Progress In Electromagnetics Research Letters, Vol. 70, 89–97, 2017

Compact Planar Dual Band Antenna for WLAN Application

Riki Patel* and Trushit Upadhyaya

Abstract—A miniaturized dual-band microstrip antenna has been designed and analyzed for Wireless LAN application. The proposed antenna comprises a $29 \times 29\,\mathrm{mm}^2$ radiating patch, fed by a microstrip line on a 1.6 mm thick FR4 dielectric material substrate. The antenna measurement illustrates impedance bandwidth of around 10% at 2.4 GHz resonance and 6% at 5.5 GHz resonance. The measured stable return loss and radiation patterns are presented for the proposed dual-band electrically small microstrip antenna for wireless applications.

1. INTRODUCTION

Electrically small antennas are becoming very popular due to their compact dimensions, and as a result, they are frequently used in many wireless applications. These antennas are also known as electrically small antenna (ESA), physically small antenna (PSA), physically constrained small antenna (PCSA) and functionally small antenna (FSA) [1]. The basic function of an antenna is to act as a transducer which converts alternating current to radio frequency waves and vice versa. Printed microstrip patch antennas offer competitive solution in day to day life, due to very wide spread wireless communication and various types of wireless technologies. They are popular due to low cost, low weight, less troublesome fabrication, ease of integration in communication system, very compact size and multi-frequencies. However, miniaturized microstrip patch antenna suffers from very narrow bandwidth typically in the order of 1%–2%. Typically, antenna compactness is achieved by engineering the antenna dimensions with antenna parameters tradeoff. Techniques such as fractal geometry [2], negative refraction [3–5] and defected ground plane [6, 7] are frequently utilized for size reduction. Available literature has addressed a few challenges of antenna gain, bandwidth and limiting Q-factor [8–12]. Many antennas are presented in literature to be mechanically and electrically compact for both near-field and far-field applications [13–16]. Essentially, antenna performance and size are significantly interconnected. To cope with demand of compact present and future wireless communication services, cost effective miniaturized microstrip antennas possessing fair radiation characteristics are fundamentally required.

Elementary method to achieve the dual-band characteristic in a microstrip patch antenna is to create slots in patch geometry. In this article, a miniaturized, low profile microstrip patch antenna is proposed for dual-band operation. The proposed antenna has an impedance bandwidth in the range of 6%–10% with respect to the corresponding resonance frequencies. In the proposed ESA, radiation characteristics are optimized by height of substrate and engineered feed line. In addition, good impedance bandwidth is achieved at dual frequencies. A note on antenna radiation efficiency (η) and Q-factor is presented for understanding the effect of antenna dimensions on antenna bandwidth and Q-factor.

Received 27 June 2017, Accepted 14 September 2017, Scheduled 25 September 2017
* Corresponding author: Rikikumar Patel (rikipatel.ec@charusat.ac.in).
The authors are with the Charotar University of Science and Technology, India.

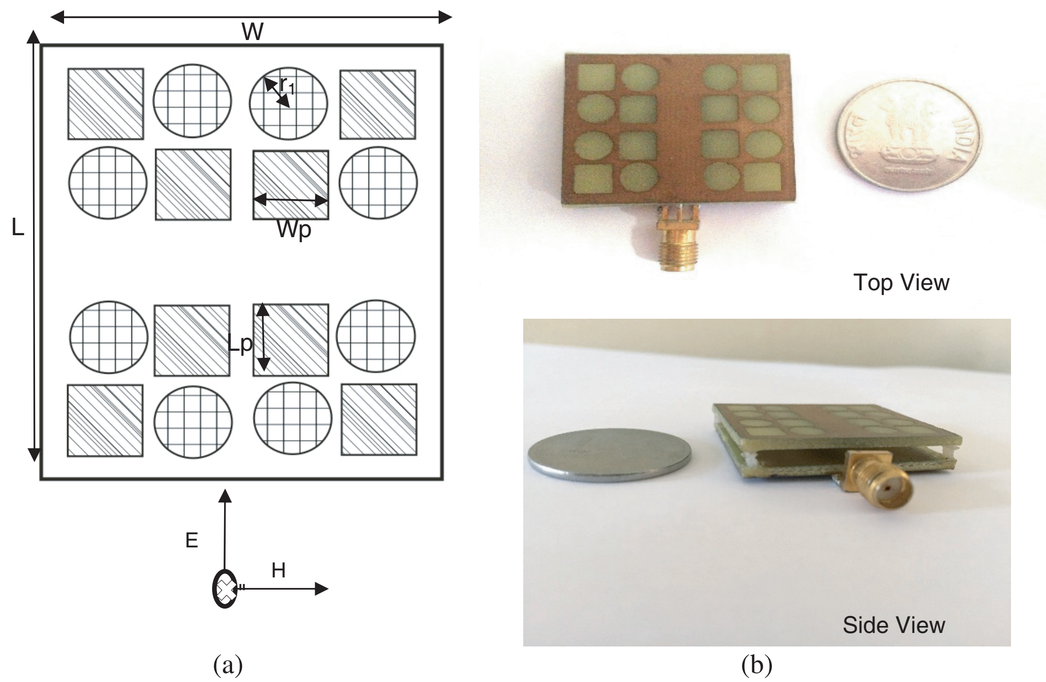


Figure 1. Model of the proposed antenna. (a) Geometry. (b) Fabrication of the prototype antenna.

2. ANTENNA DESIGN

Geometry and design parameters of the proposed dual-band electrically small microstrip patch antenna are shown in Figure 1. The designed antenna is fabricated on an FR4 substrate having thickness of 1.6 mm with relative dielectric constant $\varepsilon_r = 4.4$ and $\tan\delta = 0.02$. Finite Element Method (FEM) based full wave electromagnetic High Frequency Structure Simulator (HFSS) is utilized for designing the proposed dual-band electrically small microstrip patch antenna. A rectangular patch antenna is made electrically small by integration of square and circular shape cuts in the design. Use of square and circular shapes along the width and length of the upper side patch significantly helps to achieve the desired resonance, and uniform circular and square cuts make fabrication easier. The size of the microstrip line is optimized to get a good deal on impedance matching at target frequency bands. The size of the patch is $29 \times 29\,\text{mm}^2$, circular ring radius ($r_1$) 2.9 mm, and length and width of squares 5.6 mm.

Typical design equations for width and length dimensions of a microstrip patch antenna are as follows.

Patch width can be given as [17]

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

where

$$\begin{aligned} v_0 &= \text{Free space velocity;} \\ f_r &= \text{Resonant frequency} \\ \varepsilon_r &= \text{Relative permittivity} \\ \varepsilon_{reff} &= \text{The effective permittivity,} \\ 2\Delta L &= \text{Extension in length due to fringing effects} \end{aligned}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{2}$$

Length of patch can be given as [17]

$$L = \frac{v_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{3}$$

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left(\dfrac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.3)\left(\dfrac{W}{h} + 0.8\right)} \tag{4}$$

where hs is height of the substrate in mm.

The size of ground plane is the same as that of the substrate dimensions. Sandwich structure is made with two substrates of height 1.6 mm, each separated by air gap height of 1.6 mm. The substrates are stacked and attached with microwave adhesive to get the overall height of antenna as 4.8 mm from the ground plane as illustrated in Figure 2. Due to the presence of air gap in the substrate, effective refractive index gets significantly reduced. In addition, with increase in substrate thickness, bandwidth also gets increased. Dual-frequency operation is achieved due to the optimal use of square and circular slots. Initially the antenna resonates at 2.4 GHz, but due to addition of slots, the antenna also resonates at 5.5 GHz. The mechanical parameters of the antenna are shown in Table 1.

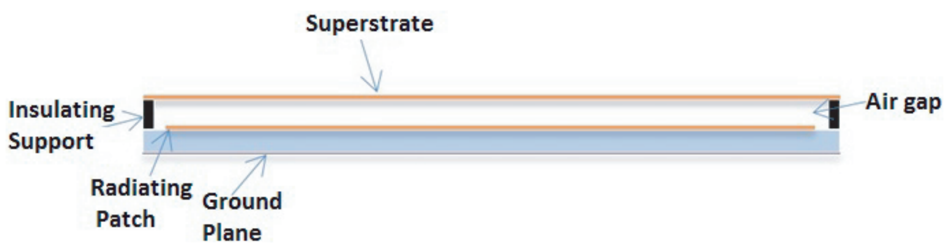


Figure 2. Layered antenna structure.

Table 1. Parameters of proposed miniaturized microstrip antenna.

Parameters	Substrate Height (hs)	Air gap Height (ahs)	Superstrate Height (shs)	Patch Width (P_{width})	Patch Length (P_{length})	Substrate (L)	Substrate (W)	Square Width (W_{p})	Square Length (L_p)
Dimension (mm)	1.6	1.8	1.6	29	29	30.18	34.94	5.6	5.6

3. RADIATION EFFICIENCY (η) & QUALITY FACTOR (Q) OF ELECTRICALLY SMALL ANTENNA

In 2014, multiple electrically small antenna design methodologies were summarized by Fujimoto and Morishita [1]. They have adequately addressed the theoretical limits of electrically small antennas. It has been entrenched that for an electrically small antenna, confined in given dimensions, the antenna possesses certain minimum quality factor (Q-factor). The constraint of Q-factor presents challenge in achieving high impedance bandwidth for the compact antennas. The higher the Q-factor is, the smaller is the impedance bandwidth of an antenna [12, 18, 19].

3.1. Radiation Efficiency

Impedance matching is a critical problem in small antennas. The efficiency of an electrically small antenna can be given as [1, 18, 19].

$$\eta_a = \frac{R_r}{(R_r + R_m)} \tag{5}$$

$$\begin{aligned} \eta_a &= \text{ESA Efficiency} \\ R_r &= \text{Radiation Loss}\,(\Omega) \\ R_m &= \text{Material Loss}\,(\Omega) \end{aligned}$$

The impedance of small antenna has more capacitive component. The overall system efficiency, i.e., matching network, antenna and feed line, can be given as [1].

$$\eta_s = \eta_a \eta_m \tag{6}$$

$$\begin{aligned} \eta_s &= \text{system efficiency} \\ \eta_m &= \text{matching network efficiency} \end{aligned}$$

$$\eta_m \sim \frac{\eta_a}{\left(1 + \dfrac{Q_a}{Q_m}\right)} \tag{7}$$

$$\begin{aligned} Q_a &= Q \text{ of small antenna} \\ Q_m &= Q \text{ of matching network} \end{aligned}$$

The matching network efficiency as shown in Equation (7) is dependent on Q of small antenna and Q of the matching network utilized in the antenna. With antenna being small in electrical dimensions, it is apparent that there shall be fundamental limitation on minimum achievable Q-factor. This sharpens the antenna selectivity. However, the presented antenna has partially increased the selectivity by introducing an air gap in the substrate. Antenna efficiency can be obtained by wheeler cap method. Near-field region of ESA is considered within the radius of $\frac{\lambda}{2\pi}$. In 1996, McLean developed further work on Q-factor for a compact antenna. The Q-factor for such antennas can be given as [18]:

$$Q = \frac{1}{(ka)^3} + \frac{1}{ka} \tag{8}$$

Figure 3 shows a graph of the minimum Q associated with the TE01 or TM01 mode of linearly polarized antenna in free space [18]. The exact curve is derived by McLean and can be used in any estimations of minimum Q.

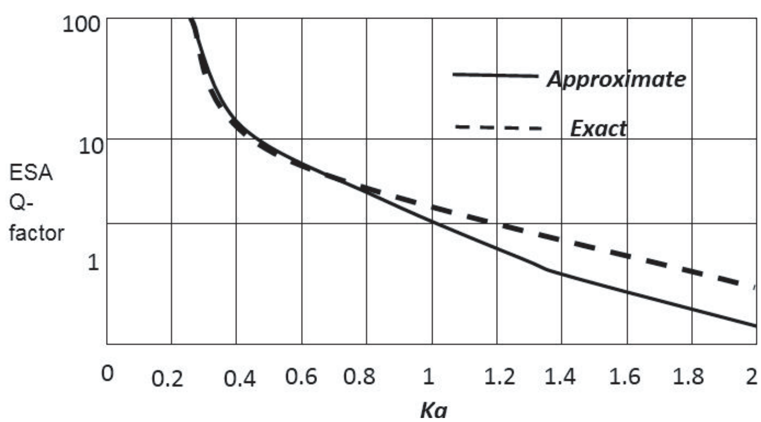


Figure 3. *ESA Q factor vs ka* curve for electrically small antenna.

3.2. Bandwidth

The approximate bandwidth for an RLC type circuit in terms of Q-factor is:

$$BW = \frac{S-1}{Q\sqrt{S}} \tag{9}$$

$$S = S:1 \text{ VSWR}$$
$$\text{BW} = \text{normalized bandwidth.}$$

Figure 4 displays the relation between radius enclosing the antenna ground plane and bandwidth of the antenna [1, 18]. When the horizontal current is flowing in the ground plane, the radiation efficiency is reduced. The storage of near-field energy increases as antenna Q-factor becomes larger, and the bandwidth becomes smaller. In many practical cases, the ground plane is closed which will reduce the achievable bandwidth of the ESA.

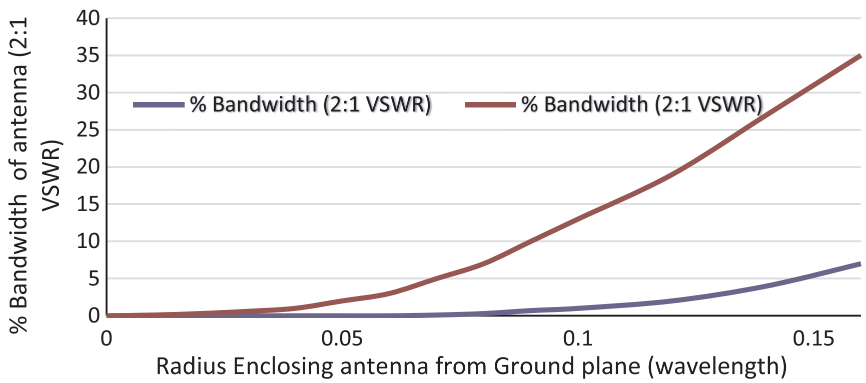


Figure 4. Fundamental limit of impedance bandwidth of small antenna.

4. RESULTS AND DISCUSSIONS

Simulated and measured reflection coefficients (S_{11}) of the antenna are illustrated in Figure 5. The antenna resonates at 2.4 GHz and 5.5 GHz frequencies. This covers the requirement of WLAN applications. The simulated Voltage Standing Wave Ratio (VSWR) for the proposed antenna is 1.029 and 1.018, respectively. The proposed antenna is fabricated, and antenna parameters are measured using Agilent Vector Network Analyzer N9912A in an unshielded anechoic chamber environment. The calibration of VNA is carried out with and without load for antenna measurement. The measured VSWRs for the target frequencies are 1.1 and 1.13, respectively. Typically, such applications require VSWR less than 1.5; therefore, the proposed prototype satisfies the VSWR requirement of the antenna.

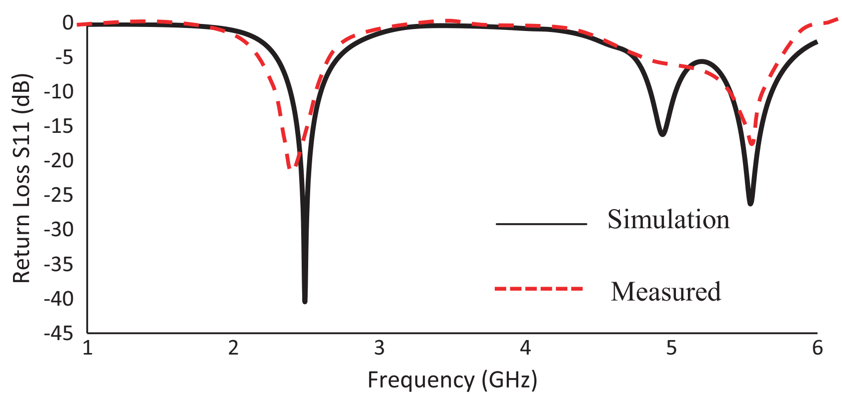


Figure 5. Return loss of proposed electrically small antenna.

Figure 6 shows the simulated refection coefficients for a parameter study of the square length and width (W_p) and (L_p) of cut on superstrate. Here, it can be seen that target frequencies are effectively optimized for W_p and L_p values of 5.6 mm.

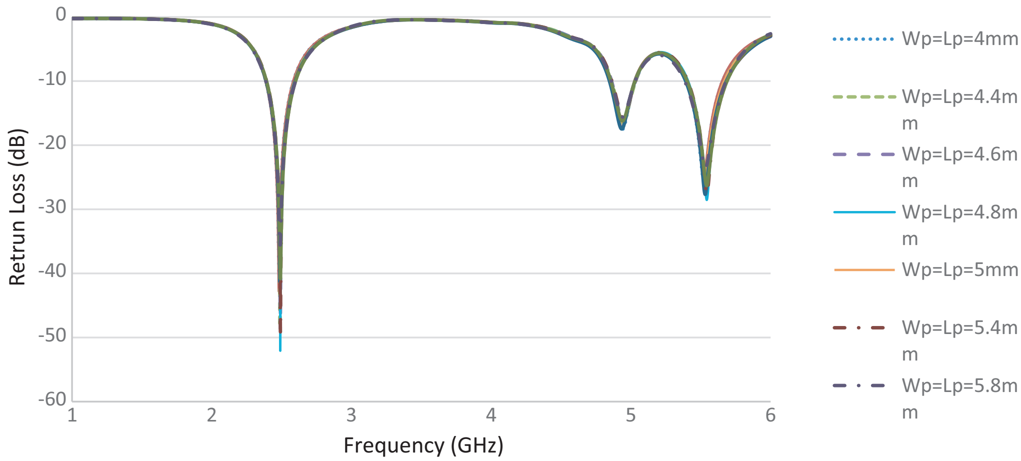


Figure 6. Return loss different values of W_p and L_p.

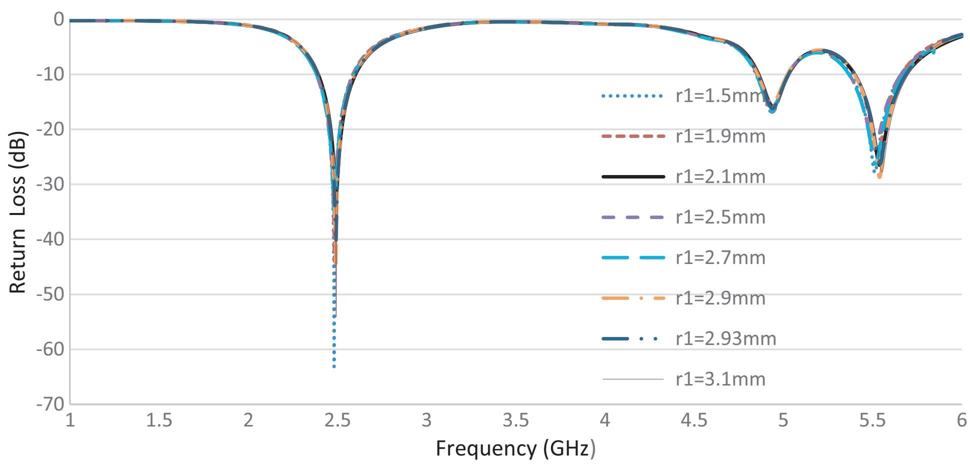


Figure 7. Return loss different values of r_1.

As illustrated in Figure 7, variation of circle on cut at superstrate value of (r_1) significantly affects the matching characteristic of the lower and higher frequency bands. It is observed that as the value of r_1 increases, the frequency bands shift towards the lower frequencies side. Also the value of r_1 decreases, and the frequency bands shift towards the higher side of resonant range. The achieved optimal value of circle (r_1) is 2.9 mm.

The value of air gap height is varied from 1.8 mm to 2.2 mm while keeping overall antenna electrical dimensions consistent. The outcome is illustrated in Figure 8. Due to reduction in effective dielectric constant, the antenna gain is improved marginally up to 1 dBi. The optimal value of ahs is found to be 1.8 mm.

The surface current density of the proposed antenna is depicted in Figure 9 which illustrates maximum current density on top copper of the design. Dielectric substrate used in the proposed design has high dielectric loss which leads to low antenna gain; however, FR4 material is less expensive, and it is readily available. Dual-band antenna resonates at 2.4 GHz and 5.5 GHz with bandwidths of 10% and 6%, respectively. The simulated and measured return losses have very good agreement. The current is uniformly distributed through much of the radiating element. The antenna measurement is carried out in a 3 m $\times$ 3 m $\times$ 3 m sized anechoic chamber as illustrated in Figure 10. The E-plane and H-plane radiation patterns for target frequencies are illustrated in Figure 11. E-plane and H-plane radiation patterns for 2.4 GHz are directive whereas at second resonance it is nonuniform.

The antenna has radiation efficiency of 78% at 2.4 GHz and 75% at 5.5 GHz. The mismatch

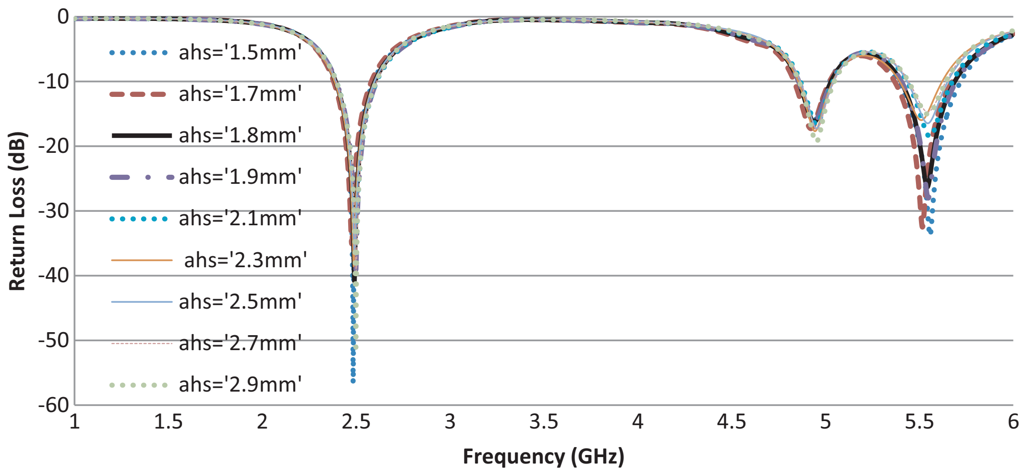
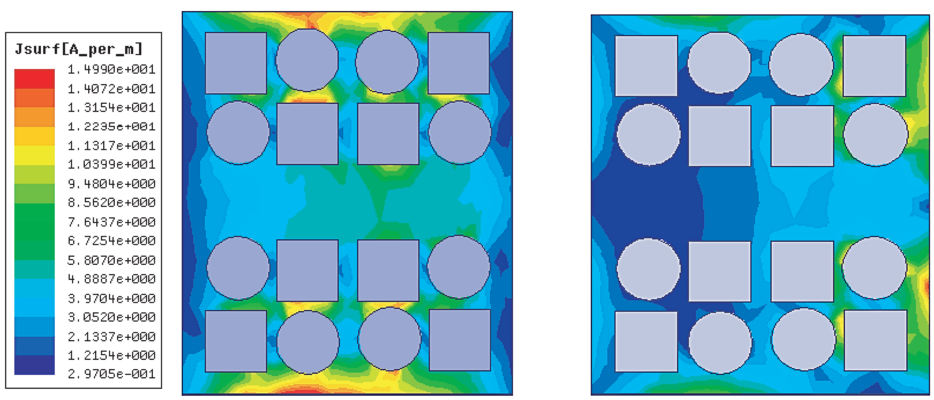
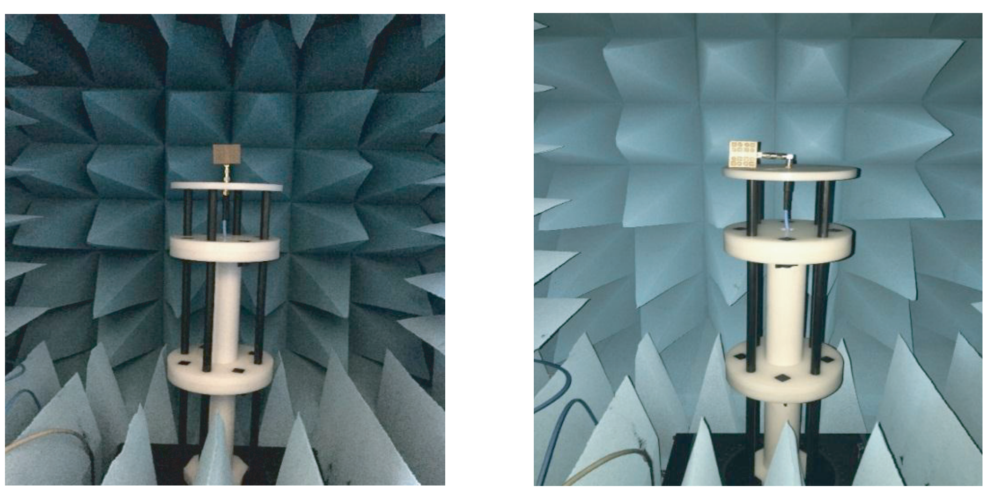


Figure 8. Effect of air gap variation.



(a) (b)

Figure 9. An electrically small antenna surface current distribution at (a) 2.4 GHz, (b) 5.5 GHz.



(a) (b)

Figure 10. Anechoic chamber for radiation measurement. (a) E-plane. (b) H-plane.

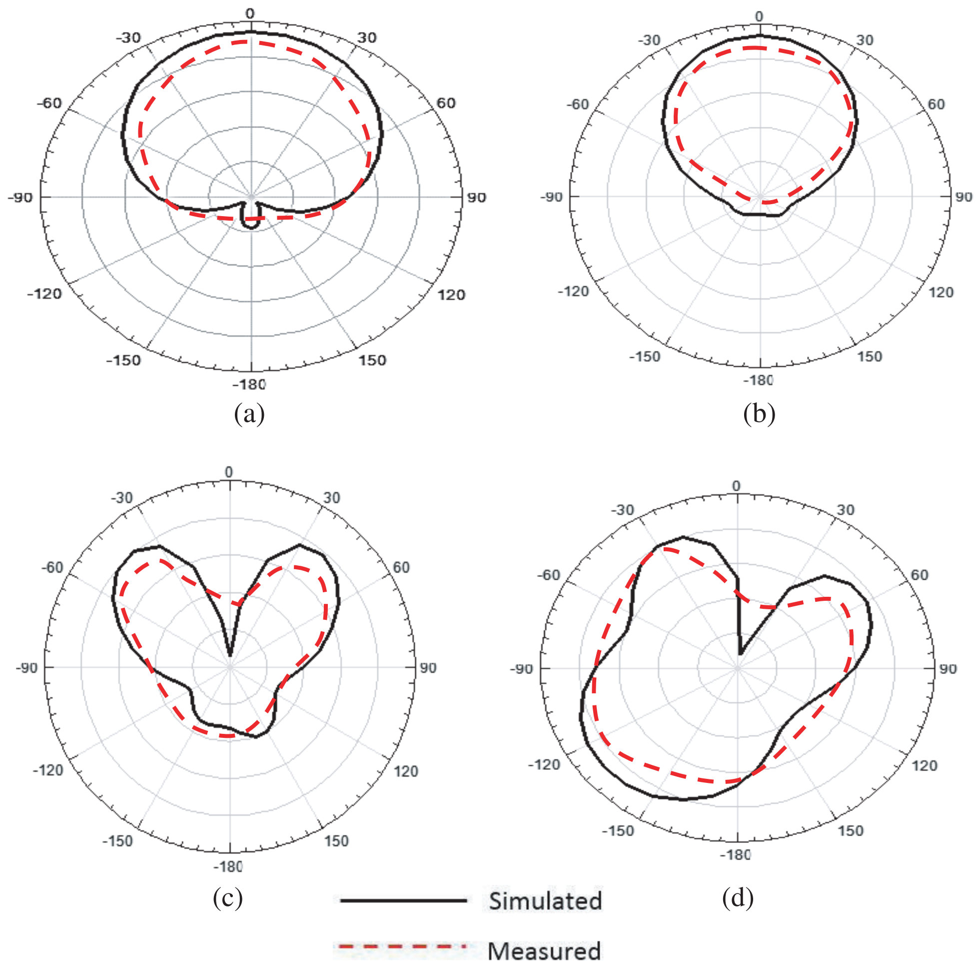


Figure 11. Simulated & measured radiation patterns. (a) E-plane at 2.4 GHz. (b) H-plane 2.4 GHz. (c) E-plane at 5.5 GHz. (d) H-plane 5.5 GHz.

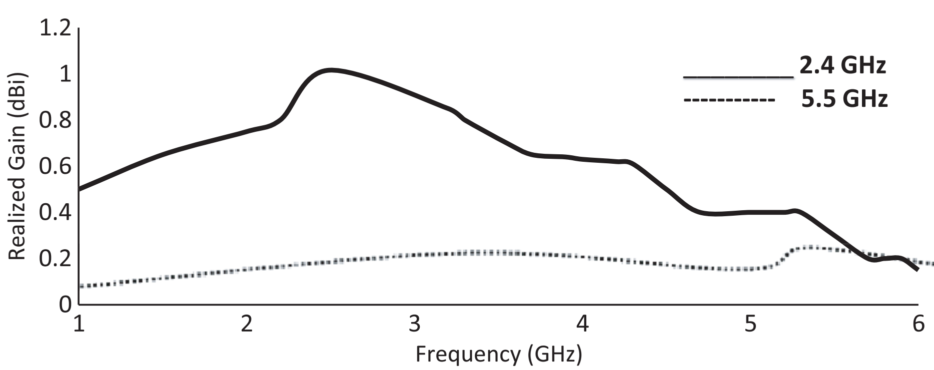


Figure 12. Realized gain of fabricated prototype.

in results is due to material tolerance, measurement error and environmental effect. The proposed electrically small antenna can effectively cover the WLAN frequency range. Figure 12 illustrates realized gain of the fabricated prototype at 2.4 GHz and 5.5 GHz frequencies. Maximum gains of 1 dBi and 0.26 dBi are achieved for 2.4 and 5.5 GHz frequency bands, respectively. Further gain enhancement techniques can be employed to improve the antenna gain.

5. CONCLUSION

A cost effective dual-band compact antenna for WLAN is presented. The vital benefit of the proposed antenna is extreme ease and simplicity in design and fabrication. By merely engineering the patches on top substrate, target frequencies in L-band and S-band can be achieved. The antenna design can be further enhanced by employing gain enhancement techniques.

REFERENCES

1. Fujimoto, K. and H. Morishita, *Modern Small Antennas*, 2014, dx.doi.org/10.1017/CBO9780511977602.
2. Palandoken, M. and H. Henke, "Fractal negative-epsilon metamaterial," *IEEE International Workshop on Antenna Technology (iWAT)*, 2010.
3. Stuart, H. R. and A. Pidwerbetsky, "Electrically small antenna elements using negative permittivity resonators," *IEEE Transactions on Antennas Propagation*, Vol. 54, 1644–1653, 2006.
4. Ghosh, B., S. Ghosh, and A. B. Kakade, "Investigation of gain enhancement of electrically small antennas using double-negative, single-negative, and double-positive materials," *Physical Review E*, Vol. 78, 026611, 2008.
5. Upadhyaya, T. K., S. P. Kosta, R. Jyoti, and M. Palandöken, "Novel stacked μ-negative material-loaded antenna for satellite applications," *International Journal of Microwave and Wireless Technologies*, Vol. 8, 229–235, 2016, doi:10.1017/S175907871400138X.
6. Kimouche, H. and S. Oukil, "Electrically small antenna with defected ground structure," *2012 9th European Radar Conference (EuRAD)*, IEEE, 2012.
7. Geng, J.-P., J. Li, R.-H. Jin, S. Ye, X. Liang, and M. Li, "The development of curved microstrip antenna with defected ground structure," *Progress In Electromagnetics Research*, Vol. 98, 53–73, 2009.
8. Thal, H. L., "New radiation Q limits for spherical wire antennas," *IEEE Transactions on Antennas Propagation*, Vol. 54, No. 10, 2006.
9. Chu, L. J., "Physical limitations in omnidirectional antennas," *J. Appl. Phys.*, Vol. 19, 1163–1175, 1948.
10. Wheeler, H. A., "Fundamental limitations of small antennas," *IRE Proc.*, Vol. 35, 1479–1484, 1947.
11. Patel, R. H., A. Desai, and T. Upadhyaya, "A discussion on electrically small antenna property," *Microwave Opt. Technol. Letter*, Vol. 57, 2386–2388, 2015, doi: 10.1002/mop.29335.
12. Yaghjian, A. D. and S. R. Best, "Impedance, bandwidth, and Q of antennas," *IEEE Transactions on Antennas Propagation*, Vol. 53, 1298–1324, 2005.
13. Zhang, Y. and H. Y. D. Yang, "Bandwidth-enhanced electrically small printed folded dipoles," *IEEE Antennas Wireless Propagation Letter*, Vol. 9, 236–239, 2010.
14. Li, L.-W., C.-P. Lim, and M.-S. Leong, "Near fields of electrically small thin square and rectangular loop antennas," *Progress In Electromagnetics Research*, Vol. 31, 181–193, 2001.
15. Dang, L., Z. Y. Lei, Y. J. Xie, G. L. Ning, and J. Fan, "A compact microstrip slot triple-band antenna for WLAN/WiMAX applications," *IEEE Antennas Wireless Propagation Letter*, Vol. 9, 1178–1181, 2010.
16. Peng, C.-M., I.-F. Chen, and J.-W. Yeh, "Printed broadband asymmetric dual-loop antenna for WLAN/WiMAX applications," *IEEE Antennas Wireless Propagation Letter*, Vol. 12, 898–901, 2013.
17. Balanis, C. A., *Antenna Theory Analysis and Design*, 3rd Edition, Wiley, Hoboken, NJ, USA, 2005.
18. McLean, J. S., "A re-examination of the fundamental limits on the radiation Q of electrically small antennas," *IEEE Transactions on Antennas Propagation*, Vol. 44, 672–676, 1996.
19. Bancroft, R. and H. A. Wheeler, "Fundamental dimension limits of antennas ensuring proper antenna dimensions in mobile device designs," *Centurion Wireless Technologies*, 2014.