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Dual-Band Patch Antenna with Simple Rectangular Shaped Slots for Local Area Networks

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Abstract
In this study, a coplanar waveguide fed patch antenna is proposed for Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) operations. To obtain multiband functionality and tune the frequencies rectangular shaped slots are embedded vertically and horizontally on the radiating part. The effects of the slots on the operating frequencies are analyzed in detail by performing parametric analyzes. The proposed antenna operates in a wide range covering WLAN and WiMAX frequencies between 2.38 and 5.46 GHz. To authenticate the simulation results an example model is manufactured using a 40×30 mm^2 FR4 dielectric substrate with the permittivity of 4.3. It has been obtained a good compatibility between the computer software results and measurment results. The measurement shows that the antenna can provide dual impedance bandwidths by having resonances at 2.74 GHz and 4.94 GHz. Consequently, the final antenna model is a good candidate to be used at the designed frequencies and one can have a clear idea how to control the resonant frequencies of the antenna for different dimension parameters of the slots.

Keywords Coplanar waveguide fed · Patch antenna · Dual-band operation · WLAN · WiMAX

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1 Introduction

New generation communication networks are almost in use but there are still many points to be researched such as reliability and security of the systems, the coverage capabilities, reducing the losses etc. So, it is clear that Wireless Fidelity (WiFi) and Worldwide Interoperability for Microwave Access (WiMAX) networks will still be active for many years in the future. While WiMAX 802.16 standards define the frequencies at 2.4/5.8 GHz there are three WiFi 802.11 wireless standards used widely which are 802.11b and 802.11 g operating at 2.4 GHz band and 802.11a operating at 5 GHz band [1]. In addition, WiFi supports data rates up to 600 Mbps in a 30 m range and WiMAX support data rates up to 75 Mbps in 50 km range [2]. To achieve all these network capabilities antenna designs are in the central point. Because of their compact dimensions, low-cost manufacturing features and easy integrate properties to other circuits microstrip antennas are in great interest for a variety of wireless network operations. Recently there are proposed many new designed antenna structures for wideband and multiband operations covering WiFi/WiMAX bands [3–9]. By using asymmetrical U-slots on a rectangular patch antenna with a shorting pin it is obtained tri-band operation covering GSM/WiFi/WiMAX bands [10]. With radial stub feeding a crooked U-slot dual-band antenna is proposed for 2.4 GHz and 5.2 GHz [11]. A C-shaped slot and a couple of twin embedded slots etched rectangular patch antennas are proposed for WiFi, WiMAX and C-band applications with good radiation characteristics [12, 13]. Different geometrical shaped of slot antennas are also used for dual band operations such as a triangular slot antenna and a square slot antenna with embedded crossed strips [14, 15]. Patch antennas with cavity ground are used for enhanced bandwidth features at 2.4 GHz and 5 GHz bands [16, 17] and an E-shaped patch antenna is designed for WiFi/WiMAX operations through cavity model approach [18]. In addition to using inverted F laptop antenna, mirrored L-monopole, and rhombic patch monopole antenna for multiband operations [19–21] using composite metamaterial resonators is also a proposed method for dual band or triple band applications [22]. Moreover, adding two simple rectangular slots on a rectangular patch antenna has resulted in covering Wireless Body Area Network (WBAN) bands in addition to WiMAX spectrum [23].

In this study a rectangular microstrip patch is modelled, investigated, and manufactured. The structure is fed by a coplanar waveguide (CPW) and is designed to operate at WLAN and WiMAX bands. To obtain dual-band characteristics and tuning the resonant frequencies rectangular shaped slots are etched on the patch vertically and horizontally. The dimension parameters of these slots such as the width and the length parameters affect the radiation characteristics of the antenna. So, detailed parametric analyzes have been performed about the dimension parameters of the slots. Consequently, the antenna with the most suitable results is proposed for dual-band operation at WLAN and WiMAX bands.

2 Antenna Design

Figure 1 depicts the form of the CPW fed microstrip patch antenna denoted as Antenna #1 for multiband WLAN/WiMAX applications and Table 1 shows the details of the design parameters. The structure of the multiband patch antenna is modelled and produced using a 40 (L) × 30 (W) mm^2 FR4 substrate with the height of 1.6 mm, relative permittivity of 4.3 and a loss tangent of 0.018. To feed the antenna a 50-Ω CPW is used.

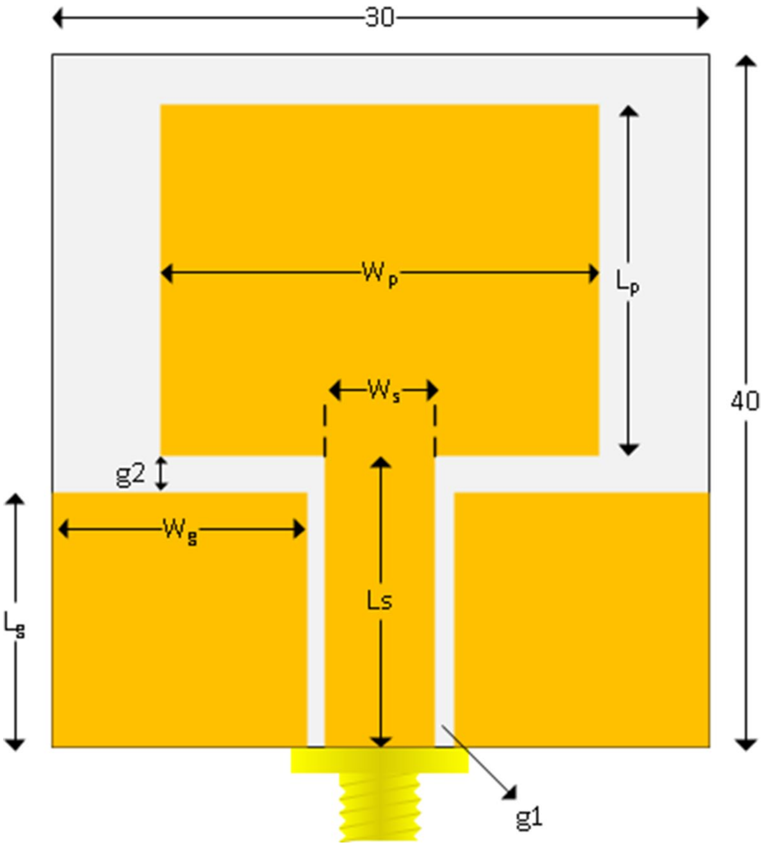


Fig. 1 Structure of the reference antenna (Antenna #1)

Table 1 Geometrical variables of the reference antenna

W_p	L_p	W_g	L_g	W_s	L_s	g_1	g_2
18 mm	19.5 mm	13.2 mm	16 mm	3 mm	18.4 mm	0.3 mm	2.4 mm

The simulation data of the Antenna #1 is obtained using commercially software CST MWS (Computer Simulation Technology Microwave Studio) [24] and the frequency responses are demonstrated in Fig. 2. It can clearly be seen that two dominant resonant modes are excited at 2.83 GHz and at 4.85 GHz. It is aimed the antenna to operate in WiMAX and WLAN frequency range. So, some modifications should be performed which includes placing embedded slots on the patch. Due to these slots the resonant frequencies are affected, and the antenna can be fine-tuned for the desired ranges at 2.4 GHz and 5.2 GHz. To have resonances at desired points we propose rectangular shaped slots etched on the metallic patch placed vertically and horizontally. The proposed antenna is designed in three steps; (1) First, a vertically placed slot is etched with a length of L_b and a width of W_b. This structure is denoted with Antenna #2, (2) A horizontally placed slot is etched at the bottom part of vertically slot with the width of W_1 and the length of L_1. This structure

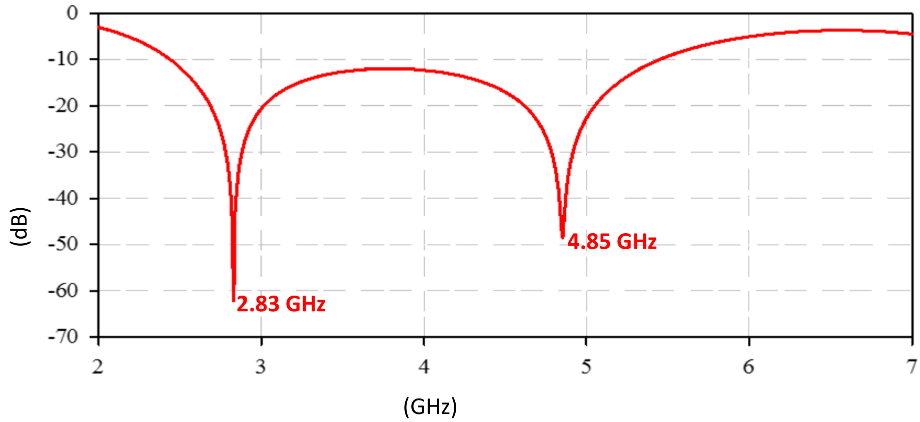
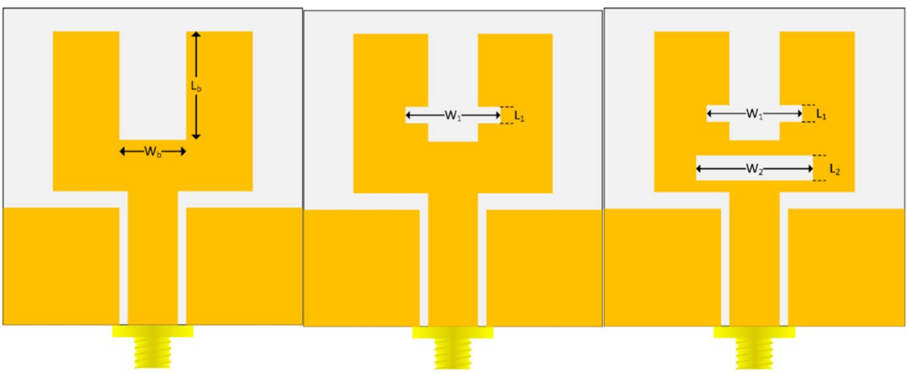


Fig. 2 The frequency response of the Antenna #1

is denoted with Antenna #3, (3) Finally the proposed antenna denoted with Antenna #4 is created by etching an additional slot at the bottom part of the antenna without intersecting the other slots. The dimension parameters of this final slot are shown with W_2 as the width and L_2 as the length. Figure 3 shows the modeling steps for proposed antenna geometry for the desired frequency range.

2.1 Impact of the Vertically Placed Rectangular Slot

To tune the resonant frequencies a rectangular shaped slot is etched vertically on the patch with the dimensions of $L_b \times W_b = 14$ mm $\times$ 2 mm forming the Antenna #2. Both parameters have effects on the operating frequencies and reflection coefficient levels. To obtain these



(a) Antenna #2 **(b)** Antenna #3 **(c)** Antenna #4

Fig. 3 The modeling steps for proposed antenna, **a** Antenna #2 is the model with a vertical rectangular slot, **b** Antenna #3 is the model with an additional horizontal slot, **c** Antenna #4 is the final model with two horizontal slots

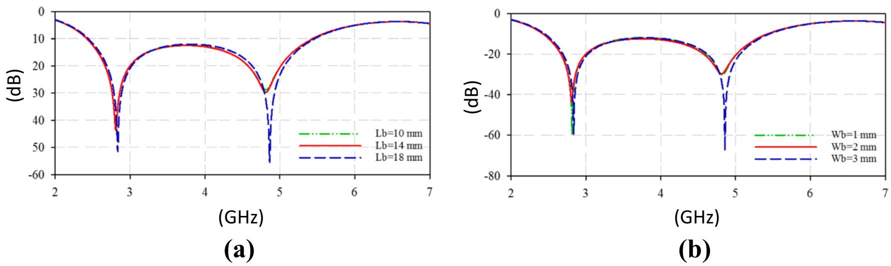


Fig. 4 The variations of the operating frequencies according to the different values of **a** L_b, **b** W_b

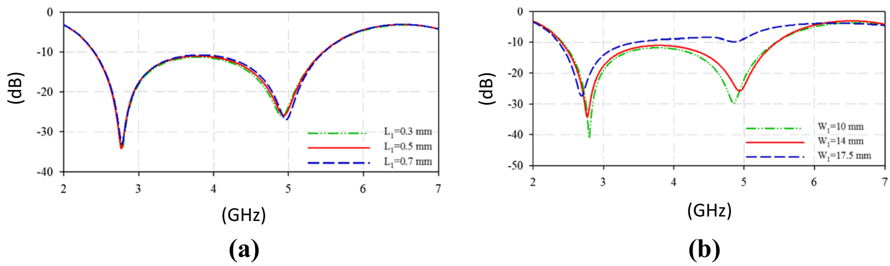


Fig. 5 The variations of the operating frequencies according to the different values of **a** L_1, **b** W_1

effects we have performed a parametric analysis about these dimensions. The results are shown in Fig. 4.

We have simulated the antenna model with three different values of L_b with 10 mm, 14 mm, and 18 mm by having the parameter $W_b = 2$ mm. The increase of L_b has mainly affected the second resonant frequency in terms of return loss levels. When L_b has increased the return loss level of the second resonance has decreased to levels lower than −50 dB. It is obtained only few decreases in return loss levels of first resonance. The operating frequency points has remained almost the same.

For $L_b = 14$ mm we obtain the best results for the bandwidth so by having $L_b = 14$ mm we have performed a parametric analysis for the parameter W_b. The change of the parameter W_b has also affected the return loss levels on the second resonant frequency more than the first one. The parametric analysis has been performed for three different values of W_b such as 1 mm, 2 mm, and 3 mm. The change of parameter W_b has not affected the operating frequency points likewise the change of parameter L_b. For $W_b = 2$ mm we obtain the best results for the bandwidth, so we fix W_b at 2 mm.

2.2 Impact of the Horizontally Placed Rectangular Slots

For the fixed values of L_b and W_b we perform a parametric analysis for the parameters of L_1 and W_1 which are the length and the width of the horizontally placed rectangular slot of Antenna #3, respectively. The effects of the change of the parameters of L_1 and W_1 on S_{11} response are shown in Fig. 5.

For the Antenna #3 the parameter L_1 has taken values from 0.3 to 0.7 mm. The step for increase is 0.2 mm and it has been obtained there were not much variation with return

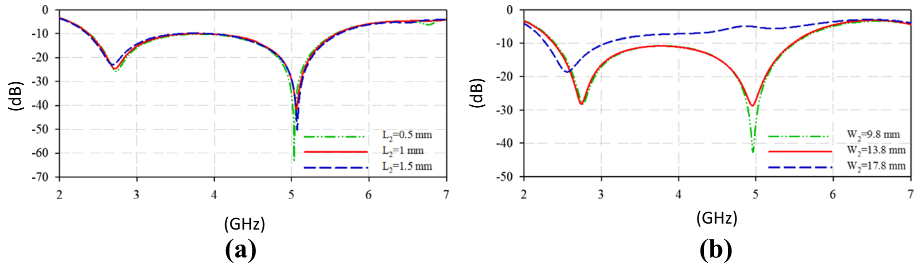


Fig. 6 The variations of the operating frequencies according to the different values of **a** L_2, **b** W_2

Table 2 Geometrical variables of the Antenna #4

L_b	W_b	L_1	W_1	L_2	W_2
14 mm	2 mm	0.5 mm	14 mm	1 mm	13.8 mm

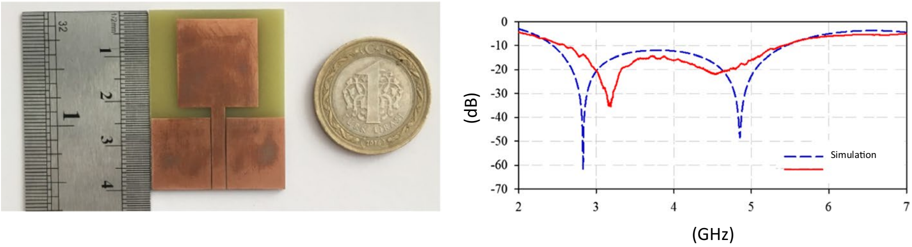
loss levels and operating frequencies. We have taken $L_1 = 0.5$ mm due to the lowest return loss level for other parametric analysis of the antenna and changed the parameter W_1 to observe the effects. On the contrary of L_1, the change of W_1 has resulted in significant effects on both bands in terms of return loss levels and resonant frequencies. For the analysis, we have taken values of 10 mm, 14 mm, and 17.5 mm for the parameter W_1. When W_1 increases the second resonant frequency has decreased to levels about − 10 dB and the first resonant frequency has shifted to lower part of the spectrum. For the best results, we have taken $W_1 = 14$ mm for the next designs.

Finally, for the Antenna #4 we etch an additional horizontal rectangular slot with the dimension parameters of L_2 and W_2. For the fixed values of L_b, W_b, L_1 and W_1 we perform a parametric analysis for the parameters of L_2 and W_2 which are the length and the width of the horizontally placed rectangular slot on the bottom part of the antenna, respectively. The results are introduced in Fig. 6. Table 2 shows the final model variables of the proposed dual-band patch antenna.

For the Antenna #4 the parameter L_2 has taken values from 0.5 to 1.5 mm. The step for increase is 0.5 mm. The effect of the increase of L_2 has been on the return loss levels of second resonant frequency. Due to the importance of large bandwidth we take the best results which are with the value of $L_2 = 1$ mm. In order to obtain the effects of W_2 we change it beginning from 9.8 to 17.8 with the steps of 4 mm. For 9.8 mm and 13.8 mm mostly the return loss level of the second frequency is affected but when W_2 takes the value of 17.8 mm both the first and second resonances are affected in terms of return loss levels and frequency shifting. As the best results, we take $W_2 = 13.8$ mm for the proposed design.

3 Experimental Results and Discussion

To verify simulation results prototypes are fabricated of the reference antenna and final model. The antenna structures have been manufactured with the use of printed circuit board milling technique following the dimensions given in Table 1. Figure 7a presents the manufactured reference antenna and Fig. 7b show the measured results with the simulation results.



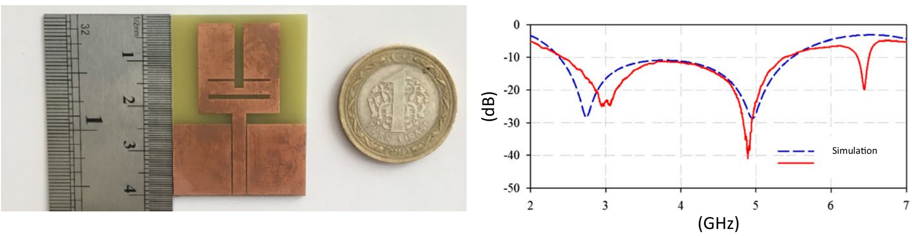
(a) (b)

Fig. 7 **a** Fabricated model of the reference antenna, **b** simulated and measured frequency response for the reference antenna for dual band operation

Figure 8a presents the fabricated proposed antenna and Fig. 8b presents the simulated and measured frequency responses of the proposed antenna for dual-band operation. It can be seen that the compatibility between the simulated and measured data is very well. The lower resonance frequency of the final model structure is at 2.74 GHz. Moreover, the second resonance frequency is at 4.94 GHz. The measured values of these two resonances are 2.99 GHz and 4.82 GHz for the lower and second operation frequencies, respectively. The simulation and measurement results appear to be in good agreement. Partial differences between results can be attributed to simulation calculation errors, manufacturing errors, and soldering errors of the SMA port. According to these results fabrication error of the proposed antenna is 9.1% for the lower band and 2.4% for the second band. These results show that the proposed antenna structure can operate simultaneously at frequency bands of 2.4/5 GHz for WiMAX and WiFi operations.

In Figs. 9, 10, and 11 it can be seen the far-field radiation patterns of the manufactured model at 2.74 GHz and 4.94 GHz for $\phi = 0°$ and $\phi = 90°$, respectively. Additionally, Fig. 11 depicts the far-field radiation patterns for $\theta = 90°$. Nearly omnidirectional radiation patterns are obtained at these frequencies.

Furthermore, gain of the designed antenna was calculated over the frequency band spanning from 2 GHz till 6 GHz. Result is shown in Fig. 12. In the figure it is seen that with the designed antenna peak gain values of 2.2 dBi and 3.6 dBi are achieved at two resonance frequencies of 2.74 GHz and 4.94 GHz, respectively. In the figure, it is also seen that the gain has a tendency to increase with the frequency.



(a) (b)

Fig. 8 **a** Fabricated model of the final structure for WLAN/WiMAX communication, **b** software results and measured frequency response of the final model antenna

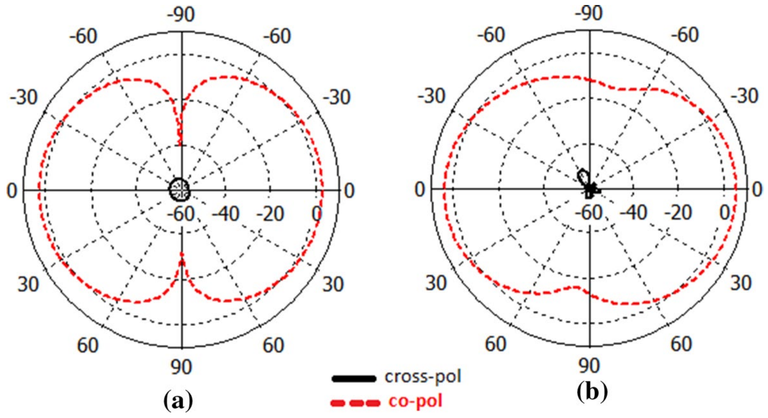


Fig. 9 Far field patterns for ϕ = 0° **a** 2.74 GHz and **b** 4.94 GHz

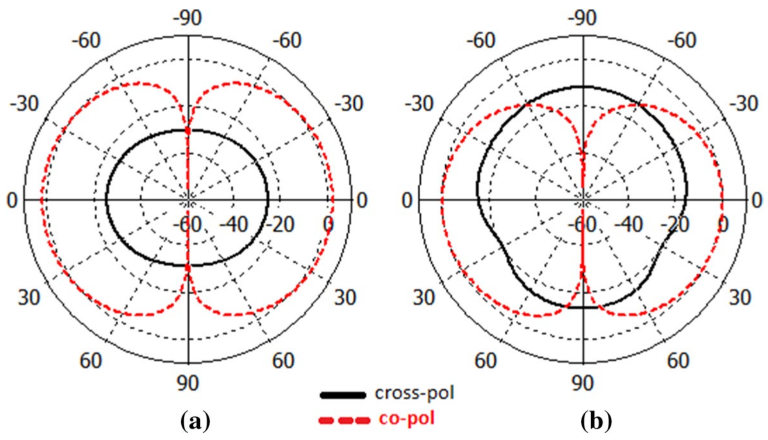


Fig. 10 Far field patterns for ϕ = 90° **a** 2.74 GHz and **b** 4.94 GHz

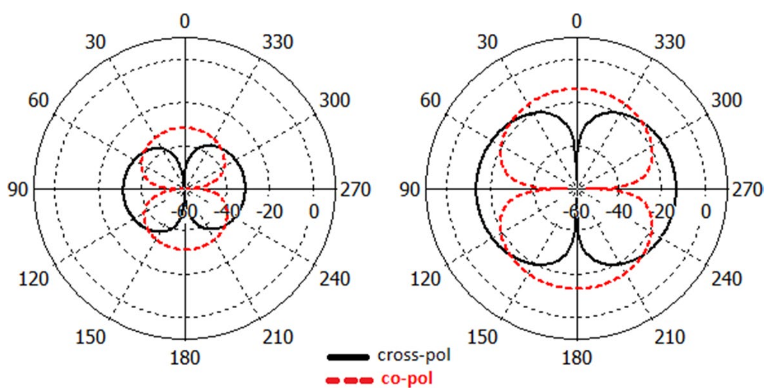


Fig. 11 Far field patterns for θ = 90° **a** 2.74 GHz and **b** 4.94 GHz

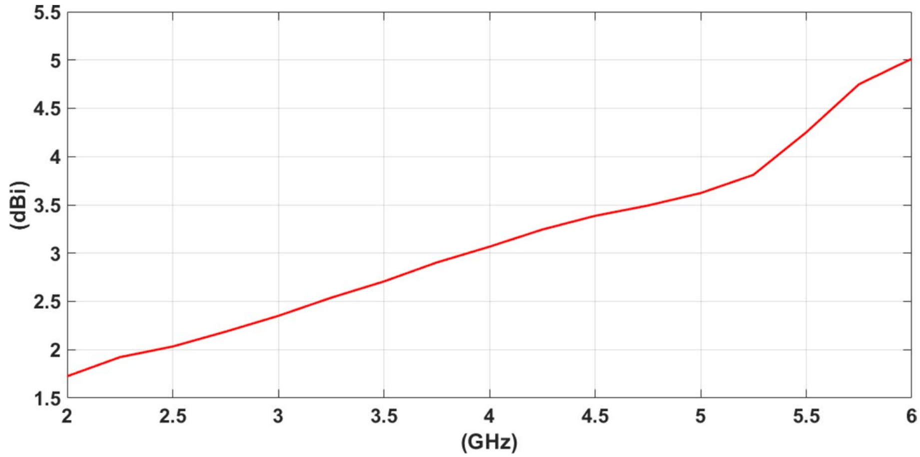


Fig. 12 Peak gain variation with frequency calculated for the designed antenna

4 Conclusions

A CPW-fed patch antenna for Wi-Fi/WiMAX applications is introduced. Dual-band operation is attained simply by embedding rectangular shaped slots into rectangular patch. The dimension parameters of these slots effect on the operating frequencies of the patch antenna. So, detailed parametric analyses have been conducted about the dimension parameters. With the parametric analysis results one can clearly have the idea about the response of the patch antenna to the modifications of the slots. Thanks to the etched slots the final model is built on a very compact structure and is proper for the whole frequency range of Wi-Fi/WiMAX. In addition, the final model owns great features for radiation characteristics and high gains in two resonances. Following from that, it can be utilized as a perfect model for multiband applications at local area bands.

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Declaration

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Banerji, S., & Chowdhury, R. S. (2013). Wi-Fi and WiMAX: A comparative study. *Indian Journal of Engineering, 2*(5), 51–54.
2. Sidhu, B., Singh, H., & Chhabra, A. (2007). Emerging wireless standards—WiFi, ZigBee and WiMAX. *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering, 1*(1), 308–313.

3. Tiwar, R., Yogi, L., Bagwari, A., & Kushwah, V. S. (2019). Design and performance analysis of triple band micro-strip patch antenna with CPW-fed. *IJ Wireless and Microwave Technologies, 1*, 36–42. https://doi.org/10.5815/ijwmt.2019.01.04
4. Chetal, S., Nayak, A. K., & Panigrahi, R.K. (2019). Multiband antenna for WLAN, WiMAX and future wireless applications. In *URSI AP-RASC*, March 09–15, New Delhi, India. https://doi.org/10.23919/URSIAP-RASC.2019.8738766.
5. Manas, M., Bhattacharjee, S., & Mitra, M. (2019). CPW-Fed dual-band dual-sense circularly polarized antenna for WiMAX application. *Progress in Electromagnetics Research Letters, 81*, 113–120. https://doi.org/10.2528/PIERL18091306
6. Birwal, A., Singh, S., Kanaujia, B. K., & Kumar, S. (2019). CPW-fed ultra-wideband dual-sense circularly polarized slot antenna. *Progress in Electromagnetics Research C, 94*, 219–231. https://doi.org/10.2528/PIERC19052005
7. Zhang, J., Chen, T., Lv, Y., & Xing, H. (2019). A practical CPW-fed UWB antenna with reconfigurable dual band-notched characteristics. *Progress in Electromagnetics Research M, 81*, 117–126. https://doi.org/10.2528/PIERM19040504
8. Mandal, D., & Pattnaik, S. S. (2019). Wide CPW-fed multiband wearable monopole antenna with extended grounds for GSM/WLAN/WiMAX applications. *Hindawi International Journal of Antennas and Propagation*. https://doi.org/10.1155/2019/4264513
9. Liu, T., Sun, Y., Li, J., & Wang, K. (2019). CPW-fed compact multiband monopole antenna for WLAN/WiMAX/X-band application. *Progress in Electromagnetics Research Letters, 87*, 105–113. https://doi.org/10.2528/PIERL19080902
10. Sharma, D., & Hashmi, M. S. (2014). A novel design tri-band patch antenna for GSM/WiFi/WiMAX applications. In *IEEE international microwave and RF conference*, December 15–17, Bangalore, India. https://doi.org/10.1109/IMaRC.2014.7038995.
11. Bae, H. R., So, S. O., Cho, C. S., Lee, J. W., & Kim, J. (2009). A crooked U-slot dual-band antenna with radial stub feeding. *IEEE Antennas and Wireless Propagation Letters*. https://doi.org/10.1109/LAWP.2009.2038937
12. Yassin, A. A., Saeed, R. A., & Mokhtar, R. A. (2014). Dual-band microstrip patch antenna design using C-slot for WiFi and WiMAX applications. In *International conference on computer and communication engineering*, September 23–25, Kuala Lumpur, Malaysia. https://doi.org/10.1109/ICCCE.2014.72.
13. Liu, W. C., Wu, C. M., & Chu, N. C. (2010). A compact CPW-fed slotted patch antenna for dual-band operation. *IEEE Antennas and Wireless Propagation Letters*. https://doi.org/10.1109/LAWP.2010.2044135
14. Wu, J. W. (2005). 2.4/5 GHz dual-band triangular slot antenna with compact operation. *Microwave and Optical Technology Letters*. https://doi.org/10.1002/mop.20730
15. Sze, J. Y., & Chang, W. S. (2008). Dual-band square slot antenna with embedded crossed strips for wireless localarea network applications. *Microwave and Optical Technology Letters*. https://doi.org/10.1002/mop.24070
16. Su, S. W., Wong, K. L., Cheng, Y. T., & Chen, W. S. (2003). High-gain broadband patch antenna with a cavity ground for 5-GHz WLAN operation. *Microwave and Optical Technology Letters*. https://doi.org/10.1002/mop.20151
17. Wang, F. J., & Zhang, J. S. (2007). Wide band cavity-backed patch antenna for PCS/IMI2000/2.4 GHz WLAN. *Progress in Electromagnetics Research, 74*, 39–46. https://doi.org/10.2528/PIER07041801
18. Hsu, H. T., Kuo, F. Y., & Lu, P. H. (2009). Design of WiFi/WiMAX dual-band E-shaped patch antennas through cavity model approach. *Microwave and Optical Technology Letters*. https://doi.org/10.1002/mop.24954
19. Chaimool, S., & Chung, K. L. (2009). CPW-fed mirrored-L monopole antenna with distinct triple bands for WiFi and WiMAX applications. *Electronics Letters*. https://doi.org/10.1049/el.2009.1390
20. Pazin, L., & Leviatan, Y. (2011). Inverted-F laptop antenna with enhanced bandwidth for WiFi/WiMAX applications. *IEEE Transactions on Antennas and Propagation*. https://doi.org/10.1109/TAP.2010.2103036
21. Si, L. M., & Lv, X. (2008). CPW-fed multi-band omnidirectional planar microstrip antenna using composite metamaterial resonators for wireless communications. *Progress in Electromagnetics Research, 83*, 133–146. https://doi.org/10.2528/PIER08050404

22. Mahatthanajatuphat, C., Saleekaw, S., Akkaraekthalin, P., & Krairiksh, M. (2009). A Rhombic patch monopole antenna with modified Minkowski fractal geometry for UMTS, WLAN, and mobile WiMAX application. *Progress in Electromagnestics Research*. https://doi.org/10.2528/PIER08111907
23. Torres, D. L., Sumba, L. P., Bermeo, J. P., & Cuji, D. A. (2017). Dual band rectangular patch antenna with less return loss for WiMAX and WBAN applications. In *IEEE second ecuador technical chapters meeting*, October 16–20, 2017, Salinas, Ecuador. https://doi.org/10.1109/ETCM.2017.8247543.
24. Computer Simulation Technology (CST) Microwave Studio, Ver. 2015, Framingham, MA, USA, 2015.

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