A Novel Compact Dual-Band Antenna Design for WLAN Applications

Peshal B. Nayak, Ramu Endluri, Sudhanshu Verma and Preetam Kumar
Department of Electrical Engineering
Indian Institute of Technology Patna
Patna, Bihar 800013, India
Email: nayak.ee10@iitp.ac.in, endluri.ee10@iitp.ac.in, sverma@iitp.ac.in, pkumar@iitp.ac.in

Abstract—A novel and compact dual band planar antenna for 2.4/5.2/5.8-GHz wireless local area network (WLAN) applications is proposed and studied in this paper. The antenna comprises of a T-shaped and a F-shaped element to generate two resonant modes for dual band operation. The two elements can independently control the operating frequencies of the two excited resonant modes. The T-element which is fed directly by a 50 Ω microstrip line generates a frequency band at around 5.2 GHz and the antenna parameters can be adjusted to generate a frequency band at 5.8 GHz as well, thus covering the two higher bands of WLAN systems individually. By couple-feeding the F-element through the T-element, a frequency band can be generated at 2.4 GHz to cover the lower band of WLAN system. Hence, the two elements together are very compact with a total area of only 11 × 6.5 mm². A thorough parametric study of key dimensions in the design has been performed and the results obtained have been used to present a generalized design approach. Plots of the return loss and radiation pattern have been given and discussed in detail to show that the design is a very promising candidate for WLAN applications.

Keywords—Dual band, F-shaped radiating element, T-shaped radiating element, wireless local area network (WLAN).

I. INTRODUCTION

Wireless communications have developed rapidly in the modern world and have covered many technical areas. Since FCC announced to allow potential users to make an unlicensed use of medical, industrial and scientific frequencies, the scientific community has seen a great opportunity to design wireless devices that would communicate over short distances. Common examples are the Bluetooth which operates at the internationally available ISM band at 2.4 GHz or the wireless local area network (WLAN) which operates at 5 GHz and the second order mode at 5.8 GHz. The PIFA was one of the most commonly used antenna models for WLAN applications. Naturally, it is recognized as a reliable, cost effective solution for wireless high speed data connectivity and a general purpose connectivity alternative for a broad range of applications. There are three operation bands in the IEEE 802.11 WLAN standards: 2.4 GHz (2400-2484 MHz), 5.2 GHz (5150-5350 MHz) and 5.8 GHz (5725-5825 MHz) [2]. WLANs working at IEEE 802.11a employ the higher frequency band from 5.15-5.35 GHz and 5.725-5.825 GHz while those working at IEEE 802.11b/g use the 2.4-2.484 GHz band. 802.11a is usually found on business networks due to its higher cost.

Nowadays, dual band WLAN systems combining the IEEE 802.11a/b/g standards are becoming more attractive [3]–[9]. Hence, to satisfy the need of wireless communications, it is necessary to design compact high performance antennas with 2.4/5 GHz dual band operation and excellent radiation characteristics. Wide impedance bandwidth, simple configuration, omnidirectional radiation pattern and low cost are some of the important features of a planar monopole antenna. Naturally, it is one of the most commonly used antenna models for WLAN systems.

A large number of WLAN antennas have been recently proposed and reported in literature. A technique of designing dual band antennas has been proposed in [10]–[20]. It suggests the use of one monopole for the lower band and another for the higher band of WLAN systems. However, this results in a large antenna size due to the large length of the monopole resonating in the lower band. Therefore, in order to achieve size reduction, an interesting method of bending this monopole to different shapes has been used in [10]–[12]. With the use of FR4 substrate with a relative permittivity (εr) of 4.4, the smallest size achieved by using this technique was about 15 × 10 mm² [12]. This is still larger than the 11 × 6.5 mm² size of our proposed antenna. Another effective size reduction technique is the use of an inverted-F structure [21]–[24]. However, for multiband operation, the use of additional radiating elements is essential. Thus, incorporating them with an inverted-F structure and achieving a compact size is a design challenge. This challenge has been tackled in [25] by using a direct fed compact sized inverted-F element and two other long slots on the ground plane to generate the 2.4 GHz, 5.2/5.8 GHz and 3.5 GHz bands. However, the slots on the ground plane result in a larger overall size as compared to our compact design. The direct fed planar inverted-F antenna (PIFA), proposed in [26], resonated in the fundamental mode at 2.4 GHz and the second order mode at 5.2 GHz. The PIFA was combined with a parasitic element which had one end shorted to the ground and was used to generate the 5.8 GHz band. The antenna was high profile and occupied a larger volume than the planar antenna due to the PIFA structure, though its height...
Another interesting design has been reported in [27], whereby two loop antennas have been combined together to achieve a dual band operation. However, since both loops required operating in one wavelength resonant modes, the element was quite large. In [28], the design generated a dual band operation by using a split-ring as a monopole radiator. However, the overall size, when fabricated on a substrate with a large \( \varepsilon_r = 6.15 \) was 16 x 13 mm\(^2\). A slot, occupying a large area of 30 x 14 mm\(^2\), in the ground plane was embedded with a pair of horizontal strips to achieve dual band performance in [29].

In order to obtain a concealed antenna for WLAN systems, that is an antenna without any protruded portions in its appearance, a printed double-T monopole antenna has been presented in [30]. Though a good performance was achieved, the overall dimensions of the design was 51(L)x75(W)x0.8(H) mm\(^3\) which is very large as compared to our proposed antenna.

In this paper, a very compact planar dual band monopole antenna to cover the WLAN operating bands of 2.4 and 5.2/5.8 GHz is proposed. A microstrip fed T-shaped element and an F-shaped element have been used to achieve a dual band operation. The F element has been coupled-fed through the T element by placing it very close to the T element. Thus, with the use of a single feed the overall size has been considerable reduced. The antenna is designed and studied with the high performance full-wave electromagnetic (EM) field simulator Ansoft HFSS software. The paper is organized as follows. In Section II, the details of the proposed antenna have been presented. This is followed by the results of a parametric study on the antenna in Section III. A generalized design methodology for achieving dual band operation at other operating frequencies has been given in Section IV. Results and discussion have been presented in Section V. Conclusion has been given in the last section.

II. ANTENNA DESIGN

The geometry of the proposed antenna has been shown in Fig. 1 and specifications of the design have been given in Table I. A 50 \( \Omega \) microstrip feed line has been used in order to achieve a dual band operation with good impedance matching. The planar monopole antenna consists of a ground plane of 40 x 20 mm\(^2\) and a radiator of 11 x 6.5 mm\(^2\) with overall dimensions of 40 x 30 x 0.8 mm\(^3\). Two radiating elements are present in the design. As these elements appear similar in shape to the letters T and F, they have been referred to as the T and F-elements. The compact size of the antenna results from the close packing achieved by the use of a single feed point for these two separate elements. The T- element has been fed by a microstrip feed line and is surrounded by a shorted parasitic F- element which has been placed coupled-fed from the T shape element via a small gap \( g \). The diameter of the via used for shorting the F element to the ground is 0.4 mm. The overall length, width and height of the antenna are represented by \( W \), \( L \) and \( h \) respectively. For the T and F- element dimensions, the prefixes \( t \) and \( f \) respectively have been used in the layout in Fig. 2. ‘F’ is the feed point and ‘V’ is the location of the via.

The T element generates a band at 5.2/5.8 GHz for the higher band of WLAN systems while the F element generates a band at 2.4 GHz for the lower operating frequency of WLAN devices. As mentioned in Table I, the antenna has been fabricated on a substrate of relative permittivity 3.5 and loss tangent 0.02. Various dimensions of the antenna have been carefully optimized with the help of computer simulations. The antenna has been fabricated by using these optimized dimensions as shown in Table II.

III. PARAMETRIC STUDY

A detailed parametric study was performed to observe the effect of various dimensions on the two resonant frequencies. In order to study the resonating frequency of the two radiating elements, the antenna was simulated using Ansoft HFSS with the T-shape element alone and a single band was obtained at 6.5 GHz. With both the elements present, a second reflection coefficient plot was obtained. The two plots have been shown in Fig. 3 and Fig. 4. It can be clearly seen that when the F-element was added, a second resonant mode was generated at lower frequency of 2.4 GHz while the higher frequency shifted to around 5.2 GHz.

Current distribution was also studied to gain further insight into the operation of the dual band antenna. The simulation results shows that at 2.4 GHz, the current was mainly on the
TABLE I. ANTENNA DESIGN DETAILS

| Material   | FR4        |
|------------|------------|
| Dielectric constant | 3.5        |
| Loss Tangent  | 0.02       |
| Substrate Thickness | 0.8 mm      |
| WLAN centre frequencies | 2.4 GHz, 5.2 GHz, 5.8 GHz |

TABLE II. VALUE OF VARIOUS DIMENSIONS IN THE ANTENNA DESIGN
(IN MM)

| f1  | 5.5 | f2  | 9  |
|-----|-----|-----|----|
| f3  | 4.3 | f4  | 1  |
| f5  | 2.6 | f6  | 3.3|
| t1  | 1.6 | t2  | 3  |
| t3  | 2   | f4  | 3.25|
| g   | 0.5 | h   | 0.6|
| L   | 40  | W1  | 20 |
| W2  | 10  | w   | 1.8|

Fig. 3. Return Loss plot of the antenna design with only T-element present

Fig. 4. Return Loss plot of the antenna design with optimized parameters (both elements present)

Fig. 5. Simulated current distribution at (a) 2.4 GHz (b) 5.2 GHz

F-element which contributed to resonance. Similarly, at 5.2 GHz, a large current was observed on the T-element which was responsible for that band. Fig. 5 shows the simulated current distribution at 2.4 GHz and 5.2 GHz.

From computer simulation results, it was confirmed that the resonant frequency was sensitive to variation in the antenna parameters such as f3, f4, f6 and g. The value of f3 was varied and return loss plots as shown in Fig. 6 were observed. It can be clearly seen that as the value of f3 decreased, the resonant frequencies of both the upper and the lower band changed with the higher band frequency changing considerable. Also, the matching for the upper band improved significantly and the bandwidth also increased by a large amount. Hence, f3 can be used to achieve a coarse tuning of both the bands. Also, a resonant frequency of 5.8 GHz was obtained while varying this length.

Next, the gap g between the two elements was increased from 0.5 mm to 0.6 mm, 0.7 mm. As expected, an upward shift was noticed as shown in Fig. 7 due to a decrease in the coupling between the two elements.

The simulated S11 for variation in the value of f4 is shown in Fig. 6. As the value of f4 increased, a good return loss was obtained while maintaining both the resonant frequencies constant. Thus, this dimension could be changed to get the required matching without disturbing the operating frequency.

Finally, the value of f6 was decreased by 0.4 mm and then by another 0.4 mm. The corresponding return loss plot is shown in Fig. 8. By changing the value of f6, the upper resonant frequency moved from 5.2 GHz to 5.35 GHz and finally 5.4 GHz. The resonant frequency of the lower band,
Fig. 6. Return Loss with variation in the length of $f_3$

Fig. 7. Return Loss with variation in the coupling gap $g$

Fig. 8. Return Loss with variation in the value of $f_4$

Fig. 9. Return Loss with variation in the value of $f_6$

however, remained constant as $f_6$ was varied. This proves that this dimension can be used to achieve a tuning of the upper resonant frequency while maintaining the lower operating frequency constant. Also, the impedance matching of both the bands improved.

IV. DESIGN METHODOLOGY FOR OTHER OPERATING FREQUENCIES

Based on the results of the parametric study, a generalized design methodology may be proposed for achieving a dual band performance at other frequencies.

1) In the first step, we set the values of $t_2$ and $t_4$, such that $t_2 + t_4 = \lambda_g/4$ and the ratio of $t_2 : t_4$ is the same as that in Table II. $\lambda_g$ is the guide wavelength. By doing so, an operating frequency higher than the desired upper frequency is obtained. The symmetry should be maintained in the T-element and the F-element should not be present.

2) Next, we insert the F-element and adjust the values of $f_2$, $f_3$ and $f_6$ such that $f_2 + f_3 + f_6 = \lambda_g/4$. This may not exactly match the desired lower frequency. Also, the higher frequency may have shifted during this step. The ratio $f_2 : f_3 : f_6$, the value of the gap ‘$g$’ and the dimensions of the via must be maintained the same as the optimized values mentioned in Table II.

3) Since, the values of the operating frequencies obtained in Step 1 and 2 do not match the desired values, we use the result of the parametric study to achieve the required dual band operation. First, the value of the lower frequency should be adjusted by varying $f_3$. The upper frequency will shift during this process.

4) Now, the value of $f_6$ should be adjusted to tune the higher frequency to the desired value. When $f_6$ is varied, the value of the lower frequency is maintained constant. Thus, we obtain the desired upper and lower desired resonant frequencies.

5) Finally, the value of $f_4$ can be adjusted to obtaining a good impedance matching without disturbing the position of the two frequency bands.

Thus, by using this generalized approach, a dual band operation can also be obtained for other wireless systems in which the lower and higher operating frequencies lie in the ranges of 2.2-2.6 GHz and 5.2-6.0 GHz respectively.
V. RESULTS AND DISCUSSION

The S11 and the radiation pattern simulation plots have been obtained with the help of Ansoft HFSS. The simulation and measured results of the return loss have been shown in Fig 4. The bandwidths (S11 < -10 dB) for the lower band was from 2.27 GHz to 2.58 GHz and for the higher band was from 4.92 GHz to 5.49 GHz. Thus, the lower and upper frequency band of WLAN systems are satisfactorily covered.

The simulated radiation pattern at 2.4 GHz and 5.2 GHz are shown in Fig 10. It can be clearly observed that the antenna has an omnidirectional radiation pattern at both the lower as well as the higher frequencies. This is one of the important properties desired of an antenna for WLAN systems. The radiation efficiency at 2.4 GHz and 5.2 GHz are 89% and 87%.

The compact size of the antenna enable the designer to save a lot of space on the device with which it is to be integrated. The designer may use the saved space to increase the number of other circuit elements and add additional features to the device. Also, due to its small size, its fabrication cost gets considerably reduced. Additionally, the antenna can be tuned to other frequencies for dual band operation by merely changing the dimensions.

VI. CONCLUSION

A novel and compact planar monopole dual band antenna for 2.4/5.2/5.8 GHz WLAN applications has been designed and studied in this paper. The antenna has a compact radiator of area $11 \times 6.5$ mm$^2$ comprising of a T-element and a F-element resonating at 5.2/5.8 and 2.4 GHz respectively. By conducting a thorough parametric study, it has been found that these two frequency bands can be tuned independently by varying certain dimensions of the antenna. Thus, the antenna can be designed to obtain a dual band performance at other frequencies by merely changing the key dimensions. The plots of reflection coefficient S11 and radiation pattern for the two frequencies have been studied. These results have shown that the design is a very promising candidate for WLAN applications.

REFERENCES

[1] Peshal B Nayak, Ramu Endluri, Sudhanshu Verma, and Preetam Kumar. Compact dual-band antenna for WLAN applications. In 2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), pages 1381–1385. IEEE, 2013.

[2] XD Song, JM Fu, and W Wang. Small cpw-fed microstrip monopole antenna for wlan applications. In 2008 Asia-Pacific Microwave Conference, pages 1–4. IEEE, 2008.

[3] Yi-Sen Cao, Chun-Lan Lu, and Yun-Long Zhang. A compact dual band miniaturized antenna for wlan operation. In 2008 International Conference on Microwave and Millimeter Wave Technology, volume 1, pages 416–419. IEEE, 2008.

[4] Peshal Nayak, Michele Garetto, and Edward W Knightly. Multi-user downlink with single-user uplink can starve tcp. In IEEE INFOCOM 2017, pages 1–9. IEEE, 2017.

[5] Peshal Nayak. AP-side WLAN Analytics. PhD thesis, Rice University, 2019.

[6] Peshal Nayak, Michele Garetto, and Edward W Knightly. Modeling Multi-User WLANs Under Closed-Loop Traffic. IEEE/ACM Transactions on Networking, 27(2):763–776, 2019.

[7] Peshal Nayak, Santosh Pandey, and Edward W Knightly. Virtual Speed Test: an AP Tool for Passive Analysis of Wireless LANs. In IEEE INFOCOM 2019, pages 2305–2313. IEEE, 2019.
[8] Peshal Nayak. Performance Evaluation of MU-MIMO WLANs Under the Impact of Traffic Dynamics. Master’s thesis, 2016.

[9] Nayak Peshal, Michele Garetto, Knightly Edward, et al. Modeling Multi-User WLANs Under Closed-Loop Traffic. 2019.

[10] The Nan Chang and Jing-Hae Jiang. Meandered t-shaped monopole antenna. IEEE Transactions on Antennas and Propagation, 57(12):3976–3978, 2009.

[11] Qing-Xin Chu and Liang-Hua Ye. Design of compact dual-wideband antenna with assembled monopoles. IEEE Transactions on Antennas and Propagation, 58(12):4063–4066, 2010.

[12] Shih-Huang Yeh and Kin-Lu Wong. Dual-band f-shaped monopole antenna for 2.4/5.2 ghz wlan application. In IEEE Antennas and Propagation Society International Symposium (IEEE Cat. No. 02CH37313), volume 4, pages 72–75. IEEE, 2002.

[13] TH Kim and DC Park. Cpw-fed compact monopole antenna for dual-band wlan applications. Electronics letters, 41(6):291–293, 2005.

[14] Bahadir S Yildirim. Low-profile and planar antenna suitable for wlan/bluetooth and uwb applications. IEEE Antennas and wireless propagation letters, 5:438–441, 2006.

[15] C-M Wu, C-N Chiu, and C-K Hsu. A new nonuniform meandered and fork-type grounded antenna for triple-band wlan applications. IEEE Antennas and Wireless Propagation Letters, 5:346–348, 2006.

[16] R D’Souza and RK Gupta. Printed dual band wlan antenna. In 2006 IEEE International Conference on Electron/Information Technology, pages 539–543. IEEE, 2006.

[17] Peshal B Nayak, Sudhanshu Verma, and Preetam Kumar. Multiband fractal antenna design for Cognitive radio applications. In 2013 International Conference on Signal Processing and Communication (ICSC), pages 115–120. IEEE, 2013.

[18] Peshal B Nayak, Sudhanshu Verma, and Preetam Kumar. A novel compact tri-band antenna design for WiMax, WLAN and bluetooth applications. In 2014 Twentieth National Conference on Communications (NCC), pages 1–6. IEEE, 2014.

[19] Peshal B Nayak, Sudhanshu Verma, and Preetam Kumar. Ultrawideband (UWB) antenna design for cognitive radio. In 2012 5th International Conference on Computers and Devices for Communication (CODEC), pages 1–4. IEEE, 2012.

[20] Ranu Endlari, Peshal B Nayak, and Preetam Kumar. A Low Cost Dual Band Antenna for Bluetooth, 2.3 GHz WiMAX and 2.4/5.2/5.8 GHz WLAN. International Journal of Computer Applications, 975:8887.

[21] Mohammed Z Azad and Mohammad Ali. A miniature implanted inverted-f antenna for gps application. IEEE Transactions on Antennas and Propagation, 57(6):1854–1858, 2009.

[22] M Gallo, O Losito, V Dimiccoli, D Barletta, and M Bozzetti. Design of an inverted f antenna by using a transmission line model. In Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP), pages 605–608. IEEE, 2011.

[23] Duixian Liu and Brian Gaucher. The inverted-f antenna height effects on bandwidth. In 2005 IEEE Antennas and Propagation Society International Symposium, volume 2, pages 367–370. IEEE, 2005.

[24] Jiang Tie-hua, Su Dong-lin, Ding Ke-jia, Wang Guo-yu, et al. Design of the low-profile inverted-f antenna with multi-parasitic elements. In 2006 7th International Symposium on Antennas, Propagation & EM Theory, pages 1–4. IEEE, 2006.

[25] Ahmad R Razali and Marek E Bialkowski. Coplanar inverted-f antenna with open-end ground slots for multiband operation. IEEE Antennas and Wireless Propagation Letters, 8:1029–1032, 2009.

[26] Hanyang Wang and Ming Zheng. An internal triple-band wlan antenna. IEEE Antennas and Wireless Propagation Letters, 10:569–572, 2011.

[27] Saou-Wen Su. High-gain dual-loop antennas for mimo access points in the 2.4/5.2/5.8 ghz bands. IEEE Transactions on Antennas and Propagation, 58(7):2412–2419, 2010.

[28] Siddik Cunluhr Basaran and Yunus E. Erdemli. A dual-band splitting monopole antenna for wlan applications. Microwave and Optical Technology Letters, 51(11):2685–2688, 2009.

[29] Lin Dang, Zhen Ya Lei, Yong Jun Xie, Gao Li Ning, and Jun Fan. A compact microstrip slot triple-band antenna for wlan/wimax applications. IEEE Antennas and Wireless Propagation Letters, 9:1178–1181, 2010.