Miniaturized Textile Antenna Using Electromagnetic Band Gap (EBG) Structure

M. Ramesh, V. Rajya Lakshmi and P. Mallikarjuna Rao

Abstract A textile antenna is a crucial component for any wireless body-centric communication. It is used to establish body-to-body or on-body communications. The proposed textile antenna is created using circular patch and staircase slots. The textile antenna without Electromagnetic band gap (EBG) structure operates at 8.9 GHz frequency and a combination of EBG structure with vias operate at 2.03 GHz frequency. The textile antenna is miniaturized using EBG structure with four vias.

Keywords Textile antenna · EBG · Patch antenna

1 Introduction

Over the last decade, the response for wearable electronic devices has been increased tremendously. Wireless communication inside wearable devices brings new level of mobility and flexibility. As a result, textile antennas are extensively used in wireless body area networks in order to communicate with each wearable devices. Wearable antennas are used for diverse applications, such as real-time monitoring of health conditions of aged people residing in remote locations, tracking of children; observe the glucose levels of athletes during practice, WLAN and for Fitness applications [1]. Conventional textile antenna is a combination of three layers: ground, substrate, and patch. The ground and patch are conducting

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materials and for the substrate dielectric materials are used [2]. In textile antennas, ground and patch are the conductive fabrics like zelt and substrate is a nonconductive fabric like felt, jeans, dacron. Commercial textile materials are cheaper, possess low dielectric constant, and also comfortable to wear [3].

In conventional textile antennas, the resonant frequency decreases with the increasing size of the antenna. This size is relatively larger in modern portable wearable devices. Miniaturization of microstrip antennas are complicated in antenna design and it affects radiating performance too [4]. So, few tactics have been available to miniaturize the patch antenna size such as using, patch antenna is λ/10 miniaturized using reactive impedance substrate, its substrate is made using Trans-Tech MCT-25 magnesium calcium titanate composition [5]. In [6], the antenna is positioned on teflon substrate, inter-digital capacitor provides negative permittivity, CSRR provides negative permeability, its combinations provides Metamaterial behavior and finally achieved significant miniaturization. In [7], using split-ring resonators and two FR-4 substrates, resonant frequency shifts from 6.6 GHz to 4.67 GHz and the antenna is miniaturized by 29.3%. In [8], using PBG Structure 75% size reduction is obtained. By loading of antenna with shorting vias [9, 10]. Using of high dielectric constant substrates and superstrates [11, 12]. In this paper, uniplanar EBG structure has been proposed as it is less sensitive to incident angle and polarization and it makes fabrication easier. The proposed antenna is useful for third-generation wireless Universal Mobile Telecommunications System (UMTS). In Sect. 2, antenna design parameters, analysis of antenna, and EBG structure are presented. Section 3 deals with Results and Discussion. Finally, conclusions are given in Sect. 4.

2 Antenna Design and Analysis

2.1 Antenna Without EBG

The dimensions of the proposed textile antenna with staircase slots and the side view of the textile antenna are shown in Fig. 1. Here, Fig. 1a represents the front view of circular patch with feed line and Fig. 1b exhibits side view of textile antenna without EBG. The order of the layers is ground, substrate, and patch respectively.

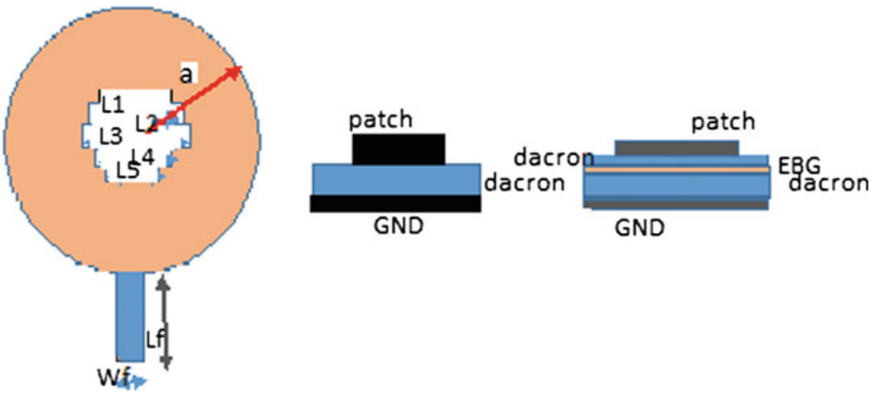
The resonant frequency of circular patch textile antenna is calculated using dominant mode as [2]

$$f_r = \frac{1.84 * C}{2\pi a_e \sqrt{\in_r}} \tag{1}$$

Here fringing is considered, f_r is the resonant frequency, a_e is the effective radius of patch, ε_r is the relative permittivity, h is height of substrate, a is the actual radius, and c is the speed of light in free space.

$$a_e = a\left\{1 + \frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \tag{2}$$

The circular patch with staircase slot textile antenna without EBG is shown in Fig. 2.



(a) Top view (b) Side view without EBG (c) Side view with EBG

Fig. 1 Geometry of textile antenna

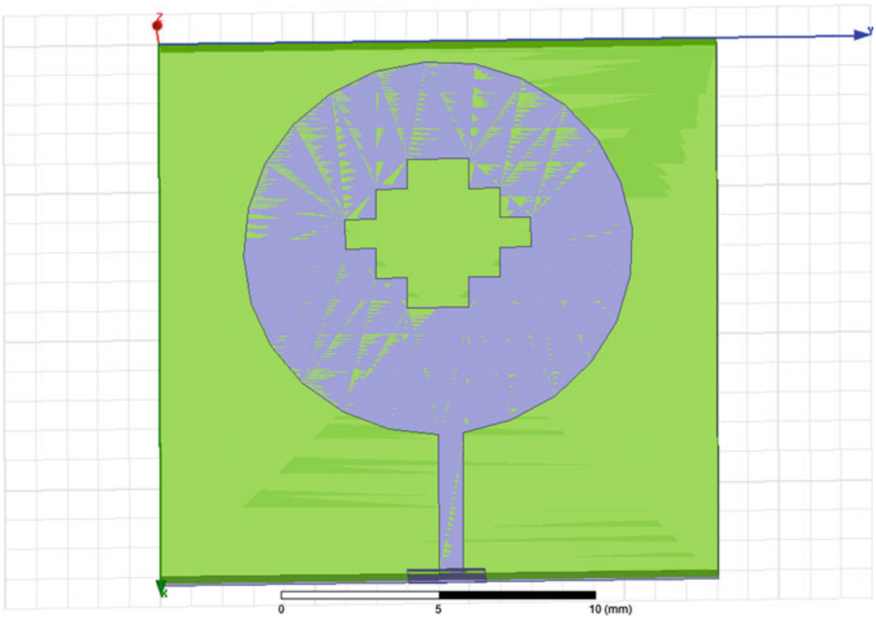


Fig. 2 Proposed textile antenna without EBG

The size of the full ground is 18 mm × 18 mm. In this case, dacron fabric is used as a substrate with dielectric constant ε_r is 3 and loss tangent is 0.025 [13, 14]. It absorbs less water when compared with other textile materials and possess high resistance to wrinkle. The size of the substrate is 18 mm × 18 mm with a thickness of 1.5 mm. The shape of the patch is circular with five slots. The radius of the circular patch, a = 6.1 mm. The length of the slots are L1 = 2 mm, L2 = 4 mm, L3 = 6 mm, L4 = 4 mm and L5 = 2 mm, respectively and the width is 1 mm.

2.2 *Antenna with EBG Structure*

The band gap structure methodology is proposed here to miniaturize the textile antenna size. Here uniplanar EBG structure is used. It is a periodic EBG structure. EBG materials are naturally unavailable. The size of a unit cell is 5 mm × 5 mm square shape with two slots. The overall antenna consists of five layers such as ground, substrate1, EBG structure, substrate2, and circular patch respectively, shown in Fig. 1c. Dacron fabric is used for Substrate1 and substrate2. Here, the same dimensions are used for circular patch except for the ground and substrate.

The circular patch having staircase slots textile antenna with EBG and vias are shown in Fig. 3. The antenna has full ground and its size is 32 mm by 32 mm. The first substrate is dacron fabric, its dimensions are 32 mm × 32 mm and thickness

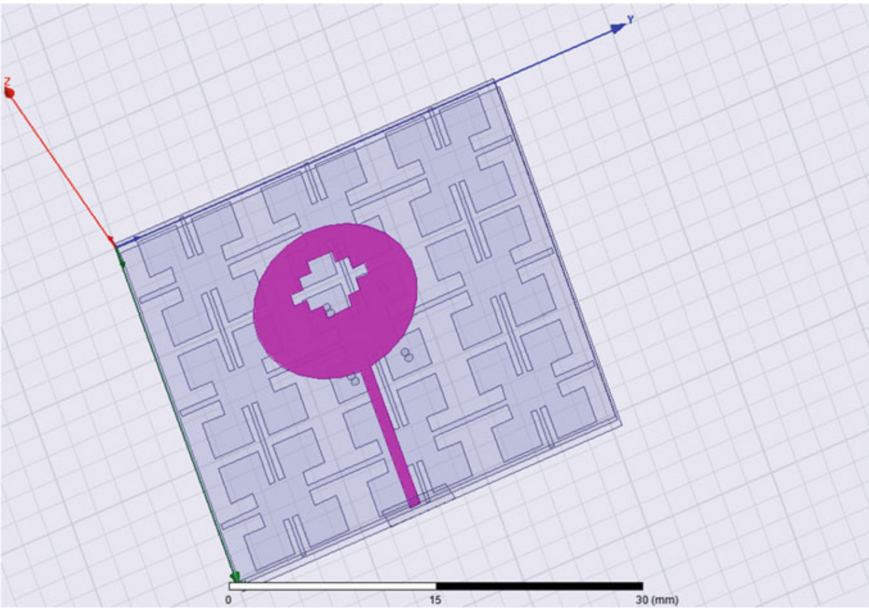


Fig. 3 Proposed textile antenna with EBG

is 1 mm. The next layer consists of uniplanar EBG structure in which 6 × 6 unit cells are used. On top of this EBG structure another substrate, dacron fabric is used having dielectric constant $\varepsilon_r = 3$, loss tangent is 0.025 and its thickness is 0.5 mm from EBG structure to patch. Its size is 32 mm × 32 mm. The next layer consists of a circular patch with staircase slot. Here four vias are used with equal radius of 0.4 mm and height of 1 mm. The vias are arranged between ground and EBG structure. Here, simple feeding technique known as microstrip line feed is used having the length L_f as 5.17 mm and width W_f as 2.5 mm. Finally the distance between ground and patch is 1.5 mm. The antenna is integrated with EBG unit cells.

3 Results

The proposed textile antenna and EBG unit cell are simulated using Ansoft HFSS software.

Figure 4 represents the simulated graph of frequency verses return loss (s11) of circular patch with staircase slot textile antenna without EBG. The simulated return loss −22.8 dB at a resonant frequency of 8.9 GHz and impedance bandwidth of 700 MHz, varying within a range (Return Loss is less than −10 dB is Reference Line) of 8.5–9.2 GHz.

The simulated return loss of the proposed textile antenna with vias and EBG structure is shown in Fig. 5. The circular patch with staircase slot textile antenna achieves resonance at 2.03 GHz frequency with return loss of −15.02 dB. Thus the antenna size is reduced by [8]

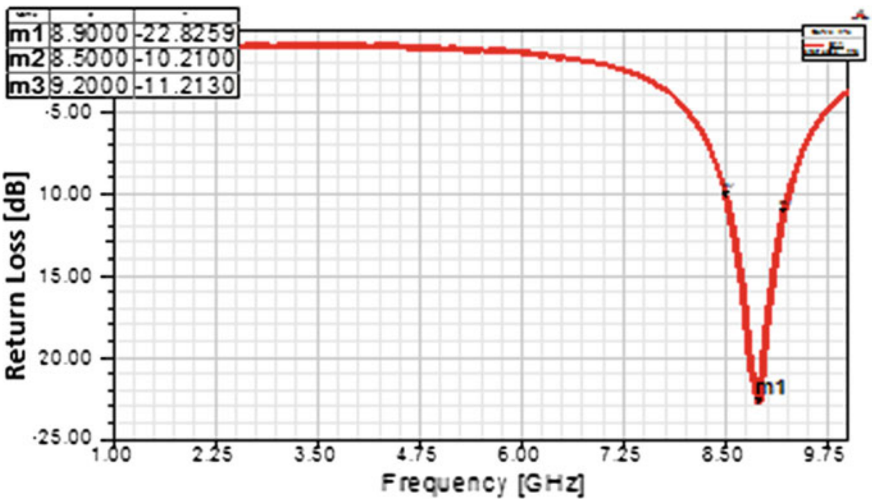


Fig. 4 Return loss of proposed textile antenna without EBG

$$\frac{8.9-2.03}{8.9}\times 100 = 77.19\%. \tag{3}$$

The simulated 3D polar plot of proposed textile antenna with EBG is shown in Fig. 6. It has a directivity of 2.16 dB at a resonant frequency of 2.03 GHz.

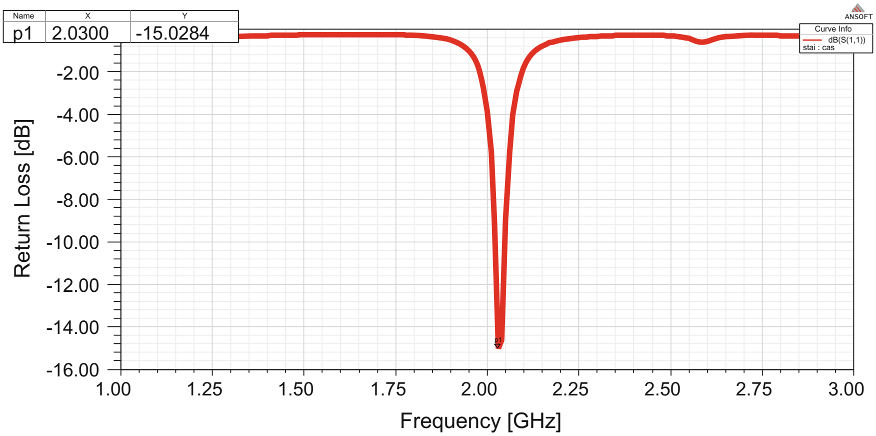


Fig. 5 Return loss of proposed textile antenna with EBG

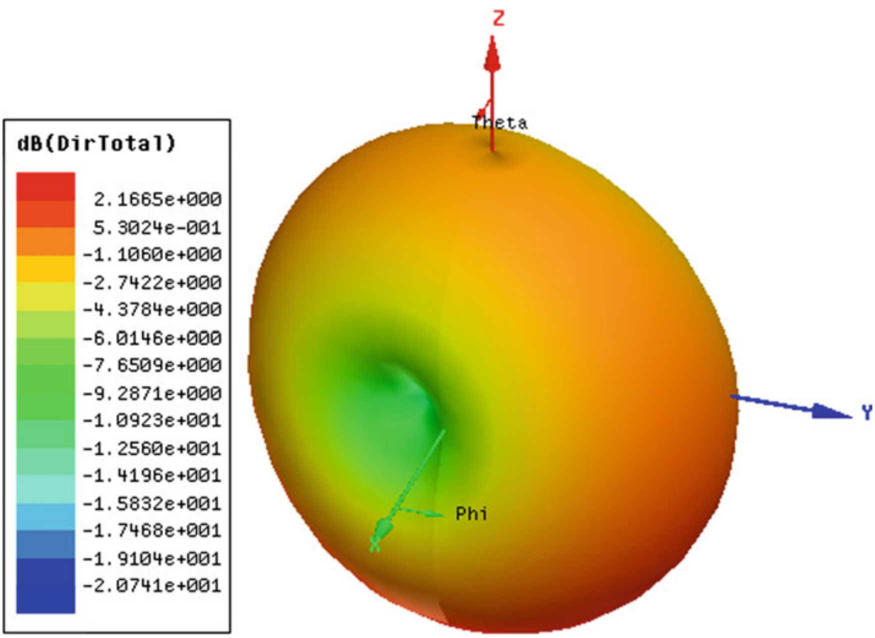


Fig. 6 3D Radiation pattern of proposed antenna

The simulated VSWR of textile antenna without EBG structure is shown in Fig. 7. The VSWR value (less than 2) is 1.15 at a resonant frequency 8.9 GHz. Figure 8 represents simulated VSWR of proposed textile antenna with EBG. The VSWR value is 1.57 at a resonant frequency of 2.04 GHz.

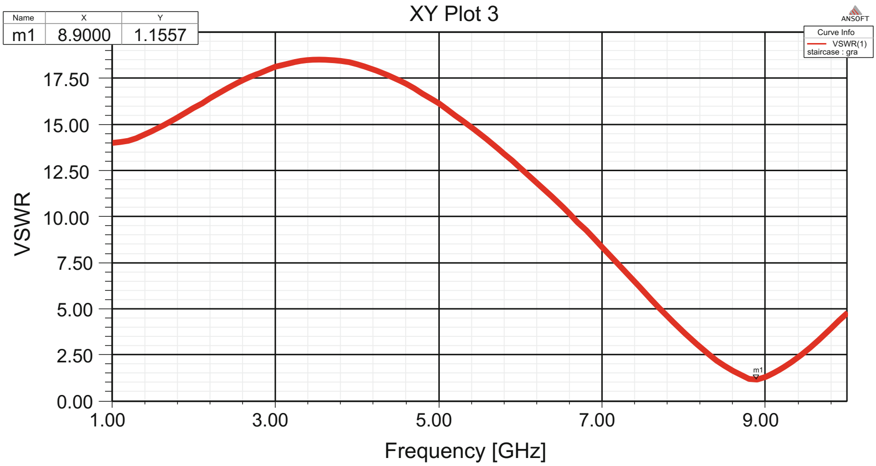


Fig. 7 The VSWR of proposed textile antenna

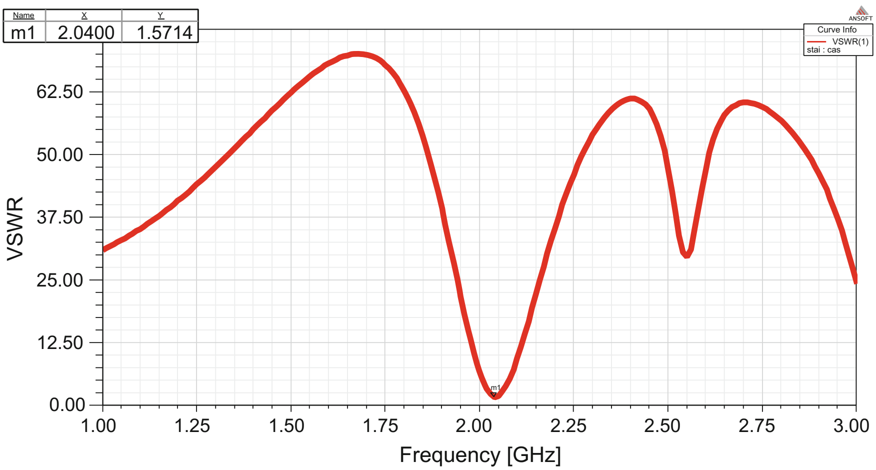


Fig. 8 The VSWR of proposed textile antenna with EBG

4 Conclusion

The resonant frequency of the proposed circular shape patch with staircase slot textile antenna using uniplanar EBG is shifted from 8.9 to 2.03 GHz without change in the size of circular patch and slots. The proposed antenna has a return loss of −15.6 dB at a resonant frequency of 2.03 GHz. The size of the antenna is reduced by 77.19% dacron fabric is used as a substrate for the proposed textile antenna.

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