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REGULAR ARTICLE

Analysis of Compact Quadruplet Arrow Slotted Notch Band Antenna with Defected Ground Structure

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In this work, a compact quadruplet arrow slotted elliptical shaped notch band printed microstrip antenna is designed and analyzed for modern wireless communication systems. Initially, a compact elliptical-shaped antenna model with defected ground structure is designed for ultra-wideband (UWB), having a working range of 3.1 to 10.6 GHz. The design was modified with a quadruplet arrow slot which resulted in single-notch band characteristics for wireless LAN bands. The realized peak gain of the recommended antenna is 5.11dBi at a frequency of 3.7 GHz. The analysis of the suggested antenna has been performed by evaluating different geometrical shapes. The surface current distribution analysis is also presented to provide a clear insight on the working principle of the antenna. The various characteristics parameters such as return loss, gain, radiation patterns are presented and discussed. The suggested antenna model occupying a total dimension of 26 × 24 × 1.6 mm³ in size is simulated and its results are investigated with *CST* tool. The designed antenna is prototyped over FR_4 substrate for measurement validation. The simulation results of the prescribed antenna are matched with experimental data for validation. The findings indicate that the suggested compact antenna is well-suited for high-speed, close-range communication and can effectively reject signals from the WLAN band.

Keywords: Printed Patch, Compact Antenna, Notch Band, Defect Ground Structure, Ultra-wideband, Wireless LAN.

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1. INTRODUCTION

Nowadays modern systems require high data rates, low size, and multipurpose communication devices that minimize interference with other equipment operating from 3.1 to 10.6 GHz opening various applications for broadband devices. UWB is a very promising technology for the future prospective among researchers and academics [1-2]. Over the exhaustive development, this antenna system's primary flaw is its susceptibility to interference from many narrowband radio frequencies, including ISM (2.4 – 2.5 GHz), WiMAX (3.3 – 3.7 GHz), Wireless LAN (5.15 – 5.35 GHz), C Band, and X - band, and others [3-4]. Various attempts have been made to insert a notch filter in the design of a UWB antenna to suppress or reject signals within the desired narrowband range. A literature survey reveals that the use of various shapes of slots and slits on the radiating patches or partial ground in printed monopole antenna (PMA) offers simplicity, ease of fabrication, improved bandwidth, suitable radiation pattern, which is all desirable characteristics for practical antenna design like flower shaped patch [5], meander line slots [6], C-slots [7], J-shape slits [8], and capsule shaped patch [9]. In ref. [10], Yadav et al. described two parasitic resonators in the ground plane with a circular patch monopole antenna for dual notch operation. Fractal patch structure techniques are often used for design compactness [11-12]. These designs often exhibit multiband operation, wideband characteristics, or improved near fields making them appropriate for modern wireless applications. Alternative methods for achieving band rejection include implementing various types of split ring resonators (*SRR*s) on the patch, such as the split ring resonator (*SRR*) itself, the complimentary *SRR* (*CSRR*), and the elliptical *SRR* (*ESRR*) [13]. These resonators can be controlled using three *RF* switches attached to the split rings, allowing for reconfigurable notch frequencies [14]. For *WLAN* (Wireless Local Area Network) 5.5 GHz band rejection for high data rate applications, various techniques have been employed to attenuate or reject the signals with specific bands [15]. The recommended antenna is contrasted with alternative antenna designs in the

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comparison Table [2, 16–20]. This work is on the development of a compact structure antenna with high gain and a large bandwidth with single-notch characteristics by Inserting a quadruplet arrow slotted structure on a circular patch antenna with a slotted ground results in the desired notch band.

2. ANTENNA DESIGN AND MODELLING

Fig. 1(a) and 1(b) show a straight forward elliptical patch-shaped monopole UWB antenna design from the top and bottom perspectives. The proposed antenna is constructed and fabricated on an FR_4 glass epoxy lossy substrate of 1.6 mm featuring an epsilon value of 4.3 and a loss tangent is 0.02. The design's length (L_s) in the Y direction and width (W_s) in the X direction are 24 mm & 26 mm respectively. The major and minor axis radii R and r are 8 and 6 mm with feed length L_f = 10 mm and feed width W_f = 2.6 mm. For achieving a UWB frequency range, a rectangular slot of a = 2 and b = 5 mm is cut on a partial ground length of L_g = 10 mm. The various design steps to reach the optimal shape of the patch geometry is illustrated through four iteration process as represented in Fig. 2. In step 1, the DGS and the shape of the Patch likely alter the electromagnetic properties of the ground plane, affecting the antenna's resonant frequency and impedance bandwidth was expanded from 3.1 to10.6 GHz. In step 2, an inset feed was inserted on a microstrip feed line to enhance the impedance matching and bandwidth of a proposed antenna. By adjusting the position and dimensions of the inset feed, altered the electrical properties of the antenna, including its bandwidth. This modification allowed, further to enhance the impedance bandwidth, expanding it from 3.1 to 13.4 GHz. To proceed, in step 3, a radiating patch is etched with a ring slot structure. This structure has a y-axis radius of 5.5 mm and an x-axis radius of 4.4 mm, which resulted in a notch band characteristic. In step 4, the design includes the addition of quadruplet arrow slots and one small elliptical ring. The slotted arrow shapes and the elliptical ring have radii of 2 mm and 1.5 mm respectively as shown in Fig. 1. It has been observed that step-4, gives the notch band frequency of the WLAN band which is from 5.22 to 6.2 GHz as illustrated in Fig. 3.

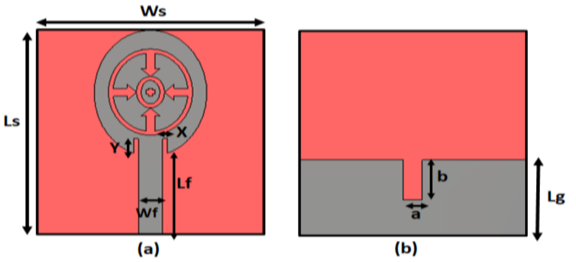


Fig. 1 – Geometry of proposed monopole antenna with defect ground (a) front view-the elliptical patch (b) reverse view-the defected ground structure.

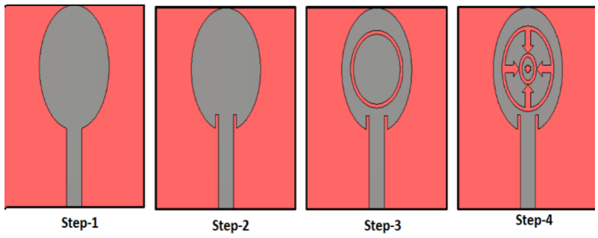


Fig. 2 – Geometry of four different iteration steps

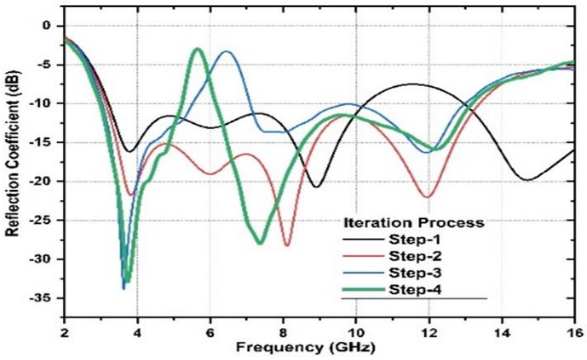
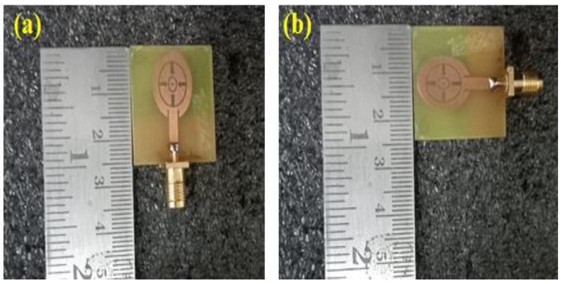


Fig. 3 – Reflection coefficient plots of four design stages

3. RESULTS AND DISCUSSION

The proposed antenna design successfully constructed and tested in an anechoic chamber using a Vector Network Analyzer. The fabricated antenna model is depicted in Fig. 4 (a) and 4 (b), while the testing setup is shown in the accompanying Comparing the simulated and experimental results, exhibit a close match, as illustrated in Fig. 5. However, there were minor differences in the results, possibly attributed to factors such as fabrication tolerances, soldering, and losses occurring from the SMA connector. Fig. 6 provides the surface current distribution at various frequencies of 3.7 GHz, 5.5 GHz, 7.3 GHz, and 12 GHz. It shows that the intensity of surface current is more near the field line and at the bottom region of the radiating structure. The surface current distribution is low at the notch band, and there is no considerable current flow either at the radiating structure or on the field line.



(a) (b)

Fig. 4 – Measurement prototype (a) and (b) length and breadth of front side view.

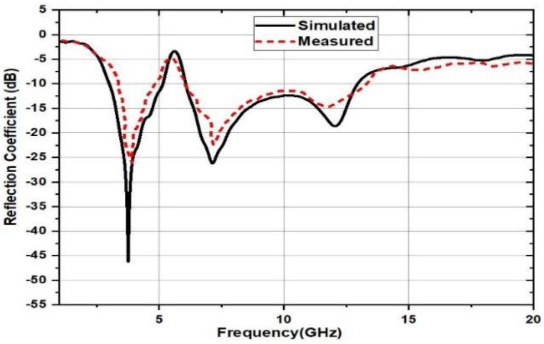
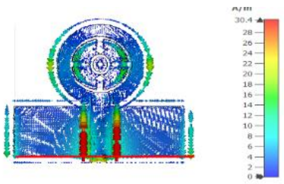
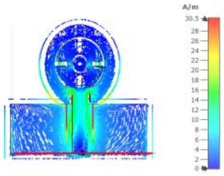


Fig. 5 – Measurement and Simulated Comparison of Reflection Coefficient (S_{11})

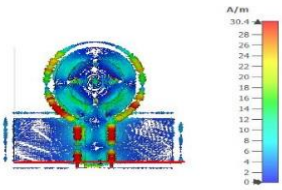


(a)



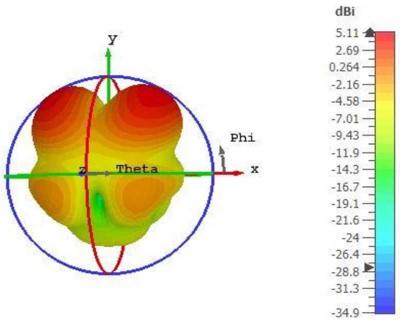
(b)

(c)

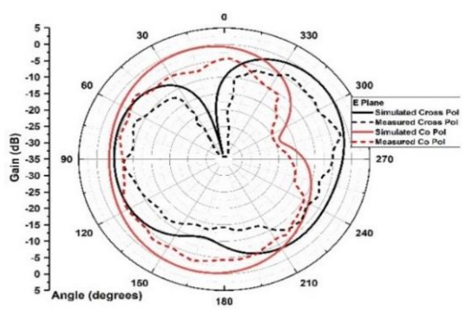


(d)

Fig. 6 – Shows the surface current distributions at frequencies, including notch band range (a) 3.7 GHz, (b) 5.5 GHz, (c) 7.3 GHz, (d) 12 GHz.



(a)



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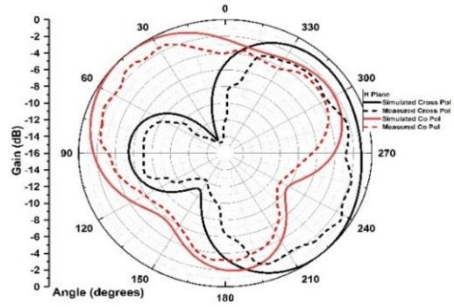
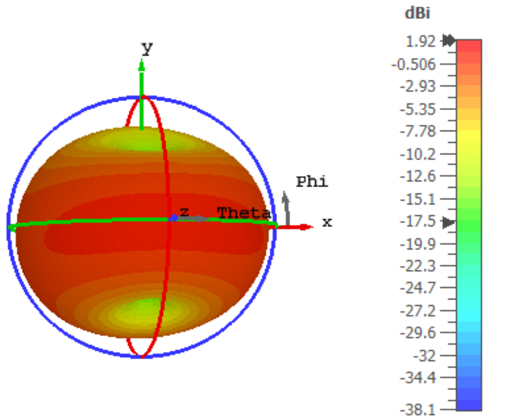


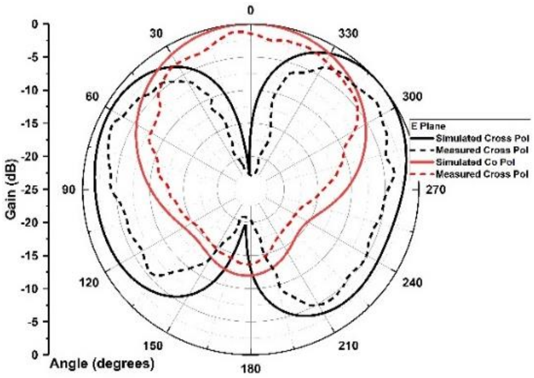
(c)

Fig. 7 – Far-field patterns of the proposed model at 3.7 GHz (a) 3D (b) and (c) polar plots

Fig. 7(a) displays 3D views of the antenna at 3.7 GHz with a gain of 5.11 dB, while Fig. 7(b) and (c) show 2D near-field patterns in polar plots of the E-plane and H-plane. Fig. 8(a) shows a three-dimensional view of the antenna at 5.5 GHz, which is a notch band with a gain of 1.92 dB, and 2D polar images of the E and H- planes are provided in 8 (b) and (c). Fig. 9 (a) shows a three-dimensional view of the antenna at 12 GHz with a gain of 4.72 dBi and 2D polar plots of the E and H-planes are presented in 9 (b) and (c).



(a)



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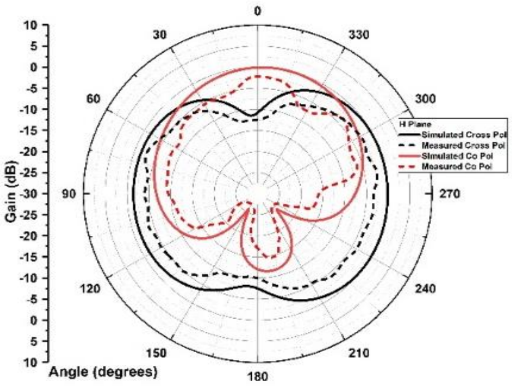
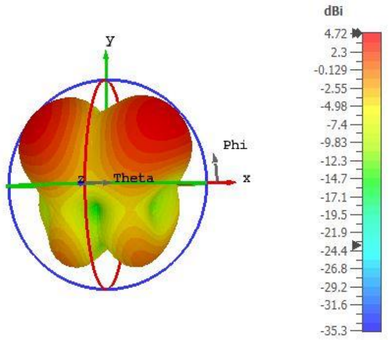
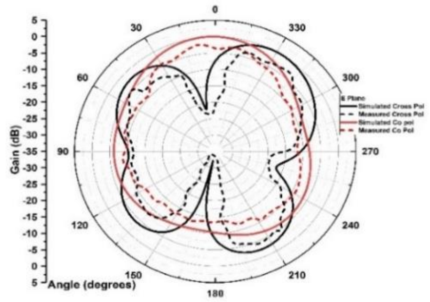


(c)

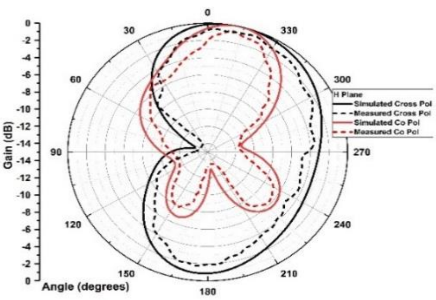
Fig. 8 – Far field patterns of the proposed antenna model at 5.5 GHz (a) 3D (b) and (c) polar plots



(a)



(b)



(c)

Fig. 9 – Far-field patterns of the proposed antenna model at 12 GHz.(a) 3D (b) and (c) polar plots

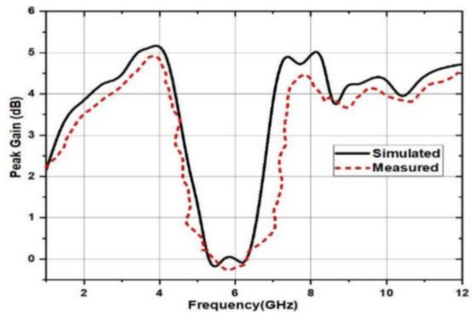


Fig. 10 – Gain *Vs* Frequency Characteristics

Fig. 10 shows the Frequency *Vs*. Gain of the antenna over the operating and notch band. The peak realized gain of 5.11 dB at 3.7 GHz and at the notch band the gain is below 0 dB.

Table 1 – Comparative Analysis

Ref.	Size (mm^3)	Bandwidth Range (GHz)	Notch band (GHz) (WLAN)	Peak Gain (dBi)
[16]	42×30×1.6	3.25-13	5.7-6.2	6.7
[17]	40×30×1.6	2.84-13.9	5	3.69
[18]	75×10×1.6	2.75-14.65	5.15-5.82	6
[19]	34×34×1.6	3.1-10.6	5.5	5
[20]	28×36×1.6	3.1-11.3	5.5	5.8
[2]	30×30×1.6	2.45-12	5.4-7.4	4.89
Proposed	**26×24×1.6**	**3.1-13.4**	**5.22-6.2**	**5.11**

The comparison Table 1 shows performance comparison of proposed UWB notch antenna with other reported designs [2, 16-20] considering antenna size, operating bandwidth, notch band frequency range, peak realized gains. The proposed antenna holds a compact dimension of 26 mm × 24 mm × 1.6 mm, operates from 3.1 to 13.4 GHz covering entire UWB spectrum with a peak realized gain of 5.11 dBi. Also, it offers notch band extending from 5.22 to 6.2 GHz for rejecting WLAN band. So, the proposed antenna shows a balanced performance by proving UWB bandwidth, good gain, notch band by maintaining its miniaturized size.

4. CONCLUSION

The proposed printed monopole antenna of compact dimensions of 24 × 26 × 1.6 mm^3 for a single notch band characteristics is fabricated and simulated. The basic and small-sized elliptical UWB antenna is designed by incorporating a rectangular slot DGS (Defective ground structure), which add a notch band in the 5.2 – 6.2 GHz WLAN frequency band. This desired notch band is achieved by incorporating a ring-shaped structure and transforming quadruplet arrow slots. With an impedance bandwidth of 10.3 GHz, the antenna operates in from 3.1 to 13.4 GHz. The compact antenna covers the maximum average gain of about to 5.11 dBi, within the operating frequency range. The recommended antenna exhibits a good radiation pattern and surface current distribution. The CST-2022 Microwave Software is utilized to simulate the structure of the printed microstrip antenna (PMA), and the findings are then validated in an anechoic chamber laboratory with appropriate measurement setup.

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Аналіз компактної чотирикутної стрілкової щілинної антени з виїмкою з дефектною структурою землі

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У цій роботі розроблено та проаналізовано компактну мікросмужкову мікросмужкову антену еліптичної форми з щілинами еліптичної форми та проаналізовано для сучасних систем бездротового зв’язку. Спочатку компактна модель антени еліптичної форми з дефектною структурою землі призначена для ультраширокого діапазону (UWB) з робочим діапазоном від 3,1 до 10,6 ГГц. Конструкцію було змінено за допомогою четвірного стрілкового слота, що призвело до характеристики смуги з одним вирізом для діапазонів бездротової локальної мережі. Реалізований пік посилення рекомендованої антени становить 5,11 дБі на частоті 3,7 ГГц. Аналіз запропонованої антени був виконаний шляхом оцінки різних геометричних форм. Аналіз розподілу поверхневого струму також представлений для чіткого уявлення про принцип роботи антени. Представлені та обговорені різні параметри характеристик, такі як зворотні втрати, посилення, діаграми спрямованості. Запропонована модель антени, що займає загальний розмір 26 × 24 × 1,6 мм^3, моделюється, і її результати досліджуються за допомогою інструменту CST. Розроблена антена створена на підкладці FR4 для перевірки вимірювань. Результати моделювання встановленої антени зіставляються з експериментальними даними для перевірки. Результати показують, що запропонована компактна антена добре підходить для високошвидкісного зв’язку на близькій відстані та може ефективно відхиляти сигнали з діапазону WLAN.

Ключові слова: Друкований патч, Компактна антена, Діапазон виїмок, Дефектна структура землі, Ультраширокий діапазон, Бездротова локальна мережа.