Design and Analysis of Metamaterial based-check board AMC Backed EBG Antenna for Body Placement Applications

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Abstract: In this paper a compact EBG antenna with Artificial Magnetic Conductor (AMC) is proposed for on body applications. The proposed antenna is designed with single SRR (split ring resonator) and double SRR to differentiate the performance of the proposed antenna. The proposed EBG antenna bending analysis is performed at different angles on human body to attain good radiation characteristics. The footprint of proposed antenna is of $0.2\lambda_0$*$0.24\lambda_0$mm2 and AMC with dimension of $0.48\lambda_0$*$0.48\lambda_0$ mm2.The proposed antenna is obtained good return loss and radiation characteristics when EBG antenna is placed on the human leg with an angle of 300 at corresponding operating frequencies 2.4GHz, 5.8GHz, 9GHz and 9.5GHz respectively. The obtained operating frequencies cover wireless applications such as GPS, ISM, and Radar and satellite communications. The proposed EBG antenna is obtained with high gain 7.05dBi at 9.5GHz operating frequency. The surface current distributions are obtained for the proposed antenna is of 137A/m. Good isometric radiation patterns are observed for the proposed antenna. The SAR analysis is performed when the EBG antenna is placed on the human leg at an angle of 30degree is of 1.23W/kg.

Keywords: Electromagnetic Band gap Structure (EBG), DSRR, SSRR, SAR.

DSRR : Double Split Ring Resonator

SSRR : Single Split Ring Resonator

SAR : Specific Absorption Ratio

1. Introduction:

2. The artificial magnetic conductors are becoming very popular these days because of their usage as high impedance surfaces in the design of low-profile antennas. Periodic slots on electrically thin grounded dielectric materials with Frequency Selective Surfaces are gaining their importance to act as high impedance surfaces. Active research is being carried out on AMC structures with the combination of electromagnetic band gap structures and metamaterials. For artificial magnetic conductor (AMC) has the characteristics of in-phase reflection, it can reduce the backward radiation of the antenna, consequently decreasing SAR. Compared with the antenna using conventional PEC, the antenna combining with AMC can maintain a low profile. Wearable antennas based on AMC have been proposed. In [6]-[7], a dual-band (i.e., 2.45 GHz and 5 GHz) textile antenna based on the electromagnetic band gap (EBG) is investigated. The dimension of the textile antenna is 120 mm × 120 mm, and especially the textile nature of fluid absorption makes the antenna gain instability under humid environment. In [8], a single band (2.45 GHz) monopole antenna integrated with a Jerusalem Cross AMC ground plane is studied. This kind of antenna can be expanded to multi-band for wide-range applications. [1-20].

Rapid developments have been taking place in the wireless communication field to fulfil the needs of the high data rates with compact modules. Antenna design is shifting towards multiband operations with high gain and large bandwidth to cater to the needs of modern communication systems [21-34]. Metamaterials are the art and heart of such antennas, whose existence in the design marking is significant with tremendous applications [15-20]. Compact antenna design for multiband applications and making it most suitable for targeted bands with greater performance characteristics is the challenging job for the researchers. Metamaterial structures are exhibiting quasi static resonant frequencies at wave lengths which are smaller than the guided wavelengths. Single split ring cell metamaterials, double split ring cell metamaterials and complementary split ring resonators are widely used structures

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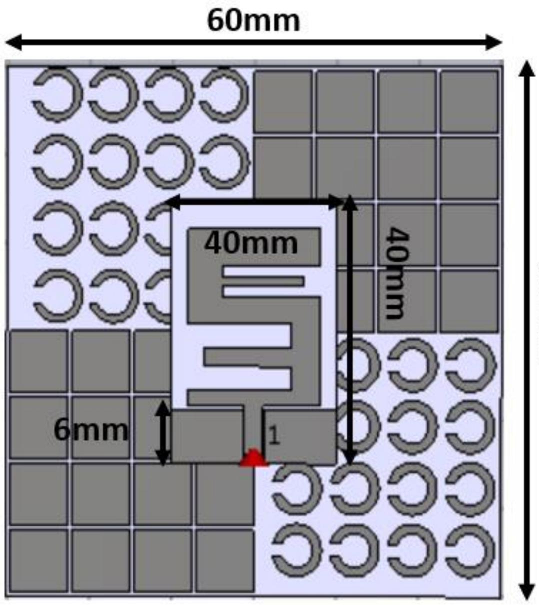
for attaining the negative permittivity or negative permeability and negative refractive index [35-40].

In most of the biomedical applications, wearable antennas are used. For an athlete and for old aged people, wearable antennas can be used. Light in weight, low cost, almost zero maintenance and no installation procedure are some of the required features of the wearable antennas [41]. SAR is the value which describes how much power absorbed in biological tissue when the Body is exposed to electromagnetic radiation. SAR values increase as the conductivity of human body tissues increases and usually decrease as the relative permittivity of human body tissues increase. The effect of the dielectric values of human body on SAR depends on orientation of the patch on the human body and frequency [42].

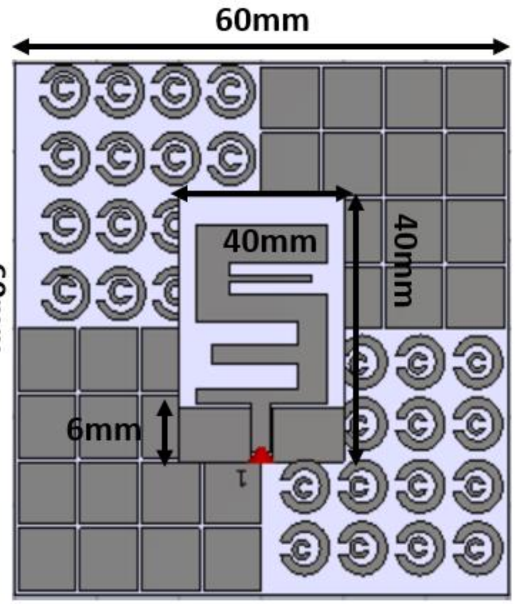
The paper is aimed to analyze the performance of the antenna in terms of SAR, reflection coefficient, Gain, radiation pattern when the antenna is placed on a human body, considering all practical cases like bending of the body parts etc.

2. Antenna Design:

SSRR and DSRR mainly consist of single loop and double loop which exhibits negative permittivity and negative permeability of the unit cell which improves the performance value of the antenna in terms of return loss, gain, SAR values. Fig 1(a) shows the s-shaped antenna on EBG structure. The EBG structure consists of check board shaped metal separations with metamaterial inspiration. The circular conducting structures are modeled into single split ring resonators and arranged as shown in the Figure 1(a). The Fig 1(b) shows double split ring resonators in the place of single split ring resonators. The design of SSRR and DSRR is done using FEM based tool and the metamaterial behavior is analyzed with unit cell analysis. Point type feeding technique is used for the proposed antenna.



(a)



(b)

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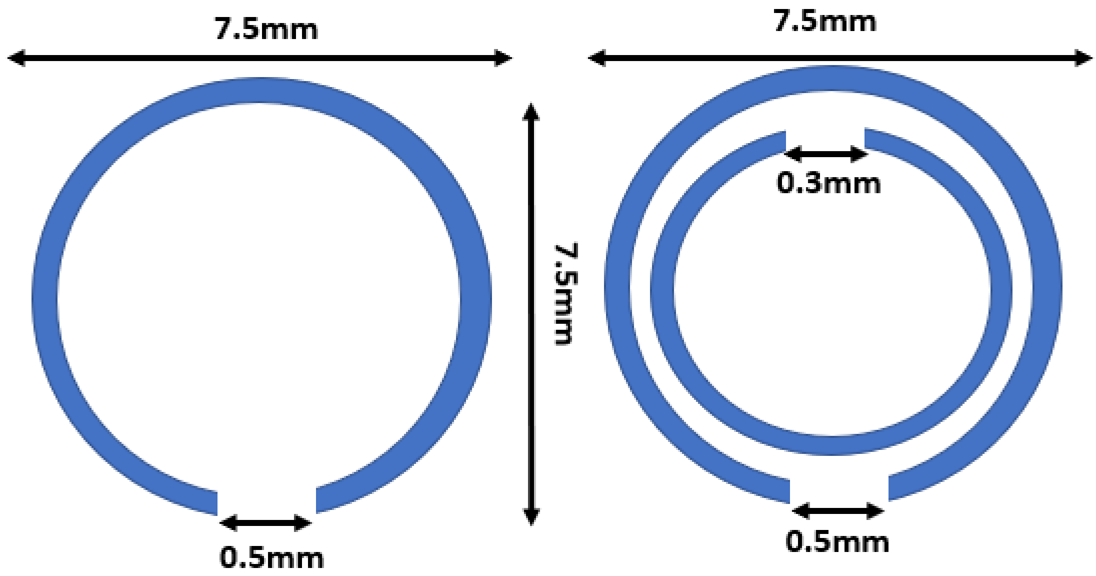

(c) (d)

Fig 1. Proposed Antenna Models, (a) Antenna Model 1 with SSRR, (b) Antenna Model 2 with DSRR, (c) SRR and (d) DSRR

The design equations are given for calculating the total capacitance, inductance and the resonant frequency.

The total capacitance of the SRR can be calculated by

$$c_t = \frac{1}{c_s + c_g + c_c}$$

----- (1)

Inductance in the loop of the Circular SRR is calculated by

$$L = \mu_0 r(\log(\frac{2r}{w}) + 0.9 + 0.2(\frac{w}{2r})^2$$

----- (2)

Where r is the radius of the circle and w is the gap between the ring

The resonant frequency of the SRR is calculated by

$$w_0 = \frac{1}{\sqrt{(L_S + 4L_M)(C_S + C_C + C_G)}}$$

----- (3)

where L_S = Self Inductance, L_M = Mutual Inductance, C_S = Surface Capacitance, C_C = Coupling capacitance, C_G = Gap Capacitance.

Table 1. Dimensions of the proposed antenna

Parameters	Dimensions(mm)
Patch length	39
Patch width	40
CPW width	40
CPW length	6

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EBG Square unit cell width	7.5
EBG Square unit cell length	7.5
EBG length	60
EBG width	60

3. Result and Analysis:

3.1 Reflection coefficient

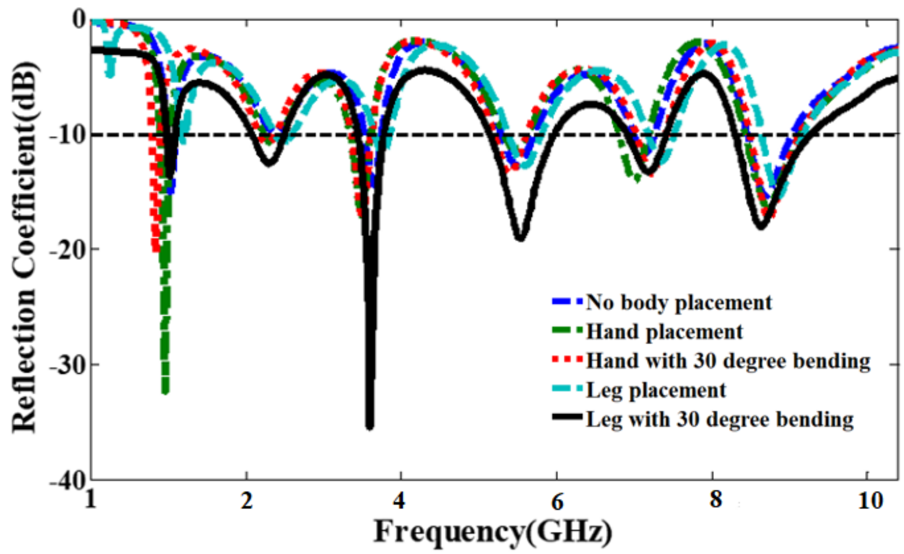

Fig.2 Measured Reflection coefficient vs Resonating frequency of Single SRR EBG antenna

The fig 2 shows a reflection coefficient value of single SRR EBG antenna at various conditions in which the antenna with a bending of 30 degree on leg stating the minimum reflection coefficient value and it was observed that antenna having minimum reflection coefficient value of -32dB at a frequency of 1.7GHz which was used for GPS application, Similarly, at a frequency of 4.9 GHz, it was having a reflection coefficient value of -37dB which was used for WBAN applications. Later, at a frequency of 6.3 GHz, it was having a reflection coefficient value of -19dB which was used for wireless applications. Finally, at a frequency of 8.1 and 8.5 GHz, it was having a reflection coefficient value of -12dB and -18dB which was used for satellite applications

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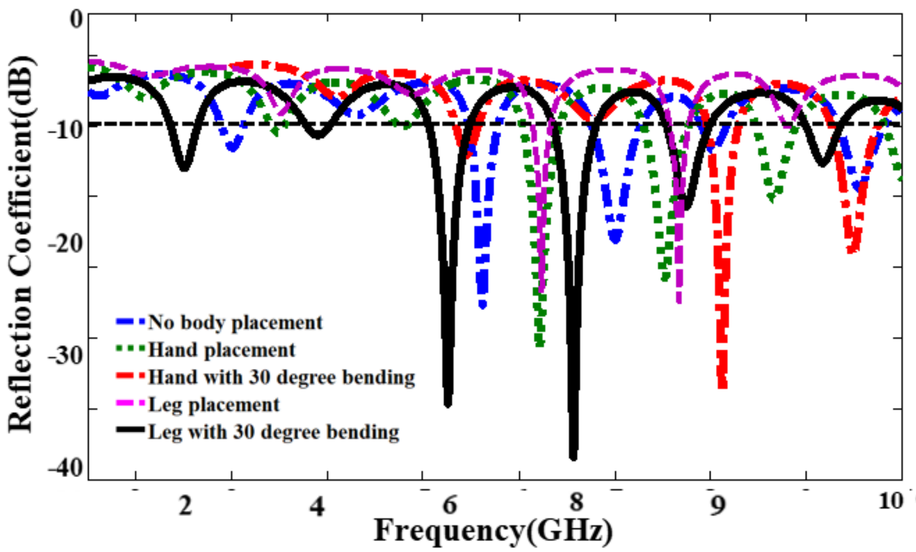
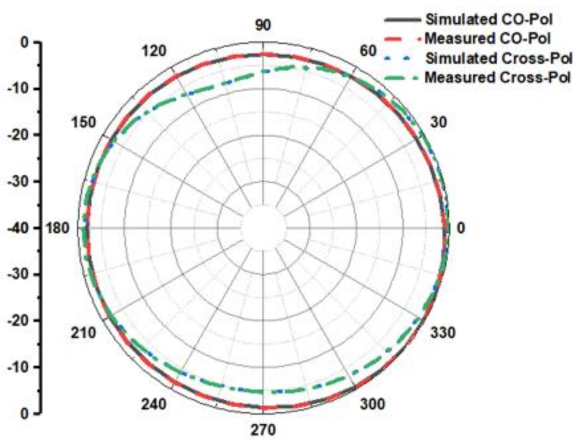


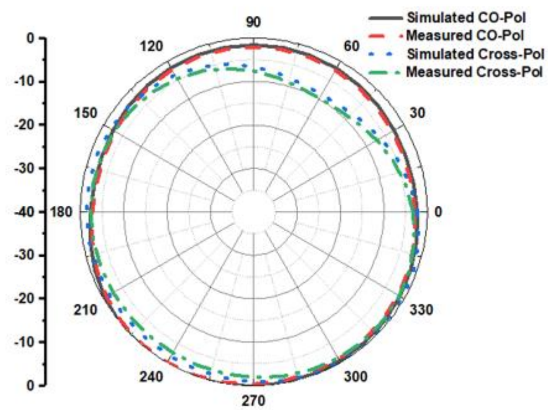
Fig.3 Measured Reflection coefficient vs Resonating frequency of Double SRR EBG antenna

The fig 3 shows reflection coefficient of double SRR EBG antenna at various conditions in which the antenna and leg bend with the inclination of 30 degree stating the minimum reflection coefficient value and it was observed that antenna was having minimum reflection coefficient value of -14dB at a frequency of 2.4GHz which was used for WLAN application. Similarly, at a frequency of 5.8 GHz, it was having a reflection coefficient value of -34dB which was used for ISM applications. Later, at a frequency of 8 GHz, it was having a reflection coefficient value of -39dB which was used for radar applications. Finally, at a frequency of 9 and 9.5 GHz, it was having reflection coefficient value of -19dB and -13dB which was used for satellite applications.

3.2 Radiation patterns



(a)At a frequency of 2.4GHz



(b) At a frequency of 5.8GHz

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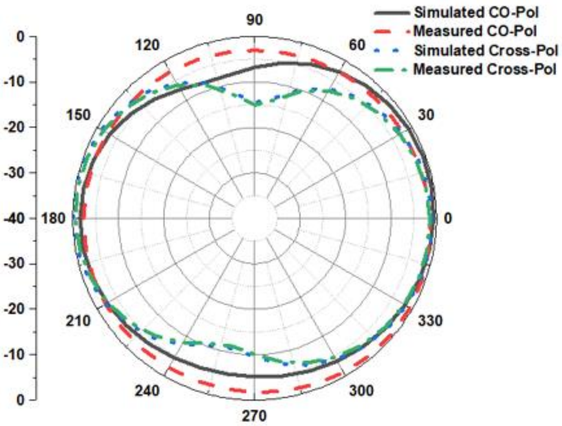
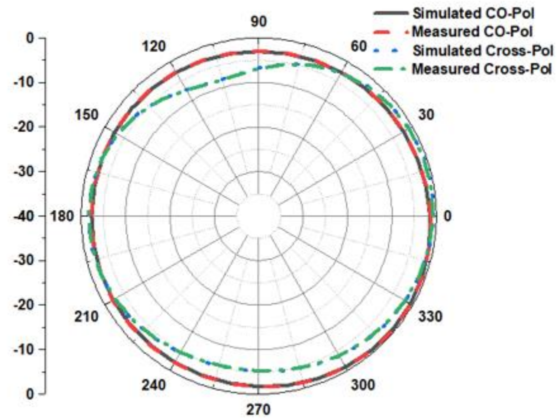
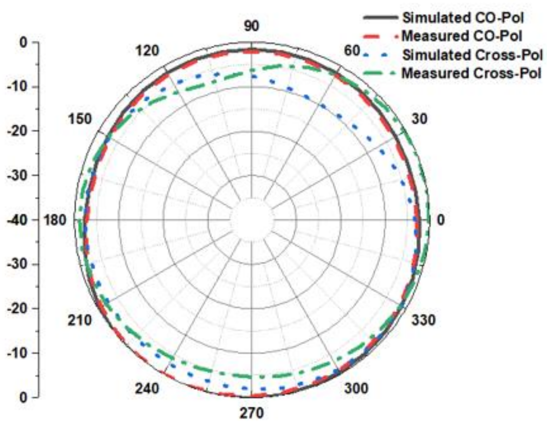


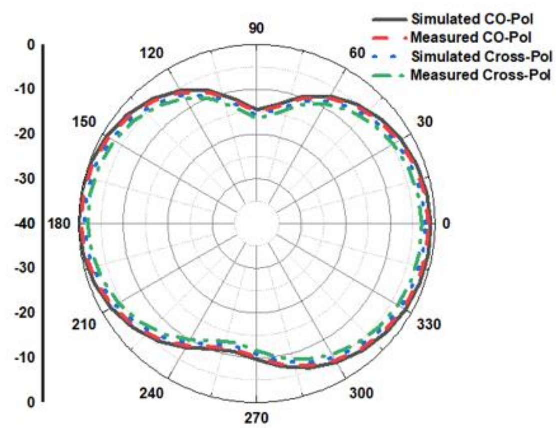
(c) At a frequency of 8GHz



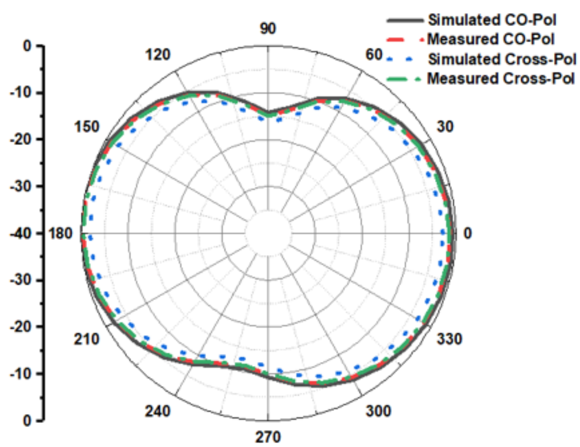
(d) At a frequency of 9GHz



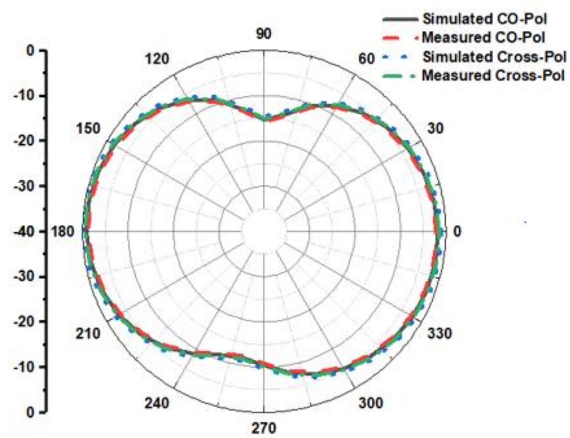
(e) At a frequency of 9.5GHz



(f) At a frequency of 1.7GHz



(g) At a frequency of 4.9GHz



(h) At a frequency of 6.3GHz

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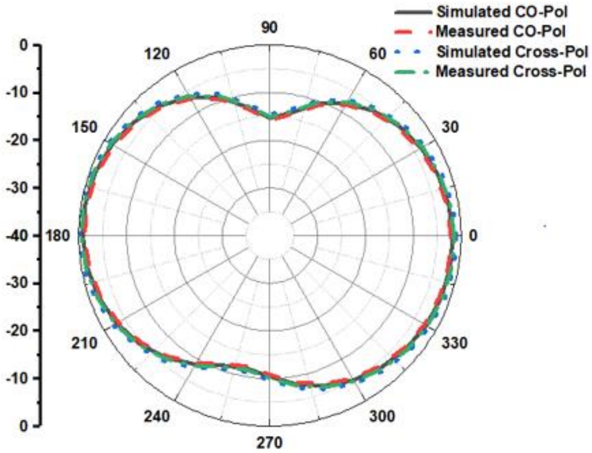
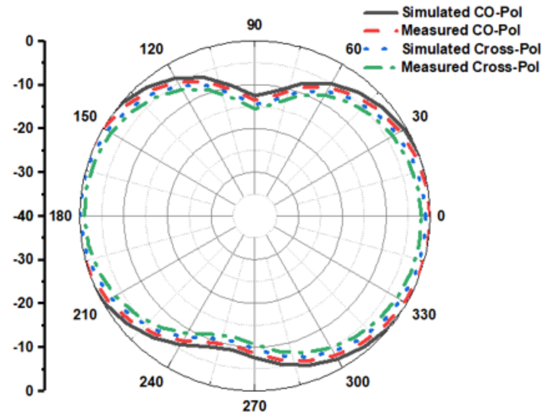


(i) At a frequency of 8.1GHz



(j) At a frequency of 8.9GHz

Fig 4. 2D-Radiation patterns of(a-e) Double SRR EBG and(f-j) Single SRR EBG antenna

The measured radiation patterns of the proposed double SRR are presented in Fig.4. The farfeild charatersitics of co and cross polarizations at corresponding resonant frequencies are given. The presented radiation charactersistics are in semi omni directional and omni directional for both co-polar and cross polar. The patterns are bidirectional in broad side direction and omni directional for co-polar. It is observed that the cros polar levels are 20 dB less than the Co-polar levels. Similarly the cross polar is omni directional and copular was like a semi omni directional and slightly converted to bidirectional shape. The patterns were at 8GHz and 9GHz and were almost like the previous bands, but the co-polar and cross polars were almost same with respect to the planes. The cross polar levels are -15dB less than co-polar level. Omni directional patterns were observed in the end fire direction for co polar and Omni directional pattern was observed for cross-polar.

3.3 Surface current distribution

Fig.5 states the surface current distribution of single SRR and double SRR EBG antenna. Fig.5(a) states the surface current distribution of double SRR EBG antenna at an operating frequency 2.4GHz with a value of 77.4 A/m which having maximum intensity across the patch. Secondly, fig .5(b) states the surface current distribution of double SRR EBG antenna at an operating frequency 5.8GHz with a value of 85.1 A/m which having maximum intensity across the patch and across the circular rings. Thirdly, fig .5(c) states the surface current distribution of double SRR EBG antenna at an operating frequency 8GHz with a value of 93.5 A/m which having maximum intensity across the patch and across the circular rings. Fourthly, fig .5(d) states the surface current distribution of double SRR EBG antenna at an operating frequency 9GHz with a value of 107/m which having maximum intensity across the patch and across the circular rings. Finally, fig .5(e) states the surface current distribution of double SRR EBG antenna at an operating frequency 9.5GHz with a value of 137 A/m which having maximum intensity across the patch and across the circular rings.

Similarly, Fig.5(f) states the surface current distribution of single SRR EBG antenna at an operating frequency 1.7GHz with a value of 69.1 A/m which having maximum intensity across the patch. Secondly, fig .5(g) states the surface current distribution of single SRR EBG antenna at an operating frequency 4.9GHz with a value of 78.3 A/m which having maximum intensity across the patch and across the circular rings. Thirdly, fig .5(h) states the surface current distribution of double SRR EBG antenna at an operating frequency 6.3GHz with a value of 79.6 A/m which having maximum intensity across the patch and across the circular rings. Fourthly, fig .5(i) states the surface current distribution of double SRR EBG antenna at an operating frequency 8.1GHz with a value of 80.6/m which having maximum intensity across the patch and across the circular rings. Finally, fig .5(j) states the surface current distribution of double SRR EBG antenna at an operating frequency 8.9GHz with a value of 81.2

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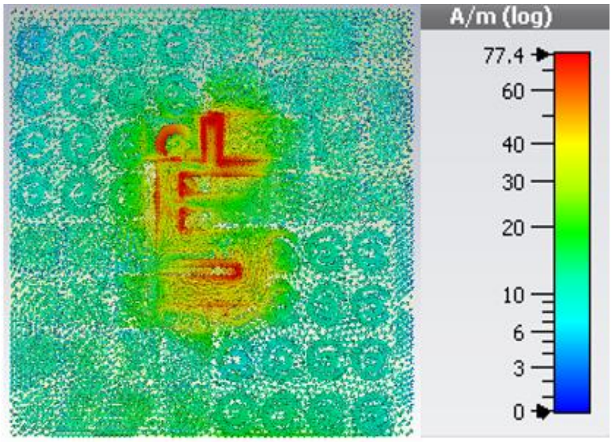
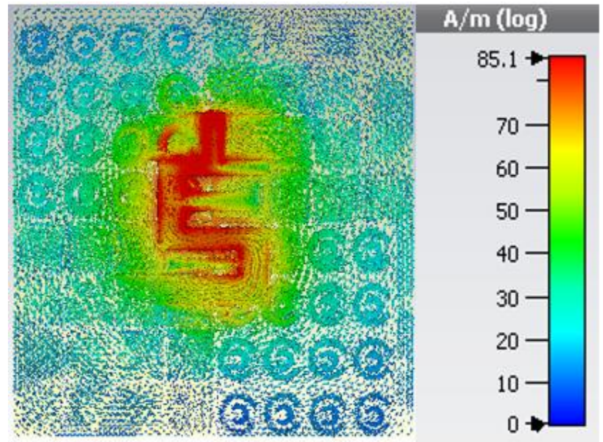
A/m which having maximum intensity across the patch and across the circular rings.

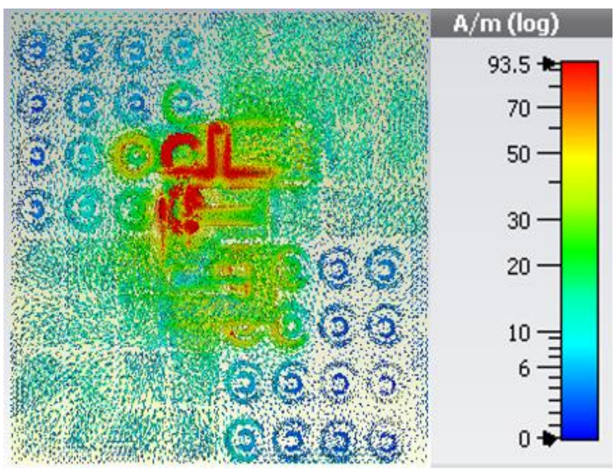
Finally, from the fig 5 (a-j) it is observed that the double SRR EBG antenna having high current distribution than the single SRR EBG antenna as the frequency shift from right to left.



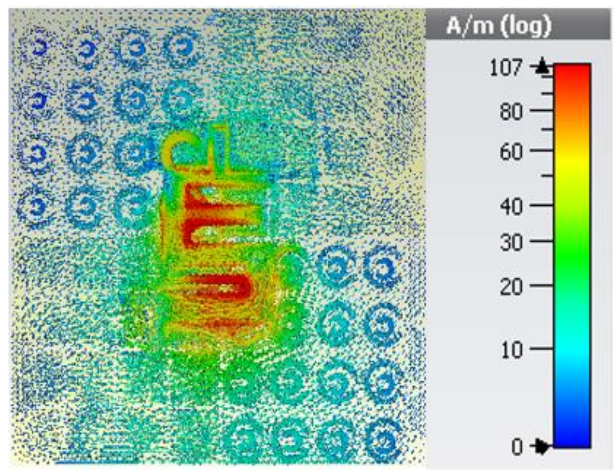
(a) At a frequency of 2.4GHz



(b) At a frequency of 5.8GHz



(c) At a frequency of 8GHz



(d) At a frequency of 9GHz

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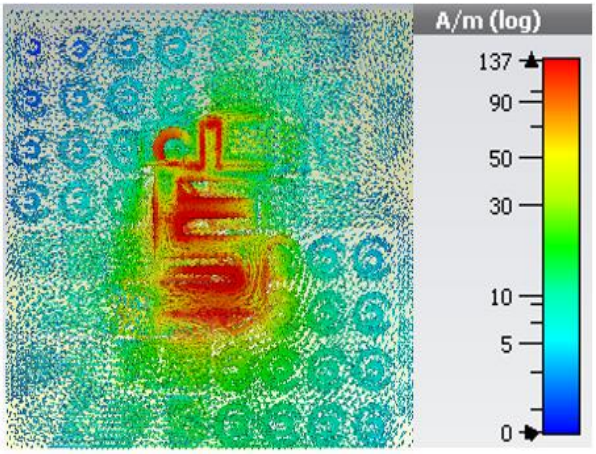
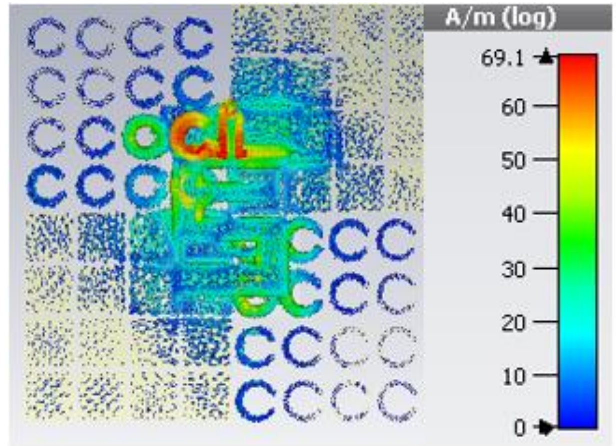
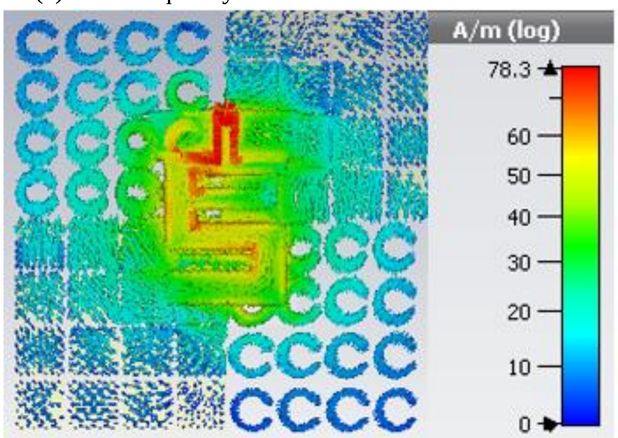


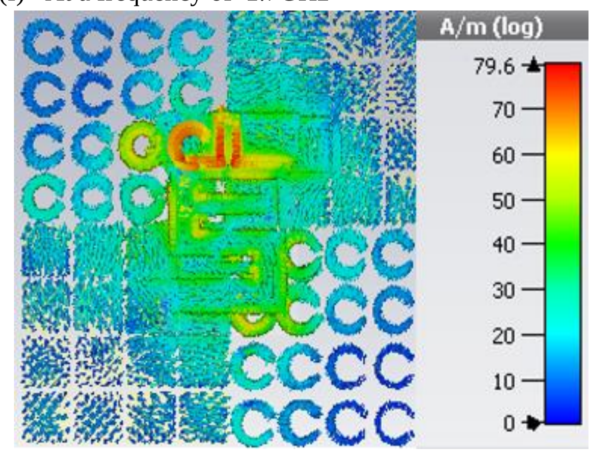
(e) At a frequency of 9.5GHz



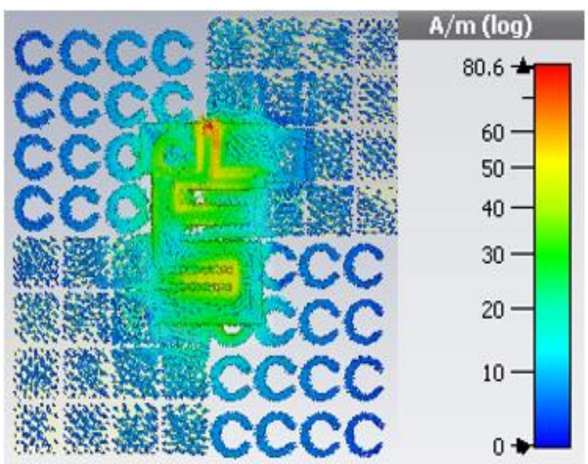
(f) At a frequency of 1.7GHz



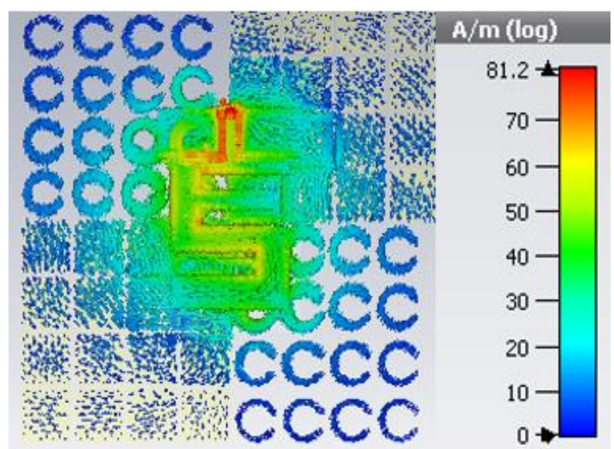
(g) At a frequency of 4.9GHz



(h) At a frequency of 6.3GHz



(i) At a frequency of 8.1GHz



(j) At a frequency of 8.9GHz

Fig 5. Surface current distribution of (a-e) Double SRR EBG and (f-j) Single SRR EBG antenna

3.4 Phase velocity and Group delay

The phase velocity is given by

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$$v_p = \frac{\omega}{k}$$

----- (4)

The group velocity is given by

$$v_g = \frac{d\omega}{dk} = v_p + k\frac{dv_p}{dk}$$

----- (5)

The group delay is given by

$$\tau_g = \frac{1}{v_g}$$

----- (6)

From equation 6 it was observed that phase velocity is inversely proportional to the group delay as phase velocity increases the group delay value decreases. Minimum group delay makes maximum stability to the device.

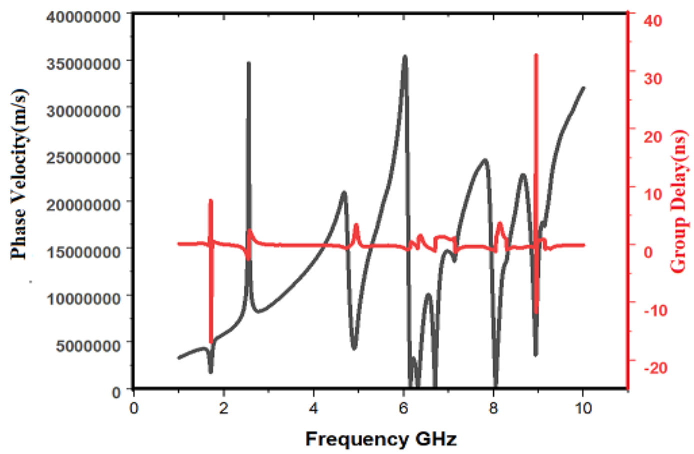

Fig 6. Frequency Vs Phase velocity and Group delay

Fig.6 states the phase velocity and group delay value of double SRR EBG antenna at various operating frequency. As the frequency shifts from right to left there is a minor non-linearity in the phase velocity. Similarly, as the group delay value of the proposed antenna having minimum which are in terms of nano seconds.

3.5 Specific Absorption Rate

The human body also has some effects on the antenna as it very closely located to the human body. The human body is lossy and disturbs the communication link between antenna and outside world. The human body impact on the antenna is of different types. The human body induced gain is the ratio of gains (in dB) between body-worn antenna and that of the antenna in free space. Human body has various tissues with various dielectric properties. Also the electrical properties on different frequencies have different values, the gain of the antenna is affected. So the gain of the wearable antenna differs from that of a normal antenna. The human body-worn efficiency is the ratio of total radiated power when antenna is worn in the body to the total radiated power in free space isolation. The overall power loss in a human body can be represented by this. The input impedance of the antenna will be low when the user is too close to the antenna. Also, the input impedance is dependent on the moisture conditions of the human body. And the position of the placement of the antenna.

According to the set worldwide rules, most extreme suitable SAR to protect the human security more than 10 g contiguous tissue is under 2 W/kg. The rules given by the IEEE C95-1-2005 norms say the 10 g of the tissue looking like cube shape should be under 2 W/kg. Net input power set to the antenna is 1w. For the calculation of specific absorption rate formula is given by

$$SAR = \int \frac{\sigma(r)\left|E(r)\right|^2}{\rho(r)}dr \quad (1)$$

Where σ is electric conductivity, ρ is sample density and E= RMS electric field of the sample.

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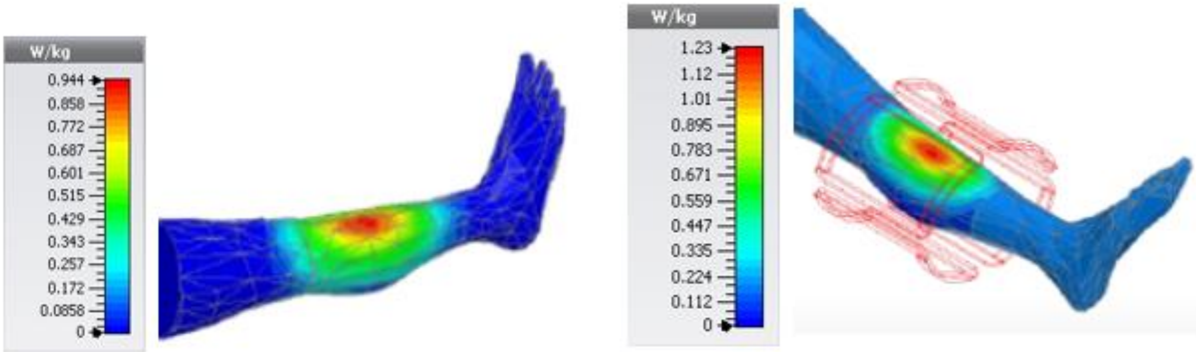

(a) (b)

Fig 7. Specific absorption rate of proposed Double SRR EBG antenna (a) without bending and (b) with 30^0 bending

Fig.7 states the SAR of the proposed double SRR EBG antenna with and without inclination. We have used SRR EBG technique for the proposed antenna in order to reduce the SAR. Initially fig 7(a) state the SAR of the double SRR EBG antenna on the leg without inclination having the value of 0.944W/kg. Similarly, Fig 7(b) states the SAR of the double SRR EBG antenna on the leg with an inclination of 30 degree. Hear both leg and antenna is inclined with an angle of 30 degree, the SAR rate of the proposed antenna with a value of 1.23 W/Kg at an operating frequency of 5.8Ghz. As the inclination increases the value of SAR decreases. Lower the SAR lower the radiations effects which were within the threshold rate as per IEEE standards.

3.6 Prototype model of Double SRR antenna with leg placement

(a)

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(b) (c)

Fig 8. Prototype model of proposed double SRR EBG antenna on leg (a) without and (b) with inclination of 30 deg and (c) zoom section of the proposed antenna on leg

Fig.8 states the placement of the proposed antenna on the leg. Initially, fig 8(a) states the placement of the proposed antenna on leg without inclination of both leg and antenna. Secondly, fig 8(b) states the placement of the proposed antenna on leg with the inclination of 30 degree. Finally, fi 8(c) states the zoom section of the antenna proposed antenna on the leg.

Table 2. Comparison of proposed antenna with previous work

Ref	Size(λ_0)	Frequency range (GHz)	Peak gain(dbi)	SAR(W/kg)	Applications
43	$0.511\lambda_0*0.7\lambda_0*0.005\lambda_0$	1.78–1.98,2.38–2.505	10.92,5.08	5.77,6.62	GS, ISM
44	$0.25\lambda_0*0.375\lambda_0*0.026\lambda_0$	2.4–2.485 5.725–5.875	3.4,2.5	-	ISM
45	$0.42\lambda_0*0.44\lambda_0*0.009\lambda_0$	0.38–0.47,2.27–2.57	12.4,16.1	5.42,4.70	MICS and ISM
46	$0.33\lambda_0*0.33\lambda_0*0.035\lambda_0$	0.4–0.405,2.35–2.57	1.2,8.9	0.05,1.13	MICS and ISM
47	$0.36\lambda_0*0.36\lambda_0*0.008\lambda_0$	1.54–1.62,2.67–2.87,3.33-3.46,5.24–5.42	5,7.2,3.8.3.7	0.2,0.6,0.3	GPS, Wi-Max and Wi-Fi
Proposed work	$0.2\lambda_0*0.24\lambda_0*0.08\lambda_0$	2.4,5.8,8,9&9.5	4.1,4.2,5.7,6.9& 7.02	0.944,1.23 at 5.8GHz	GPS, ISM, Radar and Satellite

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Conclusion:

This article presents an AMC based electromagnetic band-gap (EBG) antenna made of textile materials. The proposed wearable antenna works at IEEE standard communication applications operates at 2.4GHz, 5.8GHz, 9GHz and 9.5GHz frequency respectively. Considering the effects of single SRR and double SRR have differentiation in radiation characteristics, when the wearable antenna is placed on the human body. A comparative study is performed for the single SRR and double SRR to validate the EBG antenna. The wearable antenna achieves gain of 7.02dBi and with minimum absorption rate of 1.23W/Kg at 9.5GHzoperating frequency. The proposed EBG antenna is an excellent candidate for the GPS, ISM, RADAR and satellite applications with good gain and radiation characteristics. A prototype of the proposed EBG antenna is designed, fabricated and measured using ANRITSU-MS2037C combinational analyzer. The experiment results are matched with the simulated results.

5. References:

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