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WI-FI Reconfigurable Dual Band Microstrip MIMO Antenna for 5G and wI-FI WLAN Applications

Abstract - *In this paper, a 2×2 MIMO reconfigurable Wi-Fi notch two port antenna is presented. A 'Tee' shaped stub has been accomplished on the ground of MIMO antenna to achieve isolation more than 18dB. In addition, a parasitic elements integrated with a PIN diode is introduced on the ground of the antenna for frequency reconfigurability. However, notch is introduced with parasitic stub in the ground, which is tuned by PIN diode and controls the undesired signal and reduce the interference of signal. The operating frequency band of the two-port antenna is found to be from 3.2GHz to 3.8 GHz and 5.2 GHz to 7 GHz (with notch) whereas 3.2 to 3.8 and 4.95 to 7.2 GHz (without notch). The prototype of the proposed structure is of size 40×34×0.8 mm^3. The MIMO performance characteristics are measured and analyzed, and it is observed that the two-port antenna is appropriate for high- speed network for 5G and Wi-Fi/WLAN applications.*

Streszczenie. *W artykule przedstawiono dwuportową antenę Wi-Fi rekonfigurowalną 2 × 2 MIMO. Na uziemieniu anteny MIMO wykonano króciec w kształcie „trójnika", aby uzyskać izolację większą niż 18 dB. Dodatkowo elementy zintegrowane z diodą PIN są wprowadzane na uziemienie anteny w celu rekonfiguracji częstotliwości. Wprowadzono karb z bolcem w ziemi, który jest dostrajany przez diodę PIN i kontroluje niepożądany sygnał i redukuje zakłócenia sygnału. Stwierdzono, że pasmo częstotliwości pracy anteny dwuportowej wynosi od 3,2 GHz do 3,8 GHz i od 5,2 GHz do 7 GHz (z wycięciem), natomiast od 3,2 do 3,8 i od 4,95 do 7,2 GHz (bez wycięcia). Prototyp proponowanej konstrukcji ma wymiary 40 × 34 × 0,8 mm3. Charakterystyki wydajności MIMO są mierzone i analizowane i obserwuje się, że dwuportowa antena jest odpowiednia dla szybkich sieci dla aplikacji 5G i Wi-Fi / WLAN.* (***WI-FI rekonfigurowalna dwuzakresowa antena MIMO z mikropaskami do zastosowań 5G i WI-FI / WLAN***)

Keywords: MIMO antenna, Reconfigurable antenna, PIN diode, Mutual coupling reduction, 5G network
Słowa kluczowe: antena MIMO, antena dwuzakresowa rekonfigurowalna, pasmo 5G

Introduction

The demand for low-profile antennas with high gain and stable radiation characteristics in a new generation of wireless devices has increased with the advancement of modern communication. Since microstrip antenna can be integrated directly into the circuit board, it played a key role in wireless communication applications such as smartphones, laptops, satellites, radars, missiles, and aircraft. For the sophisticated electronic gadgets, required antenna parameters such as high data rate, channel capacity between two antenna elements during the communication usually suffer from interference, multipath, and fading [1]. The single antenna is also concerned with system performance [2] whereas MIMO is one of the techniques in which multiple antennas are used [3]. The designing of the MIMO system in a small space is challenging because the low distance between antenna elements leads to a mutual coupling whereas researchers have designed different decoupling structures in MIMO antenna to overcome this problem. The reconfigurable antennas are found desirable in MIMO systems as they suppress the interference, increases the signal strength and data rate, and improves the isolation characteristics among wireless communication systems [4] also tuned the desired operating frequencies. Many of the MIMO - based frequency reconfigurable antenna design has been studied in the literature, to combine the capabilities of MIMO and the characteristics of frequency reconfigurable antennas [5-7]. In [10], the isolation between two antennas is increased up to 16.8 dB by introducing two decoupling structures in MIMO reconfigurable antenna. In [11], the universal mobile telecommunication system (UMTS) band is increased by adaptive reconfigurable monopole and dipole antenna, hence, the channel capacity increases. The notch is introduced [8, 9] in the antenna to overcome the interference in communication system. In this work, 2x2 MIMO antenna is designed with an integrated PIN diode in parasitic stub etched on the antenna ground on backside of both radiators for Wi-Fi (5GHz) frequency notch whereas the 5G and WLAN bands are fixed.

Proposed Antenna Design for Two Port

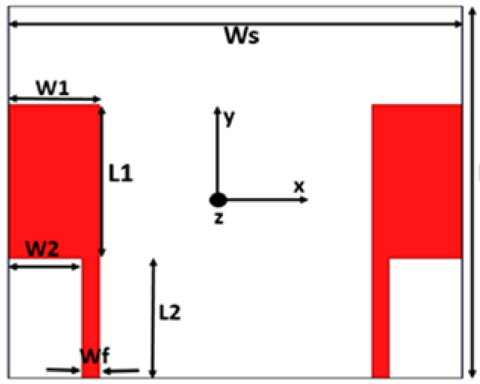
The simple geometric structure of the two-port antenna element with its geometric parameters is illustrated in Table 1. A design is printed with 0.8 mm thickness and dielectric permittivity (4.4) on FR4 substrate. The dimensions of the two-port antenna are 40 X 34mm^2. The feed length and width are 11 X 1.5 mm^2 that is working as a transmission line with 50 Ω impedance where radiating element size is 14×8 mm^2. Figures 1(a) and 1(b) show the two-port antenna geometry, and figure 1(c) depicts the hardware prototype.

Table 1. Dimensions of proposed antenna structure (mm)

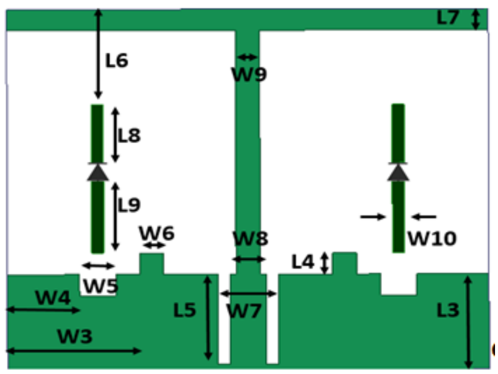
Ws	*Ls*	*Wf*	*L1*	*W1*	*W2*	*W3*	*W4*
40	34	1.5	14	8	6.5	11	6
L2	*L3*	*L4*	*L5*	*W5*	*W6*	*W7*	*W8*
11	9	2	8.5	3	2	5	3
L6	*L7*	*L8*	*L9*	*W9*	*W10*	*t*	
9	2	5.5	6.9	2	1	0.8	

In the first step, a single-element antenna is designed with a rectangular radiator and partial ground, depicted in figure2(a). The dimension of a substrate (width x length) is 40 mm x 34 mm whereas the width x length of ground and radiator are 20 mm x 9 mm and 8 mm x14 mm. The |S11| of single element antenna varies from 2.9 GHz to 3.8 GHz and 5.5 GHz to 7.1 GHz as shown in figure 2(b). In the second step, the symmetric mirror structure is accomplished in the substrate to design the MIMO antenna as depicted in figure 3(a).Now the |S11| varies from 3.1 GHz to 3.9 GHz, 5.2 GHz to 7 GHz as depicted in figure 3(b), and the isolation between the two elements is 12dB. In the third step, two symmetric open stubs are introduced into the ground to diminish the electromagnetic coupling and reduce the surface current between one element to another as depicted in figure 4(a). The variation in the ground plane further S-parameter and isolation enhances, as represented by figure 4(b). In the fourth step, the 'Tee' stub is introduced into the ground to diminish the surface current, which enhances the isolation between two antennas by more than 18 dB and the S- parameter variation in frequency ranges from 3.15 to 3.85 GHz and 4.95 GHz to 7 GHz with more than 18 dB isolation. In step 5, parasitic strip behind both radiator with BAR 6402 PIN diode is accomplished on the ground, which is approximately $\frac{\lambda}{4}$ (14 mm) of resonant frequency of notch, as depicted in figure 1(b). The s-parameter varies from 3.2 GHz to 3.8 GHz and 5.2 GHz to 7 GHz with a notch (PIN diode is ON) and 3.2 to 3.8 and 4.95 to 7.2 GHz without the notch (PIN diode is OFF) with more than 18 dB isolation, as depicted in figures 6(a) and 6(b). The RF PIN diode work like a switch using a lumped R-L-C equivalent of a diode circuit is discussed [12]. The PIN diode equivalent circuit in OFF and ON state is analysed on QUCS software as represented in figures 7(a) and 7(b) as ON and OFF conditions.

a)



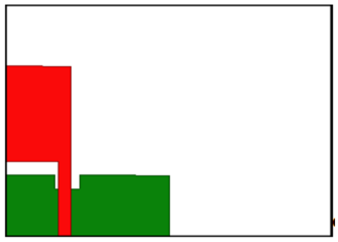
b)



c)

Fig.1.Designing of proposed two port antenna(a) in front view (b)bottom view with parasitic patch and (c) prototype

a)



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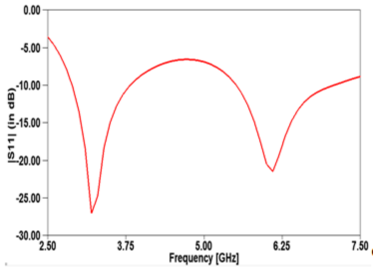
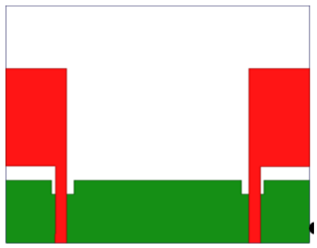


Fig2. (a)Step-1 designing of single element antenna and (b) S parameters

a)



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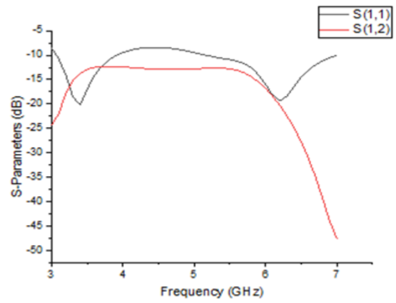
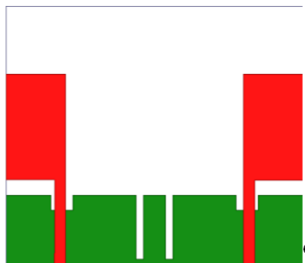


Fig3. (a)Step-2 designing of two port antenna and (b) S parameters and isolation curve

a)



b)

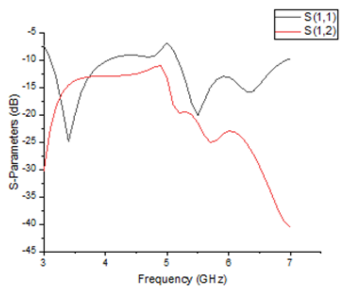


Fig.4. (a)Step-3 designing of two port antenna and (b) S parameters and isolation curve

a)

b)

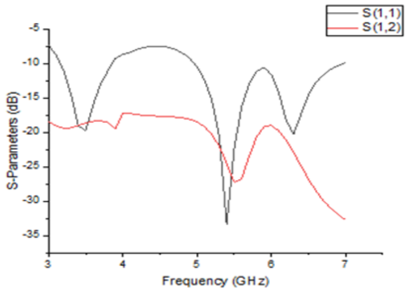
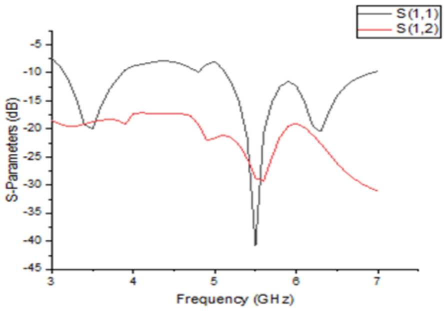


Fig.5.(a) Step-4 designing of a two-port antenna with T stub and (b) S- parameters and isolation curve

a)



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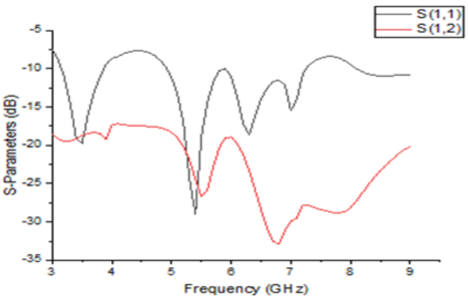
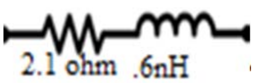


Fig 6 Simulated S-parameter and isolation curve of the proposed antenna when PIN diode (a) ON Condition and (b) OFF Condition

a)



b)

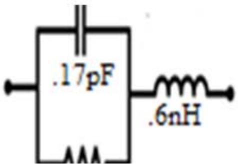
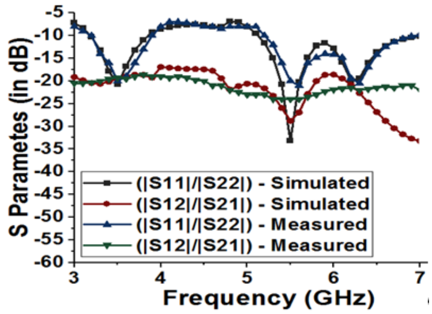


Fig.7. Equivalent circuit of PIN diode when (a) ON state and (b) OFFstate

Analysis of Experimental Results

The proposed two-port antenna is simulated with HFSS13, and performances of the prototype are measured with Anritsu VNA (MS2038C), and obtained results in different biasing states of PIN diode are illustrated in Figures.8(a) and 8(b). The |S11| varies from 3.2 GHz to 3.8 GHz and 5.2 GHz to 7 GHz when the PIN diode is ON and 3.2 GHz to 3.8 GHz and 4.95 GHz to 7.2 GHz when PIN diode is OFF with consistent isolation of more than 18 dB. The gains are depicted in figures 9(a) and 9(b) in different states and their maximum goes up to 5.4dB. The normalized radiation patterns are presented in figures 10(a)-10(d), in x-z and y-z directions where the stable radiation pattern is achieved. The high cross-polarization is achieved in the y-z plane where it can be used in portable devices such as wearable applications and mobile communication [13].

a)



b)

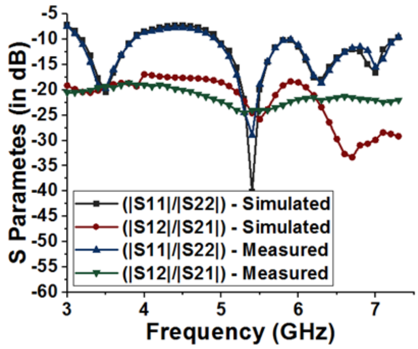
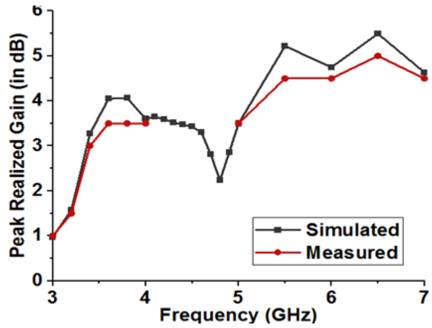


Fig 8 S- parameter and isolation curve of the proposed two-port antenna when PIN diode (a) ON condition and (b) OFF condition

a)



b)

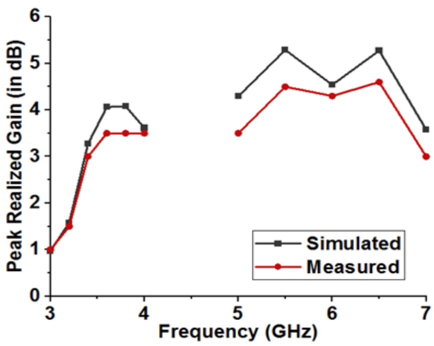
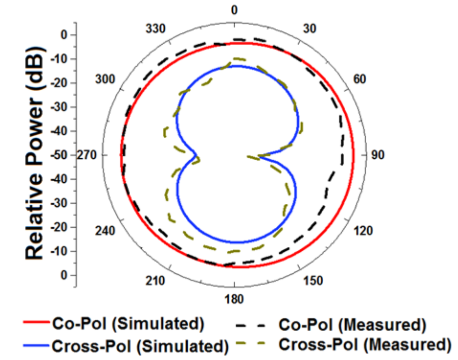
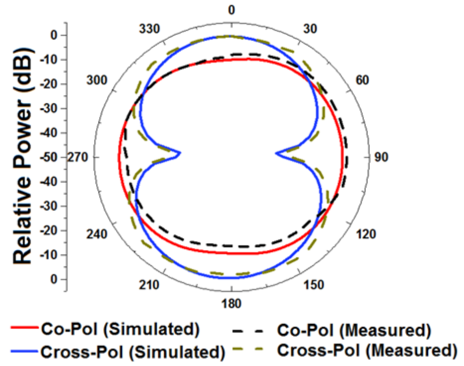


Fig.9. Peak realized Gain when PIN diode(a) ON condition and (b) OFF condition

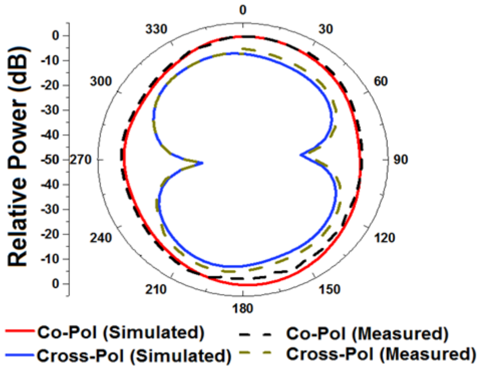
a)



b)



c)



d)

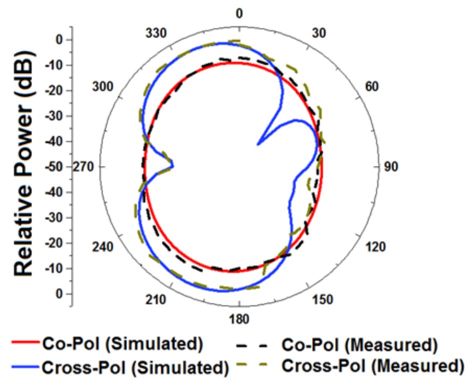


Fig.10. Normalized radiation patterns(a)at 3.5 GHz in x-z plane (b) at 3.5 GHz y-z plane (c) at 5.5 GHz in x-z plane and (d) at5.5 GHz in y-z plane

MIMO Antenna performances analysis

For the MIMO technique, the performances such as Envelope Correlation Coefficient (ECC), Total Active Reflection Coefficient (TARC), Diversity Gain (DG), and Channel Capacity Loss (CCL) are calculated and analyzed this extracted from equation (1) to equation (4)[13]. The ECC represents, how the radiation patterns of antenna elements are a distinct amount of correlation. The ECC is measured in terms of S - parameter for two antenna elements are calculated [13] by equation (1)

(1) $$ECC = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|}{\left(1-\left|S_{11}\right|^{2}-\left|S_{21}\right|^{2}\right)\left(1-\left|S_{22}\right|^{2}-\left|S_{12}\right|^{2}\right)}$$

where S11, S22 are reflection coefficients and S12, S21 are coupling coefficients. For design purposes, the acceptable value should be less than 0.5. The experimental value is 0.02 as shown in Fig.11. The second characteristics are Diversity Gain and which is measured on a dB scale and calculated [13] by equation (2). The calculated value is depicted in Figure12. The experimental DG value is close to 10 dB.

(2) $$\mathrm{DG} = 10\sqrt{1-\mathrm{ECC}^{2}}$$

Another MIMO characteristic is TARC, and which is calculated by equation (3). The calculated TARC value is less than -10 dB as shown in figure 13.

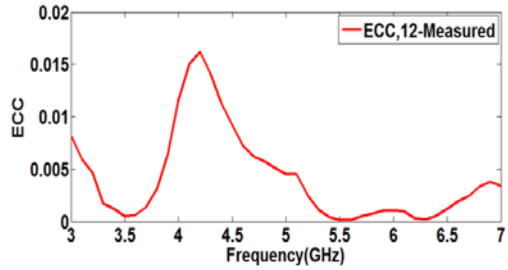
(3) $$\mathrm{TARC}=\frac{\sqrt{(S_{11}+S_{12})^{2}+(S_{21}+S_{22})^{2}}}{\sqrt{2}}$$

The last characteristic is CCL extracted from equation (4). The calculated CCL is plotted in figure 14, and its value is less than 0.04 bits/s/Hz within our useful range.

(4) $$\mathrm{CCL} = -\log_{2}\det(a)$$

where $$a = \begin{bmatrix}\sigma_{11} & \sigma_{12}\\ \sigma_{21} & \sigma_{22}\end{bmatrix}$$

a)



b)

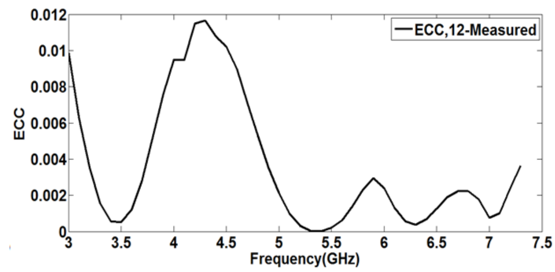
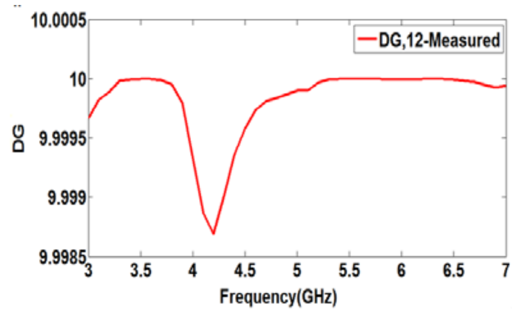


Fig.11. ECC when PIN diode (a) ON state and (b) OFF state

a)



b)

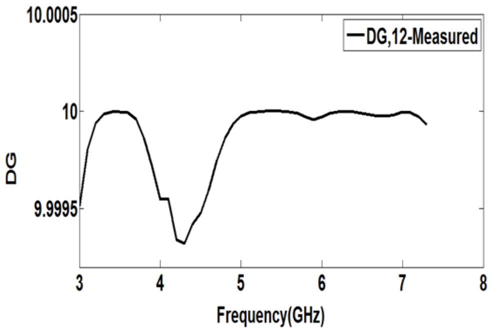
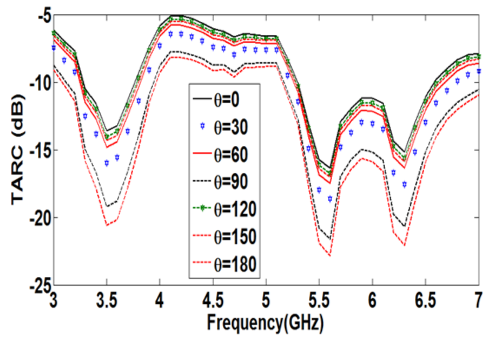


Fig.12. DG when PIN diode(a) ON state and (b) OFF state

a)



b)

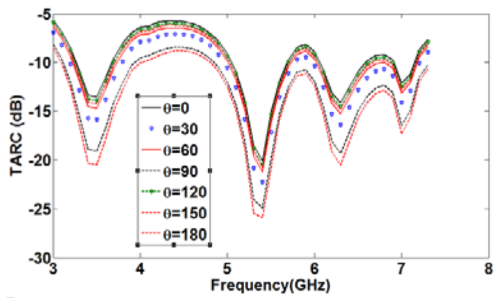
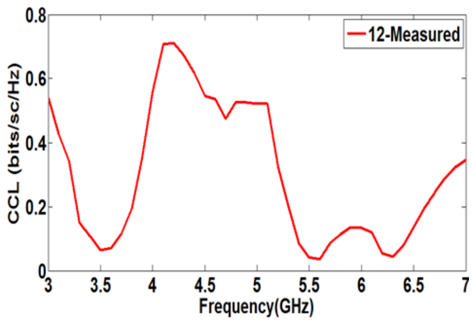


Fig.13.TARC.when PIN diode (a) ON condition and(b) OFF Condition

a)



b)

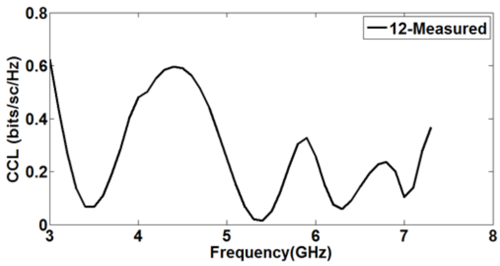


Fig.14. CCL when PIN diode (a) ON conditionand (b) OFF condition

Table.2 illustrated the proposed two-port antenna and compared it with another reconfigurable MIMO antenna. The two-port antenna has achieved high isolation with compact size. The comparison of obtained results with existing results reveals that the proposed antenna provides three frequency bands in the range of 3.2GHz- 6.8 GHz using a simple RF diode, which is better than the results reported in the available literature.

Table 2. proposed two-port antenna

Ref	Size	Type of RF Switch	Frequency range	Isolation (dB)
Ref 4	60×120 mm^2	Varactor	3.2 GHz - 3.9 GHz	=10dB
Ref 5	120×60 mm^2	Varactor	1.3 GHz- 2.6 GHz	> 12dB
Ref 6	32×98 mm^2	MEMS Switch	1.3 GHz- 5.5 GHz	> 15dB
Ref 7	66×38 mm^2	PIN	3.5 GHz	> 15dB
Ref 8	46×36 mm^2	PIN	2.4 GHz- 7 GHz	<15 dB
Ref 9	46×20 mm^2	MEMS Switch	4.9 GHz- 5.725 GHz	> 18dB
Ref 10	80×45 mm^2	PIN	2.1 GHz- 2.7 GHz	> 16.8dB
Ref 11	95×60 mm^2	PIN	UMTS bands	>14
Proposed	40×34 mm^2	PIN	**5G (3.2-3.8 GHz) , and Wi-Fi/WLAN (5-6.8 GHz) bands**	> 18dB

Conclusion

In this paper, a PIN diode integrated over a two-port antenna with a reconfigurable notch based on a parasitic slot in the ground is presented. The frequency covers from 3.2 GHz to 3.8 GHz and 5.2 GHz to 7 GHz in ON condition and 3.2 GHz to 3.8 GHz, and 4.95 GHz to 7.2 GHz in OFF condition of the PIN diode. It covers frequency ranges of different services; 5G (3.2 to 3.8 GHz), WLAN (5.15 and 5.85 GHz), and WI-FI (5GHz). A slotted rectangular 'Tee' stub and symmetric open stub considerably enrich the isolation by approximately more than 18dB.

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