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Design and Analysis of Compact Novel Tapered U Slot Antenna for UWB Systems

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Abstract: A novel, compact and miniaturized tapered U slot printed monopole microstrip antenna is designed in this paper. The antenna is fed by a single 50Ω microstrip line with truncated ground plane and is excited by a coaxial Sub Miniature Version A (SMA) connector. The antenna is fabricated on FR4 substrate of dielectric constant 4.4. The measured impedance bandwidth is 8.3GHz (i.e 3.3GHz to 11.6GHz) for Voltage standing wave ratio defined by VSWR<2. A new ultra wide band high gain antenna is demonstrated. Due to its compact structure it is attractive in low cost, compact systems. The simulation was done using Ansoft High Frequency Structure Simulator (HFSS) software. The simulation and experiment reveal that the proposed antenna exhibits good impedance match and high gain. Therefore, the performance of this antenna by simulation indicates that the proposed antenna is suitable and a good candidate for UWB application.

Keywords: UWB antennas; printed monopole antennas; VSWR; Gain; HFSS

I. INTRODUCTION

Ultra Wideband Radio (UWB) is a potentially revolutionary approach to wireless communication in that it transmits and receives pulse based waveforms compressed in time rather than sinusoidal waveforms compressed in frequency [1]. The recent allocation of the 3.1–10.6GHz frequency spectrum by the Federal Communications Commission (FCC) for Ultra Wideband radio applications has presented a myriad of exciting opportunities and challenges for antenna designers [2].

Since the United States Federal Communications Commission (FCC) adopted the first UWB Report and Order on February 14, 2002, the interest in UWB technology has increased substantially in both academics and the market place. Interest is stimulated by the expectation that UWB can solve the shortage of the available frequency resources [7].

The UWB technology offers several advantages over conventional communications systems. For instance, there is no carrier frequency. Instead, UWB emits timed "pulses" of electromagnetic energy. There is a wide range of applications for UWB technology, which includes wireless communication systems, position and tracking, sensing and imaging, and radar. [8]

As the UWB technology is employed mainly for indoor and portable devices the size of the antenna should be considerably small so that it can be easily integrated into various components [3]-[6]. Antenna plays an essential task in UWB system. UWB systems transmit extremely narrow pulses on the order of 1 ns or less resulting in bandwidths in excess of 1 GHz or more. However, the design and fabrication of high-performance transmitting/receiving antennas often present significant challenges in the implementation of these systems [9].

Printed monopole antennas (PMAs) are apt for UWB applications due to their compactness, light weight and simple structure. These can be realized easily on the printed circuit boards and can be integrated with other components on PCB. Many kinds of printed monopole antennas have been designed and presented in a number of research papers. The PMAs (printed monopole antennas) are very good for UWB technology based cost effective systems [10].

The variety in design that is possible with microstrip antennas probably exceeds that of any other type of antenna element. Microstrip antennas where size, weight cost better performance, compatibility with microwave and millimetre wave integrated circuits (MMICs), robustness, ability to conform to planar and non-planar surfaces, etc. are required. Microstrip technology using these techniques meets the demands of today's mobile communication operators.

The design of a UWB antenna is very difficult, because the fractional bandwidth is actually big, and antenna must cover multiple-octave bandwidths in order to transmit pulses that are of the order of a nanosecond in duration. Since data may be contained in the shape of the UWB pulse, antenna pulse distortion must be kept to a minimum. From a system design perspective, the impulse response of the antenna is of particular interest, because it has the ability to alter or shape the transmitted or received pulses.

In practice, attempt must be made to limit the amplitude and group delay distortion below certain threshold that will ensure reliable system performance.

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Antennas in the frequency domain are typically characterized by radiation pattern, directivity, impedance matching, and bandwidth. However, there are certain requirements for the antennas in the wireless system regardless of ultra-wideband or narrowband same as regulatory issues, antenna gain, antenna efficiency, and group delay of antenna. A tapered slot feeding structure is used to transform the guided waves to free space waves.

II. ANTENNA DESIGN CALCULATION

1. Effective Length (L_{eff})

The effective length $\mathbf{L_{eff}}$ of the antenna depends directly on the speed of the light **C**=3x10^8 m/s and inversely depends on the resonant frequency $\mathbf{f_0}$ and square root of the effective dielectric constant **εreff**.

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}}$$

2. Patch Length (L)

This equation is used to find the actual length of the patch **L**. Patch Length is given as the difference between the effective length $\mathbf{L_{eff}}$ and 2 times the length.

$$L = L_{eff} - (2 \times L)$$

3. Effective dielectric constant (εreff)

Effective dielectric constant **εreff** is inversely proportional to the square root of the height **h** and width of the antenna **W.**

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

4. Length extension (ΔL)

The length extension **ΔL** of an antenna is given b, where **εre** is the permittivity **h** is the height and **W** is the width

$$\Delta L = 0.412\, h \frac{(\varepsilon_{re} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{re} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

5. Width (W)

Width **W** of the antenna is depends directly on the speed of the light **C**=3x10^8 m/s and inversely depends on the resonant frequency $\mathbf{f_0}$.

$$W = \frac{c}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

The three essential parameters for the design of a Microstrip Patch Antenna:

1. Frequency of operation (f_0): The resonant frequency of the antenna must be selected appropriately. The Antenna was designed for radar communications, satellite uplink, one-point to multi-point systems. Hence the antenna designed must be able to operate in these frequency ranges.
2. Dielectric constant of the substrate (ε_r): The dielectric materials used are design are FR4_epoxy which has a dielectric constant of 4.4. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.
3. Height of dielectric substrate (h): For the micro strip patch antenna to be used in wireless application, it is essential that the antenna should be compact. Hence, the height of the dielectric substrate is selected as 1.5mm.

Simulations were performed using High Frequency structure simulator (HFSS) which uses the finite element method(FET) for simulations.

III. ANTENNA DESIGN

The antenna showed by Figure.1 consists of a rectangular patch printed on an FR4 epoxy dielectric substrate with a permittivity of 4.4, a tangential loss of 0.018 and a height of 1.6mm. It is fed through a 50Ω microstrip line.

The partial ground of size 24 x 11.5mm^2 is etched on the opposite side of the substrate. As the distance between the radiator and the ground changes, impedance bandwidth also changes. Thus the feed gap is adjusted during the simulations to adjust the impedance matching and finally taken as 0.5mm.

In most of the cases UWB antennas are fed by microstrip transmission line or by coplanar waveguide (CPW) feeding. In this case the lumped port excitation is provided in the simulation which touches the radiator and the partial ground plane.

The operating frequency in the simulations is assumed to be the approximately the centre frequency of the UWB range i.e. 6.8GHz.

For better impedance matching, along with the bevelling technique a notch of size 11x22.7mm^2 is cut out of the radiator to conserve space and to create a more compact antenna as shown in Figure 2.

The U slot radiating patch and transmission line are connected by tapered edges or bevel slots to obtain better impedance matching.The dimension parameters of the proposed antenna are given in Table 1.

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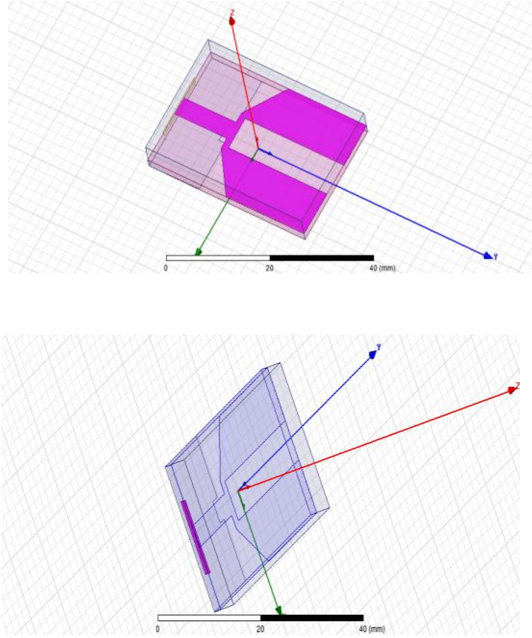

Figure 2. HFSS Simulation design of proposed antenna (a) Final design view of radiator (b) Ground view of lumped Port with the patch.

Simulations have been carried out with the Ansoft HFSS to determine the UWB antenna's performance.

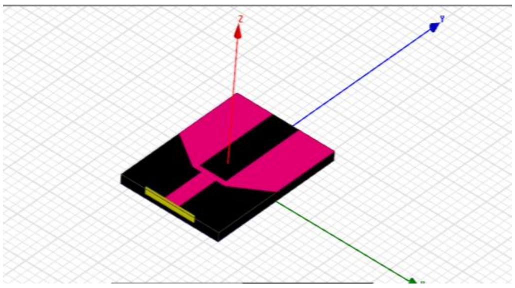

Figure3. Antenna design

In the antenna design shown above, black color refers to the substrate, pink refers to the patch, and yellow refers to the lumped port. The substrate (black) is made of a flame retardant glass epoxy laminate sheet (FR4) having a dielectric constant of 4.4 and a thickness of 1.6mm.

The patch (pink) has a dimensions of 24x36mm, is notched, cut out in the center andfurther modifications to the patch results to tuning fork structure. This 50ohm microstrip feed is excited by a rectangular lumped port (yellow).

Table 1.Detailed parameters for the proposed antenna

Serial no	Symbols used	Original size (mm)
1	L	36
2	L_1	16
3	L_2	22.7
4	L_3	1.3
5	L_4	1.5
6	L_5	0.5
7	L_6	11.5
8	W	24
9	W_1	6.5
10	W_2	10.25
11	W_3	3.5

IV. RESULTS AND OBSERVATION:

The simulation results show that the proposed antenna gives an impedance bandwidth (VSWR<2) from 4.1-12GHz. The term Antenna Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. Antenna gain is more commonly quoted in a real antenna's specification sheet because it takes into account the actual losses that occur. An antenna with a gain of 3 dB means that the power received far from the antenna will be 3 dB higher (twice as much) than what would be received from a lossless isotropic antenna with the same input power.

VSWR is the ratio of the maximum voltage to the minimum voltage in the standing wave. The larger the impedance mismatch, the larger the amplitude of the standing wave. A perfect impedance match would cause no voltage standing wave. For the proposed antenna the VSWR is less than 2 for the specified frequency range. Due to this there is lesser impedance mismatch and hence the proposed antenna is more efficient and finds larger applications.

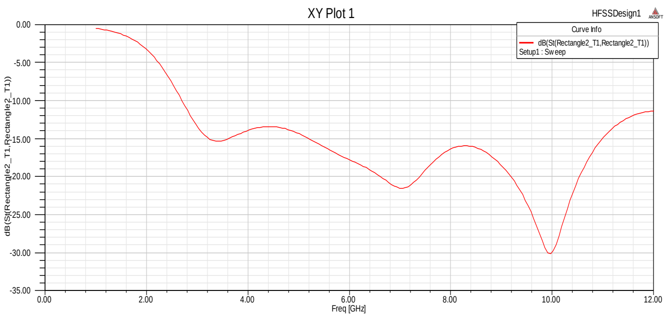

Figure 4(a) Gain vs Frequency Plot

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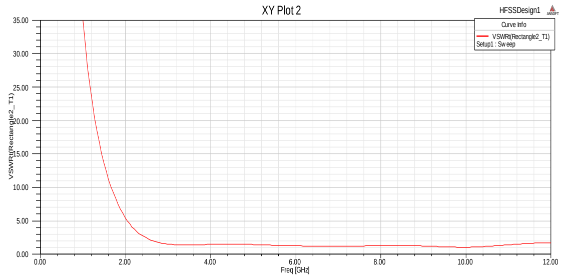

Figure 4(b) VSWR Plot

In this operating range of the antenna there are several applications like

- Satellite Communication (Uplink 5.925GHz-6.425GHz and Downlink 3.7GHz – 4.2GHz)
- WiMax (5.5GHz range)
- Wi-Fi and cordless telephone (5.4GHz)
- Electron Paramagnetic Resonance Spectrometers (9.8GHz)
- Amateur Radio (10GHz-10.5GHz) and Amateur satellite Operations (10.45GHz-10.5GHz)
- Motion Detectors (10.525GHz)
- Traffic light crossing detectors (10.4GHz)

V. CONCLUSION

A new compact UWB antenna has been designed, simulated, measured and fabricated. The antenna provides excellent performance in the entire operational bandwidth. The proposed antenna is compact and has stable input impedance. They have wide impedance bandwidth covering 4.1-12GHz and high gain properties. The antenna gives omni directional radiation which is necessary for UWB antenna. To miniaturize UWB antenna, tapering and truncated ground plains are used. In addition the proposed antenna is made of single layer printed circuit board is very low cost in fabrication. They are excellent candidates for various low cost UWB systems.

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