A Conformable Dual-Band Antenna Equipped with AMC for WBAN Applications

Yun-Hui Di, Xiong-Ying Liu
School of Electronic and Information Engineering
South China University of Technology
Guangzhou 510641, China
State Key Laboratory of Millimeter Waves
Nanjing 210096, China
liuxy@scut.edu.cn

Manos M. Tentzeris
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332, USA
etentze@ece.gatech.edu

***Abstract*—A novel dual-band antenna is investigated for wireless body area network (WBAN) applications. The design begins with a ring-shaped printed monopole antenna, operating in the Industrial, Scientific, and Medical (ISM) bands of 2.45 GHz and 5.8 GHz. To reduce the backward scattering wave towards the human body, the monopole antenna is set above a circular-shaped Artificial Magnetic Conductor (AMC) structure. The configuration of the AMC-integrated antenna is low profile with a thickness of 3.7 mm and compact with the area of 102 × 102 mm^2. Due to introducing flexible substrate, it can be conformal to the human body. Simulated results show that the proposed antenna combined with AMC has an average gain of 11.8 dBi in lower band, 8 dBi in upper band, and the front-to-back ratio of 10 dB, when placed on the phantom. Compared to conventional monopole antennas, the radiation characteristics are improved, making it a good candidate for WBAN applications.**

Keywords*—*Monopole antenna; dual-band antenna; artificial magnetic conductor (AMC); specific absorption rate (SAR); wireless body area network (WBAN).

I. Introduction

Wireless body area network systems (WBANs) have great potential in wide range of applications for future life, such as mobile-health, telemedicine and amusement [1]-[2]. Moreover, Industrial, Scientific, and Medical (ISM) band, one of the IEEE wireless standards on WBAN, is developed by IEEE 802.15.6 task group (TG6) [3]. Antennas operating in the ISM band play crucial role in WBANs for wireless communications. The radio transceiver limits (such as transmitted power *EIRP* < -16 dBm and *SAR* < 1.6 W/Kg) and the surrounding environments (e.g., lossy human body) have an impact on the complexity of antenna design. Due to severe conditions, body-worn antennas should be with the characteristics of light weight, compact, flexibility, reduced radiation on the body, *etc*. We have designed a miniascape-like triple-band monopole antenna for WBAN Applications. Due to the mismatch and loss caused by the proximity to human tissues, its gain is low [4]. Other wearable antennas are introduced for WBAN applications in literature [5]-[10]. In [5], a directional antenna with an added perfect electric conductor (PEC), acting as a reflector, is designed to improve the front-to-back ratio. Nevertheless, it has the profile with a thickness of 7.58 mm. For artificial magnetic conductor (AMC) has the characteristics of in-phase reflection, it can reduce the backward radiation of the antenna, consequently decreasing *SAR*. Compared with the antenna using conventional PEC, the antenna combining with AMC can maintain a low profile. Wearable antennas based on AMC have been proposed. In [6]-[7], a dual-band (i.e., 2.45 GHz and 5 GHz) textile antenna based on the electromagnetic band gap (EBG) is investigated. The dimension of the textile antenna is 120 mm × 120 mm, and especially the textile nature of fluid absorption makes the antenna gain instability under humid environment. In [8], a single band (2.45 GHz) monopole antenna integrated with a *Jerusalem Cross* AMC ground plane is studied. This kind of antenna can be expanded to multi-band for wide-range applications. In [9]-[10], two dual-band antennas with EBG structures for on-body applications have been proposed with the profile of thickness 7 mm and 5.72 mm, respectively.

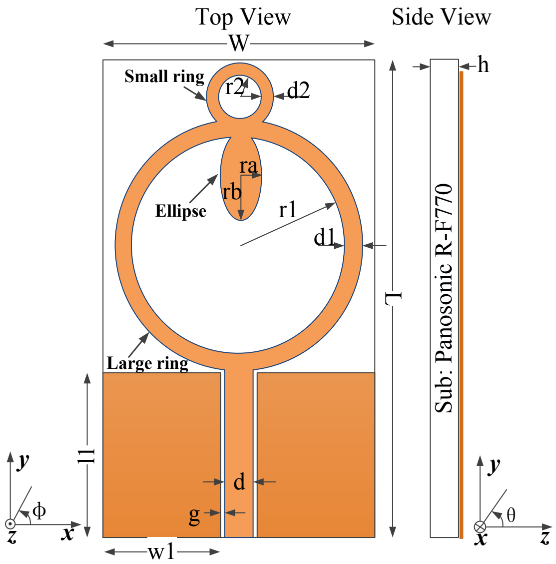
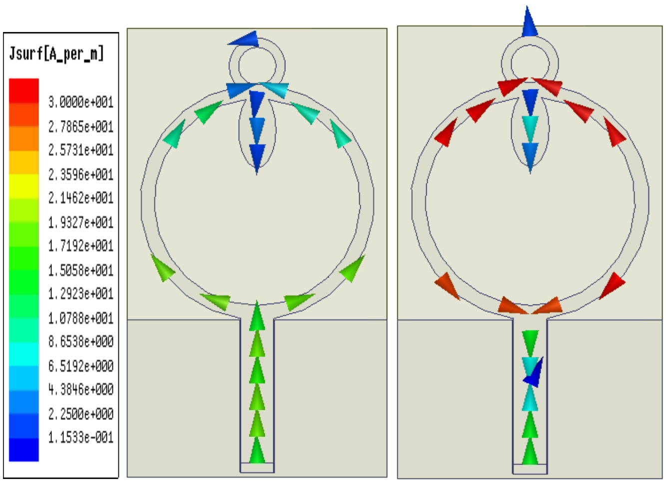


Fig. 1. The geometry of the proposed CPW-fed monopole antenna.

In this paper, a dual-band monopole antenna integrated with circular-shaped AMC is presented. This antenna covers the ISM bands of 2.45 GHz and 5.8 GHz. Due to the advantages of flexibility, low-profile, compact, and low backward scattering, it can be conformal to the human body for medical monitoring. In addition, the proposed AMC-integrated antenna reduces the electromagnetic coupling with the human body, making it put on the body harmlessly.

II. Antenna Configuration

The proposed primitive antenna as depicted in Fig. 1 consists of a large ring-shaped strip with a radius of r1, a small one with a radius of r2 and an elliptical patch with long axis of rb and short axis of ra. The antenna is manufactured from flexible Panasonic R-F770 substrate with relative dielectric constant $\varepsilon_\gamma = 3.2$, loss tangent $\tan\delta = 0.002$, and has the dimension of $28.5 \times 47.5 \times 0.05$ mm^3. Fig. 2 shows the analog currents excited at interested central frequencies of 2.45 GHz and 5.8 GHz, respectively. Half side of the symmetrical monopole antenna is analyzed to calculate current path. With reference to the Fig. 2 (a), a 1/4 physical length of the large ring-shaped strip with consistent direction of current is about 20 mm, which is approximately a quarter wavelength at 2.45 GHz. As shown in Fig. 2 (b), the top left-side of the large ring-shaped strip with length of 10 mm causes the antenna resonate at high frequency, corresponding to approximately a quarter wavelength at 5.8 GHz. The lower left-side of the large ring-shaped strip with opposite direction current distribution may weaken the electric field, leading to the lower gain in upper band than that in the lower band. The small ring-shaped strip is introduced to adjust the high frequency resonant point. The elliptical patch is utilized to enhance impedance matching within high frequency band. The characteristic of antenna impedance is marked in Fig. 3, illustrating that the antenna has a bandwidth of 500 MHz (2.23-2.73 GHz) or 20.1% at low frequency band and a bandwidth of 1.28 GHz (5.36-6.64 GHz) or 10.7% at high frequency band, respectively. It is well-known that the monopole antenna has the omni-directional radiation patterns just like dipoles. When the antenna is placed directly on the human body, the strong backward scattering wave will be harmful to people's health. In order to decrease the backward radiation, further work of adding an AMC ground plane is carried out in next section. Through adjusting the geometric structure of the proposed antenna with the aid of ANSYS HFSS v.13 based on the Finite Element Method (FEM), the following optimal values of the antenna's parameters are obtained: L = 47.5 mm, W = 28.5 mm, l1 = 16.8 mm, w1 = 12 mm, g = 0.5 mm, d = 3.5 mm, r1 = 11 mm, d1 = 1.5 mm, r2 = 1.6 mm, d2 = 1 mm, ra = 2 mm, rb = 4 mm, and h = 0.05mm.



(a) (b)

Fig. 2. Current distributions of the proposed monopole antenna at (a) 2.45 GHz, (b) 5.8 GHz.

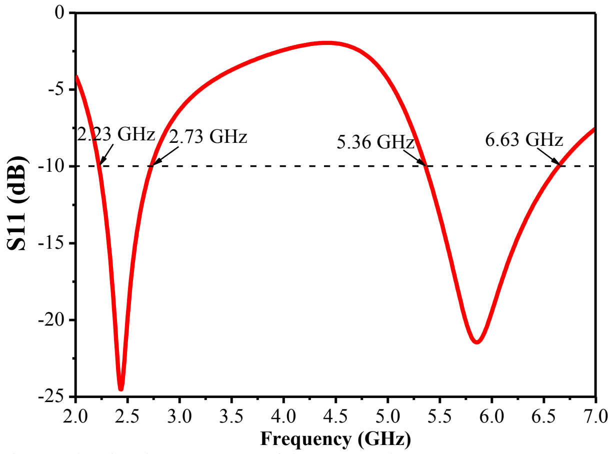


Fig. 3. Simulated S-parameter of the proposed antenna.

III. AMC Reflector Design

The AMC is constructed on a flexible vinyl substrate with a thickness of h1 = 1.7 mm, electrical properties of $\varepsilon_\gamma = 2.5$, and $\tan\delta = 0.002$. The configuration of the AMC basic element is given in Fig. 4. The geometry of the inner circular patch and outer ring-shaped loop determines the 0-degree reflection phase points of this dual-band AMC. The surface current distributions at the different frequencies of 2.45 GHz and 5.8 GHz are shown in Fig. 5, respectively. The outer loop has longer current path in order to create 0-degree reflection phase at 2.45 GHz, and the inner circular patch with shorter current path provides 0-degree reflection phase at 5.8 GHz. Fig. 6 shows that the $\pm$ 90°-phase band gaps cover the 2.4-GHz (2.4-2.48 GHz) and 5.8-GHz (5.725-5.85 GHz) band, respectively. These bands may tend to shift slightly when the AMC is set under the antenna. Hence, further adjusting the parameters of integrated AMC antenna is needed to obtain merit performance. Simulation has shown that increasing the outer loop radius of R1, the resonant point at the corresponding band of 2.45 GHz tends to be lower, while the inner circular patch radius of R2 can be adjusted to control the upper resonance. The optimized dimensions to get 0-degree reflection phase points at the selected frequency bands are as follows: Lm = 34 mm, R1 = 32.5 mm, R2 = 17.5 mm, and S = 2 mm.

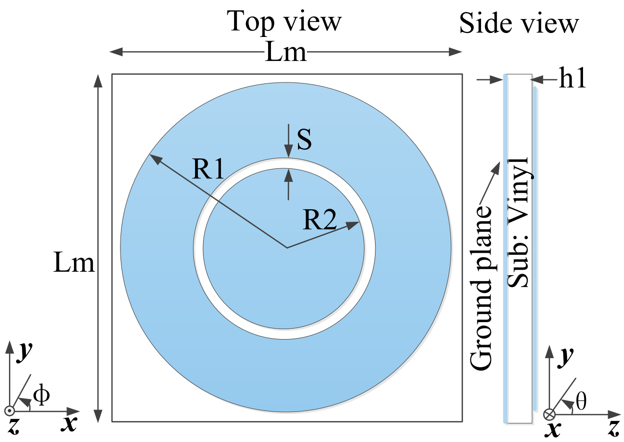
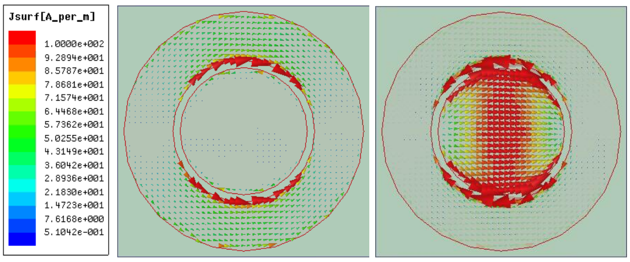


Fig. 4. Structure of the dual-band circular-shaped AMC element.



(a) (b)

Fig.5. Current distributions on the proposed AMC element at (a) 2.45 GHz, (b) 5.8 GHz.

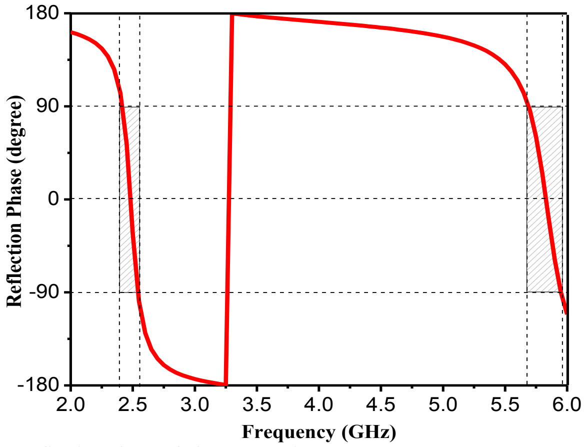


Fig.6. Reflection phase of the proposed AMC structure.

IV. INTEGRATION OF ANTENNA AND AMC

To reduce the backward scattering wave towards the skin of body and increase the forward radiation, an AMC array acting as an in-phase reflector for the proposed antenna is designed. The reflector comprises 3 × 3 unit elements with circular-shaped AMC structure, resonating at the same operating frequencies with the proposed antenna. The overall size of the dual-band AMC ground plane is 102 × 102 mm^2. The geometry of the proposed CPW-fed monopole antenna attached with circular-shaped AMC ground plane is shown in Fig. 7. Here a piece of flexible ethylene-vinyl acetate (EVA) foam with $\varepsilon_\gamma = 1.17$ and $\tan\delta = 0.04$ [11] is utilized to isolate the antenna from the AMC by a height of h2 = 2 mm, simultaneously reducing the impedance mismatch caused by the proximity of AMC. To study the human body effects on the performance, the AMC-integrated antenna is put on a three-layer phantom, as shown in Fig. 8. With reference to the Fig. 9, the simulated S11 in free space has a bandwidth of 110 MHz (2.4-2.51 GHz) or 4.5% at the lower frequency band. Whereas, the bandwidth is decreased to 80 MHz (2.4-2.48 GHz) on the three-layer tissue model. At the upper frequency band, the bandwidth in free space is about 140 MHz (5.71-5.85 GHz) or 2.4%, coinciding well with that on the phantom. Though some divergence can be found in two situations, the bands of 2.4-GHz (2.4-2.48 GHz) and 5.8-GHz (5.725-5.85 GHz) are still satisfied. As shown in Fig. 10, the antenna combined with AMC reflector has relatively low back radiation both in free space and on the body. The front-to-back ratio is about 10 dB. The gains in each case are shown in Fig. 11. Due to the superposition of the backward scattering wave reflected by the AMC and forward radiation wave, the antenna with AMC plane has a peak gain of 12 dBi on the body and 10 dBi in free space, at least 3 dBi more than the gains without AMC in corresponding situation. For the body makes the electromagnetic propagation concentrate to the forward radiation, the average gain of AMC-integrated antenna on the phantom can reach 11.8 dBi in lower band and 8 dBi in upper band.

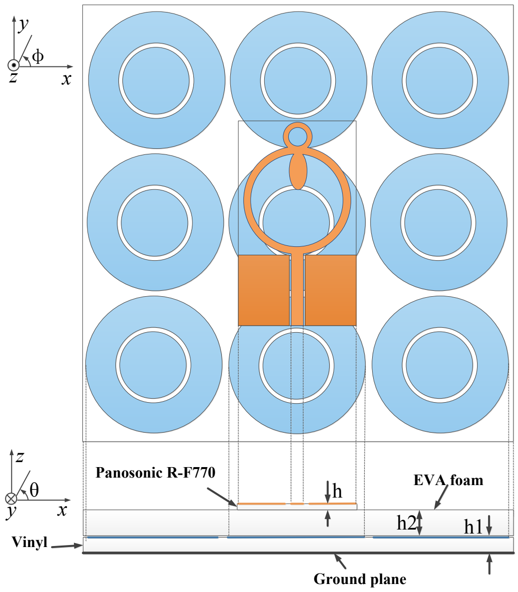


Fig. 7. The structure of the proposed CPW-fed monopole antenna with circular-shaped AMC reflector.

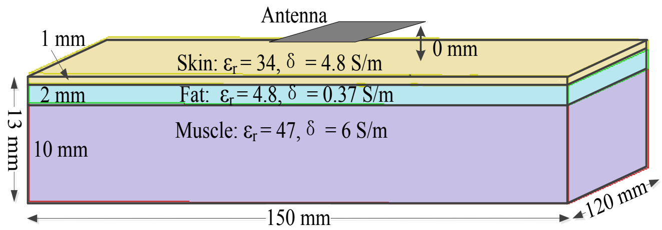


Fig. 8. Three-layer tissue model with the antenna.

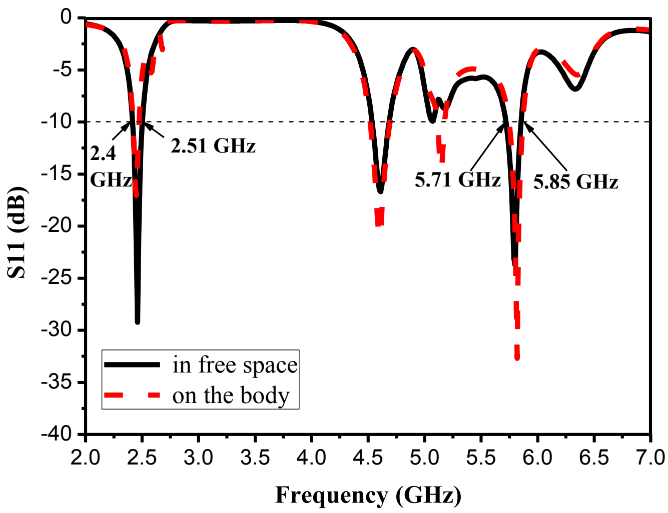


Fig.9. Simulated S-parameter of the proposed antenna with AMC in different situations.

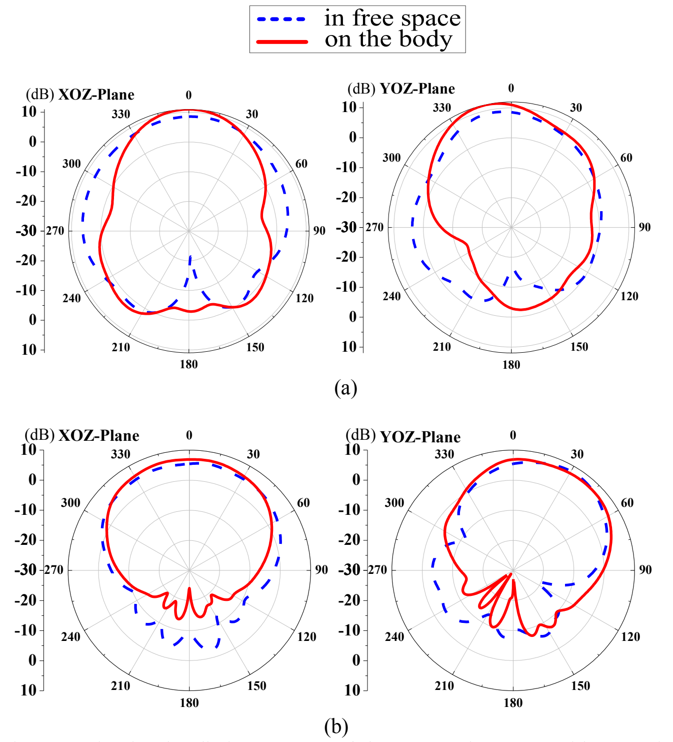


Fig. 10. Simulated radiation patterns of the proposed antenna with AMC in free space and on the body at (a) 2.45 GHz, (b) 5.8 GHz.

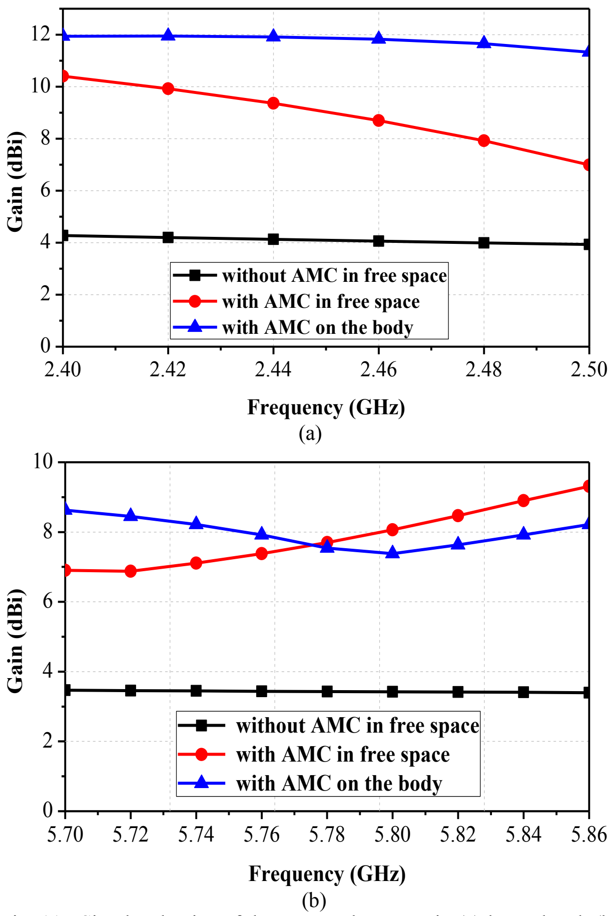


Fig. 11. Simulated gains of the proposed antenna in (a) lower band, (b) upper band.

V. Conclusions

This paper has proposed a dual-band monopole antenna equipped with a circular-shaped AMC reflector. The AMC-integrated antenna with stable central resonant frequencies covers the 2.4-GHz (2.4-2.48 GHz) and 5.8-GHz (5.725-5.85 GHz) bands either in free space or on the body. Average gains of 11.8 dBi in lower band and 8 dBi in upper band are achieved and the front-to-back ratio is about 10 dB, when the AMC-integrated antenna is put on the body. With the advantages of low-profile, flexible, compact and well radiation characteristics, the AMC-integrated antenna has the potential for WBAN applications.

There are some works left to be done in the future, such as the fabrication and measurement of the antenna. The performance of *SAR*, link-budget will be evaluated in different scenarios. The influence of different setup position on body will also be studied.

Acknowledgment

This work was supported in part by the National Science Foundation of China (61372008), in part by the Fundamental Research Funds for the Central Universities (2014ZZ0031).

References

[1] P. S. Hall, and Y. Hao, *Antennas and Propagation for Body-Centric Wireless Communications* (2nd ed.), Norwood, MA: Artech House, 2012.

[2] P. S. Hall, and Y. Hao, “Antennas and propagation for body centric communications ,” *in Proc. 1st EuCAP*, Nice, France, 2006.

[3] W. H. Astrin, B. Li, and R. Kohno, “Standardization for Body Area Networks,” *IEICE Trans. Commun.*, vol. E92–B, no. 2, pp. 366–372, Feb. 2009.

[4] C. P. Deng, X. Y. Liu, Z. K. Zhang, and M. M. Tentzeris, “A Miniascape-Like Triple-Band Monopole Antenna for WBAN Applications,” *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 1330–1333, 2012.

[5] M. Klemm, I. Z. Kovcs, G. F. Pedersen, and G. Troster, “Novel Small-Size Directional Antenna for UWB WBAN/WPAN Applications,” *IEEE Trans. Antennas Propag.*, vol. 53, no. 12, pp. 3884–3896, Dec. 2005.

[6] S. Zhu, and R. Langley, “Dual-Band Wearable Textile Antenna on an EBG Substrate,” *IEEE Trans. Antennas Propag.*, vol. 57, no. 4, pp. 926–935, Apr. 2009.

[7] S. Zhu, and R. Langley, “Dual-Band Wearable Antenna over EBG Substrate ,” *IET Electron. Lett.*, vol. 43, no. 3, pp. 141–143, Feb. 2007.

[8] H. R. Raad, A. I. Abbosh, H. M. Al-Rizzo, and D. G. Rucker, “Flexible and Compact AMC Based Antenna for Telemedicine Applications,” *IEEE Trans. Antennas Propag.*, vol. 61, no. 2, pp. 524–531, Feb. 2013.

[9] N. Chahat, M. Zhadobov, R. Sauleau, and K. Mahdjoubi, “Improvement of the On-Body Performance of a Dual-Band Textile Antenna Using an EBG structure,” *Antennas Propag. Conf. (LAPC)*, Loughborough, pp. 465-468, Nov. 2010.

[10] M. Mantash, A. C. Tarot, S. Collardey, and K. Mahdjoubi, “Dual-band CPW-fed G-Antenna using an EBG structure,” *Antennas Propag. Conf. (LAPC)*, Loughborough, pp. 453-456, Nov. 2010.

[11] H. Wang, Z. J. Zhang, Y. Li, and Z. H. Feng, “A Dual-Resonant Shorted Patch Antenna for Wearable Application in 430MHz Band,” *IEEE Trans. Antennas Propag.*, vol. 61, no. 12, pp. 6195–6200, Dec. 2013.