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The Effect of a Metamaterial Based Wearable Monopole Antenna on the Human Body

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Abstract

In this study, design and characterization of a wearable monopole antenna and metamaterial based electromagnetic band gap structure using conductive textile was reported. The pure copper polyester taffeta fabric was used as a conductive textile. The conductive textile based wearable antennas have attracted considerable attention for body centric technologies due to the ability of being integrated with clothes and easily worn. In this respect, the reflection coefficients, radiation pattern, and surface currents for proposed antenna were investigated and its performance was obtained. Then, we designed the electromagnetic band gap structure (3x3 unit cell) and integrated the wearable antenna with this structure. Finally, the specific absorption rate (SAR) values for wearable antenna and integrated structure were analyzed. The SAR values of wearable antenna and integrated structure were obtained as 17.4 W/kg and 0.329 W/kg, respectively. In addition, the electromagnetic band gap structure that has 4x3 unit cell was designed and again the wearable antenna was integrated with this 4x3 structure. Similarly, we obtained the SAR value of new integrated structure as 0.241 W/kg. It was demonstrated that the integrated structures have considerably favorable SAR value for human body. It can be used in many wearable antenna applications with this low SAR value.

Keywords: Wearable Antenna, Metamaterial, Conductive Textile Materials, SAR

1. Introduction

In the recent years, the electro-textile materials have attracted considerable attention because they can be potentially applied in the areas such as electronic, health monitoring, telecommunication, and textile sciences. The body centric wireless communication which is one of their application areas can be described the link between body mounted devices communicating wirelessly [1]. This body communication is accepted as an important part of fourth generation mobile communication systems (4G) [2] and is mostly provided by wearable devices. A big part of these wearable devices consists of the fabric-based antennas. Wearable antennas, which are known as electro-textile antenna devices, has many related attractive features such as low profile, low weight, and washability. In addition, these devices can be easily integrated within everyday clothing. Therefore, their use in daily life is of interest to researchers and there have been many investigations with the wearable electro-textile antennas [3, 4]. In this context, the researches have shown that the wearable antennas have some requirements to be flexible [5, 6]. In addition, they should provide low and stable resistivity that should be less than 1 ohm/sq. These antennas consist of an intermediate substrate which is made up of material such as felt [5], cotton [7], flannel fabric [8] or jeans [9]. In the structure of these antennas, the conductive materials like the pure copper polyester taffeta fabric are used.

The electro-textile based designs have been reported as single frequency band wearable antennas [10, 11]. In addition, in some studies, the design of the single frequency electromagnetic band gap (EBG) material based antennas have been reported [12]. The recent interest in field of electromagnetic wave engineering is on metamaterial (MTM) technology [13]. EBG structure is one of the MTMs with the property to suppress electromagnetic wave propagation in a certain frequency band. MTMs which have unusual properties that are not easily found in nature are defined as artificial electromagnetic structures. They are used in many different applications such as sensors [14], superlens [15], cloaking [16], and harvesting [17]. Commonly used EBG structures can be listed as the mushroom and via-less EBG Structures. These structures can be integrated into the wearable antennas and have the feature of

reducing the backward radiation from the antenna [18, 19]. In this sense, one of the most important issues about wearable antennas is the closeness of human body to antennas. The human body may be exposed to antenna radiation at close range, and it may be negatively affected owing to the amount of power absorbed per unit mass of the body. Here, the specific absorption rate (SAR) is measured as the exposure of power absorbed per unit mass of human body. American National Standards Institute (ANSI) has set the limit of 1.6 W/Kg absorbed per 1 g of tissue and 2 W/Kg absorbed per 10 g of tissue.

In this study, the wearable antenna that can operate at 2.45 GHz was designed and investigated the reflection coefficients, radiation pattern, and SAR value. The SAR value of the proposed antenna is evaluated on a cylindrical human tissue model. Then, the EBG structure that can operate at 2.45 GHz was designed. The SAR value of integrated wearable antenna and EBG structure was obtained. According to the results obtained, we evaluated the effects of SAR value of the wearable antenna and integrated structure on human body.

2. Design of the Wearable Antenna and EBG Structure

The electro-textile materials are important devices for wearable antenna technology. These materials are composed of the conductive fabrics [20] that are obtained by interleaving normal fabrics with conductive metal/polymer threads. In this study, pure copper polyester taffeta fabric (PCPTF) was used as conductor material. The measured resistance, electrical conductivity and surface resistance of PCPTF are 0.031 Ohm/sq, 2.5x105 S/m and 0.05 Ohm/sq, respectively [9]. In addition, the felt textile material was used as the substrate of antenna. The loss tangent, permittivity and thickness of the felt material are 0.016, 1.22 and 2 mm, respectively. There are many types of wearable antennas and they are used in various applications. Several types of wearable antennas have been proposed with different topologies, e.g., patch antennas, planar antennas and monopole antennas. In this study, wearable monopole antenna design was chosen. The geometry of wearable monopole antenna is shown in Figure 1. The patch of antenna was made up with PCPTF material, the substrate and ground plane of antenna were made up with Felt materials in the design. The proposed wearable antenna which has sizes of 40 x 60 mm consists of 3 parts as ground plane, substrate, and patch. The substrate has a thickness of 2 mm and sizes of 40 x 14 mm. The patch has a thickness of 0.8 mm and sizes 8.5 x 42.8 mm.

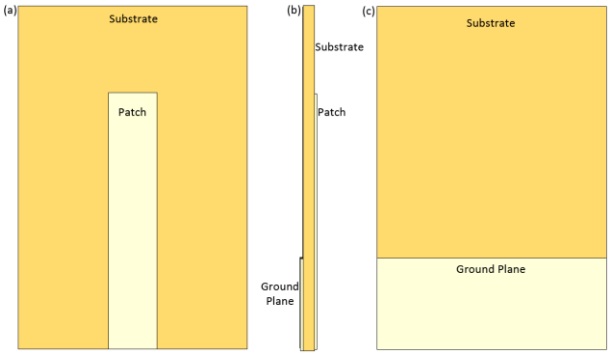


Figure 1 The electro-textile based wearable monopole antenna design. (a) The front view, (b) left view, and (c) back view.

Then, we designed the mushroom based EBG structure and integrated the proposed wearable antenna and EBG structure. The geometry of proposed EBG structure is shown in Figure 2. The EBG structure which is also designed using electro-textile materials consists of the PCPTF and felt structures. Thus, the whole of proposed integrated structure has the features of wearable materials. The proposed wearable EBG structure which has sizes of 48 x 48 mm consists of 3 parts as ground plane, substrate, and patch. The ground plane and patch has a thickness of 0.08 mm. The patch of EBG structure has sized 46 x 46 mm. the thickness of substrate is 1.1 mm. In addition, this structure has a via structure that is located in its center. The radius of the via is 0.5 mm. The EBG structure was integrated in the bottom of the antenna.

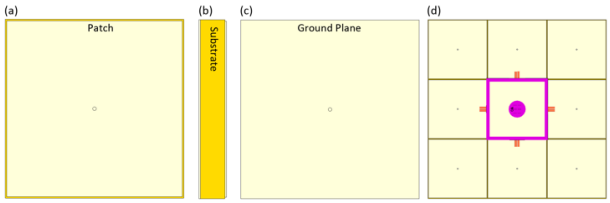


Figure 2 The unit cell of electro-textile based EBG design. (a) The front view, (b) left view, (c) back view, and (d) 3x3 EBG structure.

3. Calculation Method, Results, and Discussion

We simulated the properties of the wearable antenna structures using FIT (Finite Integration Technique) based a full-wave electromagnetic solver CST Microwave Studio. The proposed wearable antenna consists of the integration of monopole antenna and EBG structure. After designing the proposed antenna and EBG structure, numerical calculations are realized to obtain the properties of S parameters and surface currents of the model. The simulation studies of the proposed structure are carried out at 0-4 GHz frequency range. The S parameter results obtained from the antenna calculations are given in Figure 3a.

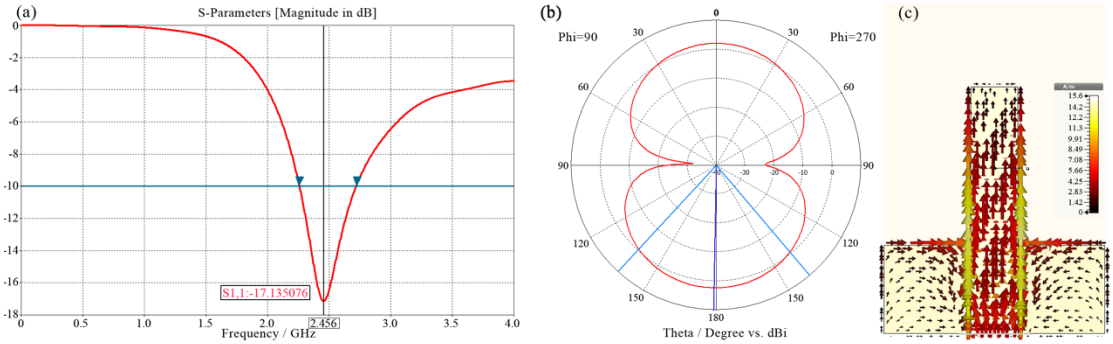


Figure 3 (a) The simulated reflection coefficient (S_{11}), (b) radiation pattern, and (c) surface currents of the wearable monopole antenna.

We investigated the performance of the wearable monopole antenna that operates in the 2.45 GHz industrial, scientific and medical (ISM) band. Proposed antenna reflects at a frequency of 2.45 GHz and has a good propagation at this frequency. It means that, this antenna works efficiently at the frequency of 2.45 GHz. The normalized radiation pattern of the proposed antenna depicted in Figure 3b at 2.45 GHz. The radiation pattern is omnidirectional in azimuth plane with a maximum gain of 2.34 dBi at 2.45 GHz. This novel electro-textile based monopole antenna can be efficiently used in wearable applications where textile technologies are the main requirement. To examine the performance and distribution of proposed antenna, we obtained the surface currents at 2.45 GHz that is demonstrated in Figure 3c. The antenna propagation in the middle parts is adequate and well done. In addition, we obtained the bandwidth values of the proposed monopole antenna between the triangle points at the -10 dB line. The first and second triangle points have 2.2576 GHz and 2.7196 GHz values. In this case, the bandwidth value of this antenna is 0.4620 (2.7196-2.2576) GHz (462 MHz). According to the results obtained, textile based monopole antenna can be easily used in industrial applications due to its geometry and frequency band.

In the maximum frequency value of the absorption $A(\omega)$ of the MTM structures, the transmission $T(\omega)$ and the reflection $R(\omega)$ minimize simultaneously. In this way, electromagnetic wave absorption with respect to frequency is determined by $A(\omega) = 1 - R(\omega) - T(\omega)$ formula with $R(\omega) = |S_{11}|^2$ and $T(\omega) = |S_{21}|^2$. Due to the equations $|S_{21}|^2 = 0$ and $T(\omega) \to 0$, the absorption equation is defined as $A(\omega) = 1 - R(\omega)$. According to this, the absorption, transmission, and reflection results of the proposed structure are shown in Figure 4a. The EBG structure shows maximum absorption of 99.39 % at the 2.4566 GHz resonance frequency. Hence, it is understood that the EBG structure has the ability to suppress the electromagnetic wave generated by the antenna at 2.456 GHz frequency. In addition, the real and imaginary part of permittivity is demonstrated in Figure 4b. In this case, the proposed EBG structure has MTM characteristic because the reel part of permittivity has the negative value in the resonance frequency.

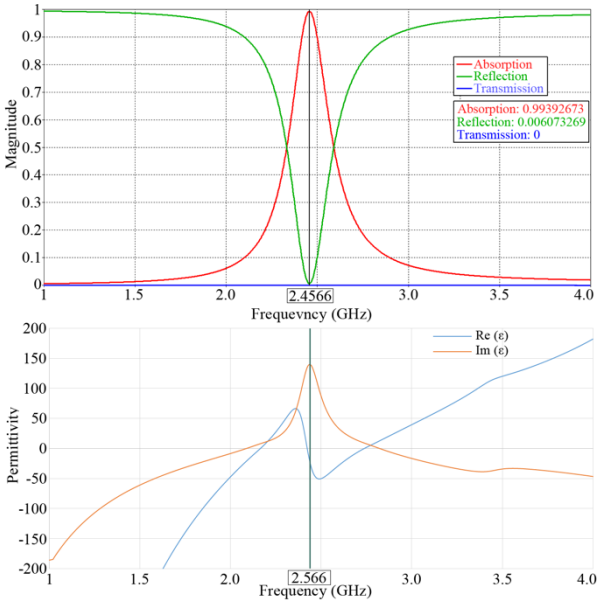


Figure 4 (a) The absorption, reflection and transmission characteristics of designed MTM structure and (b) the real and imaginary part of permittivity.

In the next phase, we have analyzed in the vicinity of a cylindrical human tissue model, as shown in Figure 5a. This human model consists of a 13 mm radius bone layer, a 20 mm radius muscle layer, a 5 mm radius fat layer, and a 2 mm radius skin layer. These tissues are located in the cylinder respectively and the total radius of the cylinder human model is 40 mm. We show in Figure 5b that the textile antenna is in direct contact with human body. This integrated system has given rise to a number of potential problems. In this context, we have realized the SAR analysis for wearable antenna. The wearable systems have leaded to exposure of the people to electromagnetic radiation by wearable equipment and then produced the biological effects towards the human body. The basic restrictions have been conducted to control the SAR towards the human body to minimize the potential health

hazard. Therefore, we placed the EBG structure between the wearable monopole antenna and human body as shown in Figure 5c and applied bending to both of the structures.

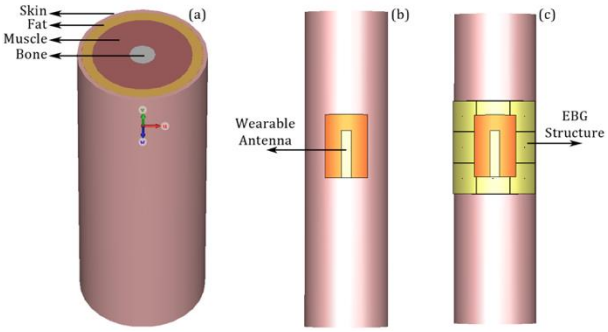


Figure 5 (a) Human body model, (b) A monopole antenna in direct contact with the human body, and (c)Integration of EBG structure between the antenna and the human body.

In the final stage, we carried out the SAR calculations of the MTM based wearable monopole antenna. The SAR results have been used for controlling the potential harmful effects on the human health. The SAR formula can be defined as:

$$SAR = \frac{P}{\sigma} = \frac{\sigma E^2}{2\rho}$$

where P is the power loss density, σ is the tissue conductivity, E is the electric filed amplitude in tissue, and ρ is the density of tissue. Then, we obtained the SAR reduction factor (SRF) of proposed structures, which is defined as:

$$SRF(\%) = \frac{SAR_{antenna} - SAR_{antena+EBG}}{SAR_{antenna}} \times 100$$

We investigated the amount of EM wave absorbed in the human body. According to the analysis results of the proposed structures, the SAR value was obtained as 17.4 W/kg when there is a direct contact between human body and monopole antenna as shown in Fig 6a. This value which is approximately the value of efficient antennas has detrimental effect on human body. If the EBG structure is used between human body and monopole antenna, the SAR value decreases to 0.329 W/kg (Figure 6b). Since, this value is lower than the European standard (2 W/kg), it can be said that the proposed structure is quite good. Later, we designed the 4x3 EBG structure and integrated the proposed monopole antenna and new EBG structure. We calculated the SAR value of this integrated structure. The SAR value of new integrated structure was obtained 0.241 W/kg when 4x3 EBG structure was integrated to antenna (Figure 6c). According to these results, the proposed structures have considerably successful SRF values which are 98.1 and 98.6% for 0.329 and 0.241 W/kg SAR values, respectively. It can be said that the proposed integrated structure has a quite good surface wave suppression feature. In addition, the other advantages of structure are low-cost and bendability. As a result, EBG based electro-textile antennas can be utilized in various applications where wearable antenna technologies are used.

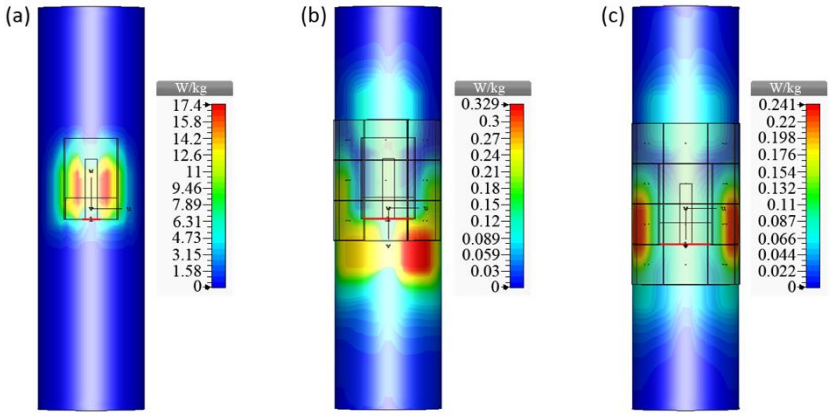


Figure 6 (a) SAR value obtained in direct contact, SAR value obtained when (b) 3x3 and (c) 4x3 unit cell EBG structure was placed between human body and antenna.

4. Conclusion

This study demonstrates an EBG structure based wearable monopole antenna that operates at 2.45 GHz for wireless communication. Firstly, we designed the electro-textile based monopole antenna and simulated the reflection coefficients. The results obtained from the simulation show that monopole antenna reflects at a frequency of 2.45 GHz. Then, we analyzed the SAR value of antenna according to result of this frequency. Secondly, we designed the mushroom based EBG structure and integrated it to the antenna. Also, we analyzed the SAR value of the integrated structure. Wearable antenna directly mounted on the body gives 17.4 W/kg SAR value taken over 10 g of tissue. This value is very high for European standard (2 W/kg). To overcome this problem, we used the EBG structure and

obtained integrated wearable antenna design. In this case, this new structure (3X3 unit cell) reduces the value of SAR to 0.329 W/kg. Similarly, the SAR value of antenna and 4x3 unit cell EBG structure was obtained as 0.241 W/kg. These are considerable values according to general SAR value standards. In addition, the proposed structures have 97.6 and 99.9% SRF values for 3x3 and 4x3 EBGs, respectively. These values are quite adequate for wearable antenna applications. Consequently, the proposed integrated antenna design can be applied to many areas such as military, health monitoring, and wireless communication.

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