Analysis of a Dumble Shape antenna with reduced ground plane for unlicensed frequency band by the regulatory body FCC

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Abstract: In this paper a novel dumble shaped microstrip patch antenna (MSA) with reduced ground plane structures has been proposed for un-licensed frequency bands i.e. ISM (2.41-2.4725GHz), and U-NII (5.16-5.35 and 5.75-5.85GHz) and Space communication (7.2-9.2 GHz). FR4 substrate has been utilized for the design and fabrication of the proposed switch having dimension 40×50×1.6 mm^3. For this purpose, the multiband and wideband operations are comprehended in a single antenna design by introducing a dumble shaped patch with reduced ground plane. The proposed antenna geometries are fabricated on the FR4 lossy. All the simulations have been carried out in finite element method (FEM) based HFSS simulator. Considering the bandwidth, gain and radiation properties the proposed MSA is applicable for unlicensed frequency band for the low-range and higher speed communications. The fabricated antenna exhibits the omni directional and figure of eight radiation pattern in H- and E-plane respectively.
Keywords: Microstrip antenna, reduced ground plane, HFSS software, ultra-wide band characteristic.

1. INTRODUCTION

Now a days the advancement in the region of wireless UWB communication technology is going to be increased gradually, mainly in the data and voice communication [1-17]. The wireless research community has experienced this as an enormous chance to increase the wireless devices to communicate in the unlicensed band i.e. ISM (Industrial Scientific Medical i.e. 2.41-2.42 GHz), and U-NII (5.15-5.35 and 5.75-5.85GHz) and Ultra-wide band (3.1 -10.61 GHz) by the dictatorial body of united state society i.e. Federal communication commission (FCC) [18-22]. The FCC specifies a bandwidth from 3.1-10.6 GHz for UWB wireless communications. But in this spectrum bans several wireless spectrum also exists Wi-MAX (Worldwide Interoperability for Microwave Access) (3.8–4.11 GHz), Wi-BAN (4.81–5.061GHz), WSN (wireless sensor network) (6.11–6.41 GHz), satellite communication band (7.41 – 7.8GHz) [23-24]. In the modern world, the demand of wider bandwidth, high speed data and novel mechanism of feeding encourage the academician and scientists to research on ultrawide band spectrum band for various wireless applications. Additionally, UWB communication system is a potentially pioneering approach to wireless technology. It sends streams of extremely brief energy pulses that can be dispersed across a wide range of frequencies, typically lasting between 10 and 1,000 picoseconds and receives the narrowband signals that are compressed in time as compared to sinusoidal that are compressed in frequency [25-26]. This is differing to the long-established convention of transmitting the signals over narrow frequency bandwidth such as 802.11a, 802.11b and Bluetooth etc. It allows the transmission over a wide frequencies range along with low power spectral density (PSD). It has been expanded rapidly for commercial as well as for military purposes, due to its cost effective and flexible way of communication [27]. Recently, due to the developments of high-rate data network with low power consumption, ultra wideband (UWB) antennas has become an attractive topic of research. Compared to narrowband, the UWB has large peak gain, multiple sharing with users and low noise PSD [28-29] . Whenever it came to flexibility and battery life, UWB has a significant advantage because the power required levels are so low that they are even lower than that for mobile handset. Furthermore, the wide frequency broadcast sets the UWB extremely interference-resistant. The potential capacity is mentioned in the more than hundreds of megabits per second, coming through much quicker than Bluetooth at 2Mbps and the most recent 54 Mbps Wi-Fi standard technology. It can also transmit a significant quantity of data. [30-31]. It has low cost due to simple hardware and low power consumption also. With UWB, security is a smaller issue because the short pulses are much more challenging to detect, but range is still a problem. Because signals can only travel 10 to 20 meters, because UWB cannot match against 802.11 WLAN technologies [32]. A broad bandwidth is acquired by the majority of the service suppliers. Since small, simple structure antennas with wider bandwidth and high gain are required for the transmission and reception of the large bandwidth. There fore in the present research work, the design and development of a dumble shaped MSA has been introduced that carry all these necessities for high data rate communications [33].

Because MSA has some admirable features like cost effective, light weight, easy to fabrication and amalgamation with complex circuitry [34-35]. On the other hand, the conventional MPA bears with some limitations as narrow bandwidth along with low gain. In literature, various techniques are offered to enhance the bandwidth of the antenna like as defected ground structure mechanism (DGS) [36-40], antenna stacked with various type of patch shapes [41-43] and by utilizing the different type of feeding mechanism such microstrip feed, coplanar waveguide [44-45], L-strip feed [46], aperture coupled feed [47-50], proximity feed [51-52] and coaxial probe feed [53-54]. Researchers and academician are work together to cover multi-band, full- band and ultrawide band (UWB). To enhance the limited bandwidth and inferior gain, the DGS instigate on the surface of ground that provides the disturbance to the flow of surface current. Additionally, it helps to improve the overall inductance and capacitance of the microstrip transmission line.

The aim of this paper is to present the advantages of Defected Ground Structure to obtain the wider frequency band, impedance matching with high gain. As a result a novel Dumble shape UWB antenna with DGS techniques has been designed and simulated on Ansys HFSS V'13 and fabricated using wet etching photolithography process. The simulated S-parameter, gain and radiation properties results of the proposed antenna are confirmed experimentally by tested it on anechoic chamber and vector network analyzer (VNA).

Table 1 summarizes a comparison between various previously reported and proposed antenna that have been published in terms of resonating band, volume, peak gain, and impedance bandwidth. It has been found that the impedance bandwidth of has less bandwidth than the suggested antenna. In terms of bandwidth, the proposed antenna operates on UWB frequencies, in contrast to the reported antennas' multiband and wide band operations. It was confirmed with certainty that the suggested antenna has a smaller volume. Table 1 show that the suggested antenna is suited for the unlicensed band (2.4–10 GHz) and has a small size, a simple structure, and entire ultra-wideband.

Table1: Comparison between the previously reported and proposed antenna design.

Reference no.	**Antenna size**	**Impedance bandwidth**
[11]	$80 \times 80 \times 5.5$ mm^3	4.15–6.26 GHz
[9]	$52.3 \times 58.7 \times 1.07$ mm^3	176, 4.77 and 335 MHz at resonant frequencies 2.54 GHz, 4.8 and 7.7
[8]	$60 \times 60 \times 3$ mm^3	3-20 GHz
[16	$70 \times 52 \times 1$ mm^3	1.1-1.46,2.23-2.9,3.41-3.95 and 5.24-5.96
[17]	$70 \times 52 \times 1.67$ mm^3	1.795 to 1.875
[12]	$50 \times 50 \times 1.52$ mm^3	NA
Proposed antenna	$40 \times 50 \times 1.6$ mm^3	2.4-10 GHz

2. CONFIGURATION OF THE DIFFERENT ANTENNA STRUCTURE

The key goal of this proposed is to design a novel dumble shaped ultra-wide band (UWB) used for un-licensed bands i.e. ISM (2.41-2.46 GHz), U-NII (5.15-5.35 and 5.75-5.85GHz) and space communication (7.2-9.2GHz). For this aspect, dumble shaped design with reduced ground plane structure has been designed as shown in figure 1(a). It is able to excite multi-band properties i.e. 3-4.4, 5.1-6.025, 7.2-9.2GHz. In order to achieve the better impedance matching and quite good gain, the dimensions of the conventional antenna configuration is optimized by parametric simulation in ANSYS HFSS software as shown in table 2. The proposed antenna geometries are built and simulated on a mechanically stable FR-4 lossy substrate with overall dimensions of $40\times50\times1.6$ mm^3. It contains the three layers like as ground structure i.e. bottom layer followed by a FR4 substrate having high dielectric constant i.e. intermediate layer, microstrip feedline and rhombic patch of copper material i.e. topmost layer. Additionally at the bottom edge of the antenna a 50 Ω microstrip feed point (width W =3mm) is utilized to for the excitation of the designed antenna. The initial dimensions of the proposed antenna such as i.e. length (L) and width (W) has been optimized using transmission line model equations given as 1-3 [12].

$$W = \frac{c}{2 f_r \sqrt{\left(\varepsilon_r + 1 \middle/ 2 \right)}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12^{h/w}\right]^{-1/2} \qquad \text{................. ....(2)}$$

$$L = \frac{1}{2cf_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad \text{...(3)}$$

Where c=3×10^8 m/s, ε_r = 4.4 , h=1.6mm , ΔL = extended length of proposed antenna design and operating frequency of 2.28 GHz which is nearly equal to simulated value i.e. 3.4GHz. The suggested antenna's dimensions have been tuned to increase its capability in respect of return loss, bandwidth, and impedance matching. The tuned parameters of the designed DRA are shown in figure 1. The proposed antennas are modelled and simulated in an Ansys HFSS software version 13.

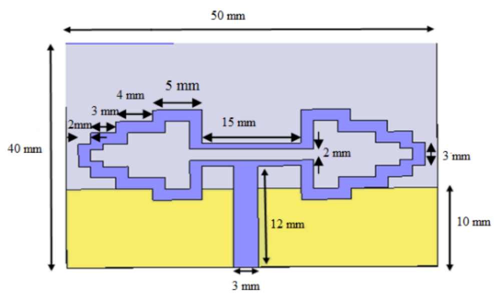


Fig.1 Structure of the designed antenna on FR4 substrate.

2.1 Effect of substrate material

In the proposed antenna design, three different materials of substrate are used, i.e. FR4, Duroid and Rogers to analyse the performance of the antenna design.These materials have different effects on proposed antenna's performance i.e. impedance bandwidth, losses. These materials are chosen for this antenna as they enhanced the bandwidth and gives better mechanical results in the presence of air. To check the performance of these different materials a combined S-paramter graph is plotted as shown in the fig. 2 and a table 1 is drawn to show the different frequency bands excited by the antenna with each material. From table 1, it is concluded that the FR4 material provides the better results in terms of impedance bandwidth.i.e. 2.6-11GHz.

Table 1 Frequency range obtained with different substrate materials

Substrate Material	Dielectric constant (ε_r)	Frequency range (GHz)
FR4	4.4	2.6-11
Rogers (3003)	3	4.1-5, 5.5-7.2, 8.5-11
RT-Duroid	2.2	2.8-3.6, 4.6-5.2, 6.4-7.6

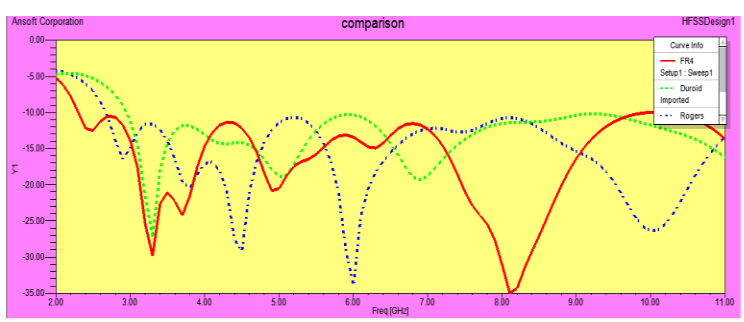


Fig 2. Comparison between the different material used in substrate.

3. FABRICATION AND TESTING OF THE PROPOSED ANTENNA DESIGNS.

FR4 substrate has been used as a substrate material for the fabrication of proposed antenna having the dimension 40×50 mm^2. To pattern the dumble shape structure on substrate wet etching photolithography technique has been utilized. To make the ground plane and dumble shape patch on bottom and top of the substrate, respectively a layer of copper material of thickness 0.35 mm has been deposited. On bottom and top of the FR4 substrate material, a thick layer of copper material having the thickness 0.035mm is deposited to be use as a ground plane and dumble shaped patch along with microstrip feed-point respectively as depicted in the figure 4 (a-b). The validity of the results obtained from ANSYS HFSS software such as radiation pattern, gain, S-parameter and VSWR is tested on the Agilent's VNA (vector network analyser). The Agilent's VNA (vector network analyser) model no. E-5063A operating from 0.1MHz to 18GHz is connected through a SMA female connector to the 50 Ω micro strip transmission lines. The comparative graph between the measured (obtained from VNA) and simulated (obtained from HFSS) results in aspects of the S-parameters as demonstrate in figure 4 and polar radiation patters as shown in figure 6 are explained with details in next subsection of this section 3.2. It is observed that designed antenna able to achieve maximum bandwidth i.e. 2.4-10 GHz for simulated case and 3.05-9.67 GHz for measured one along with appropriate impedance matching (VSWR < 2).

(a) (b)

Fig 4: Fabricated dumble shape antenna with reduced ground plane (a) Top view (b) Bottom view

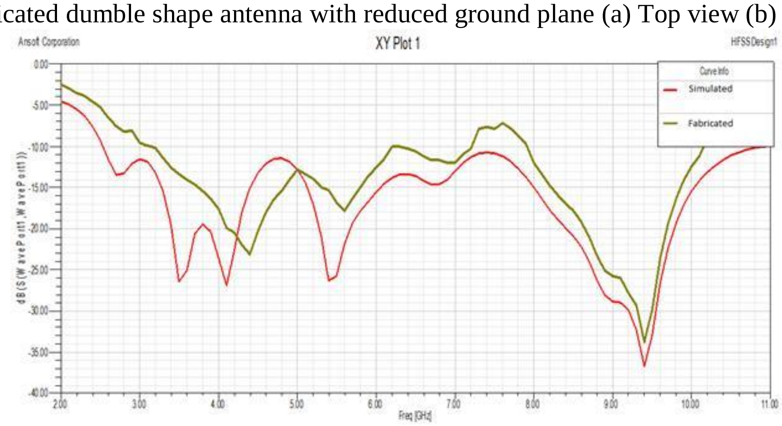
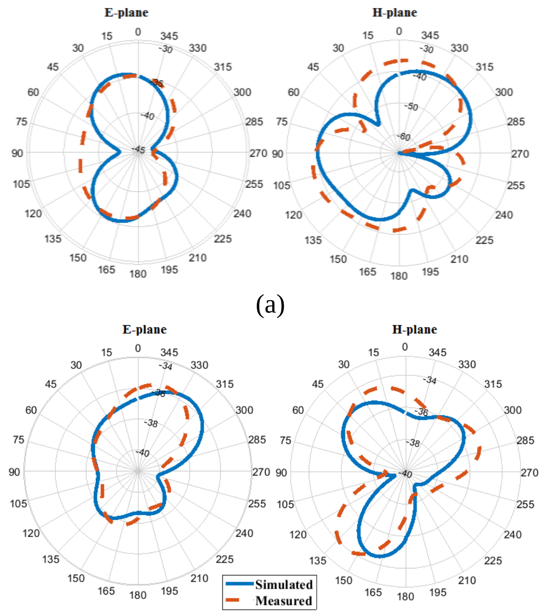


Fig.5 Comparative analysis between measured and simulated results of dumble shape antenna.

3.2 Radiation pattern

Figure 6 demonstrates the measured and simulated 2D radiation pattern of dumble shape antenna with reduced ground plane. In order to measure the radiation pattern practically, a horn antenna that is used as a transmitter is placed 1m away from the proposed antenna that is used as a receiver. The proposed structure exhibits the figure of eight radiation pattern in E plane and like omnidirectional radiation pattern in H -plane.



(a)

(b)

Figure 6 Comparison between simulated and measured radiation pattern plot at (a) 3.4GHz (b) 8.2GHz of resonant frequency for dumble shape antenna with reduced ground plane.

4. CONCLUSION

This paper Analysis the effect of Dumble Shape microstrip patch antenna with reduced ground plane for unlicensed frequency band i.e. ISM (2.4-2.4835GHz), U-NII (5.15-5.35 and 5.75-5.85GHz) and space communication (7.2-9.2GHz) for impedance bandwidth, gain and radiation properties. The total volumetric parameters of the proposed antenna designs are $(40\times 50 \times 1.6)$ mm^3. The proposed dumble shaped antenna with reduced ground plane is designed and analysed that it operates for multi-band operations i.e. 3-4.4, 5.1-6.025, 7.2-9.2 GHz along with low peak gain. All the simulations have been performed on Ansys HFSS software. The antenna's geometry benefits from a straightforward configuration, making low-cost manufacturing feasible. The suggested antenna is low profile and has the qualities indicated above, making it appropriate for all UWB applications. The designed antenna demonstrates that the simulated and measured data are concisely matched.

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