JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. 16 No 3, 03010(5pp) (2024)
ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том 16 № 3, 03010(5cc) (2024)

REGULAR ARTICLE

OPEN ACCESS

Design and Analysis of Two Element Modified Circular Shaped MIMO Antenna for 5G Application

D. Kumutha[1,*], T. Islam[2], P. Muthumari[3], K. Vijayalakshmi[4], R. Rajalakshmi[5], M. Indumathi[6]

[1] *Department of ECE, Jeppiaar Institute of Technology, Kunnam, Sriperumbudur, TN, India*
[2] *Department of Electrical and Computer Engineering, University of Houston, Houston, TX 77204, USA*
[3] *Department of EEE, KarpagaVinayaga College of Engineering and Technology, Chengalpattu, TN, India*
[4] *Department of ECE, Saveetha School of Eng., Saveetha Institute of Medical and Technical Sciences, Chennai, India*
[5] *Department of ECE, Vignan's Nirula Institute of Technology and Science for womens, Guntur, AP, India*
[6] *Department of EEE, Jeppiaar Institute of Technology, Kunnam, Sriperumbudur, TN, India*

(Received 12 April 2024; revised manuscript received 16 June 2024; published online 28 June 2024)

Printed antenna technology gained has become centre of attraction for designing MIMO antenna system for future communication applications. Antenna is an essential component for 5G communication system. MIMO technology is highly preferrable due to high data rate and simultaneous data transmission establishment. In this article, a curved slot incorporated circular shaped antenna is constructed and tested for performance utilizing conventional ground planes in an eventual Fifth Generation (5G) mobile communication network. The proposed single element system is operating from 2.6 to 12.9 GHz with an 85.84% efficiency throughout the band. The substrate of the radiator is 30 mm × 30 mm × 1.6 mm, where a circular patch is used whose size is 9.35 mm. A partial ground structure of 30 mm × 10 mm is used to obtain high efficiency and wide bandwidth. The structured antenna system has a maximum directivity of 4.8, efficiency of 89%, and maximum gain of 1.68 dB which are desired in any MIMO system to tolerate interference and maintain user bandwidth. The proposed micro strip patch two element antenna covers 10 dB return loss frequencies from 2.6 GHz to 11.8 GHz than the conventional method. The total size of the MIMO antenna system is 70 mm × 60 mm × 1.6 mm. The 2-element MIMO antenna simulated results are determined by the HFSS software with their performance.

Keywords: Multiple Input and Multiple Output (MIMO), Fifth Generation (5G), Printed Antenna; HFSS, Wireless communication

DOI: 10.21272/jnep.16(3).03010 PACS number: 84.40.Ba

1. INTRODUCTION

An interdigital split ring resonator (SRR) is used in this multi-input multi-output (MIMO) antenna to increase isolation. Utilizing interdigital SRR, an adverse outcome permeability was created while improving isolation among the two simultaneously radiating components [1]. The suggested MMW MIMO with significant shifting achieves an extremely low ambient correlation of roughly 10^{-4} with an overall diversity gain of approximately 10 dB throughout the two operational bands [2]. A coplanar waveguide (CPW)–fed adaptable spherical antenna having quadruple features is created by adding a single circular structure ST-SRR on the patch of radiation. To reduce interference from 3.5 GHz Wi-MAX systems, a second notch (3.45 – 3.80 GHz) is added to the patch by inserting another circular ST-SRR [3] [4]. For millimeter wave frequency ranges, MIMO antennas are shown to be more than 70% effective. MIMO major performance parameters, including Mean Effective Gain (MEG) and Envelope Correlation Coefficient (ECC), meet the necessary standards of < 3 dB and < 0.5, respectively [5]. The concentration of tiny base stations that are located in the transmission range of macro base stations (MBS) causes severe inter-cell interference (ICI). Likewise, drones (also known as unmanned aerial vehicles) have a wide range of applications in 5 G-supported systems, and hence uncontrolled utilization of drones causes significant drone interference (DI) [6-8]. In addition to the rapid expansion of multiple thriving wireless communication technologies that demand growing data throughputs, the traditional microwave band beneath 10 GHz, and which is currently utilized by nearly all mobile data transmission and communication systems, is expected to reach saturation in less than two years. As a result, to enhance capacity, broadcast system designers have focused their efforts on ever-higher regions of the spectrum of frequencies [8-10]. The array, which has been increased by mounting parasitic patches on the very top of one another inset-fed patches, now has 16 components in an H-plane layout. The radiating patches along with feed supply lines are organized in an alternate out-of-phase 180° revolving sequence to minimize mutual interconnection and increase the pattern of radiation homogeneity [11, 12]. The components of the

* Correspondence e-mail: kumutha.d@jeppiaarinstitute.org

Cite this article as: D. Kumutha et al, *J. Nano- Electron. Phys.* 16 No 3, 03010 (2024) https://doi.org/10.21272/jnep.16(3).03010

array include rectangular regular-shaped notched patch antennas, as well as the horizontal plane, which has a faulty circular, rectangular, zigzag-shaped grooved structure to improve the antenna's electromagnetic radiation properties [13-15].

The use of a metallic truncated slot antenna (TSA) array enables millimeter-wave multibeam enormous multiple-input multiple-output transmission [16]. The designed antenna array may provide excellent beam-shaping efficiency since the component spacing readily meets the half-wavelength criterion present in the H-plane. Three broadband monopole patched antennas (MPAs) are incorporated into a Y-shape design for multi-input-multi-output (MIMO) functioning in 3300 – 4200 MHz enabling fifth-generation (5G) accessible points. By placing four similar dual-antenna couples at both side corners of the mobile device, an 8 × 8 MIMO system is achieved [17, 18]. By examining the numerous ways employed in the study of literature, the traditional antenna described in this work retains a unique identity by creating a great performance employing the EBG Structures [19, 20].

2. MIMO SYSTEM

2.1 Design Considerations

In this section, the design of a single circular patch antenna using design equations is elaborated. The dielectric constant of the substrate (ε_r), the resonant frequency (f_r), and the height of the substrate (h) are the given values to design the antenna. The proposed work is designing an antenna for the lower 5G band (Sub 6 GHz) and ultra-wideband ranging from 2 GHz to 12 GHz. The procedure is as follows:

Specify: ε_r, f_r (in Hz), and h

$$L = 2 * 2a \tag{1}$$

L – Length of the substrate

$$W = 2*2a \tag{2}$$

W – Width of the substrate

where a is the radius of the circular patch

Length of the ground,

$$g = L + 6h \tag{3}$$

Width of the ground,

$$W_g = 6h + W \tag{4}$$

Where L & W are the length and width of the circular patch.

The radius of the circular patch is given by,

$$a = \frac{F}{\sqrt{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}}} \tag{5}$$

Where $F = \frac{8.971\times10^9}{f_r\sqrt{\varepsilon_r}}$, where $\boldsymbol{f_r}$ is the resonant frequency, effective dielectric constant **($\boldsymbol{\varepsilon_{reff}}$)** is,

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}} \tag{6}$$

Length of the feed is given by, (for microstrip in set feed)

$$X_f = \frac{L}{2\sqrt{\varepsilon_{re}(L)}}$$

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}F\left(\frac{l}{h}\right) \tag{7}$$

$$F\left(\frac{l}{h}\right) = \frac{1}{\sqrt{1+12\frac{h}{L}}};\ if\ \frac{L}{h} \geq 1$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+8\right)} \tag{8}$$

Length of the feed, $L_g = X_f + 3h$

The width of the feed line is:

$$\frac{w_f}{h} = 8\frac{e^A}{e^{2A}-2};\ if\ \frac{w_f}{h} < 2$$
$$= \frac{2}{\pi}\left[B-1-ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left(ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right)\right];\ if\ \frac{w_f}{h} \geq 2 \tag{9}$$

Where,

$$A = \frac{z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right)$$

$$B = \frac{377\pi}{2z_0\sqrt{\varepsilon_r}}$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+8\right)} \tag{10}$$

Length of Slots, $L_s = \lambda/2$, Where λ is the wavelength of the band-notch frequency.

Table 1 – Tabulation for specifications of single patch antenna

Solid Material	**Dimension**
Substrate	30 mm × 30 mm × 1.6 mm
Circular Patch	9.35 mm
Feed	11.05 mm × 3 mm
Partial Ground	30 mm × 10 mm

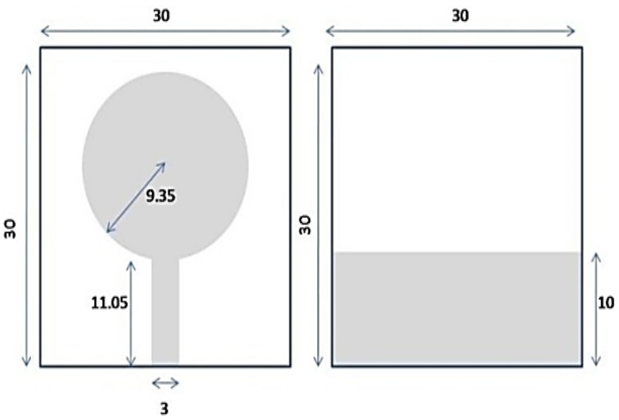

Fig. 1 – Dimension of single element antenna

Using the above equations, the dimension of proposed antenna is obtained, which are tabulated in Table 1. In the proposed design, first, the partial ground is bounded by 10 mm × 30 mm on a bottom layer, and a circular active patch is modelled on a top layer as in Fig. 1. Further, the design is calculated with a 9.35 mm radius for the circular radiating patch with two etched symmetric curved slots of 3 mm from the top layer which is placed at the center point of the antenna as shown in Fig. 2. The impedance matching line is chosen as a microstrip line of 11.05 mm × 3 mm for proper connection.

Hence these materials are brought out with many advantages such as **(i)** very low cost **(ii)** Excellent mechanical properties **(iii)** used in the applications of electronic components and the dual patch specification tabulation is shown in Table 3. The return loss is shown in Fig. 3. The proposed micro strip patch antenna covers 10 dB return loss frequencies from 2.6 GHz to 12.9 GHz which is depicted in Fig. 3. Both resonating bands fulfils the criteria of good impedance matching (S_{11} < – 10 dB) and acceptable gain

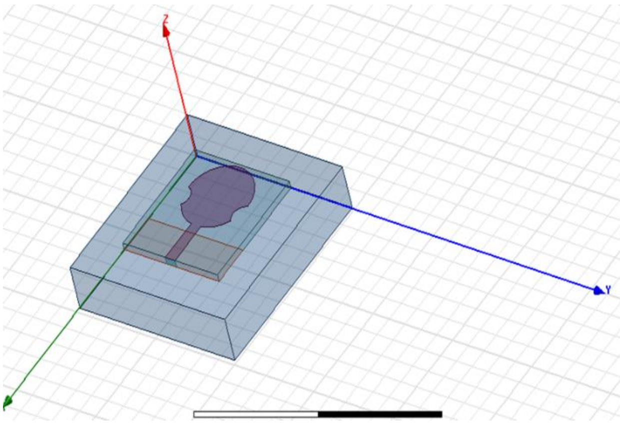

Fig. 2 – 3D view of single element antenna

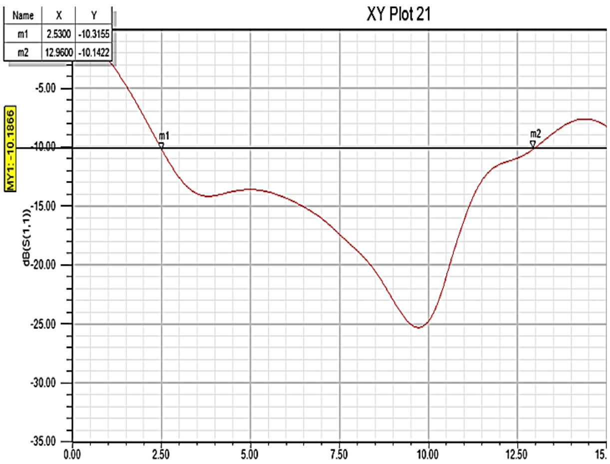

Fig. 3 – Return loss of single element radiator

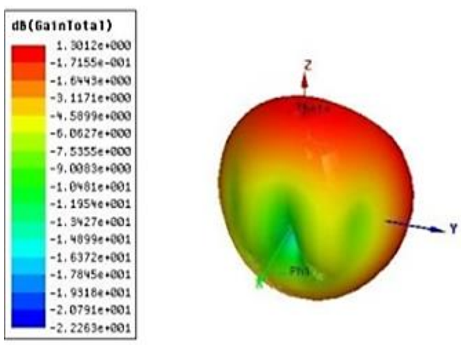

Fig. 4 – 3D gains of single element

2.2 Dual Element MIMO Design

Two-patch MIMO antenna is depicted on the 30 mm × 60 mm FR4 epoxy substrate with a loss tangent of the substrate is 0.019 and a relative permittivity is 4.4 with a thickness of 1.6 mm as given in Fig. 4. Hence, the two antenna elements are demonstrated as symmetric and parallel placement on the same substrate and partial ground. This design is modelled by the two circular active patches **(i)** partial ground on the bottom of the substrate **(ii)** on top of the substrate as shown in Fig. 5.

The circular patch of 9.35 mm radius is placed with two etched curved slots of 3 mm from the top layer. The micro strip antenna patch line of 11.05 mm × 3 mm is chosen for proper impedance matching and partial ground of 10 mm × 60 mm. The FR4 epoxy is an epoxy resin binder, which is defined as self – extinguishing (flame resistant) and composed of woven fibreglass cloth built by the composite material. This proposed system is evolved by most PCB applications based on the choice of materials in the FR4 epoxy glass substrates.

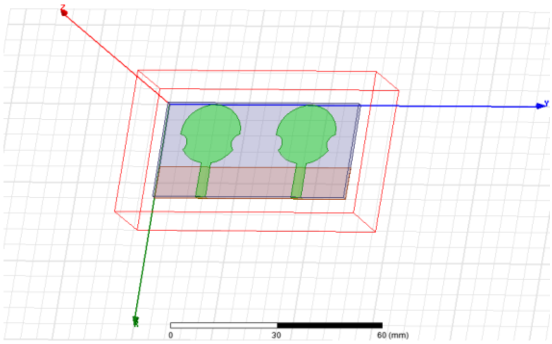

Fig. 5 – Dual-element MIMO antenna

3. MIMO RESULTS AND DISCUSSION

This microstrip dual patch antenna covers 10 dB return loss frequencies from 2.6 GHz to 11.8 GHz, which is implemented in Fig. 6.

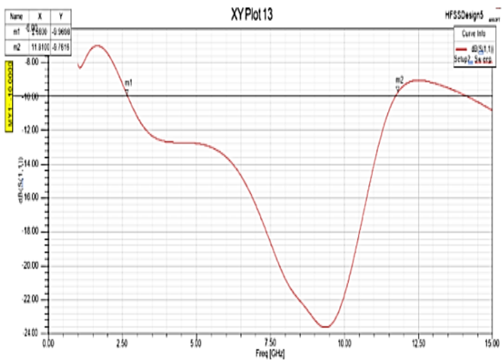

Fig. 6 – Return loss of dual Element

The gain of 1.68 dB is obtained for the dual patch antenna designed in Fig. 7. The single-element and two-element MIMO antenna are designed, and the simulated results are discussed. Then a four-element MIMO antenna with band-notched characteristics is designed and the same is fabricated to validate. The detailed discussion of the proposed work is as follows and the results of dual patch antenna is shown in Table 2.

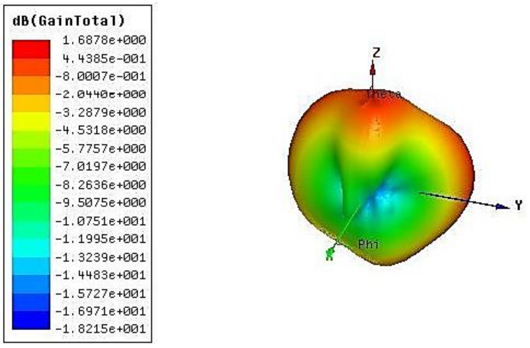

Fig. 7 – 3D Gain of dual Element

Table 2 – Results of dual patch MIMO antenna

Parameters	Value
Gain	1.68 dB
Efficiency	85.84%
Band coverage	2.6G Hz – 11.8 GHz

The simulated antenna has been designed for the lower 5G band or 5G Sub 6 GHz which ranges from 2 GHz to 12 GHz. The designed MIMO antenna is constructed with low cost FR4 epoxy substrate of dimension 70 mm × 60 mm × 1.6 mm with dielectric loss tangent 0.019 and relative permittivity of 4.4.

4. CONCLUSIONS

This work presents an overview of the MIMO characteristics performance of the four planar antenna frequency ranges from 2 GHz to 12 GHz for both lower 5G or 5G sub 6 GHz and certain mid-band frequency range applications. With U and straight-shaped slots in the radiating patch, the band-notch characteristics have been achieved. Therefore, the antennas can reject the interference that occurs from the range of Wireless Local Area Network (WLAN) to 5.5 GHz centre frequency and on the Worldwide Interoperability for Microwave Access (Wi-Max) to the limits of 3.5 GHz centre frequency. This wireless network is very sophisticated enough to be efficient for revolutionizing secure communication worldwide. Thus, the truncated patches with U and straight slots of the fabricated antenna are shown in Fig. 7. The structure of the ground is measured at 30 mm × 10 mm to yield for high efficiency of 89%. The directivity and gain of the antenna system are obtained for 4.8 and a gain of 5.78 dB. Thus, the two-element antenna is approved and yielded for return loss and frequency by using the HFSS software.

REFERENCES

1. R. Hussain, *IEEE Trans. Anten. Propag.* **68** No 3, 2410 (2019).
2. G. Srivastava, A. Mohan *IEEE Anten. Wireless Propag. Lett.* **15**, 1057 (2015).
3. J. Xu, M. Zhao, *IEEE Anten. Wireless Propag. Lett.* **16**, 829 (2016).
4. Y. Lee, C. Jachoon, *Int. J. Anten. Propag.* **2012**, 864306, (2012).
5. W. Ali, S. Das, *Microsystem. Technol.* **27**, 283 (2021).
6. Y. Ghazaoui, A. El Alami, *J. Instrum.* **15**, No 01, T01003 (2021).
7. H. Nigam, M. Mathur. *2021 IEEE Indian Conference on Antennas and Propagation (InCAP)*, 950 (2021).
8. K. Jayanthi, A.M. Kalpana, *J. Nano- Electron. Phys.* **15** No 3, 03022 (2023).
9. D. Ali Sehrai, M. Abdullah, et al., *Electronics* **9**, No 6, 1031 (2021).
10. M.H. Sharaf, I. Amira, *Sensors* **20** No 9, 2541 (2020).
11. M.S. Haroon, F. Muhammad, G. Abbas, Z.H. Abbas, A. Kamal, M. Waqas, S. Kim, *IEEE Access* 8, 102155 (2020).
12. J. Khan, D. Ali Sehrai, et al., *Comput. Mater. Contin.* **2**, 409 (2019).
13. P. Wang, Y. Li, *IEEE Commun. Magaz.* **53** No 1, 168 (2015).
14. M. Khalily, R. Tafazolli, *IEEE Trans. Anten. Propag.* **66**, 4641 (2018).
15. M. Khalid, et al, *Electronics* **9** No 1, 71 (2020).
16. B. Yang, Z. Yu, *IEEE Trans. Anten. Propag.* **65** No 12, 6721 (2017).
17. R.M. Gomathi, M. Jeyabharathi, *J. Nano- Electron. Phys.* **15** No 4, 04027 (2023).
18. El Arrouch Tarik, Najiba El, *J. Nano- Electron. Phys.* **15** No 1, 01026 (2023).
19. D. Kumutha, N.A. Prabha, *Journal of Ambient Intelligence and Humanized Computing* (2017).
20. R.M. Gomathi, M. Jeyabharathi, T. Islam, *J. Nano- Electron. Phys.* **15** No 4, 04027(5pp) (2023).

Розробка та аналіз двох модифікованих елементів MIMO -антени для 5G застосувань

D. Kumutha[1], T. Islam[2], P. Muthumari[3], K. Vijayalakshmi[4], R. Rajalakshmi[5], M. Indumathi[6]

[1] *Department of ECE, Jeppiaar Institute of Technology, Kunnam, Sriperumbudur, TN, India*
[2] *Department of Electrical and Computer Engineering, University of Houston, Houston, TX 77204, USA*
[3] *Department of EEE, KarpagaVinayaga College of Engineering and Technology, Chengalpattu, TN, India*
[4] *Department of ECE, Saveetha School of Eng., Saveetha Institute of Medical and Technical Sciences, Chennai, India*
[5] *Department of ECE, Vignan's Nirula Institute of Technology and Science for womens, Guntur, AP, India*
[6] *Department of EEE, Jeppiaar Institute of Technology, Kunnam, Sriperumbudur, TN, India*

Друкована технологія антени виявилась ефективною для проектування антени MIMO для майбутніх додатків до комунікацій. Антена є важливим компонентом для 5G -системи зв'язку. Technology MIMO високоповажна через високу швидкість передачі даних та одночасне встановлення передачі даних. У цій статті запропонований вигнутий слот, який містить антену кругової форми, побудовану та перевірену на звичайних наземних площинах, які використовують продуктивність у можливому мобільному зв'язку п'ятого покоління (5G). Пропозиція одиночних елементів працює від 2,6 до 12,9 ГГц з ефективністю 85,84% по всій смузі. Підкладка радіатора становить 30 мм × 30 мм × 1,6 мм, де використовується круговий пластир, розмір якого становить 9,35 мм. Часткова структура заземлення 30 мм × 10 мм використовується для отримання високої ефективності та широкої пропускної здатності. Структурована антенна система має максимальну спрямованість 4,8, ефективність 89%та максимальний приріст 1,68 дБ, які бажані в будь -якій системі MIMO, щоб терпіти перешкоди та підтримувати пропускну здатність користувача. Запропонована Mi-Cro Strip Patch Два елемента антени охоплюють частоту втрати 10 дБ від 2,6 ГГц до 11,8 ГГц, ніж звичайний метод. Загальний розмір системи антени MIMO становить 70 мм × 60 мм × 1,6 мм. 2-елементні модельовані результати MIMO-антени визначаються програмним забезпеченням HFSS з їх продуктивністю.

Ключові слова: Багаторазовий вхід та багаторазовий вихід (MIMO), П'яте покоління (5G), Надрукована антена, HFSS, Бездротове спілкування.