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Research Article

Printed UWB Antennas having Band Notch Feature: A Review

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ABSTRACT- A review of the design techniques to introduce band rejection capability in printed Ultra wideband (UWB) antennas is presented in this paper. UWB is a promising technology for future wireless communication systems but due to its wideband spectrum it can interfere with other narrow band systems. To overcome this issue a number of techniques are proposed to introduce a band rejection capability in UWB systems. However these techniques have some disadvantages and limitations. In this paper we studied different techniques proposed so far in open literature. After reviewing them we divided them into different categories for systematic comparison. The working operation and limitations of proposed designs are discussed. All techniques are critically assessed and based on specific advantages and disadvantages, recommendation is given to use the appropriate technique to satisfy the given design requirements. The future research work required for further exploration of UWB antenna is also proposed.

Keywords: *UWB antenna, band notch, EBG, SRR, parasitic patch, DGS*

1. INTRODUCTION

Ultra-wide band (UWB) is a promising radio technology that can be used at low power for short range, high bandwidth communications. Traditionally it has been used for radar imaging but recently it has gained a lot of interest from system designers and researchers for sensor data collection, precise location and tracking applications[1]. The home networking system consists of multimedia gadgets such as laptops, smartphones, HDTVs and DVDs. UWB is being targeted as cable replacements for these systems. Due to large bandwidth of UWB systems, the antenna design is quite challenging to meet the characteristics of wide impedance bandwidth, high gain, omnidirectional radiation pattern and compact size [2]. Along with all the benefits and advantages of UWB systems, they have a very common problem of interference with high power narrow band systems which operate within the UWB band of operation i.e. 3.1GHz to 10.6GHz [3].UWB systems share the radio spectrum with Wi-Fi, WiMAX, X-band and C-band as shown in Fig. 1.

UWB receiver consists of a low noise amplifier (LNA) at the front end to provide low noise figure and a high gain. But high power signals from narrow band systems can cause overloading of the receiver circuit[4]. This issue can be resolved by using a filter circuit in the front end, but this technique is limited in its application because it introduces the problem of increased weight, size, complexity and cost of the system.

Another innovating technique to overcome this problem is to alter the antenna design in such a way that the unwanted signals are not captured at all. For this purpose UWB antennas with band notch ability have been proposed [5]. These antennas reject unwanted bands by having VSWR >2 for the undesired frequencies. To critically review band notch designs we present a brief overview of existing techniques.

2. BAND NOTCH TECHNIQUES

The following techniques have been proposed in

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open literature to introduce band notch ability in printed UWB antennas.

2.1 Etching Slots

One of the common techniques is to etch slots in the antenna structure to create band rejection.

2.1.1 Slot in the Patch

By embedding symmetric slots in the radiating patch of the antenna the current distribution is disturbed and results in a notched band. The current distribution of a slot antenna at the operating frequency and notch frequency are shown in Fig. 2(a) and Fig. 2(b) respectively.

The current distribution is uniform and flowing in one direction at the operating frequency while at the notched frequency it is non-uniform and multi directional.

The insertion of slot is the easiest way of achieving band notch feature; in fact this technique applies directly to a UWB antenna with least modification in its shape. By changing the parameters of a slot, notched center frequency, and the notched bandwidth can be adjusted according to the requirement. Most commonly reported slots include U-shaped, L-shaped, C-shaped, square, pi-shaped, rectangular, vertical, arc shaped, V-shaped and dual arrow head slots[5-8]. In Fig. 3 UWB antenna with inverted U-shaped slot is shown, the antenna was fabricated on FR4 substrate with a thickness of 1.6 mm. The antenna has a partial ground plane. This antenna is fed by a micro strip-line feed. The reflection coefficient (S_{11}) is less than -10 dB in 3.7~11.1 GHz frequency range except for the notch band of 4.9~5.9 GHz [9]. The VSWR of the antenna, with and without slot is shown in Fig. 3 where its value is much greater than 2 in the rejected band.

The dual arrow head slot antenna proposed in [10] is shown in Fig. 4(a). It has an operating band width of 2.8 ~ 18.6 GHz, which is wider than the normally reported UWB antennas. The notch lies between 5.7 ~ 6.3 GHz. The C-shaped slot antenna proposed in [11] shown in Fig. 4(b) has a consistent VSWR curve throughout the operating band, and an excellent rejection in 5~6 GHz band having VSWR more than 11 at the center notched frequency. The width and length of the slot controls the notched frequency and bandwidth.

2.1.2 Slot in the Ground Plane

Another technique is etching slot(s) in the ground plane of antenna. It has similar effect on antenna performance as that of slot in the patch. These slot structures are sometimes referred to as defected ground structures (DGS). This technique has also been reported for the CPW ground antennas. Fig. 5shows two different antennas employing quarter-wavelength and half-wavelength tunable slots integrated into the arc shaped ground plane of the circular disk patch antennas. This introduces the desired band-rejection around 5.8 GHz. The working band varies from 1.62 GHz to 17.43 GHz [13]. A VSWR>16 at the notched frequency, and a consistent VSWR less than 2 can be seen in Fig. 6.

2.1.3 Other Slots

Use of multiple slots is extensively found in the literature to introduce multiple notched bands. Etching of slot is not limited to one part of antenna in one design, but, slots in patch, ground and feed line can all be found in a single design for multiple band notches. Fig. 7 and Fig. 8shows two such designs along with their gain and VSWR plots respectively.

Fig. 7 shows a double fed dual band notched UWB antenna, reported in [14]. This type of feed arrangement stops the excitation of horizontal currents and ensures that only the dominant vertical current mode is present in the circuit [15]. This results in the improvement of polarization properties of the circular monopole antenna. The proposed antenna provides dual notched bands at 3.4~3.8 and 4.8 ~6.2 GHz. The two slots in the patch and the ground plane provides some control over the notched frequency and bandwidth.

2.1.4 Fractal Slots

Slots in fractal shape is another interesting method being used for frequency notch purposes. Fig. 9 shows fractal binary tree slots, in which each branch is further branched into two branches. Three variations of this topology are shown in which branching angles are of 60^o, 120^o, and 180^o respectively. This is a 16 X 22 mm^2 UWB antenna with a notch frequency at 5.61 GHz for 120^o branch angle. The advantage of using fractal tree technique is the additional resonance that it creates at 10.2 GHz which is within the UWB range.

Table 1. Comparison of band notching techniques for UWB antennas.

Technique	Reference	Pass band Min VSWR	Rejected bands (GHz)	Stop band Max VSWR	Highest gain (dBi)	Size of antenna (mm^2)	Observations
Slots	[6]	1.1	5.1 ~ 6.0	>10	4.5	34 x 30	• Simple technique. • Small antenna size available. • Reconfigurable notched bands. • Multiple notched bands achievable.
	[12]	1.2	5.02~5.97	4.5	4.1	12 x 19	
	[10]	1.1	5.7 ~ 6.3	4.4	6	28 x 32	
	[14]	-	3.4 ~ 3.8 4.8 ~ 6.2	-	5	20 x 30	
	[11]	1	5 ~ 6	>10	7	32 x 30	
Resonant cells (CLL/CSRR)	[18]	1.05	5.6 ~ 5.9	4.9	-	41 x 34	• Simple technique. • Reconfigurable notched bands. • Multiple band rejection possible. • Coupling exists between multiple cells.
	[19]	1	3.3 ~ 3.6 5.15 ~ 5.35 5.725~5.825	10.1	5	27 x 34	
Parasitic patch	[21]	1.4	5.05 ~ 5.9	6.6	-1.2	13 x 11	• Small antenna size available. • Widely used technique • Notched band tuning possible.
	[24]	-	4.5 ~ 5.38	-	6.1	31 x 40	
	[23]	1	5 ~ 6	22	5.5	20 x 25	
	[26]	0.1	5.1 ~ 6.1	>12	4	47 x 37	
Stub	[27]	-	5.15~5.825	-	5	30x39.3	• Relatively complex technique.
	[29]	-	5.18~6.23	-	5.8	30x39.3	
EBG	[30]	1	5.20~5.72 5.99~6.23	>6	-	38x40	• Reduced coupling between multiple EBG structures is possible. • Fine tuning of notched bands possible. • Multiple band rejection possible.
	[35]	1	5.2 ~ 5.8	>30	4.5	43x46	
Combination of different techniques	[32]	-	3.3~3.7 5.15~5.825 8.025~8.4	-	-	40 x 40	• More advantageous features can be combined. • Better for multiple band rejection.
	[20]	1.1	3.3 ~ 4 5.15 ~ 5.4 5.8 ~ 6.1	>10	5	24 x 30	

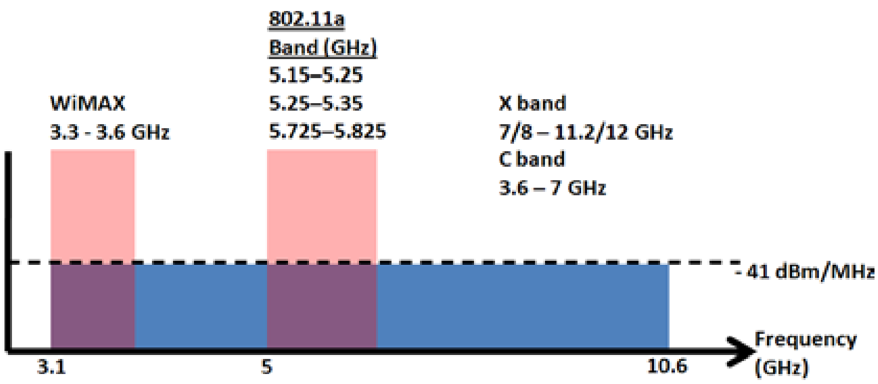
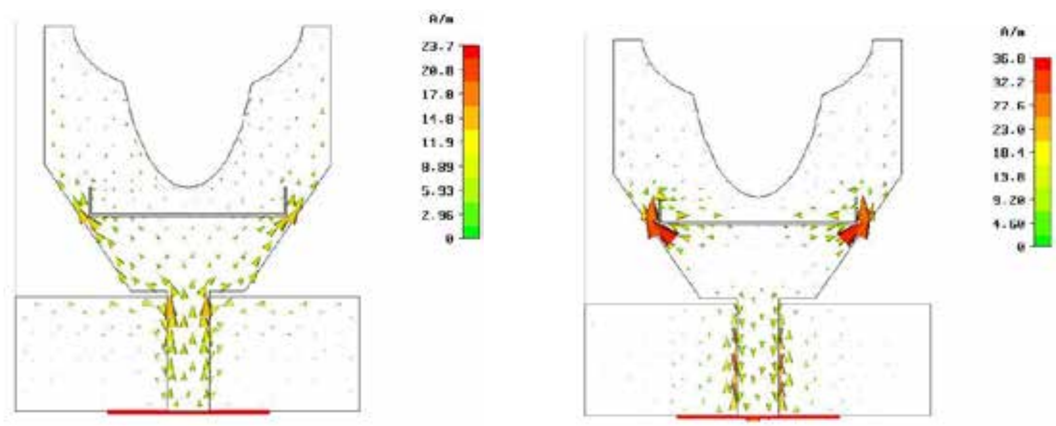
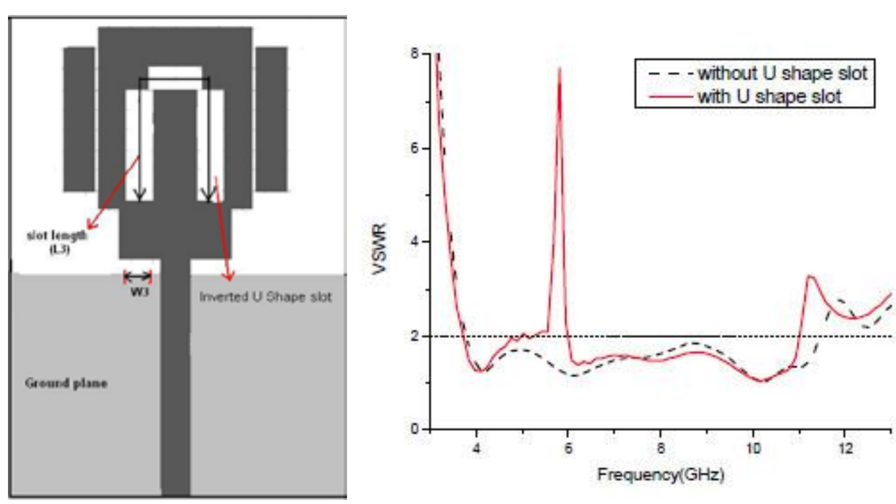


Fig.1 Common interferers to UWB systems.



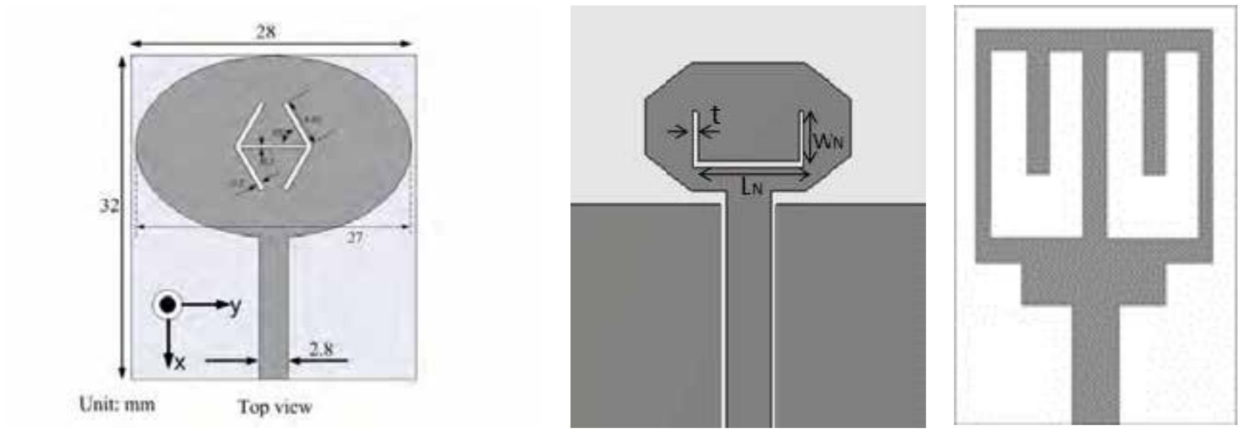
(a) (b)

Fig. 2. Current distribution at (a) notched and (b)operating frequencies [6].



(a) (b)

Fig. 3. Inverted U-shaped slot antenna (a)front view (b)VSWR of antenna [9].



(a) (b) (c)

Fig. 4. Antennas with slots in patch [10–12].

(a) (b)

Fig. 5. Antennas with slot in ground plane: (a) Quarter wave; (b) Half wave [13].

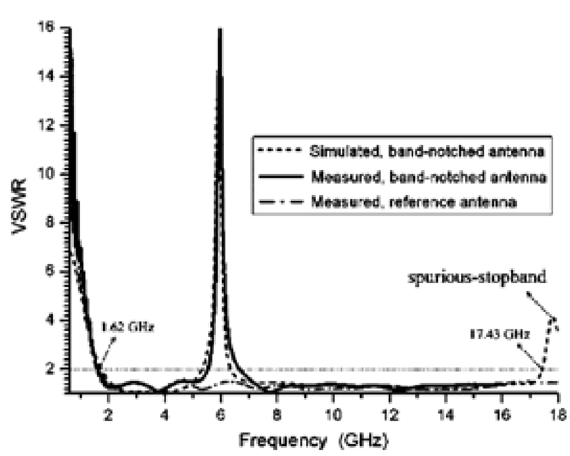
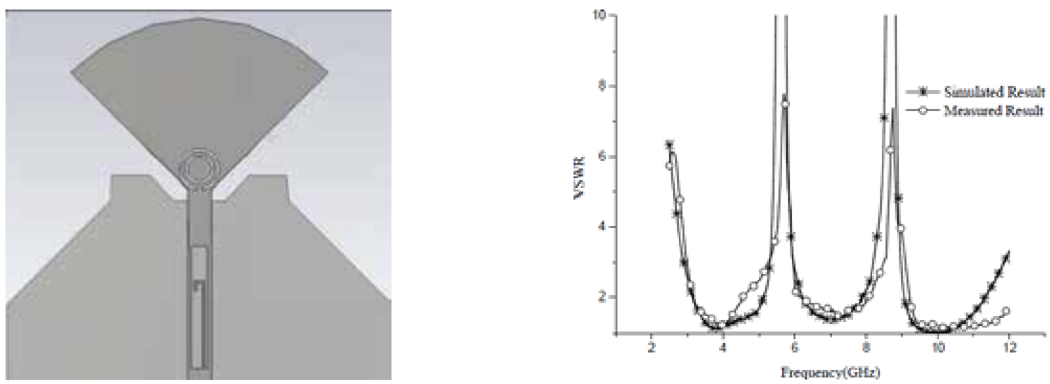


Fig. 6. VSWR of the band-notched antenna shown in Fig. 5 [13].

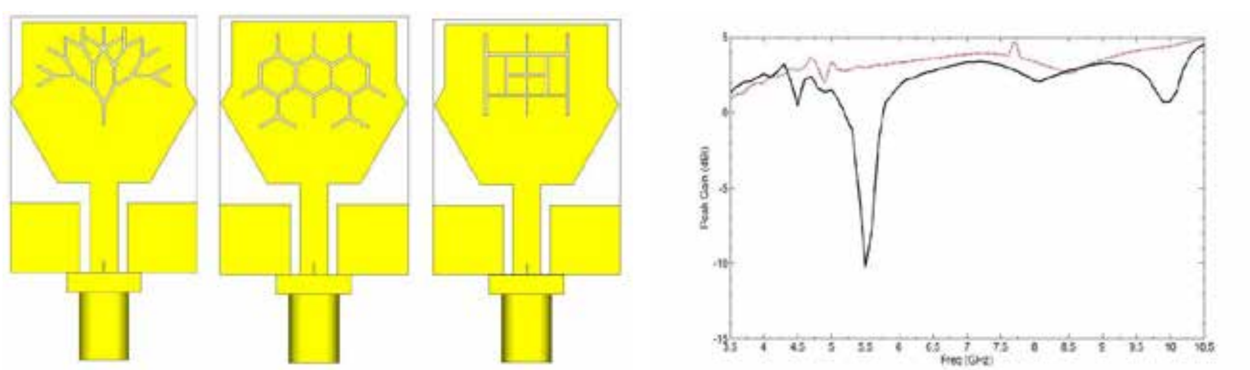
(a) (b) (c)

Fig. 7. Multiple slots antenna: (a) Front view; (b) Back view; (c) Gain of antenna [14].



(a) (b)

Fig. 8. Multiple slots antenna: (a) Front view; (b) VSWR of the antenna [16].



(a) (b)

Fig. 9. Fractal slots in patch of UWB antennas (60^o, 120^o, 180^o branch angles, respectively) [17].

2.2 Embedding Resonant Cell

Another reported technique is that of split ring resonator (SRR) which is a variation of the basic technique of etching slots in the patch. In this technique two incomplete rings with one as inner and other as the outer are etched on the patch. The open ends of the rings are co-directional in some designs and opposite in yet others as shown in Fig. 10. Fig. 10(b) shows one SRR cell.

The capacitive loaded loop (CLL) element is self-resonant like the split ring resonator (SRR) element and has a resonant frequency that is dependent on loop inductance and capacitance resulting from loop cuts. However, the CLL element has a much simpler and compact design [19]. Fig. 11 shows one such antenna with triple band notch. By varying the gap between the cuts of the CLL elements, the center notch frequency can be adjusted. The gap between the feed line and CLL element affects the rejection quality and to some extent the notched frequency.

In [20] a variation in the resonant cell is presented where an open loop resonator is placed at the center of the fork-shaped patch and fed by the patch through two tapped lines as shown in Fig. 12. The effect of parametric changes of the patch and the resonant structure is studied and presented.

It is shown that the resonator can be treated as being composed of two sub-resonators, each with a tapped line and a folded strip of open-loop resonator. A maximum suppression of 35 dB in gain at the notch frequency is achieved, which is one the lowest gains of the rejected bands reported throughout the literature. An explicit mathematical model for the functioning of antenna is also presented along with the equivalent circuit diagrams of the antenna.

2.3 Creating Parasitic Patch

Placing parasitic patch on the front face or the rear face of antenna affects the antenna performance (gain, bandwidth) according to the location, shape and dimensions of the parasitic patch. They are electromagnetically coupled to the main radiating patch to achieve band notch characteristic. The parasitic patches are designed and placed in way to cancel out the radiations of the main patch at the desired notch frequency.

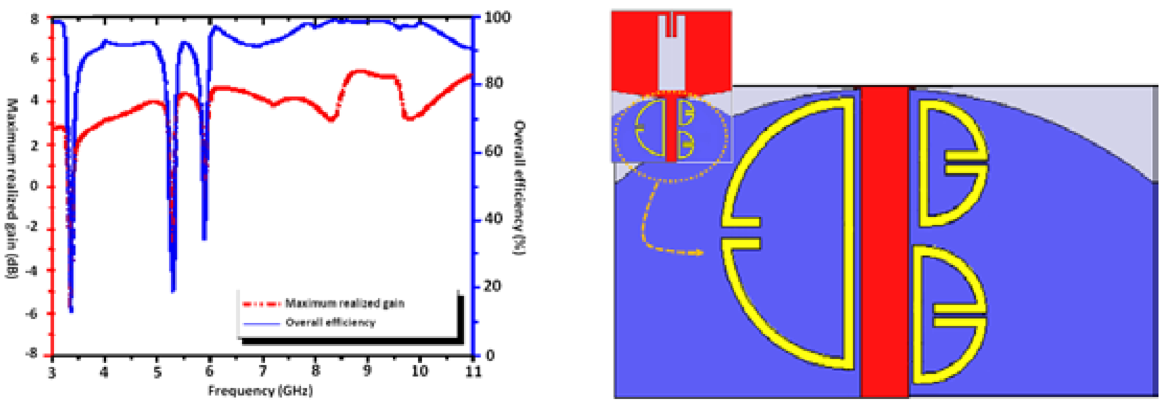
Fig. 13 shows the current distribution of the proposed antenna at the notch frequency. It can be seen that the current distribution on the patch and the parasitic patch is out of phase; hence theoretically no radiation takes place. The size of the antenna that is fabricated on the FR-4 substrate is 13 x 11mm^2. The size of the ground plane is 300 x 220 mm^2. The antenna is positioned 115 mm away from the edge of the ground plane. The antenna is excited at the center of the radiating element. Then impedance matching is achieved by cutting off both lower sides of the radiator and adjusting the distance between the radiator and the ground plane. The I-shaped parasitic element is printed on the rear side of the antenna and is electrically separated from the main radiator and ground plane. The electrical length of an I-shaped parasitic element is approximately half-wavelength at the center frequency of 5.49 GHz [21].

Fig. 14 shows the band notch realization in UWB antennas using parasitic patches, Fig. 14(a) and 14(b) shows the patch placement near the radiating patch and Fig. 14(c) shows the parasitic patch placed on the rear side of antenna. The antenna shown in Fig. 14(a) shows a promising feature of highly adjustable notch band using the width and position of the parasitic strip, further in it is shown that multiple notched bands can be achieved by placing multiple strips, each for a single notch. The design proposed in [23] also proposes two more variations of the same design by replacing the H-shaped patch with I-shaped and U-shaped patches, the rejected band in all the three cases is from 5~6 GHz. The antenna shown in Fig. 14(c) uses the innovated idea to place the notch band resonator on the back side of the substrate. This approach makes it possible to design the patch and the antenna in isolation, before combining them. This antenna has a notch at 5.15 GHz.

In [25] and [26] the band notch is apparently achieved by modifying the patch shape but actually this modification introduces the parasitic patches in the antenna, and these patches then act as band stop filters for the UWB antenna. Fig. 15(a) shows the antenna proposed in [25], in which a semi elliptical patch attached to the main patch causes out of phase current distribution with the parasitic patch placed at the rear side of antenna. Fig. 15(b) shows the segmented-patch antenna proposed in [26]. The patch of the antenna is cut into three segments, one becomes the excited patch and the other two becomes parasitic.

(a) (b)

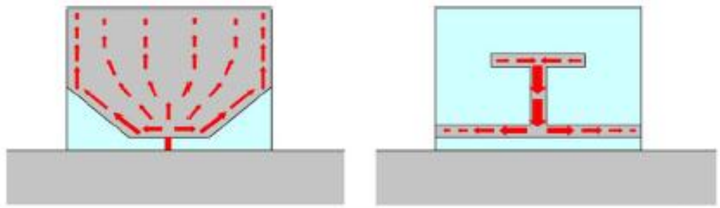
Fig. 10. (a) UWB antenna having embedded SRR in the patch; (b) SRR cell [18].



(a) (b)

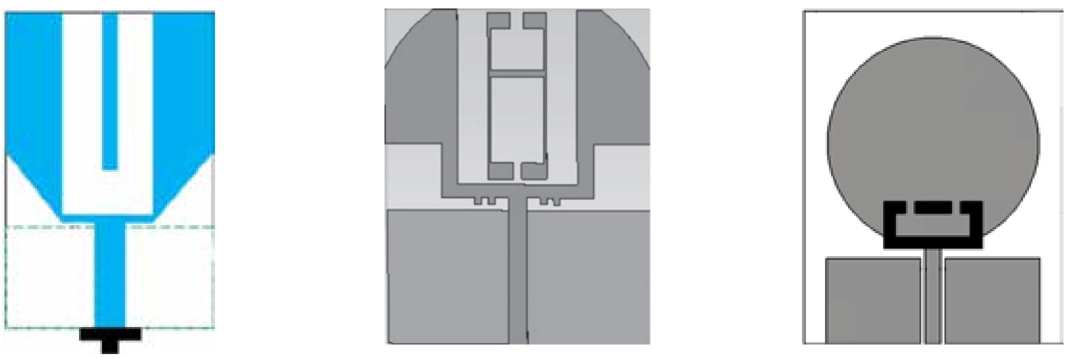
Fig. 11. (a) Gain; (b) Front view of UWB antenna with CLL resonant cells embedded in it [19].

Fig. 12. UWB antenna with an open loop resonator attached to the center of its patch [20].



(a) (b)

Fig. 13. (a) front view and (b) back view of current distribution of parasitic patch antenna at notched frequency [21].



(a) (b) (c)

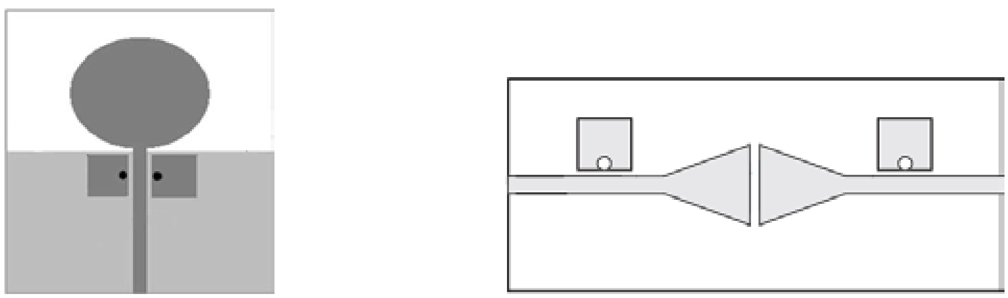
Fig. 14. UWB antennas with parasitic patches to achieve notched-band [22–24].

(a) (b)

Fig. 15. Some other forms of parasitic patch band-notched UWB antennas [25, 26].

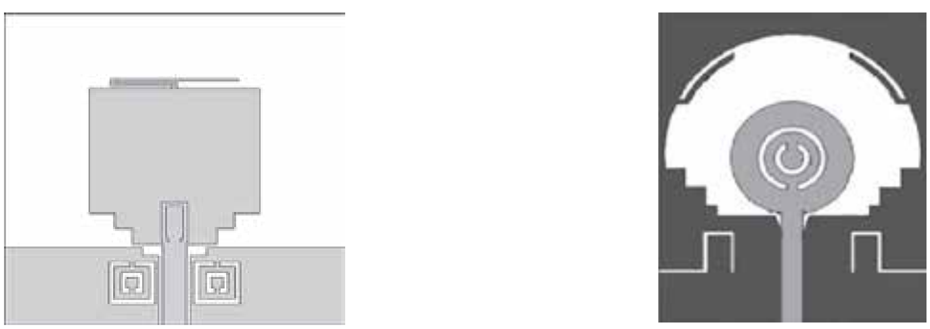
(a) (b) (c)

Fig. 16. UWB antennas incorporating stubs to achieve notched-band(s) [27]–[29].



(a) **(b)**

Fig. 17. EBG structures used in (a) UWB antenna (b) UWB filter, to achieve notched-band[30], [31].



(a) (b)

Fig. 18. UWB antennas incorporating multiple techniques to realize notched-band [20], [21].

This antenna can achieve a VSWR>12 in rejection band of 5.1~6.1 GHz.

2.4 Using Stub

The insertion of stubs in the ground plane or patch causes impedance mismatch for some frequencies. This fact is exploited to design appropriate stubs for rejection of undesired frequency bands in UWB antennas. Further, changing the length and width of the stub provides some control over the notch frequency and bandwidth.

Fig. 16(a) shows a UWB antenna with meandered ground stubs, these stubs are placed on the top surface of antenna, but connected to ground through holes drilled in the substrate. This pair of stubs provides a single notched band in the WLAN range (5.15~5.825 GHz), which can be altered by varying the various parameters of stubs.

In the antenna of Fig. 16(b) two notched bands are realized by using three slot-stubs inside the ring patch. The notched bands are controlled by the length and width of the slot-stubs. The length and width of strip type ground stubs, shown in Fig. 16(c) controls the notched bands with least effect on VSWR[29]. This design] provides rejection in 5.18~6.23 GHz band. The stubs are connected to the ground plane through via.

2.5 Using EBG Structures

An efficient approach of achieving notched band is the use of electromagnetic-band gap (EBG) structures. By placing EBG structures close to the feed line of antenna, the EBG structure works as band stop filter. Fig. 17(a) shows the use of two EBG structures for dual band notching[30]. It has been shown that the edge-located vias mushroom type EBG (ELV-EBG) is better than conventional mushroom-type EBG (CMT-EBG) in terms of compactness and frequency rejection function. The research further explores that the use of EBG structures on either sides of the feed line cause less coupling between them, and hence tuning one notch frequency has little effect on the other one. In this design the control over the notched frequency is provided by the width of the EBG patch. The band width of the rejected band is controlled by the coupling gap between the EBG patch and the feed line. The two EBG patches shown in Fig. 17(a) provide two notched bands with an excellent isolation at the notched bands and a very good rejection in terms of VSWR of notched frequencies. The two notched frequency and their bandwidth can be varied independently.

Fig. 17(b) shows a similar implementation of EBG structures. The antenna part shown is actually a band pass filter, which can be integrated into a UWB antenna or, as proposed by the researcher [32] it can be used as a filter for UWB signals. By the use of two EBG structures, two notched bands are created at 5.2 and 5.8 GHz.

2.6 Combination of Different Techniques

Some reported designs are simply the combination of earlier reported design techniques. The combination depends on the particular requirements for UWB antenna.

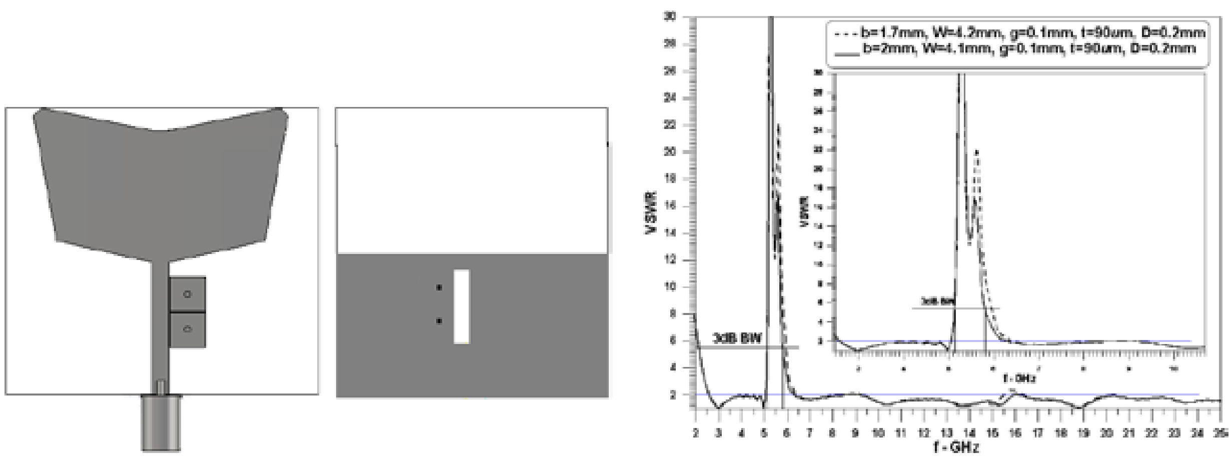
Fig. 18a shows a 40 x 40 mm^2 triple band notch UWB antenna, capable of rejecting 3.5, 5.5 and 8.2 GHz center frequencies. This design combines meandered stub, CSRR and slot technique in one antenna. This research concluded that because of completely different shapes of the three elements, they cause least coupling among them, while providing simple control over the notched frequencies.

The antenna shown in Fig. 18(b) is a 24 x 30 mm^2 UWB antenna with impedance bandwidth of 2.6~12 GHz having VSWR<2 except for the three stop bands of 3.3~4, 5.15~5.4 and 5.8~6.1 GHz. The antenna incorporates DGS, pair of open-circuit stubs and a split ring resonant cell for band rejection.

Besides the techniques categorized in the above sections, some other designs are also reported in the literature. In [12] a composite Right-and Left-Handedness (CRLH) metamaterial is proposed to create band stop filter for UWB antenna. Fig. 19(a) shows the proposed filter and the test antenna. Metamaterials are said to have simultaneously negative permeability and permittivity, this was originally proposed by Veselago in 1968 [36]. Fig. 19(b) shows an antenna which is a multilayered antenna providing triple notch bands. Closed-loop ring resonators are fabricated on each layer, only layer one contains a ring resonator with truncated ground plane fabricated on its back side as well. The resonators of each layer can be thought of as parasitic patches. The three rejected bands of this antenna are 3.3~3.7 GHz, 5.15~5.35 GHz and 5.725~5.825 GHz. The notched center frequencies are determined by the diameter of closed loop

(a) (b) (c)

Fig. 19 Use of (a) metamaterial (b) multilayered closed loop resonators (c) inter digital hairpin fingers, to realize notched-band(s) [12, 33, 34].



(a) (b)

Fig. 20 (a) Band notch realization using EBG and ground plane slot, (b) VSWR plot of antenna [35].

resonators. The volume of this antenna is 33x30x1.524 mm^3. In [34] another filter-integrated-to-antenna design is proposed. It consists of three linear identical inter digital hairpin fingers. The notched band is obtained by adding two other folded fingers on both sides. Furthermore, the notched band can be easily tuned by changing the folded part of the fingers. Fig. 19(c) shows the proposed filter and UWB antenna connected together.

A combination of EBG and ground slot technique is reported in [35], the antenna provides a radiation band that spans from 2~25 GHz, which is again much wider than those of normally reported UWB antennas. The rejected band is 5.2~5.8 GHz. The dimensions of the EBG patch and the slot controls the rejected frequency and bandwidth. In the notched band VSWR is greater than 30 which has been possible due to the combination of two techniques. The antenna with its VSWR plot is shown in Fig. 20.

3. COMPARATIVE ANALYSIS

After reviewing different band notching techniques, we present the advantages and disadvantages of different techniques. In Table 1 a brief comparison of the above discussed band notching techniques is presented. The values of antenna parameters shown in the table are the optimum values for the proposed antennas. It is observed that very small antenna sizes can be achieved by using slot or parasitic patch technique. Also notched band can be easily tuned by adjusting slot dimension and position. However this method is not suitable for multi band notch requirements. On the other hand, multiple band notches and reconfigurable designs are easily possible through the use of resonant cells. However resonant cells are complicated structures and it is difficult to control the notch band. EBG structure is an efficient technique, with a good rejection quality. However designing EBG structure requires detailed mathematical and simulation analysis before it can be integrated with UWB antenna. Also the size of antenna has to be increased to accommodate EBG structures. The hybrid combination of more than one technique is a smart approach which combines the advantages and compensates for the disadvantages of various techniques into a single design.

4. CONCLUSION

Techniques and designs for introducing band notch feature in UWB antennas have been discussed and critically analyzed in this review paper. All proposed techniques in open literature have been categorized for better comparative analysis. It is observed that all techniques provide satisfactory performance in both the pass and stop bands. However, it is seen that the UWB antennas having band rejection feature suffer from one or more limitations i.e. complex in design, having poor isolation at the notched frequencies, bad rejection quality, and inconsistent response in the pass band. Further, it is observed that most of the proposed designs aim to cancel out the interference from the WLAN band

None of the reported designs can overcome all of these limitations, however for a given application; design can be optimized by judicious combination of different proposed techniques.

In our view further research on UWB antennas having band notch feature is required for reducing antenna size, proposing application specific designs, proposing flexible antennas for emerging wearable communication products.

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