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Design of 2 x 2 U-shape MIMO slot antennas with EBG material for mobile handset applications

Z. Z. Abidin[1,2], **Y. Ma**[1], **R. A. Abd-Alhameed**[1], **K. N. Ramli**[1,2], **D. Zhou**[3], **M. S. Bin-Melha**[1], **J. M. Noras**[1], **and R. Halliwell**[1]

[1]Mobile and Satellite Communications Research Centre, University of Bradford
Bradford, West Yorkshire, BD7 2DF, UK
[2]Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia
Parit Raja, Batu Pahat, Johor, Malaysia
[3]Surrey Space Centre, University of Surrey, Guildford, GU2 7XH, UK

Abstract— A compact dual U-shaped slot PIFA antenna with Electromagnetic Bandgap (EBG) material on a relatively low dielectric constant substrate is presented. Periodic structures have found to reduce mutual coupling and decrease the separation of antenna and ground plane. A design with EGB material suitable for a small terminal mobile handset operating at 2.4 GHz was studied. Simulated and measured scattering parameters are compared for U-shaped slot PIFA antenna with and without EBG structures. An evaluation of MIMO antennas is presented, with analysis of the mutual coupling, correlation coefficient, total active reflection coefficient (TARC), channel capacity and capacity loss. The proposed antenna meets the requirements for practical application within a mobile handset.

1. INTRODUCTION

The potential for MIMO antenna systems to improve reliability and enhance channel capacity in wireless mobile communications has generated great interest [1]. A major consideration in MIMO antenna design is to reduce correlation between the multiple elements, and in particular the mutual coupling, electromagnetic interactions that exist between multiple elements, is significant, because at the receiver end this could largely determine the performance of the system. Lower mutual coupling can result in higher antenna efficiencies and lower correlation coefficients. The effect of mutual coupling on capacity of MIMO wireless channels is studied in [2]. Spatial diversity is strongly affected by mutual coupling and correlation. For minimal coupling, it has been shown in [3], than the separation between multiple antenna elements should be at least 0.5λ. A 2×2 MIMO meander planar inverted-F antenna (PIFA) at 2.6 GHz is reported in [4] to obtain a mutual coupling of -15 dB, with a separation between two antenna elements of 0.23λ. Authors in [5], introduced a U-shaped slot patch antenna operating at 2.6 GHz for mobile handset applications, with isolation of -20 dB achieved by pattern diversity and a capacity loss of 0.2 bits/s/Hz.

EBG structures have the ability to act like perfect magnetic conductors (PMC), so that the distance between the antenna and ground plane can be smaller than $\lambda/4$. This can be compared to perfect electric conductors (PEC) where a distance of $\lambda/4$ is essential so that the reflected wave interferes constructively with the emitted one [6]. When the height of the antennas to the ground plane is reduced, mutual coupling can be expected to be decreased [7, 8]

This paper presents a compact dual U-shaped slot PIFA antenna with EBG material on a relatively low dielectric constant substrate, operating at 2.4 GHz and suitable for for compact mobile handsets S-parameters for U-shaped slot PIFA antennas with and without EBG materials are compared. In addition, the MIMO antennas are analysed in terms of their mutual coupling, correlation coefficient, total active reflection coefficient (TARC), channel capacity and capacity loss.

2. MIMO

2.1. Basic Theoretical Concepts

2.1.1. Total Active Reflection Coefficient (TARC)

TARC is defined as the ratio of the square root of total reflected power divided by the square root of total incident power. The TARC for a 2×2 antenna array can be directly calculated from the scattering matrix elements as follows [5]

$$TARC = \sqrt{(|(s_{11} + s_{12}e^{j\theta})^2 + |(s_{21} + s_{22}e^{j\theta})^2)}/\sqrt{2}, \quad (1)$$

where θ represents the phase from 0 to 2π.

2.1.2. Correlation Coefficient

Previous work shows that the correlation coefficient, ρ, of a 2×2 antenna system can also be determined using S-parameters [9]

$$\rho = \frac{S_{11}^* S_{12} + S_{21}^* S_{22}^2}{\left(1 - S_{11}^2 - S_{21}^2\right)\left(1 - S_{22}|^2 - S_{12}^2\right)}. \quad (2)$$

2.1.3. Channel Capacity

Based on the channel transfer matrix, H, the Shannon capacity, C for the MIMO system channel is [1, 10]

$$C = \log_2 \left(det \left(1 + \frac{SNR}{M} HH^\dagger \right) \right) \quad (3)$$

where $H^\dagger$ is the Hermitian of the matrix H, M is is the number of receivers and SNR is the estimated channel signal-to-noise ratio.

2.1.4. Capacity Loss

In case of high SNR, the capacity loss is given by [11]

$$C(loss) = -\log_2 det \left(\Psi^R\right) \quad (4)$$

where Ψ^R is the receiving antenna correlation matrix.

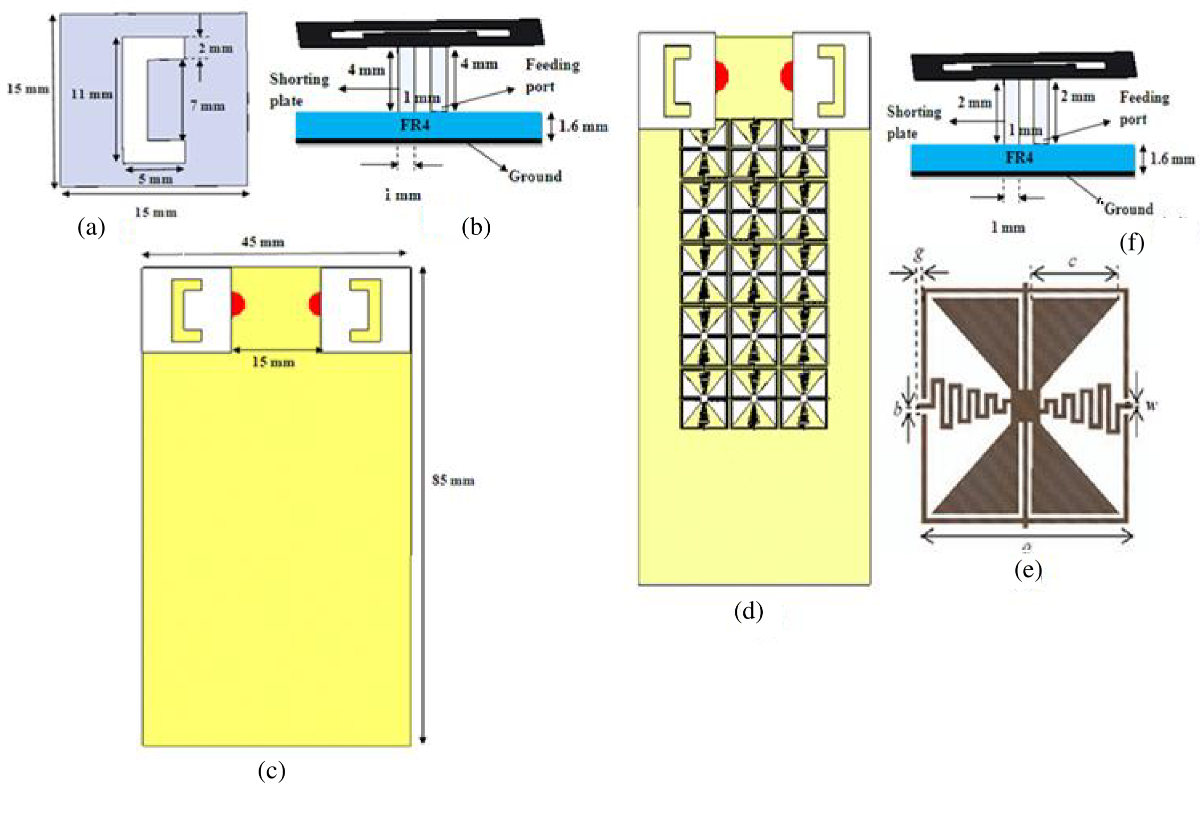

Figure 1: Geometries and dimensions: U-shape antenna (a) top view, (b) side view, (c) 2-D schematic; U-shape antenna with EBG (d) 2-D schematic, (e) EBG unit cell, (f) side view.

3. DESIGN OF 2 × 2 U-SHAPED SLOT PIFA ANTENNA INTEGRATED WITH EBG MATERIAL

The basic geometrical configuration and dimensions of the PIFA with the U-shape slot structure is shown in Figure 1. The design frequency in this study is 2.4 GHz, and the antenna assembly is mounted on a $0.36\lambda \times 0.68\lambda$ ground plane. The antennas are constructed from 0.5 mm thick plate, with a maximum area of $0.12\lambda \times 0.12\lambda$. The antenna is shorted to the ground plane by a metallic strip and fed by a standard 50 Ω SMA connector. The antennas are mounted on FR4 substrate with relative permittivity of 4.5, and loss tangent of 0.002 at 2.4 GHz. The substrate thickness is 1.6 mm, and the distance between two antenna elements is 0.24λ.

Surface waves play a dominant role in the mutual coupling between the antenna array elements. Since the EBG structure has the ability to suppress surface waves, an EBG structure [12] is implemented with the antennas as shown in Figure 1. The EBG unit cell is shown in detail in Figure 1(e), with the dimensions of $a = 9.7$ mm, $b = 0.2$ mm, $c = 4.0$ mm, $g = 0.2$ mm, and $w = 0.2$ mm. In [7], the reduction in height between the PIFAs and the EBG material is shown to mitigate the effects of mutual coupling, and thus improves the antenna efficiency. Therefore, the height of the antennas in this study has been reduced to 2 mm, with other dimensions of the antenna unchanged

4. SIMULATED AND MEASURED PERFORMANCE

Figures 2 and 3 show the simulated and measured s-parameters output for PIFAs without and with EBG material respectively. Measurements show that the predictions for return loss and mutual coupling for both PIFAs are quite accurate with impedance bandwidth approximately 11.2% for both designs. Apparent discrepancies are believed to be due to minor inconsistencies in prototyping. It can be seen that an improved isolation of −6 dB is achievable against the PIFAs

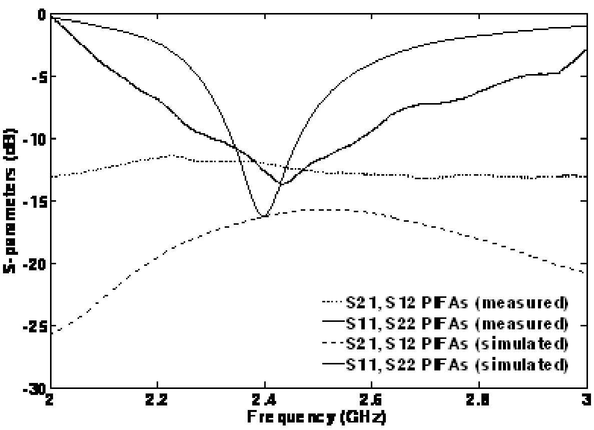

Figure 2: Comparative plot of s-parameters output for simulated and measured results for PIFAs without EBG.

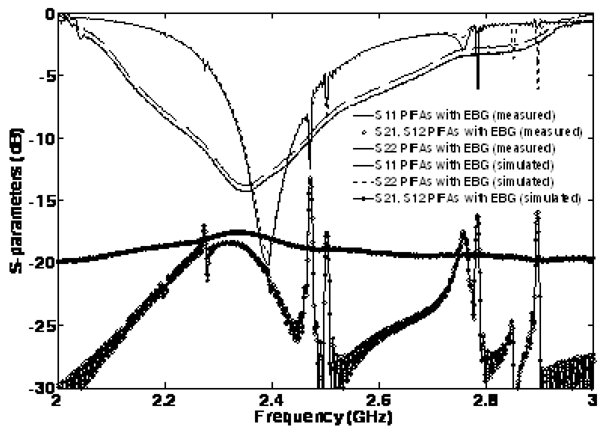

Figure 3: Comparative plot of s-parameters output for simulated and measured results for PIFAs with EBG.

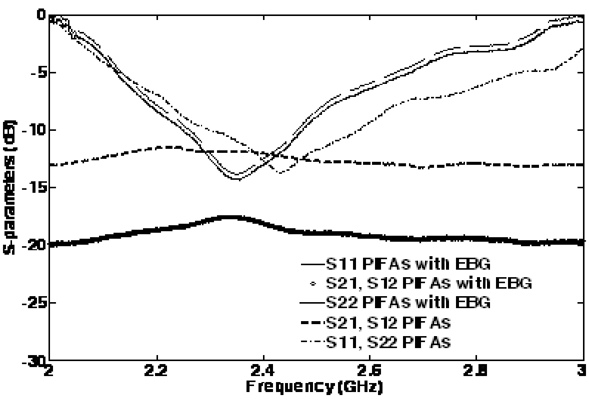

Figure 4: Measured s-parameters of PIFAs with and without EBG.

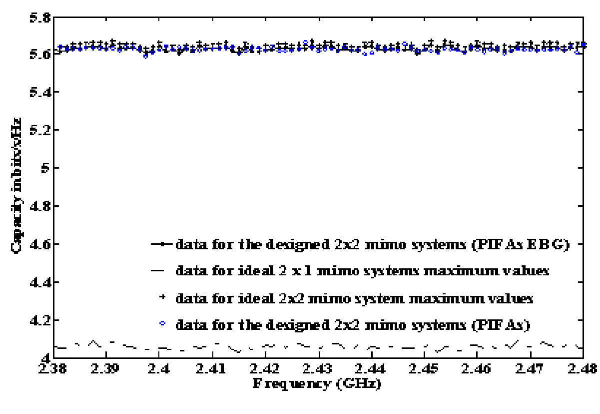

Figure 5: Measured capacity of PIFAs with and without EBG.

Table 1: Measured results for correlation coefficient, TARC and capacity loss at 2.4 GHz.

	PIFAs	PIFAs with EBG
Correlation Coefficient (dB)	−43.99	−49.53
TARC (dB)	5.65	−7.17
Capacity Loss (bits/s/Hz)	0.45	0.43

without EBG as shown in Figure 4. Next, to show the performance of the MIMO system, the correlation coefficient, TARC, capacity loss and capacity are presented in Table 1. This shows that the PIFAs with EBG material have lower loss of capacity and better performance for TARC and correlation coefficient compared to PIFAs without EBG. The channel capacity of PIFAs with and without EBG is 5.62 bits/s/Hz and 5.64 bits/s/Hz at 2.4 GHz, respectively, as depicted in Figure 5.

5. CONCLUSION

Isolation improvement using an EBG structure on 2×2 U-shape slot patch traditional PIFA antennas for 2.4 GHz WLAN operation in mobile application has been verified The proposed antenna can be effectively implemented on a thinner profile FR4 substrate with a low cost and is thus particularly suitable for compact mobile handsets The use of EBG material plays an important role in reducing the mutual coupling between dual antenna elements at 2.4 GHz. The proposed antenna design was mounted on a reasonable ground size of $0.36\lambda \times 0.68\lambda$ in which 3×5 EBG unit cells are used, has achieved a good isolation of 6 dB at 2.4 GHz. Further, the correlation coefficient, TARC, capacity and capacity loss have been analysed for PIFA with and without EBG. It has been shown that the proposed antenna has met the requirements for practical application in mobile handsets.

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