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Design and Implementation of Frequency Reconfigurable Antenna for Wi-Fi Applications

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Abstract

Due to exponential growth of wireless technology, the essentiality of the antennas which resonate at multiple frequency bands has increased. Reconfigurable antennas are the best choice to meet these demands. This work proposes the novel design and investigation of planar compact monopole frequency reconfigurable antenna. By employing Flame Retardant 4 (FR4) substrate at 0.16 cm height, the designed antenna produces multiple frequency bands with wider bandwidth. The proposed antenna resonates in one dual band mode and three single band modes reckoning upon the conditions of diode-Radio Frequency Positive-Intrinsic-Negative (RF PIN) diode switches. Various antenna parameters like Gain, radiation pattern, VSWR, return loss are simulated and validated with the measurement results. The fabricated antenna operates between 2.4 GHz- 6.3GHz frequency range. In all the operating bands, VSWR is <1.5. The designed antenna structure gives the radiation efficiency in the range of 73%-79% in all the operating resonating conditions. The designed monopole reconfigurable antenna exhibits the fair agreement between simulated and measurement results. It operates at 2.4 GHz (Wi-Fi), 3.5 GHz (sub 6 GHz for 5G applications), 4.7 GHz (Vo5G), 5.8 GHz (Vehicle-to-Everything communications) and C band (6.22 GHz-6.27 GHz). Antenna design simulation is done with High-Frequency Structure Simulator Version 17 (HFSSV17) software. This compact design antenna (35 mm × 35 mm × 1.6 mm) can be easily placed inside the modern portable communication devices.

Keywords: FR4 substrate; Antenna design; Frequency reconfiguration; Fabrication; Omni directional.
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1. Introduction

Exponential growth in communication technology for the past three decades makes the size of the modern wireless devices as diminishing one.[1] The current wireless systems have the capability to realize multifunctional ability with a single device, which aids many applications at several operating environments. Even though, each and every application works in different resonating frequency band, with unique radiation pattern or unique polarization, such a single system needs several antennas. However, antenna is considered as a static device. Its characteristics remain the same, once the antenna design is fixed. This has steered intensive research in antenna in the direction of multi functionalities to cope up with the existing modern communication. Reconfigurable antennas[2] is an exceptional research field that gives many attributes to conventional antennas, whose properties are remain fixed. Reconfigurable antenna has the capability to modify its operating peculiarities, according to the dynamic conditions. Reconfigurable antenna can be designed from conventional antenna by altering its properties such as polarization, radiation pattern and operating frequency or any amalgamation of these properties to satisfy the modern communication system objectives. It is divided into four groups as pattern reconfigurable antennas polarization reconfigurable antennas, frequency reconfigurable antennas, and compound reconfigurable antennas.

Each single application operates at certain range of frequency such as GPS at 2.45 GHz, Wi- Fi at 5.2 GHz and WiMAX at 3. 6 GHz. Multi band antenna can resonate at particular frequency bands. On the contrary modern electronic devices need antenna to be tuned to the required frequency band. Designing a compact and simple multiband antenna is a complex job for researchers. Its intricacy increases proportionally with the number of radiating bands. In wireless

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applications, designs are complex and it leads to large size. Luckily reconfigurable antenna has the competence to wrap different range of frequencies from the single patch. Frequency reconfigurable antenna[3] consists of radiating structure, that is the ability to modify its resonating frequency, while making the polarization and radiation pattern constant and it is called frequency reconfigurable antenna

In[4] higher gain is achieved by novel design of antenna which wrap up 2.45 GHz (WLAN) and 3.6 GHz (Sub 6 GHz). In this frequency reconfigurable antenna, proximity feeding is combined with differential technology in stacked structure. In pixel slot antenna,[5] higher antenna efficiency is acquired by selecting low loss substrate and appropriate position of RF MEMS switches. With the help of RF switches, radiation slot topologies are selected and radiation arrives from the slots which exists between the metallic pixels.

In frequency reconfigurable antennas, many researchers are using tunable elements like MEMS[6] switches for frequency reconfiguration. Wide band and high gain is achieved by designing micro fluidically frequency reconfigurable monopole liquid metal antenna[7] by consciously associated microfluidic channels. Based upon directed dipole, novel frequency band-reconfigurable antenna is designed. Here, folded bowtie dipole antenna resonates in wideband mode, while thin dipole length-reconfigurable antenna operates at four frequency bands by modifying the states of the RF PIN diode switches is reported.[8]

In[9] fork shaped planar dipole antenna has been intended to operate at dual band ISM 5.2 GHZ band and Wi-Fi 2.4 GHz applications) with the help of optical switches. To improve the return loss, mushroom type EBG structure is implemented at various heights of the antenna. Printed monopole antenna[10] resonates in 2 dual band mode and 2 single band modes between 2.1 to 5.2 GHz. Due to compact design, it can be accommodated in modern communication devices like laptop and tablets. Frequency-reconfiguration with circular polarization antenna has been reported.[11] By employing capacitive loading, frequency reconfigurability is accomplished, and the circular polarization is performed by enabling two orthogonal modes with two different operating frequencies (1.97 GHz and 2.53 GHz).

Combination of frequency and polarization reconfiguration[12] is perceived by open stub cascaded branch-line coupler (OSCBLC) feed network configuration. Various polarization schemes like RHCP, LHCP, VLP and HLP are enabled by concentric circle micro strip patch antenna. One wideband and two dual-band can be brought by designing the compact structure of 50 mm × 50 mm × 1.57 mm ‘C’ slot patch antenna[13] which resonates between 5 to 7 GHz frequency without affecting each other bands.

In[14] frequency reconfigurable antenna, two nested patched are constructed to bring 4 different resonant frequencies (1.87, 3.55, 3.67 and 5.6 GHz) for wireless applications, by employing 3 RF PIN diodes at suitable position between the two patches. In[15] maximum radiation efficiency (96%) is attained by designing hexa band frequency reconfigurable antenna. It resonates at two dual band and two single bands between 2.1 GHz to 5.2 GHz.

Wide band pattern-reconfigurable cone antenna is constructed by using liquid-metal reflectors is reported.[16] Here the metal cone acts as the principal radiator and the eight poles behave like reflectors for beam switching. Beam steering can be accomplished by altering the states of the poles. The cone antenna offers 6.7 dB maximum gain and 21 different kinds of beams are selected to cover the entire 360 degrees. In[17], the antenna resonates between 3GHz to 10 GHz by placing 2 RF PIN diodes in vertical and horizontal strips of ‘G ’shape antenna. It is used in Long Distance Radio Telecommunications, WiMAX and X-band Satellite Communication WLAN.

Dual band operation is established by Coplanar Waveguide (CPW)-fed monopole frequency reconfigurable antenna. Simple and easy design makes the antenna suitable for mobile applications is reported.[18] In[19] compact loop antenna size of 25*10 mm is printed on Roger’s substrate and the independent tuning of bands improves the carrier aggregation for enhancing the data rate and the capacity. Miniaturized electrically tunable triangular patch antenna[20] has the ability to operate as a wideband antenna. It consists of two serpentine stubs with CPW feed, having different number of lengths and turns. By incorporating 2 RF PIN diodes, 8 different frequencies are achieved

For closely spaced reconfigurable MIMO antenna arrays,[21] link capacity has been improved. Based on channel by channel, pattern diversity has been checked and identified as the best antenna configuration, which gives the greatest channel capacity. In[22] stacked microstrip antenna has been reported, at one frequency band (fu) with high gain directional pattern is attained which is used for satellite communication. In another frequency band (f1), it offers low gain omni directional radiation pattern. It is used for mobile radio terrestrial land applications.

From the above Table 1 and literature survey it can be culminated that the gain and bandwidth of the antenna is less and size of the antenna structure is big and complex. But the modern communication devices need compact antenna, which can be placed easily inside the device.

The proposed antenna provides the good solution for all the above drawbacks Here. novel shaped monopole antenna for

Table 1. Insight on Literature Survey.

Ref	Reconfiguration parameter	Size (mm2)	No of resonant bands	Reconfiguration Method	Max Gain (db)	Limitation
[4]	Frequency	100×100×2.5	2	PIN diodes	6.8	Big size
[5]	Frequency	40×40×1.6	6	MEMS	1.2	Less gain
[7]	Frequency	-	4	Microfluid	8	Complex structure
[9]	Frequency	-	2	Optical switches	3	Complex structure due to EBG
[10]	Frequency	33×16×1.6	6	PIN diodes	3.26	Less gain
[12]	Frequency Polarisation	150×150×2.2	10	Varactor diode	4.91	Less gain
[14]	Frequency	86.3×50×1.58	4	PIN diodes	2.3	Big size and less gain
[15]	Frequency	16×33×1.6	6	PIN diodes	2.3	Less gain
[19]	Frequency	25×10×0.2	4	PIN diodes	2	Less gain
[20]	Frequency	21×15×1.6	8	PIN diodes	2	Complex structure due to 8 PIN diodes

frequency reconfiguration is designed at the FR4 substrate height of 0.16 cm. The designed monopole antenna operates at 5 different frequencies including Wi-Fi (2.4 GHz), sub 6 GHz (3.5 GHz), Vo5G (4.7 GHz), V2X communication (5.8 GHz) and C band (6.2 GHz). Here PIN diode acts as a switch and it consists of RLC lumped components. It is placed on the surface of the patch at suitable position to obtain frequency reconfiguration. For each switch 1mm slot is allocated for the installation in the simulation environment.

2. Methodology

This section presents the proposed antenna design theory, configuration, and RF PIN diode switching methodologies of the designed monopole antenna. Frequency reconfiguration is obtained by placing lumped element switches to get three single bands and one dual band modes. Defected ground structure improves the efficiency and produce stable radiation pattern.

2.1 Proposed antenna configuration

Antenna's radiating structure is placed over the FR4 substrate, with 4.4 relative permittivity and 0.019 loss tangent. The base layer is the defective ground structure which is used to enhance the bandwidth, directivity, efficiency and gain. The FR4 material is less expensive and easily available. Excitation is given through the 50 Ω micro strip feed line width of 3 mm. Lumped port is allocated to the feed line which is used for antenna excitation. For each slot,1mm width is reserved in the radiating patch for incorporating the RF PIN diode in the circuit. The proposed monopole antenna has a foot print of 35 × 35 × 1.6 mm^3.

The effective dielectric constant (ϵ_{reff}) value is calculated by the following equation:

$$\epsilon_{reff} = \frac{\epsilon r+1}{2} + \frac{\epsilon r-1}{2}\left[1+12\frac{h}{w}\right]\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}} \quad (1)$$

w is the patch width, h is the substrate thickness, €r-relative permittivity.

Patch width is evaluated by the following mathematical equation:

$$w = \frac{c}{2fo\sqrt{\frac{\epsilon r+1}{2}}} \quad (2)$$

f_0-Resonant frequency, c-Speed of light (3×10^8 m/sec)
Fringing fields are produced by the microstrip patch antenna and that leads to extension of length (△L) of the patch. It is calculated by the following equation:

$$.\triangle L = 0.412h\frac{(\epsilon reff+0.3)\left(\frac{w}{h}+0.264\right)}{(\epsilon reff-0.258)\left(\frac{w}{h}+0.8\right)} \quad (3)$$

The length of the patch (L) is computed by the equation given below:

$$L = \frac{C}{2f0\sqrt{\epsilon reff}} \quad (4)$$

The guided wavelength (λ_f) and the resonant frequency(f_r) are related by the following equation:

$$\lambda_f = \frac{C}{fr\sqrt{\epsilon reff}} \quad (5)$$

The antenna dimensions are calculated by using above equations and their values are optimized. Table 2 recapitulates the measurements of the proposed antenna

Table 2. Measurements of the proposed antenna.

Length	Values (mm)	Length	Values (mm)
Lg	35	L2	3
Wg	35	L3	7.2
Lg1	15	L4	1
W	3	L5	3
L1	19.5	L6	9.5

2.2 Proposed Antenna theory and analysis

1 mm slot is allocated at the appropriate places in the radiating structure for incorporating the PIN diode switches. By using transmission line model, resonant length is calculated at each resonant frequency. The resonant length and guided wavelength are related by the following equations with the aid of surface current distribution:

$$S_{5.8} = \lambda_{5.8}/4 \quad (6)$$

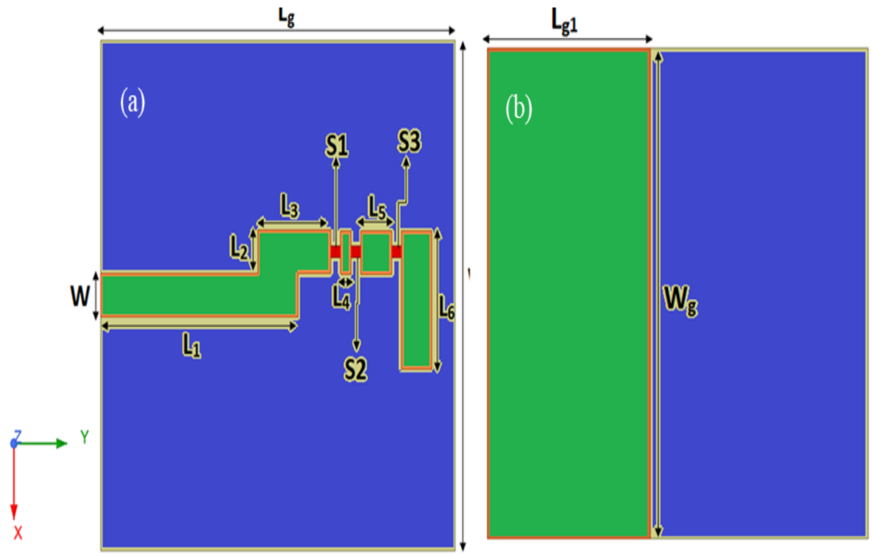

Fig. 1 Measurements of planar frequency reconfigurable antenna (a)Front view (b) Back view.

$$S_{4.7}=\lambda_{4.7}/4 \quad (7)$$

$$S_{3.5}=\lambda_{3.5}/4 \quad (8)$$

$$S_{2.4}=\lambda_{2.4}/4 \quad (9)$$

$$S_{6.2}=\lambda_{6.2}/4 \quad (10)$$

where $S_{5.8}$,$S_{4.7}$,$S_{3.5}$,$S_{2.4}$,$S_{6.2}$-Resonant Length , $\lambda_{5.8}$, $\lambda_{4.7}$, $\lambda_{3.5}$, $\lambda_{2.4}$, $\lambda_{6.2}$-Guided Wavelength.

When the antenna is properly matched, reflection coefficient will be reduced and it leads to increase in efficiency.

$$|\tau| = \frac{Za-Zo}{Za+Zo} \quad (11)$$

Za - Antenna impedance

Zo - Characteristic impedance of the feed line

$$VSWR=\frac{1+|\tau|}{1-|\tau|} \quad (12)$$

The gain (G) and directivity (D) are related by the following equation with radiation efficiency.

$G(db)=10 \log_{10}(D\ ή_{rad})$ (13)

2.3 Modelling of diode and its switching technique

In radio frequency range, PIN diode behaves like a resistor. During ON and OFF condition, it exhibits as a complex circuitry. For diode's ON and OFF states, its equivalent circuit consists of inductance (Lb). It offers low resistance (Rbs), when the diode is in forward condition. In reversed bias, the circuit analogous to parallel combination of capacitance (Cc) and high value of resistance (Rbp) as shown in Fig. 2(a). PIN diode exhibits series combination of R and L with small values during its ON condition. It performs as a close circuit, permitting current through the patch. Contradiction to this situation, during OFF condition the PIN diode shows a parallel combination with high values of RLC components, that offers open circuit behavior, so that current can't be allowed to flow along the radiator. In short circuit, it offers 3 Ω resistance and permits current flow. On the contrary in open circuit, it offers the resistance value of 5 KΩ in parallel with 0.12 pf capacitor, thus restricts the flow of current.

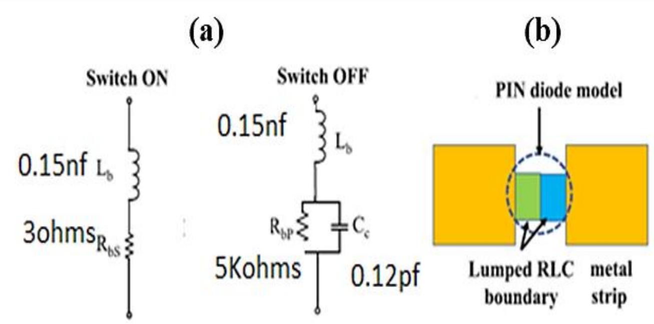

Fig. 2 (a) Equivalent circuit for ON and OFF states of the switch (b) PIN diode model.

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Table 3. Element values for different states of PIN diode.

Switching states	Resistance (Ω)	Inductance (nH)	Capacitance (pF)
ON	3 Ω	0.15	
OFF	5K Ω		0.12
L1	19.5	L6	9.5

3. Analysis of measured and simulated antenna parameters

In this work, antenna is designed with HFSS17v software and its performance is evaluated. Source is given through the lumped port for excitation of the antenna. Far field pattern, return loss, surface electric field, gain and directivity are analyzed and compared with the measured results.

3.1 Return loss

- **Mode 1 (S1, S2, S3=OFF):** When all the diodes are in OFF condition, it provides the good return loss of-23.9 db at 5.8 GHz. which is shown in 3(a).
- **Mode 2 (S1 =ON, S2 & S3=OFF):** Fig. 3(b) shows when one switch(S1) is in ON condition and other two diodes are in OFF condition, it offers single band and resonates at 4.67 GHz and its return loss is -29 db.
- **Mode3(S1, S2=ON & S3=OFF)**: Fig. 3c depicts, when 2 switches are in ON condition and the third one is in OFF(S3), the proposed antenna operates at 3.5 GHz with return loss of -38.4 db.
- **Mode 4(S1, S2, S3=ON):** when all the 3 diodes exhibit ON condition the designed antenna offers dual band at 2.4 GHz &6.2 GHz with the return loss of -34 db and-23.6 db respectively.

The designed frequency reconfigurable monopole antenna offers a maximum bandwidth of 3.06,1.48, 0.66, 0.42 and 1.46 GHz at 5.8, 4.7, 3.5, 2.4 and 6.23 GHz frequencies respectively. Fig. 3. shows the return loss at various resonating frequencies. It can be concluded that measured and simulated values are in fair agreement.

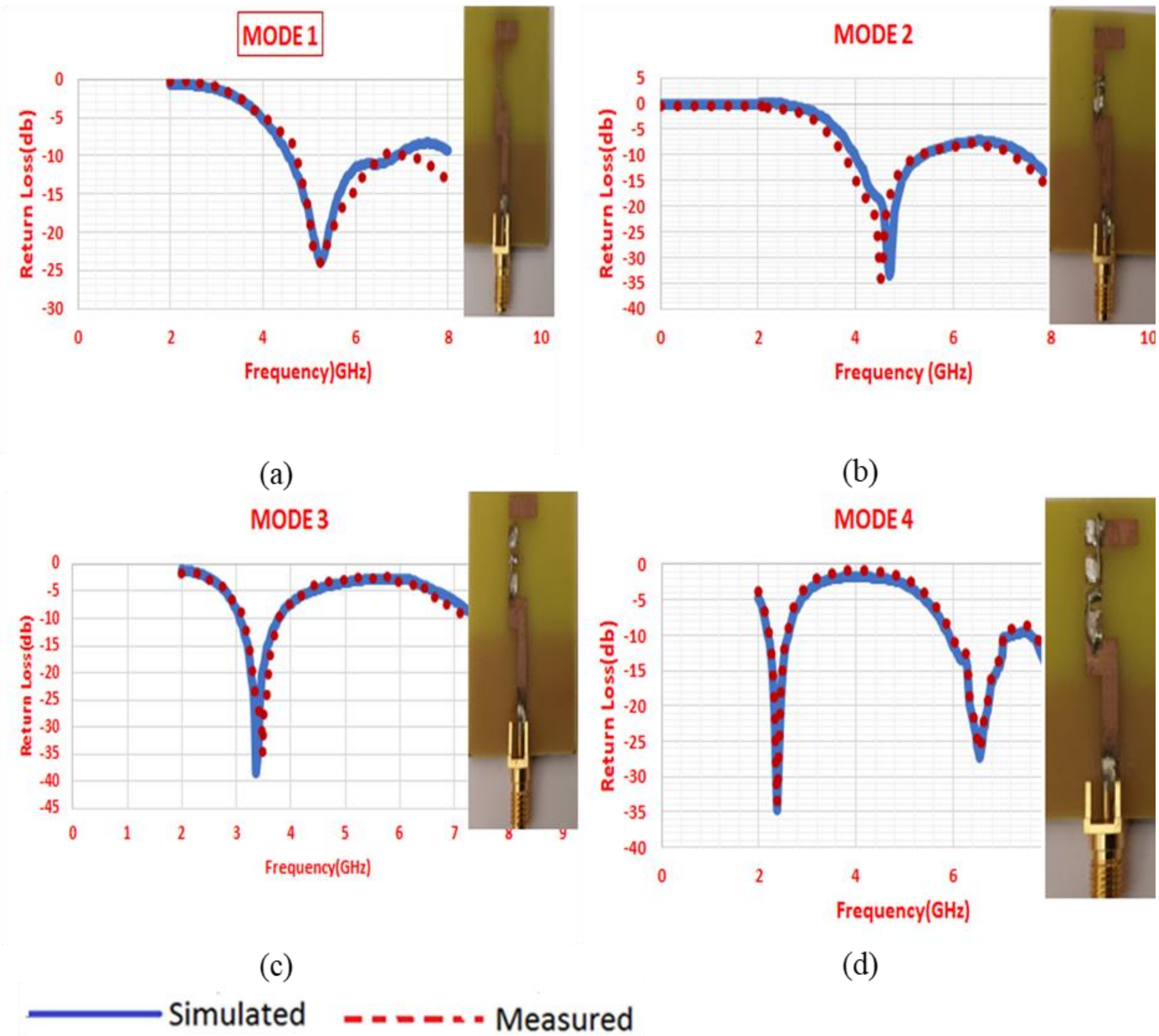


Fig. 3 Return Loss of the proposed antenna (a) 5.8 GHz (b) 4.7 GHz (c) 3.5 GHz (d) 2.4 GHz & 6.2 GHz.

From the above results, it is concluded that resonant frequency is inversely proportional to the length of the patch. When patch length is less, antenna tends to resonate at higher frequency and vice versa

3.2 VSWR

It is observed that in all the resonant conditions, the designed antenna produces various frequencies whose VSWR value is less than 1.5. It clearly shows that the antenna is designed in perfectly matched condition. The measured Voltage standing wave ratio at 6.23 GHz, 5.8 GHz, 4. 7 GHz, 3.5 GHz and 2.4 GHz are 1.4, 1.14, 1.07, 1.04 and 1.1. VSWR and its resonating frequencies are demonstrated in Fig. 4. From the graph, it is observed that the simulated and measured values of voltage standing wave ratio are in fair agreement.

3.3 Electric field distribution

Investigation on electric field distribution is studied on various resonant frequencies at 5.8 GHz, 4.7 GHz, 3.5 GHz, 2.4 GHz. Electric field distribution on various switching and resonant conditions are analyzed. From Fig. 5. It can be concluded that resonating frequency is inversely proportional with conductive path length of the radiating structure.

3.4 Fabricated antenna

Figure 6 presents the fabricated antenna. It is fabricated on1.6 mm thickness Flame retardant 4 substrate material and €r=4.4 (relative permittivity). RF PIN diode switch consists of 3 lumped elements (RLC). Different switching conditions are accountable for various resonating frequencies are exhibited in Table 4.

Table 4. Various resonating states of the designed antenna.

Switching state	Switch (S1)	Switch (S2)	Switch (S3)	Frequency Range (GHz)
1	OFF	OFF	OFF	Single Band (4.76-7.82)
2	ON	OFF	OFF	Single Band 4.5-4.8
3	ON	ON	OFF	Single Band 3.11-3.77
4	ON	ON	ON	Dual Band (i) 2.24-2.66 (ii)5.87-6.92

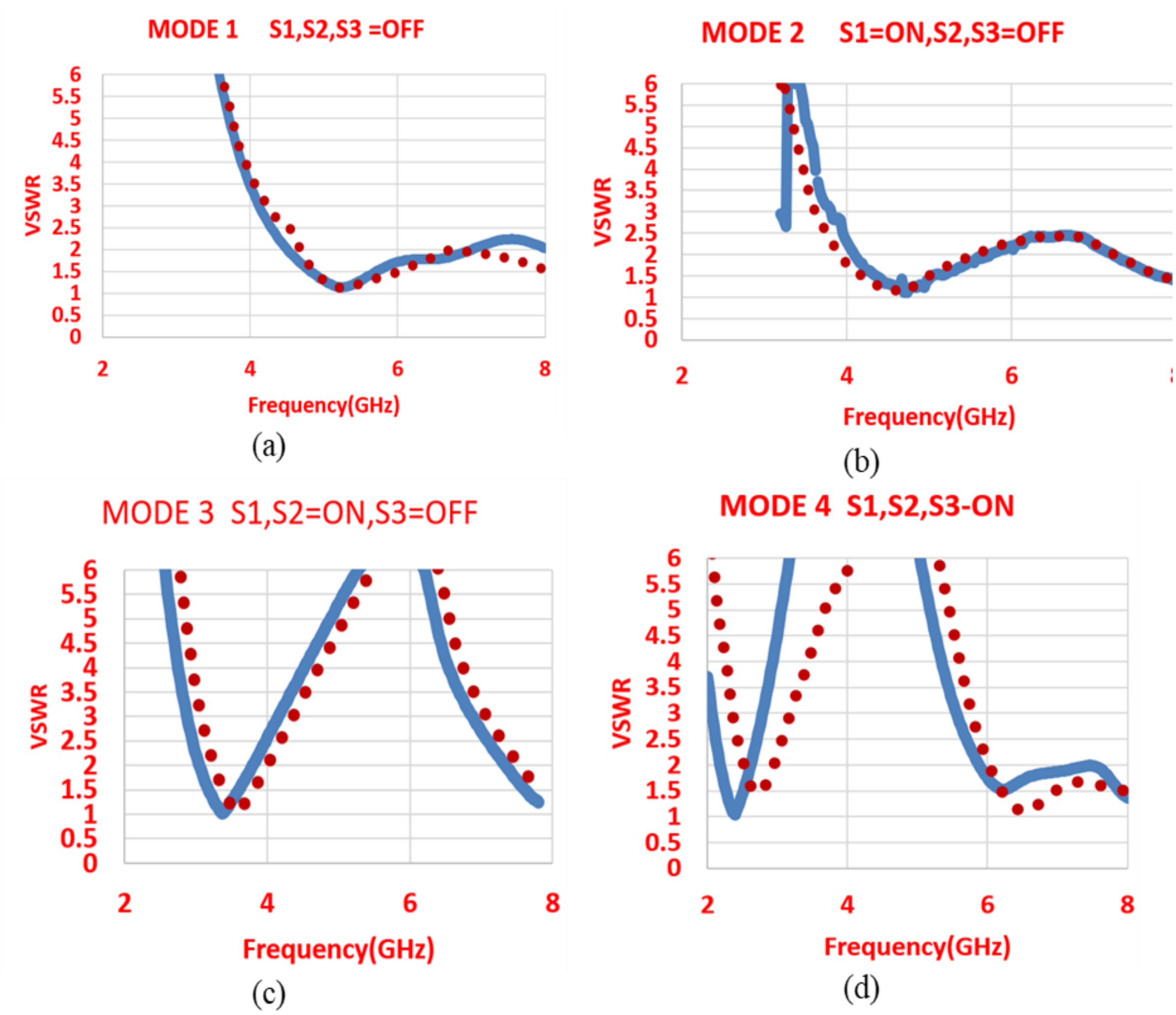


Fig. 4 VSWR of the proposed antenna (a) 5.8 GHz (b) 4.7 GHz (c) 3.5 GHz (d) 2.4 GHz & 6.2 GHz.

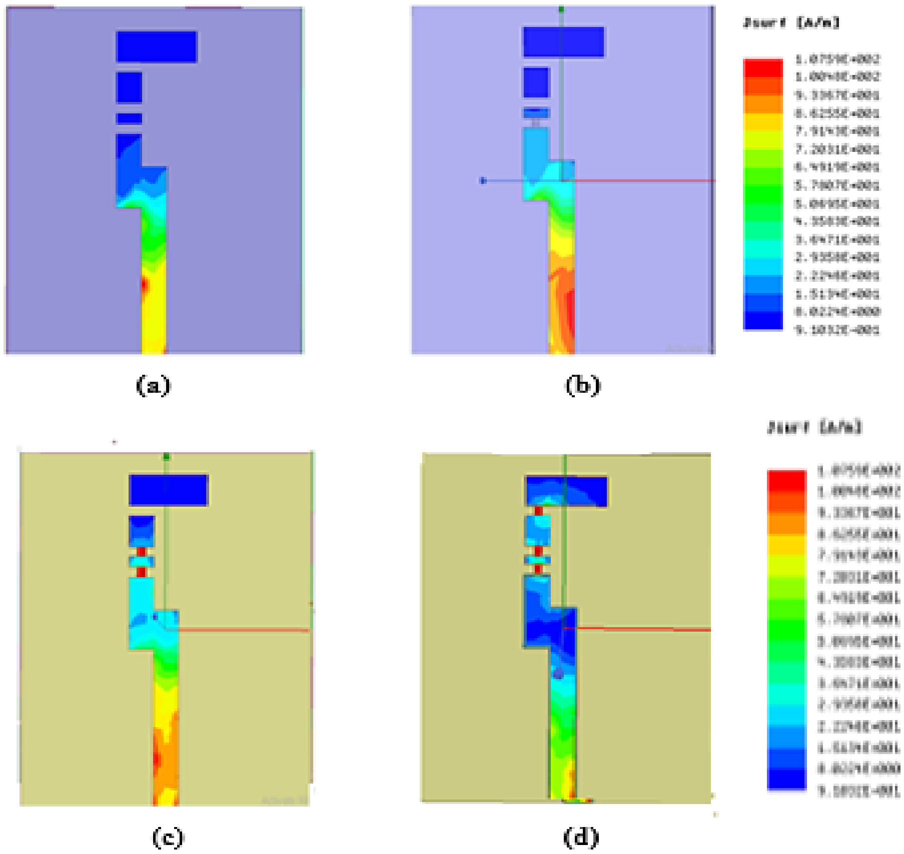


Fig. 5 Electric field distribution of the proposed antenna (a) 5.8 GHz (b) 4.7 GHz (c) 3.5 GHz (d) 2.4 GHz.

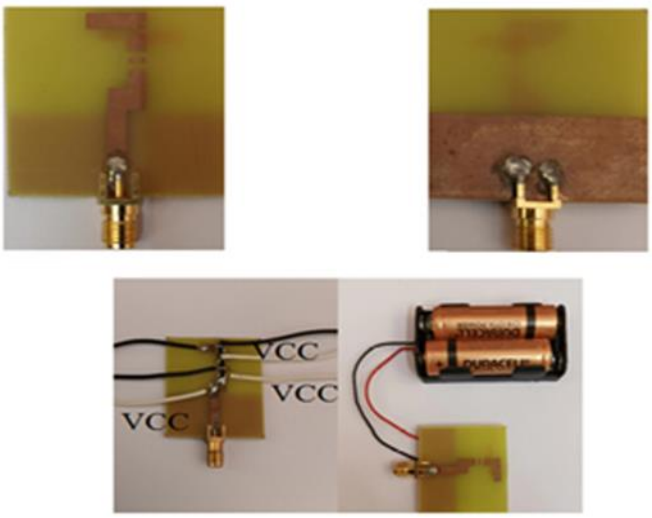


Fig. 6 Fabricated monopole frequency reconfigurable antenna.

3.5 PIN diodes and bias Tee networks

During measurement antenna is fed through the SMA connector. PIN diode is equivalent to three lumped RLC elements, which are used to get the different resonant frequencies. Switch can be modeled as 3 Ω in ON condition and parallel combination of 0.12 pf &5 KΩ in OFF condition respectively. BAR 50-02 V RF PIN diode is utilized in simulation and measurement environment. It shows good performance up to 6 GHz frequency.

PIN diodes are responsible for frequency reconfiguration. Here DC input is needed for energize the PIN diodes switches, where AC input is given as excitation for the antenna. The excitation pathway of the antenna is totally detached away from DC signal passage. Therefore, the capacitors possess the capability to restricts the Direct Current (DC signal) and allows radio frequency signal.

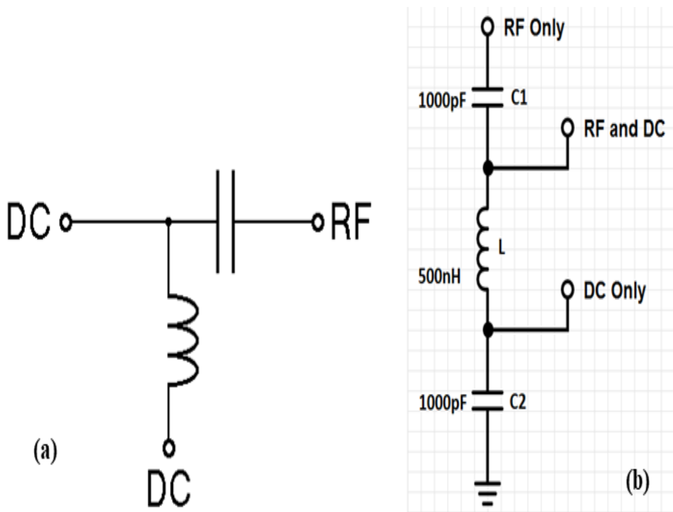


Fig. 7 (a) Structure of a bias tee (b) The circuit diagram of the bias tee.

On the other hand, RF chock passing DC signal restricts RF signal. The capacitors of 1000pf are employed to short the RF signal discharged from the inductor and 50nH inductors are employed for RF choking.3 V bias voltage is given by the two alkaline batteries. The DC bias consists of 50nH RF choke inductor to give a DC bias path to the RF PIN diode and also restricts the RF signal .0 1000 pf locking capacitor is fixed to restrict the DC bias from reaching the RF output.

3.6 Radiation Pattern and Gain

S_{11}(Reflection coefficient) of the fabricated monopole reconfigurable antenna is calculated by employing VNA, as presented in Fig. 8. Gain of the proposed antenna in vertical and horizontal planes are measured in anechoic chamber. Here log periodic antenna is the reference antenna (transmitting antenna) as shown in Fig. 8c. The antenna is locked in vertical over azimuth turn table.

Figure 9 depicts the proposed antenna radiation pattern. It yields omni directional radiation pattern in horizontal plane, where it produces 'figure of 8' in vertical plane at all the four resonating frequencies. Additional information can be obtained from 3D radiation plots which can be seen Fig.10 for the respective frequency bands. Vertical and azimuth plane radiation pattern at 5.8 GHz, 4.7 GHz, 3.5 GHz and 2.4 GHz are shown in Fig. 9 for simulation and measurement values.

The 3D radiation pattern of the proposed monopole antenna produces maximum gain of 3.59 db, 2.69 db, 2.3 db and 4.81 db at 5.8, 4.7, 3.5 and 2.4 GHz respectively. This 3D radiation shows clearly that the proposed antenna produces omni directional radiation pattern in all the resonating frequencies. Antenna radiates efficiently in all the switching states, as a result of the implementation of impedance matching excitation system at the pertinent location of the designed antenna (Table 5). The designed antenna offers reasonable radiation efficiency 73%, 78%, 79% and 73%.at 5.8 GHz, 4.7 GHz, 3.5 GHz and 2.4 GHz respectively.

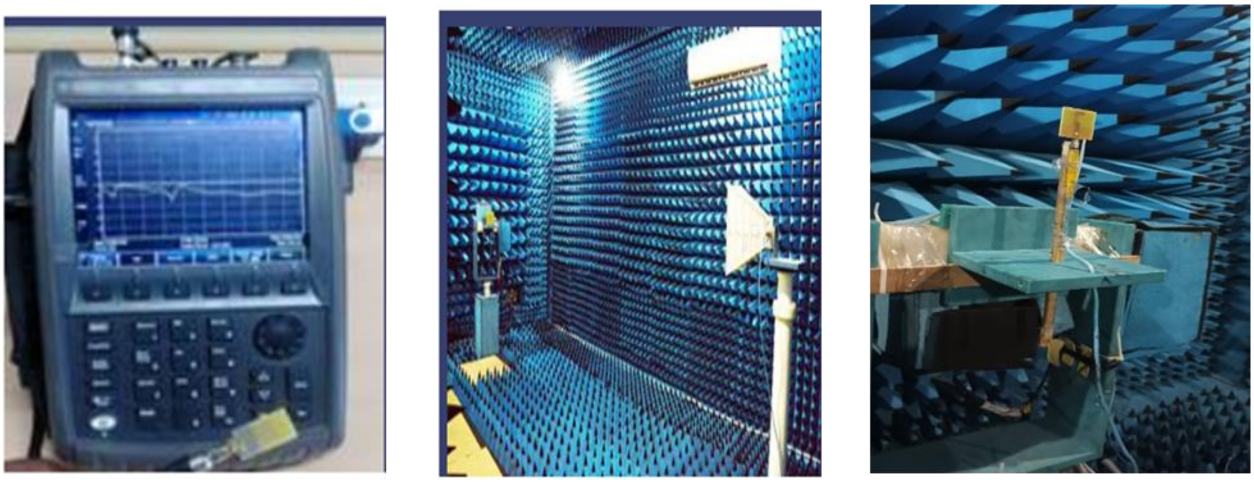
The proposed antenna produces single band and dual band as well. We can conclude that return loss is less than -10db and VSWR value is less than 1.5 in all the resonating frequencies. At 3.5 GHz, it provides the maximum return loss of -38.4 db due to good impedance matching. At 2.4 GHz the monopole antenna contributes maximum gain of 4.1 db. Good radiation efficiency is achieved for all the resonating frequency bands. Table 6 features the discrimination between the proposed work and the other existing work in terms of size reduction and number of frequency bands. The proposed antenna has secured a minimum 10% reduction in size compared to the existing works. It offers 5 radiating bands with wider bandwidth by utilizing three PIN diodes.

Table 5. Antenna parameters for different resonant frequencies and different switching conditions.

Parameters	S1, S2&S3=ON	S1=ON, S2&S3=OFF	S1&S2=ON&S3=OFF	S1, S2&S3=ON
Resonant frequencies (GHz)	5.8	4.7	3.5	(i)2.4 (ii)6.23
Gain (dBi)	3.6	2.7	2.1	(i)4.1 (ii)2.0
Return Loss (dB)	-23.86	-29.04	-38.4	(i) -34 (ii) -13.6
VSWR	1.14	1.07	1.04	(i) 1.05 (ii) 1.5
Bandwidth %	3.06	1.48	0.66	(i)0.42 (ii)1.05
Efficiencies %	73	78	79	(i) 73 (ii) 72

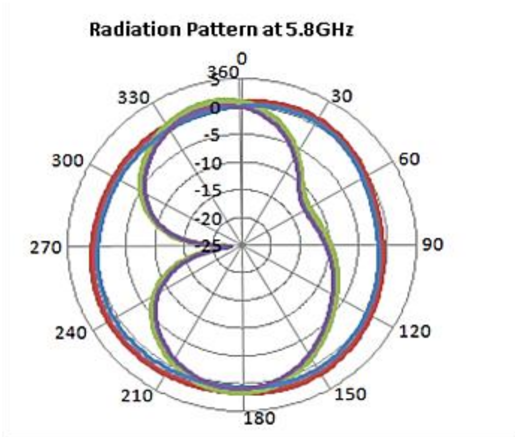
Table 6. Comparison of the proposed antenna with existing antennas.

Ref	No of resonant bands	Size (mm)	Frequency (GHz)	Bandwidth (MHz)	Gain (dbi)
[7]	Triple	35 mm × 40 mm	2.4, 3.4, 5.4	500–1250	1.92–3.02
[9]	Triple	40 mm × 40 mm	2.4, 3.5, 5.2	147–1820	1.7–3.4
[12]	Triple	35 mm × 40 mm	2.4, 3.5, 5.2	330–1250	1.48–3.26
[13]	Triple	39 mm × 37mm	2.4, 3., 5.2	550–1220	1.32–2.32
[15]	Four	20 mm × 40 mm	2.40, 3.40, 5.10, 5.80	769–1278	1.72–2.96
[17]	Four	28 mm × 30 mm	1.60, 2.50, 5.80, 9.80	200–900	1.8–2.9
Proposed work	Five	35 mm × 35 mm	5.8,4.7,3.5,2.	0.3-3.06	2.3-4.91

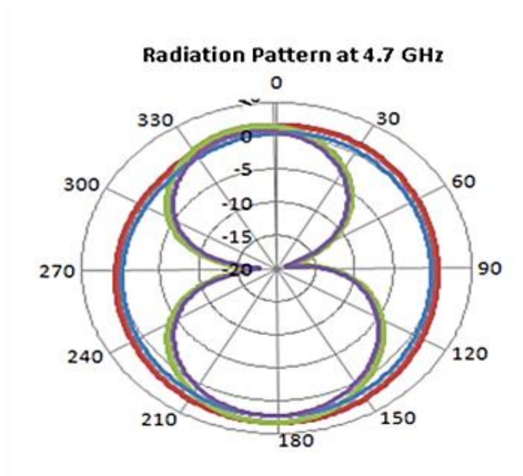


(a) (b) (c)

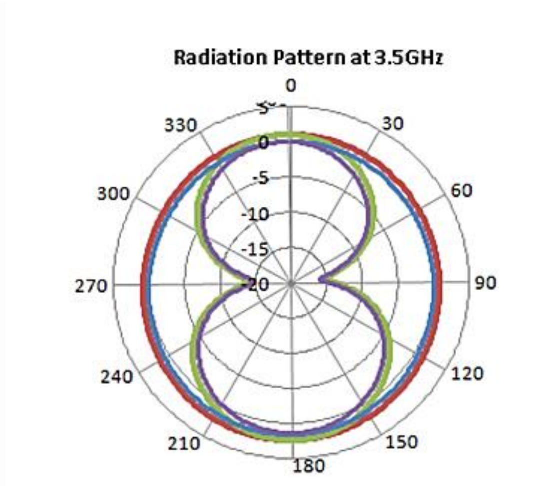
Fig. 8 (a) Vector Network Analyzer (b) Anechoic chamber (c) Proposed antenna under test in anechoic chamber.



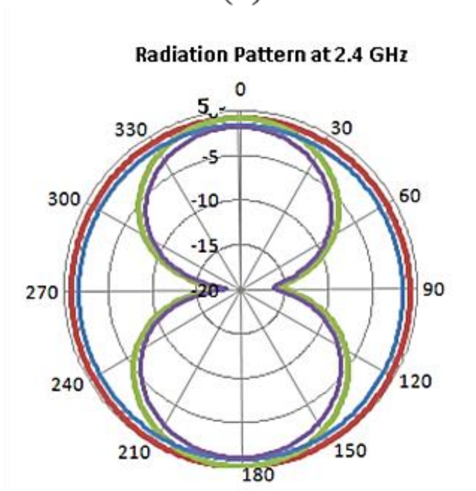
(a)



(b)



(c)



(d)

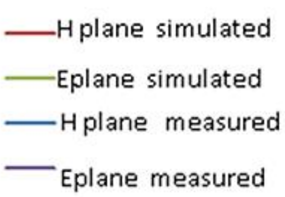


Fig. 9 Radiation pattern at various resonating frequencies (a) 5.8 GHz (b) 4.7 GHz (c) 3.6 GHz (d)2.4 GHz.

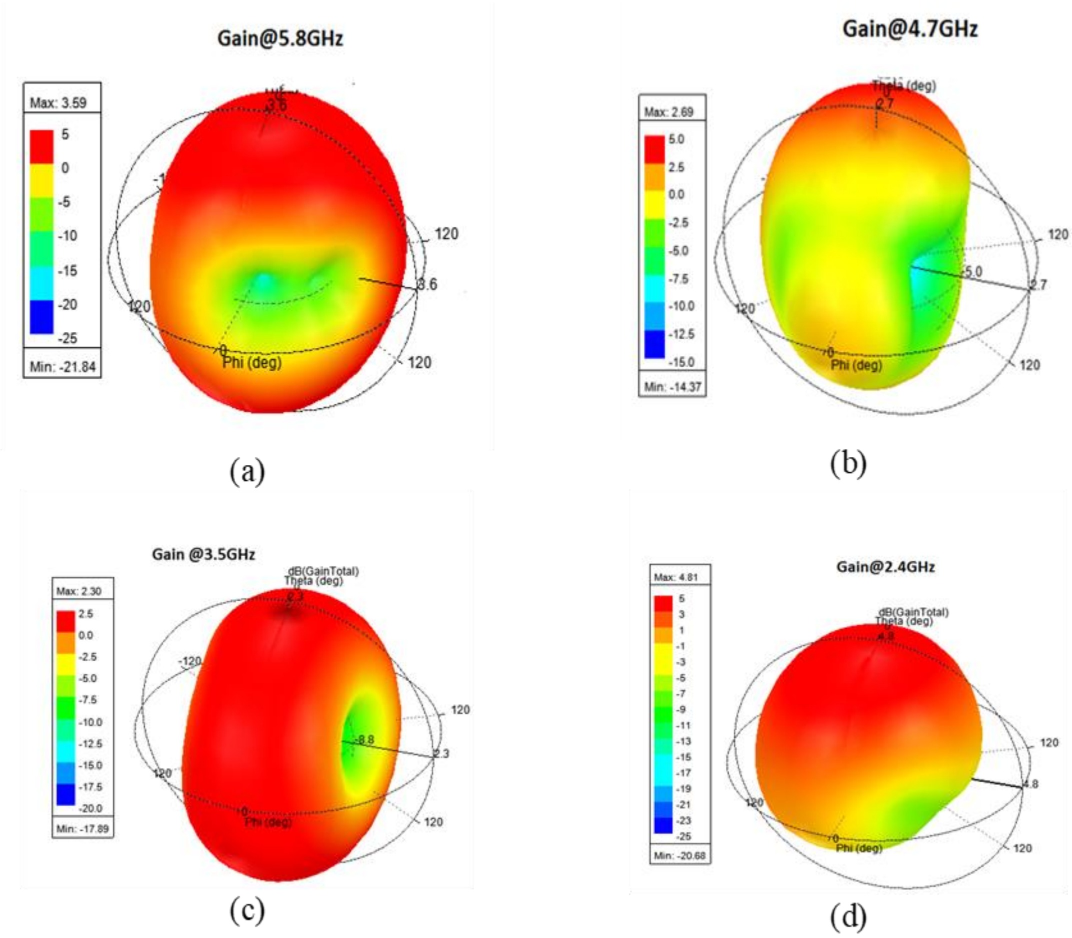


Fig. 10 3D radiation pattern at various operating frequencies (a) 5.8 GHz (b) 4.7 GHz (c) 3.6 GHz (d) 2.4 GHz.

4. Conclusion

In this paper, a novel multi band frequency reconfigurable monopole antenna is proposed. It is designed to resonate at one dual band mode and three single band modes. Desired resonating frequencies are achieved by using different RF PIN diode switching states. By employing 3 PIN diodes, the antenna has the ability to produce one dual band (2.4 at Wi-Fi applications and 6.2 at C band) and 3 single bands at 3.5 GHz (Sub 6 GHz frequency for 5G applications), 4.7 GHz (Vo5G), 5.8 GHz (V2x communications). The satisfactory efficiencies, good bandwidth, radiation pattern, gain and best impedance matching were obtained in various operating conditions of the proposed antenna. The designed antenna is compact (35mm×35mm×1.6mm), simple integration with modern devices and easy to fabricate. The measurement is done for the parameters like radiation pattern, VSWR and the reflection coefficient using BAR-50,02 V RF PIN diode in the fabricated antenna. The simulated results also validate the measurement results.

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

References

[1] U. George, L. Fang, A simple frequency and polarization reconfigurable antenna, *Electromagnetics*, 2020, **40**, 435-444, doi: 10.1080/02726343.2020.1811940.

[2] A. Iqbal, S. Ullah, U. Naeem, A. Basir, Design, Fabrication and measurement of a compact, frequency reconfigurable, modified t-shape planar antenna for portable applications, *Journal of Electrical Engineering and Technology*, 2017, **12**, 1611-1618, doi: 10.5370/JEET.2017.12.4.1611.

[3] H. Dildar, F. Althobiani, I. Ahmad, W. U. R. Khan, S. Ullah, N. Mufti, S. Ullah, F. Muhammad, M. Irfan, A. Glowacz, Design and experimental analysis of multiband frequency reconfigurable antenna for 5G and sub-6 GHz wireless communication, *Micromachines*, 2020, **12**, 32, doi: 10.3390/mi12010032.

[4] G. Jin, C. Deng, J. Yang, Y. Xu, S. Liao, A new differentially-fed frequency reconfigurable antenna for WLAN and sub-6GHz 5G applications, *IEEE Access*, 2019, **7**, 56539-56546, doi: 10.1109/ACCESS.2019.2901760.

[5] C.-Y. Chiu, J. Li, S. Song, R. D. Murch, Frequency-reconfigurable pixel slot antenna, *IEEE Transactions on Antennas and Propagation*, 2012, **60**, 4921-4924, doi:

10.1109/TAP.2012.2207334.
[6] B. A. Cetiner, G. Roqueta Crusats, L. Jofre, N. Biyikli, RF MEMS integrated frequency reconfigurable annular slot antenna, *IEEE Transactions on Antennas and Propagation*, 2010, **58**, 626-632, doi: 10.1109/TAP.2009.2039300.
[7] A. Dey, R. Guldiken, G. Mumcu, Microfluidically reconfigured wideband frequency-tunable liquid-metal monopole antenna, *IEEE Transactions on Antennas and Propagation*, 2016, **64**, 2572-2576, doi: 10.1109/TAP.2016.2551358.
[8] L. Ge, K. M. Luk, A band-reconfigurable directed dipole antenna, *2013 IEEE International Workshop on Electromagnetics, Applications and Student Innovation Competition*, 2013, 177-179, doi: 10.1109/iWEM.2013.6888803.
[9] A. Afridi, S. Ullah, I. Ali, S. Khan, J. A. Flint, Design and parametric analysis of a dual-band frequency reconfigurable planar dipole using a dual-band artificial ground plane, *IETE Journal of Research*, 2014, **60**, 3-11, doi: 10.1080/03772063.2014.890803.
[10] I. A. Shah, S. Hayat, A. Basir, M. Zada, S. A. A. Shah, S. Ullah, S. Ullah, Design and analysis of a hexa-band frequency reconfigurable antenna for wireless communication, *AEU - International Journal of Electronics and Communications*, 2019, **98**, 80-88, doi: 10.1016/j.aeue.2018.10.012.
[11] J.-S. Row, J.-F. Tsai, Frequency-reconfigurable microstrip patch antennas with circular polarization, *IEEE Antennas and Wireless Propagation Letters*, 2014, **13**, 1112-1115, doi: 10.1109/LAWP.2014.2330293.
[12] S. K. Muthuvel, Y. K. Choukiker, Wideband frequency agile and polarization reconfigurable antenna for wireless applications, *IETE Journal of Research*, 2023, **69**, 1529-1538, doi: 10.1080/03772063.2020.1871421.
[13] H. F. Abutarboush, R. Nilavalan, S. W. Cheung, K. M. Nasr, T. Peter, D. Budimir, H. Al-Raweshidy, A reconfigurable wideband and multiband antenna using dual-patch elements for compact wireless devices, *IEEE Transactions on Antennas and Propagation*, 2012, **60**, 36-43, doi: 10.1109/TAP.2011.2167925.
[14] I. Nazir, I. Elahi Rana, N. U. A. Mir, K. Afreen, Design and analysis of a frequency reconfigurable microstrip patch antenna switching between four frequency bands, *Progress in Electromagnetics Research C*, 2016, **68**, 179-191, doi: 10.2528/pierc16052405.
[15] S. Ullah, S. Ahmad, B. A. Khan, U. Ali, F. A. Tahir, S. Bashir, Design and analysis of a hexa-band frequency reconfigurable monopole antenna, *IETE Journal of Research*, 2018, **64**, 59-66, doi: 10.1080/03772063.2017.1347072.
[16] X. Bai, M. Su, Y. Liu, Y. Wu, Wideband pattern-reconfigurable cone antenna employing liquid-metal reflectors, *IEEE Antennas and Wireless Propagation Letters*, 2018, **17**, 916-919, doi: 10.1109/LAWP.2018.2823301.
[17] T. Khan, M. Rahman, Design of low-profile frequency reconfigurable antenna for multiband applications, *International Journal of Electronics Letters*, 2022, **10**, 30-47, doi: 10.1080/21681724.2020.1818836.
[18] H.-D. Chen, H.-T. Chen, A CPW-fed dual-frequency monopole antenna, *IEEE Transactions on Antennas and Propagation*, 2004, **52**, 978-982, doi: 10.1109/TAP.2004.825620.
[19] S. Subbaraj, M. Kanagasabai, M. G. N. Alsath, S. K. Palaniswamy, S. Kingsly, I. Kulandhaisamy, A. K. Shrivastav, R. Natarajan, S. Meiyalagan, A compact frequency-reconfigurable antenna with independent tuning for hand-held wireless devices, *IEEE Transactions on Antennas and Propagation*, 2020, **68**, 1151-1154, doi: 10.1109/TAP.2019.2938668.
[20] W. A. Awan, N. Hussain, S. A. Naqvi, A. Iqbal, R. Striker, D. Mitra, B. D. Braaten, A miniaturized wideband and multi-band on-demand reconfigurable antenna for compact and portable devices, *AEU - International Journal of Electronics and Communications*, 2020, **122**, 153266, doi: 10.1016/j.aeue.2020.153266.
[21] D. Piazza, N. J. Kirsch, A. Forenza, R. W. Heath, K. R. Dandekar, Design and evaluation of a reconfigurable antenna array for MIMO systems, *IEEE Transactions on Antennas and Propagation*, 2008, **56**, 869-881, doi: 10.1109/TAP.2008.916908.
[22] V. K. Kunda, M. Ali, Reconfigurable stacked patch antenna for satellite and terrestrial applications, *2003 IEEE Topical Conference on Wireless Communication Technology*, 2003, 152-153, doi: 10.1109/WCT.2003.1321465.

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