Indian Journal of Science and Technology, *Vol 9(47), DOI: 10.17485/ijst/2016/v9i47/106431, December 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Ultra-Wideband Antenna's Design Techniques

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Abstract

The main objective of this paper is to understand the different methodologies which have been adopted in the recent years in design of Ultra-Wideband Antenna. **Methods/Statistical analysis:** The patch of the UWB antenna is etched with circular rings to obtain wider bandwidth. Rabbet structured patch can also be utilized for enhancing bandwidth. Ground plane of UWB antenna's in some cases is parabolic and some have T or L-shape slots to enhance antenna characteristics like increasing bandwidth, band notching at certain frequencies etc. dielectric substrate FR4 is preferred in most of the UWB antenna designs due to less return loss and better bandwidth utilization. **Findings:** With help of circular patch, more than 160% of Bandwidth is attainable. Use of triangular slots in ground plane can help increase the bandwidth by 45%. A further alteration in ground plane such as grooved ground plane can help minimize the surface waves. **Application/Improvements:** Since T-shaped slots increases directivity so they are preferred in air-bore applications. L-shaped slots in ground plane helps in RADAR applications.

Keywords: Archimedean Spiral, Band Notching, Planar and Non Planar Antennas

1. Introduction

Antenna is a device which converts guided electromagnetic energy in transmission line to radiated electromagnetic energy in free space. It not only helps in transferring energy but also acts as a probing device. Ultra-wideband (UWB) antennas concept was first given by Oliver Lodge in 1898. But UWB antennas gained importance in 2002 when US Federal Communication Commission (FCC) provided authorization to UWB systems to be commercially used. FCC allocated the bandwidth of 3.1 to 10.6 GHz which is one of the largest band allocated by FCC for unlicensed use[1]. Owing to this large bandwidth and certain important characteristics, UWB antennas are prominent in various wireless applications like EM testing, monitoring, medical imaging, tracking etc. UWB systems employ short pulses of radio energy to transmit a signal. Usage of short pulses provides certain advantages like high data rates[2]. Due to large bandwidth occupied by short pulses, data rates up to hundred of Megabytes per second is obtained which in turn leads to high data security as it is very difficult to track data at such a speed. Moreover multipath fading is avoided as there is no overlapping between reflected signals and original signals due to short pulse transmission.

Although wide services are provided by third generation communication technologies which include fast internet access, video telephony etc but UWB provides much larger bandwidth for high data rate communication. The power required is very small which is 0.5 mW according to FCC. The major requirement of UWB antenna is that it must posses' Omni-directional radiation pattern for wireless communication with low directivity and uniform gain. Further there exists variety of narrowband systems in range of UWB systems, like IEEE 802.16 WiMAX (3.3-3.6 GHz), C-band systems (3.7-4.2 GHz), IEEE 802.11a WLAN (5.15-5.825 GHz), which interfere with UWB pattern and which must be avoided. Numerous technologies are proposed to provide band notching in order to avoid interference from the above mentioned bands. The simplest technique to this is incorporate into radiator various shapes and sizes of slots. Moreover matching circuits are introduced as these improve the performance of antenna. Not only this, due to low power requirement, UWB antenna should have high radiation efficiency[3]. Moving further, size of

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UWB antenna plays a major role. It should be as small as possible as it is used for many indoor applications and portable devices.

This paper proposes the various technologies and design considerations which are being proposed till date which have different VSWR, gain, efficiency based on the different technique used in UWB antenna design.

2. Planar and Non Planar UWB Antenna

UWB is a form of micro strip antenna with a radiating patch over a ground plane which can have planar or non planar structures. Several antennas have been proposed in recent years but planar antennas have gained high importance due to low fabrication cost, low profile, wide bandwidth and high radiation efficiency. Various shapes of planar antennas have been reported[4–6]. Comparisons were carried out between monopole planar antennas of varying length and width and with different shapes like rectangular, square, circular and elliptical. Circular was found to provide wide bandwidth[4]. Wider bandwidth was obtained by etching multiple circular rings in the radiating patch of planar conformable antenna with resonating frequency given by the equation[7]:

$$fr = \frac{1.8412c}{2\pi reff\, sqrt(\varepsilon ff)} \tag{1}$$

Where

$$reff = r\left[1 + \left(\frac{2h}{\pi r\varepsilon eff\left\{\ln\left(\frac{r}{2h}\right) + (1.41\varepsilon r + 1.77) + \left(\frac{h}{r}\right)(0.268\varepsilon eff + 1.65)\right\}}\right)\right]^{\frac{1}{2}}$$

fr=resonant frequency
c=velocity of light
r=radius of patch

Next moving to rectangular patch antenna with microstrip feed line will have resonant frequency in[5] given by equation as follows:

$$\mathbf{fr} = 14.\frac{4}{l + 2r}\ GHz \tag{2}$$

Where l=length of planar element
r=radius of equivalent cylindrical wire

The effective dielectric constant can be given by the equation as:

$$\varepsilon re = \frac{\varepsilon r + 1}{2} \tag{3}$$

Besides the simple planar structures modified structures were proposed lie the rabbet structured metallic patch for enhancing bandwidth[6]. Apart from the planar structures several conformable non planar antennas have been designed for providing flexibility to be used for various scenarios[7]. Variation of directivity of antenna with different conforming shapes is shown in Table 1.

Table 1. Variations of directivity with various shapes

S.no	Radius of curvature mm	Frequency GHz	Directivity dBi
1	27.765	3.5	2.325
		6	2.007
		9	4.086
2	18.243	3.5	2.632
		6	2.366
		9	4.742
3	8.685	3.5	2.534
		6	3.514
		9	6.029
4	Square shaped	3.5	2.430
		6	4.158
		9	5.393
5	Modified square shaped	3.5	2.593
		6	4.239
		9	4.633

3. Impact of Dielectric Constant

It has been found that dielectric constant of substrate material have the most sensitive impact on antennas performance. A small change in dielectric substrate constant can cause change in operating frequency as found in[11] given as:

$$\frac{\delta f}{fo} = -\frac{1}{2}\frac{\delta\varepsilon r}{\varepsilon r} \tag{4}$$

Among the various substrates available FR4 is considered as the best substrate due to its better utilization of bandwidth, resonating frequency, return loss[8]. Substrate thickness influences the radiation characteristics of UWB antenna. Thick substrates provide better efficiency but large element size reported by Balanis[12]. Substrate with low dielectric constant leads to increase in Omni-directional radiation bandwidth[13]. Bandwidths, resonant frequency, return loss of different dielectric substrates are given in Table 2. The effect of dielectric substrate was analyzed on frequency independent Archimedean spiral UWB antenna by shire[14].

Table 2. Antenna characteristics for different substrate material

Material	Dielectric constant	Band-width (GHz)	Resonating frequency (GHz)	Return loss(dB)
FR4	4.1	9.745 (2.9980-12.7350)	4.3356	-24.3854
			7.4765	-42.2670
			9.9732	-28.4086
			12.1477	-13.4235
Teflon	2.1	9.4893 (2.9000-12.3893)	5.3020	-27.7461
			8.4430	-20.5721
			11.1812	-16.6554
Quartz	3.78	8.28 (2.9700-12.1200)	4.4161	-27.2814
			7.6376	-26.6020
			10.2148	-21.5166
Polysty-rene	2.6	9 (2.9350-13.8230)	4.8993	-28.0574
			8.2013	-20.8018
			10.8591	-17.1622
Neltech	3	8.91 (2.9400-12.8000)	4.5772	-28.2154
			7.9597	-24.1389
			10.6174	-21.4509

4. Technologies for Improved Antenna Characteristics

For design of a UWB antenna, different applications require different antenna characteristics. Bandwidth ratio is defined as:

$$bandwidth = \left(\frac{fh}{fl}\right):1 \qquad (5)$$

Various monopole planar antennas are shown in Figure 1 with different shapes with bandwidth ratio ranging from 2:1 to 12:1. A bandwidth of more than 160 % was acquired with radiating patch of circular shape and a corner shaped ground plane with multiband characteristics by sachin Sharma[15]. Comparison of bandwidth of different geometries of planar monopoles was done where circular and elliptical planar monopole antennas have wider bandwidth which is shown in Table 3. Besides bandwidth, gain of antenna is important parameter and uniform gain is desirable. Gain of antenna can be improved by various technologies proposed like usage of Frequency Selective Surface (FSS) with multiple layers, FSS with single layer[16,17]. In case of UWB antennas, Friis's law determine the link behavior of antenna in free space where gain and power will be function of frequency, so Friis's law in form of power spectral density can be given by equation:

$$dPrx(f) = \left(\frac{c^2}{4\pi r}\right)Ptx(f)\left(\frac{Gtx(f)Grx(f)}{f^2}\right) \qquad (6)$$

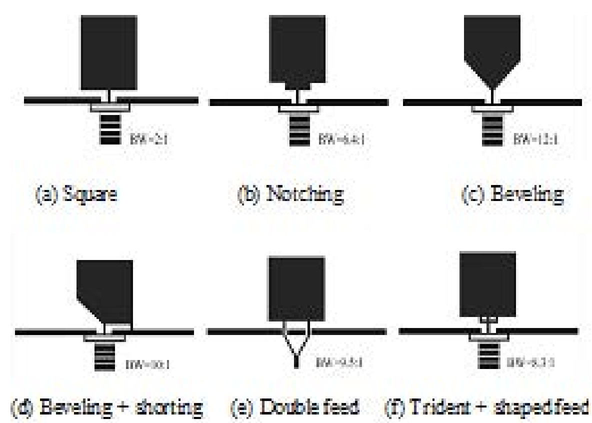


Figure 1. Monopole planar antennas with varying bandwidth.

Antenna characteristics can be improved by modifying the shape of ground plane. Triangular slots can be inserted inside the ground plane which increases the bandwidth by 45% as compared to normal ground plane[18]. A swastika antenna was proposed with inverted L shaped slot and concentric rings which provided maximum bandwidth and least return loss[19]. Since the above UWB antennas were solely used to improve bandwidth by varying ground plane, grooved ground plane antennas were developed[20] which led to suppressing of surface waves and helped in improving impedance as well as radiation performance.

Modified ground plane with parabolic ground

Table 3. Bandwidth and VSWR of circular and elliptical monopoles

Configuration	a (cm)	b (cm)	Frequency range for VSWR<2	Theoretical Lower freq. VSWR<2	Band width ratio
CDM	2.5	2.5	1.17 to12.00	1.28	10.2:1
EDM1A EDM1B	2.6	2.4	1.21 to 13 1.20 to 12.50	1.31 1.24	10.7:1 10.4:1
EDM2A EDM2B	2.7	2.3	1.38 to 11.49 1.13 to 12.00	1.37 1.20	8.3:1 10.6:1
EDM3A EDM3B	2.8	2.2	1.37 to 11.30 1.08 to 11.43	1.41 1.17	8.2:1 10.6:1
EDM4A EDM4B	2.9	2.1	1.58 to 10.45 1.09 to10.45	1.46 1.13	6.6:1 9.6:1

plane etched with T-shaped slots are used for air borne applications due to increased directivity. Apart from this UWB antennas with either L-shaped or parabolic ground plane has found its applications in radar applications and microwave imaging.

5. Band Notched Characteristics

Since various frequency bands exist in UWB's existence as shown in Table 4 which must be suppressed to stop interference of existing bands. A single, dual or triple band notched characteristics antennas were proposed in recent year which employ different technologies to attain band notching. But they all have similar working in which gain decreases and VSWR increases at that particular band notched frequency. Current distribution for frequency notching is shown in Figure 2.

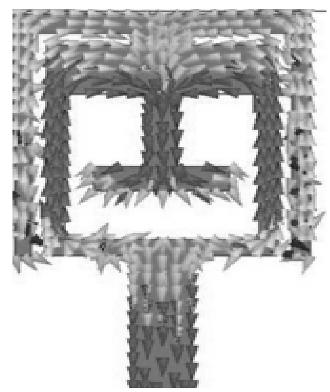
Table 4. Comparison of various bands

Unlicensed bands	Frequency of operation (GHz)	Bandwidth (MHz)
ISM at 2.4 GHz	2.4000-2.4835	83.5
U-N at 5 GHz	5.15-5.35 5.75-5.85	300
UWB	3.1-10.6	7,500

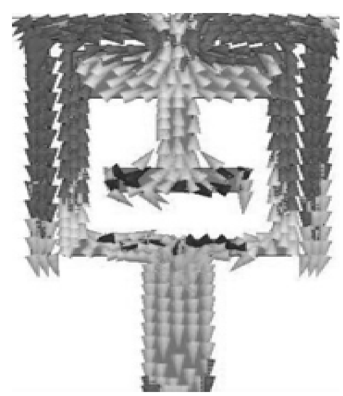
Various dual band notched antennas were proposed with different radiating patches and slotted ground plane in[20,21]. The length of slot in band notched antennas is calculated by equation reported in[22] which is given as:

$$L = \frac{c}{2fb\sqrt{\varepsilon e}} \tag{7}$$

Triple band notched characteristics can be obtained by inserting various slots in metallic patch and the ground plane with a single slot for each rejected frequency as designed by maiti[23]. So by inserting different slots or using parasitic elements as filters to certain frequency band notching in antennas is obtained.



(a)



(b)

Figure 2. Current distribution (a) normal frequency (b) band notched frequency.

5. Conclusion

This paper provides a review of various technologies being used for design of UWB antenna. Various planar monopole antennas can be designed with varying shapes but circular is preferred due to ease of fabrication. Non planar antennas were also proposed with varying shapes with increasing directivity with smaller radius of curvature. Dielectric substrate has great effect on fringing effect, resonant frequency of UWB antenna which must be chosen appropriately for its design. There are various substrates present with different electrical properties and varying bandwidth and return loss. The efficiency of the UWB antennas can be improved by decreasing dielectric constant of a substrate or by increasing the size of patch. Insertion of slots or parasitic elements helps in achieving band notched antenna with reduces interference from other unlicensed bands within the range of UWB antenna.

From all the past researches, there is need for improvement of impedance characteristics by varying pattern on the ground plane. Secondly, group delays in UWB antennas must be minimized by making arrangements for less dispersion of pulses. Thirdly, mutual coupling must be reduced between multiple elements which leads to impedance mismatch which must be improved using matching circuits.

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