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A Detailed Concept and Review on Ultra-Wideband Antennas- Characterization and Frequency Notching

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Abstract—*UWB systems provide a distinctive solution for short-range wireless communication due to large bandwidth and low power consumption in transmission and reception. However, for these systems, designing an antenna with optimal characteristics is a major challenge, because it needs to avoid interference with existing narrowband systems (e.g., WLAN, Wi-MAX, HIPERLAN, ITU-R, etc.) in the UWB spectrum. To achieve this, different techniques (e.g., Slot, parasitic elements and stub loading, Using fractals, metamaterials and electromagnetic band gap (EBG) structures) have been reported in the literature and this paper provides a comprehensive review of the mentioned techniques for achieving band notch characteristics in UWB antennas. Moreover, the challenges, future perspectives, simulated and measured results, different notched bands and their applications are also discussed in this paper.*

Introduction

Ultra Wideband Band (UWB) is employed to achieve higher data rates up to 400 Mbps or more for wireless communication by increasing operating frequency or by increasing available bandwidth. High data rates are achieved over short distances at very low emission power as compared with conventional communication systems. The 7.5 GHz bandwidth between 3.1 GHz and 10.6 GHz is allocated by Federal Communications Commission (FCC) in 2002 for unlicensed use of commercial Ultra Wide Band (UWB) systems [1]. The Equivalent Isotropic Radiated Power (EIRP) for the unlicensed indoor UWB wireless communication is lesser than -43.3 dBm/MHz. UWB technology is based on transmitting ultra short duration pulses of the order of nanoseconds or lesser. While designing an antenna for UWB applications the main challenges are employed feeding technique and compactness in turn affecting broadband response in terms of phase, impedance, radiation patterns, gain, VSWR etc. In UWB range the value of reactance is large as radiation resistance is minimal the efforts are needed to carry out successful impedance matching.

Earlier broadband antennas were extensively used and have been around for many decades. In the past, the requirements for commercial UWB communication system were satisfied by traditional broadband antennas. However, the UWB technology has gained more and more popularity and became potential candidate for high-speed short-distance wireless communication since approval by FCC. Furthermore, the different requirements of UWB antennas are needed due to its applications like mobile communication and portable electronics. Therefore conventional UWB antennas are replaced to satisfy the requirements such as gain, radiation patterns and size. Many kinds of new antennas are proposed like Bi-conical antennas, Bowtie antennas and Monopole antennas. Figure 1 depicts the evolution of monopole antennas from disc cone shaped antennas and bi-conical antennas. Two cones of infinite extent placed together are used to form a bi-conical antenna as shown in Figure 1 (a). Bi-conical antenna is one among the antennas having broadband characteristics. The structure is infinite and can be analyzed as uniformly tapered transmission line. The current create circular magnetic field when time varying voltage is applied across the gaps by which input impedance can be calculated.

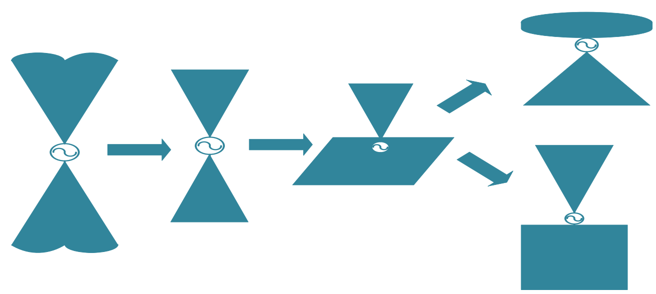

Figure 1: Evolution of monopole antenna from conventional Bi-conical antenna

Modified structure of bi-conical antennas is shown in Figure 1(b) and (c). Figure 1(c) represents a monopole UWB antenna with horizontal ground plane like structure. Trapezoidal monopole antenna on a ground plane was introduced leading to impedance bandwidth of >80% [2]. Broadband PILA (Planar inverted-L antenna) with vertical ground plane (VGP) resulted in 2:1 VSWR impedance bandwidth of >45% applicable for land mobile communications [56]. Square planar monopole antenna in the simplest form was proposed to decrease the radiation pattern degradation within the impedance bandwidth varying from 2:1 to 6:1 controlled by beveling the planar geometry [4]. These antennas are easy to fabricate making its construction possible at low cost with a single metal plate. The structure in Figure 1(e) is developed from planar monopole antenna by replacing large electrically conducting plate acting as ground plane. These planar monopole antennas received great deal of attention due to ease in fabrication, least expensive and minimum size. Moreover planar antennas are unbalanced thus do not require balun, which may have limited bandwidth. Conventional monopole antenna is shown in Figure 2 having straight wire configuration against a ground plane. Depending on radius-to-length ratio of straight wire return loss bandwidth (-10dB) is typically around 10% - 20%. Larger the radius will increase the radius-to-length ratio thereby increasing current area and hence the radiation resistance is increased. While increasing the radius of the wire impedance mismatch becomes significant and ultimately the bandwidth cannot be further increased.

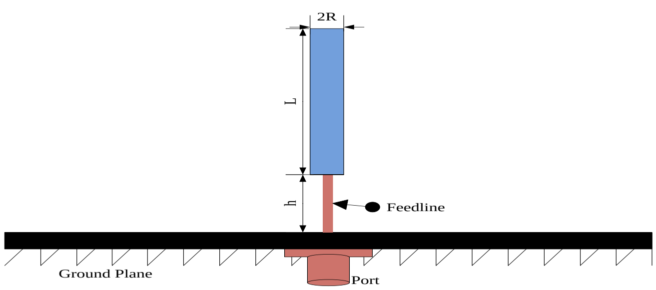

Figure 2 Geometry of Conventional Straight Wire Monopole Antenna

Ultra Wideband Antenna Characterization

UWB technology is different from narrowband technology in terms of transmitting the information. The narrowband signal uses carrier frequency to carry the modulated baseband signal while as in UWB systems short duration pulses with low duty cycle are used for the reception and transmission of information. Ultra Wideband is considered better solution for communication and radar applications because of its merits over other technologies as listed below:

- Minimum Cost.
- Large Channel Capacity.
- Minimum interference.
- High multipath interference immunity.
- Minimum interception and detection probability.
- Higher accuracy in range resolution and measurement.

At higher frequencies channel capacity varies linearly with bandwidth of the signal i.e. Gigahertz of bandwidth can be achieved at data rate of Gigabits/second. However during UWB transmission power limitation restricts the speed to shorter ranges making it suitable for short range, high data rate wireless communications [5]. UWB systems are categorized under unintentional radiators because of maximum radiation limit at -41.3dBm/MHz residing beneath the noise floor for any conventional narrowband receiver. Figure 3 depicts the coexistence of Ultra Wideband with narrowband and wideband technologies.

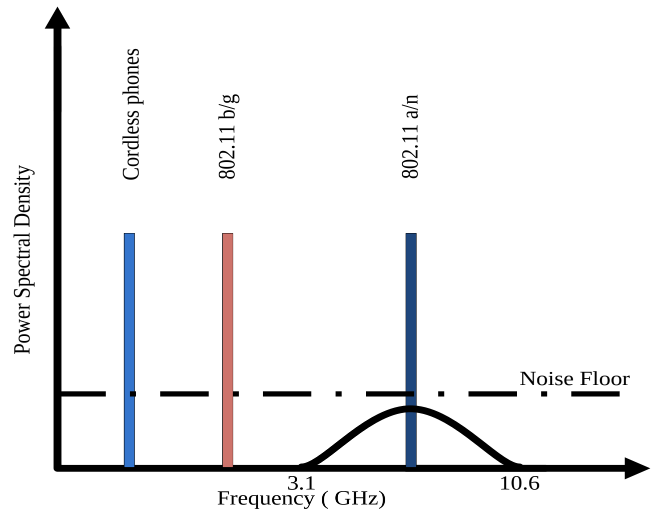

Figure 3 Coexistence of Ultra Wideband with narrowband and wideband signals

The widening of the pulse in a wideband antenna is caused by dispersion i.e., increase of full width at half maximum value (FWHM). Due to distributed antenna radiation phase centers over frequency the dispersion for a logarithmic periodic (LP) antenna is larger than of the horn antenna. The radar and communication both are influenced by dispersion. The physical effect of dispersion is described by Maxwell's equations. The radiated electromagnetic fields are obtained from the differentiation of the current distribution on the antenna. For conventional narrowband antenna the mean current can be assumed constant when plotted against frequency. In this case, for each spherical direction a signal results with constant amplitude and phase. This assumption doesn't hold true for Ultra Wideband antennas.

Frequency Notching in UWB Antennas

UWB antennas require wideband impedance with band notch characteristics. The easiest way to achieve these characteristics is by loading the structure with stubs, slots and parasitic elements in the ground plane and radiating patch. The radiating patch length gets reduced by inducing slots and stubs in turn changing the resonant frequency resulting in multiband operations [9]. The filtering of narrow band frequencies are done by introducing various kinds of slots like L-Shaped slots, U-Shaped Slots, Ring Shaped Slots etc. Moreover, by loading slots in the conducting patch element can cause meandering of the surface current distribution paths of the excited patch and results in lowering the resonating frequency [10-11]. Equations 1 to 4 are used for calculating notch frequency (F_n)

for C-Slot, U-Slot, L-Slot and Small Strip antennas respectively.

$$F_n = \frac{C}{2L\sqrt{\varepsilon_{eff}}} \quad \text{.........1}$$

$$F_n = \frac{C}{2(L_s+W_s)} \quad \text{.........2}$$

$$F_n = \frac{C}{2(H_1+L_2+h_b)\sqrt{\varepsilon_{eff}}} \quad \text{.........3}$$

$$F_n = \frac{C}{4L_s\sqrt{\varepsilon_{eff}}} \quad \text{.........4}$$

Where, L is length of slot, ε_{eff} is effective dielectric constant, $L_s$is Length of U-Slot, W_s is Width of U-Slot, $H_1$is Horizontal length, L_2 is Vertical length, h_b is height of substrate and L_s is Length of small strip. From the equations we can say the not frequency is dependent on the length and width of the slots as well as effective dielectric constant of the substrate used. Different types of slots have been presented in the literature as given in Table 1. In addition to these slot designs hybrid slots are also installed in order to achieve multi notch characteristic antenna configurations. The slots enhance the notch frequency band and radiation characteristics of the antennas.

Table 1 Notched bands and their application using different slots

	Type of Slot	Operating Frequency (GHz)	Notch Band Frequency (GHz)	Notch Band Application
[12]	L-Slot	3 – 12	3.5	Wi-Max
[13]	U-Slot	3.1 – 10.6	5.15 – 5.35 & 5.725 – 5.82	WLAN
[14]	C-Slot	2.75 – 13.98	3.38 – 3.82 & 5.3 – 5.8	Wi-Max & WLAN
[15]	H-Slot	2.9 – 10	3.3 – 3.6 & 5.1 – 5.9	Wi-Max & WLAN
[16]	T-Slot	3.1 – 10.6	5.2	WLAN
[17]	W-Slot	3.4 – 11.2	5.08 – 6	WLAN
[18]	F-Slot	3.35 – 9.4	5.3 – 8.5	WLAN
[19]	Hexagonal	4 – 11	5 – 5.7	WLAN
[20]	Spiral Slot	2.8 – 10.5	3.57, 5.12 & 8.21	Wi-Max, WLAN & X-Band
[21]	Elliptical Slot	3 – 11	3.3 – 3.8, 5 – 6 & 7.1 – 7.9	Wi-Max, WLAN & X-Band
[22]	Circular Slot	3.9 – 14	5.5	WLAN
[23]	Open End	3.1 – 10.9	5.15 – 5.825	WLAN
[24]	Arched Slot	3 – 11.5	5.15 – 5.825	WLAN
[25]	Trapezoidal	3.36 – 13.1	3.5 & 5.2 – 5.8	Wi-Max & WLAN
[26]	Non-uniform width Slot	2.5 – 12.4	3.5, 5.5 & 8.1	Wi-Max, WLAN & X-Band
[27]	Hybrid Slot	3.1 – 12	5.15 – 5.35, 5.75 – 5.85, 7.25 – 7.75 & 8.01 – 8.55	Wi-Max, WLAN, X-Band & ITU band

Metamaterials have been extensively used to enhance the antenna parameters like radiation efficiency, gain, impedance bandwidth etc. In addition to that Metamaterials can be used to achieve notch band characteristics of an antenna. Split Ring Resonators (SRR) and Complementary Split Ring Resonators (CSRR) are the common Metamaterials structures used by researchers for attaining band notch characteristics in UWB antennas. The SRR and CSRR can be circular as well as square in shape. We can calculate the resonant frequency of split ring/ square SRR and CSRR by using equations 5 – 10:

Let F_1 and F_2 are the resonation frequencies, L_1 and L_2 are the loop lengths, r_1 and r_2 is the radius of the two loops in the split rings respectively.

$$F_1 = \frac{c}{2L_1\sqrt{\varepsilon_e}} \quad \text{..........5}$$

$$F_2 = \frac{c}{2L_2\sqrt{\varepsilon_e}} \quad \text{..........6}$$

The resonance of each loop occurs at the half wavelength (k/2) and can be calculated as:

For the circular ring:

$$L_1 = 2\pi \times r_1 - s \quad \text{..........7}$$

$$L_2 = 2\pi \times r_2 - s \quad \text{..........8}$$

For the square ring

$$L_1 = 4 \times l_1 - s - 4 \times w \quad \text{..........9}$$

$$L_2 = 4 \times l_2 - s - 4 \times w \quad \text{..........10}$$

These basic equations of SRRs and CSRRs are only used for the loops with single resonant frequency or resonant mode. It can be analyzed that SRRs behaves like an LC circuit resonator that could be excited by the external magnetic field which exhibits a powerful diamagnetism beyond the first resonance and also they have cross polarization effects so that the excitation with the polarized signal is possible [28]. Different shapes of SRR and CSRR that helped in notching particular frequency bands among the recent literature is presented in Table 2 given below.

Table 2: Notched bands and their application using different resonators

	Metamaterial Resonator	Operating Frequency (GHz)	Notch Band Frequency (GHz)	Notch Band Application
[29]	Circular SRR	3.4 – 10	3.3 – 3.8 & 5.15 – 5.82	Wi-Max & WLAN
[30]	Hexagonal SRR	3 – 20	3.3 – 3.8 & 5.15 – 5.82	Wi-Max & WLAN
[31]	U Shaped SRR	2.57 – 10.75	5.028 – 6	WLAN
[32]	Square and Circular SRR	3.1 – 14	3.29 – 3.7, 3.7 – 4.10, 5.1 – 5.9 &7.06 – 7.76	Wi-Max, C-Band WLAN & X-Band
[33]	Semi-Arc SRR	3.1 – 11	3.2 – 3.7 & 7.1 – 7.76	Wi-Max & X-Band
[34]	Rectangular CSRR	1.5 – 11	3.3 – 3.7 & 5.15 – 5.82	Wi-Max & WLAN
[35]	SRR & CSRR	1 – 10	3.9, 5.2 & 5.9	C-Band, WLAN & HIPERLAN/2
[36]	Slotted CSRR	3 – 12	5.5	WLAN
[37]	M-Shaped Resonator	2.24 – 10.8	2.35 – 2.6, 3.2 – 3.7, 5.0 – 6.1, 7.2 – 7.7 & 8.1 – 8.74	Wi-Max, WLAN, X-Band & ITU 8 GHz Band
[38]	Co-directional CSRR	3.02 – 11.1	3.3 – 3.6, 5.15 – 5.35 & 5.725 – 5.825	Wi-Max & Lower & Upper WLAN

Initially fractal geometry based antenna was used in the designing of frequency selective surfaces (FSS) to provide multiband operation and miniaturization in the antenna structure. Apart from it, bandwidth and impedance of the antenna is also improved. Even though a lot of fractal geometries have been reported in the literature, but Koch snowflakes/islands, Sierpinski gasket and carpet, Hilbert Curve and fractal trees are the most popular fractal geometries [38-42]. Because of numerous advantages like effective bandwidth control, compactness, minimum effect on radiation pattern Electromagnetic Band Gap Structure have been appealing in the field of antenna design engineering. Using photonic band gap phenomena EBG structures halt the propagation of electromagnetic waves in a particular frequency band helping to achieve notch band characteristics in UWB antennas [43-44].

Conclusion and Future Work

In this paper a detailed state-of-the-art survey on UWB antennas is given. The paper provides valuable insight into the way forward in designing of these antennas. In the field of UWB antennas with band-notched operation, it shows that quite a few UWB antennas with band-notched behaviors have been achieved and published in the literature. Among UWB-MIMO antennas for wireless communications, most of the proposed designs are only able to operate over a narrow band not for the entire UWB band. For those operating over entire UWB band, mostly designed antennas have compactness issues. To address the problems identified there is a need to further investigate planar UWB antennas for future wireless commutations.

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