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Investigation on Specific Absorption Rate for Handset Antenna with Electromagnetic Band Gap structure Background

Anoob B, Unni C, S. Suresh Babu

Abstract— The Radio Frequency (RF) hazard due to the electromagnetic absorption in the human head is becoming a burning problem. The mobile phones and other personal communication services are the main sources of Electromagnetic Radiation. It is broadly accepted that mobile phones causes heating of the human organ exposed to their radiation and specifically the human head. The Specific absorption rate (SAR) of the mobile phone antenna gives an idea about amount of radiation absorbed by the human body. In this work a handset antenna is designed which is a monopole mender line configuration. A Double Spiral Electromagnetic Band Gap (EBG) structure were designed and implemented behind the antenna structure. Higher frequency bands are supported by both the meander line and the monopole since they acts as travelling-wave antennas at the high frequency bands. The high impedance surface property of the EBG structure is utilized here to reduce the radiation at the resonant frequency of the mobile band. . The proposed antenna with EBG structure supports ISM, WLAN, Bluetooth and Wi-MAX standards. The antenna exhibits certain features such compact size, the multiband operation including the low frequency bands, and the low SAR radiation. The simulations were carried out in CST Microwave studio.

Index Terms— **Electromagnetic band-gap (EBG). Industrial Scientific and Medical (ISM), Specific Absorption Rate (SAR), Wireless Local Area Network (WLAN).**

I. INTRODUCTION

With the rapid development of mobile communication technology, this has forced the worldwide mobile manufactures to design miniature multiband internal antennas which support various wireless services. Due to the continuous growth of mobile technology, the designers have started thinking about the mutual interaction between mobile phone antenna and the human body. Electromagnetic radiation from the mobile phone antenna is coupling to the human head and the radiation [3] is absorbed by the human head. In this scenario development of an antenna which is having some desirable features such as low Specific Absorption Rate (SAR) [14], [17], low profile, multiband operation, and light weight is a challenging task.

The electromagnetic absorption of a human body has become an important issue, as the government as the governments strictly limit it. Due to the extensive usage of mobile hand set, radiation from the mobile phones gives an increased attention. The electromagnetic absorption of human body can be evaluated by specific absorption rate which represents the time rate of microwave energy absorption inside the tissue, as follows: SAR= $(\sigma/2\rho)*E^2$. Where ρ and σ are the density (S/m) and electrical conductivity (kg/m^3) of the tissue, respectively, E is the internal induce electrical field (V/m). The SAR value is calculated as maximum of mass-averaged SAR. Different methods were proposed to reduce SAR [1] of the mobile phone antennas such as ferrite loading, auxiliary elements, EBG (Electromagnetic Band Gap) and metamaterials. In ferrite loading method ferrite layer is placed between the antenna and the human head which act as a protective layer. The disadvantage of this method is the use of such an expensive material with some special properties of permittivity and permeability to reduce SAR. In auxiliary antenna element an antenna element with a director or reflector is used. The disadvantage of this method is the use of extra antenna element will increase the size and cost. EBG and metamaterials are the two emerging technologies to reduce the SAR [18], [20] value of the antenna. In [19], a PIFA in mobile phone close to human tissue was analyzed. It is noted that the resonant frequency decreased and resistive losses increased when the antenna was interfered with by the human hand.

In [2], [4], [14]-[18] discuss about different methods to reduce the size and cost of the antenna in conjunction with its increasing services provided by the antenna. Ang *et al*.[7] describes about Quad-band antennas that cover the Industrial, Scientific, and Medical(ISM) 2450, GSM 900,DCS 1800,PCS 1900. In [8] UMTS 2100 band is used

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which replace the ISM 2450 band covered in [7]. But this antenna is having double size as that of antenna in [7]. Tzortzakakis *et al.* [9], Ku *et al.* [10] and Tang *et al.* [11] introduced different compact antennas with considerable reduction in size compared to [6]. Zhang *et al.* [12] introduced another type of inverted F antenna with a folded loop that covers the heptaband: GSM850, GSM900, GSM1800, GSM1900, UMTS, GPS, and wireless local area network (WLAN) (at 6-dB bandwidth) with slight size increase of the proposed antenna in [11]. With the development of LTE Bhatti *et al.* [6] introduced a compact antenna that covers the LTE 700 band. Young *et al.* [13] introduced an octaband antenna with more compact size of 46x7x11mm^3. The antenna operating bands are the LTE 700, DCS 1800, PCS 1900, GSM 850, GSM 900, WCDMA 2100, LTE 2300, and the LTE 2500 bands. Young *et al.* [13] has a compact size and covers octabands of the operating frequencies.

This work proposes a mobile phone printed antenna consisting of a monopole, meander line and an EBG structure embedded on the bottom layer of the substrate for reducing the SAR value. The antenna at -6 dB has a band width extending from 1.035 to 1.064 GHz and from 2.28 to 3 GHz. So it support following operating bands: GSM 850, GSM 900, DCS 1800, PCS 1900, UMTS 2100, ISM 2450, most LTE bands, WiMAX (2.3–2.4, 2.5–2.69 GHz), and WLAN (2.4–2.5 GHz), with a size of 27x21x0.8 mm^3. The organization of paper is as follows: Section II explains the design of the antenna and describes about the antenna performance. Section III shows the EBG implemented antenna design. Section IV discusses the result and analysis. Section V, the SAR results are introduced. Finally, Section VI presents the conclusions for this research.

II. ANTENNA DESIGN

The proposed antenna is a planar printed micro strip antenna [5] with a compact dimension of 27x21x0.8 mm^3 before applying the EBG structure is shown in Fig. 1(a). The antenna consists of a monopole and a mender line. The monopole antenna is an inverted L shape structure. The length of the monopole is a quarter-wavelength at 2350 MHz and is operating in the band of 1700-3000 MHz. The dimension of the monopole antenna is 18x6 mm^2. The antenna is designed over FR4 substrate (ε_r) with 0.8 mm thickness and loss tangent of 0.025. The meander line increases the path over which the surface current flows, and that eventually results in lowering the resonant frequency. The length of the meander line is optimized to resonate at 900 MHz (860–1020 MHz). The length of the meander line is 111mm. The meander line operates also at higher frequencies as a travelling wave antenna. This monopole mender line combination contributes to operate from 1.039- 3 GHz. A ground plane having a dimension of 25x6mm^2 area is chosen to be coplanar with the radiating elements. The length of the ground plane has a negligible effect on the performance.

To enhance the bandwidth of the micro strip antenna, different techniques have been used. The factors affecting the bandwidth of micro strip patch antenna are the shape of the radiator, the feeding scheme and the substrate. Height and dielectric constant of the substrate affects the antenna impedance bandwidth. However, the improvement in the bandwidth is quite limited. The different feeding methods are also used for enhancing the bandwidth of micro strip patch antenna. Coplanar waveguide feeding is one of them. It has several advantages compared to other feeding method such as low radiation loss, less dispersion, uniplanar configuration and easy mounting of lumped elements or active devices without drilling the via hole as for the micro strip line. In this work the CPW fed micro strip antenna is considered. The ground plane is in coplanar with the monopole meander line combination. So there is no ground plane in the lower side of the substrate. The geometry of the antenna is shown in Fig. 1(a).

III. EBG IMPLIMENTED ANTENNA

In this work a Double spiral shaped EBG structure is fabricated below the substrate. These EBG structures interact with the electromagnetic waves and those exhibits amazing properties such as frequency pass bands, stop bands or band-gaps. Electromagnetic band gap structures are defined as artificial periodic (or sometimes non-periodic) objects that prevent/assist the propagation of electromagnetic waves in a specified band of frequency for all incident angles and all polarization states. EBG structures are periodic arrangement of dielectric materials and metallic conductors. EBG structures normally classified into three groups: (1) Three dimensional volumetric structures, (2) two-dimensional planar surfaces, and (3) one-dimensional transmission lines.

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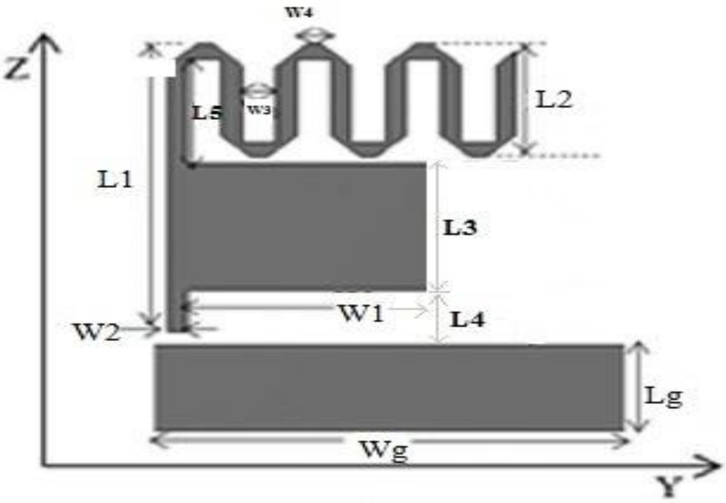

Fig. 1(a) Geometry of the proposed antenna

The planar electromagnetic band gap (EBG) structure exhibits some distinctive electromagnetic properties with respect to incident electromagnetic waves [20]. The operation mechanism of this EBG structure can be explained using an effective medium model with equivalent lumped LC elements. The resonance frequency of the equivalent lumped LC element is $f=1/2\pi\sqrt{LC}$. At low frequencies, the impedance is inductive and supports TM surface waves. At high frequencies it becomes capacitive at and TE surface waves are supported. Near the resonance frequency high impedance is obtained and the EBG does not support any surface waves, resulting in a frequency band gap. The high surface impedance also ensures that the reflected plane wave should not have phase reversal that occurs on a perfect electric conductor (PEC).

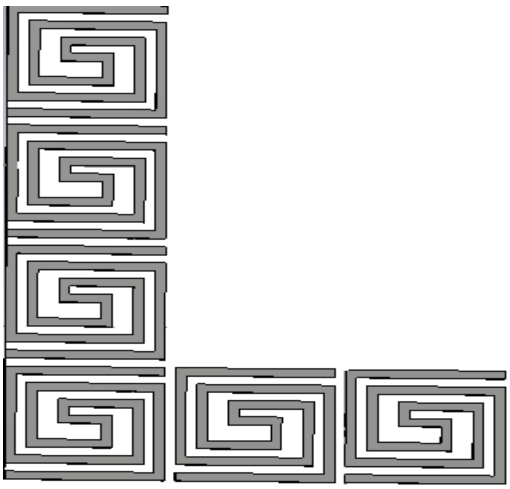

Fig. 1(b) EBG structure

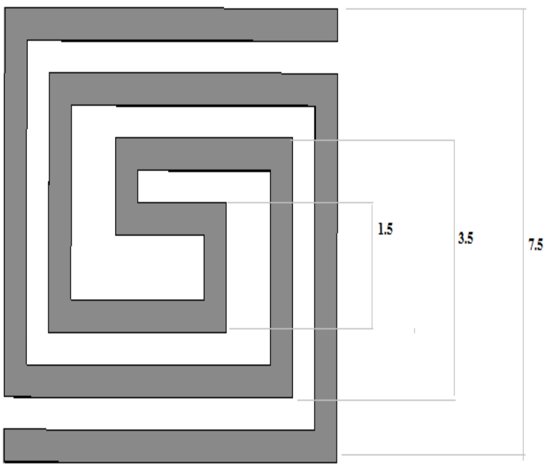

Fig. 1(c) unit EBG cell

The characteristics of the EBG structure shown in Fig. 1(b) and (c) are tested by a micro strip line over one column of the EBG unit with a 0.5-mm gap. The proposed EBG configuration reveals stop bands at most of the mobile applications bands. This means that the structure has high surface impedance within these bands. The EBG structure is positioned perpendicular to the two antennas, the monopole, and the meander line. The EBG structure acts as an artificial magnetic conductor (AMC), within its stop bands. This AMC enhances the radiation in the direction opposite to the position of the human body. So, it reduces the SAR absorbed within the human tissues.

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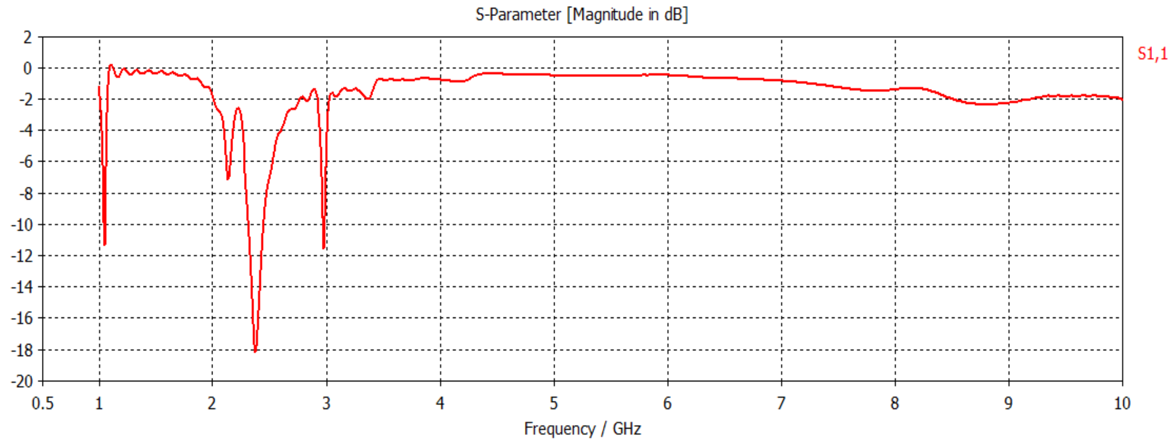

Fig 2(a) Return loss of the antenna without EBG

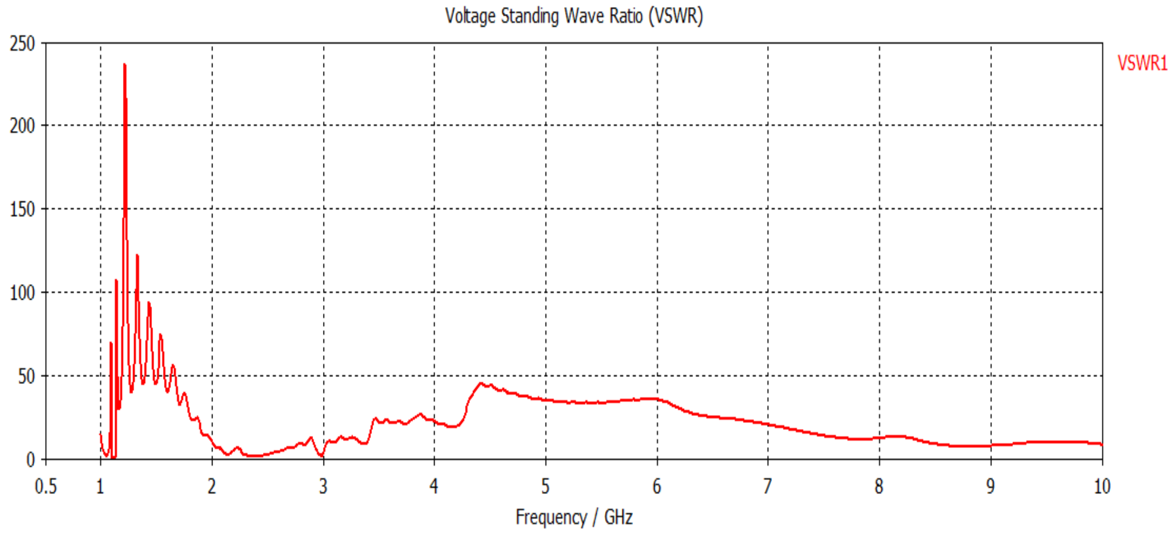

Fig. 2(b) VSWR of the antenna without EBG

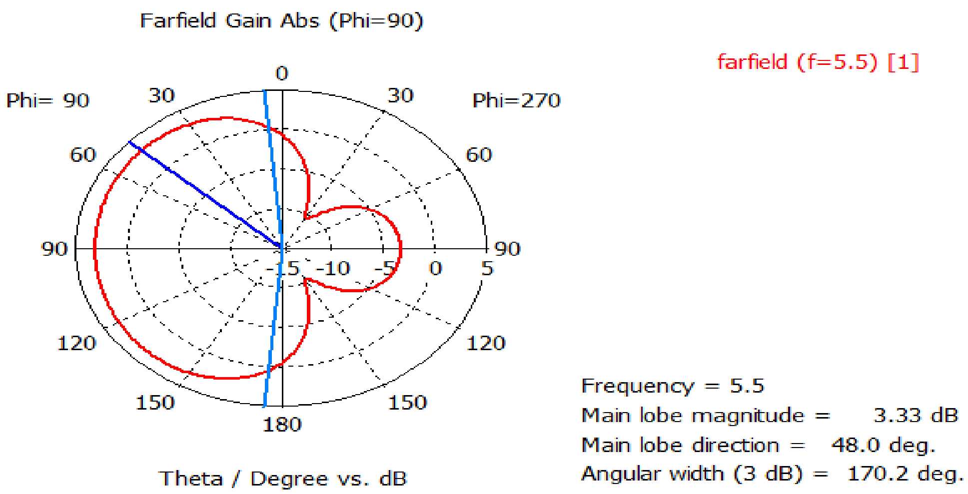

Fig. 2(c) Polar plot of the antenna without EBG

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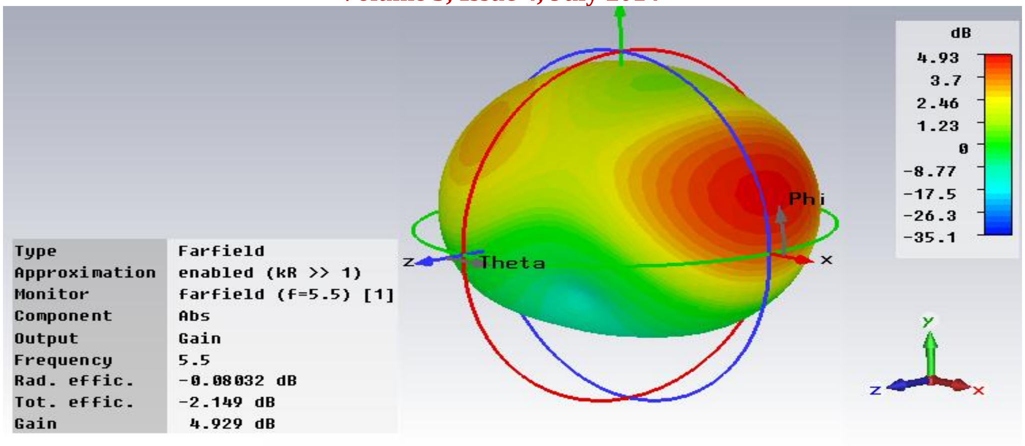

Fig. 2(d) 3D radiation pattern of the antenna without EBG

IV. RESULTS AND ANALYSIS

Simulated return loss of the proposed antenna [5] without EBG structure is shown the Fig. 2(a). From the Fig. 2(a) it is clear that the antenna radiates in mobile band width as well as it support Wi-Fi and Wi-Max. From the figure it is clear that the antenna is having a gain of -11.05dB at a resonating frequency of 1.054 GHz having a band width of 25 MHz. By taking -6dB as reference level three operating bands were obtained having resonance frequency of 1.054, 2.395, 2.954 GHz. The proposed antenna has a broad bandwidth covering the required bandwidth of IMT standard for 2300-2400MHz, 2700-2900MHz. WLAN for 2400-2484MHz. Bluetooth for 2400-2500MHz and Wi-MAX standard for 2500-2690MHz. Fig.2(b) shows the simulation of the voltage standing wave ratio (VSWR) for the proposed antenna. The VSWR for the proposed antenna is very close to 1 for frequencies of 1.054, 2.395, 2.954 GHz which means that antenna is perfectly matched and there is no mismatch loss. The 3D Radiation pattern for the proposed antenna is shown in Fig.2 (d). Radiation pattern plot shows the relative strength of the radiated field in different direction from the antenna at particular distance. From the pattern it is clear that the proposed antenna is having again of 4.93dB.

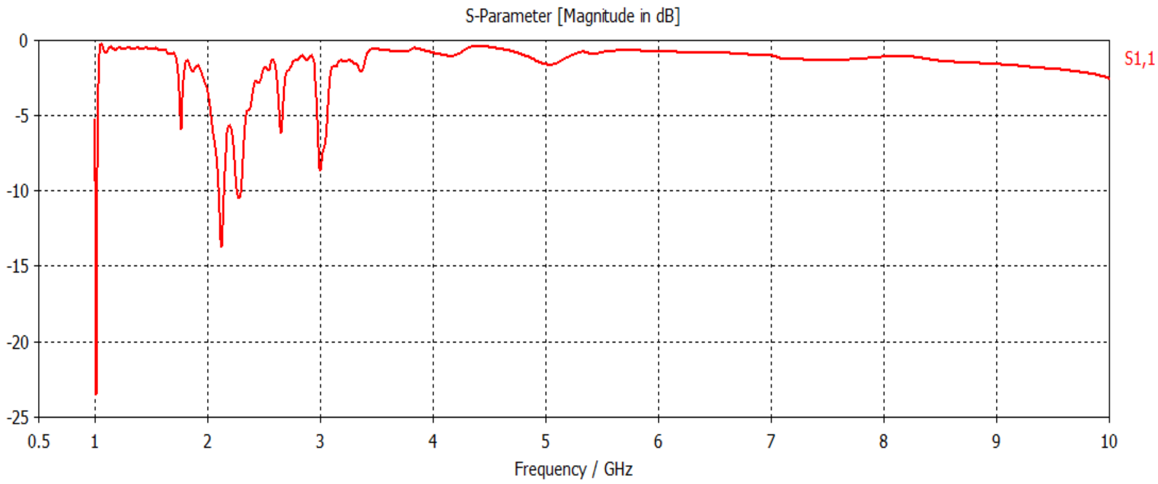

Fig. 3(a) return loss of the antenna with EBG

Fig. 2(c) shows the polar plot of the radiation pattern for phi=90^0. The polar pattern clearly shows a back lobe which is the back radiation from the antenna. This radiation is absorbed by the human head. With the use of EBG structure this back radiation should be completely removed from the pattern.

The polar plot of the proposed antenna shows the main lob having a gain of 3.33dB in a direction of 48^0.

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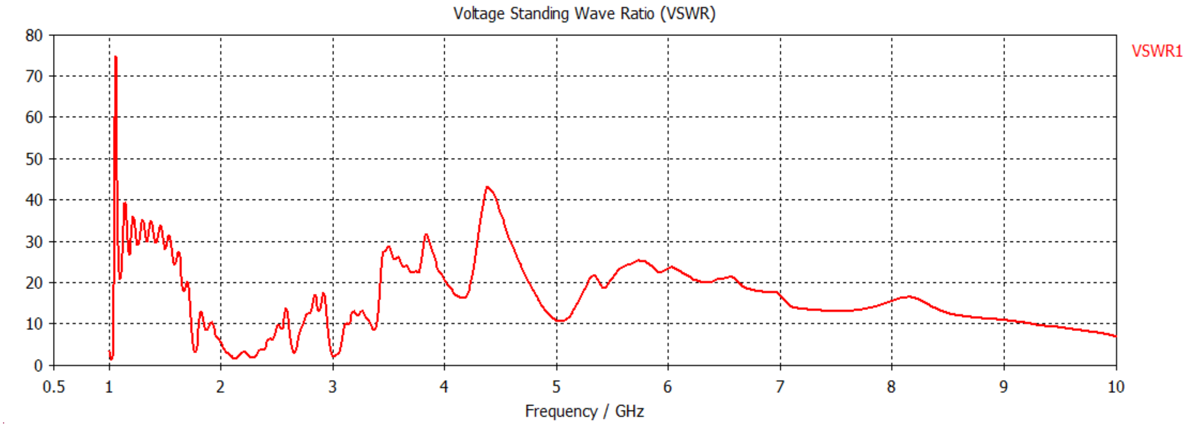

Fig. 3(b) VSWR of the antenna with EBG

Simulated return loss of the proposed antenna with EBG structure is shown the Fig. 3(a). From the Fig. 3(a) it is clear that the antenna support the mobile band width as well as Wi-Fi and Wi-Max as like proposed antenna without EBG.

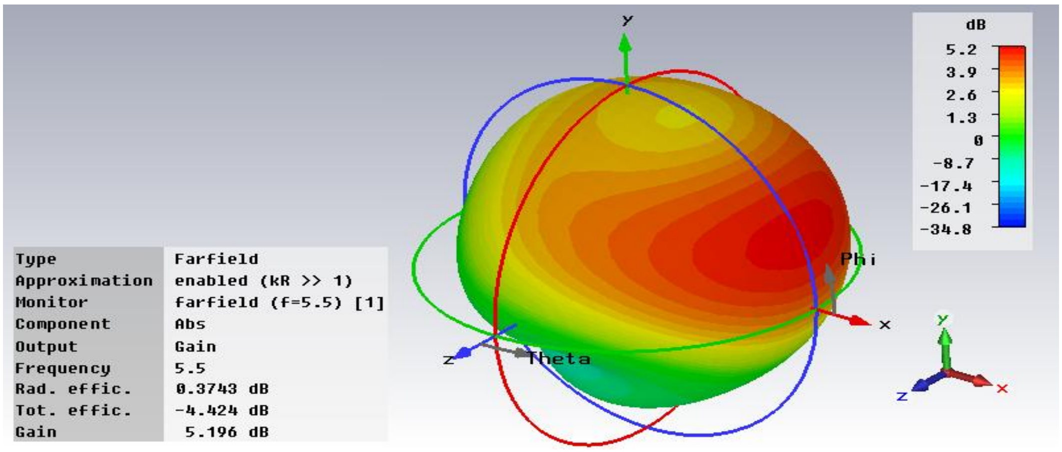

Fig. 3(c) 3D radiation pattern of the antenna with Double spiral EBG

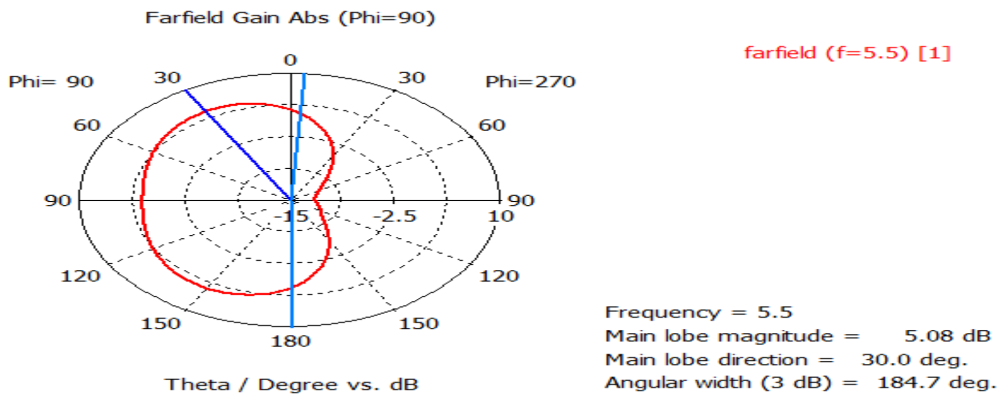

Fig. 3(d) polar plot of the antenna with Double spiral EBG

The figure shows that the antenna is having a gain of -23dB at a resonating frequency of 1.018 GHz having a band width of 25 MHz. Both these values are double as that of the antenna without EBG. The return loss graph gives a clear idea that with the implementation of the EBG structure the antenna gain is increased at mobile band and the antenna is radiating in a direction opposite to the human body. By taking -6dB as reference level three operating bands were obtained having resonance frequency of 1.018, 2.395, 2.954 GHz. The proposed antenna has a broad

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bandwidth covering the required bandwidth of IMT standard for 2300-2400MHz, 2700-2900MHz. WLAN for 2400-2484MHz. Bluetooth for 2400-2500MHz and Wi-MAX standard for 2500-2690MHz. Fig. 3(b) shows the simulation of the voltage standing wave ratio (VSWR) for the proposed antenna The VSWR for the proposed antenna is very close to 1 for frequencies of 1.018, 2.395, 2.954 GHz which means that antenna is perfectly matched and there is no mismatch loss. The 3D Radiation pattern for the proposed antenna is shown in Fig. 3(c). From the pattern it is clear that the proposed antenna is having again of 5.2dB.

Fig. 3(d) shows the polar plot of the radiation pattern for phi=90^0. From the polar pattern it is clearly shows that the back lobe is almost removed. This means that less radiation is absorbed by the human head and so the SAR value can be reduced. With the use of EBG structure the back radiation is almost removed from the pattern. The polar plot of the proposed antenna shows the main lob having a gain of 5.08dB in a direction of 30^0.

TABLE I. PARAMETERS OF THE PROPOSED ANTENNA (ALL DIMENSIONS IN MILLIMETERS)

Parameter	Value
L1:L2	28:14
L3:L4	6:7
Lg:W1	6:17
W2:W3	1:2
W4:wg	1:25
L5:L6	7.5:23.5
g	0.5

V. SAR CALCULATION

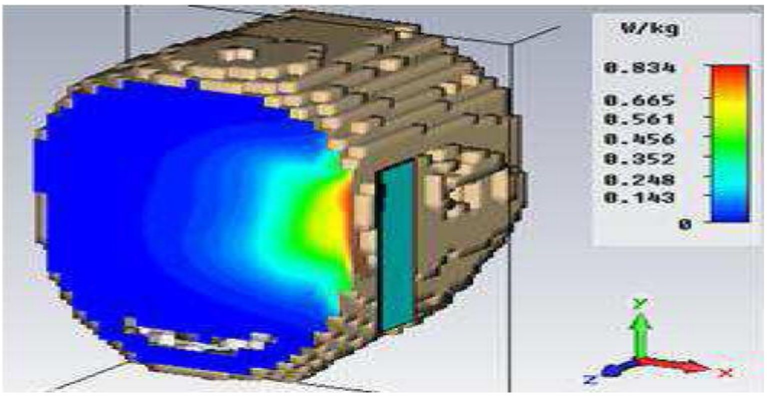

Fig. 4 SAR calculation of antenna with Double spiral EBG

Due to the fast development of mobile services and smart phones, the usage of mobile phone is increased rapidly. This has leads to the research on health risk due to the mutual interaction between the human body and the mobile phone antenna. Many factors may affect the EM interaction while using a cellular handset in close proximity to the head and hand [16]. By varying the hand position and the antenna position the EM interactions to the human body is varying [15]. The SAR is a defined figure of merit to evaluate the power absorbed by biological tissues. The SAR limit specified in IEEE C95.1: 2005 has been updated to 2 W/kg over any 10 g of tissue [21], which is comparable to the limit specified in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [22]. It is very important to investigate the SAR value produced by the radiation from the mobile handsets, while designing antenna for mobile phone. In this work, the reference power of the cellular phone is set to 500 mW. The SAR values are calculated according to the 10-g standard of the human tissue mass. The SAR calculations are done using the CST 2012 commercial package with Hugo model CST Microwave Studio [23]. For an operating frequency of 1.018GHz the SAR value obtained is 0.8W/kg shown in Fig. 4. This SAR value is very less than the limit specified by the ICNIRP.

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VI. CONCLUSION

A printed monopole micro strip antenna for mobile phones has been proposed. The proposed antenna at -6dB has a bandwidth extending from from 1.035 to 1.064 GHz and from 2.28 to 3 GHz and it support following operating bands: GSM 850, GSM 900, DCS 1800, PCS 1900, UMTS 2100, ISM 2450, most LTE bands, WiMAX (2.3–2.4, 2.5–2.69 GHz), and WLAN (2.4–2.5 GHz). EBG structures are introduced in the back side of the substrate for reducing the back side radiation from the antenna. Double Spiral EBG structures are introduced in this paper which gives a return loss of -23dB comparing the antenna without EBG having a return loss of -11.05dB. EBG structure provides a high impedance path so that no surface wave can propagate through the surface at the resonating frequency. SAR calculation is done by using the Hugo Voxel model in CST studio [23]. The SAR value for the proposed antenna is 0.8W/Kg over 10 gram of tissue which is very less than the SAR limit specified in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. From this research work it is evident that the use of EBG structure reduces the SAR value up to 75%. The proposed antenna with EBG structure can be implemented on new smart phones so that the health risk due to the electromagnetic radiation from the mobile phone antenna can be reduced to certain extent.

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AUTHOR BIOGRAPHY

Anoob B was born in Kerala, India. He received the B.Tech. degree in Electronics with communications from Mahatma Gandhi University, Kottyam in 2011 and M Tech degree from the University of Kerala in Communication systems Engineering, in 2014. His research interest includes Handset antenna design and frequency and pattern reconfigurable antenna design, digital signal processing.