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CONDUCTIVE TEXTILE EBG UNIT CELL AMC SURFACE ANALYSIS FOR 2.45GHZ AND 5.5GHZ BAND OF FREQUENCIES

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Abstract
EBG (Electromagnetic Bandgap) metamaterials are unique artificially designed structures which possess various attractive properties of electromagnetic radiations. The property of High Impedance Surface (HIS) is used in modify the electromagnetic radiations which does not occur naturally. This most promising application of artificially formed structure is in wearable microstrip patch antenna designing. Where the antenna has to be a part of our clothing for various applications such as tracking, Personal Area Network communication, navigation, patient monitoring, mobile computing and public safety etc. where in such application conductive textile materials has to be used. Microstrip patch antenna conventionally designed on the solid dielectric substrate but when the antenna has to be developed on textile to make it wearable the dielectric and conductive material replaced by the textile. Though the textile microstrip patch antenna has to be worn on human body and due to the close vicinity of human tissues the performance parameters of antenna degrades and most importantly the antenna radiations are being absorbed by the human tissues. This leads to increase the safety range of Specific Absorption Rate (SAR) of antenna. This paper describes design, development and parametric analysis of the EBG surface unit cell, which will absorb the back radiations on human body generated by the textile microstrip patch antenna.
Keywords EBG, HIS, Artificial Magnetic Conductor, Microstrip patch antenna, wearable antenna, SAR, Textile Conductive Fabric
摘要

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EBG（电磁带隙）超材料是独特的人工设计结构，具有各种吸引人的电磁辐射特性。高阻抗表面 (HIS) **的特性用于修改非自然**发生的电磁辐射。这种人工形成结构最有前途的应用是可穿戴微带贴片天线设计。天线必须成为我们服装的一部分以用于各种应用，例如跟踪、个人区域网络通信、导航、病人监护、移动计算和公共安全等，在此类应用中必须使用导电纺织材料。微带贴片天线通常设计在固体介电基板上，但当天线必须在纺织品上开发以使其可穿戴时，介电和导电材料被纺织品取代。虽然纺织微带贴片天线必须佩戴在人体上，并且由于靠近人体组织，天线的性能参数会降低，最重要的是天线辐射被人体组织吸收。这导致增加了天线比吸收率（SAR）**的安全范**围。本文介绍了 EBG **表面晶胞的**设计、开发和参数分析，它将吸收纺织微带贴片天线产生的人体背辐射。

关键词 EBG, HIS, **人造磁**导体, **微**带贴片天线, **可穿戴天**线, SAR, 纺织导电织物

1 Introduction

The recent advancement in the field of electromagnetism opens the door for the high performance applications in which artificially formed materials are used to design the wearable microstrip patch antenna. These materials are not naturally available but formed / designed with unique properties, this is why known as Artificial Magnetic Conductor (AMC) [1]. Their vast properties made them useful for Nano science, optics, composite smart materials and communication devices. For the designing of communication devices such AMC could be useful to mimic the properties of Band stop, Band pass etc.

The wearable antenna has to be placed against the human body, it doesn't have any ground plane protecting the human body from its radiations. To compensate this problem antenna has been integrated with a dual band periodic Artificial Magnetic Conductor structure to isolate the human body from its electromagnetic radiations. This artificial magnetic conductor material is also known as EBG (Electro Band Gap) in microwave domain but it was initially developed by the name of photons band gap (PBG) of the optics.

The combination of such EBG structure and wearable microstrip patch antenna can open the scope for the smart body worn application. Where the devices are to be worn on human body at the same time they are not absorbing radiation from the electromagnetic radiations from the devices.

The EBG originated from the Solid state physics and optic domain and since then it is named as photonic band gap in the field of optics but for the microwave it is popularly known as EBG. The macroscopic and microscopic resonance is responsible for the formation of band gap in EBG structure. When these two types of resonance coincide, the structures possess a maximum width band gap and that make this surface better for some specific applications. The band gap structure has to be designed carefully because depending upon their structural characteristics and perpendicular polarization of wave (most preferred) the stop band mechanism reflects back all the EM waves and at other remaining Frequencies it will act as a transparent medium [2][3].

This AMC structure could also be used to improve the radiation property along with reducing the backward radiation (as in this proposed work) to the human body this combination makes this structure more popular among antenna designers. Resonance frequencies, bandwidth of this AMC reflector structure are determined by unit cell geometry, dielectric property and substrate thickness [4].

This wearable antenna provides continuous information about the wearer's health/ communication signals, an antenna requires that must be completely textile based antenna. So now the requirement of two different textiles arises. One is non-conducting for substrate and other is conducting textile for radiation of EM wave.

The conducting textile materials also knows electro textile, it makes comfortable to wearer while communicating the information.

Textile antenna has to be placed in on human body so due to the lossy nature of human tissue the efficiency of antenna reduces drastically. When the textile antenna placed closed to the human body it affects the dielectric constant of the substrate textile which may reduce the radiation characteristics and ultimately change the other parameters such as S11(Return loss), VSWR, radiation patterns, efficiency of the antenna. In literature various textile fabrics are used as substrate such as Fleece, silk, flannel, wool, polyester, denim, Cardura and felt. For conducting patch Shieldit, copper sheet, Zelt, flexion, pure copper taffeta fabrics are popular.

In this paper dielectric fabric Felt is used as the substrate of antenna and unit cell and conductive ground is designed using conductive textile Shieldit Super.

Felt has dielectric constant 1.36, loss tangent 0.023 with thickness of 2.5mm. Shieldit Super has conductivity of 6.67 x105 S/m, with the thickness of .15mm. Shieldit Super conducting textile is a strong polyester substrate which is plated with nickel and copper. This fabric is coated on one side with non-conductive hot melt adhesive which make the attachment process easier by ironing the conducting fabric on the top of the substrate textile which is Felt in this work.

There are various shapes and designs are reported which could be used as the Unit cell geometry to create the band stop or band pass surface structure. In this proposed work the Square shaped structure is used to form the high impedance surface for the application of 2.45 GHz and 5.5 GHz resonance frequency bands.

The reported square shape dimensions are selected on the basis of their parametric analysis report which is included in this research. For both the above mentioned frequency bands the response of unit cell shows the good bandwidth.

Selection of conductive textile is very crucial because it has to worn on human body so at the same time it has to radiate the signals. This fabric should be inelastic as the electrical properties of the elastic fabrics might change when bending occurs. Also material must be homogenous over the antenna area the variance of the resistance through the material should be small, so losses could be minimized.

Table 1 Dielectric and conductive Textile used in proposed work

Name	Dielectric Constant	Thickness	Loss Tangent
Felt	1.36	0.02mm	0.023
Shieldit Super	-	0.15mm	-

2 Properties of EBG unit cell

The property of High Impedance Surface plays a role in the designing of EBG surface because whenever two dissimilar media are used for propagation surface waves occurs. Surface waves are propagating electromagnetic waves and they decay exponentially to surrounding space.

The EBG plane prevents the surface waves, leading to less backward radiations of an antenna. Thus, power wasted in the undesired direction is reduced. Surface waves propagates parallel to the interface and diminish exponentially away from the interface.TM surface waves are supported on inductive surface and TE surface waves are supported on capacitive surface as reprented in equation (1) and (2) respectively

$$Zs(TM) = j\alpha / \omega\varepsilon \quad (1)$$

$$Zs\ (TE) = -j\omega\mu/\alpha \quad (2)$$

Where ω is the angular frequency (rad/sec), ε is the dielectric permittivity (F/m),μ is the permeability (Wb/Amp) and α is the propagation constant.

The impedance vs. frequency curve of High Impedance Surface (HIS) at low frequency the impedance is inductive and at high frequency the characteristic is capacitive. So it below the reference it supports the TM surface waves and above the resonance it supports the TE waves. At the resonance it exhibits high/ infinite as could be calculated by the following equation

$$Z(\omega) = j\omega L/1- 2\omega LC \quad (3)$$

At resonance it shows that it does not support any surface wave. This is the major property of HIS and used as an conducting surface for the patch ground where the back radiations creates adverse effect on human body for wearable applications. Human body behave like lossy dielectric medium when radiations are closely placed so the performance parameters also affects drastically.

Other important property of HIS is its property of Dual to PEC (Perfect electric conductor).

The perfect electric conductor (PEC) has the property of having abounded electrons and when electric field applied on the PEC surface these electrons gets excitation and creating the surface current. PEC surface impedance is ideally zero and it does not support any electric field inside the conductor, whatever radiation strikes on its surface they will reflect by 1800 phase. When the impedance is very small (practically) as compared to free space impedance such as

$\Phi = \pm \pi$

When it matches the free space impedance it is equivalent to

$\Phi = \pm \pi/2$

When the impedance becomes high, phase becomes zero, that is at resonance where the reflection phase is zero.

It also has the property to block the electric field and no electric field can penetrate the surface. The counterpart of PEC is Perfect Magnetic Conductor (PMC) this is not naturally formed this is hypothetically designed and conceptualize surface that can block magnetic field instead of electric. As compared to the PEC the PMC surface impedance Zs is very high and it is not present in any natural material but the property of PMC can be mimic in the form of artificially formed sheets where different techniques are used to show the above mentioned property of PMC.

Artificial Magnetic Conductor (AMC) is a type of PMC, by using the periodic arrangement of identical or similar structure the property of magnetic conductor could be introduced in this PMC sheet.

Broadly the AMC, FSS and SRR all comes under the Metasurface/ Metamaterial. So AMC is the subpart of Metamaterial. It is most important to know the property of this PMC surface.

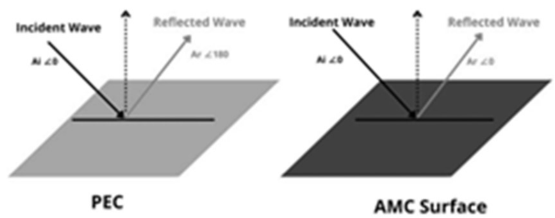

Fig.1. PEC and AMC surface basic property

In Fig. 1 it shows the basic property of PEC and AMC surface that when any incident wave strike on the PEC surface after reflection the phase of reflected wave shifted by 1800 but when the wave reflect to the AMC surface the reflected wave does not shift the phase of the incident wave. It shows that AMC does not invert the phase of the incident input signal. So to enhance the performance of patch antenna and to reduce the back radiation this AMC surface has vast applications.

To understand the concept of surface current before and after the AMC surface could be understand by the Fig. 1, where the current in patch and current in metal ground part is out of phase in microstrip patch antenna but when instead of metal PEC ground if the AMC sheet is replaced the phase shift reduced to zero. Now both incident and reflected wave after reflecting from the AMC surface both will be in same phase.

To determine the absorption of surface wave the bandwidth of the AMC surface must be calculated first. The bandwidth of the AMC is the difference of two frequencies when they cross the reflection phase/degree by +900 to -900[5].

Various studies is being conducted on such artificially formed conductor and also used as bandwidth enhancer for microstrip patch antenna [6-7]. Electromagnetic wave and its back scattering are controlled by such AMC surfaces which demonstrated as the reflective Metasurface [8-11].

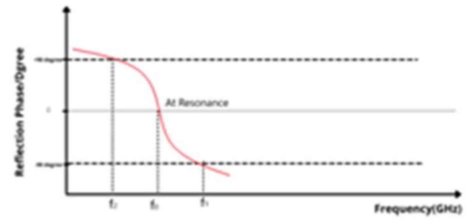

Fig. 2. Bandwidth of the AMC surface structure resonating at f0

Fig. 2. Shows the bandwidth of AMC surface where the frequency at which reflection phase is at zero is the resonance frequency and before and after the resonance the upper and lower cut off frequency is shown. Within this range of the frequency the AMC will not invert the phase of the reflected wave.

3 Design and parametric analysis of unit EBG cell

After understating the concept of reflection phase now need to design the structure for this reflecting surface. The TM (Transverse Magnetic) wave can only propagate on an inductive surface while the TE (Transverse Electric) surface wave is only supported by a capacitive surface. So to eliminate propagation of both TM and TE surface waves, it is necessary to design special surface structures which simultaneously possess inductive and capacitive surface impedance. This could be thought of as a LC resonance structure. Surface waves can be prevented over a finite frequency band by texturing periodic lumped element resonance structure on the surface.

As the surface wave scatter from the discontinuity, the radiation interference prohibits them from propagating, producing a high impedance band gap over certain frequency ranges. A periodic structure is obtained by cascading the two port network as unit cells. Effective surface models are used to describe its properties. These models usually consist of lumped inductor and capacitor, presenting high impedance property in certain frequency range. There are various periodic similar structure researched and simulated to design to absorb the back radiations radiated from the microstrip patch antenna.

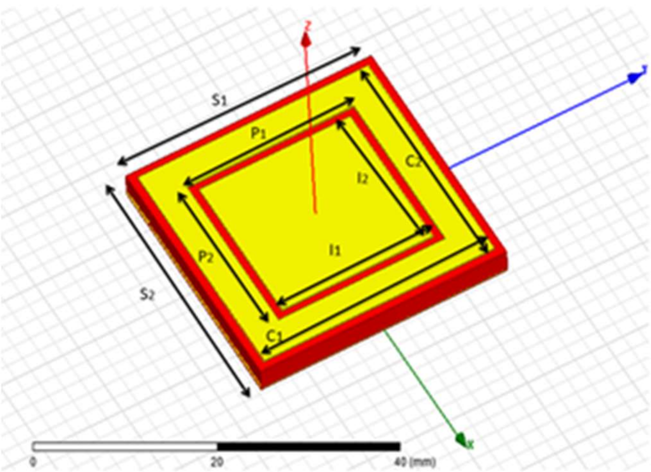

Fig.3 Unit EBG Cell designed in the Ansys HFSS simulator.

In Fig. 3 the unit EBG cell design is shown, this is designed and simulated in Ansys HFSS simulator. The unit EBG Cell dimensions taken for parametric analysis are S1 and S2 from 30mm to 31mm, P1 and P2 from 28mm to 29mm, C1 and C2 from 20 to 21mm and I1 and I2 kept constant at 19mm.

By varying the dimensions of outer patch (P1 and P2) along with S1 (dimension of unit cell), cuts(C1 and C2) and keeping the inner patch constant the required Bandgap for 2.45GHz and 5.5 GHz could be get. The EBG Bandgap bandwidth has been taken between ±900.To analyses the EBG unit cell flouted port is used in Ansys HFSS simulator.

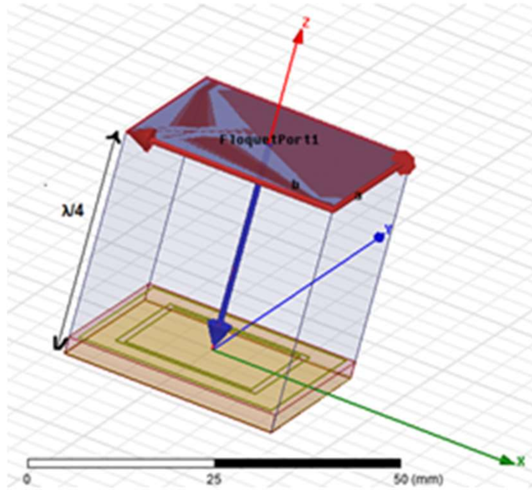

Fig.4. EBG Unit Cell with Floquet Port

Floquet port is shown in Fig. 4, the distance from the top of the patch is taken as λ/4 for the case of Floquet port to check the reflection phase/degree in the analysis of unit cell geometry.

For the simulation of unit cell the boundaries has to be decided. There are two models popular by which the boundary condition could be defined, here in this work the Master and Slave boundaries are defined, the direction of the respective master and slave has to be assigned in same direction.

4 SIMULATION AND RESULTS

Parametric study reveals the exact dimensions at which the desired resonance bands will give the band stop performances; here the desired bands are standard

2.45 GHz and 5.5 GHz frequency.

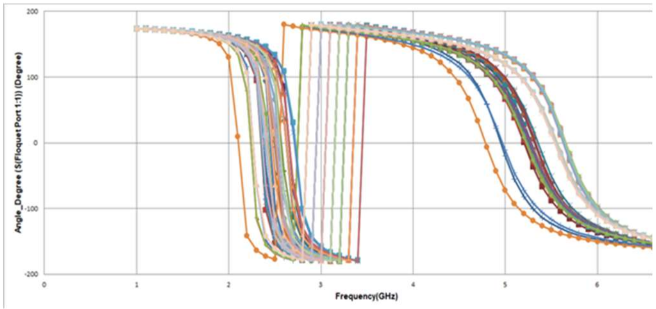

Fig. 5. Simulation result of parametric analysis of Unit EBG Cell

Table 2 Variable parameters used for parametric analysis to find the desired Bandgap in proposed work

S.no	Variable parameters	Range of Variables	Final Selection
1	S_1	30 mm to 31mm	31 mm
2	S_2	30 mm to 31 mm	31mm
3	P_1	28 mm to 29 mm	29 mm
4	P_2	28 mm to 29 mm	29 mm
5	C_1	20 mm TO 21 mm	21 mm
6	C_2	20 mm TO 21 mm	21 mm

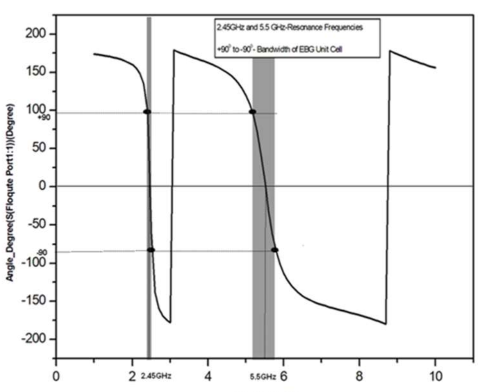

Fig. 6. AMC bandwidth between ±900 at resonance at 2.45GHz and 5.5 GHz

Table 2 shows the variable parameters and the selected values of variable which provides the desired band of frequencies for EBG Cell. Finally selected EBG unit cell graph along with the EBG Bandwidth is shown in Fig. 6. For both 2.45GHz and 5.5GHz band of frequencies the Unit cell provides adequate bandwidth. The bandwidth calculated by the upper frequency, lower frequency and the resonance frequencies as shown in the Fig. 7.

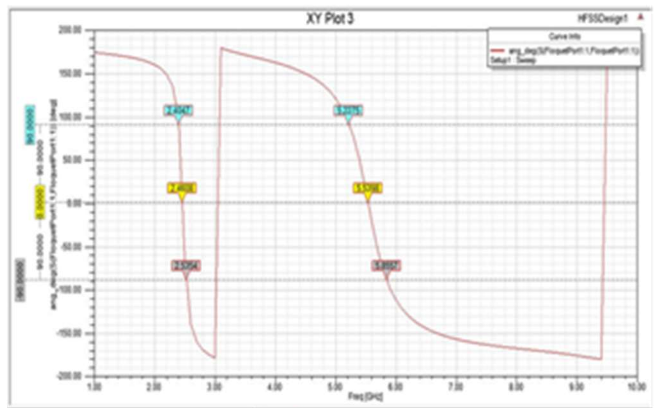

Fig. 7 finally selected EBG Unit cell results for both resonances along with bandwidth

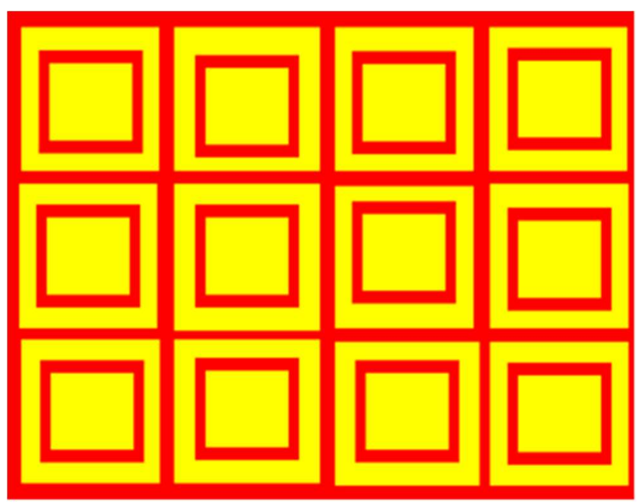

Fig. 8 Complete AMC 3 x4 EBG cell surface

In Fig. 8 the complete EBG cell based AMC surface is shown where the ground and EBG

Cells are formed using Shieldit Super textile (Yellow) and the dielectric substrate is Felt textile (Red). This surface will behave like a PMC and will not change the phase of reflected wave and absorbing the radiations on back side for both the resonance frequencies.

This artificially formed PMC will be best for body worn applications it will protect the human tissues to absorb the radiation from the radiating patch.

5 Conclusion

The Shieldit Super conductive textile and Felt based designed AMC surface with dual band application will be best suited for the mentioned range applications. The simulation result shows that this surface will be best for the absorption of the back radiation in the resonance frequency band 2.45GHz and 5.5GHz for the application of standard ISM band and WLAN also. Designing of this AMC surface EBG cells are simple and Vialess so it could be easily fabricated on the textile. Shieldit Super textile is coated on one side with non-conductive hot melt adhesive which makes the attachment process easier by ironing the conducting fabric on the top of the substrate textile Felt in this proposed work. Radiating patch along with the CPW feed can be designed on the top of the AMC surface to get the desired communication in both the resonance frequencies

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Compliance with ethical standards

Conflict of interest There are no conflicts to declare.

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