Progress In Electromagnetics Research M, Vol. 61, 205–213, 2017

Improved Performance of Double-T Monopole Antenna for 2.4/5.6 GHz Dual-Band WLAN Operation Using Artificial Magnetic Conductors

Zahra Chamani and Sajad Jahanbakht*

Abstract—A novel artificial magnetic conductor (AMC) structure for realizing gain enhancement of a double-T monopole antenna for 2.4/5.6 GHz dual-band WLAN operation is presented. First, an initial AMC unit cell is proposed, and a 2×5 array of this unit cell is placed behind a double-T monopole antenna as a ground plane, then the AMC structure is modified and improved to achieve better performance. Briefly, more than 4 dB gain improvement and other desirable characteristics including suitable radiation patterns and adequate bandwidths are reported from the simulation results of the final designed structure, and the simulation is performed by CST MWS 2014 in any of the mentioned frequencies. Finally, the validity and applicability of this design are demonstrated through experimental results of the fabricated antenna.

1. INTRODUCTION

Nowadays, planar antennas have attracted considerable attention due to the advantages such as low cost, low weight, low profile, simple fabrication and adaptability with different kinds of surfaces [1]. However, low gain, low power, low efficiency and narrow bandwidth are regarded as the disadvantages of these antennas [2].

Using a perfect electric conductor (PEC) ground plane as a reflector is one method for enhancing the gain of these antennas which can result in up to about 3 dB increase in antenna gain. However at the same time, it also inverts the phase of the reflected waves which causes destructive interference with waves in other directions and also considerably destroys the bandwidth [3]. Another approach for improving performance of these antennas is to use an AMC structure as a ground plane [4]. This periodic structure provides the ability of increased gain, forward-to-back radiation ratio, broadening bandwidth and reduced back radiation [5, 6]. Of course all these advantages can be achieved when the AMC structure actually acts as a perfect magnetic conductor meaning that it reflects the vertical incident wave with phase shift in the interval of $[-90°, +90°]$, especially near $0°$ [7, 8]. The frequency band corresponding to phase shifts in the mentioned interval is defined as the AMC in-phase frequency band [7–9].

The objective of the present work is to improve the performance of a double-T monopole antenna especially gain using an AMC structure with appropriate radiation pattern without much reduction of bandwidth in both of the mentioned WLAN frequencies.

The initial single antenna is a double-T monopole antenna in 2.4/5.6 GHz for WLAN applications with optimized dimensions which is based on [10] and is presented in Section 2. The unit cell of AMC structure which has two AMC in-phase frequency bands covering both of the WLAN frequency bands is proposed in Section 3. Section 4 is dedicated to studying the effects of the array of designed AMC unitcells on the initial antenna and methods of modifying the structure, then the final fabricated antenna

Received 3 September 2017, Accepted 18 October 2017, Scheduled 2 November 2017
* Corresponding author: Sajad Jahanbakht (jahanbakht@kashanu.ac.ir).
The authors are with the Department of Electrical and Computer Engineering, University of Kashan, Kashan, Iran.

and its measurement results are provided for verifying the simulation results in Section 5. Eventually, conclusions are presented in Section 6.

2. ANALYSIS OF THE SINGLE DOUBLE-T MONOPOLE ANTENNA

This planar antenna consists of a double-T patch with two resonance frequencies, shown in Fig. 1(a), and is etched on a 0.81-mm-thick dielectric substrate of Rogers Ro 4003 material ($\varepsilon_r = 3.55$, $\tan\delta = 0.0027$) with dimensions of $48 \times 72\,\text{mm}^2$. A microstrip line with the width and length of 1.78 mm and 24 mm is used for feeding the patch which leads to a 50-Ω line impedance. The length of the feeding ground plane is chosen the same as the microstrip feed line length shown in Fig. 1(b). The first resonance frequency of this dual-band antenna is controlled by the size of the longer arm, and the second resonance frequency is controlled by the size of the smaller arm. The full-wave simulation of this antenna is done by CST MWS 2014 in time domain and is optimized for reducing the amounts of the reflection coefficient of the structure to less than -10 dB (SWR < 1.925) in 2.4 and 5.6 GHz frequencies, shown in Fig. 2. The gains of this antenna in 2.4 GHz and 5.6 GHz frequencies are equal to 1.985 dB and 3.991 dB, respectively, which are relatively small. Therefore, an AMC structure which is achieved by repeating a unit cell [7–11] is suggested as a solution for increasing gain and accordingly directivity of the antenna.

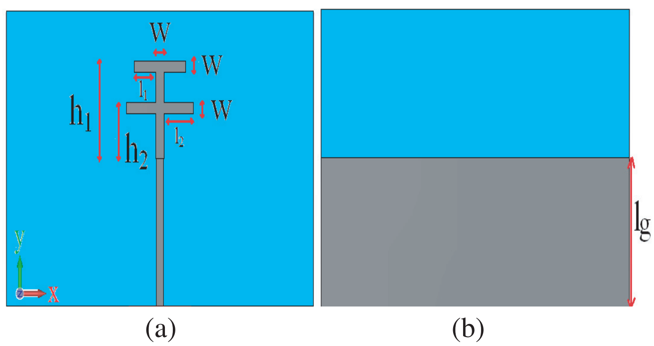


Figure 1. Configuration of the single double-T monopole antenna. (a) Top view. (b) Back view. ($w = 1.92$, $l_1 = 5.08$, $l_2 = 6.91$, $h_1 = 15.84$, $h_2 = 9.12$, $l_g = 24$, all in mm).

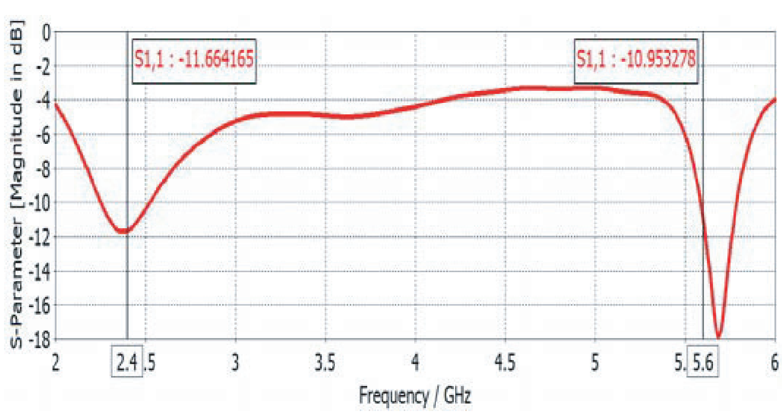


Figure 2. Reflection coefficient of the single double-T monopole antenna.

3. DESIGN AND SIMULATION OF THE UNIT-CELL

Based on the stated concepts in Section 1, a unit cell with two AMC in-phase frequency bands around two mentioned WLAN frequencies is required which is designed by tuning and optimizing [12]. The

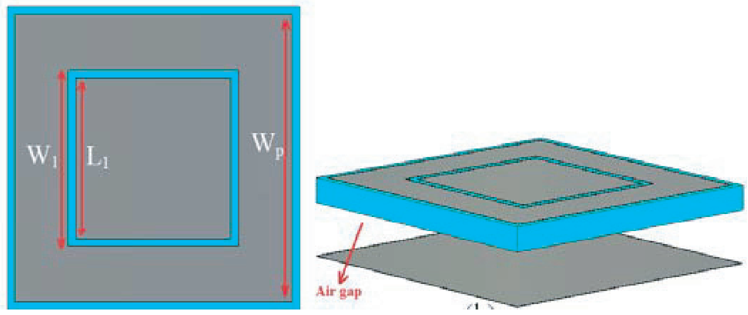


Figure 3. The geometry of the unit cell. (a) Top view. (b) 3-D configuration. ($W_p = 19$ mm, $W_1 = 11.6$ mm, $L_1 = 10.6$ mm and the width of all the slots is 0.5 mm).

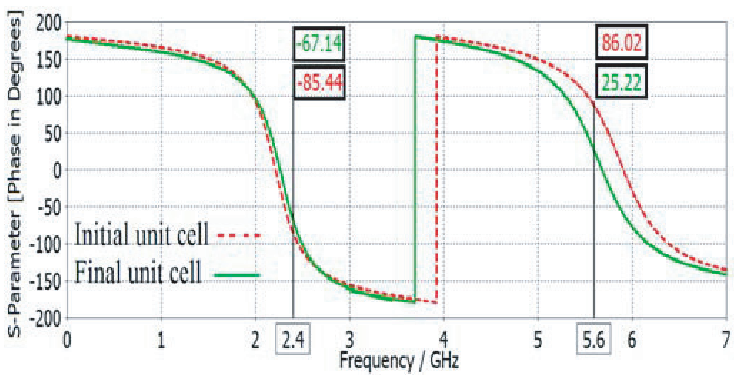


Figure 4. The reflection phase of the initial and final unit cell.

initial proposed unit cell consists of a metal square plate on top with a square slot in the center of the plate, as shown in Fig. 3(a). The metal plate is placed on a $20 \times 20\,\text{mm}^2$ dielectric substrate with the same material of double-T monopole antenna and 1.62 mm thickness. The first resonance frequency of the unit cell is more affected by the overall dimensions of the unit cell and also the size of the metal square plate while the second one is more affected by the size of the square slot in the center of the plate [13]. There is a 3.5-mm air gap between the ground plane of the unit cell and the dielectric substrate which is determined in Fig. 3(b). A wider AMC in-phase frequency band with better performance and also a reduced AMC substrate height are obtained by the existence of this air gap. Reducing AMC substrate thickness and accordingly decreasing weight and cost are more evident at low frequencies [3–14]. The unit cell simulation is performed in frequency domain, and the reflection phase diagram versus frequency is depicted in Fig. 4 which is marked as the 'initial unit cell'. The 'final unit cell' will be presented in the next section.

4. DOUBLE-T MONOPOLE ANTENNA WITH THE PROPOSED AMC STRUCTURE

Several arrays of the initial proposed unit cells with different numbers of elements in different transversal directions were tested and placed behind the monopole antenna as a ground plane. Finally, a 2×5 array as shown in Figs. 5(a) and 5(b) was selected because of the most similar reflection coefficient (Fig. 6) to the desirable result. It should be considered that no unit cells are placed under the microstrip feed line because the transmission characteristic of the line may be destroyed by these unit cells [15, 16].

As realized from Fig. 6, the initial obtained reflection coefficient is not quite favorable. For achieving demanded result, resonance frequencies must change so that the amounts of the reflection coefficient in 2.4 and 5.6 GHz frequencies are decreased to values less than -10 dB.

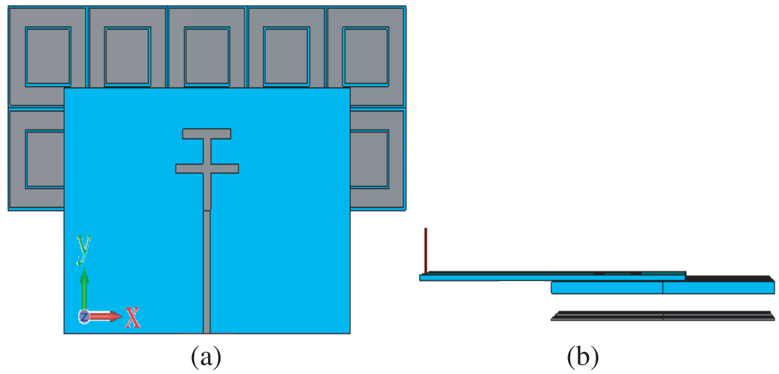


Figure 5. Topology of the initial proposed structure. (a) Top view. (b) Side view. (There is a slot with width of 1 mm between unit cells).

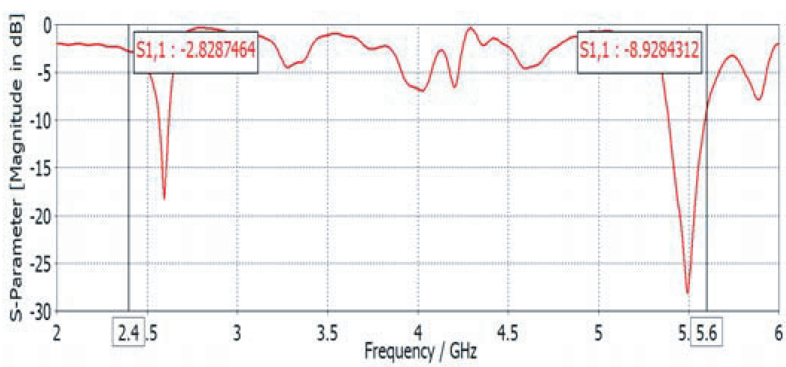


Figure 6. Reflection coefficient of the antenna on the initial proposed 2×5 AMC ground plane.

The overall dimensions and also size of the metal square plate of the unit cell mostly influence the first resonance frequency, as mentioned before. However, increasing the overall dimensions of the AMC structure for decreasing the first resonance frequency is not preferred. One method for decreasing the first resonance frequency is adding slot in every side of the metal square plate in order to increase its length [17, 18]. First, adding one slot in every side of the square plate is tested and optimized for achieving the desirable result which is stated above. With the sizes of these obtained slots and due to the existence of a little distance between the slots specified in Fig. 7, probably the fabrication of this structure faces some challenges. Therefore, using two slots with smaller sizes is chosen, as illustrated in Fig. 8. In this optimization step, the air gap is increased to 5 mm. Also the size of the square slot in the center of the unit cell is decreased for enhancing the second resonance frequency. The final unit cell's reflection phase is shown in Fig. 4. Further reviews show that the gain and radiation patterns of the antenna are more improved by enlarging the ground plane of the unit cells to the end of the microstrip feed line and with size of $64 \times 100\,\text{mm}^2$. The final proposed structure can be seen in Fig. 9 in different views.

Reflection coefficients of the monopole antenna with and without final AMC ground plane are shown in Fig. 10. The amounts of the reflection coefficients of the antenna over the new AMC structure in 2.4/5.6 GHz frequencies are reduced to -14.01 dB and -17.86 dB, respectively, and the bandwidths of this dual-band structure remain in an acceptable level without much reduction. As observed from reflection coefficient of the monopole antenna with new AMC structure in Fig. 10, there is another resonance frequency between two mentioned frequencies due to the inductive and capacitive properties of the new added slots [17–19]. However, because of the lack of sufficient gain and suitable patterns, this resonance frequency is not very useful.

It is observed that the gain of the total structure in 2.4 GHz and 5.6 GHz frequencies reaches the desirable values of 6.446 dB and 8.423 dB which show 4.461 dB and 4.432 dB improvement compared to

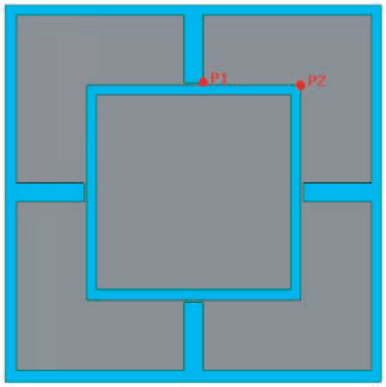


Figure 7. The first proposed slotting structure for adjusting the operational bands. The distance between specified slots is 0.16 mm.

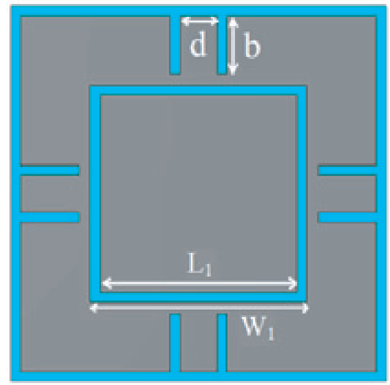


Figure 8. The final proposed unit cell. ($L_1 = 10.53$, $W_1 = 11.53$, $d = 2$, $b = 3.1$, all in mm and the width of all the slots is 0.5 mm).

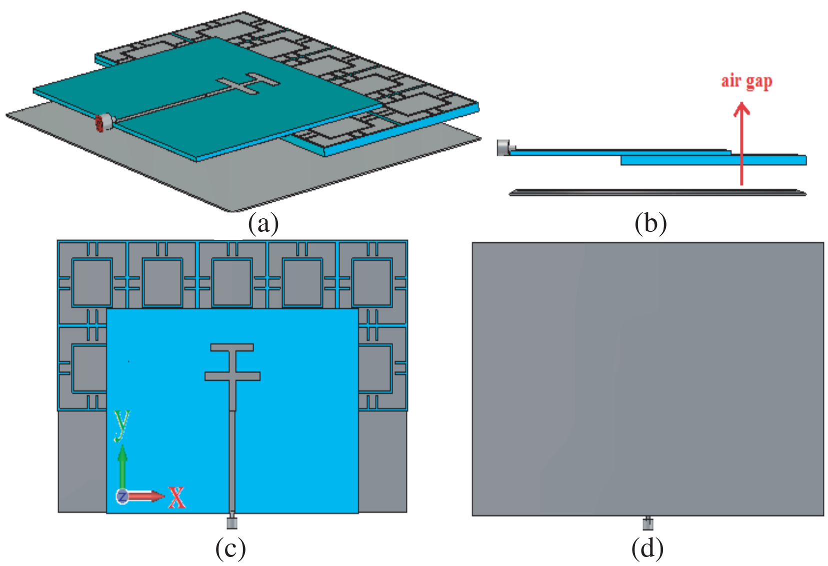


Figure 9. Topology of the final proposed structure. (a) 3-D configuration. (b) Side view. (c) Top view. (d) Back view.

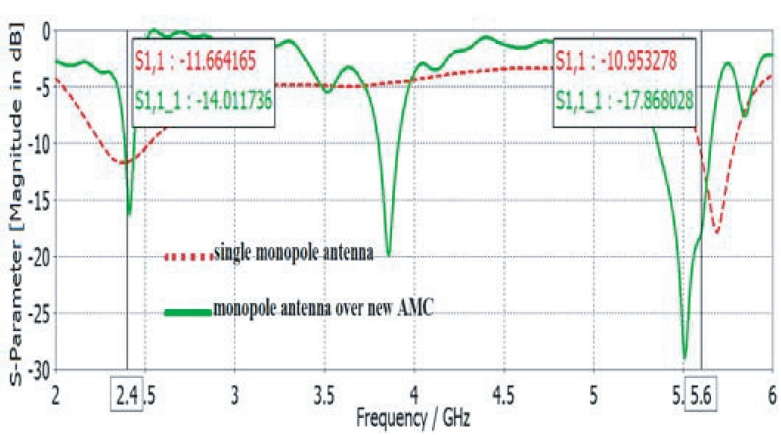


Figure 10. Reflection coefficients of the monopole antenna with and without final AMC ground plane.

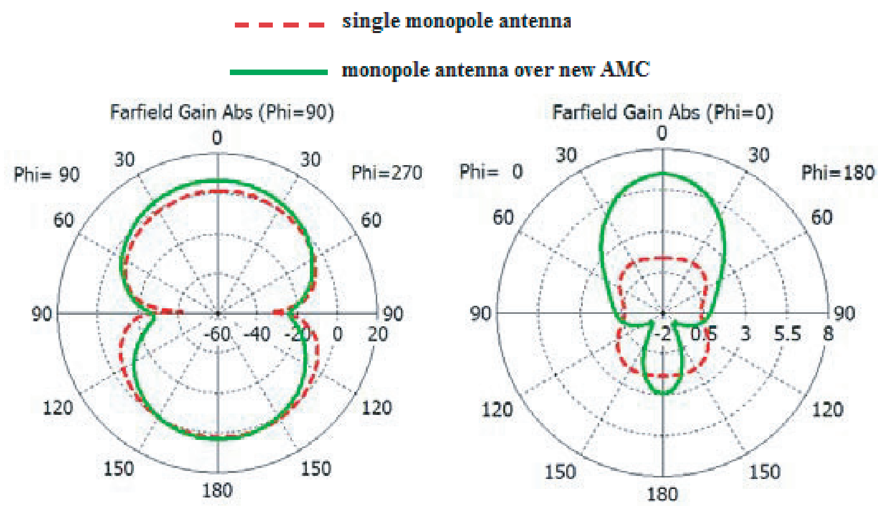


Figure 11. Radiation patterns of the antenna with and without new AMC structure in 2.4 GHz frequency in $\varphi = 90^\circ$ and $\varphi = 0^\circ$ planes.

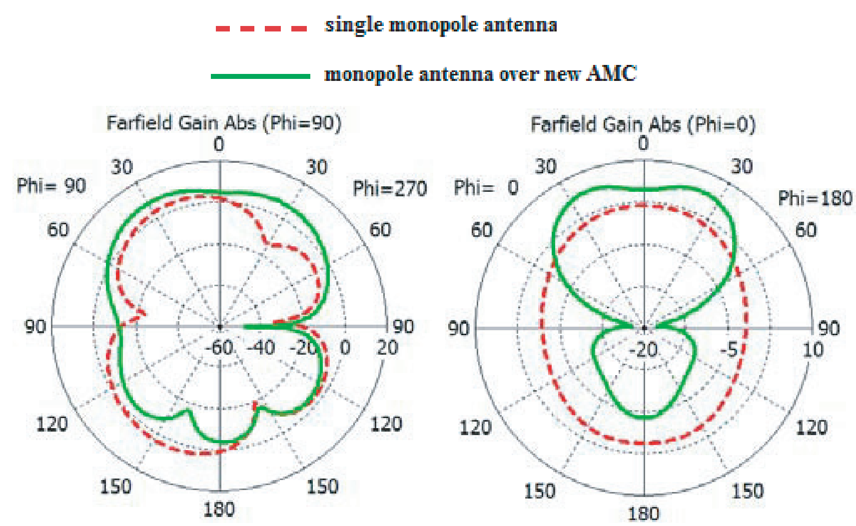


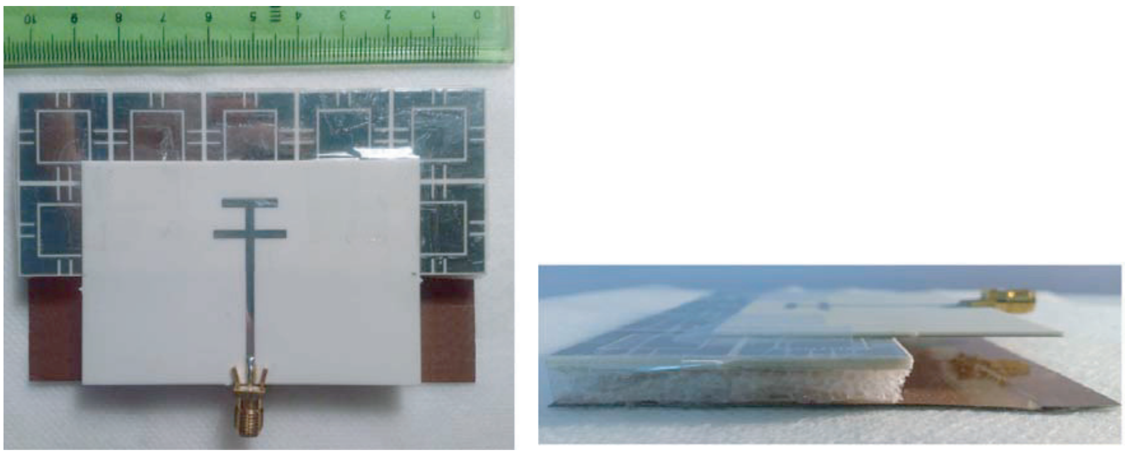
Figure 12. Radiation patterns of the antenna with and without new AMC structure in 5.6 GHz frequency in $\varphi = 90^\circ$ and $\varphi = 0^\circ$ planes.

the gains of the single double-T monopole antenna at these frequencies. The radiation patterns of the single monopole antenna and antenna with new AMC structure in 2.4 GHz and 5.6 GHz frequencies are drawn in Figs. 11 and 12, respectively.

As can be seen from the patterns in Fig. 11, the main lobe magnitude of the antenna is increased from 1.88 dB to 6.45 dB in $\varphi = 90^\circ$ plane and is enhanced from 1.92 dB to 6.45 dB in $\varphi = 0^\circ$ plane by using the AMC ground plane as a reflector in 2.4 GHz frequency. Also as comprehended from Fig. 12, the main lobe magnitude of the antenna is increased from 3.9 dB to 8.47 dB in $\varphi = 90^\circ$ plane and is improved from 1.83 dB to 6.45 dB in $\varphi = 0^\circ$ plane by using the new AMC structure in 5.6 GHz frequency. In fact, as observed from both Figs. 11 and 12 especially in $\varphi = 0^\circ$ planes, the AMC reflector guides the radiation patterns of the monopole antenna to the opposite direction of itself; therefore, the gain and directivity of the antenna are improved. It is manifested that all of the goals of the design including gain improvement of the double-T monopole antenna for 2.4/5.6 GHz dual-band WLAN operation with appropriate bandwidths and radiation patterns are achieved by using this novel AMC ground plane. Because of the planar structure, the final design is very easy to fabricate.

5. FABRICATION AND TESTING OF THE FINAL DESIGNED STRUCTURE

Top and side views of the fabricated antenna are shown in Fig. 13. A foam layer is used between the substrate and ground plane of the AMC structure instead of air which has a dielectric constant very close to the dielectric constant of air as presented in Fig. 13(b). The simulated and measured reflection coefficients of the final designed structure are depicted and compared in Fig. 14. As can be seen, the values of the measured reflection coefficient in 2.4/5.6 GHz frequencies are equal to −21 dB and −25 dB, respectively.



(a) (b)

Figure 13. Configuration of the fabricated antenna. (a) Top view. (b) Side view.

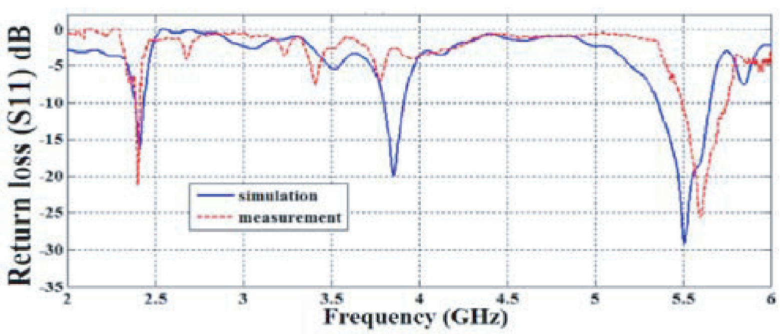


Figure 14. The simulated and measured reflection coefficients of the final designed structure.

The measured gains of the antenna are equal to 5.941 dB and 7.824 dB with 0.5–0.6 dB reduction compared to the simulated gains in 2.4 GHz and 5.6 GHz frequencies. This reduction is a result of the practical losses which are present in the experiment. The simulated and measured radiation patterns of the double-T monopole antenna over the final designed AMC structure are normalized and illustrated in Figs. 15 and 16 in $\varphi = 90°$ and $\varphi = 0°$ planes in both of the desired frequencies of the WLAN bands. Because of the experimental limitations, the back lobes are not present in the measured radiation patterns. As observed from Figs. 14–16, there is a good agreement between simulated and fabricated antennas on reflection coefficients, gains and radiation patterns, and the simulation results are confirmed by the measurement ones with good accuracy.

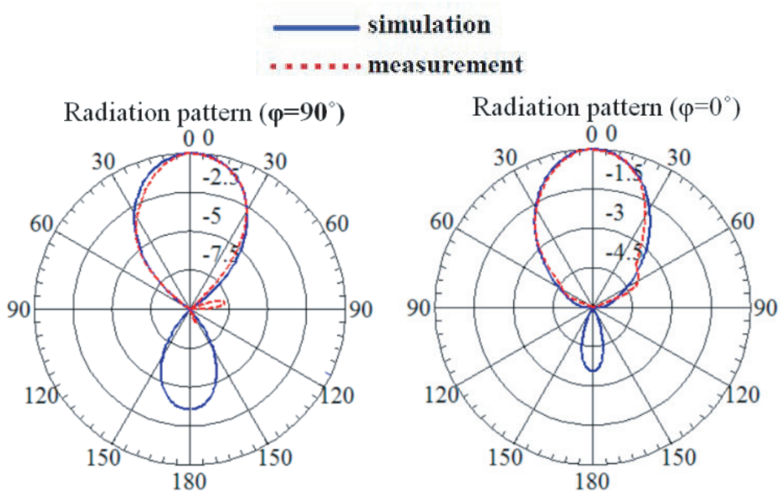


Figure 15. The simulated and measured radiation patterns of the final designed structure in 2.4 GHz frequency in $\varphi = 90^\circ$ and $\varphi = 0^\circ$ planes.

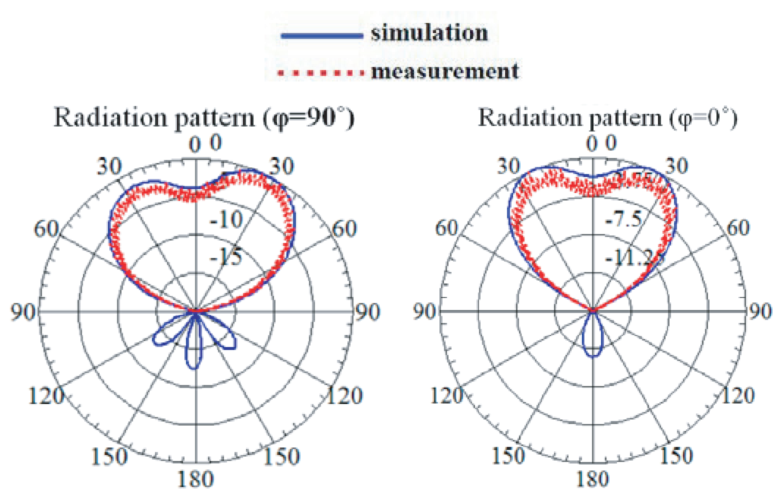


Figure 16. The simulated and measured radiation patterns of the final designed structure in 5.6 GHz frequency in $\varphi = 90^\circ$ and $\varphi = 0^\circ$ planes.

6. CONCLUSIONS

In this paper, a novel AMC structure is investigated for realizing the purpose of gain enhancement of a double-T monopole antenna for 2.4/5.6 GHz dual-band WLAN operation with suitable radiation patterns and bandwidths. A 2×5 array of the final AMC unit cell is located behind the monopole antenna, and the ground plane of the structure is enlarged for achieving better gain and radiation pattern. Nearly 4.461 dB and 4.432 dB improvements of gain compared to the single double-T monopole antenna with desirable radiation patterns and bandwidths are resulted in 2.4/5.6 GHz frequencies, respectively.

Using the air gap idea in designing unit cells results in a thinner dielectric substrate which in addition to decreasing weight and cost, causes narrower microstrip feed line. This in turn reduces spurious feed radiations which results in smoother radiation patterns. Experiments on the fabricated antenna indicate that using this AMC structure is a robust and reliable way for improving performance of this dual-band antenna.

REFERENCES

1. Balanis, C. A., *Antenna Theory Analysis & Design*, 3rd Edition, John Wiley and Sons, New York, 2005.
2. Garg, R., P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House, 2001.
3. Mohamed-Hicho, N. M., E. Antonino-Daviu, M. Cabedo-Fabres, and M. Ferrando-Bataller, "A novel low-profile high-gain UHF antenna using high-impedance surfaces," *IEEE Antennas and Wireless Propagation Lett.*, Vol. 14, 1014–1017, 2015.
4. Wang, B., C. Huang, W. Luo, and W. Ruan, "Low-profile broadband dual-polarized dipole antenna on AMC reflector for base station," *Progress In Electromagnetics Research C*, Vol. 74, 171–179, 2017.
5. Elwi, T. A., A. I. Imran, and Y. Alnaiemy, "A miniaturized lotus shaped microstrip antenna loaded with EBG structures for high gain-bandwidth product applications," *Progress In Electromagnetics Research C*, Vol. 60, 157–167, 2015.
6. Muhammad, N., et al., "High gain FSS aperture coupled microstrip patch antenna," *Progress In Electromagnetics Research C*, Vol. 64, 21–31, 2016.
7. Sievenpiper, D., L. Zhang, R. F. Broas, N. G. Alexopolous, and E. Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, No. 11, 2059–2074, Nov. 1999.
8. Rexhepi, T. and D. Crouse, "A study of composite substrates for VHF and UHF artificial magnetic conductors and their application to a SATCOM antenna," *Progress In Electromagnetics Research C*, Vol. 64, 1–9, 2016.
9. LibiMol, V., et al., "Radar cross section reduction property of high impedance surface on a lossy dielectric," *Progress In Electromagnetics Research M*, Vol. 46, 19–28, 2016.
10. Kuo, Y. and K. Wong, "Printed double-T monopole antenna for 2.4/5.2 GHz dual-band WLAN operations," *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 9, 2187–2192, 2003.
11. Zhang, L. and T. Dong, "RCS reduction using a miniaturized uni-planar electromagnetic band gap structure for circularly polarized microstrip antenna array," *Progress In Electromagnetics Research Letters*, Vol. 66, 135–141, 2017.
12. Meriche, M. A., H. Attia, A. Messai, and T. A. Denidni, "gain improvement of a wideband monopole antenna with novel artificial magnetic conductor," *17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)*, 1–2, IEEE, 2016.
13. El Ghabzouri, M., A. E. Salhi, P. Anacleto, and P. Mendes, "Enhanced low profile, dual-band antenna via novel electromagnetic band gap structure," *Progress In Electromagnetics Research C*, Vol. 71, 79–89, 2017.
14. Zheng, J. and S. Fang, "A new method for designing low RCS patch antenna using frequency selective surface," *Progress In Electromagnetics Research Letters*, Vol. 58, 125–131, 2016.
15. Yang, W., H. Wang, W. Che, and J. Wang, "A wideband and high-gain edge-fed patch antenna and array using artificial magnetic conductor structures," *IEEE Antennas and Wireless Propagation Lett.*, Vol. 12, 769–772, 2013.
16. Majid, H. A., M. K. Abd Rahim, M. R. Hamid, M. F. M. Yusoff, N. A. Murad, N. A. Samsuri, O. B. Ayop, and R. Dewan, "Wideband antenna with reconfigurable band notched using EBG structure," *Progress In Electromagnetics Research Letters*, Vol. 54, 7–13, 2015.
17. Ta, S. X. and I. Park, "Design of miniaturized dual-band artificial magnetic conductor with easy control of second/first resonant frequency ratio," *Journal of Electromagnetic Engineering and Science*, Vol. 13, No. 2, 104–112, Jun. 2013.
18. Li, H., Q. Cao, and Y. Wang, "A novel miniaturized frequency selective surface with very stable performance," *Progress In Electromagnetics Research C*, Vol. 75, 131–138, 2017.
19. Jaglan, N., B. K. Kanaujia, S. D. Gupta, and S. Srivastava, "Triple band notched UWB antenna design using electromagnetic band gap structures," *Progress In Electromagnetics Research C*, Vol. 66, 139–147, 2016.