Metamaterial-Inspired Split Ring Monopole Antenna for WLAN Applications

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Abstract **─** This paper describes the design of a compact dual band monopole antenna for WLAN (2.4/5.2/5.8 GHz) applications. The antenna is printed on a 22.5×24×0.8 mm^3 FR-4 substrate with a partial ground plane and is fed by a microstrip line. The proposed structure consists of a simple hexagonal ring with a split arm along its center. The split in the arm in turn creates a quarter wavelength resonance in the higher frequency range. It also induces magnetic resonance which accounts for band notch between the WLAN lower (2.4 GHz) and upper bands (5.2/5.8 GHz). The extraction of negative permeability of the split ring structure is also discussed. A prototype of the proposed structure is fabricated and the measured results comply greatly with the simulated results. The antenna has consistent radiation pattern and stable gain over all the working region.

Index Terms **─** Hexagonal monopole antenna, negative permeability, notch frequency, split ring, WLAN.

I. INTRODUCTION

Wireless Local Area Network (WLAN) is a significant component of the wireless computer network which interconnects two or more devices. It is based on IEEE 802.11 standard and operates in the 2.45 (2.4-2.48) GHz, 5.2 (5.15-5.35) GHz and 5.8 (5.75-5.825) GHz frequencies. Design of single antenna capable of operating at all these specified frequencies have attracted many researchers in the recent past. Besides obtaining multiple frequencies, the antenna also demands compactness, cost effectiveness and flexibility to be integrated with other microwave integrated devices. Printed monopole antennas seem to be a good choice to meet these aforementioned challenges. Multi branched radiators [1, 2], slotted monopoles [3-5], meander monopoles [6], fractal shapes [7] are few among them to obtain dual band operation in the WLAN 2.5/5.2/5.8 GHz range. However, these antennas suffer from either complicated geometry [1, 5] or larger dimensions. Reactive slots in the radiating patch [3] have compact dimensions, yet it resulted in poor impedance matching at the lower resonant band. Recently, electromagnetic (EM) metamaterials inspired split ring elements and its complementary are also used as radiating structures for achieving compact and dual band antennas in the WLAN range. Their role in antenna design becomes attractive because of their ability to achieve miniaturization [8, 9], multiband resonances [10] gain and bandwidth enhancement [11]. Split ring monopole antenna proposed in [12] has impedance matching problem in the lower WLAN band, whereas the dual band antennas with CSRRs [13] and triangular split ring resonators (SRRs) [14] has larger dimensions. In general, the overall dimension of these antennas are large compared with the proposed one as shown in Table 1 below. Also, unlike these antenna analysis, this paper emphasizes on the role of metamaterial property (negative permeability) in antenna design, which many papers have failed to prove. As a result, the antenna designer can enjoy the privilege of tuning the operating frequency to the desired range.

In this paper, a simple and compact hexagonal split ring radiating element is proposed for WLAN applications. The split in the ring element is capable of creating band separation (notch band) between the operating bands due to its induced magnetic resonance. The proposed geometry is very simple with good resonant and radiation characteristics, making it a good choice for commercial use.

Table 1: Comparison of the existing antennas with the proposed antenna

Ref.	Dimensions, L x W (mm^2)	Metamaterial Property Verification
[12]	20 x 32	Not verified
[13]	34 x 30	Not verified
[14]	40 x 35	Not verified
Proposed antenna	24 x 22.5	Verified

II. PROPOSED ANTENNA DESIGN

The evolution of the proposed split ring radiating antenna is shown in Fig. 1. Configuration A shows a hexagonal ring monopole fed by a 50 Ω microstrip line and a partial ground plane. The monopole considered in our antenna design is hexagonal in shape whose resonant frequency will be similar to that of a circular monopole

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[15], hence the resonant frequency is given as $fr \approx \frac{1.8412*c}{4\pi S\sqrt{\varepsilon_r}}$. Here, c is the velocity of light, S is the side length of the hexagon and ε_r is the dielectric constant of the substrate. Hence, for a side length of 9 mm, the antenna resonates at 2.4 GHz. Now, in configuration B, a vertical arm is introduced at the center which in turn is connected to the feed directly. This vertical arm, opens up the higher order resonance. Finally, in configuration C, a split is introduced at the center of the vertical arm, which in turn opens up the quarter wave resonance corresponding to length L1 and also, induces a narrow magnetic resonance due to its capacitive effect and creates a sharp notch corresponding to the split width, yielding two resonant bands centered at 2.4 GHz and at 6 GHz. A detailed layout of the proposed antenna is shown in Fig. 2 along with its side view and its dimensions are listed in Table 2. Photograph of the proposed structure is shown in Fig. 3.

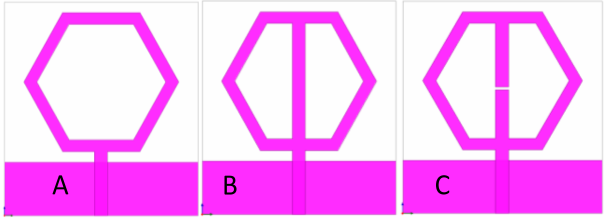

Fig. 1. Evolution of the proposed antenna.

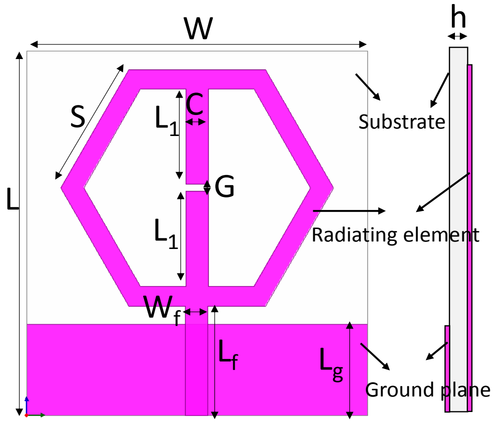

Fig. 2. Geometry of the proposed antenna: (a) top view and (b) side view.

Table 2: Dimensions of the proposed antenna

Parameter	Dimension (mm)	Parameter	Dimension (mm)
L	24	W	22.5
S	9	C	1.5
G	0.3	L_1	6.3
L_f	7.2	W_f	1.5
L_g	6	h	0.8

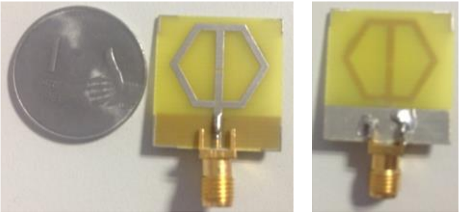

Fig. 3. Photograph of the fabricated dual band antenna (top view and bottom view).

III. SIMULATION RESULTS

Simulations are performed using the Ansoft High Frequency Structure Simulator (HFSS) V.15.0 commercial software package. Figure 4 shows the simulated return loss characteristics of three configurations shown in Fig. 1. Configuration A shows resonance around 2.4 GHz. When the vertical arm is introduced (configuration B), a higher order resonance is noted. The width of the vertical arm plays an important role in determining the higher order resonance. Finally, in configuration C, a split is introduced at the center of the vertical arm to induce magnetic resonance. Now, the higher order resonance is opened from 4 GHz to 7.5 GHz, covering the upper WLAN frequencies (5.15–5.35) and (5.75–5.825). Figure 5 shows the parametric study on the return loss characteristics of configuration C for various vertical arm's width C, ranging from 1.5 mm to 6 mm in steps of 1.5 mm. It is inferred that, as the width C increases, the notch frequency is shifted towards the lower frequencies, opening the upper WLAN band. The lower frequency limit of this band (5.2/5.8 GHz) is determined by the dimension L1 × C. For L_1 = 6.3 mm and C = 1.5 mm, the lower frequency limit is the quarter wave resonance of length (6.3 mm + 1.5 mm). Thus, C = 1.5 mm is chosen to be optimum for our design, which corresponds to the notch around 4 GHz. It is also inferred that, for C = 6 mm, the WiMAX band (3.5 GHz) is also covered.

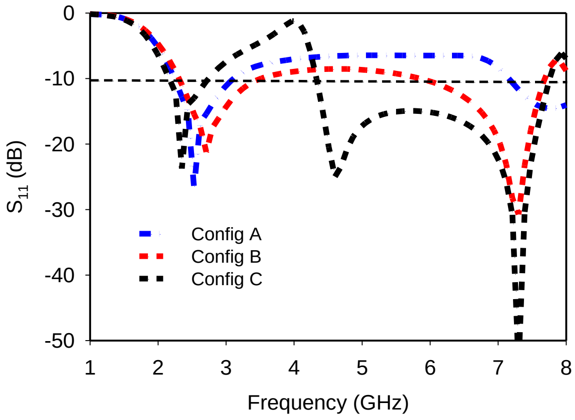

Fig. 4. Simulated return loss characteristics of the three configurations A, B, and C.

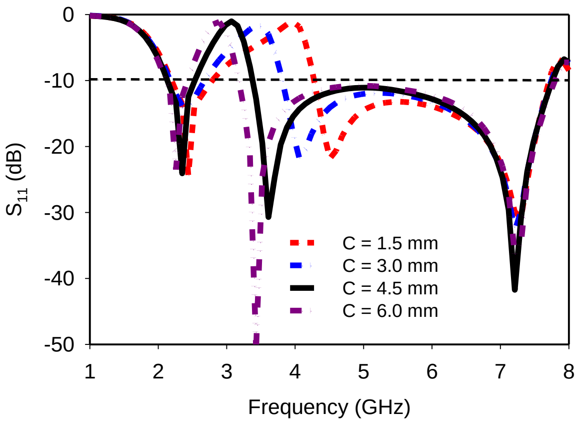

Fig. 5. Simulated return loss characteristics of configuration C for various width G.

Similarly, the split gap G plays an important role in determining the notch frequency. Figure 6 shows the parametric study on the return loss characteristics of configuration C for various split width G ranging from 0.3 mm to 0.9 mm in steps of 0.2 mm. It is observed that, as the split gap G increases, the notch frequency also increases correspondingly. Hence, G = 0.3 mm is chosen for our design, for a notch to occur around 4 GHz.

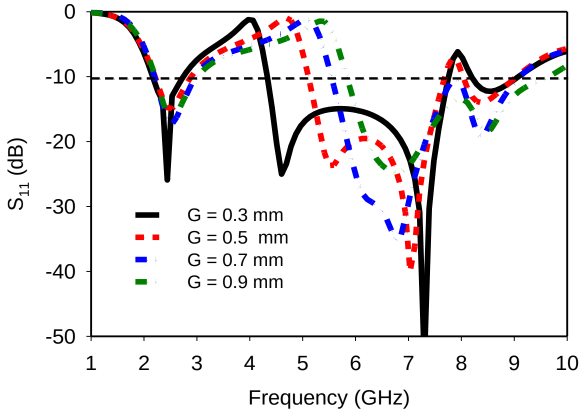

Fig. 6. Simulated return loss characteristics of configuration C for various width C.

IV. SPLIT RING ANALYSIS

The radiating element is itself a split ring structure which is analyzed using the classic waveguide theory approach. The transmission and reflection coefficients are noted and from which the effective material parameters, permeability and permittivity are extracted. Figure 7 shows the real parts of extracted effective permeability values plotted along with the return loss characteristics of the proposed structure. It is inferred that the permeability is negative around 4 GHz. This negative permeability region has in turn led to the notch frequency, which can be clearly understood by the dashed grey region. Due to the negative permeability, no transmission is practical in this region, thus the S_{11} curve exhibits notch band over this region.

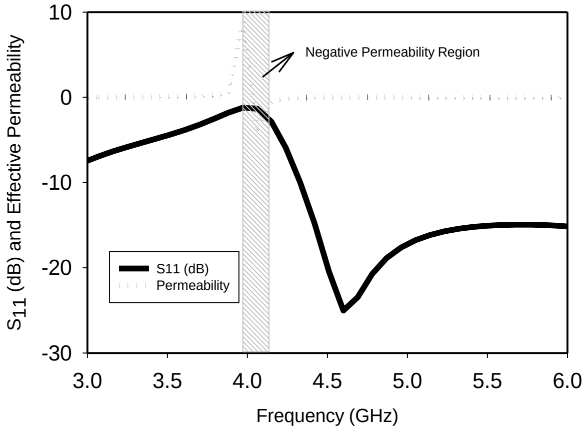

Fig. 7. Comparison of extracted real parts of effective permeability and S_{11} (dB).

V. MEASUREMENT RESULTS

The return loss characteristics are measured using a vector network analyzer. Figure 8 shows the simulated and measured return loss results. The measured data shows dual band resonance centered at 2.4 GHz (2.0 – 2.7 GHz) and at 4.4 GHz and 7.12 GHz (4.12 – 7.66 GHz). The measured data greatly agree with the simulated results. The radiation pattern of the proposed antenna is measured in an anechoic chamber, which is shown in Fig. 9. A consistent omnidirectional pattern is observed in the H plane and a bidirectional pattern is observed in the E plane over all the operating region (2.4, 5.5 GHz).

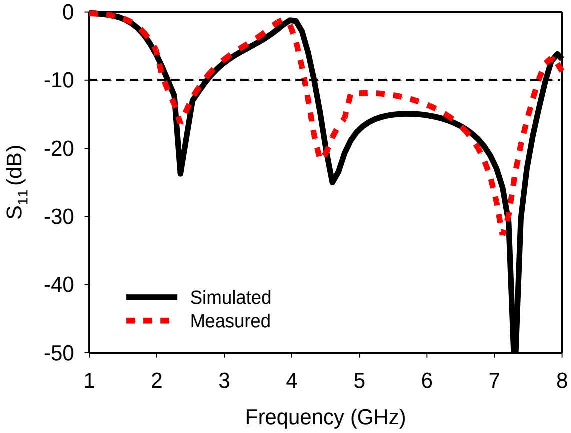

Fig. 8. Simulated and measured return loss characteristics of the proposed antenna.

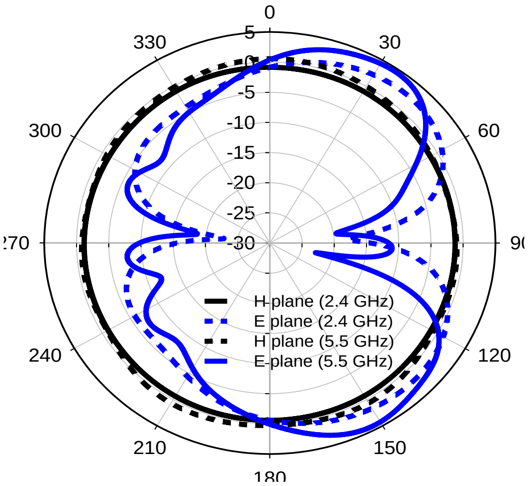

Fig. 9. Measured H plane and E plane pattern of the proposed antenna at 2.4 GHz and 5.5 GHz.

VI. CONCLUSION

A dual band monopole antenna suitable for WLAN 2.4/5.5 GHz applications is presented in this paper. The antenna makes use of a metamaterial inspired split ring structure for achieving the dual band resonance. The antenna geometry is very simple and also compact making mass production easy. The radiation pattern and gain are consistent over all the operating bands making the proposed antenna a good choice for wireless applications.

REFERENCES

[1] Y. Xu, Y.-C. Jiao, and Y.-C. Luan, "Compact CPW-fed printed monopole antenna with triple band characteristics for WLAN/WiMAX applications," *Electron Lett*., vol. 48, pp. 1519-1520, 2012.

[2] X. L. Sun, L. Liu, S. W. Cheung, and T. I. Yuk, "Dual-band antenna with compact radiator for 2.4/5.2/5.8 GHz WLAN applications," *IEEE Trans. Ant. P*, vol. 60, pp. 5924-5931, 2012.

[3] W.-C. Liua, C.-M. Wua, and N.-C. Chu, "A compact low profile dual-band antenna for WLAN and WAVE applications," *AEU Int. J. Electron. C*, vol. 66, pp. 467-471, 2012.

[4] C.-Y. Huang and E.-Z. Yu, "A slot monopole antenna for dual band WLAN applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 500-502, 2011.

[5] X.-Q. Zhang, Y.-C. Jiao, and W.-H. Wang, "Compact wide tri-band slot antenna for WLAN/WiMAX applications," *Electron. Lett*., vol. 48, pp. 64-65, 2012.

[6] H.-Y. Chien, C.-Y.-D. Sim, and C.-H. Lee, "Dual band meander monopole antenna for WLAN operation in laptop computer," *IEEE Antennas Wireless Propag. Lett*., vol. 12, pp. 694-697, 2013.

[7] R. Ghatak, R. K. Mishra, and D. R. Poddar, "Perturbed Sierpinski carpet antenna with CPW feed for IEEE 802.11 a/b WLAN application," *IEEE Antennas Wireless Propag. Lett*., vol. 7, pp. 742-744, 2008.

[8] D. Laila, R. Sujith, V. A. Shameena, C. M. Nijas, V. P. Sarin, and P. Mohanan, "Complementary split ring resonator-based microstrip antenna for compact wireless applications," *Microw. Opt. Technol. Lett*., vol. 55, pp. 814-816, 2013.

[9] R. O. Ouedraogo, E. J. Rothwell, A. R. Diaz, K. Fuchi, and A. Temme, "Miniaturization of patch antennas using a metamaterial-inspired technique," *IEEE Trans. Ant. P*, vol. 60,pp. 2175-2182, 2012.

[10] Y. H. Xie, C. Zhu, L. Li, and C. H. Liang, "A novel dual-band metamaterial antenna based on complementary split ring resonators," *Microw. Opt. Technol. Lett*., vol. 54, pp. 1007-1009, 2012.

[11] L.-W. Li, Y.-N. Li, T. S. Yeo, J. R. Mosig, and O. J. F. Martin, "A broadband and high-gain metamaterial microstrip antenna," *Appl. Phys. Lett*., vol. 96, pp. 164101-164103, 2010.

[12] S. C. Basaran and Y. E. Erdemli, "A dual band split ring monopole antenna for WLAN applications," *Microw. Opt. Technol. Lett*., vol. 51, pp. 2685-2688, 2009.

[13] S. C. Basaran, U. Olgun, and K. Sertel, "Multiband monopole antenna with complementary split ring resonators for WLAN and WiMAX applications," *Electron. Lett*., vol. 49, pp. 636-638, 2013.

[14] K. Yang, H. Wang, Z. Lei, Y. Xie, and H. Lai, "CPW-fed slot antenna with triangular SRR terminated feed line for WLAN/WiMAX applications," *Electron. Lett*., vol. 47, pp. 685-686, 2011.

[15] C. A. Balanis, *Antenna Theory: Analysis and Design*. John Wiley & Sons, 2005.