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SPECIFIC ABSORPTION RATE REDUCTION USING EBG STRUCTURE AS SUPERSTRATE FOR TEXTILE ANTENNA

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ABSTRACT

The Wireless Body Area Network (WBAN) band textile antenna is designed with novel E-shape Electromagnetic Band Gap (EBG) structure as superstrate for reduction of Specific Absorption Rate (SAR) for wearable applications in this paper. The performance of textile antenna is evaluated with and without E-shape EBG array on phantom model of human body. The Return loss and VSWR of proposed textile antenna are simulated and measured.

Keywords: textile antenna, WBAN, E-shape EBG, SAR, VSWR, return loss.

1. INTRODUCTION

From last decade, the demand is increased for wearable textile antennas because compact size electronic devices are available, so electronic devices can be easily integrated with garments. The implemented on and off body devices can communicate to each other through wearable textile antennas. The devices can communicate to each other through wearable textile antenna is called Wireless Body Centric Communication. The applications of wearable antennas are tracking of children's and monitor the health condition of old person from remote location [1]-[2].

The wearable textile antennas are preferred for body -worn applications, as they are mainly compact in size, light weight, inexpensive and comfortable, flexible to wear on a human body. For implementation of textile antennas, conductive (Shieldit, Flectron and Zelt) and non-conductive (Felt, Jeans, Fleece, Dacron and polyester) fabrics are used. The dielectric constant of nonconductive fabrics are very low [3] - [4].

The Electro Magnetic (EM) waves are produced by textile antennas, when wearable textile antennas used near to the human body, the human body absorbs more EM energy so the body tissues are more effected due to these radiation. The amount of EM energy is absorbed by the body tissues are calculated using Specific Absorption Rate (SAR) [5].

$$SAR = \frac{\sigma E_i^2}{\rho} \quad (1)$$

σ-conductivity(S/m), E_i-Electric-field (V/m) and ρ - Density (kg/m^3) of body tissue respectively. As for FCC standards, the averaged SAR value must be less than 1.6W/kg for 1g of tissue and for European, the value must be less than 2W/kg for 10g of tissue.

In [6], the authors proposed new substrate material i.e. Magneto-Dielectric Nano Composite (MDNC) for SAR reduction. The meander PIFA micro strip antenna resonates at 900MHz and SAR value is 0.72W/kg for 1g of tissue on human head model. In [7], the shape of the EBG structure is a miniaturized slotted Jerusalem Cross (JC) which is used as a ground plane for SAR reduction. M-shaped monopole antenna is integrated with Artificial Magnetic Conductor (AMC) structure then the SAR value is reduced to 0.68W/kg from 1.88W/kg with AMC on human body and input power is 125mW. In [8], the authors designed Integrated Inverted-F Antenna (IIFA); textile antenna with two different polymeric ferrite sheets for SAR reduction that are WDNRC, WDHTV and it resonates at 2.4GHz. The WDHTV provides better result when input power is 250mW. In [9]; the proposed method is a phased array antenna with two elements for SAR reduction. Using array antenna, the spatial nulls are provided in the direction of the human body then the SAR value is minimized. In [10], Wearable Monopole antenna is integrated with 2X2 I-shape array and SAR is reduced to 0.66W/kg over 1g of tissue at 100mW power. The Rogers RO3003 is used as substrate material. In [11], two-rod reflectors create additional field and is kept near to the radiating element then the fields are decreased in human body. So SAR value is decreased. In [12], partial ground plane wearable antenna is implemented with anon-conductive denim jeans fabric thickness is 0.7mm (substrate), Shield it conductive fabric thickness is 0.17mm (patch and ground) and it resonant at ISM band. The SAR value is reduced by using 2 X2 EBG array and gain is enhanced. The EBG array is used under the ground plane. The shape of EBG cell is square loop with four T-shape straplines. In [13], the author's proposed FIFA antenna with Taconic RF35A as a substrate for WDMA band wearable application. Metamaterials are placed beneath of the patch antenna for reduction of SAR value. In [14], the authors designed quarter mode integrated substrate smart textile antenna, it is implemented with copper plate polyester taffeta conductive fabric and rubber foam as a substrate, then the SAR valued minimized to 0.45mW/g over the 1g of tissue for 500mW of input power.

This article is arranged as, design, prototype of WBAN band textile antenna and proposed EBG method

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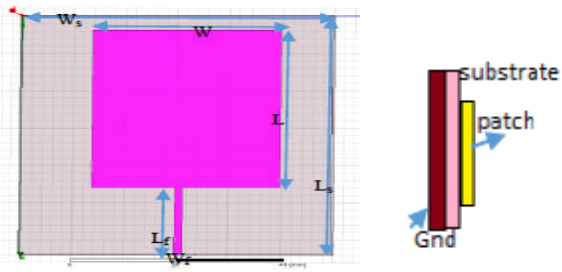
are given in Section II. In section III, results and SAR analysis of proposed textile antenna are shown. Finally, the conclusion is given in Section IV.

2. TEXTILE ANTENNA DESIGN

The schematic view of the proposed wearable textile antenna is shown in Figure-1.



(a) (b)

Figure-1. Schematic of textile antenna, (a) Front view, (b) Side view.

Initially, the dimensions of Rectangular patch are calculated using the following equation [15]. Next, the parameters are optimized for better results

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

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

L-length of patch, W-width of substrate, f_r-resonant frequency, ε_r-relative permittivity of substrate, c-velocity of light in free space. Consider the effective dielectric constant,

$$\varepsilon_{re}(\mathrm{L}) = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}} \quad (4)$$

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

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

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{re}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{re}-0.258)(\frac{w}{h}+0.8)} \quad (6)$$

ΔL-effective length due to fringing fields.

The front view of the designed rectangular textile antenna without EBG and without phantom model of the body is shown in Figure-1(a) and 1(b) shows the side view. The ground plane size is 70mm x 66mm. The substrate has the dimensions of L_s=70mm, W_s=66mm, h=3.5mm and it is made by jeans fabric with dielectric constant 1.67, loss tangent 0.025[4]. The Length and width of the patch is L=43mm, W=34mm. The textile antenna is excited with microstrip line feed and the dimensions are L_f=26 mm, W_f=2mm. For substrate, multiple layers of jeans fabric is used to achieve the desired height for the proposed textile antenna.

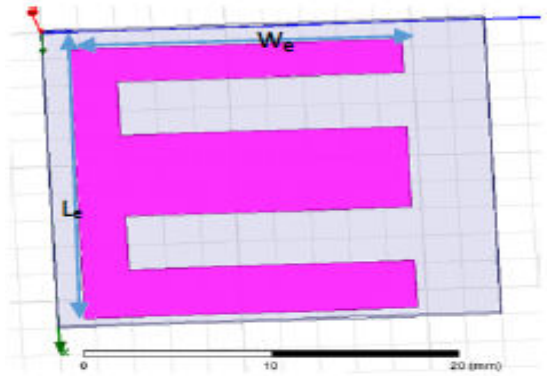
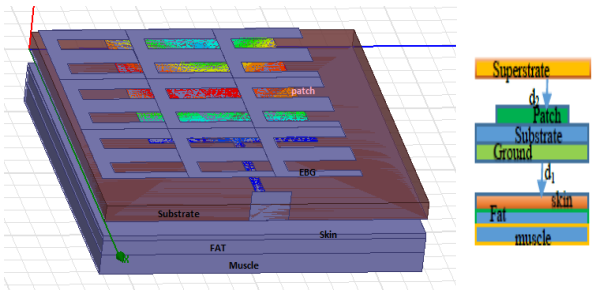


Figure-2. Schematic of proposed E-shape EBG cell.

The proposed E-shape EBG cell is shown in Figure-2. The length is L_e=20mm and width is W_e=17.5mm of E-shape EBG cell. The width of the first arm is 4mm, second arm is 5mm and third arm is 4.5mm. the width of the arms effect the phase reflection of the E-shape EBG cell. The E-shape EBG array size is3X3.The gap between the adjacent cells is 0.3 mm, then the periodicity of the cell is 17.8mm along the y-direction. The width of the arms of E-shape EBG cell effects the reflection phase at a particular frequency of the cell, so the width of the arms are optimized to achieve zero reflection phase at a desired frequency.



(a) (b)

Figure-3. Textile antenna with E-shape EBG array, (a) Front View, (b) Side View.

The proposed textile antenna with E-shape EBG structure as superstrate on phantom model of human body is shown in Figure-3(a) and Figure-3(b) which shows the side view of the proposed antenna. The dimensions of textile antenna with and without E-shape EBG array are same but E-shape EBG structure is used as superstrate at height d_2=0.8mm from the patch of textile antenna. The gap is filled with foam because the foam and air has same relative permittivity, so E-shape EBG superstrate structure is supported by foam. The distance between the skin layer of phantom model of body to ground plane of textile antenna is d_1=2mm.

(a) (b)

Figure-4. Prototype of textile antenna, (a) Front view, (b) With EBG array.

The fabricated Rectangular Textile antenna front view is shown in Figure-4(a). The E-shape EBG structure used as a superstrate and it is kept 0.8mm distance above from the patch of textile antenna that is shown in Figure-4(b). The layers of wearable textile antenna are fixed with tape and layers are cut manually by scissor. The foam is kept between the patch of textile antenna and E- shape EBG structure.

3. RESULTS AND DISCUSSIONS

All the results are simulated using Ansoft HFSS software for the proposed Textile antenna. The reflection phase of the E-shape EBG cell is simulated by using periodic boundary conditions and Floquet ports in HFSS simulator.

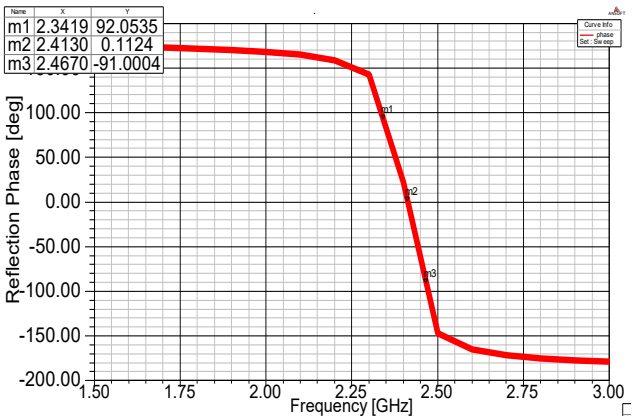


Figure-5. The reflection phase of E-shape EBG cell.

The proposed E-shape EBG unit cell has Reflection phase of 0^0 at 2.41GHz that is shown in Figure-5. Generally, the reflection phase varies from $+180^0$ to -180^0 but reflection bandwidth is calculated between $+90^0$ to -90^0, these two points are references for calculation of reflection bandwidth. The reflection bandwidth is 120MHz from 2.34GHz ($+90^0$) to 2.46GHz (-90^0).This band shows the Electromagnetic Band Gap for the proposed E-shape EBG cell.

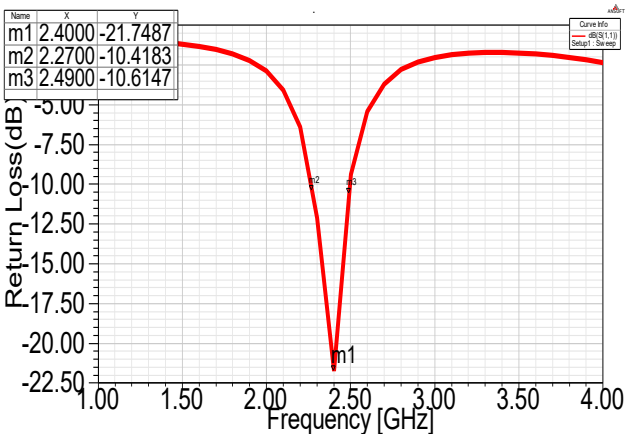


Figure-6. The textile antenna without EBG array and without phantom model.

The textile antenna without EBG array and without phantom model resonates at 2.4GHz with return loss-21.7dBis shown in Figure-6. The impedance bandwidth is 220MHz, lower cut off frequency is 2.27GHz and upper cutoff frequency is 2.49GHz and -10dB is reference line for calculation of the impedance bandwidth.

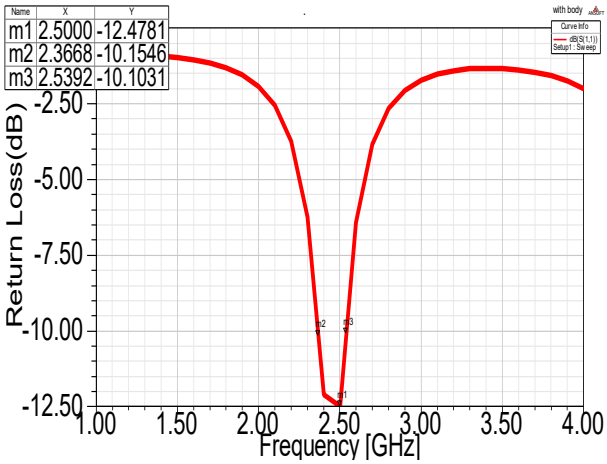


Figure-7. The textile antenna without EBG on phantom model.

The return loss is -12.4dB at 2.5GHz of the textile antenna without E-shape EBG array on phantom model is shown in Figure-7. The return loss and resonant frequency of the textile antenna are effected due to human body.

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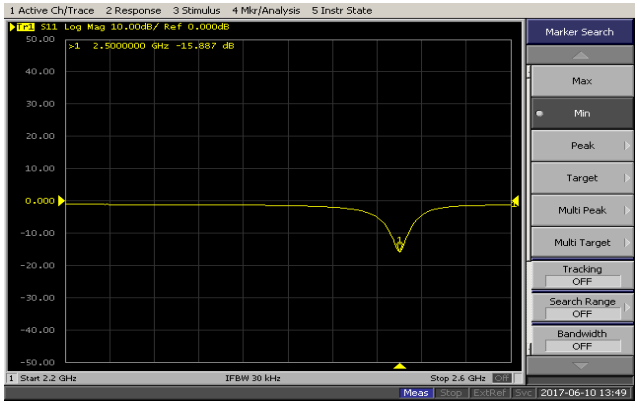


Figure-8. The textile antenna without EBG on body.

Figure-8 shows the measured return loss of textile antenna without EBG array on body. It resonates at 2.5GHz with return loss is -15.8dB.

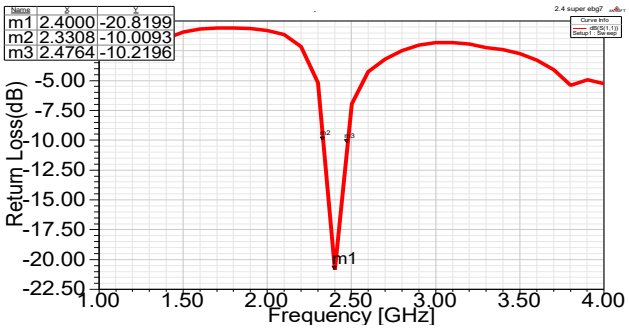


Figure-9. Return loss of textile antenna with E-shape EBG on phantom model.

The proposed textile antenna with E-shape EBG array as superstrate on phantom model of human body is operating at 2.4GHz with return loss -20.8dB is shown in Figure-9. The impedance bandwidth is 140MHz from 2.33GHz to 2.47GHz. The better return loss is attained due to E-shape EBG structure.

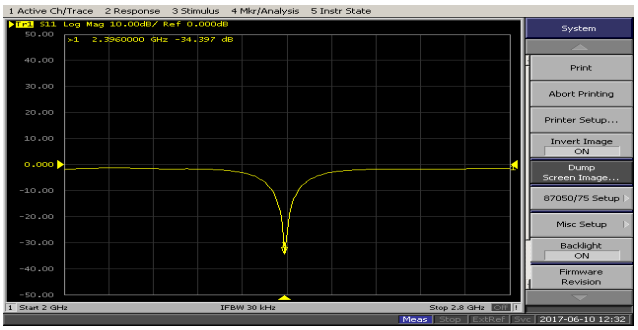


Figure-10. Measured return loss of textile antenna with E-shape EBG on human body.

The measured return loss of textile antenna with EBG array as superstrate on human body is shown in Figure-10. The antenna resonates at 2.39 GHz with return loss is -34.3dB. The Figure-11 shows the VSWR value is 1.2 at 2.4GHz of the proposed textile antenna with E-shape EBG structure on phantom model of body. This value is less than 2.

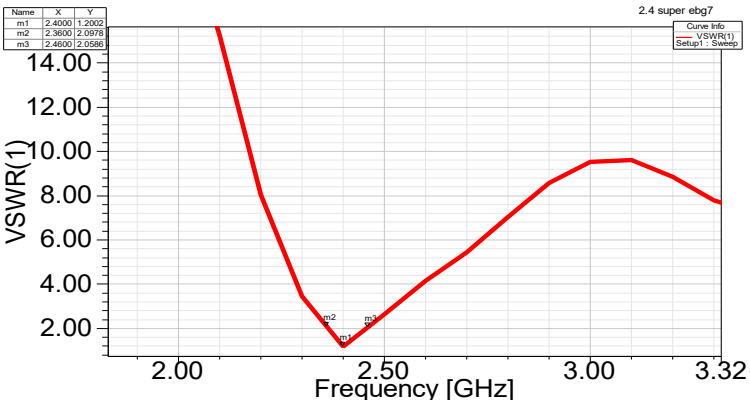


Figure-11. VSWR of textile antenna with E-shape EBG on phantom model.

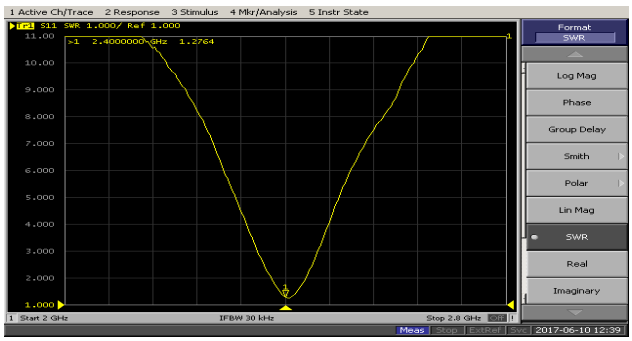
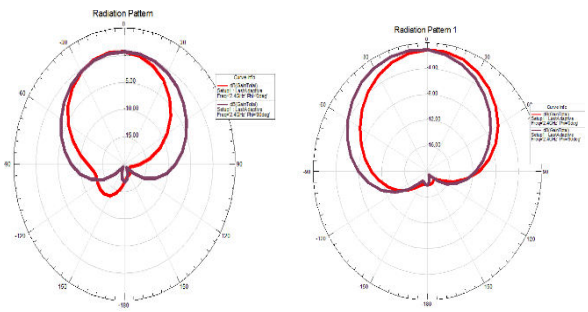


Figure-12. Measured VSWR of textile antenna with EBG structure on body.

Figure-12 shows the measured VSWR of the fabricated Textile antenna with E-shape EBG array as a superstrate and the antenna is positioned on the human body. The measured VSWR is 1.27 at 2.4GHz.



(a) (b)

Figure-13. Radiation pattern of textile antenna on body, (a) without EBG structure (b) with EBG.

The Radiation pattern of textile antenna without and with E-shape EBG array on phantom model is shown in Figure-13(a) and 13(b) respectively. The back radiation is reduced due to E-shape EBG array.

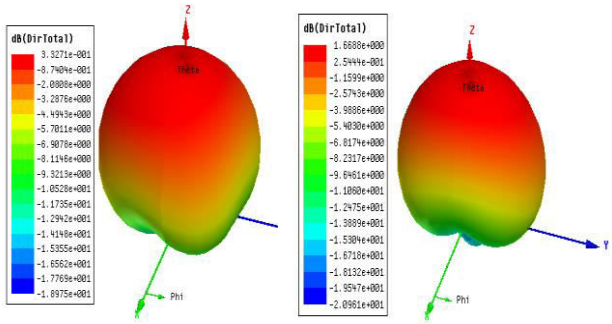


Figure-14. Directivity of textile antenna on body (a) without EBG array, (b) with EBG array.

The directivity of the textile antenna without EBG array on phantom model is 0.3dB shown in Figure-14(a) and with E-shape EBG array is 1.66dB shown in Figure-14(b). The area of the radiation field of textile antenna is increased by the waves reflected between the superstrate and ground plane of textile antenna, then the directivity is enhanced. The surface waves are by product in textile antennas, when relative permittivity is more than one. The diffraction of surface waves increases the back lobe radiation and decreases directivity. So, the proposed E-shape EBG array suppress the surface waves, then the directivity is increased and back lobe radiation is decreased.

Analysis of SAR

The Rectangular phantom model of human body is created with Skin (wet), Fat and Muscle [16]. The dimension of the created rectangular phantom model is 70 X 66 X14 mm^3. The thickness and dielectric properties of tissues for the phantom model of human body are given in Table-1.

Table-1. Dielectric properties of tissues for human body at 2.4GHz.

Tissues	Thickness (mm)	Conductivity [S/m]	Relative permittivity	Loss tangent
Skin	1	1.5618	42.923	0.27253
Fat	3	0.10235	5.2853	0.14503
Muscle	10	1.705	52.791	0.24191

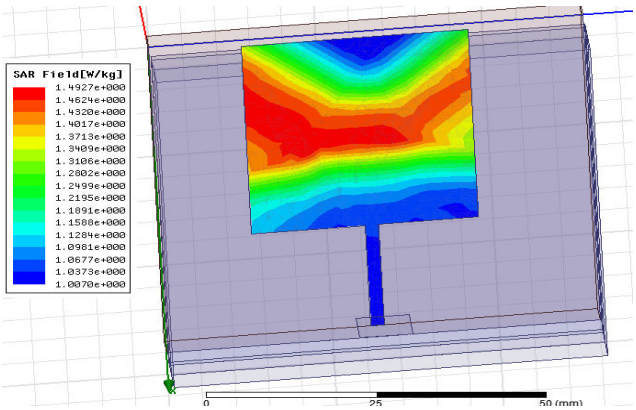


Figure-15. SAR value of the textile antenna without EBG on phantom model.

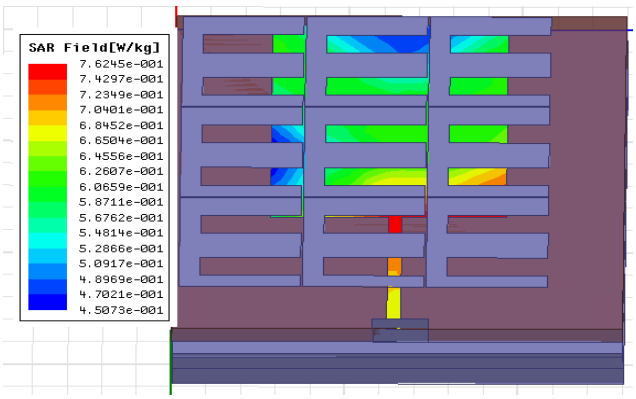


Figure-16. SAR value of textile antenna with E-shape EBG structure on phantom model.

The textile antenna without EBG array on phantom model has averaged SAR value of 1.49W/kg over 10g of tissues is shown in Figure-15. The proposed E-shape EBG array is used as superstrate with textile antenna on phantom model has averaged SAR value is 0.76 W/Kg at 2.4GHz over 10g of tissue is shown in Figure-16.

The EM wave radiating outward is ultimately obtained by amplitude-phase weighting of each EBG cell, then the backward radiation is reduced, so radiation hazardous on human body is minimized using E-shape EBG structure.

Table-2. SAR values without and with EBG structure.

Paper	SAR W/O EBG	Substrate type	EBG shape	SAR (10 g) with EBG
[7]	1.88	Inkjet paper	Jerusalem Cross	0.68
[17]	8.9	jeans	Z	1.26
Proposed Antenna	1.49	Jeans	E	0.76

The given Table-2 shows the comparison of ISM band antennas without and with EBG structure of SAR values. The proposed E-shape EBG array used as superstrate of patch of the textile antenna and the position of EBG array under the patch of antenna in references [7], [17]. All the averaged SAR values are calculated over the 10 g of tissues as a reference.

4. CONCLUSIONS

The fabricated textile antenna with E-shape EBG structure on human body resonates at 2.39GHz. It is used for wearable applications. The proposed E-shape EBG structure is used as superstrate, then the SAR value is reduced from 1.49W/kg (without EBG) to 0.76W/kg (with EBG) over 10g of tissue for 0.2Watts of input power and also directivity is enhanced from 0.3 dB to 1.66 dB.

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