# Time Domain Modeling Of A Band-Notched Antenna For UWB Applications

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**ABSTRACT**

The time domain modeling of a coplanar wave guide (CPW) fed band-notched antenna for UWB applications is presented. The annular ring antenna has a dimension of 36x36 $mm^2$ when printed on a substrate of dielectric constant 4.4 and thickness 1.6 mm. The uniplanar nature and compact structure of the antenna make it apt for modular design. The crescent shaped slot provides a notch in the 5.2-5.8 GHz frequency band to avoid interference with WLAN. The pulse distortion is insignificant in the operating band and is verified by the measured antenna performance with high signal fidelity and virtually steady group delay.

**Keywords:** Ultra wideband, UWB antenna, monopole antenna, and wireless communications.

## 1. INTRODUCTION

High data rate and excellent immunity to multi-path interference make Ultra-wideband (UWB) technology one of the most promising solutions for future short-range high-data wireless communication applications. The allocation of the frequency band from 3.1 to 10.6 GHz by FCC [1] with a –10 dB bandwidth greater than 500 MHz and a maximum equivalent isotropic radiated power spectral density of – 41.3 dBm/MHz for UWB radio applications presents an exciting opportunity to antenna designers. UWB reaps benefits of broad spectrum in terms of the bit rates it can handle. By Shannon's theorem, the channel capacity C is given by,

$$C = W.\log_2\left(1+\frac{S}{N}\right) \qquad (1)$$

where W is the bandwidth and S/N is the signal to noise ratio. It can be seen that the bit rate (capacity) can be easily increased by increasing the bandwidth instead of the power, given the linear – versus- logarithmic relationship. Range of operation of such systems are determined by the Friis formula,

$$d \propto \sqrt{\frac{Pt}{Pr}} \qquad (2)$$

d being the distance, Pt the transmit power and Pr the receive power. Equations (1) and (2) together suggest that it is more efficient to achieve higher capacity by increasing bandwidth instead of power, while it is equally difficult to achieve a longer range. Thus, UWB primarily is a high-bit, short-range system.

UWB technology is a derivative of the time hopping spread spectrum (THSS) technique, a multiple access technology particularly suited for the transmission of extremely narrow pulses. It has been standardized in IEEE 802.15.3a as a technology for Wireless Personal Area Networks (WPANs). The challenges in UWB antenna design are bandwidth enhancement, size miniaturisation, gain and radiation pattern optimization.

Monopole antennas are used in communication systems at a wide range of frequencies. Electrical properties of these antennas are dependent upon the geometry of both the monopole element and the ground plane. The monopole element is either electrically short with length much less than a quarter-wavelength or near-resonant with length approximately a quarter-wavelength. This element can be thin with length-to-radius ratio much greater than $10^4$ or thick with length-to-radius ratio of $10^1$ -$10^4$. In addition, the ground-plane dimensions may vary from a fraction of a wavelength to many wavelengths. Traditionally, a monopole geometry consists of a vertical cylindrical element at the center of a perfectly conducting, infinitely thin, circular ground plane in free space. Electrical characteristics of such antennas are primarily a function of only three parameters; the element length, element radius, and the ground-plane radius, when each is normalized to t he excitation wavelength. Radiation pattern of such antennas are uniform in the azimuthal direction. UWB monopole antennas fall in to volumetric and non-volumetric categories based on their structures. Non-volumetric UWB antennas are microstrip planar structures evolved from the volumetric structures, with different matching techniques to improve the bandwidth ratio without loss of the radiation pattern properties. A number of traditional broadband antennas, such as self-complementary spiral antenna, bi-conical antenna, log-periodic Yagi-Uda antenna [2], etc., were developed for UWB radio systems in the past. However, most of these antennas may be too bulky to be applicable in compact UWB communication equipments, such as handsets, PC cards, personal digital assistants (PDAs) and so on. In order to reduce system complexity and cost, it is necessary to develop miniature, light weight, low cost UWB antennas. Many efforts have been made to design such antennas. The fundamental design practice to realize ultra wide bandwidth is to match multiple resonances by suitable techniques [3-8]. Antenna design for UWB systems calls for special care, for if the surface currents on different parts of the antenna undergo significant time delays before summed up at the antenna terminal or transmitted as a free wave, signal dispersion may result [9].

The UWB printed monopole antenna consists of a monopole patch and a ground plane, both printed on the same or opposite side of a substrate, while a microstrip line or CPW is located in the middle of the ground plane to feed the monopole patch. Compared with the ultra-wideband metal-plate monopole antenna, the UWB printed monopole antenna does not need a perpendicular ground plane. Therefore, it is of smaller volume and is suitable for integrating with monolithic microwave integrated circuits (MMIC). To broaden the bandwidth of this kind of antennas, a number of monopole shapes have been developed, such as heart-shape, U-shape, circular-shape and elliptical-shape etc. The UWB printed monopoles are more suitable for smaller portable devices where volume constraint is a significant factor.

Due to the co-allocation of the UWB frequency band with frequency bands reserved for narrowband wireless technologies, there is a need to provide filtering in those bands to avoid interference from or causing interference to narrowband devices. So the use of a band stop filter becomes necessary. Several antennas have been reported in literature aiming at size reduction, bandwidth enhancement and WLAN interference avoidance [10-14]. Planar monopole and dipole antennas show good promise for use in UWB systems. Coplanar waveguide (CPW) fed antennas have the advantage of a balanced structure, since the feed lines and the radiating structure are on the same side of the substrate. [15-16].

CPW fed slot antennas are also very good candidates for UWB applications. The antennas discussed in [17] use a large slot for bandwidth enhancement and L or T shapes for size reduction. A CPW fed tapered ring slot antenna which can achieve a relatively large bandwidth is introduced in [18]. The wide band slot antenna [19] uses a large aperture and a modified microstrip feed to create multiple resonances. In another technique, a rotated slot is proposed [20] wherein two modes of close resonances are excited by a microstrip feed line. A tapered slot feeding structure is used to transform the guided waves to free space waves in [21]. In [22], a microstrip fed triangular slot antenna with a double T shaped tuning stub is introduced. The double T shaped stub is fully positioned within the slot region on the opposite side of the triangular slot. But the antenna has large dimension of 55x65mm2 with limited bandwidth of 3.3GHz.

The uniplanar nature and compact structure of the CPW fed annular ring antenna presented in this paper make it apt for modular design. The crescent shaped slot inserted into the UWB antenna aims at rejecting the 5.15-5.825GHz band limited by IEEE 802.11a and HiperLAN/2.

## 2. ANTENNA GEOMETRY

The structure comprises of a slotted annular ring shaped monopole antenna fed by a 50Ω CPW with a serrated ground plane as shown in Fig.1. The antenna is printed on a substrate of $\varepsilon r$ = 4.4, loss tangent tan $\delta$ = 0.02 and thickness h=1.6 mm.

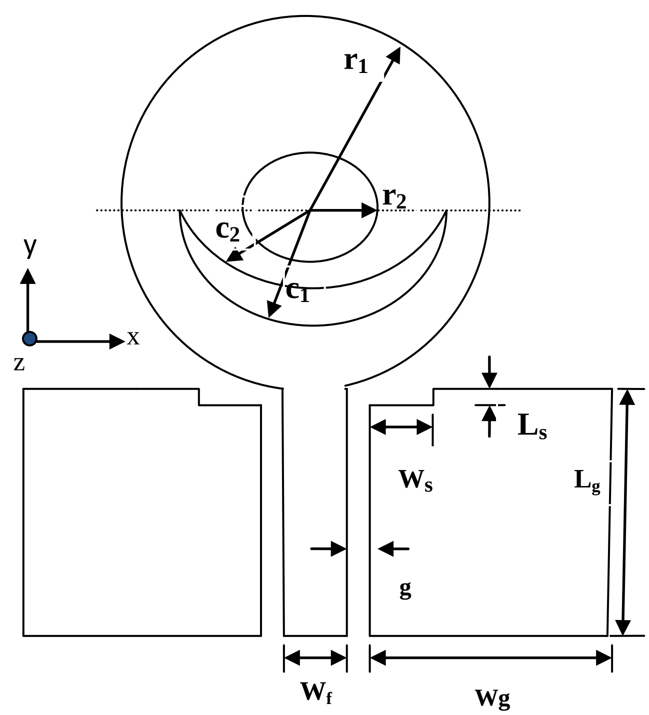


Fig.1 Antenna Geometry (all dimensions in mm)
Lg=15, Wg=16, g=0.35,Wf=3, Ls=1.2,Ws= 3
r1=11, r2=2.3, c1=6.5, c2=6.2

The strip width ($W_f$) and gap (g) of the Coplanar Waveguide (CPW) feed are derived using standard design equations for 50Ω input impedance [23]. The dimensions are optimized for ultra wideband performance after exhaustive simulation using Ansoft HFSS V.12.The accuracy of the antenna dimension is very critical at microwave frequencies. Therefore photolithographic technique is used to fabricate the antenna geometry. Photolithography is the process of transferring geometrical shapes from a photo-mask to a surface.

## 3. FREQUENCY DOMAIN RESULTS

Fig.2. illustrates the reflection characteristics of the antenna, measured using HP 8510C Vector Network analyzer. The antenna exhibits 2:1 VSWR bandwidth from 2.9 GHz to 17.4 GHz, with a notch in the 4.8 GHz – 5.8 GHz band. The antenna is developed from a conventional CPW fed disc antenna of radius $r_1$. The inner disc of radius $r_2$ inserted into the disc results in an annular ring antenna, shifting the lower edge of the resonant band from 3.26 GHz to 3.09 GHz, thus catering to the UWB requirement from 3.1 to 10.6 GHz. The crescent shaped slot of dimensions $c_1$,$c_2$ introduces a notch in the reflection characteristics. The serrations in the ground plane are responsible for fine tuning and precise positioning of the notch.

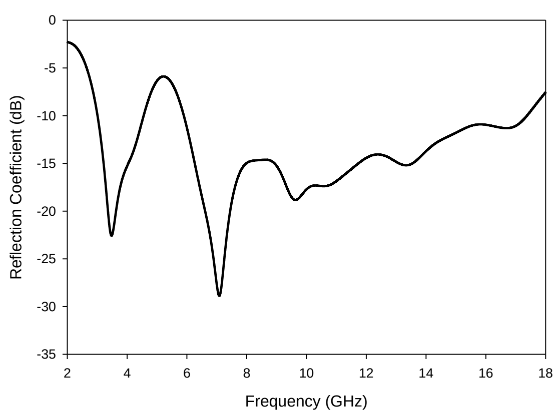


Fig.2.Reflection characteristics of the antenna

The current distribution in the antenna at different resonant frequencies in the operating band is illustrated in Fig.3. The bi-directional currents in the crescent shaped slot at 5.6 GHz [Fig.3(c)] account for the notch in the reflection characteristics. Typical measured radiation patterns of the antenna at 3.5 GHz and 7.1 GHz are shown in Fig.4. The antenna is linearly polarized along Y direction with good cross polar isolation in the entire band of operation. The antenna exhibits an average gain of 0.9dBi in the operating band. These characteristics confirm the suitability of the antenna for UWB operations.

## 4. TIME DOMAIN RESULTS

Good frequency domain performance does not necessarily ensure satisfactory time domain behavior. Linear phase delay or constant group delay is a mandatory requirement for an UWB antenna. A flat group delay is required so that the high and low-frequency signal components arrive at the receiver simultaneously. To study the time domain behaviour, two identical prototypes of the antenna are used as a transmitter – receiver system [24]. As shown in Fig.5, the measured group delay remains almost constant with variation less than 2 nanosecond for the face to face orientation. Similar results are obtained for the side by side and back-to-back orientations. This indicates a good time domain performance of the antenna throughout the operating band, barring the notch band.

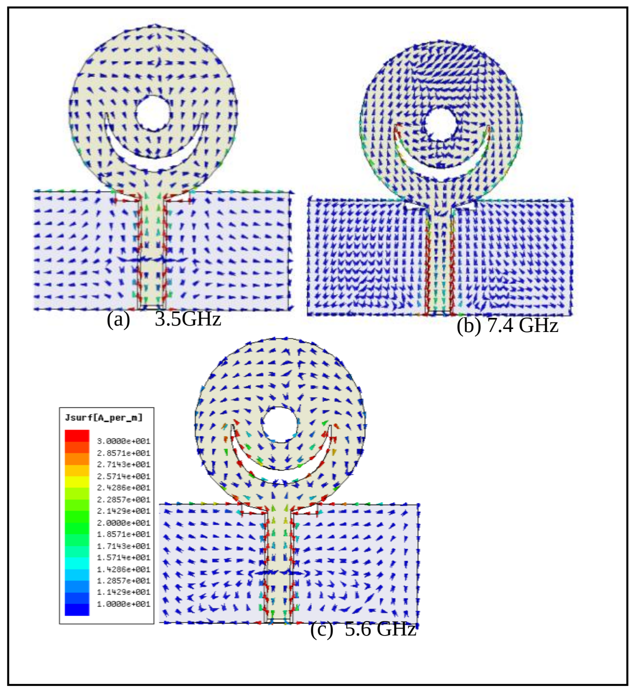


Fig.3. Current distribution at various frequencies in the operating band of the antenna

Transient response of the antenna is studied by modeling the antenna by its transfer function. For this, the transmission coefficient $S_{21}$ is measured using HP8510C Network analyzer in the frequency domain for the face-to-face and side-by-side orientations placing the antennas at a distance R=10cm. From the $S_{21}$ values of the UWB antenna system thus measured, the transfer function of the system is computed as follows.

$$H(\omega)=\sqrt{\left(\frac{2\pi Rc\cdot S_{21}(\omega)\cdot e^{\frac{j\omega R}{c}}}{j\omega}\right)} \quad (3)$$

Where c is the free space velocity and R is the distance between the two antennas. This transfer function is multiplied with the spectrum of the input signal, which is chosen as a fourth order Rayleigh Pulse given by

$$S_i(t) = \frac{(16x^4 - 48x^2 + 12)e^{-x^2}}{\sigma^4}\ ; \quad (4)$$

$$where \quad x = \frac{t-1}{\sigma} \quad , \sigma\ is\ the\ pulse\ width$$

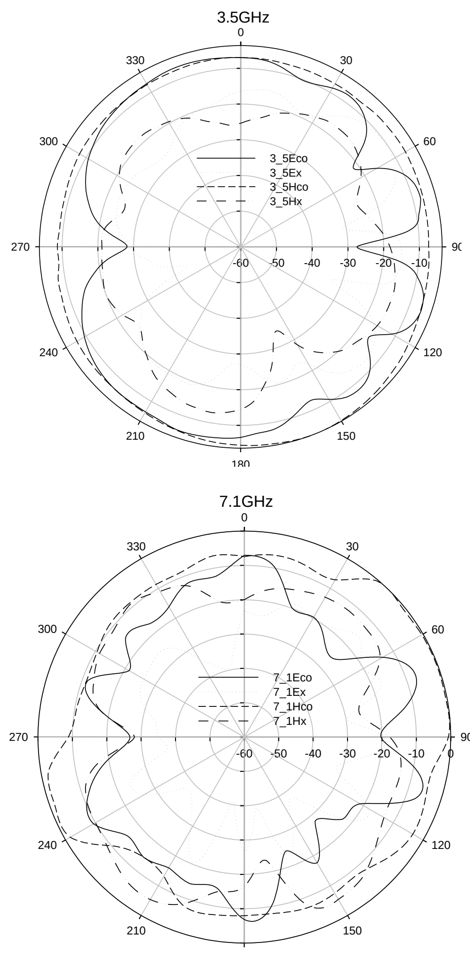


Fig.4 Measured Radiation Pattern

The inverse FFT of the product of H(ω) and the spectrum of the input signal gives the waveform at the receiver. The transmitted and received wave forms for the face-to-face and side-by-side orientations of the antenna are shown in Fig.6. It is evident that the received pulses are almost identical.

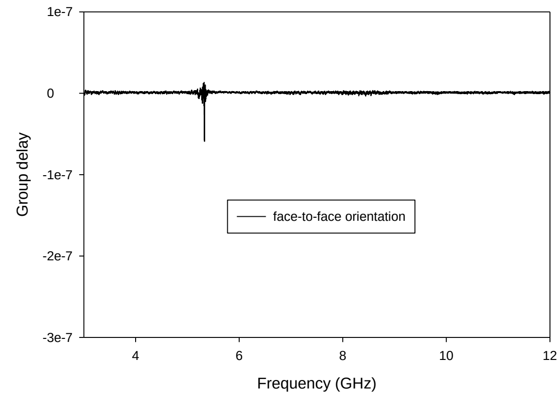


Fig.5. Measured group delay of the antenna (nsec)

In UWB systems it is very important to characterize the transient behavior of the radio propagation channel, specifically for impulse radio systems. Pulse fidelity involves the autocorrelation of two different time domain waveforms and compares the shape of the pulses disregarding the amplitude and the time delay. A low fidelity between transmitted and received pulse means that the dis- tortion of the received pulses is high and hence loss of system information is high [25]. The fidelity factor between transmitted and received signals in Tx/Rx setups between two identical antennas in different orientations are calculated for the fourth order Rayleigh pulse [Fig.7].

$$F(\theta,\varphi) = \underbrace{max}_{\tau}\left[\frac{\int_{-\alpha}^{\alpha} S_t(t)S_r(t+\tau,\theta,\varphi)dt}{\sqrt{\int_{-\alpha}^{\alpha} {S_t}^2(t)dt \int_{-\alpha}^{\alpha} {S_r}^2(t,\theta,\varphi)dt}}\right] \quad (5)$$

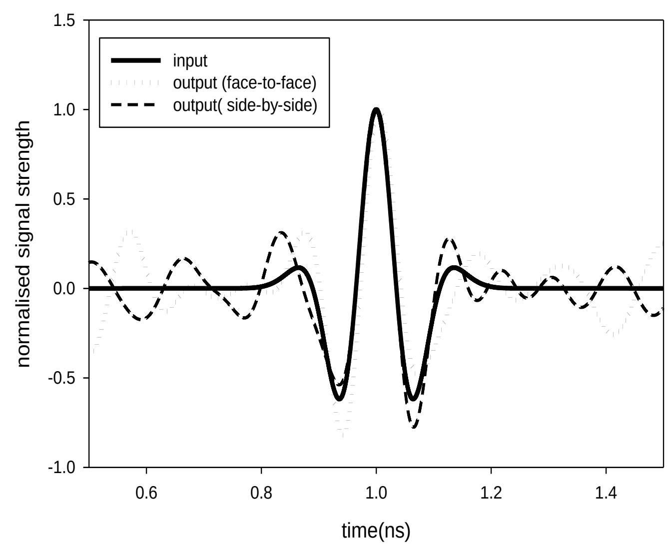


Fig.6 Transmitted and Received Pulse for different orientations of the antenna

It is clear from the figure that fidelity factor is greater than 0.9 for τ=50ps, where τ is the pulse width fidelity factor. These values for the fidelity factor show that the antenna imposes negligible effects on the transmitted pulses.

According to FCC regulations, UWB systems must comply with stringent EIRP limits in the frequency band of operation. EIRP is the amount of power that would have to be emitted by an isotropic antenna to produce the peak power density of the antenna under test. To obtain EIRP, we use similar transmit and receive antennas and total frequency response of the system H(ω) is calculated as

$$EIRP = S_i(f)\sqrt{H(f)} \cdot \frac{4\pi r f}{c} \qquad (6)$$

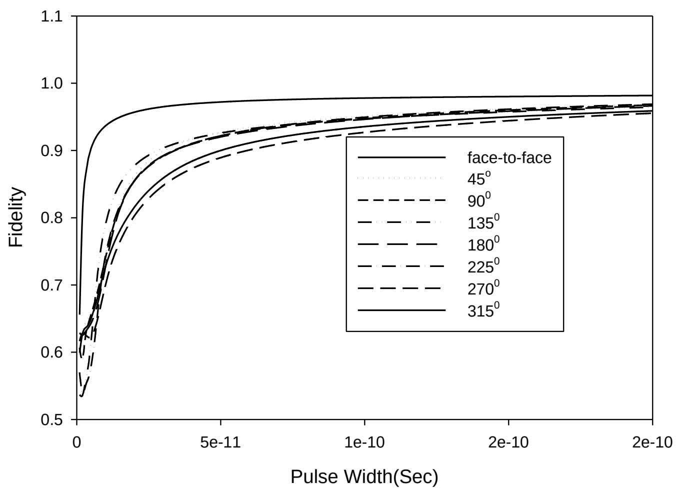


Fig.7 Fidelity of the antenna in different orientations

Fig.8 shows the measured EIRP emission level of the antenna excited with a fourth order Rayleigh pulse with pulse width factor τ =50ps. As it is clear from the figure, EIRP of the antenna satisfies the FCC masks for the entire UWB band.

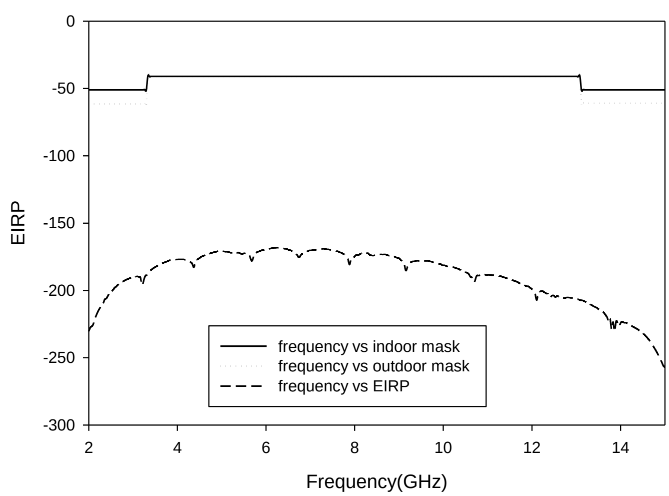


Fig.8 Measured EIRP of the antenna

## 5. CONCLUSIONS

The time domain modeling of a compact UWB wideband monopole antenna with band-rejection characteristics is presented. The prototype offers -10dB impedance band from 2.9 GHz to 17.4 GHz, with an overall size of 36mm x 36mm, catering to the UWB frequency requirement. Furthermore, the crescent shaped slot inserted into the radiator rejects the 5.2 - 5.8 GHz WLAN band. Broad impedance bandwidth, stable radiation patterns, reasonable gain and excellent time domain characteristics are the main attractions of this antenna.

## 6. ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support by the AICTE, Govt. of India under the scheme RPS(C) File.No: 8023/BOR/RID/RPS-12/2008-09 dt 30.10.2008. They are also thankful to C.M.Nijas, Research scholar, CREMA, Department of Electronics, CUSAT for the help rendered in fabrication and measurement.

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