INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2020, VOL. 66, NO. 2, PP. 261–266
Manuscript received July 21, 2019; revised April, 2020. DOI: 10.24425/ijet.2020.131872

Modified Groove Coupled Compact EBG Unit Cell as Notch Filter in a UWB Antenna

Kumaresh Sarmah, Sivaranjan Goswami, Angana Sarma, and Sunandan Baruah

***Abstract*—In this paper, a conventional mushroom-type EBG unit cell is made compact by etching a C-slot at its conducting surface. Further, the C-slotted mushroom-type EBG unit cell is coupled with a microstrip line using a novel groove-coupling technique to design a notch filter. The arrangement has achieved in the reduction of the electrical size of the mushroom type EBG unit cell by 46.15% and create a stop band suppression of -12 dB. The proposed EBG is applied to notch a narrow band centered at 5.2 GHz along with an ultra-wideband antenna. The far field gain of the antenna is suppressed by -5.8 dBi along the direction of its major lobe at 5.2 GHz. The overall size of the antenna system is $19 \times 27 \times 1.6mm^3$ which is compact. The performance of the antenna is validated from the simulation and measured results.**

***Keywords*—EBG, Groove Feed, UWB Antenna, Band Notch**

I. Introduction

Electromagnetic band-gap (EBG) structures are electromagnetic counterparts of photonic band-gap (PBG) structures which are applicable to optical regime [1] [2]. EBG structures have received a growing interest worldwide in the design of low-profile, high-performance antennas for wireless communication [3] [4]. Periodic structures of dielectric and metallic elements used for notching unwanted frequency bands are the primary EBG structures to be introduced. The problem with these structures was their large size which is attributed to the frequency dependent gap between the EBG unit cells [5]. Mushroom type EBG cell with smaller periodicity was introduced as a solution to this problem for the design of compact microstrip antennas. Further, it has been seen that EBGs enhance the isolation between different components constituting patch, microstrip line or array antenna systems and considerably mitigate the effects of electromagnetic interference (EMI).

Ultra-Wide Band (UWB) Frequency band, 3.1 GHz to 10.6 GHz started to gain popularity from the year 2002, after US Federal Communication Commission (FCC) allocated this band for commercial application [6]. This UWB band has wider bandwidth and permits simultaneous transmission and reception of many communication channels with high data rate communication links [7]. The UWB communication is prone to interference from other communication channels within this range such as the WiMAX ($3.3 - 3.6$ GHz) and WLAN ($5.15 - 5.35$ GHz and $5.735 - 5.825$ GHz) [8]. Band notch UWB antenna is a viable option to address this issue [9]. Some of the popular approaches to design band notch UWB antennas include the introduction of slotted structures within the UWB patch and parasitic elements near the patch [10], loading multiple slotted structures to eliminate multiple bands of frequency [11] [12].

Slotted structures often involve a design specific approach and hence they have less flexibility in tuning the notch band which is viewed as a limitation of these structures [13]. EBG unit cell structures are reported as a solution to this problem [14]. EBG unit cells are placed near the patch and microstrip line to achieve band notching at the desired frequency band [15]-[17]. Implantation of the EBG unit cell near the microstrip line plays an important role in controlling the radiation pattern and gain of the antenna at the desired notched band [18]. Compared to other structures, mushroom type EBG unit cells are more compact, which can be integrated along with the UWB antenna. A mushroom-type EBG structure suppresses surface wave propagation at its resonant frequency thereby behaving as a notch filter.

In the present work, a compact mushroom-type EBG unit cell is proposed which can notch out the 5.2 GHz ISM band from a UWB antenna. The compact size of the EBG unit cell is achieved by the introduction of a C-shaped slot within the unit cell. The coupling between the EBG unit cell and the feed line is improved by the introduction of a groove in the feed line.The remaining of the paper is organized as follows. Section II covers a detailed analysis of the proposed C-slotted compact mushroom-type EBG unit cell. The design and of the UWB antenna loaded with the C-slotted compact unit cell is covered in Section III. It is followed by the experimental results and analysis of the antenna in Section IV. Finally, the work is concluded in Section V.

II. Design and Analysis of the Modified C-slotted Mushroom EBG Structure

Sievenpipe [19] first proposed the mushroom-like EBG structure. The basic EBG structure consists of four vital parts, a metallic patch over a dielectric substrate separated by a conducting ground plane with a cylindrical conducting via through the substrate.

A. Size Reduction of EBG Structure using C-slot

When a mushroom type EBG unit cell is fabricated near a microstrip line, it behaves as a notch filter. The equivalent

Kumaresh Sarmah is with the Department of Electronics and Communication Technology, Gauhati University, Guwahati, INDIA (e-mail: kumaresh@gauhati.ac.in).

Sivaranjan Goswami and Angana Sarma are with the Department of Electronics and Communication Technology, Gauhati University, Guwahati, INDIA (e-mail: sivgos@gmail.com,sarmaangana@gmail.com).

Sunandan Baruah is with the Department of Electronics and Communication Engineering, Assam Don Bosco University, Assam, INDIA (e-mail: sunandan.baruah@dbuniversity.ac.in).

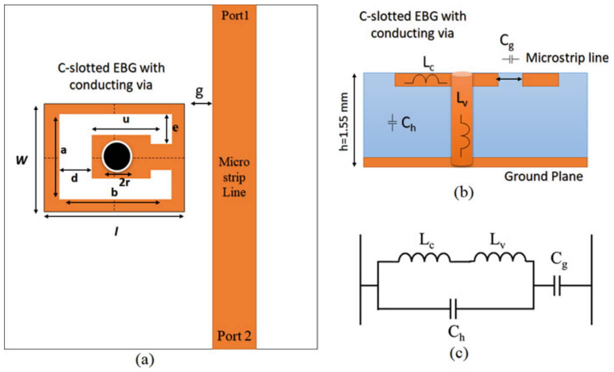

Fig. 1. (a) Simulation setup for evaluating the performance of the proposed size reduced C-slotted mushroom-type EBG. (b) Side view of the EBG with Microstrip line (c) equivalent circuit model of EBG unit cell.

circuit of a mushroom type EBG can be viewed from Fig. 1(c), as aparallel L-C resonator circuit.The various L-C parameters of mushroom type EBG is given in the following equations (1-3) [13]- [18].In this representation,$C_g$is the capacitance between EBG and microstrip line, L_v is the inductance due to the current flowing through the via connector and C_g is the capacitance between the ground plane and the EBG unit cell. The analytical expressions for these three terms are given by equations (1-3). Where, ε_0 is the permittivity of free space, ε_r is the relative permittivity of the FR4 epoxy substrate and h is the height of the substrate.

$$C_g = \frac{w\varepsilon_0(1+\varepsilon_r)}{\pi} \times (cosh^{-1}(\frac{w+g}{g})) \tag{1}$$

$$L_v = 0.2h(ln(\frac{2h}{r}) - 0.75) \tag{2}$$

$$C_h = \varepsilon_0\varepsilon_r(\frac{w^2}{h}) \tag{3}$$

The resonant frequency of the mushroom type EBG is given in eq 4.

$$f_0 = \frac{1}{2\pi\sqrt{L_v(C_g+C_h)}} \tag{4}$$

To achieve a reduction in the electrical size of the unit cell f_0 need to decrease for which, any of the three lumped parameters, L_v, C_g or C_h must be increased. As substrate height is fixed at 1.5 mm, hence C_h cannot be varied. The gap between the microstrip line and the unit cell is crucial to maintain the desired coupling between the unit cell and the microstrip line. Hence, C_g also cannot be increased. To increase the inductance value, a C-slot is introduced in the top conducting plane of the EBG unit cell as shown in Fig. 1. This C-slot adds an additional transmission path in the unit cell which accounts for an additional inductance term, LC in series with L_v. The dimension of the C-slot is summarized in Table I.

To design and analyze the resonant frequency of the EBG structure, an experimental setup is created using Ansoft HFSS®. Here, the mushroom-type EBG structure is placed near a microstrip line to study its effect on the transmission

TABLE I
DIMENSION OF THE PROPOSED C-SLOTTED EBG STRUCTURE

Dimensions of C- slot etched at EBG Unit cell	**l**	**w**	**a**	**b**	**d**	**u**	**e**	**r**
Values in (mm)	4.4	4.4	3.4	3.4	0.5	2.4	1.2	0.5

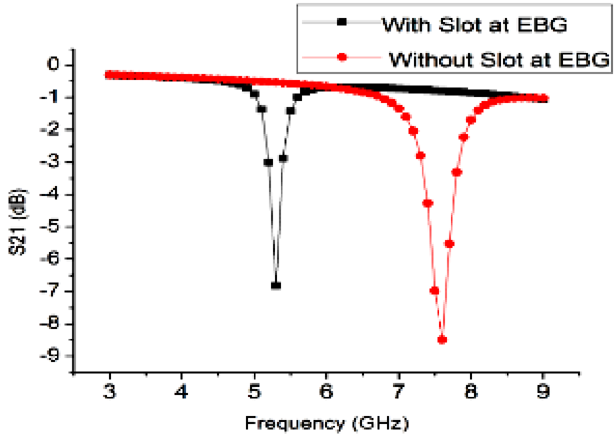

Fig. 2. Comparison of S_{21} versus frequency plot of conventional mushroom-type EBG structure and C-slotted mushroom-type EBG structure

parameter, S_{21} of the microstrip line.The modified resonant frequency of the unit cell is given by eq5.

$$f_0 = \frac{1}{2\pi\sqrt{(L_v+L_c)(C_g+C_h)}} \tag{5}$$

To evaluate the reduction in the resonant frequency and hence the electrical size of the unit cell, the S_{21} parameter of the microstrip line as shown in Fig. 2. The comparison is done for a conventional mushroom-type EBG unit cell of size $4.4mm \times 4.4mm$ and with proposed C-slotted EBG unit cell of the same size as mentioned in Table I. The notch filtering behavior of the mushroom type EBG unit cell is evident from Fig. 2.At the resonant frequency of the EBG unit cell, the S_{21} parameter exhibits a steep fall indicating a notched band. It is observed that for the conventional mushroom-type EBG unit cell, the resonant frequency is 7.6 GHz. After the C-slot is introduced, the same EBG unit cell resonates at 5.25 GHz. The reduction in the resonant frequency of the EBG unit cell because of the C-slot results in the reduction of the electrical size of the unit cell by 44.76%.

B. Grooved Microstrip Line loading EBG unit cell

Although the electrical size of a mushroom type EBG unit cell is reduced by the introduction of the C-slot, it also reduces the conducting surface area of the unit cell. As a result, the coupling between the unit cell and the microstrip line has decreased. From Fig. 2, it can be observed that the S_{21} parameter values reduce from -8.5 dB to -6.5 dB at its resonant frequency. This is due to the reduction in the coupling between the EBG unit cell and the microstrip line.To enhance the coupling between the microstrip line and the EBG unit

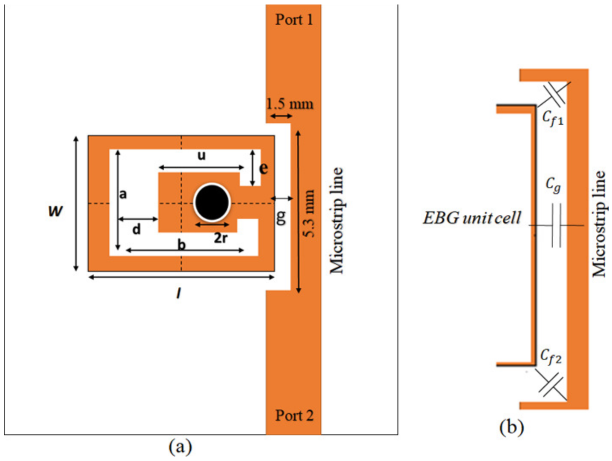

Fig. 3. (a) Grooved microstrip line loaded with slotted EBG unit cell.(b)equivalent capacitance model showing the capacitive coupling between the microstrip line and EBG unit cell.

cell, a groove of dimension $5.3mm \times 1.5mm$ is introduced in the microstrip line where the slotted mushroom-type EBG cell is coupled. Fig. 3 shows the modified microstrip line coupled to the EBG unit cell. Due to this new geometrical modification in the microstrip feed line, in the truncated areas new capacitance C_{f1},C_{f2} are developed. From Fig. 3, it can be observed that, all the capacitance C_g and C_{f1},C_{f2} are parallel to each other, therefore the total capacitance due to groove will be C_{g0}=C_g+C_{f1}+C_{f2}. The expression for C_{f1} and C_{f2} is as follows [20] in eq 6.

$$C_{f1}, C_{f2} = \frac{1}{2}[\frac{\sqrt{\varepsilon_r}}{cZ0} - \frac{\varepsilon_0 \varepsilon_r w}{h}] \tag{6}$$

As the $\frac{w}{h} \geq 1$ for the EBG unit cell Z_0 the characteristics impedance of the microstrip line is given as,

$$Z_0 = \frac{120}{\sqrt{\varepsilon_{re}}}(\frac{w}{h} + 1.339 + 0.667ln(\frac{w}{h} + 1.444))^{-1} \tag{7}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\sqrt{1 + 10\frac{h}{w}} \tag{8}$$

The new resonant frequency of the EBG unit cell is given in eq 9. Here, the value of c_{g0} will be bigger than c_g and hence there will be a further reduction in the resonant frequency of the unit cell.

$$f_0 = \frac{1}{2\pi\sqrt{(L_v + L_c)(C_{go} + C_h)}} \tag{9}$$

Fig. 4 shows a comparison of the frequency response of the S_{21} parameter of the microstrip line coupled with the mushroom type EBG unit cell with and without the groove geometry. It is observed that with the introduction of the groove, the resonant frequency of the unit cell has shifted to 5.2 GHz and the value of S_{21} parameter is suppressed to -12 dB. It can be shown that this shift has resulted in a further reduction in the electrical size of the mushroom type EBG unit cell to 46.15%.

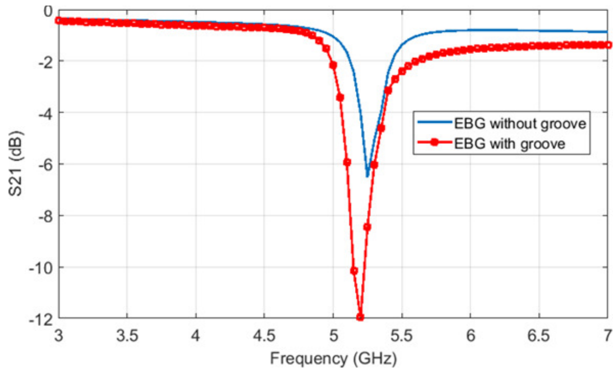

Fig. 4. Frequency response of the S_{21} parameter without and with a groove coupled EBG in the microstrip line

TABLE II
DIMENSIONS OF THE PROPOSED UWB ANTENNA

Dimensions of the UWB antenna	L_p	W_p	L_{sub}	W_{sub}	L_g	W_g	W_f	L_f
Values in (mm)	13	12	27	19	19	10	3	12.5

III. DESIGN OF A BAND-NOTCHED UWB ANTENNA WITH MUSHROOM TYPE EBG UNIT CELL

In this section, the designed EBG unit cell presented in section II is used to notch the same frequency from a UWB antenna. For this purpose, a UWB antenna of width W_{sub}= 19 mm, Length L_{sub}= 27 mm is designed. The EBG unit cell is placed near the microstrip feed line to achieve a frequency notch at 5.2 GHz. The topology of the designed UWB antenna is shown in Fig. 5(a).The patch antenna is designed on anFR4 epoxy substrate with a dielectric constant (ε_r) of 4.4 and substrate height h = 1.5 mm.To achieve UWB operating frequency behavior, a partial ground plane L_g = 19 mm with slotted structures at the radiating patch has been adopted. The detailed dimensions of the antenna are listed in Table II .Fig. 6 shows the VSWR plot of the proposed UWB patch antenna for the dimensions listed as in Table II. It is observed that for most parts of the UWB frequency band, the designed antenna archives VSWR well below 2.

Fig. 7 shows the VSWR plot of the UWB antenna with EBG loading near the microstrip feed line. The VSWR of an antenna should maintain value below 2 for its operating frequency band. The notch band can be observed from the VSWR plot as it rises to values above 2 at the notch bands. It is observed that when the groove is applied on the feed line, there is an improvement in the suppression. Further, the introduction of the groove reduces the notch frequency from 5.25 GHz to 5.2 GHz. The notch behavior is further validated from the simulated far field gain of the antenna along the direction of the major lobe. The frequency response of the far field gain is shown in Fig. 8. Without grooved microstrip line, the gain is suppressed to a maximum of -1.6 dBi which is not enough to filter out possible interference in an effective manner. The introduction of the groove geometry in the feed line enhances the gain suppression to -5.8 dBi at 5.2 GHz. The propose groove structure improves the coupling between

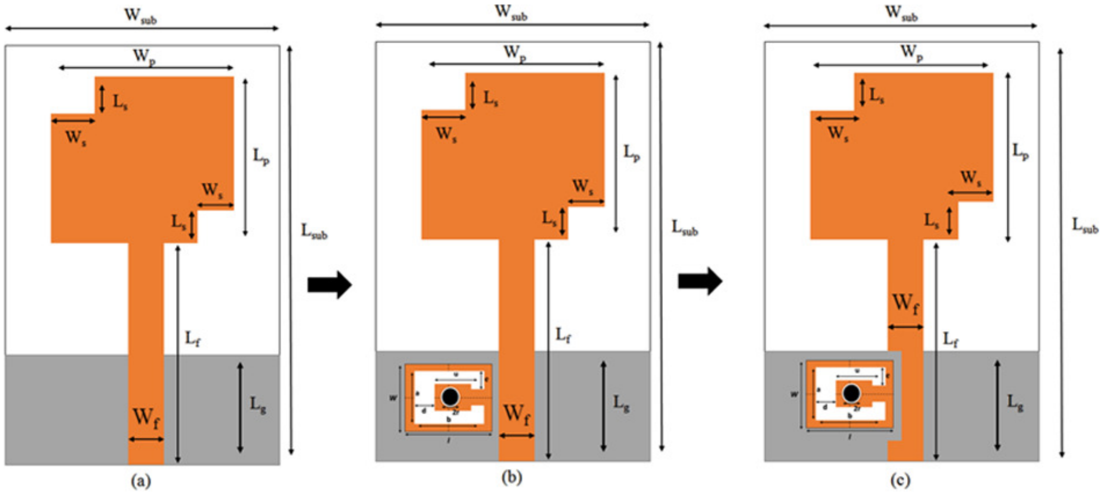

Fig. 5. Topology of the (a) UWB antenna, (b) UWB antenna loaded with the proposed C-slottedEBG unit cell (c) UWB antenna with modified grooved feed microstrip line coupled EBG unit cell as a notched filter.

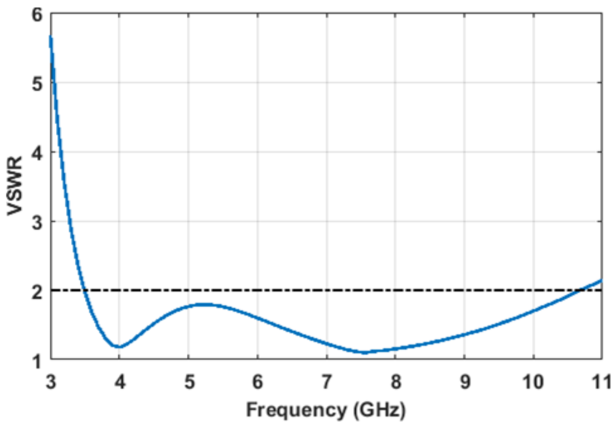

Fig. 6. VSWR plot of the proposed UWB patch antenna for slot dimension of W_s=L_s=1mm

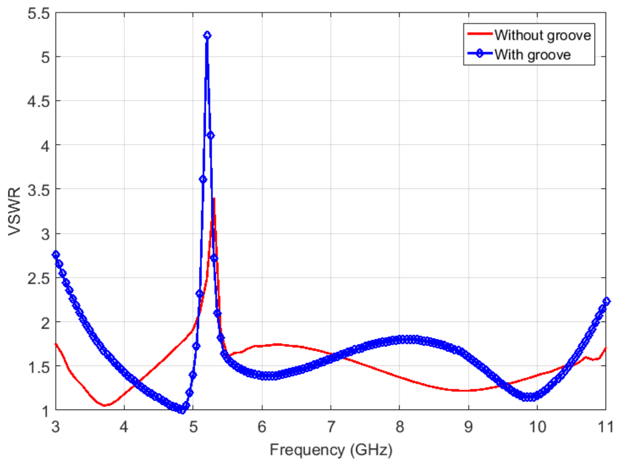

Fig. 7. Frequency vs. VSWR plot of the UWB antenna with and without Grooved loaded EBG.

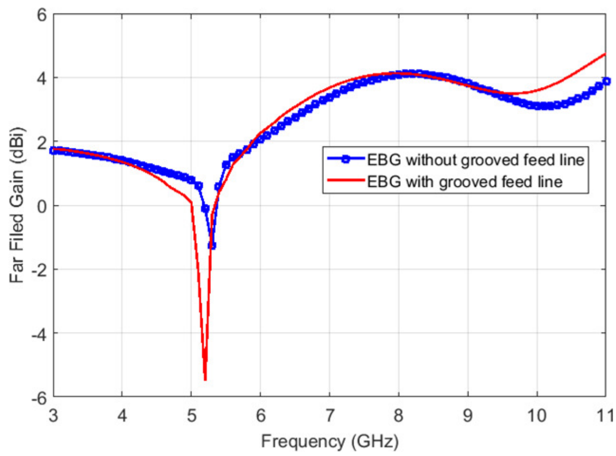

Fig. 8. Gain vs Frequencyplot of the band notched UWB antenna along the z-axis ($\theta = 0$, $\phi = 0$)

the feed line and the mushroom type unit cell, and the effect is clearly visible from the notch performance of the antenna.

IV. Evaluation and Analysis of the Proposed Antenna from Simulated and Measured Result

The antenna with the grooved feed line coupled EBG unit cell is fabricated on a copper-FR4 epoxy PCB. The fabricated antenna is shown in Fig. 9 Various simulation and measurement results are analyzed in this section to validate the band notch behavior of the antenna and to understand its properties.

A. Validation of the band notch behavior of the antenna from the VSWR and Far Field Radiation Pattern

The performance of the antenna is evaluated based on VSWR and far field gain from the simulation as well as a measured result. The measurements are performed using Rhode and Schwarz® ZNB20 Vector Network Analyser (VNA). Fig. 10 shows the simulated and measured results of VSWR in the UWB band of the patch antenna with grooved EBG. The notch filtering effect of the EBG cell is observed at 5.2 GHz, where the VSWR becomes high. To further validate this behavior,

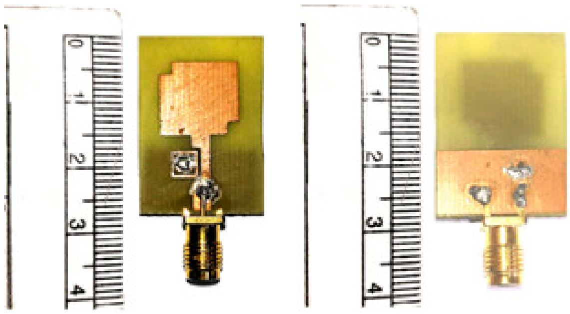

Fig. 9. The fabricated EBG loaded UWB Antenna with top view and bottom view

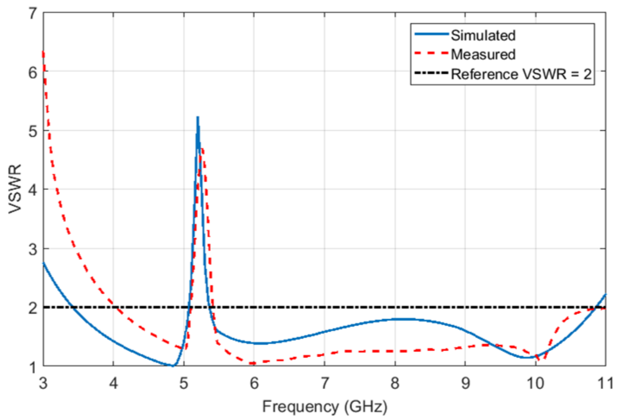

Fig. 10. Simulated and measured values of VSWR of the proposed antenna with c- slotted EBG with the grooved microstrip feed line.

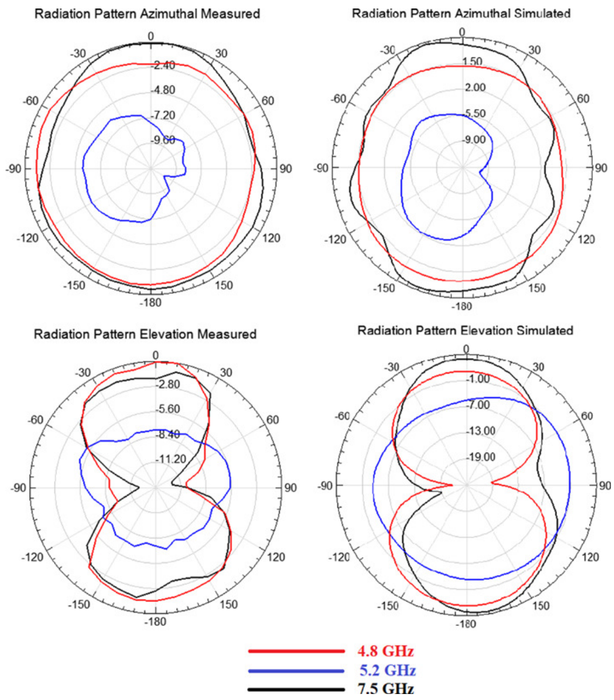

Fig. 11. Far-field radiation pattern of the antenna in (a) Azimuthal Plan (simulated), (b) Azimuthal plan (measured), (c) Elevation Plan (simulated) and (d) Elevation Plan (measured) at three different frequencies 4.8 GHz, 5.2 GHz, and 7.5 GHz is shown.

the simulated and the measured far-field radiation patterns of the antenna at the elevation plane and the azimuthal plane are observed. The far-field radiation patterns are observed at three different frequencies. The first frequency at which the far field radiation pattern is observed is 4.8 GHz; where the values of the VSWR close to 1. The second frequency is 5.2 GHz, where the maximum notch is yielded in terms of VSWR. The third frequency is 7.5 GHz where VSWR more then 1. Here, the measured results are normalized with respect to the maximum gain achieved. From Fig. 10, the band notch behavior of the antenna can be properly understood. The antenna shows a sharp notch at 5.2 GHz which is close to the resonant frequency of the EBG unit cell. There is a slight disagreement between the simulation and measurement results which may be attributed due to fabrication errors.

B. Analysis of the Surface Current Distribution on modified EBG Unit Cell Coupled to UWB Antenna

The surface current density of the proposed antenna system is observed from the simulation results to study the notching behavior of the proposed antenna loaded with grooved EBG unit cell. The current density is observed at above mentioned three frequencies 4.8GHz, 5.2 GHz and 7.5 GHz for which the far-field radiation patterns are also measured.The surface current density of the antenna at these three frequencies is shown in Fig. 12. At 4.8 GHz, the current density is the maximum at the feed line, indicating that most of the power is perfectly transferred to the antenna as impedance is perfectly matched at that frequency. Fig. 12(b) shows that at the resonating frequency 5.2 GHz of the EBG unit cell, most of the current field is confined around the EBG structure and hence a very negligible amount of power is delivered to the radiating antenna. At 5.2 GHz it can be considered that EBG unit cell absorbs most of the power coupled in the microstrip line. The peak gain at 7.5 GHz can be explained from the current density plot shown in Fig. 12(c). Here, it is observed that most of the power is coupled to the radiating patch. An observation which is common in Fig. 12(a) and 12(c) is that the EBG structure does not resonate and hence part of the power transferred from the feed line to the EBG structure also gets transferred to the patch.

It is observed that the current density is higher at the portion of the patch close to the EBG structure. The same is not true for 5.2 GHz. In this case, as the EBG structure resonates, it stores most of the energy within itself and does not allow it to pass to the patch antenna. However, if observed minutely, the current density is slightly higher at the portion of the patch close to the EBG structure.

V. CONCLUSIONS

The electrical size of a mushroom type EBG unit cell is significantly reduced by the introduction of a C-slot in the unit cell. The EBG unit cell is coupled with a microstrip line to design a band notch filter. A novel groove coupling method is proposed which enhances the coupling between the microstrip line and the mushroom type EBG unit cell. This arrangement

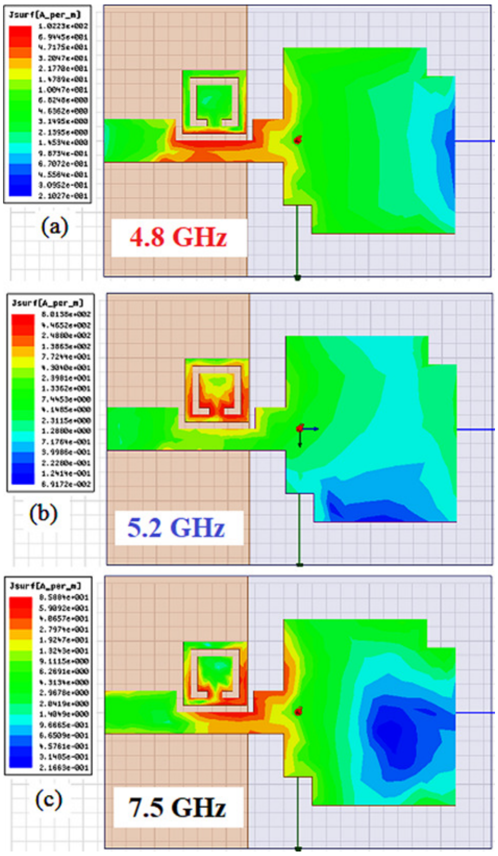

Fig. 12. Surface current density of the UWB antenna loaded with C-slotted EBG unit cell at (a) 4.8 GHz, (b) 5.2 GHz and (c) 7.5 GHz showing the effect of a grooved coupled microstrip line on EBG unit cell

has resulted in the stop band suppression of the filter to -12 dB at 5.2 GHz. The proposed filter comprising of the compact mushroom-type EBG unit cell coupled with a microstrip line is used to excite a UWB patch antenna. The resultant suppression of the far field gain of the UWB antenna was -5.8 dBi at 5.2 GHz. The notch behavior of the antenna is valued from the VSWR and far-field radiation pattern obtained from simulation and measurement. The behavior of the antenna is also studied by analyzing the surface current distribution of the antenna at various frequencies.

REFERENCES

[1] Yablonovitch E.“Inhibited spontaneous emission in solid-statephysics and electronics”, *Phys. Rev. Lett.*, vol. 58, issue. 20, pp. 2059-2062, 1987.

[2] John S. “Strong localization of photons in certain disordered dielectric superlattices”, *Phys. Rev. Lett.*, vol. 58, issue. 23, pp. 2486-2489, 1987.

[3] Yang F.,RahmatSamii Y. “Microstrip Antennas Integrated with ElectromagneticBand-Gap (EBG) Structures: A Low Mutual Coupling Design for Array Applications”, *IEEE Trans., Antennas Propag.*, vol.51, issue. 10, pp. 2936-2946, 2003.

[4] Abedin M. F., Azad M. Z. “Ali M.Wideband Smaller Unit-Cell Planar EBG Structures, and their Application”, *IEEE Trans., Antennas Propag.*, vol. 56, issue. 3, pp. 903-908, 2008

[5] Peng L., Ruan C.,Xiong J. “Compact EBG for Multi-Band Applications”, *IEEE Trans., Antennas Propag.*, vol. 60, issue. 9, pp. 4440-4444, 2012

[6] FCC. “First Report and Order, Revision of part 15 of the commission’s rule regarding ultra-wideband transmission system"’, 2002 USA: pp. 98-153.

[7] Zhuang W., Shenand X., Bi Qi.“Ultra-wideband wireless communications”, *Wireless Com. Mobile Computing*, John Wiley and Sons Ltd., vol. 3, pp. 663-685, 2003.

[8] Wong K. L., Chi Y. W., Su C. M., Chang F. S. “Band-notched ultra-wideband circular-disk monopole antenna with an arc-shaped slot”, *Microw. and Opt. Technol. Lett.*, vol. 45, issue. 3, pp. 188-191, 2005.

[9] Chu Q. X., Yang Y. Y.“A compact ultra-wideband antenna with 3.4/5.5GHz dual band-notched characteristics”, *IEEE Trans., Antennas Propag.*, vol. 56, issue. 12:pp. 3637-3644, 2008.

[10] Kumar, A. and Singh, M.K. “Band-Notched Planar UWB Microstrip Antenna with T-Shaped Slot”, *Radioelectron.Commun.Syst.*, vol. 61, pp. 371, 2018.

[11] Peng L., Ruan C. L., Yin X. C. “Analysis of the small slot-loaded elliptical patch antenna with a band-notched for UWB applications”, *Microw. Opt. Technol. Lett.*, vol. 51, issue. 4, pp. 973-976, 2009.

[12] Peng L., Ruan C. L., Chen Y. L., Zhang G. M. “A novel band notched elliptical ring monopole antenna with a coplanar parasitic elliptical patch for UWB applications”, *J. Electro. Waves Appl.*, vol. 22, issue. 4, pp. 517-528, 2008.

[13] Jaglan N., Gupta S. D., Kumar B. K., Srivastava S. “Band notched UWB circular monopole antenna with inductance enhanced modified mushroom EBG structures”, *Wireless Newt.*, vol. 24, issue. 2, pp. 383-393, 2018.

[14] Trinh Van S., Dao Ngoc C. “Dual band-notched UWB antenna based on electromagnetic bandgap structures”, *Review-Journal on Electronics and Communications*, vol. 1, issue. 2, pp. 130-136, 2011.

[15] Kushwaha N., Kumar R. “Study of different shape electromagnetic band gap (EBG) structures for single and dual-band applications”, *J. Microw. Optoelectron. Electromagn. Appl*, vol. 13, issue. 1, pp. 16-30, 2014.

[16] Peng, L., Ruan C. L. “UWB band-notched monopole antenna design using electromagnetic bandgap structures”, *IEEE Transactions on Microwave Theory and Techniques*, vol. 59, issue. 4, pp. 1074-1081, 2011.

[17] Xu, F., Wang Z. X., Chen X., Wang X. A. “Dual band-notched UWB antenna based on spiral electromagnetic-bandgap structure”, *Progress in Electromagnetics Research B*, vol. 39, pp. 393-409, 2012.

[18] Kovacs P.,Urbanec T. “Electromagnetic band gap structures: practical tips and advice for antenna engineers”, *Radioengineering*, vol. 21, issue. 1, pp. 414-421, 2012.

[19] Sievenpiper D., Zhang L., Romulo F., Jimenez B., Alexopolous N. G., Yablonovitch E. “High-impedance electromagnetic surfaces with a forbidden frequency band”, *IEEE Trans., Antennas Propag.*, vol. 47, issue. 11, pp. 2059-2074, 1999.

[20] Gupta K.C., Garg R., Bhal I.,Bhartia P. “Microstrip Lines, and Slotlines,2nd edition”, Norwood, MA, 1996.