Recent Advances in Ultra-Wideband Antenna Design: A Review

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Abstract - *Narrow Band antennas are not able to send very short signals across a wide range of frequencies. As a result, Ultra - Wideband (UWB) technology, which allows antennas to transmit across a wider range of frequencies, has become more popular in recent years. An UWB antenna uses frequencies between 3.1 and 10.6 GHz, which is a much wider range than narrow band antennas. UWB antennas are used in a variety of applications, such as ground-penetrating radar, disaster relief, medical testing, and commercial applications such as USB dongles and crack detection in roads and bridges. Ultra-wideband (UWB) technology is a promising future wireless communication technology. This article provides a comprehensive review of UWB antennas and their design methodology. It also discusses UWB notch antennas, which are used to reduce interference from other frequency bands. The article details various methods for obtaining notch characteristics, such as slots, parasitic resonators, and filters. Additionally, the article presents various types of important notch antenna designs, along with their technical specifications.*

Key Words: **Ultra-Wideband (UWB) antenna, UWB notch antenna**

1. INTRODUCTION

Antenna is one of the frontend elements in the communication system which play a vital role in vehicular, airborne, communications, SIGINT (signal intelligence), and ISR (intelligence, surveillance, and reconnaissance) According to the Webster's Dictionary Antenna is defined as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves." [1]. In recent years, Ultra-Wideband (UWB) antennas have become increasingly popular in wireless communication systems due to two main factors. First, UWB offers a number of advantages over traditional narrowband wireless technologies, including: High data rates: UWB can achieve data rates of up to several gigabits per second, making it ideal for applications such as streaming video and transferring large files. Precise location data: UWB can be used to accurately measure the distance between two devices, down to a few centimetres. This makes it ideal for applications such as indoor positioning and asset tracking.

Low power consumption: UWB signals require very little power to transmit and receive, making them ideal for battery-powered devices. Second, UWB antennas can be used to simplify the design of portable wireless devices. Traditional wireless devices often require multiple antennas to operate at different frequencies. This can increase the size and complexity of the device. UWB antennas, on the other hand, can operate over a very wide range of frequencies, eliminating the need for multiple antennas.

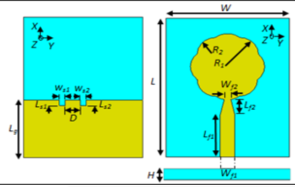
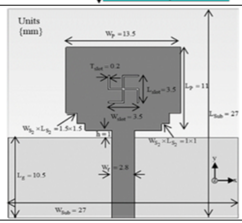
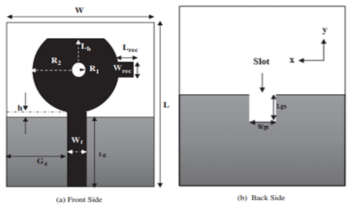
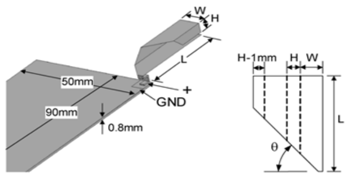
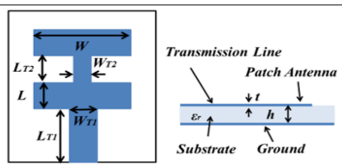
In 2000, the Federal Communications Commission (FCC) allocated the frequency band 3.1 to 10.6 GHz for UWB use. This band is well-suited for a variety of applications, including wireless communication, localization and identification, radar, and sensing [2]. UWB is a versatile communication technology that can be used for a wide range of tasks, including streaming video, transferring movies, downloading camera photos, printing files, and sharing MP3 files.

This article is organized into five sections. Section 2 addresses the early stages of applications that communicate using UWB technology. Section 3 discusses the various UWB antenna designs that have been developed since 2006. Section 4 provides a comprehensive overview of UWB notched antennas, which are used to reduce electromagnetic interference (EMI) between sub-bands.

2. The ULTRA-WIDEBAND TECHNOLOGY

Satellite-based synthetic aperture radar (SAR) systems using ultra-wideband (UWB) communication have the potential to provide high-resolution images of the Earth's surface. In one study, researchers designed a SAR system that can be used to communicate from a satellite using two antennas with a gain of 10 to 20 dB [3]. The antenna was designed to work in the C-band, which is a frequency band that is often used for satellite communications [4]. Another study investigated the use of UWB communication for detecting targets at sea [5]. The proposed method employed the broad bandwidth of UWB antennas to reduce sea clutter and enhance the target-to-clutter ratio, resulting in more effective identification of targets. UWB communication is particularly attractive for satellite-based SAR systems because it is resistant to radio interference. The International Telecommunication Union (ITU) has already allotted the frequency range 2025 MHz-2110 MHz for Earth-to-space communication, which conflicts with terrestrial radio communication channels. As a result, UWB communication is necessary for satellite-based SAR systems to avoid interference.

Table -1: The emergence of UWB technology and its applications.

Reference No.	Size (mm^2)	Gain (dB)	Efficiency (%)	Reason for UWB performance	Operating Frequency	Applications	Proposed Antenna Design
[9]	50 × 40	3.3	69	Cutting two slots in the ground plane	2.2- 25	5G Wireless communication	
[8]	27 × 27	1.75–5.6	90.6	A partial ground surface with a slot in the patch and bottom notches	3.1–10.6	Wireless body area network (WBAN)	
[10]	24 × 35	6.8	82.22	ring-shaped with additional slot and slotted ground plane	3.1–12.3	UWB Application	
[11]	5 × 8	-	88	Utilization of tapered structu re	0.8- 6	Mobile phone	
[13]	33.4 × 34.3	14	-	Doppler radar technique	10	Human respiration and heart rate detection	

Early research on the use of UWB communication for satellite-based SAR systems was conducted by the Wireless World Research Forum (WWRF) [6, 7]. The WWRF investigated the requirement for new wireless interfaces and the issues related to the consumption of the then-available 3G communication spectrum. This research helped to lay the foundation for the development of UWB communications for satellite-based SAR systems. Ultra-wideband (UWB) technology is a promising candidate for wireless body area networks (WBANs) due to its high data rate capability, low power consumption, and ability to penetrate the human body.

In [8], the authors designed a new patch antenna, termed the Swastika slot-ultra-wideband (SS-UWB) antenna, for WBAN applications. The SS-UWB antenna operates in the frequency range of 3.1 to 10.6 GHz and has a wide bandwidth and high gain. In [9], the authors proposed a novel flexible UWB antenna for WBANs. The antenna is made by attaching a conductive fabric to a PDMS substrate. It is lightweight, conformal, and has a good radiation pattern. In [10], the authors designed a bird face monopole antenna that can operate over a wide frequency range (3.10–12.30 GHz). The antenna has a simple design and is easy to fabricate. However, its gain varies across the frequency range, and the authors did not discuss the cross-polarization levels.

Overall, the research on UWB antennas for WBANs is still in its early stages. However, the results so far are promising, and UWB technology has the potential to revolutionize WBANs in the near future. Researchers have explored the use of Ultra-WideBand (UWB) technology in mobile devices [11, 12]. For example, one paper designed a small antenna for UWB operation in the 1.0–6.0 GHz frequency band [11]. Another paper surveyed reconfigurable adaptive CMOS circuits that use UWB signals for 4G mobile applications [12]. In addition to mobile devices, UWB technology has also been used for life detection in critical situations such as earthquakes and collapsed coal mines [13]. Table 1, describes the emergence of UWB technology and its applications.

3. DEVELOPMENT OF THE UWB ANTENNA

Ultra-wideband (UWB) technology was developed to meet the need for a high-bandwidth, low-interference wireless communication system. UWB antennas offer several advantages over other wireless technologies, including high gain and low interference. These advantages have led to the adoption of UWB antennas in a variety of applications (Section 2).

Table 2 lists the most important UWB antennas proposed in research papers, along with their design specifications.

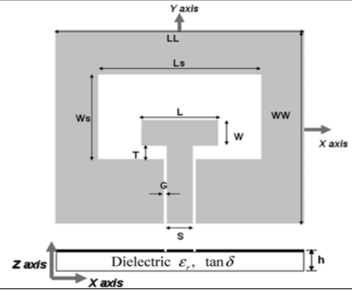
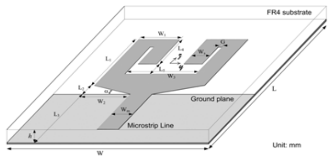
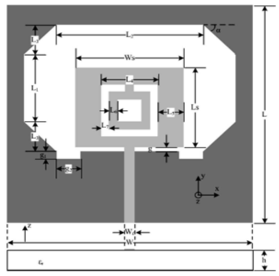
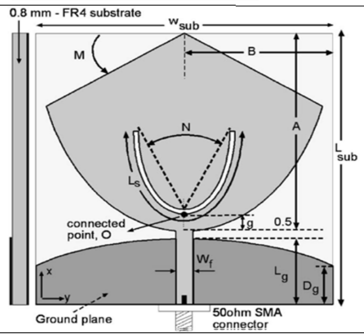
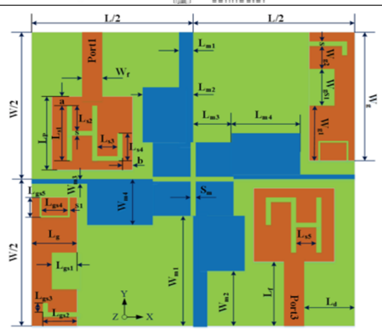
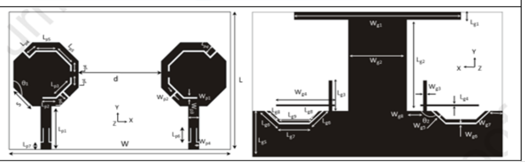
Several authors have proposed various UWB antenna designs. In [14], a rectangular monopole antenna with a sleeved transmission line and a small ground plane is described. The folded metallic element in the antenna proposed by Giuseppe Ruvio et al. [15] creates multiple paths for the current to flow, increasing the antenna's bandwidth and resulting in a quasi-omnidirectional radiation pattern. A UWB leaky lens antenna using the principle of Cherenkov radiation has also been designed [16], resulting in a directional antenna with non-dispersive properties. A planar ultra-wideband (UWB) elliptical monopole antenna with a UWB ratio of 12.4:1, which is significantly higher than the 10.2:1 UWB ratio of a circular monopole antenna, has also been proposed [17]. Finally, a UWB plate antenna with a shorting wall attached to the radiator, excited by an L-shaped plate, has been presented [18].

Table 2 lists different design approaches and key features of simple UWB antennas with radiation characteristics. All the antennas discussed in this section radiate in the UWB frequency range without any notches. However, with the advancement of UWB technology, the need to create notches at specific frequencies, such as those used by Wi-Fi and WiMAX, to avoid interference has emerged. This led to the development of slotted antennas, which have slots of different shapes and sizes in different positions to generate notches. Section 4 reviews the literature on slotted antennas, which can be used to mitigate the effects of electromagnetic interference (EMI) between other devices operating in the UWB frequency range.

Table -2: The Progress/Development of UWB Antenna

Reference No.	Size (mm^2)	Gain (dB)	Reason for UWB performance	Operating Frequency	Design methodology
[14]	40 × 38	7	CPW fed with a U-shaped tuning stub and elliptical slot	3.1–10.6	Elliptical slot with U shaped stub
[15]	30 × 46	3.8	Beveling the bottom border of planar monopole antenna	3.1–12	Slot cut in the ground plane
[16]	160 × 108	18	Slot etching on the ground plane with a central point feed	4–40	leaky slot line
[17]	90 × 90	8.2	Elliptical monopole antenna	12–12.6	Elliptical monopole antenna
[18]	100 × 100	5.2	Suspended plate antenna with the shorting wall together with the L-probe feed	3–12	Parasitic L-shaped plate
[19]	50 × 46	1.54	The curves of the antenna edge by a binomial function which gives the wider impedance bandwidth	2.5–10.9	Use of a binomial function
[20]	30 × 8	4	The planar monopole has strong vertical currents, which leads to large impedance bandwidth.	2.7–16.2	A triangular feeding strip is used. Rectangular monopole with an equal-width ground plane
[21]	30 × 20	4.13	There are electric and magnetic radiators. Energy stored in matching stubs is radiated because of the CPW-slot line transition.	3.1–10.6	Two rectangular slots

Table -3: The emergence of design of UWB notch antenna

Reference No.	Size (mm^2)	Gain (dB)	Design methodology	Notching Structure	Notching Frequency (GHz)	Proposed Antenna Design
[24]	35 × 30	7	The rectangular aperture is designed by minimizing the aperture area and causing impedance matching.	Rectangular slot with T stub feed	5-6	
[27]	30 × 30	7	The concentration of current on the conductor's outer edge and the fork-shaped strip causes band rejection in selected bands	T shaped slot in a fork-shaped strip	5.1–5.8	
[28]	29 × 30	4	Square ring resonator is used to achieve notching.	Octagonal slot with a rectangular stub for tuning	5.2–5.9	
[29]	26 × 26	5	A semi-elliptical patch with dielectric material on both sides of the patch increases the effective patch, thereby increasing the bandwidth.	Two arc-shaped slots which are connected	5.1–5.9	
[37]	9 × 39	3.2	Use of decoupling structure, multi-slit, and multi-slot concepts	Multi-slot	3.2–3.7, 5.0–5.9, 7.0–7.9	
[38]	9 × 30	2.91	UWB antenna with T-shaped stub and open-ended slot	Open-ended slot	4.3–5.9, 6.5–7.4	

4. THE DEVELOPMENT OF THE UWB NOTCH ANTENNA

Ultra-wideband (UWB) systems pose a significant challenge to narrowband systems in terms of overcoming interference due to their wide bandwidth [22]. Current wireless technologies, such as WiMAX, Wireless LAN, and the C and X bands of the International Telecommunication Union (ITU), operate in frequency ranges that overlap with the UWB band. This can cause serious interference to UWB systems, reducing their capacity and performance. To mitigate interference between UWB and narrowband devices, researchers have developed novel modifications to UWB antenna structures. These modifications allow UWB antennas to suppress signals in specific frequency bands without affecting their performance in other bands [23]. Several antenna designs have been proposed that can create a frequency notch response.

Some common techniques used to achieve this include:

- Modifications to the radiator
- Modifications to the ground plane or signal line
- Integrated filter techniques

Frequency notches in printed UWB antennas can be created by modifying the radiator and ground planes using slots, stubs, and slits. Planar monopole antennas with modified radiator characteristics are commonly used for this purpose. These configurations change the current path in printed antennas, affecting the antenna's input impedance. The different geometrical structures, with varying sizes, yield different notching results by changing the current distribution on the radiator of the UWB antenna. For example, in [24], the authors proposed a rectangular antenna fed by a coplanar waveguide (CPW) with a T-shaped stub and a rectangular slot. This design creates a notch in the antenna's frequency response between 5 and 6 GHz. Similarly, in [25], the authors described a new type of ultra wideband antenna with a single parasitic element. This antenna has a slot with an elliptical shape and three steps, and a parasitic strip is attached to the bottom of the antenna. The length of the parasitic strip can be changed to create a notch in the antenna's frequency response between 5.1 and 5.8 GHz.

Researchers have developed a wide range of UWB antennas with notch characteristics using various slot designs and configurations. One design uses a C-shaped slot on a monopole patch antenna to create a single notch in the UWB operating band [26]. Others use slotted radiating surfaces, such as T-shaped, octagonal, arc-shaped, tapered, and U-shaped slots, to reject unwanted bands from the UWB spectrum [27-31]. Fractal geometry has also been incorporated into slot designs to achieve more complex and precise notch characteristics [32-35]. Additionally, some researchers have proposed UWB notch antennas with multiple notch bands, using decoupling structures, multi-slits, and multi-slot concepts [36, 37]. UWB antennas can also be modified by changing the ground plane or signal line to create notches in their operating frequency band, which prevents the antenna from radiating at certain frequencies and can be useful for avoiding interference [38]. Table 3 summarizes these sharp band rejection techniques, highlighting their key design features and radiation characteristics to prevent overlapping the UWB spectrum with the interference bands.

5. CONCLUSIONS

This article reviews the performance of different notch antennas that are designed to be used in UWB systems and to avoid interference from existing narrowband communication systems. The article also discusses almost all of the major techniques that are used to create notch behavior in antennas in a comprehensive and detailed way. This article has discussed UWB antennas and their diverse applications. UWB technology can be used in disaster relief, medical diagnostics, and commercial products such as USB dongles and mobile phones. Pure UWB antennas transmit radio waves in the 3.1 to 10.6 GHz range without frequency notch. Notching was introduced in UWB technology to reduce interference from WLAN and WiMAX frequency bands.

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