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A Comprehensive Analysis of realizing Ultrawideband Antenna and Multiple Band Notches

Tanweer Ali
Manipal Institute of Technology, MAHE, Manipal, India, tanweer.ali@manipal.edu

Research Article

A Comprehensive Analysis of realizing Ultrawideband Antenna and Multiple Band Notches

Praveen Kumar, Tanweer Ali*, Om Prakash Kumar, Jaume Anguera, Pradeep Kumar

Email: tanweer.ali@manipal.edu

Abstract

This paper presents a detailed review of UltrawideBand (UWB) antennas having band notch characteristics. Each technique used has its advantages and limitations. Among the different techniques applied for eliminating the same number of frequency bands, some can get a good radiation pattern. A few techniques exhibit a low group delay and others have achieved a good gain. The review will aid designers to have a broad overview of the different technical parameters such as gain, operating frequency (bandwidth), radiation efficiency, number of notches produced, and the respective techniques used to model each notch, and size in different types of UWB antennas.

Keywords: Ultrawideband (UWB), band notch, gain, group delay.

Introduction

In recent years, due to the immense technological advancements in the wireless communication system, ultrawideband (UWB) technology has drawn significant attention because of various advantages such as achieving high data rates, low power spectral density, omnidirectional patterns, low cost, and their wide operating bandwidths (3.1 to 10.6 GHz). In the wide operating bandwidth, existing narrow bands such as C Band (3.8 to 4.2 GHz), WiMAX (5.25 to 5.85 GHz), X Band (7.25 to 7.5 GHz) are used for uplink, and X Band (7.9 – 8.3 GHz) are used for downlink. UWB has its benefits of high-speed data rate, very low spectral power density, low cost, wide bandwidth, good omnidirectional pattern, and compactness. However, design complexity is a major drawback of such antennas. Additionally, UWB antennas are sensitive to nearby electromagnetic radiation due to the narrowband wireless communication systems. This presents a challenge to UWB antenna designers to eliminate these narrowband frequencies, which fall under the UWB category. To suppress the interfering signal or to create notches at required bands, different types of techniques have been incorporated in recent years. Many of them include the creation of slots/slits in the radiating monopole or the ground plane. The slots are of different types such as U-shaped [1], S-shaped [2], Rectangular slots [3], C-shaped [1], [4-5]. In addition to these defected ground structures [6], meander lines [7], complementary split-ring resonator (CSRR), and symmetrical split ring resonators pair (SSRRP) [4] have also been used. This communication aims to explore the different mechanisms used to create single and/or multiple band notches in the UWB frequency range. The paper is organized as follows - Section 2 represents the design aspects of the antenna, such as the creation

Praveen Kumar[1], Tanweer Ali[1], Om Prakash Kumar[1], Jaume Anguera[2], Pradeep Kumar[3]

[1] *Department of Electronics and Communication, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, India.*

[2] *Fractus Antennas, Barcelona, Spain and Electronics and Telecommunication Department, Universitat Ramon Llull, Barcelona, Spain.*

[3] *Discipline of Electrical, Electronic and Computer Engineering, University of KwaZulu-Natal, Durban-4041, South Africa.*

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* Corresponding Author

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of notches by incorporating different types of design techniques. Section 3 includes a critical review of the literature followed by the concluding remarks.

Antenna Design Specifications

This segment depicts the primary requirement of UWB antenna design, such as selecting appropriate substrate, improving impedance bandwidth, and necessary and sufficient conditions to create desired band notches in the UWB spectrum [8-18].

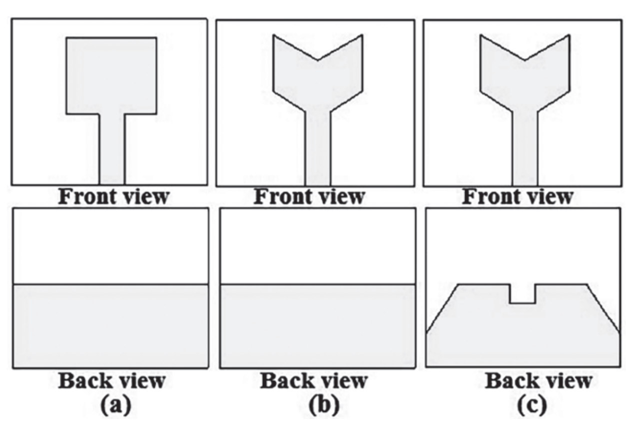
A. *Choosing the Substrate*

Choosing the substrate is one of the most important aspects of antenna design. A wise selection of the substrate should be performed by considering the following criteria such as thickness, cost, and viability. The length of the antenna is inversely proportional to the square root of the relative permittivity of the substrate. Therefore, an increase in the dielectric constant results in the miniaturization of the antenna. At the same time bandwidth of the antenna increases at the cost of moving away from the designed resonant frequency. The increase in substrate thickness trend has a limitation. If it exceeds 0.1 times of effective wavelength, surface waves are generated and resulting in performance degradation particularly a decrease in gain and impedance mismatching. Therefore, choosing substrate is a critical task and antenna application orientated.

B. *Implementing Ultrawideband*

The literature reveals that there are many approaches to improve the impedance bandwidth of the antenna. As the aforementioned increase in thickness or decrease in the dielectric constant of the substrate approximately 1 will increase bandwidth. Different feeding techniques specifically proximity and aperture coupled feeding also increases the bandwidth to a certain extent. Other popular methods such as lowering ground plane, modifying ground plane, inserting parasitic elements, metamaterial loading also help in realizing wider impedance bandwidth. One such technique to design an ultrawideband antenna is demonstrated below. Achieving ultrawideband by modifying radiating plane and using the defective ground structure is shown in Figure 1. The criteria were to obtain a UWB spectrum ranging from 3.1 to 10.6 GHz by assuring the reflection coefficient below -10 dB or voltage standing wave ratio less than 2.

At the first stage, a rectangular monopole antenna is designed with a lowered ground plane as shown in Figure 1 (a). The reflection coefficient curve for this design has two frequency portions are below -10 dB at 3 to 5 GHz and between 9 to 10 GHz. The radiating plane is altered from a rectangular shape to a Y-shape and the ground plane is unaltered as depicted in Figure 1 (b). The obtained result has no significant difference compared to the previous design except a sharp dip in the resonant frequency. In the last stage of the antenna ground plane is modified by a rectangular slot at the center and two slant line slots at the edges of the ground plane as depicted in Figure 1 (c). This antenna arrangement achieves impedance bandwidth covering the entire UWB range as shown in the reflection coefficient curve. The ground plane modification will decrease the quality factor and alter the value of the inductor and capacitor thereby enhancing bandwidth.



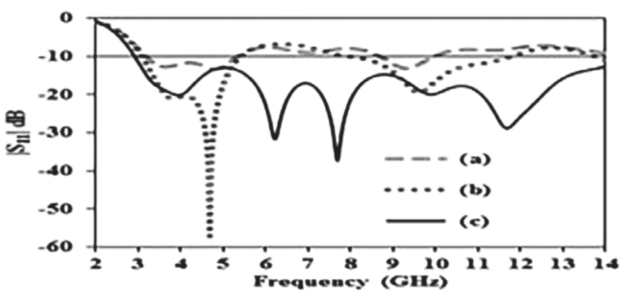


Figure 1: UWB Antenna evolution and its reflection coefficient curve [16].

C. Realizing Notch Bands

The allocated unlicensed UWB frequency from 3.1 to 10.6 GHz by the Federal Communication Commission covers many existing narrowband frequency operations. These narrowband create interference to the UWB communication system. Therefore, it is important to eliminate/filter the existing narrow bandwidth. To accomplish this introduction of a filter circuit will meet the requirement with additional complexities which may not be feasible for the applications where antenna miniaturization is required. The other viable solution is incorporating the slit, slot, and stubs on the radiating or ground plane. Insertion of such parasitic elements creates a discontinuity in the current distribution results in band notches without any external circuitry. The critical problem in this method is to obtain a proper length of the slit/slot and stub. To calculate the length of the parasitic elements following equation can be used

$$L_{parasitic\ element} = \frac{\lambda_g}{2} \qquad (1)$$

Where λ_g is the guided wavelength and is equal to

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}$$

$$\therefore L_{parasitic\ element} = \frac{\lambda_0}{2\sqrt{\varepsilon_{eff}}}$$

$$L_{parasitic\ element} = \frac{C}{2f_r\sqrt{\varepsilon_{eff}}} \qquad (2)$$

Where ε_{eff} is the effective dielectric constant, f_r is the resonant frequency in GHz, and C is the speed of light.

The effective isotropic radiated power (EIRP) is limited to the -41.3 dBm/MHz or 75 nW/MHz for indoor UWB applications. The UWB technology uses short pulses for communication. Therefore, it is significant to evaluate a few more design parameters compared to the narrowband antennas. One important parameter is group delay signifies the amount of correlation between the transmitted and received pulse shape. The modification of conducting plane of the antenna to achieve notches at the desired frequency affect the gain, bandwidth, and efficiency of the antenna. Consequently, Table 1 to 5 below demonstrates the technique used to create single, double, triple, four, and five notch bands and their effect on antenna parameters. The gain at the notch frequency is expected to be less than 0 dB at the notched frequency to ensure that a particular frequency will not create any degradation to the UWB antenna.

Table 1: UWB single-band notch antenna design techniques

Ref	Design method	Gain	Time delay (ns)	Radiation Pattern	Size (mm³)	Operating Frequency (GHz)	Efficiency
[8]	A strip is attached to the hollow center of a winged-shaped monopole.	The gain varies from 0 to 4 dB across the passband. Curve varies across the desired frequency. At the notch band region, there is a sharp decrease in the gain of about -6dB.	<1	Though this technique has a good time delay, observed radiation patterns will not follow omnidirectionally.	15x15x1.6	3.05 - 11.5	-

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[9]	Vertical coupling strip placed at the center of square slot patch.	This technique maintains gain in the range of 3 to 3.5 dB overall frequency ranges. At the notch frequency range, there is a sharp drop in the frequency of 5 dB which is to -2 dB.	-	Approximately omnidirectional.	15x15x1.6	3.05 - 11.5	-
[10]	Placing octagonal slots and two pairs of differently fed mono pole orthogonal to each other.	Observed gain varies linearly from 2 to 5 dB and negative at the notch frequency.	<1	As frequency increases both E-plane and H-plane get distorted. Compared to the H-plane radiation pattern, the E-plane radiation pattern degrades as frequency increases.	64x64x0.8	3 - 11	80% pass band
[11]	Placing a Y-shaped slot in the radiator of the Sierpinski carpet fractal shaped with octagonal boundary.	Before notch frequency region gain varies between 0 to 2 dB but after notch region, it is showing a linear increase in gain up to a maximum of 6 dB. At the notch, the gain is -3 dB.	>1	Approximately omnidirectional	33x32x1.59	3 - 12	-

Table 2: UWB dual-band notch antenna design techniques

Ref	Design method	Gain	Time delay (ns)	Radiation Pattern	Size (mm³)	Operating Frequency (GHz)	Efficiency
[3]	Etching a single tri-arm resonator near the patch.	The gain varies from -6 to 2 dB. At the notch frequency gain decreases.	<2	Lower frequency omnidirectional.	20.5x29x1.6	2.98 - 10.76	-
[12]	Three rectangular slots on the patch.	Gain is 2.5 dB in all passband regions.	<2.4	The omnidirectional pattern will not follow.	26x30x1.6	3.15 - 10.63	>90% for passband
[13]	Adding independent strips for notch frequency and fork-shaped for the width of band notches.	Increases gradually from 0 to 4 dB.	<1	Nearly omnidirectional, distortion at high frequencies.	24x36x1.524	3 - 12	>80% pass band

Table 3: UWB tri-band notch antenna design techniques

Ref	Design method	Gain	Time delay (ns)	Radiation Pattern	Size (mm³)	Operating Frequency (GHz)	Efficiency
[14]	Half-circle patch with an open rectangular slot and a half-circle ground plane.	Gain lies in between 0 to 2.5 dB.	-	E-plane remains considerably undistorted over all working frequencies. But H-plane starts to distort at higher frequencies.	-	-	-
[4]	Insertion of two round-shaped slots of half wavelength in the rectangular ground plane.	Gain lies in between 1 to 4 dB.	-	Omnidirectional	31x22x0.8	3 – 15	-
[15]	Using fractal Koch and T-shaped stub on the center-fed monopole.	Varies from 2 to 5 dB	-	Omnidirectional	50x50x1.6	1.78 - 11	70% - 95% Passband
[2]	Using complementary split ring resonators (CSRR) and S-shaped slot on the microstrip feed line on the circular microstrip patch antenna.	A gain of 2.5 dB is observed overall passband frequencies.	-	Nearly omnidirectional	26x30x1.6	3 - 11	Pass band >80%

Table 4: UWB Four-band notch antenna design techniques

Ref	Design method	Gain	Time delay (ns)	Radiation Pattern	Size (mm^3)	Operating Frequency (GHz)	Efficiency
[7]	Using four pairs of meander lines as resonator with elliptical radiator.	Varies across the frequency range peak is of 5 dB	-	Nearly omnidirectional.	30x39.3x0.8	2.5 - 11	70% - 95% pass band
[5]	Using 3 inverted U-shaped and single I-shaped slots on an ellipsoidal patch.	Varies across the operation of frequency.	<1	Nearly omnidirectional.	27×36×1.6	2.8 - 14	-

Table 5: UWB five-band notch antenna design techniques

Ref	Design method	Gain	Time delay (ns)	Radiation Pattern	Size (mm^3)	Operating Frequency (GHz)	Efficiency
[16]	Using an inverted U and C-shaped slot placed on a Y-shaped radiating patch. While three different C-shaped slots on the ground plane.	For all passband region gain is above 1.5 dB.	<1.3	Nearly omnidirectional.	36x38x1.6	2.86 - 13.3	-
[18]	Three CSRR on the radiating semi-circular patch, with SRR at the junction of the feedline, with defected ground structure (DGS).	This increases gradually from 2 to 6 dB over the passband region.	-	Omnidirectional.	30x28x0.5	2 - 10	>90% Pass band

*- not available

Summary

This article analyses many types of UWB antennas, including monopole antennas with different structures of a radiating plane, tapered slot antennas, as shown in Table 6. To have a clear understanding of creating notches, different tables are created based on the number of band notches. This review article's findings can be summarized in the following points: (1) shows several methodologies that may be used to get notch characteristics, (2) may assist industries/manufacturers in selecting the best one according to their intended application, and (3) provides insight into future research that may be valuable for future researchers.

Conclusion

The literature on UWB antennas with notch features has been classified into distinct parts in this review article. Various structures that provide UWB and band notch characteristics such as square, circle-shaped monopole antenna with the different shapes of slots, slits, stubs, and metamaterial loading on the ground and radiating plane are considered for understanding in this paper. To make an easy analysis article is organized based on the techniques used for achieving single, double, triple, four, and five frequency band notches. It has been observed that almost all antennas operate in the frequency range of 3.1 to 10.6 GHz and exhibit one or more notch characteristics. Furthermore, it has been observed that notch antennas designed to reject frequency bands like X band, C band, Industrial, Scientific and Medical (ISM) band, and so on are rather uncommon in the literature. Furthermore, quadruple-featured and reconfigurable notch antennas are less prevalent in the literature than single, dual, and triple-notch antennas.

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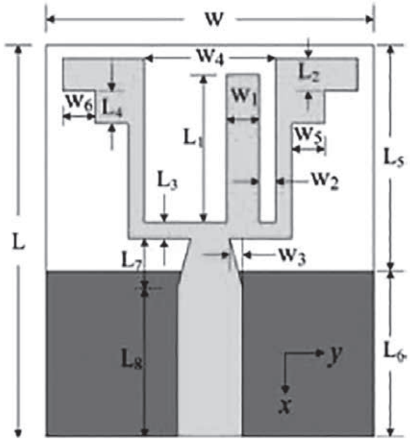
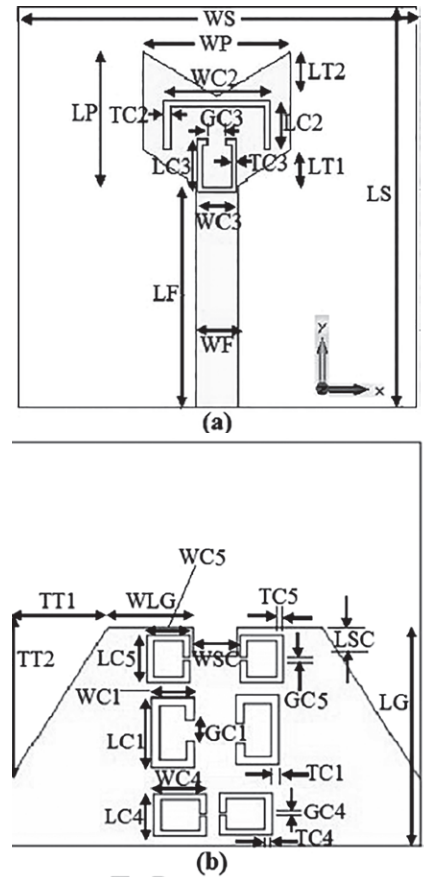
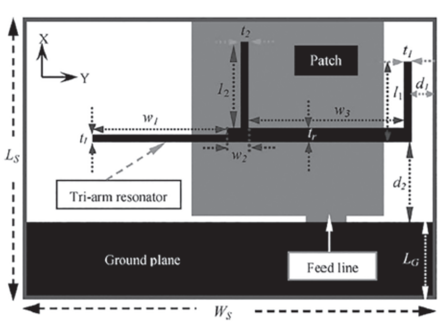
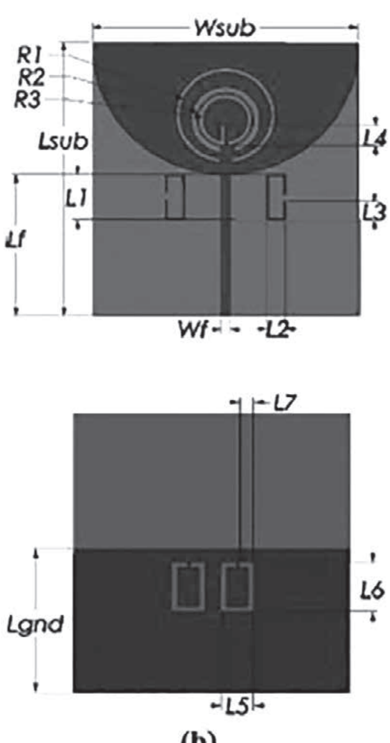
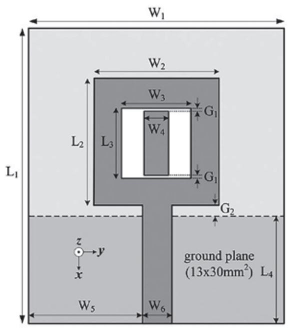
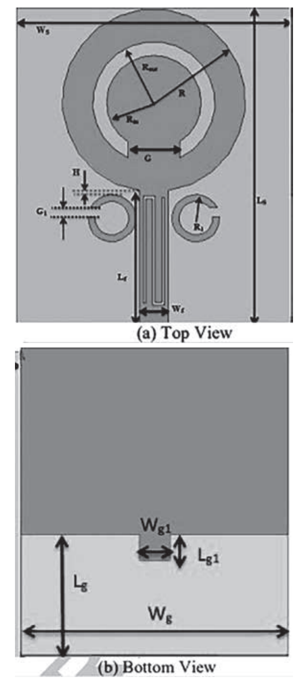
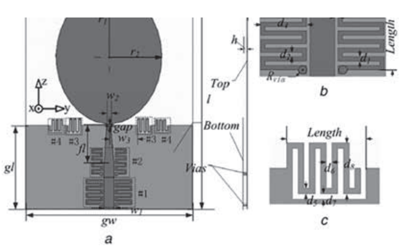
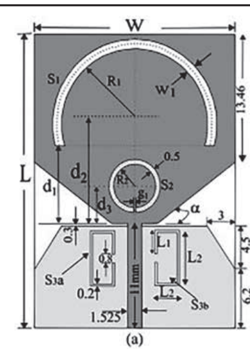
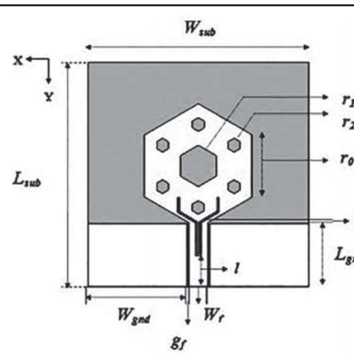
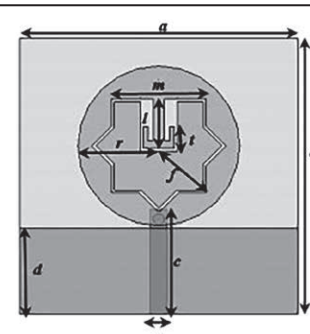
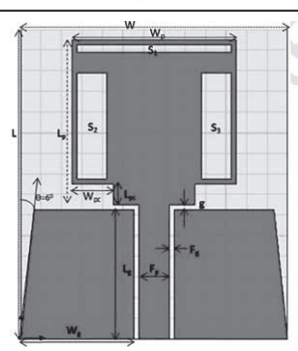
Table 6: Antenna structures available in the literature with notch band characteristics.

Ref	Antenna Structure	Notches (GHz)	Ref		Notches (GHz)
[18]		Single notch 6.7-7.1.	[16]		Five notches 3.45-4, 5.15-5.90, 6.77-8.0, 8.3-9.1, 9.3-10.6.
[12]		Two notches 3.5-5.5.	[6]		Four Notches 3.30-3.60, 5.150-5.350, 5.725-5.825, 7.0-7.40, and 8.10-8.50.

[9]		Single Notch 5.12-6.08.	[2]		Three Notches 3.30-3.60, 5.10-5.80, 7.25-7.75.
[7]		Four notches 3.14, 4.34, 5.4, and 6.4.	[4]		Three notches 3.3-3.7, 5.2-6.0 and 7.5-8.1.
[11]		Single Notch 5.15-5.825.	[15]		Three Notches 2.8-3.45, 3.45-3.8, 5.6-6.3.
[3]		Two Notches 5.18-5.82, 7.25-8.39.			

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