

Bandwidth Enhancement of UWB slot Antenna with EBG Structures

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ABSTRACT: In this research work, various electromagnetic band gap structures (EBG) are proposed for improving the return loss and impedance bandwidth of an UWB antenna. The comparative parametric analysis has been made on the basis of factors such as return loss, gain, radiation pattern characteristics and impedance bandwidth. The analysis has been made on an UWB antenna consisting of four slots in its radiating patch with five different types of EBG configurations using HFSS (High Frequency Structural Simulator).

KEYWORDS: Ultra Wideband (UWB), Microstrip Patch Antenna, Electromagnetic Band Gap Structure (EBG)

I. INTRODUCTION

There has been immense utilization of electromagnetic band gap (EBG) structures in the electromagnetic and antenna community nowadays [1]. These structures are artificially engineered objects which may be periodic or non-periodic in nature, which helps prevent the propagation of electromagnetic waves within a specific frequency band regardless of different incident angles and state of polarizations [2]. The primary advantage of employing an EBG structure in the ground plane is their ability to suppress the currents generated by the surface waves which reduce an antenna's efficiency and its radiation pattern. These EBG structures enhance the performance of a microstrip antenna by utilizing the inherent properties of the dielectric materials used. There are two ways to improve the gain of an antenna by utilizing EBG structures by using it as superstrate [3-4] or as a ground plane [5-6]. The EBG characteristics can be governed by Shape, Size, Symmetry and Material used. There are numerous advantages of EBG and mainly is to enhance the Bandwidth and gain of an antenna. Even, it helps to improve isolation gain and diversity in MIMO systems [7-9], also provides notch characterization in UWB antennas [10], can suppress noise and reduce EMI in high speed circuits [11-14].

II. RELATED WORK

Marie Chantai Mukandatimana et. al. (2004) [26] proposed a multi-resonator microstrip line fed patch antenna for dual band operation using two rectangular patches separated by an air gap which was U-shaped in nature. The two resonant frequencies obtained were 2.3 and 5.5 GHz which were characterized by good omnidirectional radiation patterns and acceptable input impedance, because monopole antennas offered wider bandwidth on being fed by microstrip line.

E. Cheltiar et. al. (2004) [27] obtained wideband characteristics by employing a U-shaped slot on the rectangular patch. This paper presented the analyzed results for higher as well as lower dielectrics on the basis of different empirical equations for calculating the resonant frequencies simulated by different parametric conditions. It was concluded that the resonant frequencies obtained by both formulations were in good agreement for low permittivity substrates used for the U-shaped slot antennas, and the accuracy decreased in the case of high permittivity substrates since they required more and longer cycles for optimization to obtain results suitable for wideband communication.

Jihak Jung et. al. (2005) [29] proposed a novel compact microstrip-line fed monopole antenna for UWB application. Its geometry referred to the design of antenna for handheld devices, which incorporated a pair of notches at the two lower corners of the patch. Also the ground plane was truncated and the notch structure was embedded into it.

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The paper discussed both the simulated and experimentally investigated results for return loss and radiation pattern of the antenna.

Evangelos S. Angelopoulos et. al. (2006) [30] tested four prototype antennas with circular and elliptical slot, three being fed by CPW and one being fed by microstrip feed line method. The prototypes were studied in terms of impedance bandwidth, radiation efficiency and characteristics of radiation patterns and the measured impedance bandwidths were obtained beyond 175 %. It was observed that by transforming the feed line from CPW to microstrip line helped preserve the UWB characteristics along the radiation profile.

Mohammad Ojaroudi et. al. (2009) [32] proposed an Ultra Wideband antenna consisting of rectangular slots in the square radiating patch accompanied by a T-shaped notch in the ground plane. The prototype was investigated for the effects of both with and without slots and the notch and was optimized for the antenna dimensions. The optimized design yielded a fractional bandwidth of 120% and an enlarged bandwidth range from 3.12 to 12.73 GHz.

Dalia Nashaat Elsheakh et. al. (2009) [34] designed and characterized a UWB antenna using a semicircular radiating patch and used the Spiral Artificial Magnetic Conductor (AMC) as the ground plane which helped diminish the antenna size and the cross polarization effect, and an increase in the gain of the antenna and bandwidth. Furthermore holes were drilled in the substrate surrounding the radiator to remove the discontinuities and surface wave propagations. The investigated bandwidth came out to be from 1 to 35 GHz with an efficiency of 0.92.

Hsien-Wen Liu et. al. (2010) [35] fabricated and tested a UWB antenna with band notching characteristic. The prototype developed was very compact compared to other antennas. It consisted of a square slot patch with a coupling strip in vertical direction which flexibly controlled the rejection of frequency interferences from WLAN (5.15-5.85 GHz) and WiMAX (5.25-5.85 GHz) in UWB operations. The proposed prototype was found to be suitable for integration into portable UWB devices due to features like omni directionality, stability in transmission characteristics and very efficient pulse handling for high data rate systems.

Jianjun Liu et. al. (2010) [36] proposed a multiband printed UWB antenna for wireless systems. The geometry was comprised of an elliptical radiating patch accompanied with a tapered microstrip feed line. The simulated results reported an extremely wide impedance bandwidth of 1.08 to 27.4 GHz. Thus, the antenna was found capable for serving multiple wireless services as well as wide spectrum monitoring RF based scavenging applications.

Rezaul Azim et. al. (2011) [39] introduced a very compact tapered shaped slot antenna fed by a microstrip feed line. It also consisted of a tuning stub etched on the opposite side of the radiating patch. The prototype was studied on the basis of several parameters such as the effect of various tuning stubs, effect of different slot shapes and that of the feeding gap too. The proposed antenna was found in accordance with the appropriate impedance matching, constant gain, omnidirectional pattern and an enlarged bandwidth from 3-11.2 GHz.

Zheng Guo et. al. (2013) [43] introduced an enhanced bandwidth monopole UWB antenna suitable for all mobile applications. Two methods were employed to increase the bandwidth; the first one was the introduction of new slots in the ground plane which enhanced the bandwidth to 9.33 GHz and the second method was to embed the antenna structure with conventional mushroom type electromagnetic band gap (CMT-EBG) which further enhanced it to 9.47 GHz. Both these methods posed least effect on radiation patterns and the basic frequency curves compared to that of the conventional prototype antenna.

III. METHODOLOGY OF STUDY

We have utilized the ground plane as an EBG structure for studying the effect of various shapes of these structures over the bandwidth of the proposed antenna. Also, here we have used full ground plane instead of the partial one. Five types of EBG structures are studied in this section whose configurations are DISCUSSED in the following sub-sections.

1.3.1 Ground Plane with Circular Shaped Holes as EBG:For designing circular holes as EBG in the ground plane, circles of radius 1.5mm are made with a distance of 1mm between each other which may result in reduced weight and volume [18]. Hence, the whole ground plane is represented by these EBG structures

1.3.2 Ground Plane with Square Shaped Holes as EBG:In order to make square shaped holes as EBG structures in the ground plane, 2 mm squares are cut in the full ground plane separated by a distance of 2 mm. Here the square holes are arranged in matrix order to study the effect on surface waves [19]

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1.3.3 Ground Plane with Square Shaped Holes separated by Cylinders as EBG: For further reduction in the surface waves of the antenna and for reducing the interference the square shaped EBG's are separated by cylinders in the middle [19]. This design is an extension of the design taken in the previous section with an addition of cylinders drilled along the center of the substrate so as to avoid the mutual coupling between the two square arrays. These cylinders have radii of 1.5 mm, a height of 1.6 mm and distance between their centers as 2 mm.

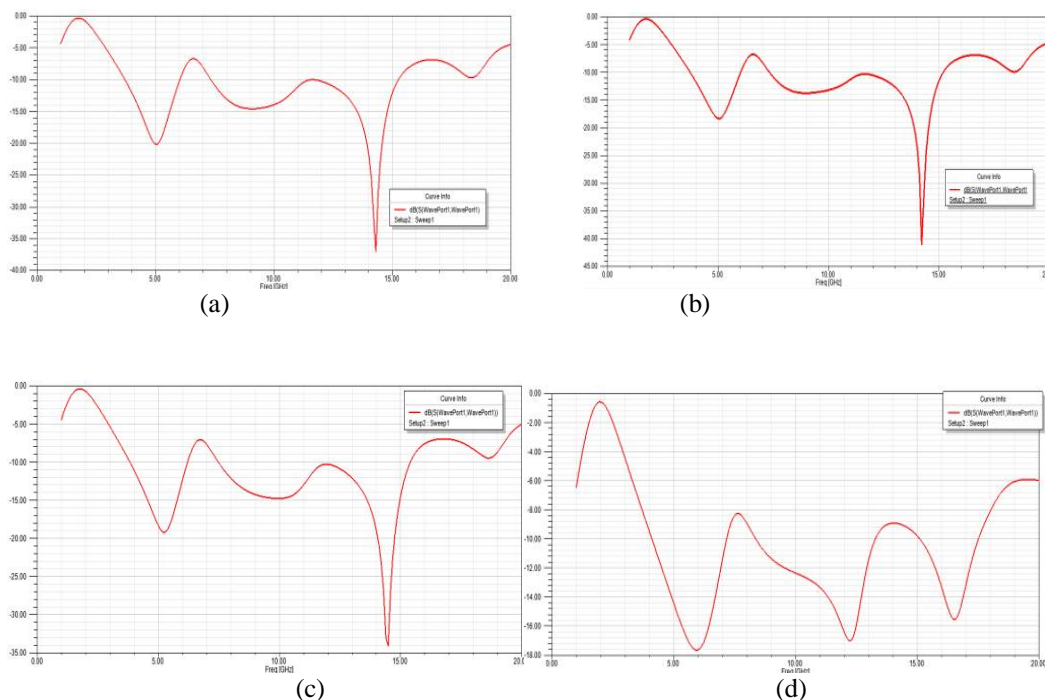
1.3.4 Ground Plane with Cylindrical Holes as EBG: In this configuration, the cylindrical holes are embedded throughout substrate thickness in triangular lattice form to study its effect on bandwidth and the surface wave radiations [16]. The radius of each individual cylinder is 1.5 mm, with a height of 1.6 mm separated at a distance of 4.5 mm along Y-axis and 4 mm along X-axis in order to be in triangular lattice form structure.

1.3.5 Ground Plane with Mushroom Type EBG: This EBG structure is the most conventional type of three dimensional structures used which consists of a solid patch with a cylindrical via. The transmission response of mushroom type EBG depends upon the size of the patch, diameter of via and the gap between the unit elements. The transmission characteristic also depends upon the thickness of the substrate and the substrate material [17]. The size of unit element for building the mushroom type structure is 1.5 mm × 1.5 mm at a height of 0.8 mm. The via diameter is taken as 0.6 mm while the gap between unit element is taken as 1 mm.

IV. EXPERIMENTAL RESULTS

In lieu of drawing a comparative analysis between the different types of EBG structures used here, we have studied the performance characteristics by using FR-4 Epoxy ($\epsilon_r = 4.4$).

1.4.1 Return Loss Characteristics: This is the very first parameter under study which is carried out at the solution frequency of 3.5 GHz for the three different materials stated above. Here also we get two resonating frequencies due to EBG structures in the ground plane. Also these EBG structures have effects on lower and upper frequencies which will ultimately affect the impedance bandwidth of the antenna. The following fig 5.35 – 5.39 depict the return loss plots for different EBG configurations of the slot antenna.



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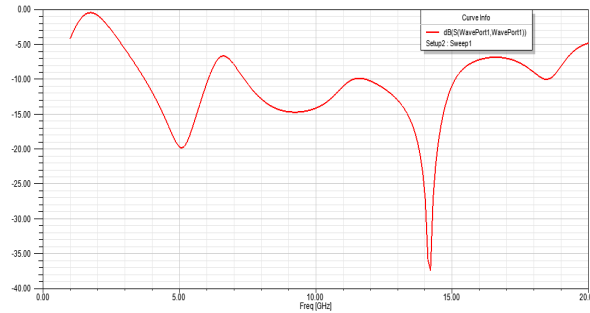


Fig.1.1: Return Loss Plots for Circular Shaped Holes , Square Shaped Holes, Square Shaped Holes separated by Cylinders, Cylindrical Holes, Mushroom Type

The table 1.1 represents the minimum return loss values obtained for the five different EBG configurations under study with three different substrate materials namely; FR-4, Rogers and Neltec. It is observed on comparative analysis; the minimum value of -41.0228 is obtained for square shaped holes EBG with the FR-4 material being used. Also from moving left to right of the table we observe a gradual increase in the values with the change of respective materials under consideration.

Table 1.1: Obtained Return Loss Values for Different EBG Configurations

TYPE OF EBG CONFIGURATION	RETURN LOSS S_{11} (dB)		
	FR-4 EPOXY ($\epsilon_r = 4.4$)	ROGERS - RT / DUROID 5880 ($\epsilon_r = 2.2$)	NELTEC ($\epsilon_r = 3.5$)
CIRCULAR HOLES	-37.1027	-28.0555	-24.6722
SQUARE SHAPED HOLES	-41.0228	-27.0834	-26.3281
SQUARE SHAPED HOLES SEPERATED BY CYLINDERS	-34.0412	-33.6896	-23.0848
CYLINDRICAL HOLES	-17.6174	-30.9103	-18.8367
MUSHROOM TYPE	-37.3295	-28.4093	-25.0780

1.4.2 Radiation Pattern Characteristics

For efficient performance of an antenna the radiation pattern characteristics also play a major role as it depicts the direction of maximum radiation of the antenna. The radiation pattern of the five varying EBG configurations are studied at the solution frequency of 3.5 GHz which are as shown as below.

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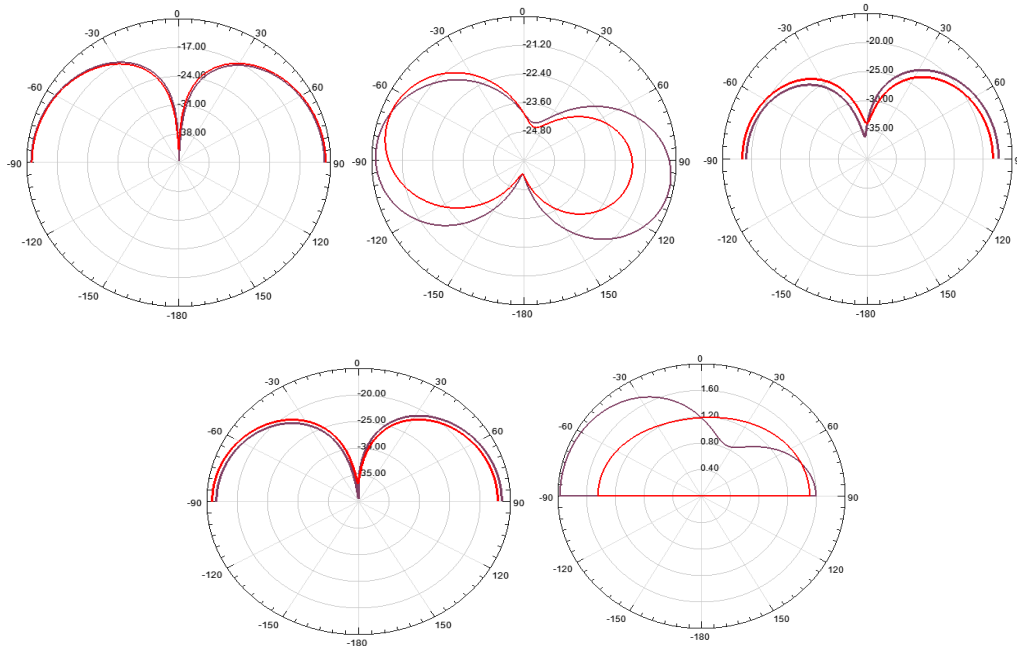


Fig 1.8: Radiation Pattern of Mushroom Type EBG (a) FR-4 (b) Rogers (c) Neltec

Table 1.2 below depicts the maximum gain values obtained for the different EBG structures under study. The gain values are calculated at the solution frequency of 3.5 GHz for the three respective materials under consideration. We observe that the maximum value is 4.7160 and 4.5738 respectively for the square holes as EBG in the ground plane when FR-4 epoxy and Rogers is used as the substrate, while the highest value is 5.1634 for circular holes as EBG when Neltec is used as the substrate.

Table 1.2: Maximum Gain Values for Different EBG Configurations

TYPE OF EBG CONFIGURATION	MAXIMUM GAIN (dB)		
	FR-4 EPOXY ($\epsilon_r = 4.4$)	ROGERS - RT / DUROID 5880 ($\epsilon_r = 2.2$)	NELTEC ($\epsilon_r = 3.5$)
CIRCULAR HOLES	4.2660	3.7545	5.1634
SQUARE SHAPED HOLES	4.7160	4.5738	3.0838
SQUARE SHAPED HOLES SEPERATED BY CYLINDERS	3.2118	3.3539	4.1888
CYLINDRICAL HOLES	2.1833	3.2596	3.0889
MUSHROOM TYPE	4.6054	3.9663	4.2526

1.4.3 Impedance and Percentage Bandwidth

The following table 1.3 shows the calculated values for the different EBG configurations. It is important here to note that we are making calculations only for the FR-4 substrate as the return loss plots for the remaining two materials is having fringing effects due to surface waves propagation. Hence almost two band notches are observed for both Rogers

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and Neltec substrates, while in case of FR-4 we have a constant trace characteristic in the return loss plot which can be utilized for the bandwidth calculations.

Table 1.3: Calculated Values of Impedance and Percentage Bandwidth for FR-4 Epoxy as Substrate

PARAMETER	CIRCULAR HOLES EBG	SQUARE HOLES EBG	SQUARE HOLES SEPERATED BY CYLINDERS	CYLINDRICAL HOLES EBG	MUSHROOM TYPE EBG
UPPER FREQUENCY, f_H (GHz)	15.3174	15.1925	15.4422	17.5412	15.1717
LOWER FREQUENCY, f_L (GHz)	3.6629	3.6629	3.8085	4.0999	3.7253
CENTER FREQUENCY, f_C (GHz)	9.49	9.4277	9.6253	10.82	9.4485
IMPEDANCE BANDWIDTH, $BW_{(UWB)}$ (GHz)	11.6545	11.5296	11.6337	13.4413	11.4464
PERCENTAGE BANDWIDTH, % BW (%age)	122.8	122.29	120.86	124.23	121.14

From the above evaluated values, we observe that the maximum impedance bandwidth obtained is 13.4413 GHz while the percentage bandwidth is 124.23% for cylindrical holes drilled in the substrate as EBG in the ground plane.

V. CONCLUSION

From the above parametric analysis, we deduce that the best candidate for bandwidth enhancement is the cylindrical holes EBG configuration having the return loss of -17.6174 dB, gain value equal to 2.1833 dB, maximum impedance bandwidth of 17.5412, omnidirectional radiation characteristics and also the maximum percentage bandwidth of 124.23% compared to rest of the EBG configurations under consideration.

Hence, from our study we conclude that EBG structures help mitigate the effect of surface waves accompanied by an increase in the impedance bandwidth of an UWB antenna. And the cylindrical air holes EBG structure with four slots in the radiating patch of our proposed antenna proves out to be the best candidate.

The future scope of this work may focus on the following factors:

- i. Constant gain over entire impedance bandwidth.
- ii. To observe multiple band notch characteristics.
- iii. More focus on having constant group delay.
- iv. Employment of multiple substrates.
- v. Utilization of dual band EBG structures for bandwidth enhancement.

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