TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 1, February 2020, pp. 10~18
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i1.12699

Frequency reconfigurable monopole antenna with harmonic suppression for IoT applications

Alaa Imran Al-Muttairi, Malik Jasim Farhan
College of Engineering, Mustansiriyah University, Iraq

Article Info

Article history:

Received Mar 17, 2019
Revised Jul 2, 2019
Accepted Jul 21, 2019

Keywords:

IoT
Reconfigurable antenna
Harmonic suppression
Wi-Fi 6

ABSTRACT

This work proposes a new reconfigurable printed monopole antenna for IoT devices working with the promising wireless technology Wi-Fi 6. Based on effective resonant length value, the antenna has the ability to reconfigure its operating band between 2.4 GHz and 5 GHz ISM bands. Therefore, the designed antenna works as an RF band-pass filter which reduces receiver complexity and supports network scalability. One PIN diode with complete biasing circuit is integrated to the antenna radiator to obtain re-configurability. Furthermore, two stubs are added to the antenna structure in order to suppress harmonic component which appears near to the higher band (5 GHz) when antenna forced to work at the lower band (2.4 GHz). The design built over commercially available FR-4 substrate with a compact size of (33.5x16x1.6) mm^3. CST software is used to simulate antenna performance in terms of flection coefficient, radiation pattern, efficiency, and gain.

Corresponding Author:

Alaa Imran Al-Muttairi,
College of Engineering,
Mustansiriyah University,
Baghdad, Iraq.
Email: al_al_44@itnet.uobabylon.edu.iq

1. INTRODUCTION

Internet of Things (IoT) technology aims to map all physical objects in real life to the virtual world to create an intelligent environment [1, 2]. Due to the natural of IoT technology, a few data rate in transmission, relax bandwidth, small physical size and acceptable communication range are required [3, 4]. Moreover, most IoT devices use free license ISM bands to contact world. Based on the above requirements, the sixth generation of Wi-Fi wireless standard named Wi-Fi 6 or (IEEE 802.11 ax) is expected to be available in the next few months. This series implemented TWT mechanism which supports IoT devices [5]. According to cisco publication, Wi-Fi 6 device will use 2.4 GHz and 5 GHz bands and it has a high degree of compatibility with older Wi-Fi versions. However, it is estimated in 2021, there will be 50 billion IoT devices able to communicate and share information over the internet such as automation system, home appliances, vehicles, smart cities, e-health [2, 5-7]. This large number of wireless devices will rise band congestion problem, increase packet collisions in uplink access channels, and hence consume limited power resources. To fulfill all previous problems with a compact physical size, the reconfigurable antenna is one of the best available solutions. Reconfigurable antenna is a dynamic antenna which has the ability to modifying its properties such as frequency, radiation patterns and/or polarization in order to adapt the environment [8-12]. Comparing to multiband antennas, reconfigurable antennas offer many advantages like pre-filtering, reduce complexity, saving space and relatively low cost. Frequency re-configurability can be realized by integrating lamped element such as PIN diodes, MEMS switches, or varactors in antenna body. Basically, these elements may modify the effective length of an antenna and hence change antenna's operating frequency [13].

By using affordable and cheaper materials, numerous frequency reconfigurable antennas are reported in the literature. In [14], Frequency reconfigurable monopole antenna is designed to switch between several bands using three PIN diodes. Actually, these diodes altered antenna effective length to change resonant frequency. In [15], they designed F-shape frequency reconfigurable antenna which has the ability to hope among six frequencies. Cheap materials like RF-4 substrate, two PIN diodes, and truncated ground plane, are used to build the antenna. While this antenna covered almost ISM bands, it has a big size and high order harmonic component which clearly appeared in the reflection coefficient plot for each switch mode. Starting from the multiband antenna, authors in [16] developed a reconfigurable antenna for Wi-Fi, WiMax, and WLAN applications. The design has compact size put it did not cover the entire 5 GHz band in one switch mode. [17] showed a reconfigurable monopole antenna which can be used for multi-radio wireless systems. Good antenna performance is observed at the four bands. In addition to large size, any system attached to this antenna needs a filter to reject some bands. In [18], a dual-band monopole antenna for WiMax system has been introduced. The designed antenna used varactor diode to tune frequency bands. However, it has low efficiency and gain with a relatively large area. The study in [8] presents compact size and ten bands frequency reconfigurable antenna for WLAN and WiMAX systems. Design process implemented SPICE models together with miniaturization technique to achieve all author's goals. In [19], two frequency reconfigurable monopole antennas are proposed for WiMax and WLAN utilization. The antennas have a real small size and good performance. Unfortunately, the authors obtained configurability by utilizing copper tape and gab to simulate ON and OFF diode states respectively.

To this end, obtaining compact size and single-band reconfigurable monopole antenna is still a challenge. In this paper, a small size and frequency reconfigurable monopole antenna are designed over commercially available FR-4 substrate. Two single-bands (2.4 GHz or 5 GHz) in the ISM spectrum region are obtained. The proposed antenna has the ability to hope between the 2.4 GHz and the entire 5 GHz bands of Wi-Fi 6. Therefore, the designed antenna will work as a band-pass filter which reduces receiver complexity. RF PIN diode with a complete biasing circuit is integrated into the antenna body to observe re-configurability.

2. ANTENNA GEOMETRY AND DESIGN

Compact size antenna with overall dimensions of (33.5x16x1.6) mm^3 is proposed using CST simulation tool. The designed antenna geometry and optimized dimensions are depicting in Figure 1 and Table 1 respectively. The designed antenna printed on both sides of the substrate. Commercially available FR-4 substrate (h = 1.6 mm, ε_r = 4.4 and tangent losses tan δ = 0.019) is used. Antenna's radiator consists of two segments separated by one PIN diode. The first one takes T-shape which generates the higher band (5 GHz). While, the second segment represented by C shape arm which is used to obtain the lower band (2.4 GHz). Microstrip feed-line of 3 mm width (50 Ω) is used to feed radiator. In addition, three slits of 1 mm and one slit of 0.7 mm are etched in the radiator in order to integrate diode and biasing elements respectively. The PIN diode works as a switch to control antenna operating band. The lower band is obtained when the diode at forward biasing (ON state) while the higher band is obtained at reverse biasing (OFF state). Also, the design implemented partially ground plane beneath the radiator at distance 1.6 mm. Two slots are made in the ground plane to increase impedance matching.

The proposed structure is inspired from the conventional printed monopole antennas reported in the related literature. Transmission line model in [20] is used to find, approximately, the required effective resonant length of each radiator segment at a specific frequency. Then all calculated lengths are optimized using parameters sweep process. Basically, the design process passed through four stages until the final geometry and performance are obtained as shown in Figure 2. In (Ant 1), copper tape and gap are used to simulate diode status in ON and OFF respectively. In this fundamental stage, the designed antenna resonated near to 2.45 GHz at ON state and near to 5.4 GHz at OFF state with acceptable bandwidth as shown in Figure 3 (purple and red curves). Also, a big harmonic component at 5 GHz region appears when diode force antenna to work at the 2.4 GHz band as shown in Figure 3 (red curve). Therefore, a large opened slot is made in the inner side of the C-arm to reduce that harmonic as shown in Ant 2 and Figure 3 (brown curve). It is worth mentioning that the big slot did not affect the value of the reflection coefficient at the higher band.

In Ant 3, PIN diode with its biasing circuit components are selected and integrated to CST model to make final optimization. However, by embedding these elements, the high order harmonic component becomes worst again. In order to suppress that component, two stubs are added to the C-arm as illustrated in Ant 3 and Ant 4. The positions of these stubs are determined using try and error method then parameters sweep process is used to calculate each stub dimensions. The first stub with dimensions (L2*W2) is attached to the arm's base while the second one with dimensions (L3*W3) is added to arm's top side. It is clear in Figure 4 (a) that the increasing of W2 to the same width of the arm's base shifts harmonic component out of the 5 GHz band while in Figure 4 (b) increasing L3 lead to push up S11 value above -10 dB. So that, W2 and L3 are selected to be 4mm and 2mm respectively. In the other side of substrate, partially ground with dimension of (Wg*Lg) is used. Two slots are etched in the ground to increase impedance matching at both operating bands. All dimensions related to the designed ground plane are calculated then optimized using parameters sweep function.

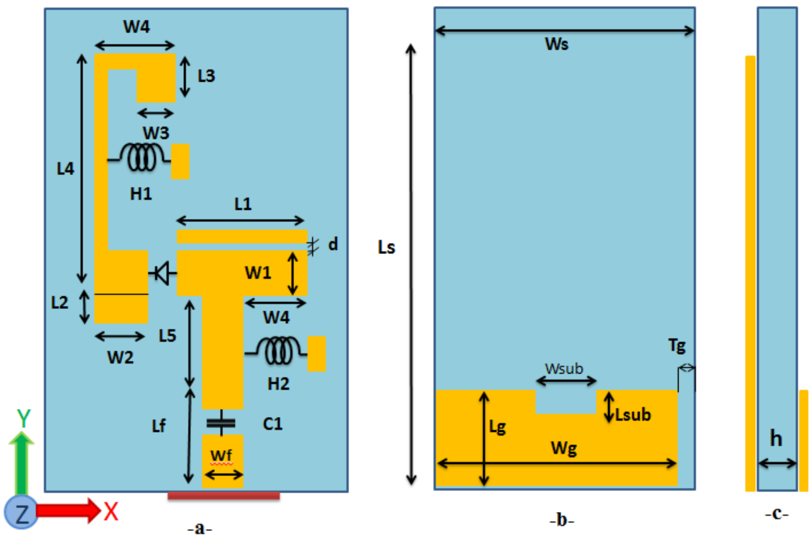


Figure 1. Antenna geometry: (a) Antenna radiator, (b) Ground Plane, (c) Side View

Table 1. Designed antenna dimensions

Parameter	Value (mm)	Parameter	Value (mm)
Ls	33.5	Wf	3
Ws	16	Lf	7.5
Lg	7.5	W1	2
L1	7.8	W2	4
L2	1.5	W3	2
L3	2	Lsub	1.5
L4	20	Wsub	5
L5	5.5	d	0.5
Tg	1.5	Wg	14.5

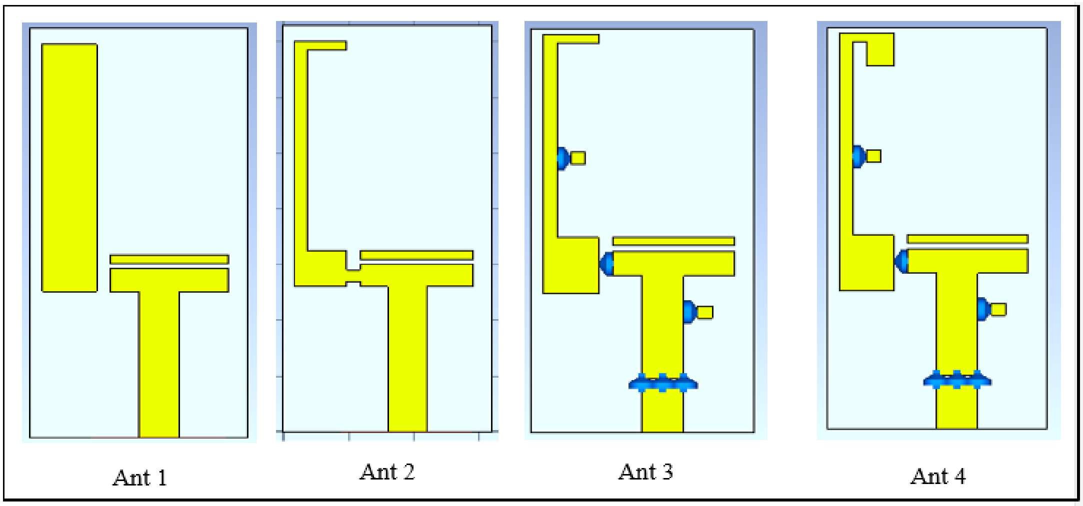


Figure 2. Antenna design stages

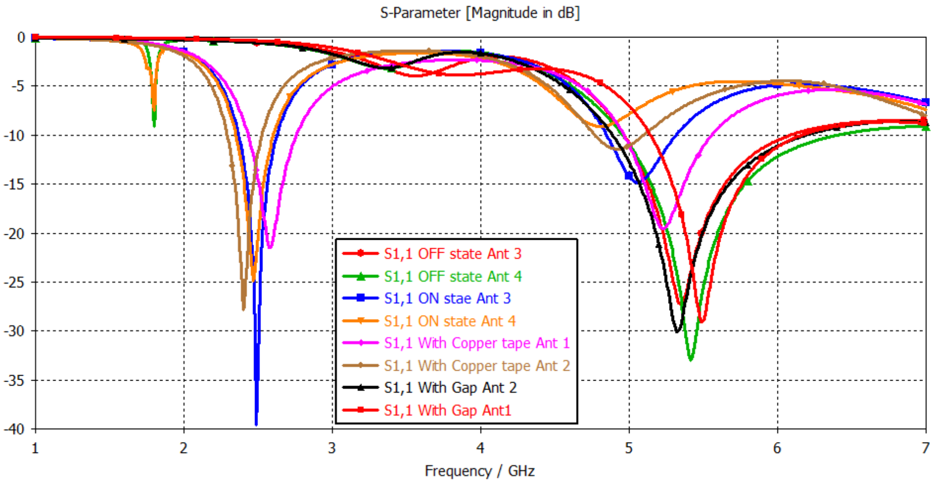
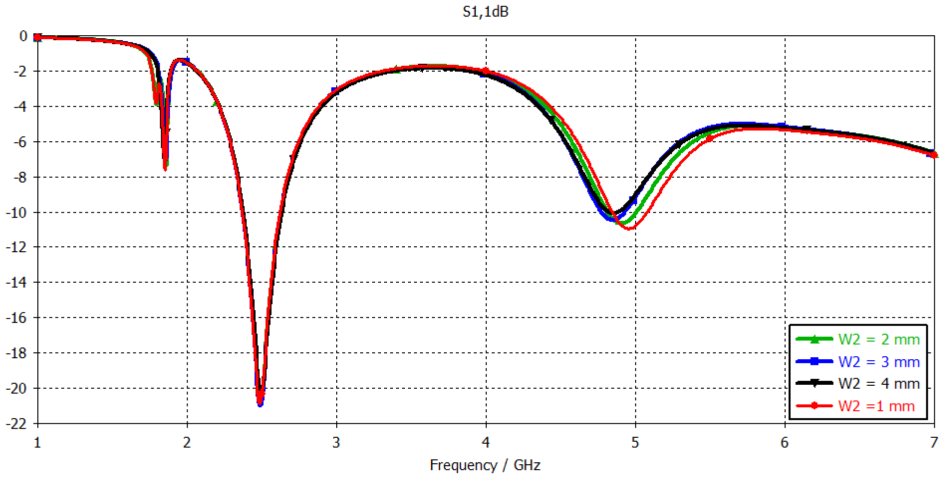
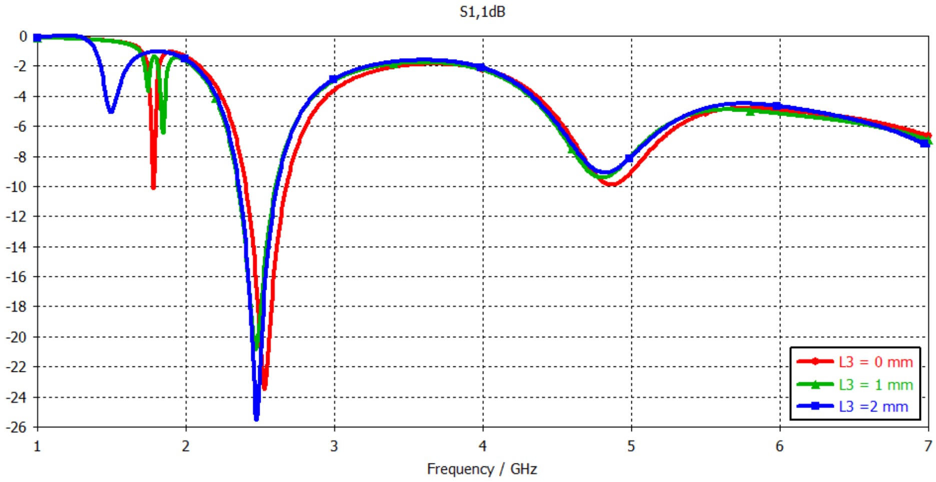


Figure 3. Reflection coefficient for Ant 1 to Ant 4



(a)



(b)

Figure 4. Harmonic component removing (a) Shift harmonic to left due to change in W2, (b) Left up harmonic component greater than -10 dB

3. DIODE SELECTION AND BIASING CIRCUIT

Beam-lead PIN diode (DSM8100-000) from Skyworks is used to obtain electrical frequency reconfigurability. Based on its interest advantages, such as high switching speed, small forward resistance (Rs), very low capacitance (Ct), low packaging inductance, and wide frequency range of operation, selection has been done. As illustrated in the data sheet [21], these specifications lead to minimize insertion losses in forward biasing (ON state) and increase isolation in reverse bias case (OFF state). In addition, a biasing network is designed as shown in the Figure 5. This circuit consists of two 47 nH inductors (H1 and H2) and three 1µF DC block capacitor (Cdc) [22, 23]. The two inductors values are selected using SRF value which is selected to be near to 2.45 GHz [24]. While, dc capacitors are selected based on parameters sweep until maximum dc buffering is obtained [25].

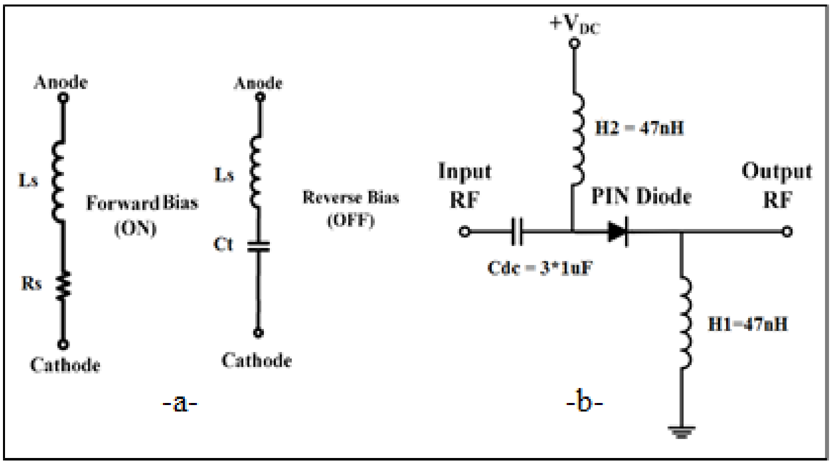


Figure 5. Equivalent circuit of PIN diode for ON and OFF stats

4. RESULTS AND DISCUSSION

AC In this section, simulation results for the input reflection coefficient, radiation pattern, gain, efficiency, and surface current distribution of the designed antenna are presented. Figure 6 shows both input reflection coefficients and impedance bandwidths at diode ON and OFF conditions. When diode in OFF state then this antenna covers the entire 5 GHz bands (4.95 GHz to 6.4 GHz) with an impedance bandwidth of 25.4 % and return loss near to -32.9 dB. On the other hand, the antenna covers a single narrow band starting from 2.35 GHz to 2.6 GHz when the diode in ON state. At this mode, the obtained impedance bandwidth and input reflection coefficient are 10.1% and -24.9 dB respectively. In fact, implemented harmonic suppression technique makes antenna operate in a a solo band at diode ON state. It should be noted here that the two slots in the ground plane and the parasitic element give good impedance matching for both bands. Figure 7 illustrates the radiation patterns for both PIN diodes ON and OFF states. In this work, YZ-plane has been taken as the E-plane (Phi = 90), and the XZ- as the H-plane (Phi = 0). An omnidirectional pattern at H-plane and bidirectional pattern at E plane are observed in both frequency bands. Little deviation in radiation null is occurred due to several reasons such as utilization of partial ground plane, patch asymmetric, and C-arm parasitic effect.

The designed antenna delivered gain of 1.5 dB and 3.5 dB at 2.4 GHz and 5 GHz bands respectively as in Figure 8. In fact, reductions in both gains occurred when an ideal switch is replaced by a real PIN diode. This is due to the effect of the internal resistor in ON forward biasing. However, these gains are acceptable for indoor communication. On the other hand, the obtained maximum radiation efficiencies are 80% in the 2.4 GHz band and 95% in the 5 GHz band as shown in Figure 9. In order to understand antenna performance and validate our theoretical calculations in both diode conditions, surface current distributions at two resonant frequencies (i.e. 2.45 GHz and 5.4 GHz) have been studied and illustrated in Figure 10. When diode in OFF state, surface current concentrates at the lower edges of the T-shape radiator segment with an overall resonant length value of (0.5*Lf+L2 = 9.25 mm). At ON state, surface current approximately, concentrates over the entire C-arm part and some edges of T-shape with overall resonant length value equal to (Lf+L5+L4+(L1-6.8) = 26.5 mm). According to the author's calculations, the required length to generate resonant frequency at 2.45 GHz and 5.4 GHz was 17 mm and 8mm respectively. These lengths are calculated using (1) in [15]. Actually, the above current distribution results come as expected. The small deviation between calculation and simulation (optimized lengths) may be due to different radiator width, diode and biasing effects, and the using of slots in the ground. Also, it is clear that both chocks are blocked the RF signal while DC capacitors at feed line pass RF signal to the antenna.

$$L_{monopole} = \frac{3*10^8}{4*f_r*\sqrt[2]{\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}(1+12(\frac{h}{W}))^{-0.5}}} \quad (1)$$

where $W = width\ of\ radaiting\ element$
$h = Substrate\ hight$
$\epsilon_r = relative\ permittivity\ for\ substrate$

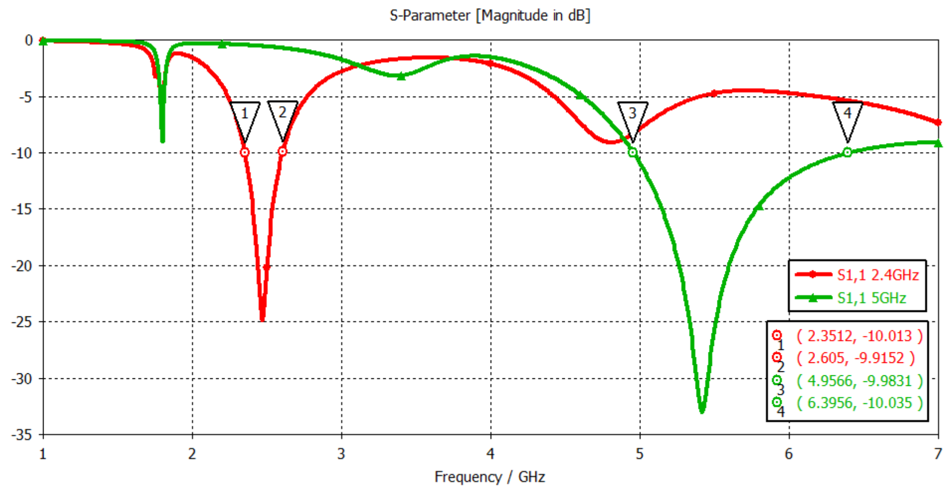
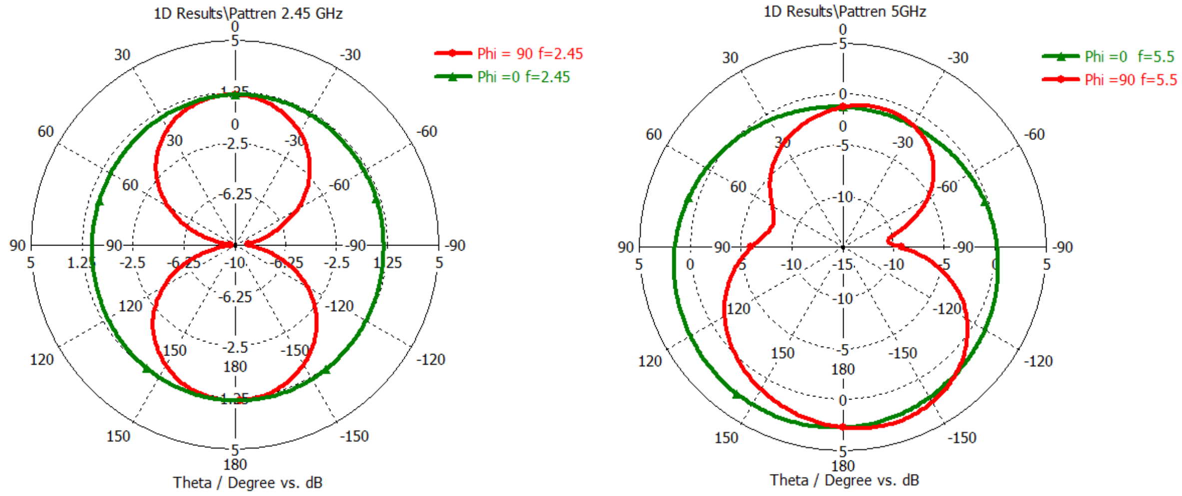


Figure 6. Refection coefficient for both obtained bands 2.4 GHz and 5 GHz



(a) (b)

Figure 7. E-plane (Phi = 0) and H-plane (Phi = 90) of designed antenna radiation pattern:
(a) ON state for 2.45 GHz, (b) OFF for 5.5 GHz state

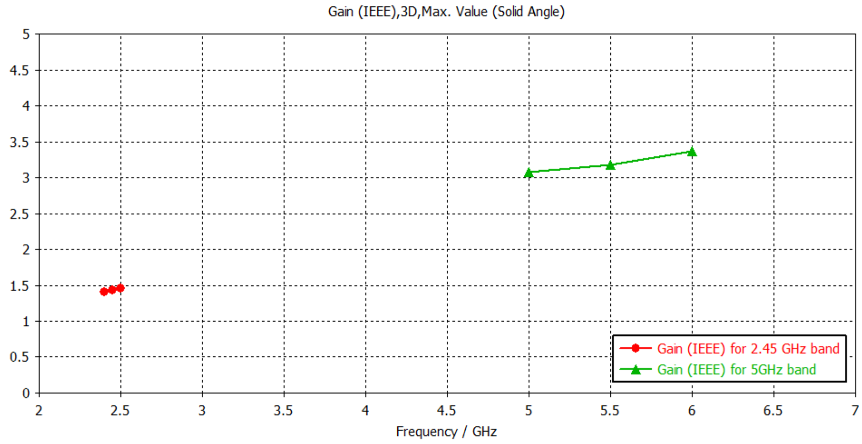


Figure 8. Designed antenna gains at 2.45 GHz and 5 GHz

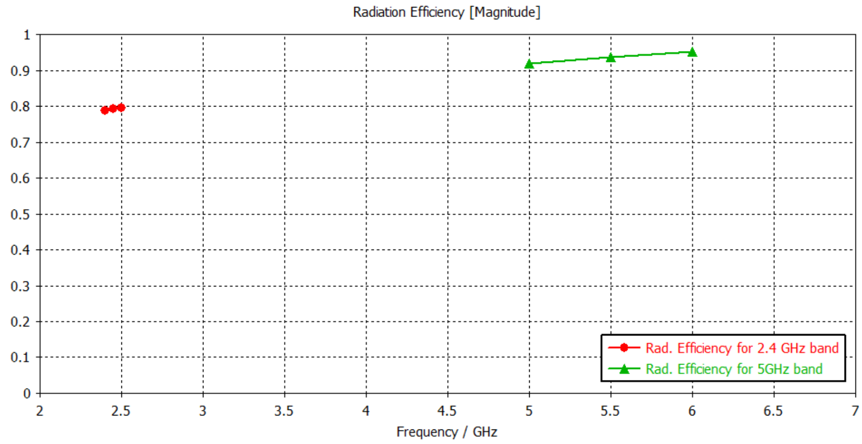


Figure 9. Designed antenna rad. Efficiency at 2.45 GHz and 5 GHz

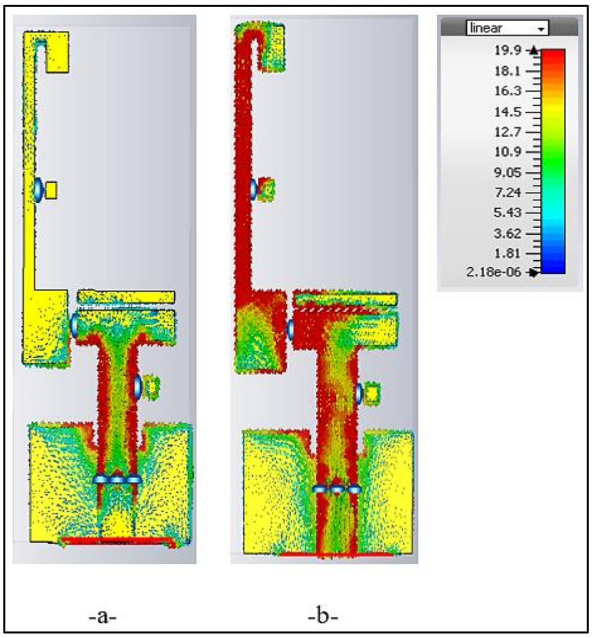


Figure 10. Current distribution of the proposed antenna:
(a) ON state at 2.45 GHz resonant freq., (b) OFF state at 5.4 GHz resonant freq.

5. CONCLUSION AND FUTURE WORK

This paper presents the design and simulation of a new frequency reconfigurable monopole antenna. The configurability is obtained by modifying antenna effective length using PIN diode as an electrical switch. When diode in OFF state, the antenna resonant at 5.4 GHz with an impedance bandwidth of (1.45 GHz) which covers the entire 5 GHz spectrum region. In contrast, when the diode to ON, the antenna resonant at 2.45 GHz with narrow bandwidth near to (0.25 GHz) covering the common 2.4 GHz band. At this state, a single band is obtained by eliminating associated harmonic component. Moreover, good impedance matching is obtained at the two bands with the help of two slots in the ground plane and one parasitic element. The designed antenna has many advantages such as compact size, low in cost, easy to fabricate. The proposed antenna was intended for IoT applications which use Wi-Fi 6 wireless technology. In the future work, we will investigate to put the designed antenna for MIMO channel.

ACKNOWLEDGEMENTS

The authors would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq) Baghdad-Iraq for its support in the present work.

REFERENCES

[1] Il-Gu Lee, Myungchul Kim, "Interference-aware self-optimizing Wi-Fi for high efficiency internet of things in dense networks," *Computer Communications*, vol. 80-90, pp. 60-74, 2016.
[2] Mansour, N. Shehata, et al., "Cognitive Band Manipulations using Twistable Paper-based Antenna for IoT Applications," *IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*, pp. 1265-1270, 2018.
[3] Hu, Peng Fei, et al., "Electrically Small, Planar, Complementary Antenna with Reconfigurable Frequency," *IEEE Transactions on Antennas and Propagatio*n, vol. 67, no. 8, pp. 5176-5184, 2019.
[4] L. Lizzi, F. Ferrero, et al. "Design of antennas enabling miniature and energy efficient wireless IoT devices for smart cities," *IEEE International Smart Cities Conference (ISC2)*, pp. 1-5, 2016.
[5] Baños-Gonzalez V, et al. "IEEE 802.11 ah: A technology to face the IoT challenge," *Sensors*, vol. 16, no. 11, pp. 1-21, 2016.
[6] Houret T, et al. "Energy efficient reconfigurable antenna for ultra-low power IoT devices," *in IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, pp. 1153-1154, 2017.
[7] Raad H., "A Yagi antenna array for conformal IoT and wireless charging applications," *Microwave and Optical Technology Letters*, vol. 61, pp. 1-5, 2018.
[8] Abdulraheem Y. I., et al. "Design of frequency reconfigurable multiband compact antenna using two PIN diodes for WLAN/WiMAX applications," *IET Microwaves, Antennas & Propagation*, vol. 11, no. 8, pp. 1098-1105, 2017.
[9] Han L, et al., "Compact frequency-reconfigurable slot antenna for wireless applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1795-1798, 2016.
[10] Basaran SC and Sertel K. "Dual-band frequency-reconfigurable monopole antenna for WLAN applications," *Microwave and Optical Technology Letters*, vol. 1, pp. 55-58, Jan. 2015.
[11] Kuo YL, and Wong KL. " Printed double-T monopole antenna for 2.4/5.2 GHz dual-band WLAN operations,". *IEEE Transactions on Antennas and Propagation*, vol. 9, pp. 2187-2192, 2003.
[12] Romputtal A, and Phongcharoenpanich C., "Frequency reconfigurable multiband antenna with embedded biasing network," *IET Microwaves, Antennas & Propagation*, vol. 11, pp. 1369-1378, 2017.
[13] Yang X, "Frequency reconfigurable circular patch antenna using PIN diodes," *in IEEE International Conference on Microwave and Millimeter Wave Technology (ICMMT)*, vol. 2, pp. 606-608, 2016.
[14] Shah IA, et al., "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.
[15] Ullah S., "A multi-band switchable antenna for Wi-Fi, 3G Advanced, WiMAX, and WLAN wireless applications," *International Journal of Microwave and Wireless Technologies*, vol. 10, no. 8, pp. 991-997, 2018.
[16] Shah S. A., "Design and measurement of planar monopole antennas for multi-band wireless applications," *IETE Journal of Research*, vol. 63, no. 2, pp. 194-204, 2017.
[17] Kumar A, and Sharma M. M., "A quad-band reconfigurable microstrip-fed circular disc monopole antenna for multiradio wireless systems," *in 2016 Asia-Pacific Microwave Conference (APMC) New Delhi*, pp. 1-4, 2016.
[18] Sun X. L., et al. "Frequency reconfigurable dual-band monopole antenna for WiMAX wireless devices," *Microwave and Optical Technology Letters*, vol. 56, pp. 49-55, 2013.
[19] Ullah S., "Design, fabrication and measurement of triple band frequency reconfigurable antennas for portable wireless communications," *AEU-International Journal of Electronics and Communications*, vol. 81, pp. 236-242, 2017.
[20] Balanis, Constantine A., "Antenna theory: analysis and design," John Wiley & Sons, 2016.
[21] Skyworks, "DSM8100-000: Mesa Beam-Lead PIN Diode data sheet," 2008, [Online], Available: https://www.mouser.com/datasheet/2/472/200096E-1079486.pdf.
[22] Coilcraft, "Chip Inductors-0402HP Series datasheet," 2018, [Online], Available: https://www.mouser.com/datasheet/2/597/0402hp-270660.pdf.

[23] AVX, “General Purpose Dielectric for Ceramic Capacitors X5R Dielectric datasheet,” Available: https://www.tme.eu/Document/73f8fd69a3c583056066ce6caf567110/AVX-X5R.pdf.
[24] Ismail M. F., Rahim M. K., Majid H. A., "The Investigation of PIN diode switch on reconfigurable antenna," *in 2011 IEEE International RF & Microwave Conference*, vol. 12, pp. 234-237, 2011.
[25] Yang, H., et al., "Design of reconfigurable monopole antenna with switchable dual band-notches for UWB applications," *International Journal of Microwave and Wireless Technologies*, vol. 9, pp. 1065-1071, 2018.

BIOGRAPHIES OF AUTHORS

Alaa Imran was born in Tekrit-Iraq. He received the B.E. degree in electrical engineering from Babylon in 2005 and M.sc degree in electronics and communications engineering from the same university in 2013. He is working as lecturer in Information Technology college in Babylon University from January 2013. He is currently working his PhD degree at electrical engineering department in college of engineering at Mustansiriyah University in Bagdad. He has two patents and several researches published in high score journals. His research interests include IoT, antennas design, reconfigurable antenna design, and automation, etc.

Assit. Prof. Dr. Malik Jasim Farhan Al-Khalidi received his B.E. Degree in Electrical engineering from the college of Engineering/Mustansiriyah University in 1997. Then he received M.sc degree in Electronic and Communication engineering form the same university in 2000. In 2015, he got Ph.D. Degree in Electrical Engineering (Electronic and Communication) from the College of Engineering- Basrah University. He is currently the head of electrical engineering department/College of Engineering/Mustansiriyah University since 7/10/2018 until now. Furthermore, he active researcher in antenna field. He interested in UWB antenna, design of MIMO and reconfigurable antennas. He published several articles in high score journals