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Hybrid Shaped Multiband Microstrip Patch Antenna for Wireless Communication Applications

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In this proposed article authors present the design, analysis and development of the hybrid shaped multiband microstrip patch antenna for various wireless communication applications. Multiband characteristics of the proposed antenna is achieved by modifying the conventional circular radiating patch into "DUMBBELL" shaped hybrid patch geometry along with slotted reduced finite ground plane. A circular shaped reference patch is modified into dumbbell shaped patch by loading another circular shaped patch. Initial ground plane of same dimension as substrate is first decreased in width and four rectangular shaped slots are loaded in the appropriate locations to construct the final ground plane. Physical and electrical dimension of the proposed antenna are 24 mm × 40 mm × 16 mm and $0.18\lambda \times 0.3\lambda \times 0.12\lambda$ where λ represents wavelength corresponding to lowest operating frequency of 2.3 GHz. Proposed antenna is designed using FR-4 substrate (1.6 mm thick, loss tangent ($\tan\delta$) of 0.02, dielectric constant (ε_r) of 4.4) and simulated by CST Microwave Studio software. Antenna prototype is fabricated, measured and compared with the simulated results. The proposed hybrid shaped antenna exhibits measured multiband characteristics (2.3-2.5 GHz, 2.6-3 GHz, and 6.9-7.1 GHz) with centre frequency at 2.4, 2.7 and 7 GHz. Observed Reflection Coefficient, efficiency, peak gain and *E* plane and *H* plane radiation pattern of the antenna are very close to simulation result. Antenna can be suitably used for 2.4 GHz Wi-Fi and Bluetooth application, 5G mid band spectrum (3 GHz) and 7 GHz VSAT applications as well.

Keywords: Hybrid, Multiband, Microstrip patch antenna, Wireless communication.

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1. INTRODUCTION

For the first few decades, the Microstrip Patch Antenna (MPA) has long been the preferred option for contemporary wireless communication applications Because of its low profile, inexpensive construction, multi frequency support, matching with existing modular design etc. But at the same time constant research had also been going on to overcome some inherent disadvantageous property of MPA like low gain, low bandwidth etc. Multiband antenna design is one of the solutions to tackle the narrow bandwidth property of MPA. Every day, there is a growing need for wireless communication devices that can function at several standards or have applications in different frequency bands. As a result, there is a growing need for multiband antenna design to be included and integrated into various wireless communication devices D.H. Patel and G.D. Makwana in [1] presented a detailed review about classification, general design methodology and performance analysis on multiband MPA. Slot loading on the radiating patch, ground plane and applying different feeding techniques are the most popular techniques for designing multiband antenna. A.S. Debele in [2] reviewed various types of multiband antenna I. Ahmad [3] described the most recent futuristic investigations on the various antenna categories along with performance improvement methods. A. Gollapalli et al. [4] proposed novel multiband antenna operating at five resonant frequencies employing five different shaped radiators. In [5] M. Sharma proposed compact multiband MPA which is attained by inserting optimum dimension stubs and loading matching slots on the glass shaped radiating patch at optimum position. S. Mukherjee et al. [6-7] introduced notch at particular frequency in wideband antenna characteristics by inserting slots on patch, feedline and ground plane so that it works like a multiband antenna. T. Tewary et al. [8-9] modified microstrip line feed into staircase structure along with radiating patch and ground plane modification to achieve multiband and wideband characteristics. In [10] T. Tewary et al. proposed hybrid shaped simple configuration monopole MPA. A slot of ellipse shape is loaded onto a radiating patch of another ellipse shape to

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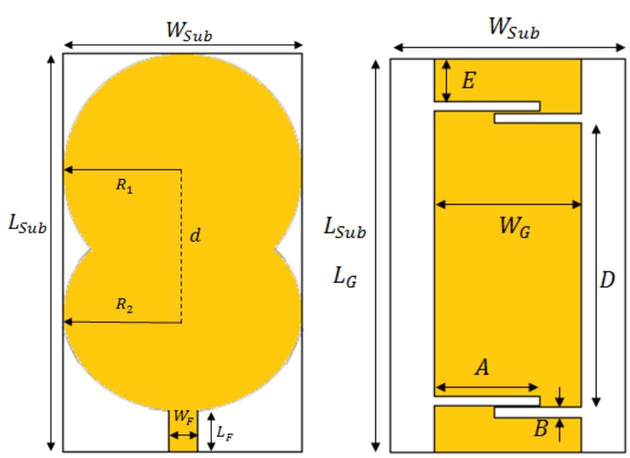
create the hybrid radiating patch pattern. S. Maity et al. [11-13] proposed various complex hybrid shape radiating patch with reduced ground plane to achieve multiband and wideband monopole antenna.A.J.A. Al-Gburi et al. [14] presented MPA having a hybrid shaped patch and reduced ground plane for 5G and sub 6 GHz Applications. The 'TREE' shaped patch has been designed by overlapping five circles with different radius. For wireless applications, R.K. Saraswat and M. Kumar [15] suggested the design and study of an octagonal form multiband metamaterial loaded MPA with the use of hybrid fractal geometry. A Sharma et al. [16] proposed hybrid, frequency and pattern reconfigurable multiband MPA with two V-shaped extrudes in radiating patch and defected ground plane. T. Islam and S. Roy [17] and S. Bhunia et al. [18] proposed low profile meander line multiband MPA for various wireless applications.

To comply with the increasing demands of multiband planar antennas, this article proposes a triple band microstrip line fed MPA consists of hybrid shape radiating patch and slot loaded reduced ground plane which yields three frequency bands across whole operating frequency band. CST Studio Suite simulator is used to design, characterize, and simulate the proposed antenna. The simulated results have also been validated by measured outcomes which also highlights noticeable aspect of this work. Various wireless communication applications utilizing Wi-Fi, mid-band 5G communication, VSAT communication can benefit from this suggested antenna.

2. DESIGN, DEVELOPMENT AND WORKING PRINCIPLE OF ANTENNA

The radiating plane and ground structure of the proposed antenna have been portrayed in Fig. 1(a) and 1(b), respectively. A circular shaped reference patch is modified into dumbbell shaped patch by loading another circular shaped patch. Initial ground plane of same dimension as substrate is first decreased in width and four rectangular shaped slots are loaded in the appropriate locations to construct the final ground plane.



(a) (b)

Fig. 1 – Proposed antenna (a) Radiating plane (b) Ground plane

All of the proposed antenna's variable values are tabulated in Table 1.

Table 1 – Variables of the antenna and their value (mm)

Variable	Value (mm)	Variable	Value (mm)	Variable	Value (mm)	Variable	Value (mm)
W_{Sub}	24	d	14	L_F	4.8	B	1
L_{Sub}	40	W_G	15	R_1	12	D	28.8
W_F	2.92	A	10.7	R_2	12	E	3.5

The five development stages of the antenna are shown in Fig. 2, and the reflection coefficients corresponding to each of the five design phases are displayed in Fig. 3.

Step 1: Step 1 shows reference antenna with a finite ground plane and a circular shape radiating patch. The designing equation of a circular microstrip patch is given below[19-20].

For resonant frequency of f_r Hz,

$$a = \frac{F}{(1+\frac{2h}{\pi\epsilon_r F}(\ln\left(\frac{\pi F}{2h}\right)+1.7726)^{\frac{1}{2}}} \quad (1)$$

$$F = \frac{8.791\times10^9}{f_r\sqrt{\epsilon_r}} \quad (2)$$

Where h = substrate material height, ϵ_r = Relative dielectric constant, a = Radius of the circular patch, f_r = Resonant frequency in Hz

The fringing field effect is not considered in equation (1-2).So equation 3 is used to determine the effective radius of the patch since fringing increases the patch's electrical size.

$$r_{eff} = a\left[1+\frac{2h}{\pi\varepsilon_r a}\left\{\ln\left(\frac{\pi a}{2h}\right)+1.7726\right\}\right]^{\frac{1}{2}} \quad (3)$$

The formula (4) provides the resonant frequency for the dominant mode.

$$f_r = \frac{1.8412\, c}{2\pi r_{eff}\sqrt{\varepsilon_r}} \quad (4)$$

However, for this finite ground plane, Instead of resonating at 5 GHz, the reference antenna does so at 6.8 GHz. The final proposed antenna has been achieved by successive steps whose results are shown in Fig. 3.

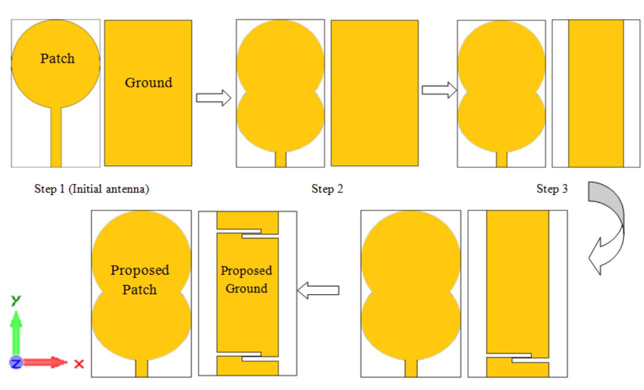


Fig. 2 – Development of the proposed Antenna

Table 2 – Reflection Coefficients of Developments Steps

Design Steps	Antenna Bandwidth (GHz)
1	6.7-6.9, 7.9-8
2	Not Available
3	Not Available
4	2.3-3, 6.2-6.4
5	2.23-2.54, 2.9-3.6, 7.25-8

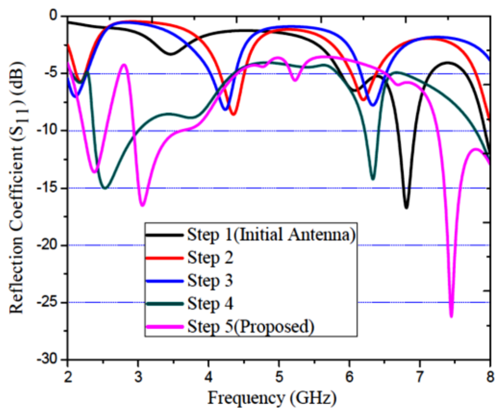


Fig. 3 – Variation of S_{11} for all development steps

3. RESULTS AND DISCUSSIONS

The findings of the simulation are experimentally verified by measuring the antenna prototype characteristics. Fig. 4 and 5 represents proposed hybrid shaped antenna's simulated and observed reflection coefficient and corresponding snapshot of the measurement. Presented antenna exhibits multiband characteristics with simulated resonant frequencies located at 2.4, 3 and 7.5 GHz with – 14, – 16 and – 26.5 dB reflection coefficients respectively. Measured reflection coefficient characteristics also shows very close resembles with the simulated result with resonant frequencies at 2.4, 2.7 and 7 GHz.

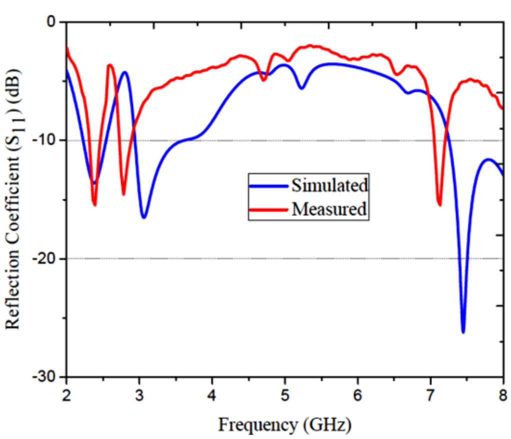


Fig. 4 – Measured and simulated S_{11}

Fig. 6 illustrates simulated and observed peak gain. At 4.2 GHz simulated maximum gain of 4 dBi and observed maximum gain of 3.98 dBi at same frequency is accomplished.

Fig. 7 illustrates simulated and observed efficiency (%) for the proposed antenna. As can be observed from the figure that simulated efficiency closely go along with measured efficiency.

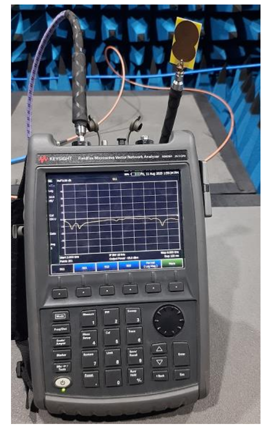


Fig. 5 – S_{11}(Reflection Coefficient) measurement set up (Courtesy: CIT Kokrajhar, Assam)

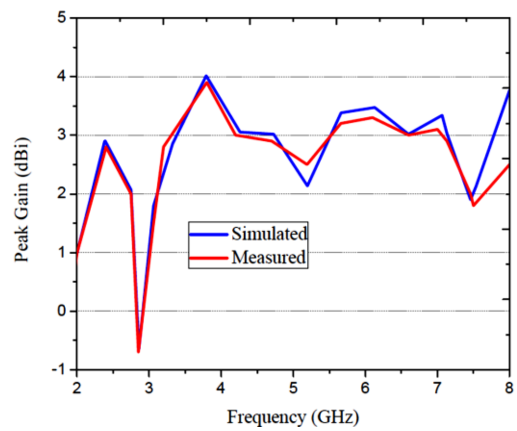


Fig. 6 – Peak gain variation with frequency

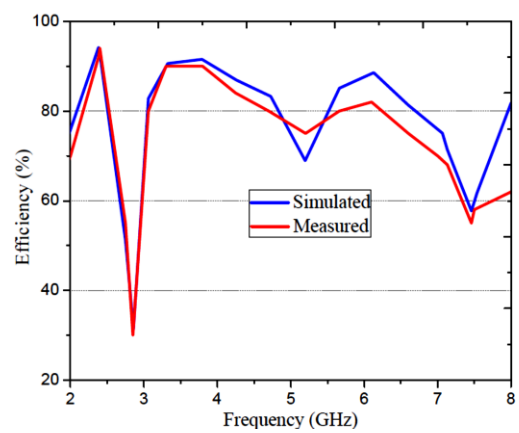


Fig. 7 – Efficiency (%)

Fig. 8 and 9 shows normalized simulated and measured radiation pattern for the proposed antenna for the *YZ*-plane (*E* plane) and *XZ*-plane (*H* plane) respectively

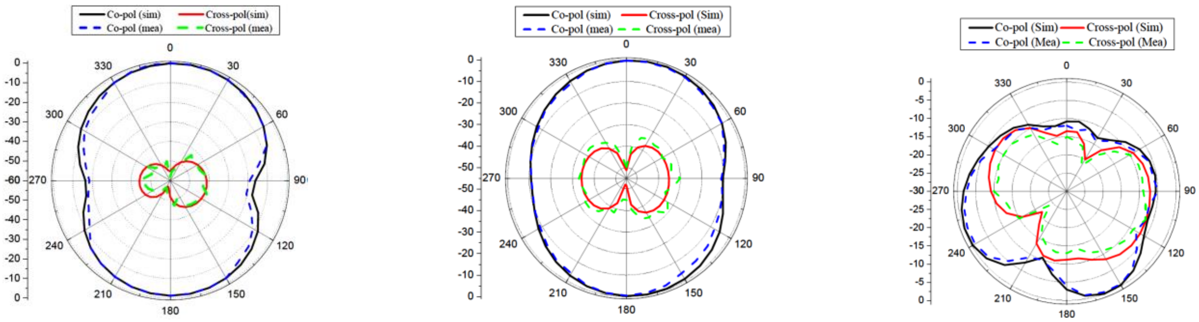


Fig. 8 – Normalized Radiation Patterns at (a) 2.4(b) 2.7and (c) 7 GHz in *E* plane

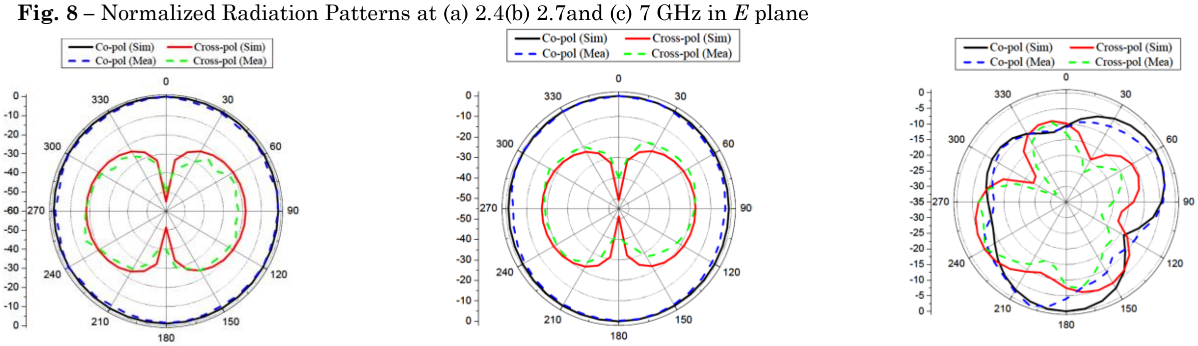


Fig. 9 – Normalized Radiation Patterns at (a) 2.4(b) 2.7and (c) 7 GHz in *H* plane

4. CONCLUSIONS

This proposed article has represented a design and its practical implementation of multiband antenna having nonconventional shaped radiating patch surface showing triple band (2.3-2.5 GHz, 2.6-3 GHz, and 6.9-7.1 GHz) characteristics. The proposed hybrid shape patch is constructed by overlapping two circular shaped patch. CST MWS, electromagnetic equation solver has been used to simulate the suggested design. Measured outcomes from standard Microwave set up were used to validate the simulated findings. The suggested antenna's practicality and applicability are established by the near matching of all simulated outcomes to measured data. The omni-directional and quasi-directional radiation patterns allow for the practical use of the antenna for various wireless communication applications.

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Гібридна багатодіапазонна мікросмугова патч-антена для бездротового зв’язку

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У цій статті автори представляють дизайн, аналіз і розробку гібридної багатодіапазонної мікросмужкової антени для різних програм бездротового зв’язку. Багатодіапазонні характеристики пропонованої антени досягаються шляхом модифікації звичайної круглої випромінюючої ділянки в гібридну геометрію зони у формі «ГАНТЕЛІ» разом із щілинною зменшеною кінцевою площиною заземлення. Еталонний патч круглої форми змінюється на патч у формі гантелі шляхом завантаження іншого патча круглої форми. Початкова площина заземлення того самого розміру, що й підкладка, спочатку зменшується в ширину, а чотири прямокутні слоти завантажуються у відповідних місцях для побудови остаточної площини заземлення. Фізичні та електричні розміри запропонованої антени становлять 24 мм × 40 мм × 16 мм і $0{,}18\lambda \times 0{,}3\lambda \times 0{,}12\lambda$, де λ представляє довжину хвилі, що відповідає найнижчій робочій частоті 2,3 ГГц. Запропонована антена розроблена з використанням підкладки FR-4 (товщина 1,6 мм, тангенс втрат ($\tan\delta$) 0,02, діелектрична проникність (ε_r) 4,4) і змодельована програмним забезпеченням CST Microwave Studio. Прототип антени виготовляється, вимірюється та порівнюється з результатами моделювання. Запропонована гібридна антена має багатодіапазонні характеристики (2,3-2,5 ГГц, 2,6-3 ГГц і 6,9-7,1 ГГц) із центральною частотою 2,4, 2,7 і 7 ГГц. Спостережуваний коефіцієнт відбиття, ефективність, пікове підсилення та діаграми спрямованості антени в площині E та H дуже близькі до результатів моделювання. Антену також можна використовувати для додатків Wi-Fi і Bluetooth на частоті 2,4 ГГц, середніх частот 5G (3 ГГц) і VSAT на 7 ГГц.

Ключові слова: Гібрид, Багатодіапазонний, Мікросмугова антена, Бездротовий зв’язок.