Various Slotted UWB Antenna for IEEE 802.15.3a Application

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Abstract- The basic circular monopole antenna exhibits a 10 dB return loss bandwidth over the entire frequency band, the paper proposed a modified version of simple circular monopole antenna for WPAN application. The antenna offers excellent performance in the range of 2-12 GHz.. The antenna is designed on FR4 substrate and fed with 50 ohms micro strip feed line. The antenna is suitable for operating frequency of 7 GHz. It is shown that return loss of the antennas at 7 GHz is better than -10 dB and VSWR obtained is less than 2. Proposed geometry is design and simulated using HFSS11 Details of the proposed antenna design and measured results are presented.

Index Terms- Wireless communication, UWB, circular monopole, WPAN

I. INTRODUCTION

Ultra-Wideband (UWB) was approved by the Federal Communications Commission (FCC) in Mar. 2002 for unlicensed operation in the 3.1-10.6 GHz band subject to modified Part 15 rules. The rule limits the emitted *power spectral density (p.s.d)* from a UWB source measured in a 1 MHz bandwidth at the output of an isotropic transmit antenna at a reference distance to that shown in Figure1. Further, the transmitted signal must instantaneously occupy either i) a fractional bandwidth in excess of 20% of the center frequency or ii) in excess of 500 MHz of absolute bandwidth to be classified as a UWB signal. The maximum allowable p.s.d for UWB transmission of -41.3 dBm/MHz corresponds to approximately 0.5 mW of average transmit power when the entire 3.1-10.6 GHz band is used, effectively limiting UWB links to short ranges. Nevertheless, the potential for exploiting such low power UWB links for *high data rate* wireless PAN connectivity (in excess of 100 Mbps) at ranges up to 10 m particularly for in-home networking applications has led to considerable recent interest in this technology .Ultra-wideband (UWB) radio technologies draw big attentions considering the applications to the short range wireless communication, ultra-low power communication, ultra-high resolution radar etc., among them, the standardization of the UWB radio is ongoing under IEEE 802.15 WPAN

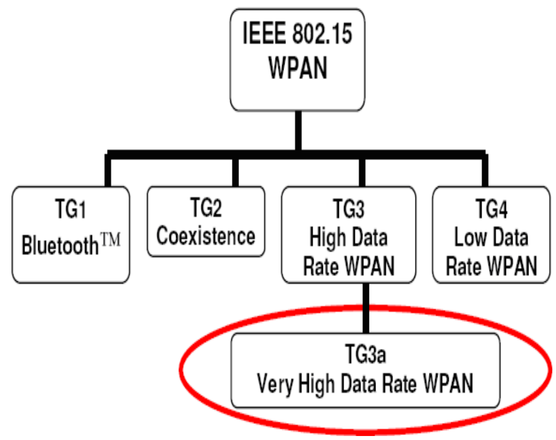


Figure 1: IEEE 802.15, standard group is responsible for WPAN Standard [4]

High Rate Alternative PHY Task Group 3a (IEEE802.15.3a) [1, 2] and wireless personal area network (WPAN) is originated by the Bluetooth (IEEE802.15.1). IEEE802.15.3a is trying to establish the new standard of WPAN to drastically increase the data rate, which is a weak point of Bluetooth. Now IEEE802.15.3a considers the use of UWB, following the tentative regulation of FCC (Federal Communications Commission, USA), to achieve the bit rate of 110 Mb/s at 10 m and 200 Mb/s at 4 m [3] Although the standardization has been at the final voting stage for more than half a year, the first candidate Multi-Band OFDM [4] has not been able to gain the required 75 % approval, and has been in competition with the second candidate DS-UWB [5].

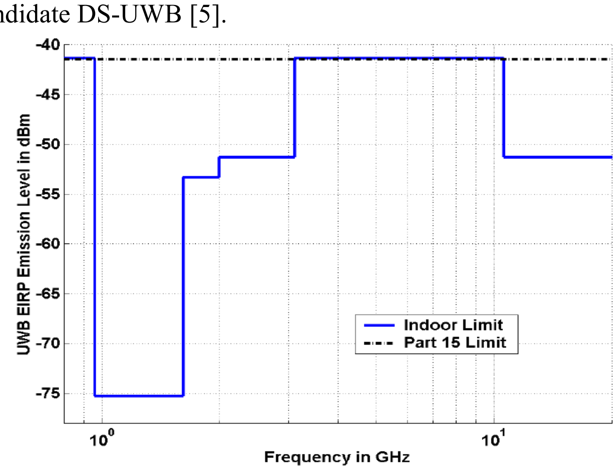


Figure2: UWB Spectral Mask Per FCC (Modified) Part 15 Rules [1]

Ultra wideband (UWB) is a leading candidate for short-range, wireless personal area networks, or WPANs. With this technology, people will be sharing photos, music, video, data and voice among networked consumer electronics, PCs and mobile devices throughout the home and even remotely. For example, users will be able to stream video content from a PC or consumer electronics (CE) device, such as a camcorder, DVD player or personal video recorder, to a flat screen HDTV (high-definition television) display without the use of any wires. In this application, a wireless universal series bus (W-USB) is required to replace cables and build up high speed wireless link between personal computers and other devices. The W-USB has strong demands for high performance UWB antennas which will be facing three most hallenging issues namely miniaturized size, reduced ground plane reliance, and enhanced diversity performance [1]. This paper proposes a miniaturized size of UWB antenna design to fit the existing USB dongles with a typical width of 18-22 mm. The design is based on a small printed UWB antenna [2] with dimension of 25 mm × 25 mm × 1.5 mm. A narrow strip is asymmetrically attached to the top side of the radiator to reduce the length of the radiator.

A rectangular notch is asymmetrically cut from the radiator. The ground-plane effect on impedance performance of the antenna has been significantly reduced due to the notch cut from the radiator. The notch extends the effective current path and concentrates majority of the current on the radiator instead of the system ground plane. This idea is an effective method to alleviate the problem of the ground plane reliance. This small printed antenna should be reduced further in order to fit within the W-USB dongle. The study of the UWB radio had started from the impulse radio which is advantageous in the hardware simplicity [1,20,21] but more complicated systems such as MB-OFDM and DS-UWB are considered now. In MB-OFDM system, a sub-band with 128 OFDM carriers occupies 528 MHz band, and different sub-bands are selected from time to time to achieve the frequency hopping (FH). Contrary, DS-UWB uses only two sub-bands to avoid IEEE802.11a band, i.e. the mandatory low band with 2.05 GHz bandwidth and the optional high band with 4.775 GHz bandwidth, which is more like the impulse radio. Recently, another task group IEEE802.15.4a has formed to standardize the low rate PHY using UWB [1,20,21]. It focuses on the high precision ranging, as well as the communications, with ultra low power, longer range, and lower cost. Properties and the antenna related issues.

A. IEEE 802.15 WPAN STANDARDS:

Originally, the IEEE 802.15 group was the Bluetooth™ group, but it has evolved to include other short-range Wireless Personal Area Network (WPAN) systems. The initial version, 802.15.1, was adapted from the Bluetooth specification and is fully compatible with Bluetooth 1.1. As it is now described by the IEEE, "The IEEE 802.15 Working Group proposes two general categories of 802.15, called TG4 (low rate) and TG3 (high rate). The TG4 version provides data speeds of 20 Kbps or 250 Kbps. The TG3 version supports data speeds ranging from 11 Mbps to 55 Mbps. Additional features include the use of up to 254 network devices, dynamic device addressing, support for devices in which latency is critical, full handshaking, security provisions, and power management. There will be 16 channels in the 2.4-GHz band, 10 channels in the 915-MHz band, and one channel in the 868-MHz band." The 802.15.3 Standard for high data rate services, which continues to be reviewed and enhanced, includes the following features and goals: • Data rates of 11, 22, 33, 44 and 55 Mbps.

- Quality of Service (QoS) isochronous protocol
- Ad hoc peer-to-peer networking
- Security
- Low power consumption
- Low cost

The higher data rate of this standard is designed to meet the requirements of portable consumer imaging and multimedia applications. The IEEE 802.15 Task Group 5 is studying mesh networking, determining the necessary mechanisms that must be present in the PHY and MAC layers of WPANs to enable mesh networking, in both full mesh and partial mesh topologies. Mesh networks are useful for intending network coverage without increasing transmit power or receive sensitivity, enhancing reliability with redundant routing, easy network configuration and, ultimately, longer device battery life due to fewer retransmissions. The IEEE 802.15.3 Study Group 3c, formed in March 2004, is developing a millimeter-wave-based alternative physical layer (PHY) for the existing 802.15.3 WPAN Standard 802.15.3-2003. This mm- Wave WPAN will operate in a band that includes the 57-64 GHz unlicensed band. The millimeter-wave WPAN will allow very high data rate applications such as high-speed internet access, streaming content download (video on demand, HDTV, home theater, etc.), real time streaming and wireless data bus for cable replacement. Optional data rates in excess of 2 Gbps are to be provided.

Table 1: lists a variety of wireless applications in the WPAN space and their estimated requirements for data rates.

Application	Min Data Rate	Max Data Rate
H.323 / T.120 Video Conferencing	188+ Mbps	1.4+ Gbps
Home Theater	43 Mbps	56.8 Mbps
Interactive Application (e.g. gaming)	76.8+ Mbps	unknown
Content Downloading (e.g. photos, MP3, CD, movies)	90+ Mbps	unknown

Table1: Estimated Data rates for various WPAN applications [21, 22, 23]

II. REVIEW OF THE STATE-OF-ART

The concept of ultra wideband communication originated in the early days of radio. In the 1900s, the Marconi spark gap transmitter (the beginning of radio) communicated by spreading a signal over a very wide bandwidth. This use of spectrum did not allow for sharing, so the communications world abandoned wideband communication in favor of narrowband or tuned communication in which the FCC governed spectrum allocation. The FCC provides guidelines for radiated power in the bandwidths of these communications systems and for incidental out of band radiated power. This incidental radiated power limits were the motivation for various organizations to challenge the paradigm of narrowband communications, in an ongoing effort to squeeze capacity out of a highly regulated spectrum. The Shannon-Hartley theorem states that channel capacity grows linearly with increases in bandwidth and decreases logarithmically with decreases in the signal to noise ratio (SNR). Although this relation is only exact under a considerable caveat, it does suggest how capacity is an impetus for UWB communication. Many companies argued that they should be allowed to intentionally transmit at the incidental radiated power limits (where they could already transmit accidentally) over an ultra-wide bandwidth to take advantage of this capacity potential. This argument was the motivation for the FCC approval of UWB devices. In February of 2002, the FCC amended their Part 15 rules (concerning unlicensed radio devices) to include the operation of UWB devices without a license. The FCC defines UWB signals as having a fractional bandwidth of greater than 0.20 or a UWB bandwidth greater than 500 MHz. UWB bandwidth is defined as “the frequency band bounded by the points that are 10 dB below the highest radiated emission” [1,3,4,24]

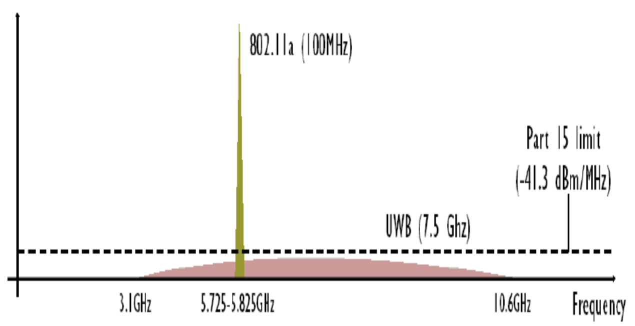


Figure3: **Spectrum of UWB Signal Compared with Wi-Fi (802.11a) Signal [21, 22].**

The FCC ruling allows UWB communication devices to operate at low power (an EIRP of -41.3 dBm/MHz) in an unlicensed spectrum from 3.1 to 10.6 GHz (see Figure 1). The low emission limits for UWB are to ensure that UWB devices do not cause harmful interference to (i.e. coexist with) “licensed services and other important radio operations” [1,20,21] (e.g. 802.11a devices).

A. IMPORTANT PARAMETERS IN THE DESIGN OF UWB ANTENNA FOR WPAN APPLICATION:

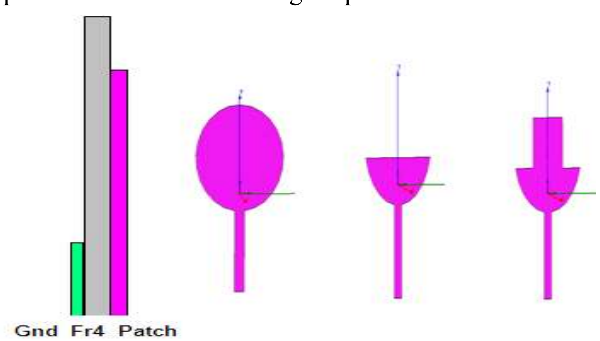
The following properties are required for the UWB antennas: *Linear phase and constant group delay in directivity:* If the group delay is not constant, the pulse waveform is spread out in the time domain. *Low return loss over ultra wide bandwidth:* If there are mismatches both at the antenna end and the circuitry end, the overall dispersion characteristic is much degraded due to the multipath within the feeding cable. *Constant directivity over ultra wide bandwidth:* The variation of the directivity according to the frequency results in the ripples of the frequency transfer function in some citation direction. The dispersion characteristic is then degraded. There are two fundamental principles to achieve the broadband or UWB property of the antennas [9]:

1.1 SELF SIMILARITY ANTENNA*:* A self similarity antenna is with the constant electric shape over the wide frequency bandwidth. Here, the electric shape means the shape described in the dimension of the wavelength. A biconical antenna, a bow-tie antenna, a discone antenna, an equiangular spiral antenna are the examples of this class.

1.2 SELF COMPLEMENTARY ANTENNA*:* A self complementary antenna is usually composed of planar conductor(s), and its complementary structure is identical to the original structure. Here, complementary structure is obtained by replacing the conductor and the non-conductor parts in the plane. Among the self complementary antennas, the log-periodic antenna is well known. Note that both structures require the infinite size of the conductor. The shape is therefore truncated in reality, and it limits the lower bound of the bandwidth.

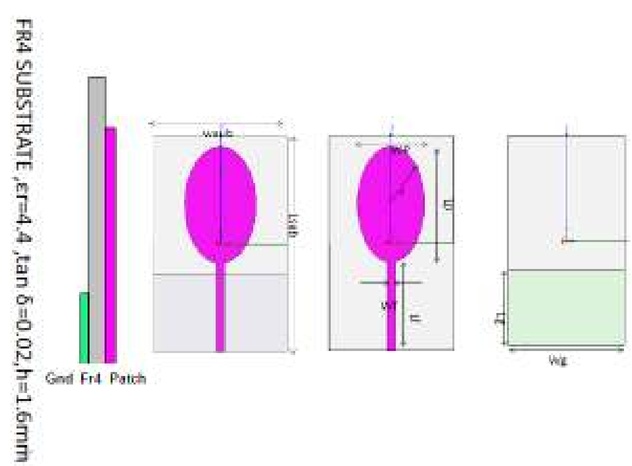
III. ANTENNA DESIGN AND CONFIGURATION

Figure 4 shows the evolution of the proposed printed monopole antenna. The structure is evolved from the circular monopole radiator to annular ring shaped radiator.



Circular semicircular AUD (proposed)

Figure 4: Evolution of the proposed dual band antenna.



a) Whole structure (b) Top view c) Bottom view

Figure5: Geometry of circular monopole antenna

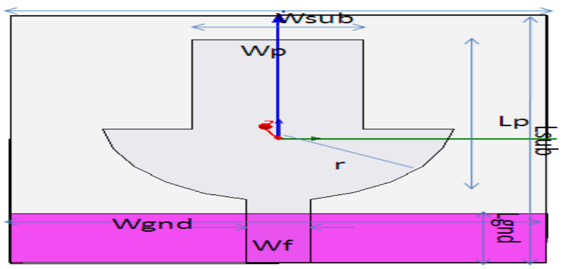


Figure 6: Geometry of Basic antenna

The geometry of the proposed antenna is shown in Fig. 4 is fed by a 50- microstrip line and fabricated on a 1.6-mm-thick FR4 substrate with 25× 25 mm surface area. The relative permittivity and loss tangent of the substrate is 4.4 and 0.02, respectively. The antenna structure is a variation of a circular monopole antenna. The radius (r) of the circular monopole [10] is obtained by using the equation no 1.

$$f_L = \frac{7.2}{2.25\, r + g}\ \text{GHz} \qquad (1)$$

Where g is the gap between the radiating patch and ground plane, and fL is the lowest resonant frequency corresponding to VSWR=2 .

The resonant frequency of a TMnm mode is

$$f_{nm} = \frac{X_{nm}}{2\pi a\sqrt{\mu_0 \varepsilon}} = \frac{X_{nm}c}{2\pi a\sqrt{\varepsilon_r}} \qquad \textbf{(2)}$$

The first five values of Xnm are:

(n,m)	(1,1)	(2,1)	(0,2)	(3,1)	(1,2)
X_{nm}	1.841	3.054	3.832	4.201	5.331

Equation 2, which is based on the perfect magnetic wall assumption, yields resonant frequencies which differ from measurements by about 20%. To take into account the effect of fringing field, an effective radius was introduced. This was obtained by considering the radius of an ideal circular parallel plate capacitor which would yield the same static capacitance after fringing is taken into account. A detailed calculation yields the formula.

$$a_e = a\left[1 + \frac{2t}{\pi a \varepsilon_r}\ln\left(\frac{\pi a}{2t} + 1.7726\right)\right]^{1/2} \qquad (3)$$

Using ae , the resonant frequency formula becomes

$$f_{nm} = \frac{X_{nm}c}{2\pi a_e\sqrt{\varepsilon_r}} \qquad \textbf{(4)}$$

Equation 4 yields theoretical resonant frequencies which are within 2.5% of measured values.

Table 2. Optimum dimensions of the Basic design antenna (all dimensions are in mm).

SLOTS	Wr1	Lr1	Wr2	Lr2	Wr3	Lr3
L-slot	2.5	7	6.5	1.8	----	---
T-slot	4	2	1.5	6	---	---
U-slot	1.5	3	7	1.5	1.5	3

IV. PARAMENTRIC STUDY

Parametric study has been conducted to optimize the design of the antenna. This study is crucial as it gives approximation measure before antenna fabrication can be done. The performance of annular shaped dual band antenna with WLAN band notched characteristic depends on number of parameters, such as gap (g) between radiating patch and ground plane, width (ws) and length (ls) of the substrate,length and width of the ground plane, width (w) and length (l) of the symmetrical step slot in radiating patch (rectangular strip inside circular annular ring and inner (r) and outer radius (R) annular ring. Beside these, antenna performance also depends on ground plane size and shape. The parameters which have significant effects on dual band with WLAN band notched characteristic are discussed and their parametric studies are reported in this section. The gap `g' between the radiating patch and the ground plane affects the impedance bandwidth as it acts as a matching network. The impedance bandwidth of the proposed antenna at different Lg is shown in Figure7. The optimum impedance bandwidth is obtained at Lg=6mm, the capacitance that results from the spacing between edge of ground plane and radiating patch reasonably balances the inductance of the antenna. Figure 8 shows return loss S11 (dB)

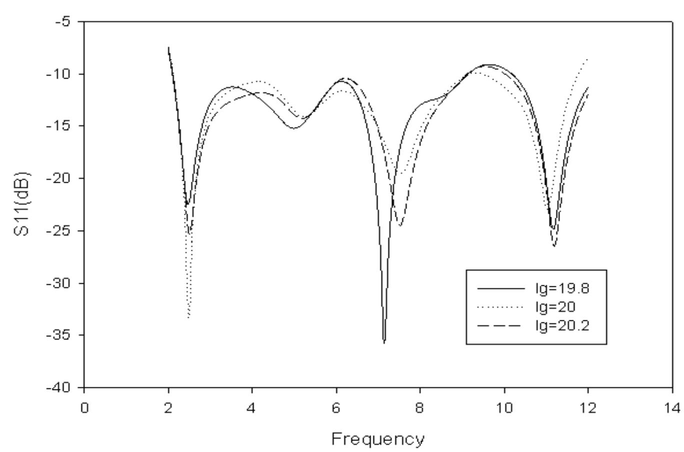


Figure7: Simulated return loss (S11) curves of Circular monopole antenna for different ground length

BAND NOTCH CHARACTERISTICS USING DIFFERENT SHAPE SLOTS:

To achieve the desired WLAN band notched characteristics, a T, U, L-shaped slots on the radiating patch is etched. The dimensions of quarter-wave resonating (mention-shaped) slot at central band-notched frequency can be postulated as

$$f_{notch} = \frac{c}{4(L+2\Delta l)\sqrt{\varepsilon_{eff}}}\ \text{GHz} \qquad \text{(5)}$$

$$\varepsilon_{eff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}\left(\sqrt{1+\frac{12H}{w_g}}\right)^{-1} \qquad \text{(6)}$$

$$\Delta l = \frac{0.412H(\varepsilon_{eff}+0.3)\left(\frac{w_g}{H}+0.262\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w_g}{H}+0.813\right)}\ \text{cm} \qquad \text{(7)}$$

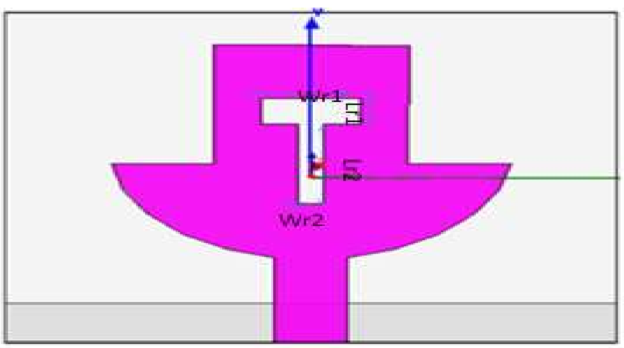


Figure8: Basic design with T slot

It is observed that for Lgnd of 6 mm, the antenna is able to operate as a narrowband antenna. However, the return loss of the antenna improves dramatically when the length ground patch reduces gradually and the best result is obtained at the height of ground plane, Lgnd of 5.4 mm.

The partial ground shows better return loss compared to full ground patch on the bottom because the antenna is transformed from patch-type to monopole-type by the partial ground. In order to further improve its overall bandwidth two steps of feed line can be used but that may be used for different application. The feed line is connected to SMA center pin with width of 3 mm

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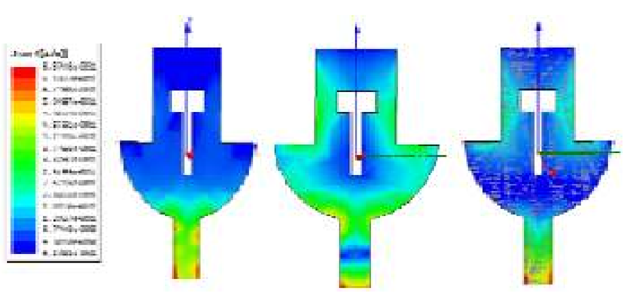

Figure 9: Surface current distributions of basic antenna at 3, 5 and 7 GHz

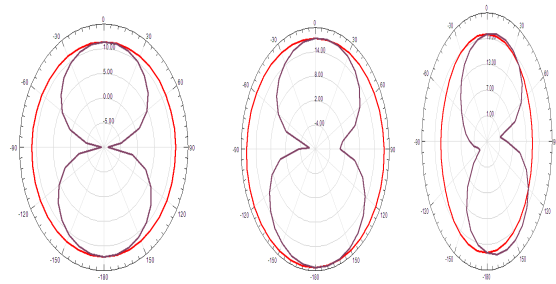

Figure10: radiation patterns in the φ =0° and φ =90° planes of a proposed patch with εr =4.4 at 3, 5,7GHZ

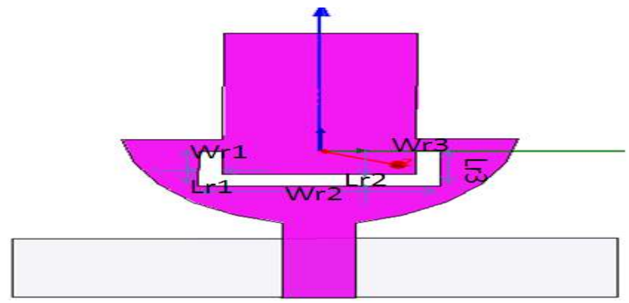

Figure11: Basic design with U slot

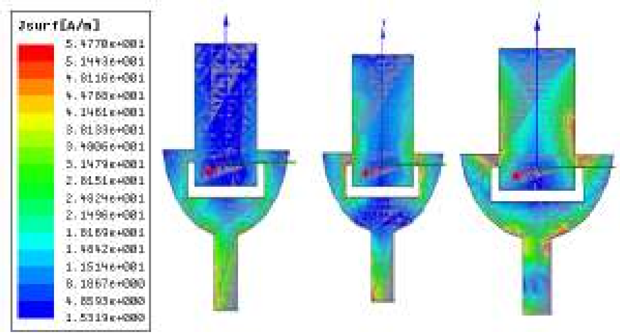

Figure12: Surface current distributions of basic shape antenna at 3, 5 and 7 GHz

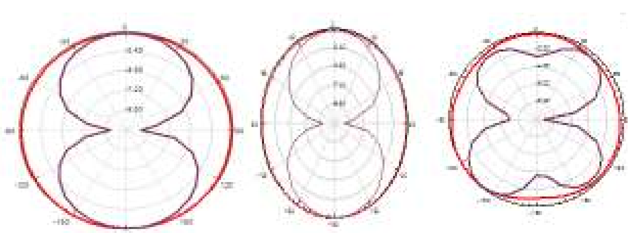

Figure13: radiation patterns in the φ =0° and φ =90° planes of a proposed patch with εr =4.4 at 3,5,7GHZ

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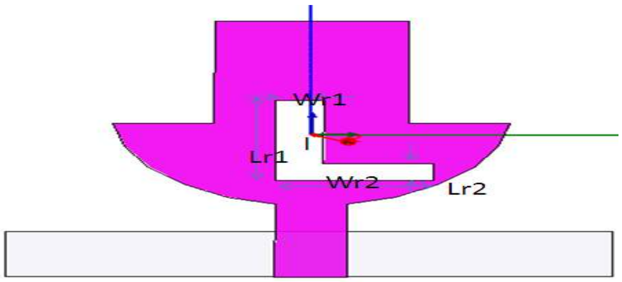


Figure14: Basic design with L slot

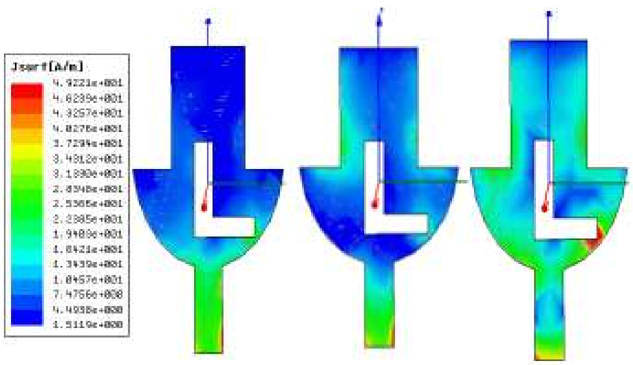


Figure15: Surface current distributions of basic antenna at 3, 5 and 7 GHz

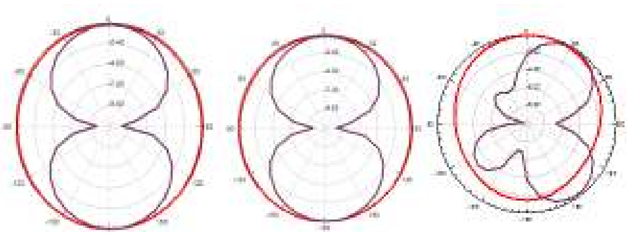


Figure16: radiation patterns in the φ =0° and φ =90° planes of a proposed patch with εr =4.4 at 3,5,7GHZ

Varies slotted antenna is reported and studied. The antenna is analyzes from their current distribution and radiation pattern behavior. The required band width which could be used for Bluetooth (2.4-2.484 GHz) and UWB (3.1-10.6 GHz) applications with WLAN (5.15-5.825 GHz) band-notched characteristics could not achieved with above slots. The modification in the basic design is done to achieve the desired band.

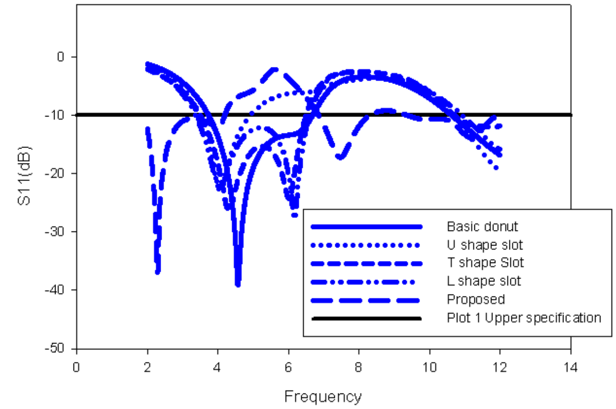


Figure17: Simulated return loss (S11) curves of all four ant at Lg=5mm.

V.MODIFICATION IN THE BASIC DESIGN TO ACHIEVE PROPOSED ANTENNA:

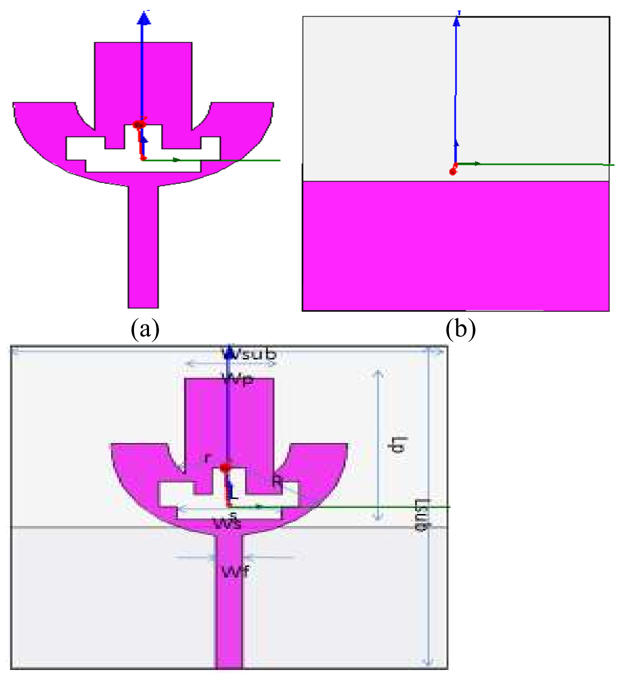
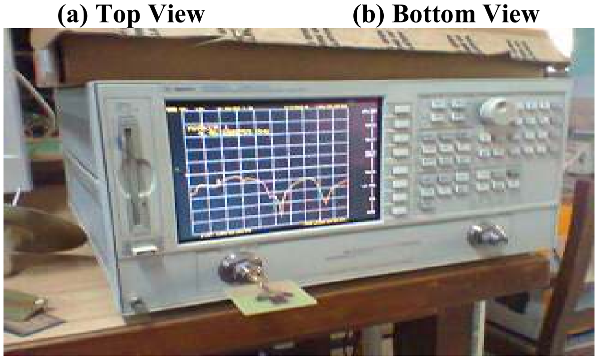


Figure18: Geometry of proposed antenna for UWB communication (a) Top View (b) bottom View (C) Design geometry

The antenna structure is fabricated on a printed circuit board (PCB) using Photolithography technique and tested. The fabricated antenna is shown in Figure11. Below fig clearly show the process for S11 (dB) measurement. The measured results reasonably agree with simulated results. The proposed antenna rejects the WLAN band and still performs good impedance matching over the UWB band.

(a) Top View **(b) Bottom View**



(c) Antenna under Test

Figure19:.Photograph of the proposed antenna

Table3. Optimum dimensions of the proposed antenna (all dimensions are in mm).

Parameters	Wsub	Lsub	Wp	Lp	Lf	Wf	Lg	Wg	R	r
Basic ant	25	25	8	16	6.4	3	4.5	25	—	8.25
Proposed Design	50	50	8.5	24	19.5	3	19.5	50	13.5	7.5

V. CONCLUSION

A User centric concept in mobile communication has attracted increasing interest and attention recently. Future communication systems are driven by the concept of being connected anywhere anytime. These systems are powered by the emergence of small and lightweight wireless systems such as Bluetooth and UWB enabled devices. Since power required for small wireless devices is at very low level so the UWB antenna is a good candidature for WPAN applications. In this paper a simple, low-cost, and compact printed Trisul shaped dual-band antenna is proposed. This microstrip line fed antenna can be easily integrated within the printed circuit boards (PCBs) of various systems. Dimensions of the central arm govern the Bluetooth band, while dimensions of ground plane govern the UWB band. Hence, the proposed antenna provides effective control over two operating bands. The antenna provides more than 80% antenna efficiency, and its gain varies from 3–6 dB over two bands. The antenna has nearly omni directional radiation pattern, which indicates that the proposed antenna is suitable and a good candidate for Bluetooth and UWB applications.

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