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Electromagnetic Band Gap based compact UWB Antenna with Dual Band Notch Response

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ABSTRACT- In Antenna Technology, Electromagnetic Band Gap (EBG) structures are one of the mostly used structures to improve gain of antenna, suppress surface waves and band notching. In UWB frequency spectrum more number of small frequency bands are exists and these bands cause electromagnetic interference, to reject such bands more number of EBG structures are required. Due to limited monopole antenna's ground plane, it is required to have EBG with small in size and single EBG to reject two or more bands. The simulated results of proposed new C-shaped EBG by placing near the feedline of fork-shape Ultra-Wide Band (UWB) antenna to reject two bands namely Lower Wireless Local Area Network(L-WLAN) band range from 5.15 GHz to 5.35GHz and X-band of satellite downlink communications networks (7.25GHz –7.75GHz) within a UWB antenna's spectrum and EBG occupying less area compared with the reported Conventional Mushroom Type (CMT) EBG, semi-circular EBG, slotted-patch ELV EBG and TVS EBG. Fabrication and measurement results of the newly proposed antenna attain an enormous bandwidth *i.e.*, from 2.8 GHz to 11.5 GHz while eliminating frequency bands between 5.15 GHz to 5.35 GHz (Lower WLAN) & 7.25GHz to 7.75GHz (X-band of satellite downlink).

Keywords: Ultra-Wide Band (UWB), Electromagnetic Band Gap (EBG) structures, WLAN, X-band and C-Shaped EBG structure.

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1. INTRODUCTION

The International Federal Communications Commission (FCC) allocated & approved frequency band for Ultra-Wide Band (UWB) technology about 3.1 –10.6 GHz in 2002 and this technology having advantages over traditional wireless communication systems are higher data transfer rate, cheap cost, high precision range, low spectral power density, minimal complexity and easy hardware configuration[1]. However, an electromagnetic interference issue is existing in UWB band frequency spectrum due to narrow bands of WiMAX frequency band exhibits from 3.3 GHz to 3.6GHz, WLAN band exhibits from 5.15 GHz to 5.35GHz and also from 5.725GHz–5.825GHz and satellite communication downlink band range from 7.25GHz to 7.75 GHz [2]. So, a UWB antenna should notch a few of these interfering bands within its operating frequency band. The various band elimination techniques such as etch slots of different shapes in ground plane or in the radiating patch, adding of parasitic elements, creating different types of stubs and creating resonating structures of different types on the radiator or near the radiator [3-5]. To notch multiple interfering bands, the design to be embedded with several parasitic elements or slots, these slots may be occupied more space and increase of mutual coupling effect. These type of deigns such as by creating slots on the structure of radiating patch may affect performance of antenna, not much flexible to tune notch frequency. One of the sever problem in Micro-strip antenna is formation of surface wave, these surface waves decrease the efficiency, directivity, gain of the antenna & mutual coupling increased. By embedding EBG structures in the antenna in periodically either 1-Dimentional/2-Dimentional form, the high impedance surface are created, these high impedance will not allow the surface waves propagated over the substrate and it will helpful to increase in radiating power couples to the space waves and lowers back radiation. In addition to this 2D-EBG with novel shape will not only decreases the mutual coupling accompanied by the patches of antenna array, and also avoid the generation of second harmonic, reduces the power level of the side & back lobes and gives results better than conformist 2D-EBG shapes like circle and square. The group delay is one of the important parameters in a time domain that represents performance of antenna in time domain. While calculating the group the negative derivative of the phase response with respect to frequency delay is taking. When group delay variation exceeds 2 ns, it is an indication that phases of impulse response of different frequency components are not linear in far field.

2. SYSTEM MODEL

Many Researchers have proposed that by embedding EBG structures close to the feed of the antenna to eliminate the frequency nosy bands in the UWB band spectrum. In [5], the author used both EBG structures such as ELV EBG and CMT

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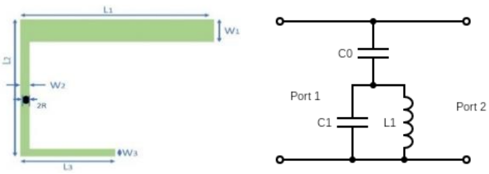
EBG to notch frequency band of WLAN, and over that ELV-EBG is occupies less area and gives better band notch characteristics compared to CMT EBG. In [6], two notch bands are achieved by embedded slotted patch ELV EBG in monopole UWB antenna. A customized mushroom kind of semi-circular EBG structures are used to achieve band notches at the centre frequencies of 5.2 GHz and 5.8 GHz [7-8]. In [9], 4 CMT EBG is proposed to eliminate WiMAX and WLAN bands. In [10], to notch the WLAN spectrum the author is used another kind of inductance enhanced EBG structures are placed side of circular UWB antenna feed line spectrum. In [11], to notch IEEE-INSAT C-band of 6.5 GHz - 7.2 GHz, a new kind of uniplanar EBG was used, and 2-cells uniplanar EBG structures were incorporated on either sides of the antenna feed. In [12], the author proposed line fed UWB monopole antenna with EBG to notch satellite up-link X-band and Lower WLAN. In [13-14], a slitted EBG structure has been proposed to notch WiMAX and WLAN bands, and in [16] [17], Two *via* Edge Located (TVEL) EBG and a fractal EBG structures are incorporated to achieve 3-different notch bands. So, to reject multiple frequency bands many EBG structures are required. Due to area constrain of monopole antenna ground plane it is more difficulty to place multiple EBG structures in the antenna ground plane, therefore, it is more important to maintain the EBG structures must compact in size.

In this article, a new type C-shaped EBG structure is proposed and its bandgap properties using dispersion diagram is explained in *Section 3*. In *Section 4*, illustrates the reference UWB antenna of fork shaped structure. In *Section 5*, a proposed design of UWB antenna embedding with C-shaped EBG is presented and also explained simulation results at notch bands such as the Lower WLAN of 5.15GHz –5.35GHz frequency band and X-band of satellite downlink of 7.25GHz –7.75GHz frequency band. Design antenna Simulation results and physical antenna results of UWB antenna with & without C-shaped EBG were explained in the *Section 6*. In *Section 7*, Comparison of area occupied by C-shaped EBG with various EBG structures which are already used by other researchers is presented. Finally, *Section 8* concludes this paper.

3. C-SHAPED EBG STRUCTURE

EBG structures are created by arranging the metal patches over a dielectric substrate in periodic manner. The electromagnetic band gap property of the C-shaped EBG structure is studied with the LC equivalent circuit of a resonator, the inductance L in the EBG will appear due to the current pass through the via, and the capacitance effect *i.e.* C will appears due to the space existing in between the nearby EBG cells. Thus, occurrence of bandgap in EBG structures at the resonant frequency of the LC resonator circuit with centre frequency, i.e., $f_r = \frac{1}{2\pi\sqrt{LC}}$ [15]. An equivalent LC characterises of the EBG structure, which produced by *via* loaded metallic patch to ground. *Figure 1* also shows an equivalent circuit of the EBG. According to the study, the EBG cells have centred resonant frequency, following equation can be used to find out the notched band's centre frequency, i.e. $f_r = \frac{1}{2\pi\sqrt{L_1(C_0+C_1)}}$ [4]. Where C_1 is the voltage between antenna ground plane and patch, while C_0 is the coupling between feedline and EBG. The current passing via the shorting pin, accordingly, causes the inductance L_1. LC resonant circuit model will describes the EBG unit cell, and its capacitance effective & inductance values are evaluated using the equations, $C = \frac{w\varepsilon_0\,(1+\varepsilon_r)}{\pi} cosh^{-1}\left(\frac{w+g}{g}\right)$& L = μh where 'w' represents the unit EBG cell width, 'g' is a gap width of two EBGs, and 'h' represents the height of the substrate. As a result, by altering the dimensions of EBG suitably, the notch band can be generated at the required frequency.

In this paper, all the dimensions of C-shaped EBG with L_1 = 8mm, L_2 = 6.2mm, W_1 = 1.2mm, W_2 = 0.6mm, L_3 = 4.8mm, W_3= 0.4mm and to validate the bandgap properties the proposed EBG structure is designed and simulated using one of the EM tool i.e. HFSS-2021/R1 version to attain the rectangular type Brillouin-zone dispersion diagram. In *figure 2*, the dispersion diagram is shows a band gaps between mode 1 & mode 2 and mode 2 & mode 3 with the electromagnetic band gap of 5.15GHz to 5.35GHz and 7.25GHz to 7.75GHz respectively.



(a) (b)

Figure 1: (a) C-shaped EBG (b) LC equivalent circuit of C-shaped EBG

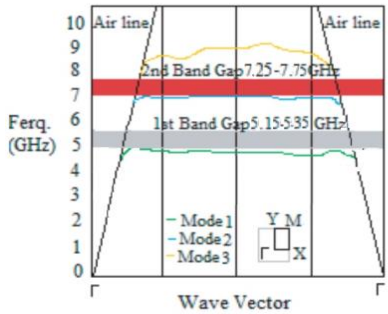


Figure 2: Dispersion diagram

4. FORK SHAPED UWB MONOPOLE ANTENNA

A fork-shaped UWB antenna [4] was considered as a reference antenna and same as treated as Antenna 1. The UWB antenna is intended on a substrate RT/ duroid 5880 with εr of 2.2, the loss tangent i.e. tan δ is of $9x10^{-4}$, and the patch height (h) is of 0.8 mm. The structure of UWB antenna consists of fork-shaped tuning stub fed with microstrip line radiating element and the ground plane is etched as a quasi-semi-circular shape is shown in *figure 3*. The UWB antenna (Antenna 1) design dimensions as shown in *table 1*. *Figure 4* illustrates various antenna parameters like Return loss S11, Radiation Pattern, Gain and Group delay of UWB antenna simulated using HFSS and got good simulated results.

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Table 1: Proposed UWB antenna design dimensions

Parameter	Dimension
X1 & Y1	35 mm
X2	9mm
X3	13.6 mm
Y2 and Y3	2.1mm
Y4	6mm
Y5	1.8mm
R1	15mm

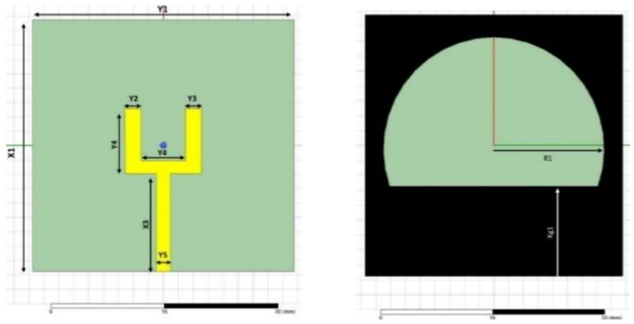
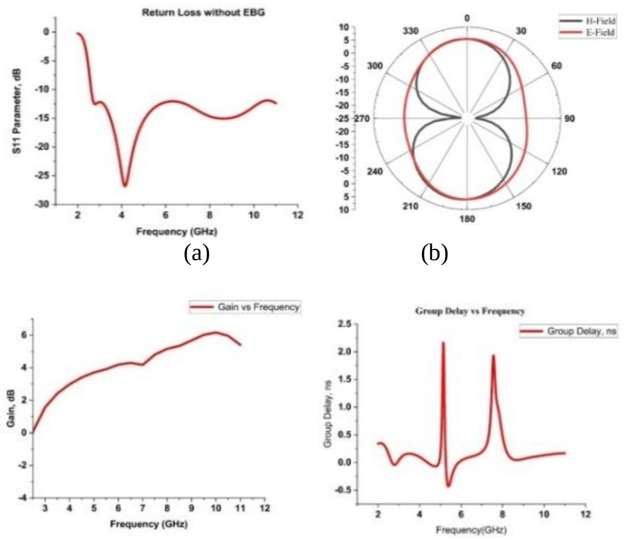

(a) (b)

Figure 3: The proposed UWB Antenna (Antenna-1) (a) Top-view (b) Bottom-view



(a) (b)
(c) (d)

Figure 4: Simulated results of proposed antenna without EBG (a) Return loss S_{11} (b) Radiation Pattern (c) Gain (d) Group delay

5. CONCLUSION

The C-shaped EBG as mentioned in section 3 is integrated near a feedline of Antenna 1, as mentioned in *figure 5*, with a spacing between feedline and EBG i.e., gap g1 = 0.5mm and g2 = 0.2mm, and d1 = 2.8mm. This antenna is known as Antenna 2, and the remaining dimensions of the fork shaped UWB antenna remain unchanged as mentioned in section 4. *Figure 6* illustrates the simulated results of antenna with EBG i.e. antenna 2. It is observed that two notch bands are achieved, one band ranging from 5.15GHz to 5.35GHz with 5.25GHz centre frequency and one more frequency band ranging from 7.25GHz to 7.75GHz with 7.5GHz centre frequency (where S11> -10 dB). In *figure 6(b)*, Radiation pattern in the pass band at 4.54GHz is shown. It is also found that gain was negative at the notch bands as shown in *figure 6(c)*, and group delay be shown in *figure 6(d).*

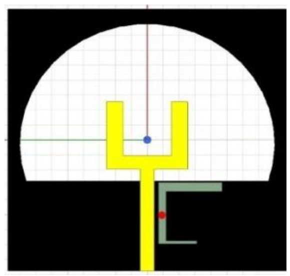
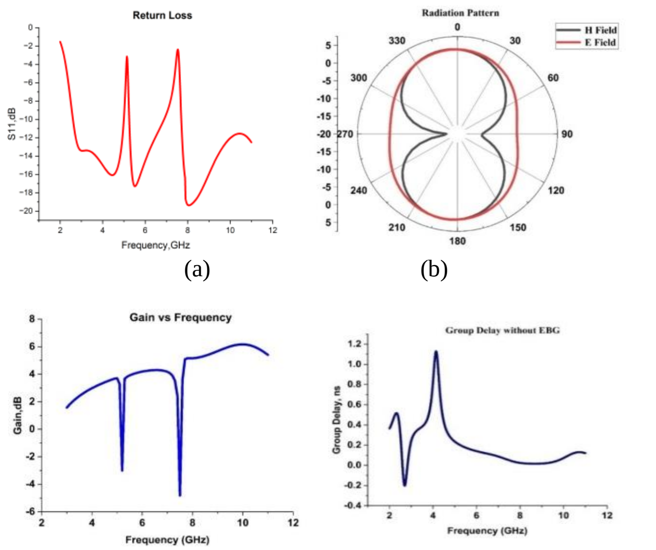


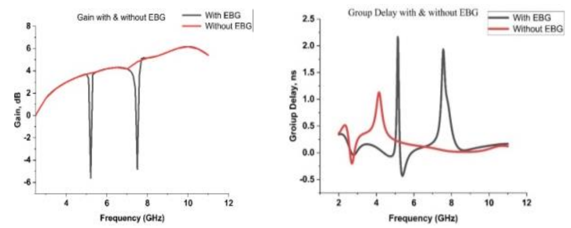
Figure 5: Fork shape antenna embedded with C-shaped EBG structure (Antenna 2)



(a) (b)
(c) (d)

Figure 6: Simulated results of proposed antenna with EBG (a) Return loss S_{11} (b) Radiation Pattern (c) Gain (d) Group delay

The simulation results such as gain and group delay of fork-shaped UWB without EBG (Antenna 1) and fork-shaped UWB with C-shaped EBG (Antenna 2) are shown in *figure 7*. It is clearly indicated that at rejected frequency bands of 5.15 GHz–5.35GHz and 7.25 GHz–7.75 GHz, the gain is positive for antenna without EBG, whereas the gain is negative for the antenna with EBG. According to the simulated results, the two frequency bands are reported by use of C-shaped EBG structure in antenna design, and the group delay at stop band is significantly improved due to EBG structures.



(a) (b)

Figure 7: Simulated results of Antenna 1 & 2 (a) Gain (b) Group delay

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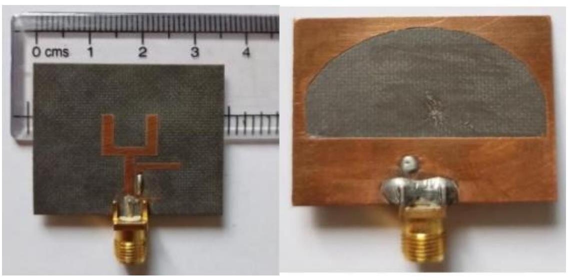
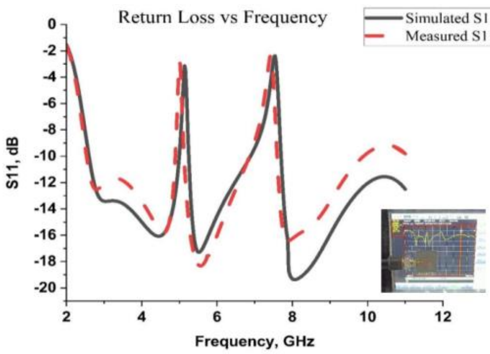
6. ANTENNA FABRICATION AND MEASUREMENT RESULTS COMPARISON

In this presented work, the designed antenna using EM simulation software is fabricated using Rogers RT/Duriod 5880 substrate as mentioned in section 4. All the antenna design parameters are chosen as illustrated in the *Section 3, 4 & 5*. At the end of the antenna a 50Ω SMA connector is used as microstrip feed. By use of Network Analyzer the fabricated antenna measurements such as return loss and VSWR will be measured. The fabricated (physical antenna) antenna front view & back view is presented in *figure 6*. In *figure 9*, presented the comparison of simulation results with measured results such as return loss S_{11} and gain, it is observed that parameter values of the fabricated antenna and simulated antenna are almost same but slight frequency shift happened due to the fabrication of physical antenna and soldering of connector. The measured results like return loss values of the physical antenna shows that good frequency bandwidth ($S_{11} < -10$ dB) with band ranging from 3GHz to 12GHz due the electromagnetic band gaps are occurred at the frequencies bands of 5.15 GHz to 5.35 GHz and 7.25 GHz –7.75 GHz. Here only one pass band frequency is chosen at a frequency of 4.54 GHz to observe the far-field pattern, the gain is about to 5.2dB. Anechoic chamber is used to evaluate the far-field pattern performance of the fabricated antenna (*figure 8*). In *figure 10*, the far-field pattern of physical antenna is detailed in both E and H planes at 4.54 GHz frequency and the antenna exhibits good omnidirectional radiation pattern at resonant frequency i.e. in the H-plane, the pattern shows circular in shape and in E plane it shows in dumbbell shape, the radiation pattern of physical antenna is good correlation with simulated antenna.

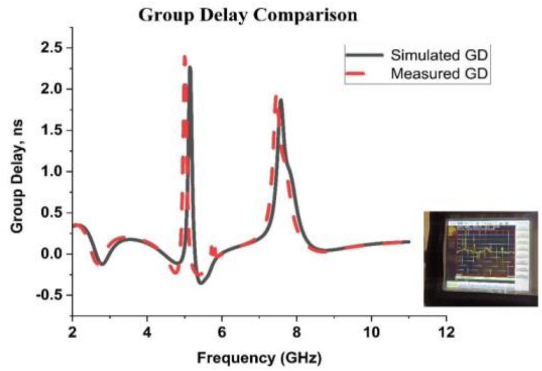


(a) (b)

Figure 8: Fabricated antenna 2 (a) Front view (b) Back view



(a)



(b)

Figure 9: Comparison of simulated results with measured results (a) Return loss, S_{11} (b) Group Delay

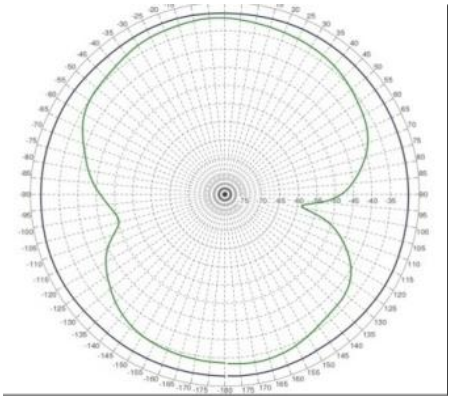


Figure 10: Radiation pattern of fabricated Antenna 2 in pass band at 4.54 GHz

7. COMPARISON OF C-SHAPED EBG WITH SOME OF THE REPORTED EBG STRUCTURES

The *figure 11* shows the different kind of shapes and dimension of various EBG structures namely CMT-EBG, slotted-patch ELV-EBG, semi-circular EBG and Two *via* Edge Located (TVEL) EBG structures. *Figure 12* presents the area occupied by the various EBGs on the ground plane & VSWR at notch frequency band of C-shaped EBG and some other reported EBGs mentioned in figure 11, wherein the C-shaped EBG occupies the least area and VSWR at notch band is high. While comparing above mentioned reported EBGs, the new C-shaped EBG is notched two unwanted frequency bands, but remaining EBGs are notch only single frequency band.

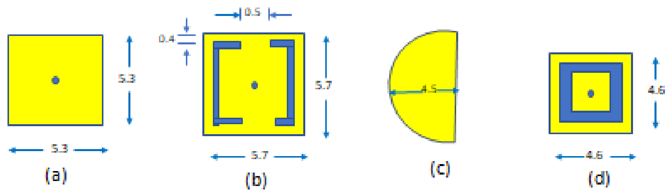
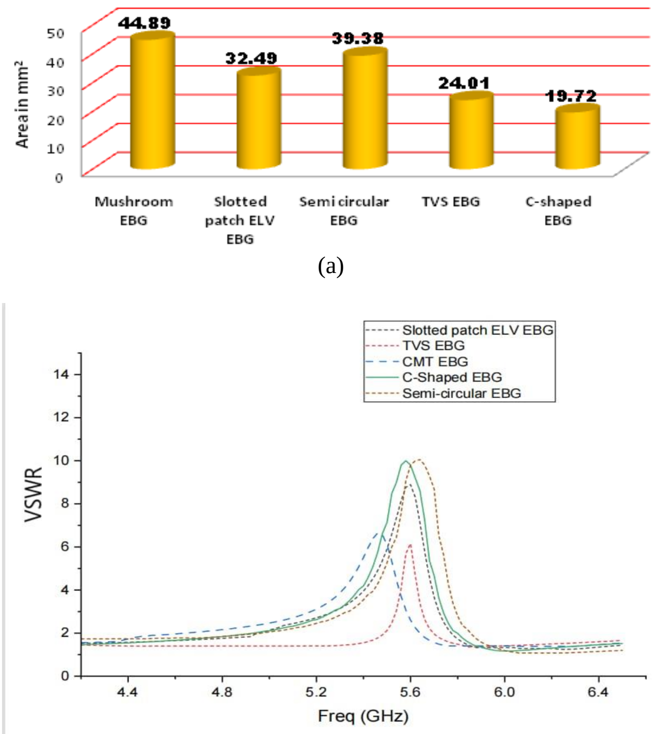


Figure 11: Various type of EBG Structures (a) CMT-EBG (b) Slotted patch ELV (c) semi-circular EBG (d) TVS EBG



(a)

(b)

Figure 22: Comparison of various EBG structures (a) Ground plane area occupied (b) VSWR

8. CONCLUSION

A dual band notch UWB antenna with a new C-shaped EBG with band notching frequencies of Lower WLAN of 5.1 GHz–5.3 GHz band and X-band of satellite downlink communications networks of 7.25 GHz–7.75 GHz band is designed using HFSS and same antenna is fabricated & tested. The simulation results confirmed that by embedding a new C-shaped EBG near the feed of the UWB antenna is improves overall antenna performance like the pass band gain is improved up-to 20-44%, the VSWR at notch band increases up-to 15-35%, the area occupied by EBG on ground plane is also reduced up-to 15-80% and more importantly the new C-shaped EBG structure provide two notch bands whereas the reported EBGs notch only single band. The bandgap characteristics were explained with the help of a dispersion diagram, and it was also proved that the newly invented EBG gives better band notching characteristics. In addition to C-shaped EBG by embedding some other EBG with different shapes it is possible to eliminate more number of inference bands within UWB band.

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