

Design and Analysis of Textile Antenna using EBG Structure

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

Abstract- In this article, the rectangular textile antenna is embedded with E-shape Electromagnetic Band Gap (EBG) Structure for reduction of SAR. It is positioned on human phantom model. The E-shape EBG array is positioned between ground and patch of rectangular textile antenna. It is resonant at 2.4GHz. The substrate material for the rectangular Textile antenna is jeans cloth. The Specific Absorption Rate (SAR), Reflection coefficient and Impedance Bandwidth are obtained with and without EBG structure using HFSS software and also measured.

Index: -Textile Antenna, EBG, SAR.

I. INTRODUCTION

In the modern era, the demand for wireless communication around human body is increased due to the availability of miniaturization of electronic devices. Body Centric Communication is used for different applications like telemedicine, battleground, tracking of person and for players to monitor their health conditions. For Body Centric Communication, Textile antennas are used. It supports on body and off body communications [1]. For microstrip antenna, ground, patch is made with conductive materials such as copper and substrate is made with dielectric materials such as FR4, RT/Duroid. But textile antennas are made with conductive and non-conductive fabrics. The conductive clothes are used for ground, patch like ShieldIt, Electron. Non-conductive clothes like jeans, felt and Dacron are used for substrate [2]. Textile antennas are used for WBAN applications because Textile materials are comfortable and flexible to wear on human body when compared with conventional microstrip antennas. For wearable applications, the wearable antennas are used very close to human body. The wearable antenna radiates EM waves, when close to the human body and the tissues of human body are more affected by EM waves. The SAR value must be less than 1.6 Watts/kg (over 1g of tissue) by FCC standards and less than 2 Watts/kg (over 10g of tissue) by ICNIRP [3]. Previously, SAR can be minimized using different methods which are proposed here. In [4], multiband monopole antenna was designed using FR4 substrate with square shape EBG cells, gap between the cells is 1mm and SAR value is reduced to less than 2W/kg. PIFA antenna is designed using Interdigitated and square shape via EBG cells for reduction of SAR [5]. The Authors designed PIFA antenna with strip shape Artificial Magnetic Conductor (AMC) for reduction of SAR.

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The strips are positioned above and below the substrate [6]. The folded loop antenna is operating at 2GHz. The antenna and human body are separated by reflector and SAR is reduced to 85%. The SAR can be reduced by using RF Shields, the reduction of SAR depends on the position of RF Shields [7]. Radiation effect can be reduced by using polymeric ferrite sheets and resonant frequency is not influenced by ferrite shield but reduces the SAR value [8]. In [9], the authors proposed reconfigurable textile antenna for ISM band applications. The metamaterials are used for minimization of SAR value and bending effects, it is embedded with felt substrate. In [10], the authors proposed inverse E-shape wearable antenna combined with four strap lines and square loop EBG cells for minimization of SAR value at ISM band wearable applications. The overall antenna is implemented with jeans and ShieldIt fabric. The two by two EBG array is positioned under the antenna. In [11], the novel Z-shape EBG structure is combined with textile antenna, then the averaged SAR value is reduced to 1.26 W/kg over 10 g of tissue at 0.3 watts of input power. In [12], the authors proposed negative refractive index Metamaterials for reduction of SAR value and it is used for multiband antenna applications. In this paper, section II represents the design of textile antenna and novel E-shape EBG structure. The analysis of results and the proposed method are given in Section III. Finally, the section IV represents the conclusions. The proposed Textile antenna is used for application of wearable.

II. TEXTILE ANTENNA DESIGN

A. Analysis of Rectangular Textile Antenna

Initially, a rectangular textile antenna is designed. It consists of three different layers like ground, substrate and patch respectively.

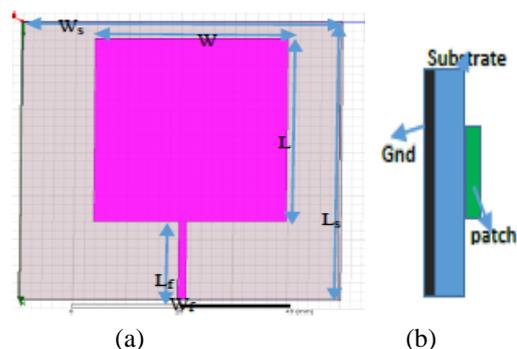


Fig.1 Schematic of rectangular Textile antenna, (a) Front view, (b) Side View.

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The copper material is used for the patch, ground and jeans fabric for the substrate. The figure 1(a) shows the schematic front view of rectangular textile antenna and figure 1(b) shows the side view.

Initially, the parameters of Rectangular shape patch are calculated using the following equation [13]. Next, the parameters are optimized for better results

$$f_r = \frac{c}{2L\sqrt{\epsilon_r}} \quad (2)$$

$$f_r = \frac{c}{2W\sqrt{\frac{2}{\epsilon_r+1}}} \quad (3)$$

L, W are length and width of patch, f_r - resonant frequency, ϵ_r -relative permittivity of substrate, c-speed of light. Let the effective relative permittivity,

$$\epsilon_{re}(L) = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[1 + 12 \frac{h}{W}\right]^{-\frac{1}{2}} \quad (4)$$

ϵ_{re} -effective permittivity of substrate, h-thickness of substrate,

$$f_r = \frac{c}{2f_r\sqrt{\epsilon_{re}}} - 2\Delta L \quad (5)$$

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{re}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{re}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (6)$$

ΔL -effective length due to fringing fields.

The length is 70mm and width is 65mm of the ground plane. Next, the size of substrate is $L_s=70$ mm, $W_s=65$ mm with thickness of 3.3mm. The dielectric constant of jeans fabric is 1.67 with loss tangent 0.023[2]. The multiple layers of jeans cloth is used as substrate to achieve a particular height of the substrate for a proposed textile antenna. The size of the patch is $L=43$ mm and $W=36$ mm which is positioned on the substrate. The proposed feed is Microstrip line, its length and width are $L_f=30$ mm, $W_f=2$ mm respectively.

B. Design of E-shape EBG structure

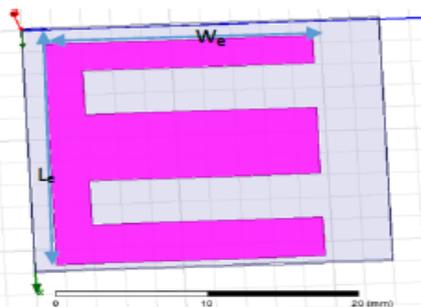


Fig.2. Dimensions of Proposed E-shape EBG cell.

The figure 2 shows the dimensions of E shape EBG cell. The length is $L_e = 20$ mm, width is $W_e = 17.5$ mm and the position of the rectangular EBG structure from ground plane is 2.4mm. The array size of EBG structure is 3x3. The gap between adjacent cells in horizontal direction is $g=0.5$ mm. The E-shape EBG cell has periodicity is 18mm. Here the substrate is implemented with jeans fabric. The width of the

slots of EBG cell influence the reflection phase of E-shape EBG cell, then the width of the slots are optimized to achieve a zero phase at desired frequency.



Fig.3. Fabricated (a) Rectangular textile antenna (b) E-shape structure

The front view of the fabricated rectangular textile antenna is shown in figure 3(a) and top view of the E-shape EBG structure is shown in 3(b). The E-shape EBG structure is kept between ground and patch at 2.4mm distance from the ground plane. The E-shape cells, jeans fabric and rectangular patch are manually cut with scissor and tape is used to stack them.

C. E-shape EBG array embedded Rectangular textile antenna

The Figure 4(a) shows the textile antenna is embedded with E-shape EBG structure on a phantom model of human body and side view of the antenna is shown in 4(b). The array of EBG structure is positioned at 2.4mm from the ground plane. Here, ground surface and EBG structure are separated with jeans cloth as a substrate. Next, the rectangular patch is positioned on EBG structure at a height of 0.8mm, whereas jeans fabric is placed between EBG and patch. The ground structure is positioned at 2mm from the Human body.

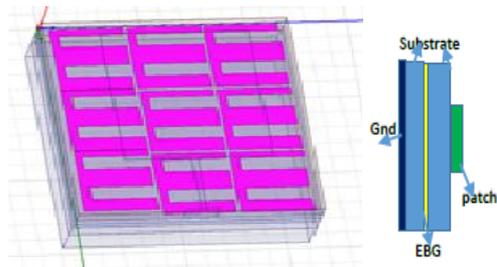


Fig.4. Textile antenna with E-shape EBG array view (a) Front (b) Side

III. ANALYSIS OF RESULTS

All the Results are verified using Ansoft HFSS software for Textile antenna and EBG cell.

A. Phase Reflection of EBG Cell

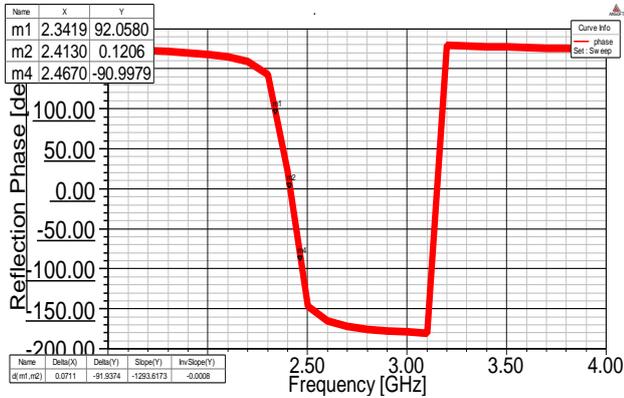
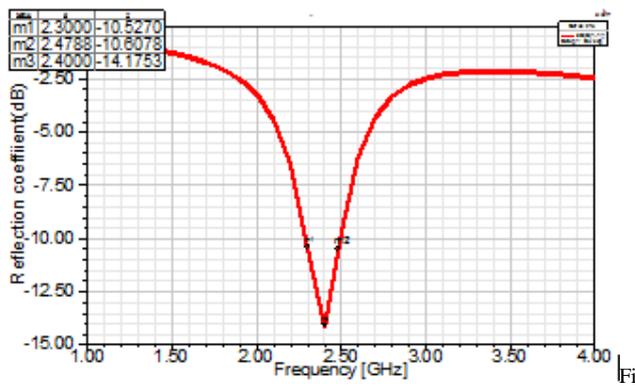


Fig.5. Reflection Phase of E- shape EBG cell.

The graph between the reflection phase and frequency for the proposed E-shape EBG cell is shown in figure 5. The E-shape EBG cell is excited with incident of plane wave at normal incidence. The reflection phase varies from $+180^\circ$ to -180° but from $+90^\circ$ to -90° , this interval represents reflection phase bandwidth and reflection phase is zero degrees at 2.41 GHz. The structure behaves as Electromagnetic Band Gap from 2.34GHz ($+90^\circ$) to 2.46 GHz (-90°), in this interval the surface waves are suppressed, it is a unique feature of EBG structure.

B. Reflection coefficient



g.6.Rectangular textile antenna w/o Phantom Model and EBG

The figure 6 shows the simulated reflection coefficient is -14.17dB at 2.4GHz of rectangular textile antenna without EBG structure, without Phantom model and impedance bandwidth (< -10 dB) is 170MHz. Here, $f_l = 2.3$ GHz as lower cutoff frequency, $f_h = 2.47$ GHz as upper cutoff frequency.

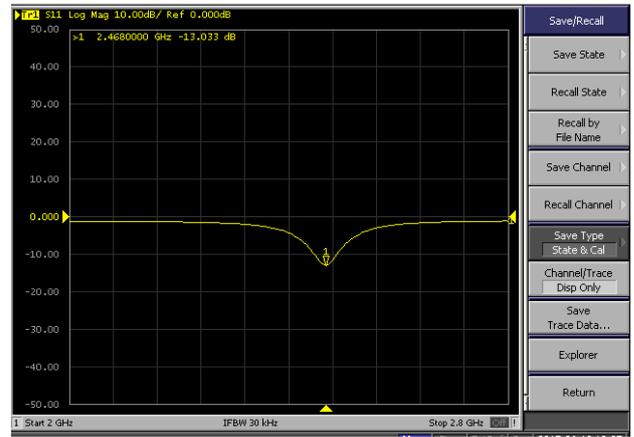


Fig.7 Measured Reflection coefficient of rectangular textile antenna without EBG

The figure 7 shows the measured reflection coefficient is -13.03dB at 2.46 GHz of the rectangular textile antenna without EBG, without human body.

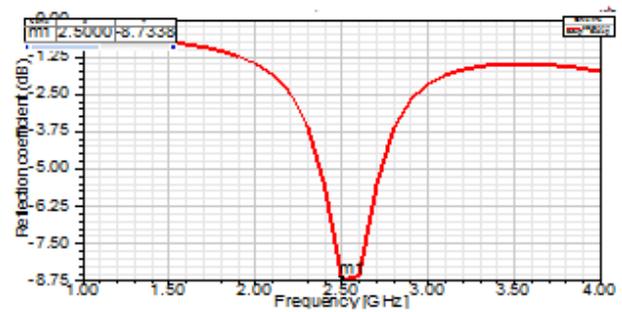


Fig.8. Textile Antenna with phantom model and without EBG.

The figure 8 shows Reflection coefficient of the rectangular textile antenna with Phantom model, without EBG structure. The antenna is resonant at 2.5 GHz with Reflection coefficient of -8.67dB. The Reflection coefficient of the rectangular textile antenna is affected due to the Human body since it is a lossy medium. This effect can be reduced using E-shape EBG structure.

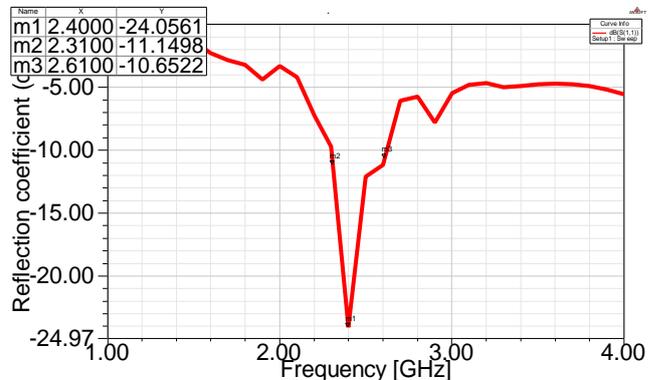


Fig.9.Reflection coefficient with E shapes EBG on human phantom model.

The figure 9 shows the reflection coefficient is -24.05dB at 2.4GHz of rectangular textile antenna with E-shape EBG array on human phantom model.

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The Impedance bandwidth ($<-10\text{dB}$) is 300MHz (from 2.31GHz to 2.61 GHz). The impedance bandwidth is increased due to E-shape EBG structure.

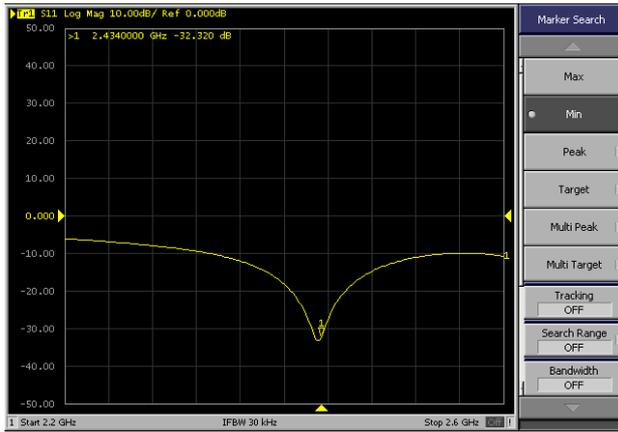


Fig.10.Measured Reflection coefficient of rectangular textile antenna with EBG structure on human body

The measured Reflection coefficient of rectangular textile antenna with E-shape EBG structure on human body is shown in figure 10. The measured resonant frequency is 2.43GHz with reflection coefficient -32.3dB.

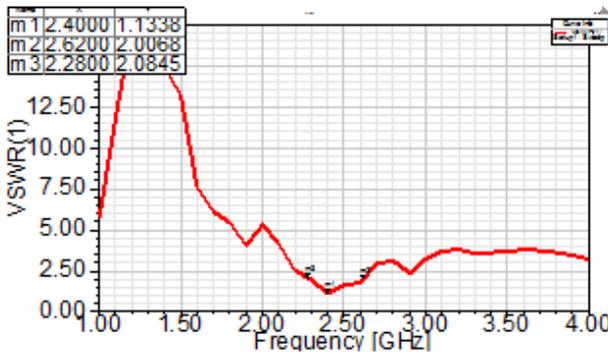


Fig.11 VSWR of rectangular textile antenna by E shape EBG structure.

The VSWR of rectangular textile antenna combined with human phantom model and E-shape EBG array. The VSWR value (<2 is reference line) is 1.13 at 2.4GHz.

C. Radiation Pattern

The figure 12 shows the radiation pattern of rectangular textile antenna embedded E-shape EBG array and it is positioned on human phantom model. The graph shows back lobe radiation is reduced.

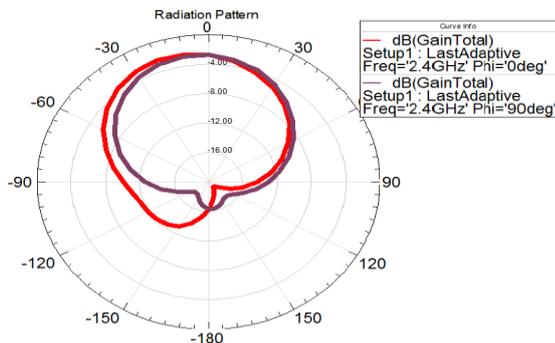


Fig.12.Radiation Pattern of Antenna with EBG structure.

D. Calculation of SAR

The shape of the human phantom model is rectangular and it is created by Skin, Fat and Muscle [14]. The overall dimensions of the rectangular box of human phantom model is $70 \times 65 \times 16 \text{ mm}^3$. The table I give the properties of human tissues

Table I: Electrical properties of human tissues at 2.4GHz

Tissues	Thicknes s(mm)	Conductivity [S/m]	Relative permittivity	Loss tangent
Skin(wet)	2	1.5618	42.923	0.27253
Fat	4	0.10235	5.2853	0.14503
Muscle	10	1.705	52.791	0.24191

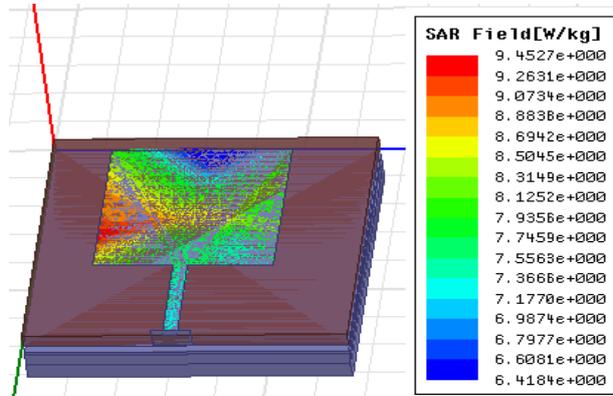


Fig.13.Simulated SAR of rectangular textile antenna w/o EBG structure

Here the input power is 0.2W. The gap between the rectangular textile antenna and human phantom model is 2mm. The SAR value is calculated w/o EBG surface using human phantom model is shown in figure 13. The averaged SAR value is 9.45Watts/Kg for 10g of tissue is more than that of FCC standards ($<2\text{W/kg}$) and as a result of this, tissues are more effected. The surface waves are generated when the dielectric constant of substrate is more than one. The back lobe radiation is increased due to the diffraction of surface waves, and then the SAR value is increased.

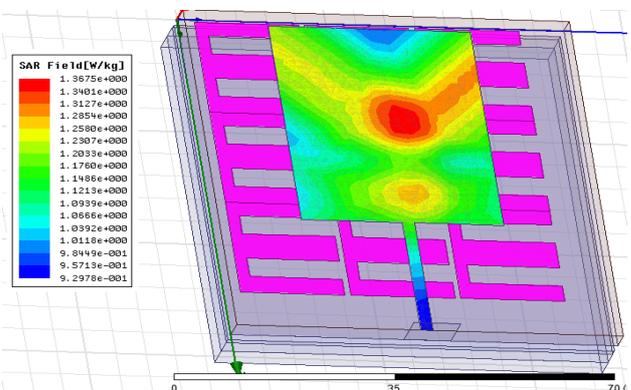


Fig.14.Simulated SAR of rectangular textile antenna with E shape EBG array.

Figure 14 shows the SAR value of proposed antenna with E-shape EBG array on human phantom model.

The E-shape EBG structure suppress the surface waves, then the back lobe radiation is reduced, so SAR value is minimized. The averaged SAR value is 1.36 Watts/Kg over 10 g of tissue is achieved due to E-shape EBG array. It must be less than the value specified by FCC. The E- shape EBG structure provides more isolation between textile antenna and human body.

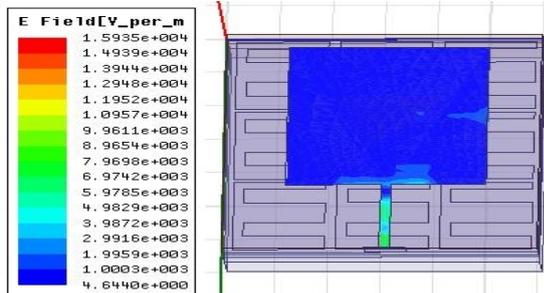


Fig.15. Field distribution of rectangular textile antenna with E shape EBG array

The E-field distribution of proposed antenna with E-shape EBG array on human phantom model is shown in figure 15.

TABLE-II: Textile antenna with and without E shape EBG

	Antenna w/o EBG and body	Antenna with body and w/o EBG	Antenna with EBG+ body
Reflection coefficient(dB)	-12.71	-8.67	-25.04
Bandwidth(MHz)	150	-	300
SAR(10g)(W/kg)	-	9.45	1.36

The comparison of the rectangular textile antenna w/o and with E- shape EBG structure on human phantom model is given in Table-II. The textile antennas with E-shape EBG enhance the impedance bandwidth and reduce the SAR value.

TABLE-III: Comparison of Textile antennas

Paper	f_r	Substrate type	EBG shape	EBG Cell size(mm ²)
[15]	2.4	Photo Paper	Single ring	25.3 X 25.3
[16]	2.4	Rogers 3003	I	26.87 X 16
Proposed Antenna	2.4	Jeans	E	20 X17.5

The proposed Textile antenna compared with other EBG structures that are given in Table –III. The proposed compact E-shape EBG cell is implemented on jeans fabric.

IV.CONCLUSION

The proposed E-shape EBG structure is integrated with rectangular textile antenna. The averaged SAR value is reduced from 9.45W/kg (without EBG) to 1.36 W/kg (with E shape EBG) for 10g of tissue. The Reflection coefficient is -8.67dB without EBG due to human body. The textile antenna with EBG is resonant at 2.4GHz with Reflection coefficient of -24.05 dB on phantom model. The 85.6% reduction in SAR value is obtained and impedance bandwidth is increased due to the E-shape EBG structure.

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