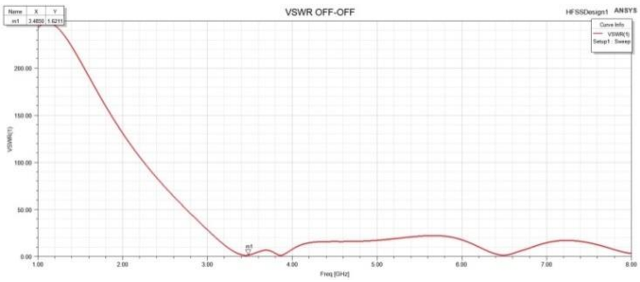

Fig. 13. VSWR of proposed antenna in OFF-OFF condition

From the graph (in figure 13), the obtained VSWR value is 1.62 for the proposed antenna in OFF-OFF condition and this is also proved that the proposed antenna design is good.

4. Comparative Analysis

The below Table 2 show the comparison of various antennas mentioned in the references with different parameters like size, peak gain, bandwidth, return loss and substrate etc.

Table 2. Comparison of Various Antennas with Different Parameters

Antenna	Size (mm^2)	Peak Return Loss (dB)	Band width (GHZ)	Peak Gain (dB)	Substrate
[5]	51 x 31.8	-32	6	5	Rogers R04003
[7]	31 x 28	-33	7.4	4.1	FR4
[8]	18 x 18	-28	7.5	2.99	RT/Duroid 6010
[10]	27 x 28	-48	9.7	4.5	FR4
[12]	86 x 77.9	-	7.5	5.34	RT/Duroid 3003
[15]	22 x 29.5	-48	14.4	2.9	FR4
[16]	540 x 220	-38	1	5.36	FR4

The below Table 3 explains the comparative analysis of switching conditions such as ON-ON, ON-OFF, and OFF-OFF of the proposed frequency reconfigurable microstrip patch antenna with RF MEMS shunt capacitor switch. The results obtained such as Return loss, Bandwidth, Gain, Radiation pattern, and VSWR are shown in the Table 3.

Table 3. Results of Proposed Antenna obtained from Simulation for Various Switching Conditions

Switching conditions	Return loss (dB)	Bandwidth (GHz)	Gain (dB)	Radiation pattern (dB)	VSWR
ON-ON	-27.06	0.11	4.3	21.6	1.95
ON-OFF	-25.69	0.11	4.2	21.6	1.6
OFF-OFF	-23.08	0.11	4.2	21.5	1.62

From the above table (Table 2), the return loss is obtained for the ON-ON, ON-OFF, and OFF-OFF conditions of the proposed antenna is -27.06, -25.69, and -23.08 dB respectively. Here, the return loss from the condition of ON-ON is performed well compared to the other conditions. The bandwidth is obtained similar for all conditions which is 0.11 GHz respectively. The gain of the proposed antenna is obtained as 4.3, 4.2, and 4.2 dB for the conditions of ON-ON, ON-OFF, and OFF-OFF respectively. The VSWR of the proposed antenna is obtained as 1.95, 1.6, and 1.62 for ON-ON, ON-OFF, and OFF-OFF conditions respectively. Similarly, the radiation pattern for the conditions ON-ON, ON-OFF, and OFF-OFF are obtained as 21.6, 21.6, and 21.5 dB respectively. Overall, the proposed frequency reconfigurable microstrip patch antenna design performed well in all switching conditions with better values in Return loss, Bandwidth, Gain, Radiation pattern, and VSWR.

5. Conclusion

The main goal for the presented work is to provide a potential ultra-wideband antenna design by reconfiguring the frequency for the application of wireless communication. Here, the novel frequency reconfigurable microstrip patch antenna with RF MEMS shunt capacitor is proposed for the wireless communication system. The design and simulation are performed on the computer software named HFSS which is the platform of ANSYS. First, the microstrip patch antenna is designed with two RF MEMS shunt capacitor switches and the simulation is conducted based on three switching conditions such as ON-ON, ON-OFF, and OFF-OFF. The performance of the proposed frequency reconfigurable microstrip patch antenna with RF MEMS shunt capacitor switch is validated by the antenna performance matrices such as Return loss, Bandwidth, Gain, Radiation pattern, and VSWR. The simulations results are taken for all three conditions based on the antenna performance metrics' and the results show that the proposed frequency reconfigurable microstrip patch ultra-wideband antenna is performed efficiently and it is suitable for the wireless communication system.

References

[1] Dakulagi, V. and Bakhar, M. "Advances in smart antenna systems for wireless communication," *Wireless Personal Communications*, vol. 110, no. 2, pp. 931-957, 2020.

[2] Ojaroudi Parchin, N., Jahanbakhsh Basherlou, H., Al-Yasir, Y.I., Abd-Alhameed, R.A., Abdulkhaleq, A.M. and Noras, J.M. "Recent developments of reconfigurable antennas for current and future wireless communication systems," *Electronics*, vol. 8, no. 2, pp.128, 2019.

[3] Rajan, S.P. and Vivek, C. "Analysis and design of microstrip patch antenna for radar communication," *Journal of Electrical Engineering & Technology*, vol. 14, no. 2, pp.923-929, 2019.

[4] Hussain, N., Jeong, M., Park, J., Rhee, S., Kim, P. and Kim, N. "A compact size 2.9‐23.5 GHz microstrip patch antenna with WLAN band‐rejection," *Microwave and Optical Technology Letters*, vol. 61, no. 5, pp.1307-1313, 2019.

[5] Prakasam, V., LaxmiKanth, K.A. and Srinivasu, P. "Design and simulation of circular microstrip patch antenna with line feed wireless communication application," *In 2020 4th International Conference on Intelligent Computing and Control Systems (ICICCS)*, pp. 279-284, IEEE, 2020.

[6] Islam, M.S., Islam, M.T., Ullah, M.A., Beng, G.K., Amin, N. and Misran, N. "A modified meander line microstrip patch antenna with enhanced bandwidth for 2.4 GHz ISM-band Internet of Things (IoT) applications," *IEEE Access*, vol. 7, pp.127850-127861, 2019.

[7] Karami, F., Rezaei, P., Amn‐e‐Elahi, A., Abolfathi, A. and A. Kishk, A. "Broadband and efficient patch array antenna fed by substrate integrated waveguide feed network for Ku‐band satellite applications," *International Journal of RF and Microwave Computer‐Aided Engineering*, vol. 31, no. 9, pp. 22772, 2021.

[8] Shamim, S.M., Uddin, M.S., Hasan, M.R. and Samad, M. "Design and implementation of miniaturized wideband microstrip patch antenna for high-speed terahertz applications," *Journal of Computational Electronics*, vol. 20, no. 1, pp. 604-610, 2021.

[9] Mohamadzade, B., Simorangkir, R.B., Hashmi, R.M. and Lalbakhsh, A. "A conformal ultrawideband antenna with monopole-like radiation patterns," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 8, pp. 6383-6388, 2021.

[10] Ghosh, A., Mandal, T. and Das, S. " Design and analysis of triple notch ultrawideband antenna using single slotted electromagnetic bandgap inspired structure," *Journal of Electromagnetic Waves and Applications*, vol. 33, no. 11, pp. 1391-1405, 2019.

[11] Shereen, M.K., Khattak, M.I. and Nebhen, J. "A review of achieving frequency reconfiguration through switching in microstrip patch antennas for future 5G applications," *Alexandria Engineering Journal*, 2021.

[12] Shah, I.A., Hayat, S., Basir, A., Zada, M., Shah, S.A.A. and Ullah, S. "Design and analysis of a hexa-band frequency reconfigurable antenna for wireless communication," *AEU-International Journal of Electronics and Communications*, vol. 98, pp. 80-88, 2019.

[13] Iqbal, A., Smida, A., Mallat, N.K., Ghayoula, R., Elfergani, I., Rodriguez, J. and Kim, S. "Frequency and pattern reconfigurable antenna for emerging wireless communication systems," *Electronics*, vol. 8, no. 4, pp. 407, 2019.

[14] Shojaei-Asanjan, D., Bakri-Kassem, M. and Mansour, R.R. "Analysis of thermally actuated RF-MEMS switches for power limiter applications," *Journal of Microelectromechanical Systems*, vol. 28, no. 1, pp. 107-113, 2019.

[15] Sailaja, B., & Naik, K. "Design of elliptical-shaped reconfigurable patch antenna with shunt capacitive RF-MEMS switch for satellite applications," *International Journal of Microwave and Wireless Technologies*, vol. 13, no. 9, pp. 969-978. DOI:10.1017/S1759078720001634, 2021.

[16] Shanthi G, Rao K and Sravani K. "Performance analysis of EBG bandstop filter using U: shaped meander type electrostatically actuated RF MEMS switch," *Microsystem Technologies*, vol. 27, no. 10, pp. 3743-3750, 2021.

[17] Bhatia S, Sivia J and Sarao A. "Lantern Logo Shaped Novel Monopole Antenna with Semi-Circular Notch Loaded Partial Ground Plane for Ultra-Wideband Wireless Applications," *Wireless Personal Communications: An International Journal*, vol. 126, no. 4, pp. 3211-3231, 2022.