Design a compact square ring patch antenna with AMC for SAR reduction in WBAN applications

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ABSTRACT

In this paper presents a compact square ring patch antenna with miniaturized AMC structure at 5.8 GHz for WBAN applications. To minimize detuning, keeping its radiation efficiency high and acceptable gain while keeping the SAR levels low for safety is a challenging task. One of the critical issues in WBAN antenna design is the size of the antenna for portable devices, because the size affects the gain and bandwidth. The AMC configuration decreases the back radiation and the effect frequency detuning results from the high loss in the human body. Furthermore, the AMC also increases the front-to-back ratio (FBR) of 15.3 dB. The proposed antenna has dimensions of 15.27×15.27×2.2 mm^3 and provides a 404 MHz impedance bandwidth, with a gain improvement of 8.69 dBi and a 93.7% reduction of the initial SAR value. For this reason, the antenna is suitable for WBAN application in various fields, particularly in medical technology.

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1. INTRODUCTION

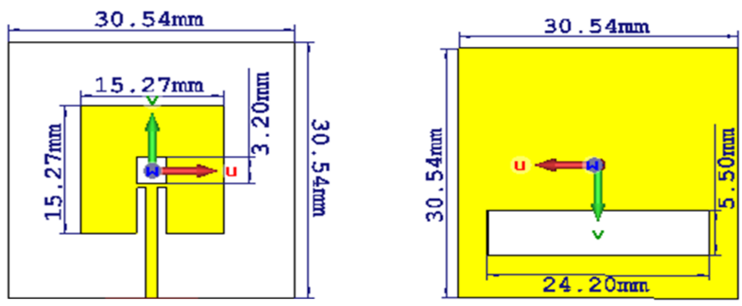
Wireless body area network (WBAN) has attracted greater attention to providing the necessary communication needed for applications such as network applications, health monitoring, military and personal navigation entertainment [1-5]. However, the design of the WBAN antenna faces the biggest challenge in using the particles needed to fully understand the characteristics of the antenna and the loss of propagation in the existence of the human body [6]. For this reason, the importance of a high-efficiency antenna during body proximity becomes a necessity. In particular, the proximity of the body minimizes the efficiency of the antenna and maximizes radiation pattern irregularities and impedance detuning. Additionally, the impact of WBAN radiation on the human body is characterized by a specific absorption rate (SAR), which must be considered to avoid any effect on the human body, and the value must be a minimum [7]. Several types of antennas have been investigated such as a fully textile patch antenna and other structures of patch antennas [8-13], an inverted F antenna planar [14-15], and antennas related on integrated waveguides to the substrate, metamaterials are presented [16]. A planar waveguide fed slots and monopole antennas are demonstrated [7]. 61 GHz Yagi-Uda antennas is presented for on-body communication [17]. Microstrip, planar and vertical monopole antennas were presented and their suitability as wearable antennas [18-24]. Alternatively, the electromagnetic bandgap structure (EBG) is included in the design of the antenna, which can be used to provide a high level of isolation from the human body and to reduce SAR in tissue. However, since most of the EBG-based designs are electrically large, the structure is still suffering high front-to-back ratio (FBR) with the cost of increased structural complexity [25]. AMC and DGS were proposed for gain enhancement [26-27].

In this paper, a miniature single-band antenna for WBAN at 5.8 GHz is proposed. To achieve body performance adjusted easily and evenly at the same time a lower (SAR). In addition, the dimensions are 15.27×15.27×2.2 mm^3, which demonstrate further size reduction compared to previously published studies. The preparation of this paper is described below II. The section introduces the antenna structure and developed multilayer human head tissue III. The comparison between the simulated and measured results are presented. Finally, the effect of the body on the performance of antenna and SAR value on human head are evaluated and draws the conclusion.

2. ANTENNA DESIGN

2.1. Antenna geometry

The structure of the demonstrated antenna is illustrated in Figure 1(a) and Figure 1(b). The presented antenna has a dimension of $L \times W$. Where L and W are the length and width of the resonance patch. This antenna is powered by a microstrip power supply having a characteristic impedance of 50 ohms. RT5880 substrate with permittivity of 2.2 with low tan loss of 0.0009 was used as substrate materials. This antenna was designed and simulated using a commercially available electromagnetic wave simulator CST Microwave Studio. Various substrates were used and evaluated in order to determine the performance of antenna and the effects of the different substrates of the proposed antenna. Table 1 summarizes the dimension of the proposed antenna while Table 2 shows the comparisons of the proposed antenna with other references.



(a) (b)

Figure 1. Geometry of the proposed antenna, (a) Front view, (b) Back view

Table 1. Dimensions of proposed antenna

Parameters	RT5800	FR4
Design frequency	5.8GHz	5.8 GHz
Dimensions of patch	L=W=15.27 mm	L=W= 12.28 mm
Dielectric Constant	2.2	4.3
Tan δ	0.0009	0.025
Height	1.57	1.6
slot	3.20 mm	3.20 mm
Lf	13.40 mm	9.43 mm

Table 2. Comparison of gain, radiation, and sar of the proposed antenna with other references

Reference	Gain	Radiation efficiency	Reduced SAR
21	5.9	35.7	70%
22	7.1	N/A	58.5%
23	9.6	46.3%	80%
10	0	76%	47%
Proposed	8.69	95%	90%

In order to achieve the desired resonant frequency, the following mathematical approach is applied [20].

$$Lo = W_0 = 0.46 \frac{\lambda}{\sqrt{\varepsilon r}} \quad (1)$$

2.2. AMC structure

The 2x3 AMC current plays an important role in reducing the proposed antenna profile and is placed under the emitted element as the PEC ground. The geometry of the AMC is shown in Figure 2. RT5880 substrate with permittivity of 2.2 with low tan loss of 0.0009 with thickness 1.57 mm was used the proposed AMC as substrate materials as shown in Figure 2. The useful bandwidth of an AMC is in general defined as +90º to -90º on either side of the central frequency (+90° to −90°) on either side of the central frequency. As shown in Figure 3, use the multi-layer human head model to determine antenna performance in human body scenarios. The multilayer human phantom constructed with five layers of tissues based electromagnetic properties and these tissues represent parts of the human head such as skin, fat, cerebrospinal fluid, bone, and brain. The thickness and electrical properties at 5.8 GHz are listed in Table 3.

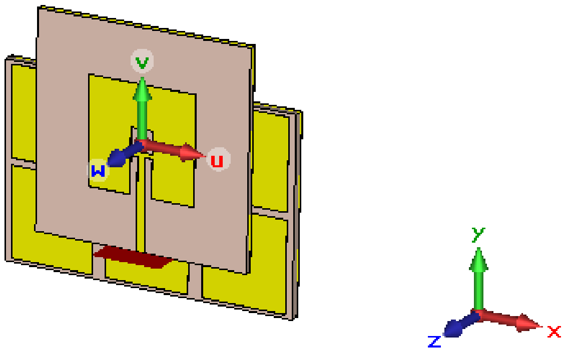


Figure 2. The geometry of the AMC unit with proposed antenna

Table 3. Dielectric properties of biological tissues used human head at 5.8 GHz

Tissues	Relative Permittivity (εr)	Tan δ	Thickness (mm^2)
Skin	35.11	0.33	2
Fat	9.86	0.26	2
Bone	60.47	0.37	7
CSF	60.47	0.40	1
Brain	44.00	0.35	35

(a) (b)

Figure 3. Proposed phantom models of human head, (a) Spherical phantom, (b) Cubical phantom

3. RESULTS AND DISCUSSION

The use of a single-band antenna is proposed and some important parameters should be carefully considered. The simulation results show that the antenna performance strongly influenced on the dimensions, the short pins, and the AMC reflectors. The structure of AMC unit was demonstrated the reflection characteristics of proposed AMC reflector as shown in Figure 2. The AMC surface resonance frequency corresponds to a degree of reflection coefficient to the 0°. The AMC reflection phase bandwidth is described by a phase range between -90° to 90°. Hence the dimension of the AMC, Ls is varied to obtain resonance at the desired frequency. The reflection phase varies from 150° to -150° at resonance, which is at 5.8 GHz, the reflection phase is 0° the frequency is laid 5.79 GHz. Furthermore, the rectangular patch AMC has a reflection magnitude of -0.129 dB. The key parameter used to control the phase shift is the length of patch. Moreover, increasing or decreasing the lengths causes the fundamental resonance frequency to shift to higher or low frequencies. This type of unit cell offers simple and less fabrication complexity technique: Reflection phase with varying dimensions for the proposed AMC structure is shown in Figure 4.

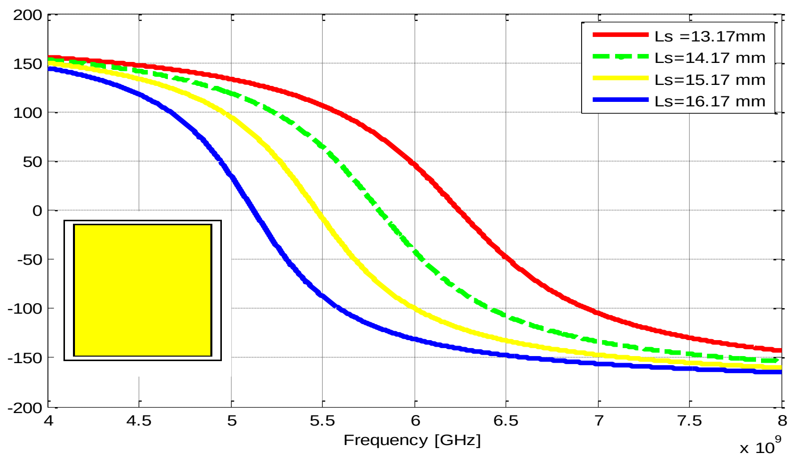


Figure 4. Simulated reflecting phases of the AMC unit

In the previous section, patch antenna designs with AMC covering 5.8 GHz is proposed, to compare the antenna performance various configurations of AMC were performed. Furthermore, the antenna performance enhanced by applying AMC and this signifies that the structure has a better effect for resonance frequency compared for the rest AMC structure which has been presented in previous works. As increasing AMC case with three to five columns, the structure will have a larger size and lower improvement. The simulated S-parameter was shifted after using 5-column with a good matching S-parameter of less than-10 dB. As shown in Figure 5, the simulated s-parameter for antenna without using AMC pointed at 5.8 GHz with matching S_{11} equal to -22.72 dB.

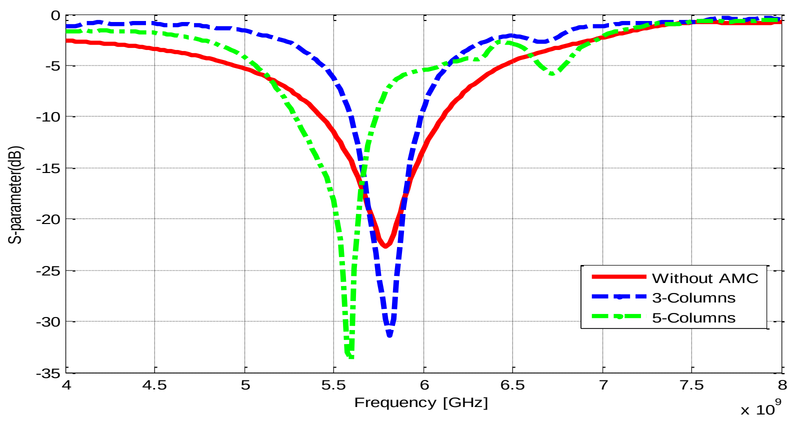


Figure 5. Comparison reflection curves without and with AMC structure

As shown in Figure 6, the simulated and measured results of S-parameters. Therefore, the comparison between the simulated and measured impedance bandwidths are 608.9 MHz and 404 MHz respectively. VSWR is falling below 2. The simulated and measured s-parameters of the proposed antenna in free space with and without the AMC structure are compared as shown in Figure 6. The operation of the optimized AMC layer is considered wider than the S_{11}<-10 dB and bandwidth of conventional square slot. As shown in Figure 7 and Figure 8, the simulated and measured radiation pattern of the demonstrated antenna. The measured gain of the demonstrated antenna is around

8.67 dBi. The comparison between the simulated and measured radiation pattern indicated a good agreement. Therefore, there are slight differences between the simulated and measured which is attributed to fabrication error and soldering.

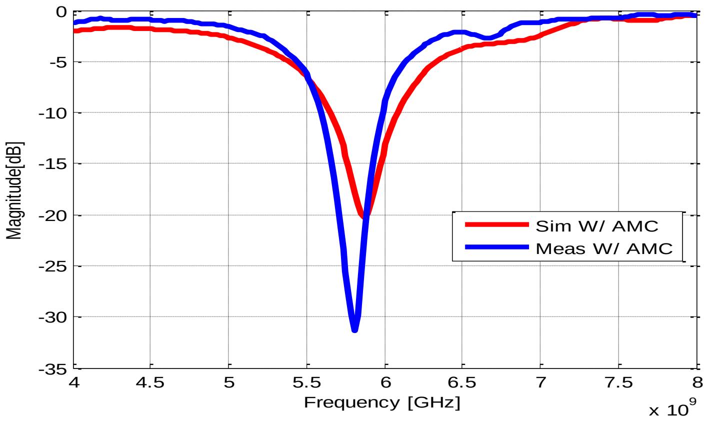


Figure 6. Comparison simulated *s*-parameters with AMC structure

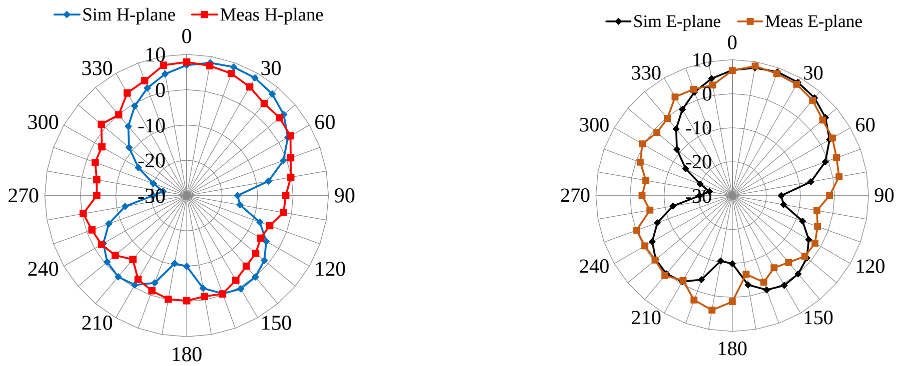


Figure 7. The comparison between simulated measured E-Plane and H-Plane radiation patterns with DGS at 5.8 GHz using RT 5880 substrate

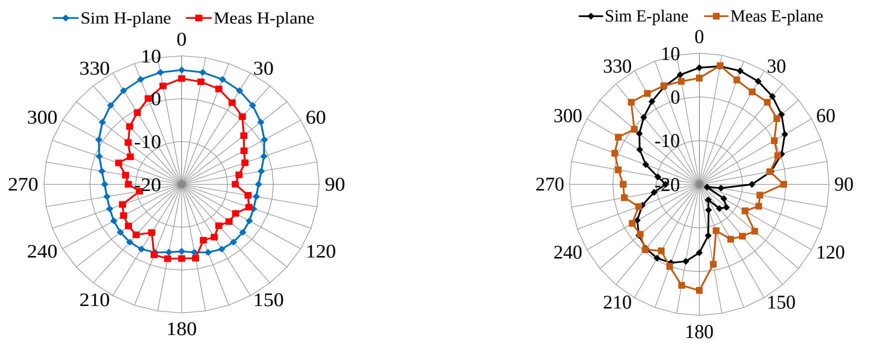


Figure 8. The comparison between simulated and measured E-Plane and H-Plane radiation patterns with AMC at 5.8 GHz using RT 5880 substrate

3.1. Investigation of specific absorption rate (SAR) in human head

In this section is discussed the effect of body on the antenna performance and SAR value on human head, when the human head experience higher frequency exposure of 5.8 GHz from a portable device. The various substrate of patch antenna also influences the SAR of a human head. Figure 9 exhibits the comparison scattering parameter (S_{11}) at 5.8 GHz frequency after the placement of an electromagnetic

AMC reflector. The placement of the absorber in between the microstrip antenna and the bio-tissue offers significant improvement and reduction SAR. The shift of the antenna resonant frequency is mainly due to the high permittivity characteristic and the shape of the phantom head model. The simulated impedance bandwidth in with AMC as 396 MHz (5.6 GHz-5.99 GHz), as 472 MHz (5.62 GHz-6.12 GHz) and as 419 MHz (5.63 GHz-6.1 GHz) as shown in Figure 9. Furthermore, the simulated S_{11} is below -10 dB with the magnitude of S_{11} -31.39 dB while the cubical and spherical phantom with the magnitude of S_{11} -16.53 dB and -16.48 dB respectively. The numerical result of the antenna performance and the SAR value due to the patch antenna placed in proximity to the different types of phantom head models are presented in this section. two different types of phantom head models including cubical phantom, spherical phantom are used for estimating the antenna performance and the SAR value is investigated further studies on the effects of two different types phantom head models are analyzed. The effects of the antenna performance and the SAR value of the patch antenna with the phantom head models are also included. The simulated results of the antenna performance including return loss are discussed. The maximum local averaged SAR over 10g of tissue and SAR distribution on the phantom head is also analyzed.

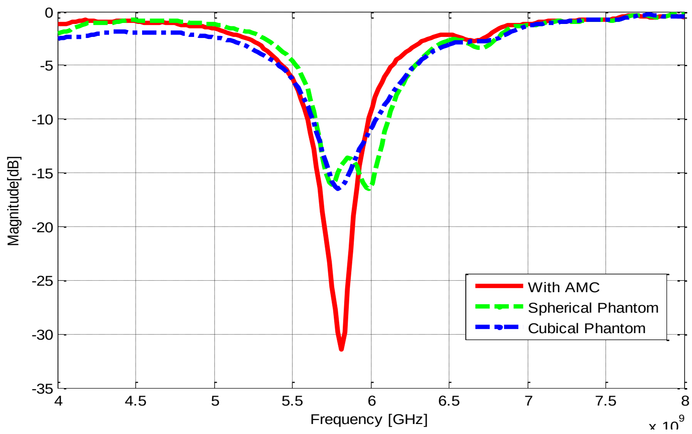


Figure 9. Simulated s-parameters with and without AMC reflector structure on human head phantom

Overall, the simulated SAR at 5.8 GHz distributed on the human head surface is much higher than the maximum limit defined by ICNIRP averaged over 10 g of any tissue which should be less than 2 W/Kg. The proposed antenna was placed on the human head phantom in order to perform SAR evaluation. The initial results indicated that simulated SAR value is higher than the maximum limit, In order to reduce SAR value, AMC is used. At this frequency exposure, a square antenna with a substrate of RT-5880 substrate with spherical phantom has the highest SAR value 5.66 W/Kg, while antenna with AMC contributed the lowest SAR value of 0.353 for 10 g tissue at 5.8 GHz frequency exposed. Figure 10 shows the SAR distribution of the phantom head models.

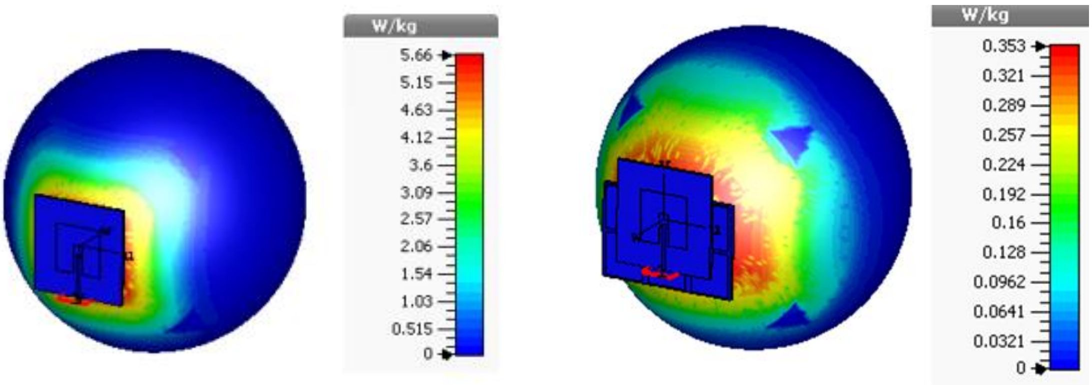


Figure 10. Simulated SAR value on a spherical phantom with and without AMC reflector structure on human head phantom

4. CONCLUSION

The main purpose of this research was to investigate the main factors that degrade the performance of antenna after placing in the vicinity of the human body. Then design antennas to avoid or minimize the effect of those factors. Square ring patch antenna with compact AMC structure for wireless body area network application was successfully designed, simulated and measured. The AMC structure and miniaturized reflector reduce the back radiation and the impact of frequency detuning due to high losses of the human body and the two proposed techniques are mounted on a human head phantom. In addition, AMC improved the front-to-back ratio (FBR) by 15.3 dB with enhanced gain 8.69 dBi and radiation efficiency more than 80%. The AMC has achieved a 93.7% reduction of the initial SAR.

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