Design and Performance Analysis of an Inset Feed and Slot Configuration on Circular Patch Ultra-Wideband Antenna

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Abstract - *This paper presents a new design for a compact omnidirectional monopole antenna, suitable for broadband applications. The antenna features a modified circular patch, with a size of 40×45×1.6 mm³, and is simulated and fabricated using FR-4 substrate. The proposed design covers a frequency range of 2.4-11.24 GHz, which meets the UWB range of 3.1-10.6 GHz. The paper explores the effect of incorporating an inset feed on the circular patch. The resulting low-profile monopole antenna has a return loss of -27.94 dB and -31.07 dB, resonating at 3.38 GHz and 5.36 GHz respectively, which includes the WLAN and Wi-Max bands. The antenna's performance parameters, such as reflection coefficient, bandwidth, and radiation pattern, are simulated using CST-2022 Microwave simulation software, and the results are compared with experimental data.*

Key Words: *Omnidirectional antenna, Inset feed, UWB antenna, Wi-Max, WLAN.*

1. INTRODUCTION

With the rapid expansion of modern communication, there is a growing need for high data rates, reduced power consumption, and minimal interference with other communication devices [1]. Ultra-wideband (UWB) antennas offer a wide bandwidth and are ideal for wireless communication systems due to their increased gain, simplicity, and high data rates [2]. UWB technology allows for short pulses in a broad range of frequencies with straightforward structures [3]. The decision by the Federal Communication Commission (FCC) in February 2002 to authorize low power with large bandwidth between 3.1 to 10.6 GHz has opened up numerous possibilities for broadband applications. Several methods have been used in the literature to achieve UWB applications, including inset feed [7-9], taper feed [10, 11], CPW feed [12], among others. The current study proposes the design of a circular monopole antenna (40×45×1.6 mm3) for UWB applications, featuring an impedance bandwidth range from 2.4-11.24GHz. The impact of incorporating an inset feed and truncated ground on the antenna is also examined. The microstrip patch antenna presented in this study is compared to previous literature, demonstrating greater compactness, enhanced bandwidth, and increased gain. The antenna's performance is focused on WLAN frequencies (2.9 to 4.5 GHz), Wi-MAX frequencies (5.4 GHz to 6.45 GHz), and VSWR values below 2.

2. ANTENNA DESIGN AND PERFORMANCE

The proposed antenna's geometry is illustrated in Figure 1, displaying both its top view and bottom view, as seen in Figure 1(a) and Figure 1(b). The monopole circular patch antenna's dimensions are as follows: a width of Ws=45 mm, a length of Ls=40mm, and a substrate (FR-4 epoxy) height of T=1.6 mm, featuring an epsilon value of 4.3 and a loss tangent of 0.02. The circular patch has a radius of R=9.5 mm, and its feed line has a length of Lf=20.3mm and a height of t=0.02mm. To modify the traditional circular shape, the antenna has three semicircular slots with a radius of r =1.75mm. To investigate the effect of inset feeding, the proposed antenna was modified with an inset feed, featuring a length of y=3mm and a width of x=0.5 mm, which was selected after parametric analysis to ensure good impedance matching of 50Ω. The other side of the substrate is ground. The ground structure of the proposed antenna has a copper material with a length of 20 mm, a width of 40 mm, and a height of t=0.02 mm. Initially, the ground structure was a full-plane structure which resulted in a narrowband antenna. To improve the antenna's performance and convert it into an ultra-wideband antenna, the ground structure was modified to be partially grounded with the incorporation of three square slots with dimensions of 1×1 mm². The simulated results of the return loss are shown in the figure, and the resonant frequency is measured with a reference line of -10 dB.

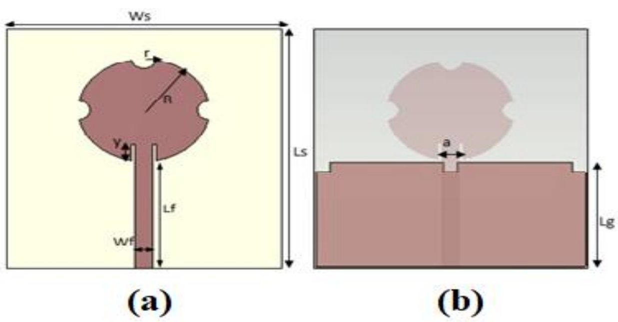


Figure. 1: Diagram of Proposed Antenna (a) front view-The Patch (b) back view-Ground structure

2.1 A STEP-BY STEP PROCESS FOR DESIGN OF THE PROPOSED ANTENNA

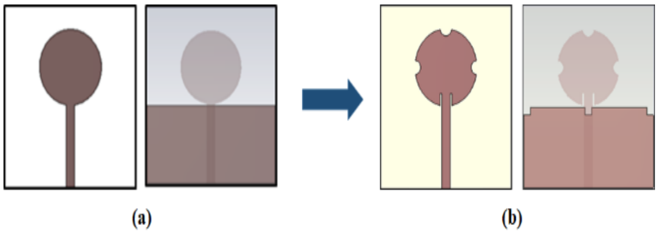


Figure. 2: Design process of the proposed monopole UWB antenna (a) Circular Patch antenna with partial ground (b) addition of three semicircular slots with inset feed

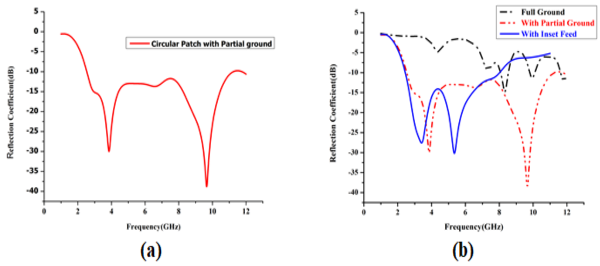


Figure. 3 Reflection coefficient vs. frequency plot (S11-parameter) (a) Circular Patch with Partial Ground (b) S11-parameter different stages

3. RESULTS AND DISCUSSION

Previous studies have explored various techniques for achieving compactness in antenna design, as shown in Table 1 [13-18].

Table -1: Comparison Table

Reference	Size(mm)	Bandwidth Range(GHz)	Gain(dBi)
13	350×240	3.1-12.3	6.8
14	300×300	3.5-12.9	≥5
15	70.45×46	2.59-10.97	1.54
16	46×44	2.83-13.7	≥5
17	42×50	2.59-10.97	3.7-6.7
18	48×38	2.5-10.6	≥5
Proposed	**45×40**	**2.4-11.24**	**4.4**

3.1 FABRICATION AND VALIDATION OF PROTOTYPE

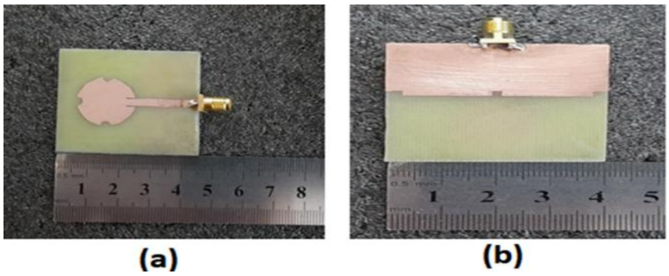


Figure.4: Fabrication model (a) Front view, (b) Back view

The proposed antenna was manually fabricated on a PCB using the same dimensions as in the simulation. The front and back view of the fabricated antenna are depicted in Figure. 4(a) and 4(b). The antenna's operating frequencies and radiating performance were validated in an anechoic chamber.

3.2 OPERATING FREQUENCY

The antenna's operating frequencies, which range from 2.4-8.0GHz, were validated in an anechoic chamber using a network analyzer. Fig. 5 illustrates a comparison between the simulated and measured results of the reflection coefficient. A minor discrepancy between the resonance frequency of the simulated and experimental results was observed, which is attributable to the manual fabrication process. The measurement setup is depicted in Figure 6.

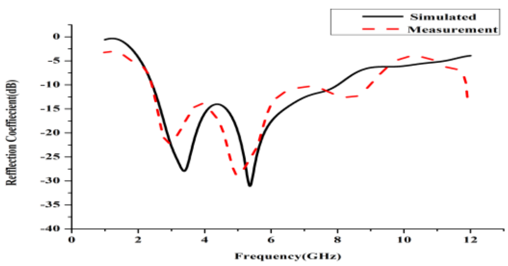


Fig.5: The Comparison study simulated and measurement results of reflection coefficient (S11)

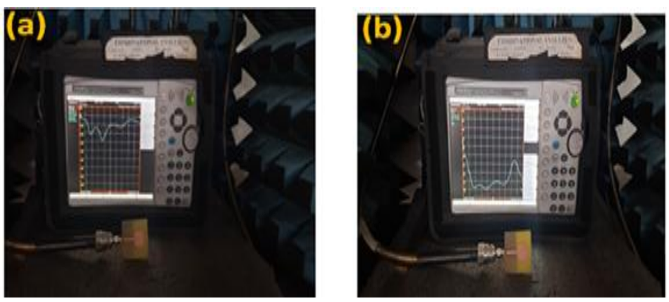


Figure.6: Measurement setup inside the anechoic chamber (a) Reflection coefficient (b) VSWR

The circular monopole antenna proposed in this study was designed for UWB applications using CST Microwave Studio-2022. To achieve a better impedance of 50Ω, an inset feed line was used, and the ground was truncated to enable the antenna to cover a bandwidth of 5.58 GHz (2.42-8.00GHz) with a reference line of -10 dB. By using a circular patch, the narrowband feature was overcome to make it suitable for broadband applications. The dual resonance covers the frequency range from 2.42 GHz to 8.00 GHz, with the first resonance at 3.4 GHz for WLAN (from 2.9 to 4.5 GHz) and the second resonant frequency for Wi-Max (from 5.4 GHz to 6.45 GHz). The return loss was -27.96 and -35.27dB, respectively, as shown in the 2D polar plot and 3D radiation pattern for Far-field radiation at 3.36 GHz in Fig. 7(a, b) and (c,d). This omnidirectional radiation pattern is suitable for broadband applications such as location confirmation, radar application, remote sensing, etc. The maximum gain achieved in the entire

Range was about 4dBi. Additionally, the study presents the relation between gain and frequency in Figure. 8.

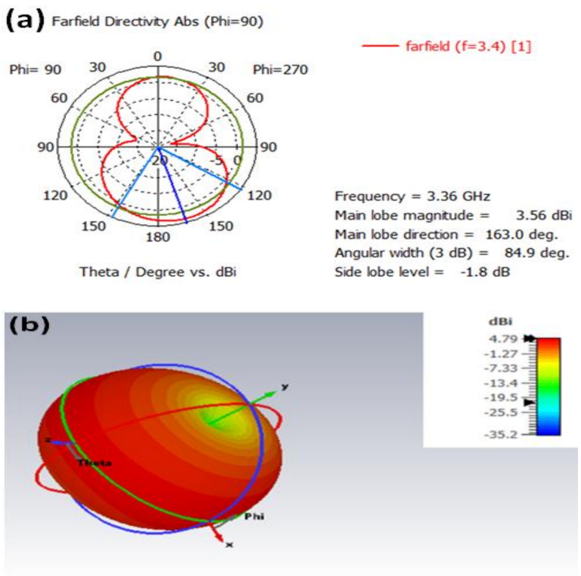
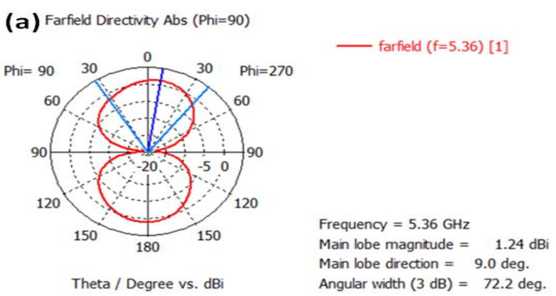
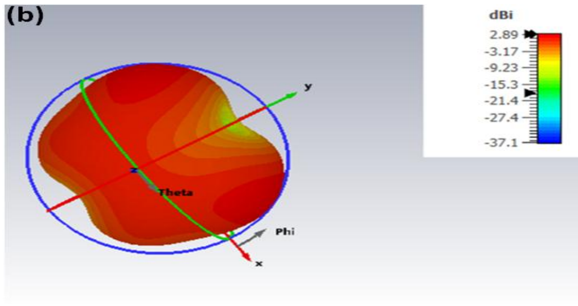


Fig.7: Far field Radiation pattern (a) 2D polar plot at 3.36 GHz (b) 3D radiation at 3.36 GHz





(c) Far field Radiation pattern of 2D polar plot at 5.36 GHz (d) 3D radiation at 5.36 GHz

3.3 GAIN VERSES FREQUENCY

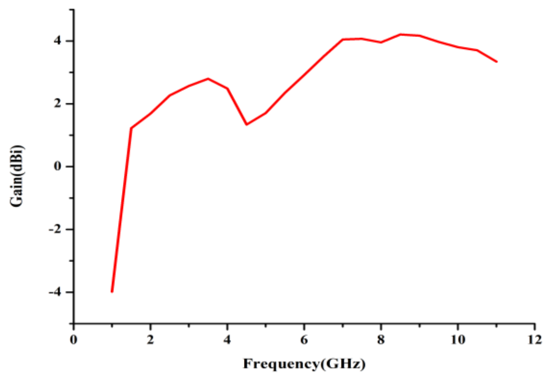


Fig.8.The Gain vs frequency Graph

Fig.8 shows the simulated gain vs frequency curve of proposed antenna. From the graph it is observed that the average gain is 4.2dBi in the entire frequency ranges as gain is directly proportional to frequency.

4. CONCLUSIONS

This work proposes a modified circular monopole UWB antenna designed on an FR-4 substrate with dimensions of 40×45×1.6 mm^3 and a relative permittivity of 4.3 and loss tangent of 0.025. The traditional circular antenna is modified with three semicircle slots, and the partial ground is modified with three square cuts, making it highly suitable for UWB broadband applications. The proposed antenna also features an inset feed, which provides good impedance matching of 50 ohm. The monopole microstrip patch provides enhanced bandwidth of 5.6 GHz, covering dual operating frequencies of 3.4 GHz (WLAN) and 5.3 GHz (Wi-MAX). The maximum gain achieved is about 4.2 dBi, making it applicable to various broadband UWB applications.

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