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Upper WLAN Band Notched UWB Monopole Antenna Using Compact Two via Slot Electromagnetic Band Gap Structure

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Abstract—Electromagnetic Band Gap (EBG) structures can be employed near the feed line of a UWB monopole antenna, to reject the already existing narrowband radio signals operating within the spectrum of an Ultra Wide Band (UWB) antenna. Multiple EBG structures are required to reject multiple interfering bands. However, since the ground plane of a monopole antenna is limited, there is a need for compact EBG structures. This paper presents the application of a Two Via Slot (TVS) EBG to reject the interfering upper Wireless Local Area (WLAN) band (5.725 GHz–5.825 GHz) from the spectrum of a fork-shaped UWB monopole antenna. The simulated results demonstrate that the TVS EBG gives better performance in terms of higher and sharper Voltage Standing Wave Ratio (VSWR) value at the rejection band while occupying least ground plane area than Conventional Mushroom Type (CMT) EBG, Edge Located Via (ELV) EBG, slotted-patch ELV EBG, and semi-circular EBG. The proposed design is fabricated and measured. The measurement results prove that the antenna successfully achieves wide impedance bandwidth from 3 GHz to 12 GHz while rejecting the frequencies from 5.4 GHz to 5.9 GHz.

1. INTRODUCTION

Federal Communications Commission (FCC) in 2002 approved and allocated the frequency band 3.1 GHz–10.6 GHz for UWB technology [1]. Since then, this technology has gained significant popularity for future high data-rate short-range indoor wireless communications. A planar monopole antenna, with partial ground plane, has emerged as a good candidate for UWB technology due to its characteristics such as large impedance bandwidth, low profile, low cost, ease of fabrication, easy integration with microwave-integrated circuits, and good omnidirectional radiation pattern [2–5].

However, there is an issue of electromagnetic interference due to some existing standard narrow bands operating within the UWB spectrum, such as Worldwide Interoperability for Microwave Access (WiMAX) band (3.3–3.6 GHz), WLAN band (5.15–5.35 GHz and 5.725–5.825 GHz), and International Telecommunication Union (ITU) satellite downlink band (7.25–7.75 GHz). So a UWB planar monopole antenna must reject these interfering bands from its operating bandwidth. Different researchers have proposed different methods to design band-notched UWB antennas [6–15]. One such method is to etch slots of different shapes in the radiating element or ground plane [6–9]. Another method is to add parasitic elements [10], stubs [11–13], and resonating structures on or near the radiator [14, 15]. Multiple slots or parasitic elements need to be embedded in the design to reject multiple interfering bands, which may occupy more space and have strong coupling effects. These slots on the radiating element also affect far-field performance like radiation pattern, gain, and efficiency of the antenna. Another problem is that these methods are specific to a particular monopole antenna design and do not offer flexibility to tune the notch frequency.

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Recently, many authors have proposed the use of EBG structures near the feed line of the monopole antenna to reject the interfering bands in the UWB spectrum with minimal effect on the radiation properties of the antenna [16–25]. In [16], four CMT EBG structures are placed near the feed line of circular-shaped UWB monopole antenna to obtain band notch at the center frequency of 5.5 GHz. In [17], both CMT EBG and ELV EBG are studied to notch WLAN band, and it is concluded that ELV EBG is smaller in size than CMT EBG and gives better band rejection characteristics. In [18], slotted-patch ELV EBG is used to reject two bands from the operating bandwidth of the UWB monopole antenna. A modified mushroom type semi-circular EBG structure is proposed and used in [19] to obtain band notches at 5.2 GHz and 5.8 GHz. In [20], WiMAX and WLAN bands are rejected using four CMT EBG structures. In [21], inductance enhanced EBG structures are proposed and placed near the feed line of a circular UWB monopole antenna to notch the WLAN band. In [22], a novel uniplanar EBG structure is proposed, and two cells of this uniplanar EBG structure are placed on both sides of the feed line of the UWB antenna to notch IEEE INSAT applications C-band, i.e., from 6.5 to 7.2 GHz. EBG structures are also used in [23], to notch Lower WLAN and satellite uplink X-band from the operating bandwidth of microstrip line fed UWB monopole antenna. Recently, in [24], a slitted EBG structure has been proposed to notch WiMAX and WLAN bands, and in [25], a fractal EBG structure and Two Via Edge Located (TVEL) EBG structures are employed to notch three different bands.

Therefore, multiple EBG structures are required to reject multiple interfering bands. As the ground plane of a monopole antenna is limited, and multiple EBG structures are placed, it is, therefore, important that EBG structures are compact in size. In the present work, we have done an extension work of [26], which proposed a compact TVS EBG structure. We have presented the application of a TVS EBG structure to notch the upper WLAN band, i.e., 5.725–5.825 GHz from the operating band of the UWB monopole antenna. The advantages of TVS EBG are its compact size, capability to tune the band notch center frequency without changing the overall size of the unit cell, and sharper and higher VSWR values at the notched band. Section 2 illustrates the bandgap property of TVS EBG using dispersion diagram. Section 3 discusses the reference UWB monopole antenna. Section 4 presents the design of monopole antenna embedded with TVS EBG to notch the upper WLAN band. Experimental and measurement results of the UWB monopole antenna embedded with TVS EBG are presented in Section 5. Performance comparison of monopole antenna in the notched band when other reported EBG structures replace TVS EBG is presented in Section 6. Finally, Section 7 concludes the paper.

2. TWO VIA SLOT EBG STRUCTURE

An EBG structure is a periodic arrangement of metal patches over a dielectric substrate. This periodic arrangement possesses unique properties such as surface wave propagation bandgap and zero phase reflection bandgap [27]. The bandgap property of a via-loaded EBG structure can be explained by characterizing it with an equivalent LC resonator, where inductance L appears because of current flow through the via, and capacitance C appears because of the gap between the adjacent EBG cells. Thus, EBG structure will present a bandgap centered at the resonant frequency of the LC resonator circuit, i.e., $f_c = \frac{1}{2\pi\sqrt{LC}}$ [28]. The TVS EBG structure proposed in [26] is a compact EBG structure compared to many other reported EBG structures. Figures 1(a) and (b) present the top view and side view, and Figure 1(c) shows the equivalent circuit diagram of the unit cell of TVS EBG. The two vias and the slot in the unit cell of the TVS EBG give an effective increase in the values of L and C per unit cell. This decreases the resonant frequency of TVS EBG compared to conventional EBG structure or, in other words, for a particular resonant frequency, reduces the size of unit cell of TVS EBG compared to conventional EBG structure. In Figure 1(c), capacitance C1 is present because of the neighbouring TVS EBG cell, and C2 and C4 are the capacitances between the inner patch and outer patch of TVS EBG. C3 and C5 are the capacitances between the top plane and ground plane of the TVS EBG, and inductances L1 and L2 represent the current flowing from the patch to the ground plane through the two vias.

In this paper, the dimensions of the unit cell of TVS EBG are optimized so that it exhibits bandgap in the range of frequencies that cover the upper WLAN band. The optimized unit cell parameters of TVS EBG are taken as: radius of each via$(r) = 0.15$ mm, $W3 = 2.5$ mm, $W2 = 3.9$ mm, $W1 = 4.9$ mm, and period of unit cell, $P = 5.9$ mm. To validate the bandgap property of TVS EBG, the unit cell

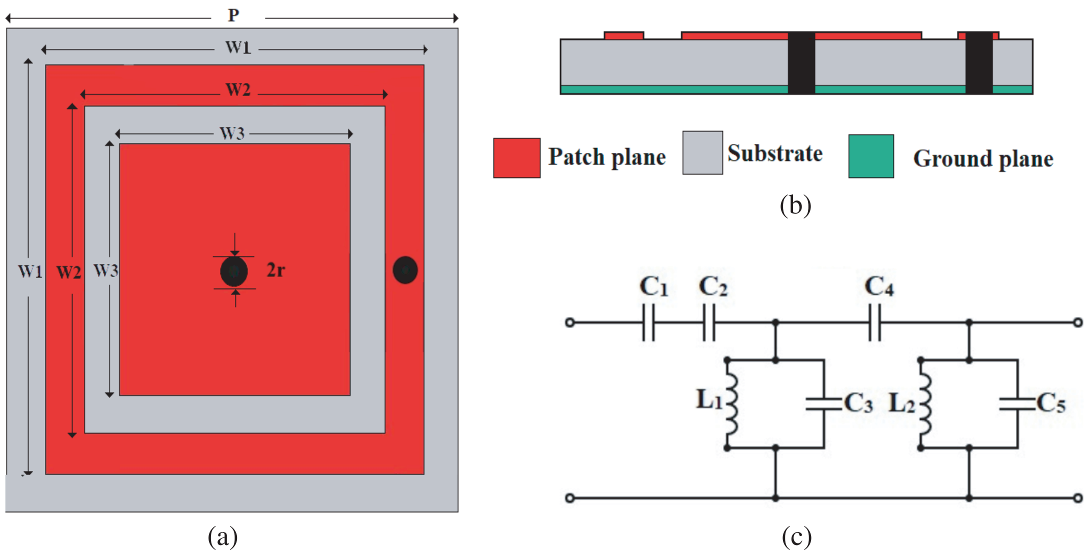


Figure 1. Unit cell of TVS EBG. (a) Top view. (b) Side view. (c) Equivalent circuit diagram.

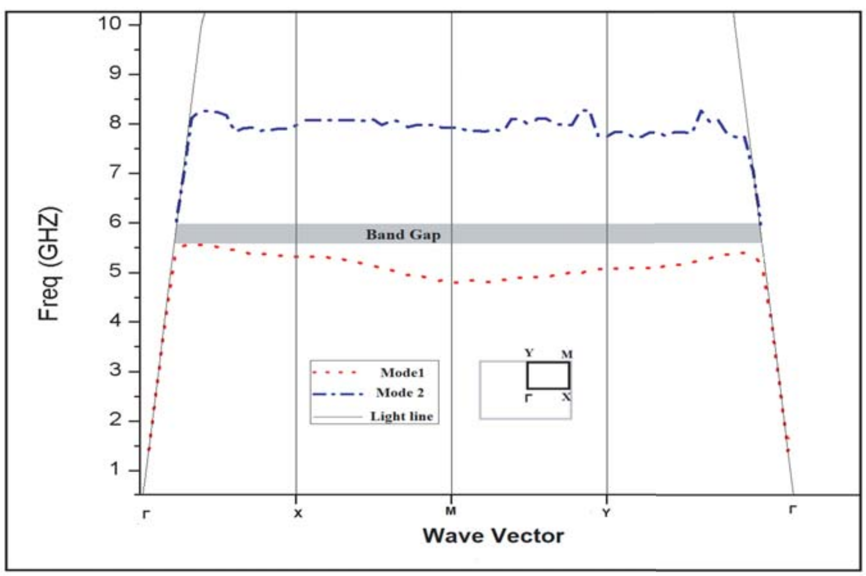


Figure 2. Dispersion diagram of TVS EBG.

of TVS EBG is simulated in the Eigen mode solution of High Frequency Simulation Software (HFSS) to obtain the rectangular irreducible Brillouin-zone based dispersion diagram. From the dispersion diagram, as presented in Figure 2, it is observed that there is a bandgap between mode 1 and mode 2 of the TVS EBG. The bandgap is centered at 5.75 GHz with lower cut-off frequency at 5.55 GHz and upper cut-off frequency at 5.95 GHz with a bandgap bandwidth of 6.95%.

3. FORK SHAPED UWB MONOPOLE ANTENNA

A fork-shaped UWB monopole antenna [19] is used as a reference antenna in this paper. The antenna is simulated on a substrate having dielectric constant (ϵ_r) = 2.2, loss tangent ($\tan\delta$) = 0.0009, and substrate height (h) = 0.8 mm. This antenna, referred to as Antenna 1, consists of fork-shaped tuning

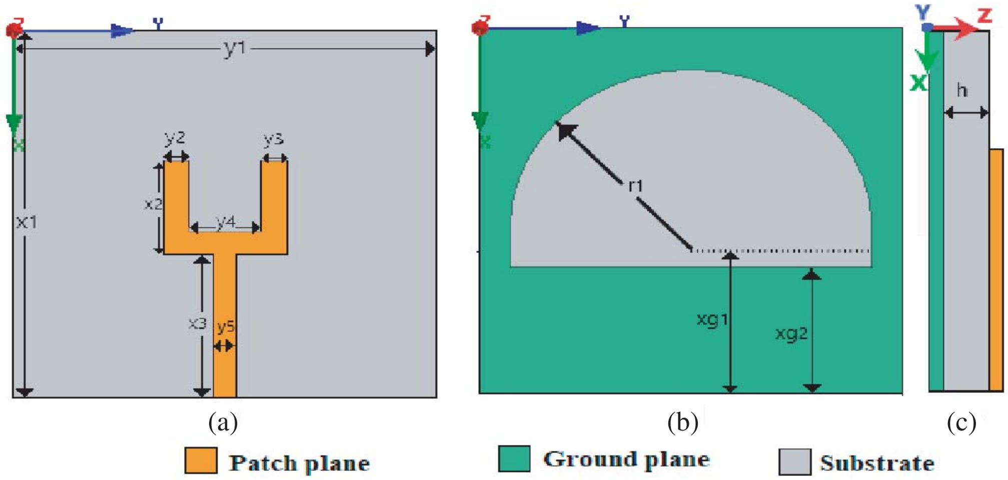


Figure 3. Fork shaped UWB monopole antenna (Antenna 1). (a) Top view. (b) Bottom view. (c) Side view.

stub fed using microstrip line as the radiating element with a quasi semi-circular slot etched ground plane as shown in Figure 3. The design parameters of Antenna 1 are as follows: $x1 = y1 = 35\,\text{mm}$, $x2 = 9\,\text{mm}$, $x3 = 13.6\,\text{mm}$, $y2 = y3 = 2.1\,\text{mm}$, $y4 = 6\,\text{mm}$, $y5 = 1.8\,\text{mm}$, $xg1 = 16\,\text{mm}$, $xg2 = 12\,\text{mm}$ and $r1 = 15\,\text{mm}$. Figure 5 presents the VSWR of antenna simulated using HFSS. From Figure 5 it is clear that the antenna has got a good impedance bandwidth for the entire UWB.

4. UWB MONOPOLE ANTENNA DESIGN EMBEDDED WITH TVS EBG

A TVS EBG with optimized dimensions, as discussed in Section 2, is embedded near the feed line of Antenna 1, as shown in Figure 4 with a gap $g1 = 0.2\,\text{mm}$ and $g2 = 0.2\,\text{mm}$. The other dimensions of the fork-shaped UWB monopole antenna are kept the same, as mentioned in Section 3. Simulated VSWR values of Antenna 1 and Antenna 2 are compared in Figure 5. From Figure 5, it is observed that

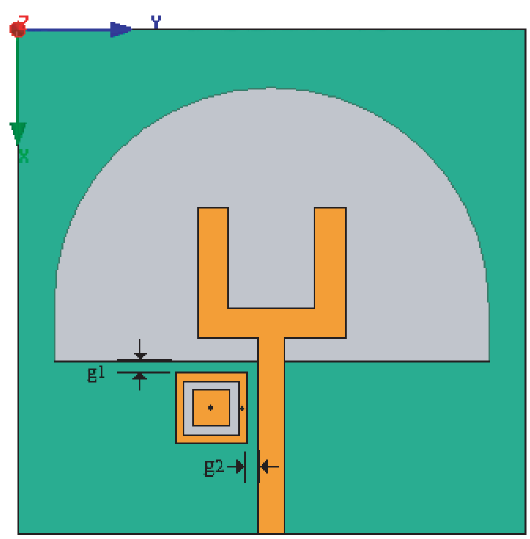


Figure 4. Fork shaped UWB monopole antenna embedded with TVS EBG (Antenna 2).

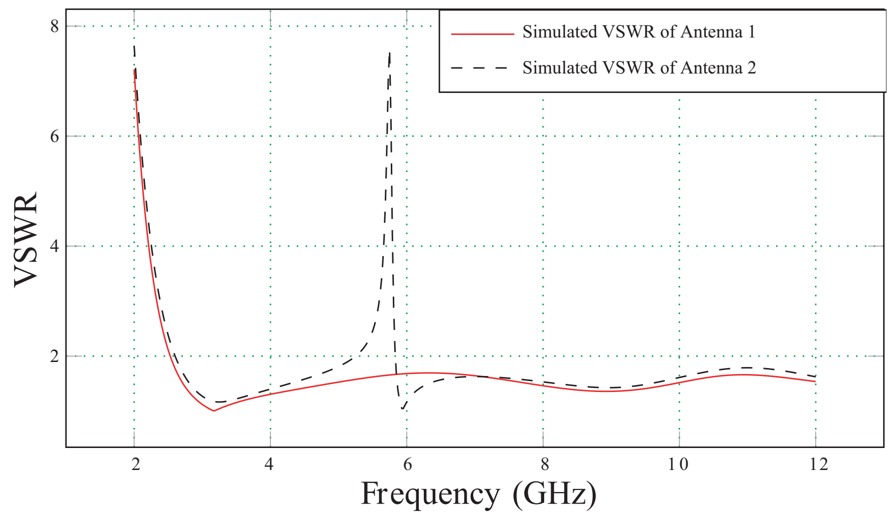


Figure 5. Simulated VSWR of Antenna 1 and Antenna 2.

embedding TVS EBG produces a band notch in the operating band of the antenna. The frequency of the notched band is from 5.34 GHz to 5.83 GHz centered at 5.75 GHz (where VSWR > 2). The variation of the real and imaginary impedances of Antenna 1 and Antenna 2 with frequency are presented in Figure 6. It is observed that the real impedance is tuned near $50\,\Omega$, and imaginary impedance is tuned near $0\,\Omega$ for the entire range of frequencies except for the frequencies near 5.8 GHz, where high mismatch is observed in both real and imaginary impedances. Simulated gain versus frequency plot of Antenna 1 and Antenna 2 is presented in Figure 7. From Figure 7, it is observed that both Antenna 1 and Antenna 2 possess good gain performance for the entire band of frequencies, except for the sharp decrease in the gain of Antenna 2 in the vicinity of the notched band. Figure 8 presents the simulated current distribution of Antenna 2 at 3.1 GHz and 5.8 GHz. It is observed that at 3.1 GHz, most of the current is concentrated towards the radiating element through the microstrip line, but at 5.8 GHz, maximum current is concentrated on the EBG structure. This verifies that 5.8 GHz is the resonant frequency of TVS EBG structure, and very little current is, therefore, propagated to the radiating patch at this frequency.

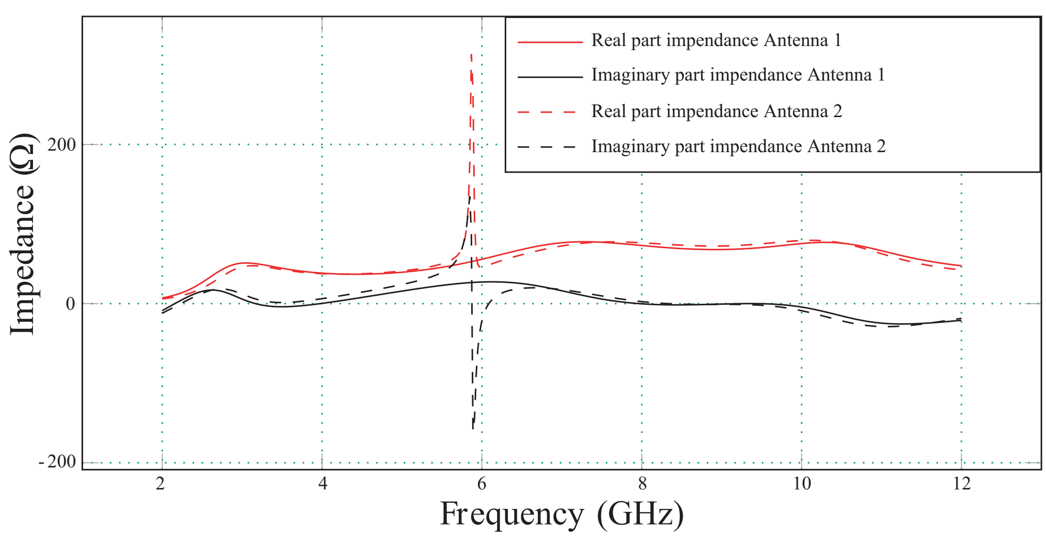


Figure 6. Simulated real and imaginary impedance of Antenna 1 and Antenna 2.

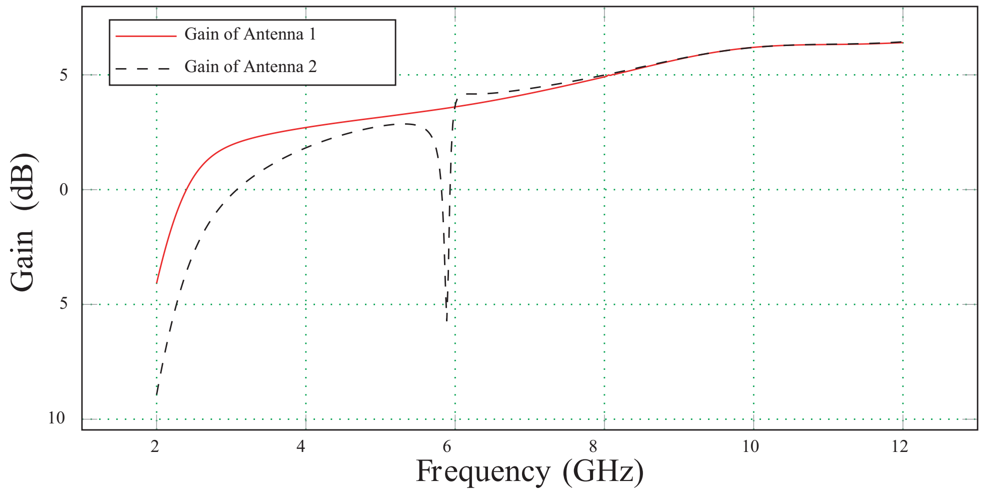
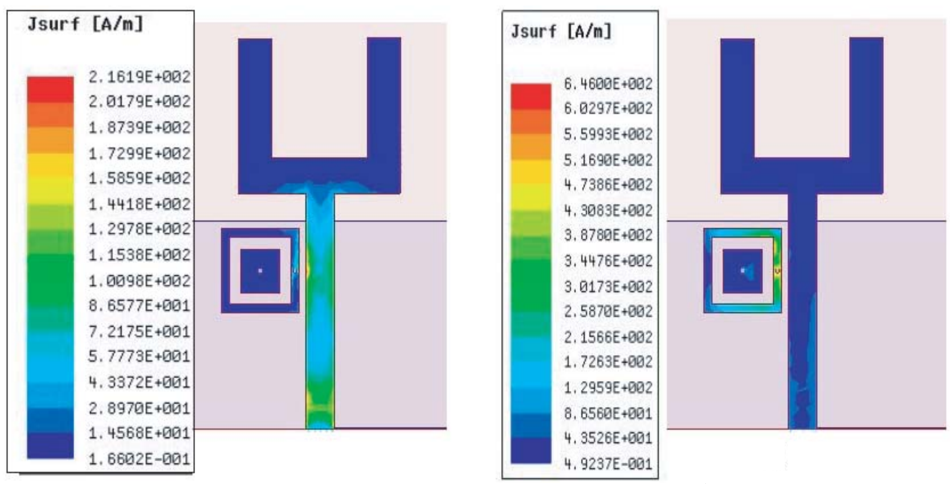


Figure 7. Simulated realized gain of Antenna 1 and Antenna 2.



(a) (b)

Figure 8. Current distribution in Antenna 2 at (a) 3.1 GHz, (b) 5.8 GHz.

5. FABRICATION AND MEASUREMENT

The fork-shaped UWB monopole antenna embedded with TVS EBG is fabricated on a Rogers 5880 substrate with dielectric constant $(\epsilon_r) = 2.2$, substrate height $= 0.787$ mm, and $\tan\delta = 0.0009$. All dimensions are taken as discussed in Section 2, Section 3, and Section 4. A 50 Ω SMA connector is connected at the end of the microstrip feed. Anritsu VNA (Vector Network Analyzer) Master is used for return loss measurements. The front and back views of the fabricated prototype, and simulated and measured return loss values of the fabricated antenna are presented in Figure 9. The measured return loss values are in good agreement with simulated values, but a slight frequency shift is observed, which may have occurred because of the fabrication tolerances and soldering of the SMA connector. The measured return loss values prove that the fabricated prototype shows good impedance bandwidth ($S_{11} < -10$ dB) from 3 GHz to 12 GHz while rejecting the frequencies from 5.4 GHz to 5.9 GHz. Since the bandwidth of the proposed antenna is very wide, only two in-band frequencies, i.e., 4 GHz and 8 GHz, are chosen to observe the far-field radiation pattern. The far-field radiation performance of the fabricated prototype is measured in an anechoic chamber. Figure 10 presents the simulated as well as measured far-field radiation patterns in the E-plane and H-plane, at both 4 GHz and 8 GHz.

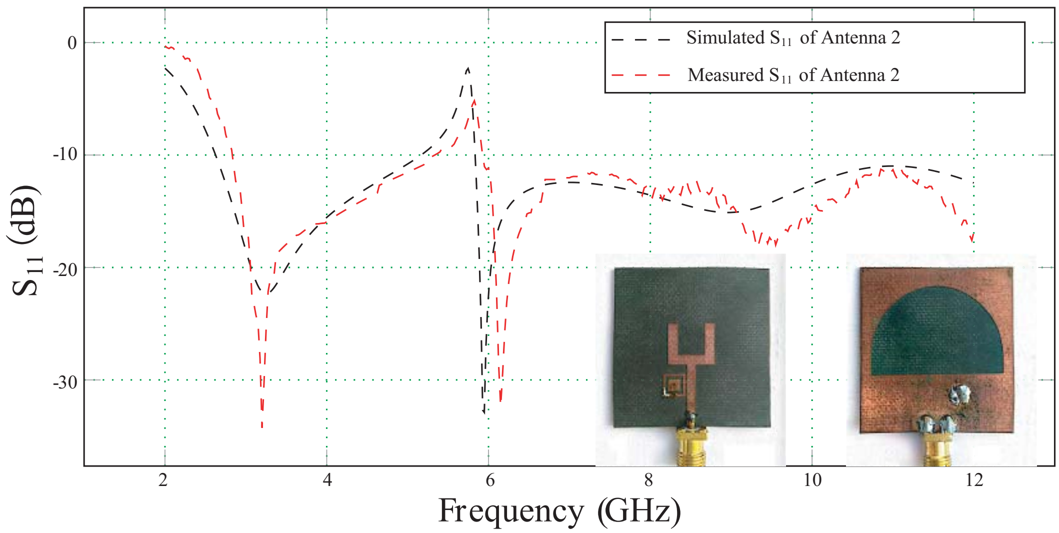


Figure 9. Simulated and measured return loss of Antenna 2 with top and bottom view of fabricated prototype.

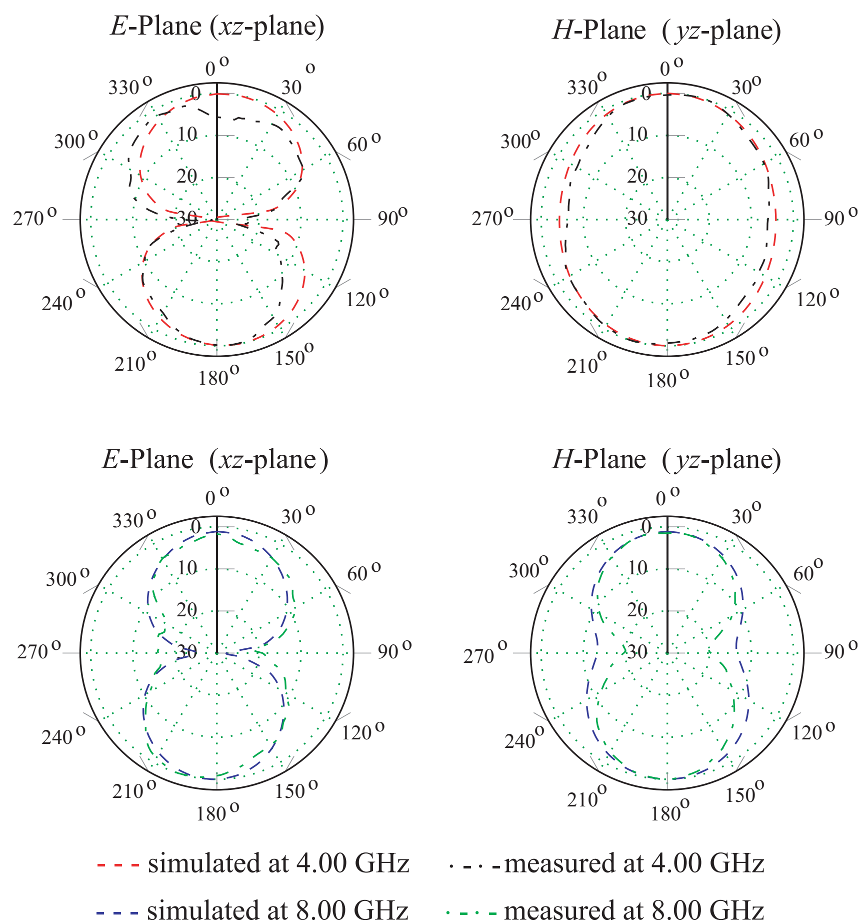
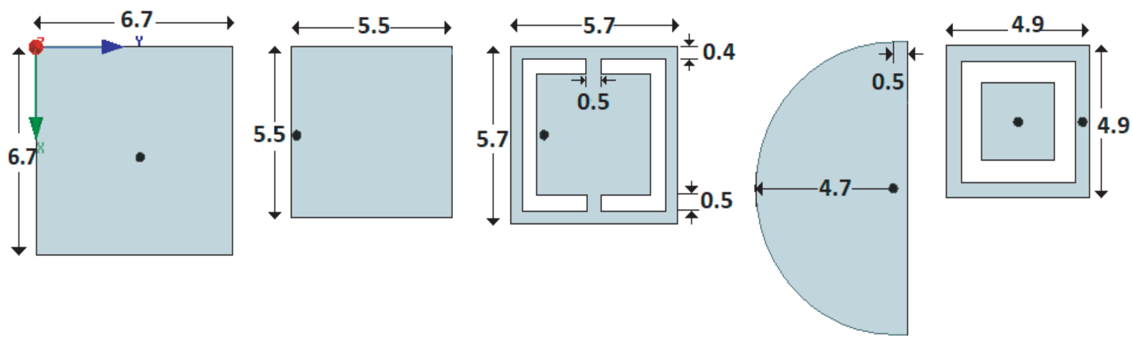


Figure 10. Simulated and measured radiation patterns of the Fork UWB antenna embedded with TVS EBG.

It is observed that the antenna has got nearly omnidirectional radiation pattern in the H-plane and dumbbell-shaped radiation pattern in the E-plane.

6. COMPARISON OF TVS EBG WITH OTHER REPORTED EBG STRUCTURES

In this section, the performance of the monopole antenna in the notched band is studied and compared when other reported EBG structures replace the TVS EBG. For the study and comparison, CMT EBG, ELV EBG, slotted-patch ELV EBG, and semi-circular EBG structures are mainly considered. The dimensions of the above mentioned EBG structures are optimized using HFSS so that when being placed near the feed line of a monopole antenna, they all band notch the upper WLAN band. Figure 11 presents the optimized dimensions of above-mentioned EBG structures. For simulations, the TVS EBG in Antenna 2 is replaced by CMT EBG, ELV EBG, slotted-patch ELV EBG, and semi-circular EBG while the gaps $g1$, $g2 = 0.2$ mm, while radius $r = 0.15$ mm, and all other dimensions are kept same. Figure 12 compares the simulated VSWR values in the band from 5 GHz to 6 GHz, as obtained with CMT EBG, ELV EBG, slotted-patch ELV EBG, semi-circular EBG, and TVS EBG. It is observed from Figure 12 that TVS EBG produces higher and sharper VSWR values in the notched band. Further, Figure 13 presents the comparison of the area occupied by all the above-mentioned EBG structures, wherein it is observed that TVS EBG occupies the least area.



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

Figure 11. Shape and dimensions of different EBG structures (a) CMT EBG (b) ELV EBG (c) Slotted-patch ELV EBG (d) Semi-circular EBG (e) TVS EBG.

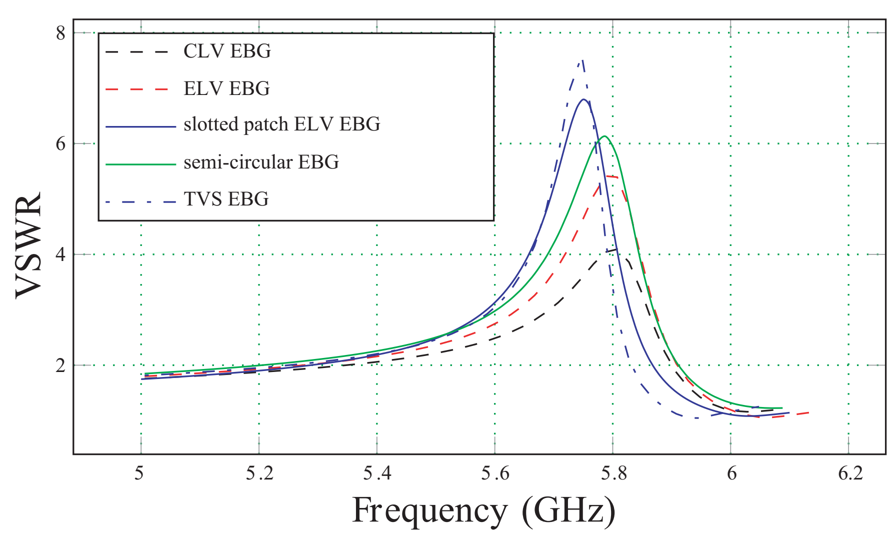


Figure 12. VSWR comparison obtained by embedding different EBG structures.

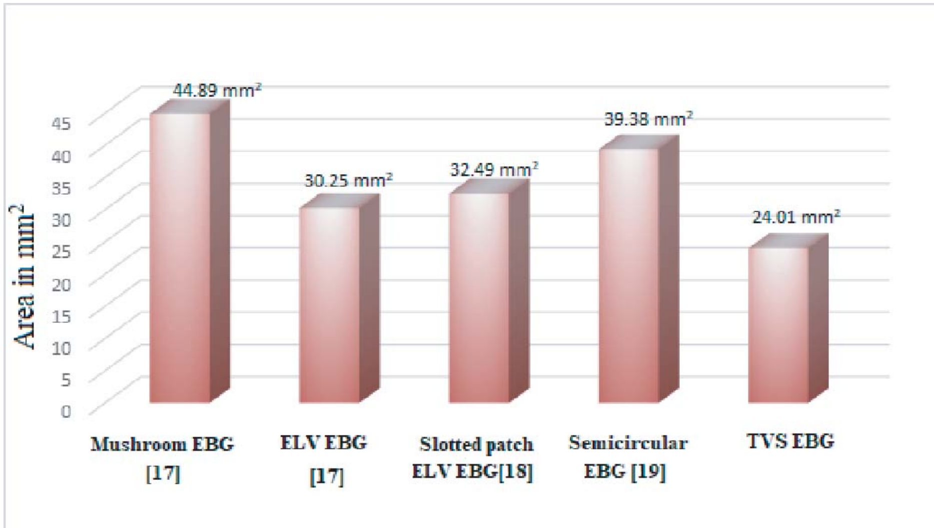


Figure 13. Comparison of space occupied by different EBG structures.

7. CONCLUSION

In this paper, an upper WLAN band-notched UWB monopole antenna is realized by embedding TVS EBG near the feed line of the antenna. The prototype of the antenna is fabricated and tested. The far-field and return loss measurements closely follow the simulated predictions. From the simulation results, it is demonstrated that embedding TVS EBG near the feedline gives sharper and higher VSWR values in the notched band. Moreover, TVS EBG occupies less ground plane area than other popular EBG structures such as CMT EBG, ELV EBG, slotted-patch ELV EBG, and semi-circular EBG. Thus, TVS EBG can be a good candidate for the design of compact size band-notched UWB monopole antennas.

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