Realization of Band-Notch UWB Monopole Antenna Using AMC Structure

Pradeep Kumar[1], Zachariah C Alex[2]
School of Electronics Engineering, VIT University
Vellore, Tamil Nadu, India
[1] infopradeep7@gmail.com
[2] zcalex@gmail.com

***Abstract*—This article presents the design, simulation and testing of an Ultra Wide Band (UWB) planar monopole antenna with WLAN band-notch characteristic. The proposed antenna consists, the combination of planar monopole antenna with partial ground and a pair of AMC structures. The AMC structure used for the design is mushroom-like. Design equation of EBG parameters is also proposed for FR4 substrate using transmission line model. Using proposed equations, Mushroom-like EBG structure is integrated along the feed line of a monopole antenna for WLAN (5 GHz – 6 GHz) band rejection. The Current distribution and equivalent circuit model of antenna is used to explain band-notch characteristic of EBG resonator. The proposed antenna is fabricated on an FR4 substrate with a thickness of 1.6 mm and ε_r = 4.4. The measured VSWR characteristic is less than 2 for complete UWB band except for WLAN band i.e. 5 GHz – 6 GHz. The gain of the proposed structure is around 2 dBi – 6.7 dBi for complete UWB band except for WLAN band where it is reduced to -4 dBi. The measured radiation pattern of proposed antenna is omnidirectional along H plane and bidirectional in E plane. A nearly constant group delay with variations < 2ns, except for the notched bandwidth makes proposed antenna suitable for UWB application.**

Keyword-Artificial Magnetic Conductor (AMC), Ultra Wide Band (UWB), Electromagnetic Band Gab (EBG) structure, Mushroom-like EBG, Band-notch

I. INTRODUCTION

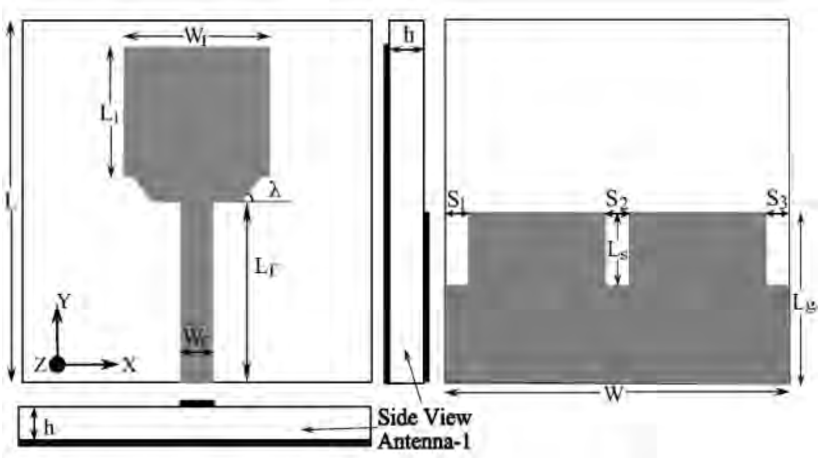
In the last decade, there is a growing demand from users for faster and higher data rate capacity wireless devices. To accomplish such demand, ultra wide band (UWB) covering the frequency band between 3.1 GHz - 10.6 GHz [1] has become one of the most promising technologies for future high data-rate wireless communications. As a key component of UWB communication systems, planer UWB monopole antenna has drawn attention of many researchers of both industry and academia because of its compact size, wideband properties and good omni-directional radiation pattern. Many UWB antennas with different techniques like ground tapering, parasitic element with radiating patch has been proposed to improve the impedance matching over a broad frequency spectrum [2 - 3], parasitic patches are also used for reducing the cross-polarization [4]. However, over the UWB frequency band, existing WLAN band (5.15 GHz - 5.825 GHz) may cause electromagnetic interference to the UWB system. Various techniques have been introduced in the literature [5 - 12] to notch the specific band in planar UWB antennas. The most common method is by cutting slots either in radiating element [5, 6] or in ground [7, 8]. In these methods, the radiation pattern and the time-domain behaviour of the antenna may be affected by disturbing the radiating element. Parasitic element was also used by many researchers to suppress a desired band. Parasitic element can be applied either near to radiating patch [9 - 11] or closer to feed line for band-notch characteristic [12]. It was introduced that the Artificial Magnetic Conductor (AMC) also known as Electromagnetic Band Gap (EBG) structure is having a band stop property [13, 14], thus it can be used for the design of UWB antennas with a band-notch characteristic. Recently UWB band pass filter with band-notch characteristic using EBG structures have been proposed [15]. However, the filter generally follows the antenna as an independent passive component and, antennas along with filters are not compact, as the sizes is an issue for many applications.

In this paper, we have integrated the UWB antenna with AMC structure into a single module, which can achieve the same band-notched characteristic as like other methods. The AMC structure used for our design is mushroom-like EBG. For this work, a reference planer UWB monopole antenna (Antenna-1) is designed with partial ground technique (Fig. 1). Further mushroom-like EBG structure is optimized for FR4 substrate of thickness 1.6mm by using transmission line model [18] at 5.5 GHz. The proposed antenna (Antenna-2) is the integration of both Antenna-1 and EBG structure on the same substrate (Fig. 5). The achieved band-notch through this configuration is from 5 GHz – 6.06 GHz. For structural optimization, we have used commercially available CST Microwave Studio 2011. The prototype of the proposed antenna is fabricated over an FR4 substrate of ε_r = 4.4 and thickness 1.6 mm. It observed that simulated and measured results are in good agreement.

II. Design And Implementation

A. Antenna Design

The geometry of reference antenna (Antenna-1) is shown in Fig. 1(a). The dimension of the proposed antenna is 32×30 mm^2. The antenna is optimised using basic microstrip patch design equations [16]. Antenna-1 consists of a rectangular radiator ($W_1 \times L_1$) with a tapering by λ at bottom corners. The tapered edges are introduced for increasing the percentage bandwidth. The ground plane (Fig.1 (b)) consists of a partial ground plane with three slots (S_1, S_2 & S_3) of equal width (S) and length (L_s). These slots are etched out for the better impedance matching between the feed line and radiator.



(a) (b)

Figure 1: Geometry of (Antenna-1), L = 32 mm, W = 30 mm, L_1 = 11.5 mm, W_1 = 13.2 mm, L_f = 16.2 mm, W_f = 2.8 mm, $S_1 = S_2 = S_3$ = 2.2 mm, L_S = 6.4 mm, L_g = 14.9 mm, $\lambda = 51^0$, h= 1.6 mm. (a) Front view and (b) Back view.

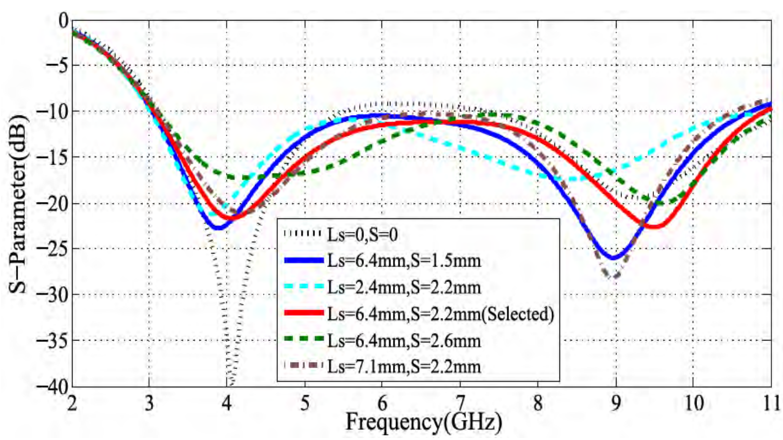


Figure 2. Analysis of return loss graph with respect to variation in the Width (S) and Length (L_S) of the S_2 slot.

A 50 microstrip line of length (L_f) and width (W_f) is used to feed the antenna. First we have optimised the length (L_S) and width (S) of the S_2 slot. The variation in return loss characteristic with change in L_S and S is shown in Fig. 2. The better impedance matching is obtained with S = 2.2 mm and L_S = 6.4 mm. The optimised S_2 is further etched from the ground plane in various combinations as shown in Fig. 3, to improve the impedance matching. It can be noticed from the Fig. 3, that the return loss characteristic is best when all the three slots (S_1, S_2 & S_3) are provided together to the ground.

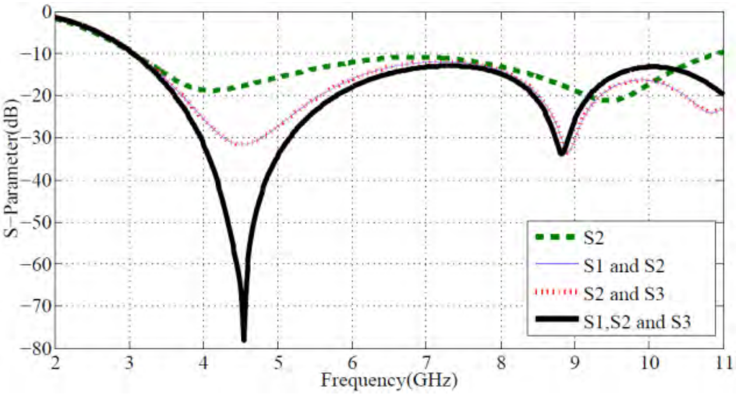
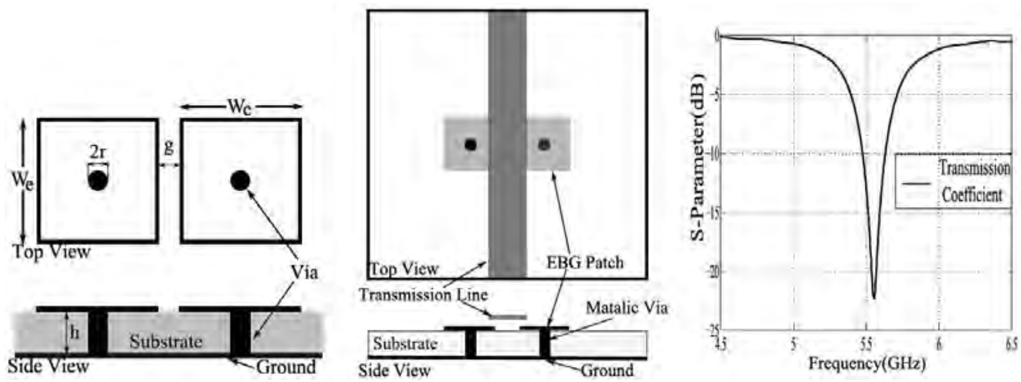


Figure 3. Analysis of return loss graph with respect to variation in the different combination of slots of Width (S) = 2.2mm and Length (L_S) = 6.4mm, over the partial ground plane.

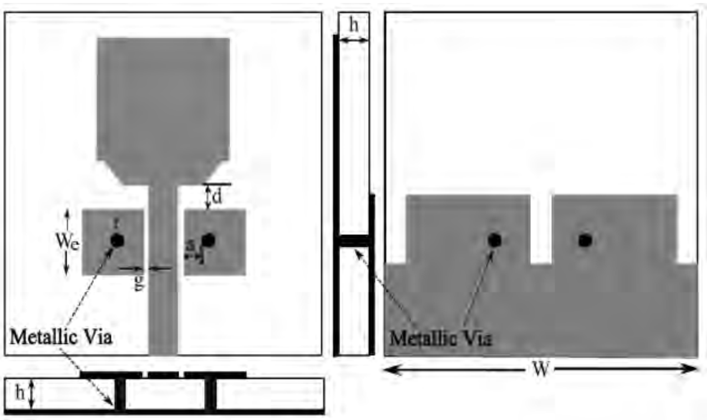
B. EBG Optimisation and Implementation

The mushroom-like EBG structure is first integrated with microstrip antenna in [13]. The band stop characteristic of M-like EBG structure for a specific band depends on different parameters like width of the EBG patch (W_e), vai radius (r), height(h) of substrate or via and gap between the patches (g) as shown in Fig. 4 (a). Design equations for these parameters are given in [17] but according to that the substrate height (h) is varying with frequency. In this case, we have used FR4 substrate of h=1.6mm. So we need to optimise the dimension of mushroom-like EBG parameters for FR4 substrate. For this purpose, transmission line model [18] is used as shown in Fig. 4 (b). The transmission characteristic of the transmission line model is shown in Fig. 4 (c).



(a) (b) (c)

Figure 4. (a) Unit cells of EBG Structure with its different parameters, (b) Transmission line model for the optimization of EBG structure and (c) Transmission characteristic of T-line model.



(a) (b)

Figure 5. Geometry of proposed Antenna (Antenna-2), W_e = 6.2 mm, a = 2.5 mm, r = 0.5 mm, g = 0.7 mm, d = 2.4 mm. (a) Top view and (b) Bottom view.

It can be noticed from the figure that the optimised EBG parameters provide a stop-band between 5 - 6 GHz. With the optimised result, the design equations of EBG parameters for FR4 substrate of height 1.6 mm are proposed in (1) – (3).

- W = 0.11 $\lambda_{5.5\ GH}$ (1)
- g = 0.05 $\lambda_{5.5\ GHz}$ (2)
- r =0.009 $\lambda_{5.5}$ (3)

Using Eqs. (1) – (3), EBG parameters are integrated with Antenna-1 over the same substrate to obtain the proposed band-notch antenna (Antenna-2) as shown in Fig. 5. The EBG patch is of square shape of width (W_e) placed at a distance d = 2.4 mm from radiating patch and with the gap of g = 0.7 mm from the feed line. Metallic via of radius r = 0.5 mm is used to short EBG patch with the ground plane. Both metallic vias are shifted from the centre towards the feed line having a distance of a = 2.5 mm from patch end, to increase the mutual coupling between them. The final dimensions of Antenna-2 using simulated analysis are listed in Table 1. The proposed antenna is fabricated over FR4 substrate as shown in Fig. 6, and measured for time domain analysis.

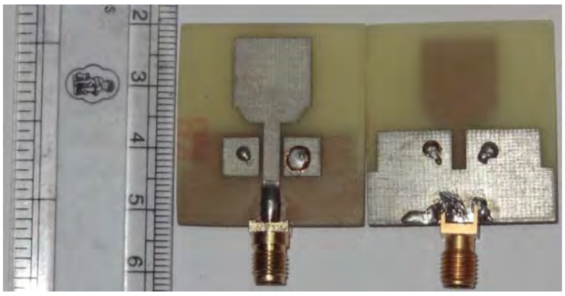


Figure 6. Fabricated prototype of Antenna-2

TABLE I
The Final Dimension of the Fabricated Antenna in mm

W	L	W_1	L_1	S	L_s	L_f	W_f
30	32	13.2	11.5	2.2	6.4	16.2	2.8
Lg	W_e	d	g	r	a	λ	h
14.9	6.2	2.4	0.7	0.5	2.5	510	1.6

III. Measurement And Analysis

A. Current Distributions and Circuit analysis

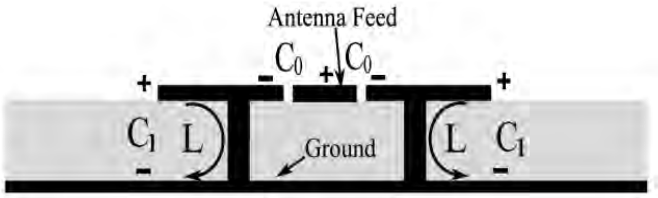
In order to understand the band-notch mechanism of the proposed antenna, the simulated current distribution of the Antenna-2 is obtained over the pass-band and notch-band region as shown in Fig. 7 (c) & Fig. 8 (b). The conceptual circuit models of proposed antenna for both bands are discussed in this section. The schematic view of proposed antenna is shown in Fig. 7 (a). Based on schematic diagram, equivalent circuit model of Antenna-2 is obtained over pass band at 3.5 GHz as shown in Fig. 7 (b). Over pass-band, EBG resonator is acting as short circuit and the effective current is passing directly through the antenna. This can be better explained by Eq. (4) of the parallel resonant circuit [17]

$$Z = \frac{j\omega L}{1-\omega^2 LC} \quad (4)$$

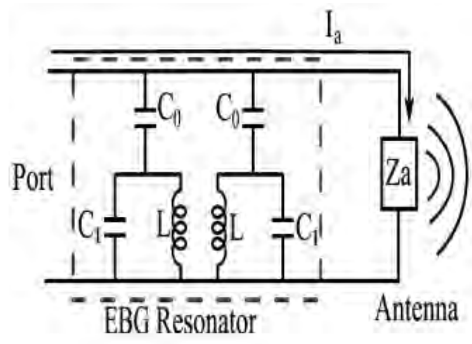
Where the resonant frequency of the circuit is given by Eq. (5)

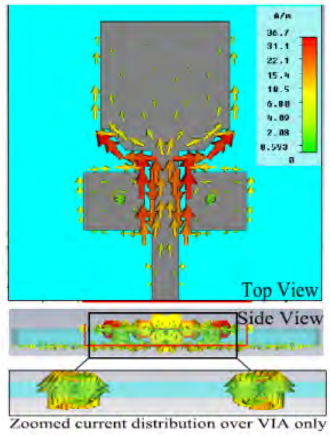
$$\omega_o = \frac{1}{\sqrt{LC}} \quad (5)$$

At low frequencies, the impedance is inductive and supports TM waves. At high frequencies, the impedance is capacitive and TE waves will be supported. Near the resonant frequency ω_0, high impedance is obtained and the EBG does not support any waves, resulting in a frequency band gap. Thus the EBG resonator is inactive over pass-band as shown in Fig. 7 (b). We can also understand the working of EBG resonator over the pass band through current distribution of antenna as shown in Fig. 7 (c). From the figure, we can observe that the current passing through via are opposite directions and very small in magnitude. And the resultant current is towards feedline which will be added with the effective current passing through the antenna. While in case of band-notch region, the current coming from the feedline is directly passing through via to the ground as shown in Fig. 8 (b). It means that the EBG resonator is providing a very high impedance to the feedline leads to the desired impedance mismatching near the notch frequency. Thus, EBG resonator behaves as an open circuit over the notched band as shown in Fig. 8 (a) and no current will pass through the antenna.



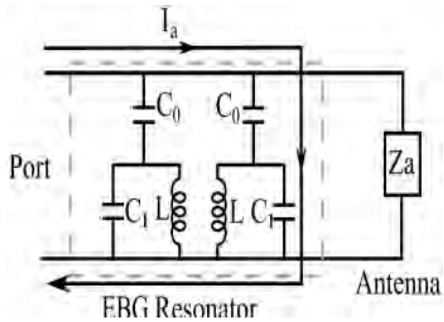
(a)

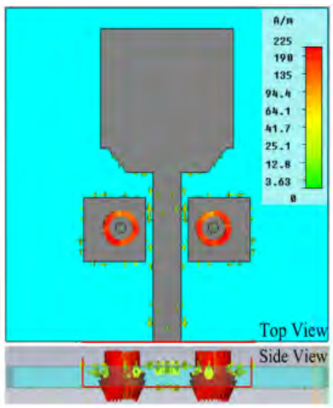




(b) (c)

Figure 7. (a) Schematic view of Antenna-2, (b) Equivalent circuit model of Antenna-2 over pass band, and (c) Current distribution of Antenna-2 at 3.5 GHz.





(a) (b)

Figure 8. (a) Equivalent circuit model of Antenna-2 in band-notch region, and (b) Current distribution of Antenna-2 at 5.5 GHz.

B. Parametric Study

The Antenna-1 is simulated with the single EBG cell and double EBG cells (Antenna-2), and their responses are compared with the reference antenna (Antenna-1) as shown in Fig. 9. It can be observed from the figure that the effective resonance is obtained by double EBG patches as compared to single EBG patch with Antenna-1. This is due to the mutual coupling between the two EBG cells, which provides higher mismatching to the feedline. The resonance over notch band can also be adjusted by varying the gap (g) between the feed line and EBG structure as shown in Fig. 10. This is due to the change in capacitance (C_0) of EBG resonator. It is observed that with the decrease in gap (g), the magnitude of VSWR increases sharply, at the same time the percentage bandwidth of stop-band also increase, i.e. resonance band increase due to the increase in effective capacitance. The desired notch band from 5.07 GHz-5.9 GHz is achieved by using two EBG patches with keeping the gap g=0. 7 mm. The measured VSWR of Antenna-1 and Antenna-2 are compared in Fig. 11.

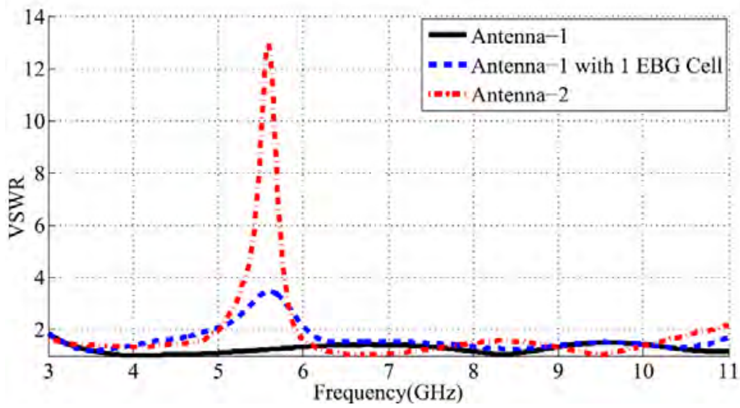


Figure 9. Simulated VSWR of Antenna-1 with no EBG cell (Antenna-1), single EBG cell and double EBG cell (Antenna-2)

It can be seen clearly from the figure that the proposed antenna has an impedance bandwidth range from 3 GHz to 11 Ghz for VSWR > 2, except the band-notch frequency from 5 Ghz – 6.06 GHz. Both the measured and simulated results are in good agreement and depicts that proposed antenna is suitable for a UWB application with a notched band from 5-6 GHz.

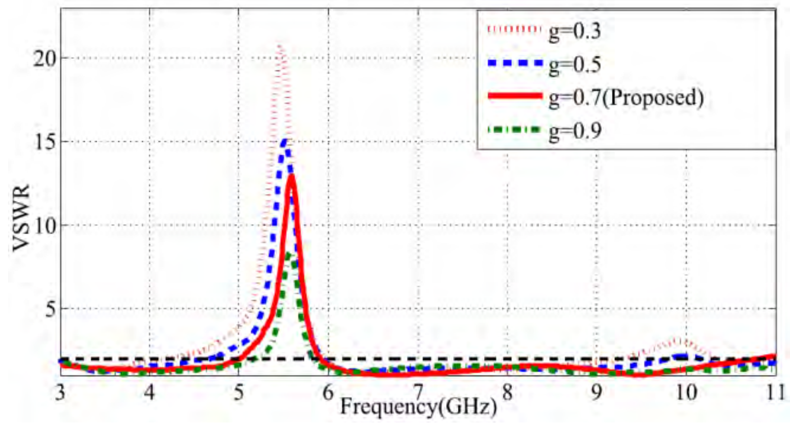


Fig. 10 Simulated VSWR of Antenna-2 with the variation in gap(g)

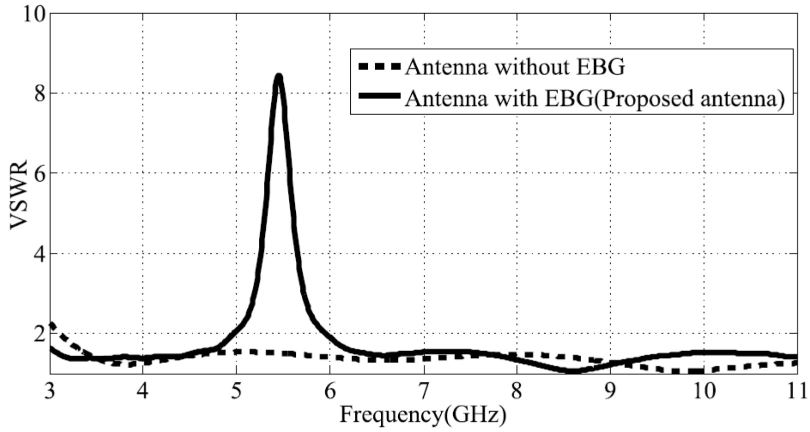
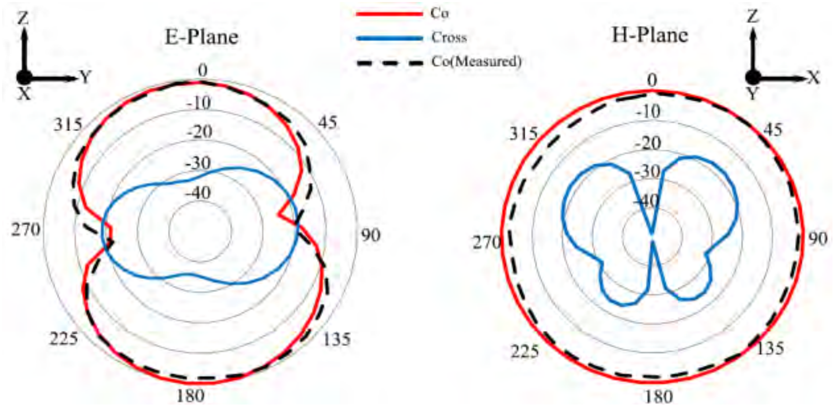


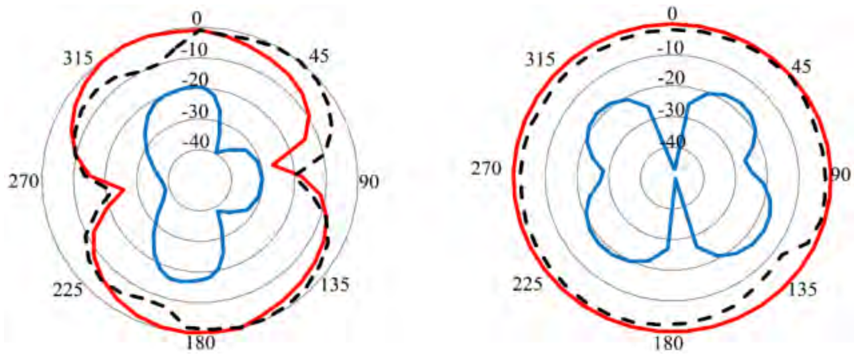
Figure 11. Measured VSWR of Antenna-1 and Antenna-2

C. Radiation pattern

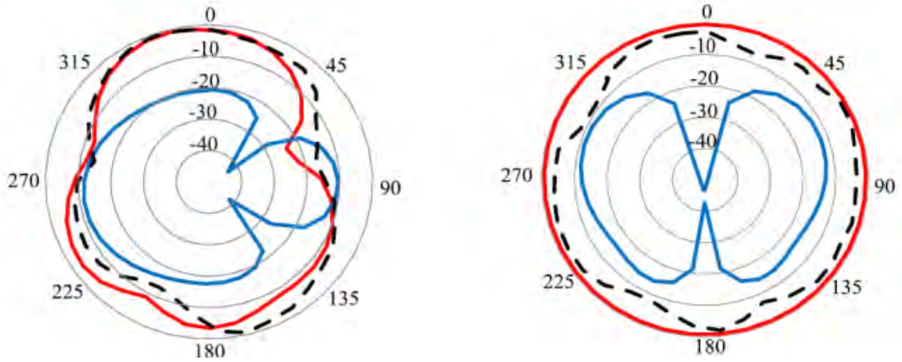
The antenna is designed in xy-plane and it is y-polarized because the monopole is in the y-direction. Therefore, the E -plane for the antenna is the yz -plane and the H -plane is the xz-plane. It can be notice from the figure that nearly dipole-like radiation patterns in the E-plane and omni-directional radiation patterns in the H-plane are obtained for the proposed antenna.



(a)



(b)



(c)

Figure 12. Radiation patterns of Antenna-2 at (a) 4 GHz, (b) 7 GHz and (c) 10 GHz.

D. Gain and Group Delay

The peak gains of Antenna-1 and Antenna-2 are shown in Fig. 13. It can be observed from figure that the peak gains of the Antenna-2 range from 2 dBi to 6.9 dBi over the operating band except the 5 - 6 GHz WLAN band, where it is around -4.34 dBi. The magnitude of group delay is measured by keeping two identical antennas in the face-to-face orientations. Since UWB technology is developed for short range communication systems, in the measurements the transmitting and receiving antennas were placed at 30 cm apart. The measured group delay of proposed antenna is shown in Fig.14. The variation of the group delay is within 2ns across the whole band except the notched band, in which the maximum group delay is more than 5ns. The more delay in notched band is because of the very low input and output signal power in that region and it is difficult to detect this signal in a measuring system.

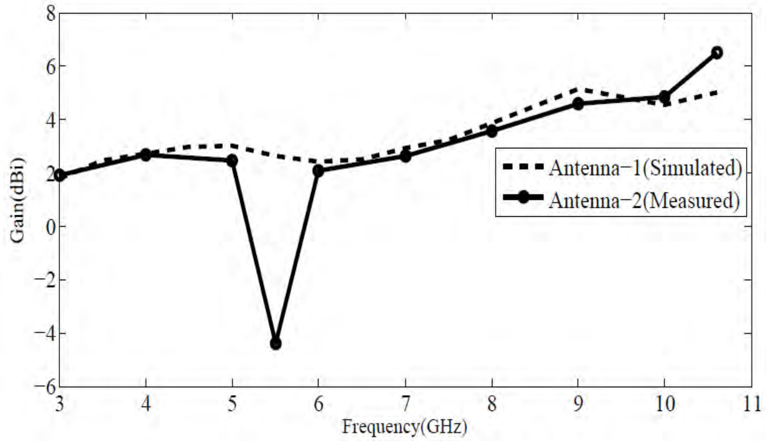


Figure 13. Gain Plot

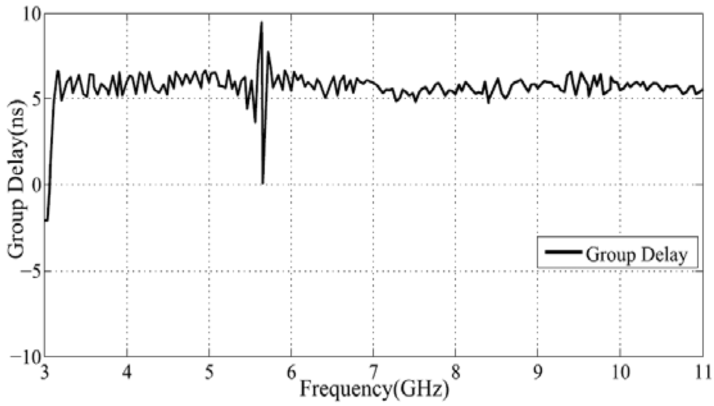


Figure 14. Group delay of Antenna-2

IV. CONCLUSION

In this paper, a compact UWB planer monopole antenna with WLAN band-notch is presented. The band-notch is provided by using AMC structure, for this design we have used Mushroom-like EBG. With this technique, there is no need to disturb radiating patch. Transmission line model is used to optimise the band gap response of EBG structure. On the basis of optimized result the design equation of EBG parameters for FR4 substrate is proposed. Using proposed equation, EBG structure is integrated with Antenna-1 to achieve the band-notch characteristic. The analysis shows that a band-notch can be achieved by adjusting the dimensional parameters and number of EBG unit cells around the feed line. The performance of the proposed antenna (Antenna-2) is compared with a reference antenna (Antenna-1). The radiation patterns are approximately omnidirectional and the measured results are in good agreement with simulated results. The gain of proposed antenna is 2 dBi to 6.7 dBi for entire impedance bandwidth, except the notched region. Measured results depicts that the proposed antenna can be used for UWB applications without any interference by the local WLAN based applications. A nearly constant group delay and stable radiation pattern makes proposed antenna suitable for low profile UWB applications.

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