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A Flower-Shaped Quad-Port Dual-Band MIMO Antenna of 29/39 GHz Millimeter-Wave for 5G Applications

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This research presents a flower-shaped design of a multi-input multi-output (MIMO) antenna with dual wide operating bands in the millimeter-wave (MMW) region proposed for 5G applications. The antenna system consists of a quad-port antenna array placed with a 90-degree shift; it was etched on a low-cost FR-4 dielectric substrate with a full size of 22×22×1 mm^3. The objective of this work it to enhance the bandwidth of the proposed MIMO antenna as well as to increase the antenna gain. To increase the gain, we used multiple single antennas and to enhance the bandwidth we added some slots to the suggested antennas. The array antennas are designed to provide dual-band operation at the frequencies of 29 GHz (n257) and 39 GHz (n259). The results are simulated using HFSS, acceptable gain reaches 3.04 dB and 8.11 dB in the first and second bands, respectively, while the impedance bandwidth achieved by the design is about 1600 MHz (28.9-30.5 GHz) at 29.8 GHz and about 2330 MHz (38.43-40.76 GHz) at 39.6 GHz with a reflection coefficient S_{11} of about – 16.20 dB and – 19.27 dB, respectively. The proposed antenna can be a desire choice for 5G applications because of its low cost, small size, high performance in terms of bandwidth and gain.

Keywords: 5G, MIMO antenna, Dual-band antenna, Peak gain, Bandwidth.

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1. INTRODUCTION

5G has been in development for a few years, and full coverage of this network should be achieved by 2030. The 5G technology is not limited to digital networks, unlike 3G and 4G, it is expected to have impacts in many sectors, for example, video games, with the development of virtual reality, autonomous transport and connected cars, robotics, or telemedicine (remote diagnosis and surgical operations conducted on the other side of the planet via robotic arms) [1]. The 5G network also enables the automation of logistics platforms and large infrastructures such as ports or factories [2]. 5G NR is much more complex as it has to allow a greater download capacity and it will be able to support a greater number of simultaneous connections and its response time will also be shorter than that of previous generations of mobile networks , all that's causing the push for more research about massive MIMO and dual bands antenna for 5G, like the 4-ports hybrid MIMO antenna with an open-ended slot proposed in [3] operates in the two lower frequencies 800 MHz, 2 GHz as well as the MMW frequency 28 GHz. A Quad-Port Dual-Band MIMO Antenna Array for 5G Smartphone Applications proposed in [4] to operating in 3.5 GHz band (3.4-3.6 GHz) and 5 GHz band (4.8-5 GHz) for 5G smartphone applications.

In this paper, we propose a flower-shaped MIMO antenna configuration that operates at two MMW bands 29 GHz and 39 GHz. In fact, for 4G the base stations can use 4 × 4 arrays, however for 5G technology we can use up to 64 × 64 MIMO arrays [5, 6]. Authors in [7] propose a new modulation scheme to support data over 5G application. The proposed method showed its good performance in terms of data rate and consumption. In [8], an array antenna of 18.67 × 18.26 × 0.35 mm^3 for 5G application is proposed. This later has a bandwidth of 1.14 GHz along with a gain of 14 dB. In [9] an array antenna working at 28 GHz bands is suggested. The antenna bandwidth is of about 27.56-28.381 GHz with a peak gain of 15.85 dBi. A 2 × 2 MIMO antenna operating for 5G wireless communications is implemented in [10]. This antenna covers three 5G bands. Aghoutane et al. proposed in [11] an antenna array for 5G application, the proposed antenna showed a good impedance bandwidth but suffer from less gain. In [12] A 2 × 2 MIMO antenna for 28/38 GHz 5G is carried out. In [13], Njogu et al. have implemented an On-body patch antenna operating at 28 GHz for 5G applications. In [14], An array antenna is tested and analyzed for the 5G mm-wave applications. In [15], A dual band MIMO antenna is proposed over 5G bands. The antenna showed better performance in terms of gain and bandwidth, but it suffers from radiation efficiency. This work consists of 3 steps. First, we start by explaining the work done on the basic single element to generate the dual-band feature in the MMW frequency range. The second part deals with the construction of the MIMO configuration based on the single flower element. Finally, a discussion of the simulated MIMO S-parameters as well as the simulated radiation characteristics.

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2. PROPOSED DUAL-BAND ANTENNA DESIGN

The geometry of the proposed single antenna is shown in the Fig. 1. The flower patch is printed on the top side of a 10 × 10 mm² FR-4 substrate having a ε_r of 4.4 and a thickness of 1 mm and fed by a 50 Ω transmission line, while the partial ground plane is printed on the bottom side. The concluding parameters of the suggested structure are listed in Table 1.

The first objective is to obtain dual-band characteristics in the MMW region of 25-45 GHz and the presented design steps are carried out to obtain high performance in terms of gain, reflection coefficient, and bandwidth from a single antenna element. In the first step (Configuration I), We can say that we have achieved our first objective, which is the resonant frequency around 29 GHz and 39 GHz for the intended 5G applications. In the two following design steps (Configuration II and proposed configuration), a circular slot is incorporated in the midst of the radiating patch, and three identical triangle slots are placed with a 90-degree shift in the sides of the regular octagon to further improve the gain and reflection coefficient of the antenna.

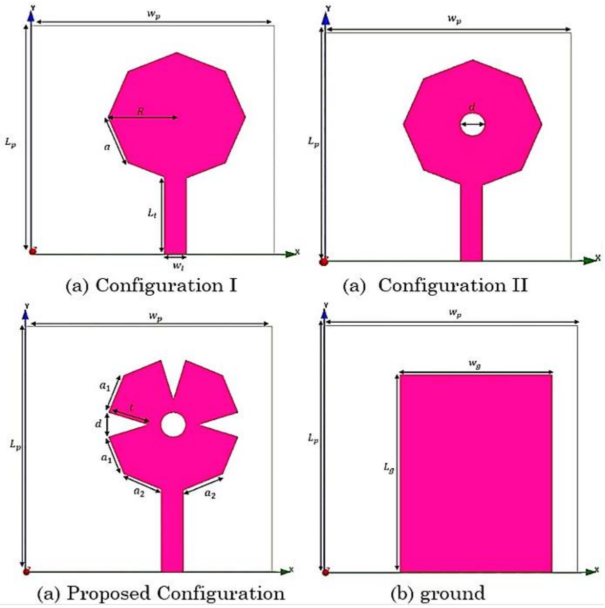


Fig. 1 – Geometric evolutions of the proposed flower-shaped antenna, (a) top view and (b) bottom view

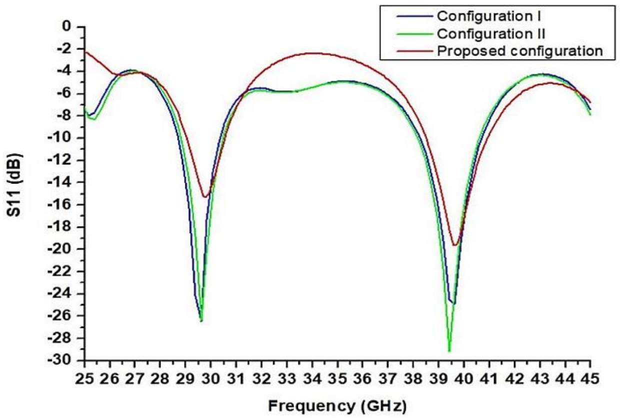
Table 1 – Dimensions of the basic element antenna

Parameter	Value (mm)
Wp	10
Lp	10
Wg	6
Lg	8
W_l	0.9
L_l	3.5
R	4
d	1
a	3.06
a_1	2.56
a_2	2.61
t	1.63

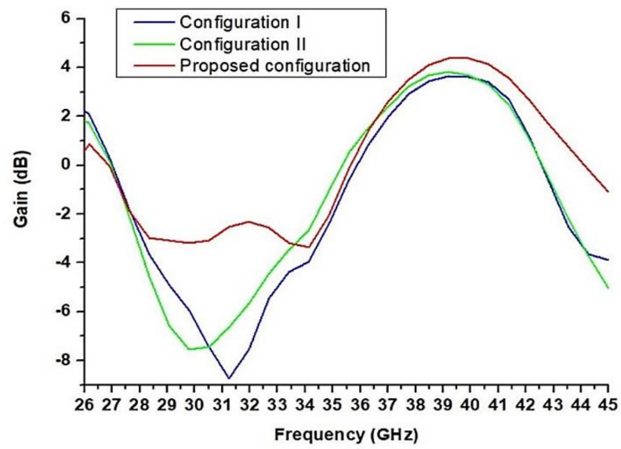
The simulation results of the three steps are demonstrated in Fig. 2. Indeed, the comparison between the simulation results of the proposed antenna configuration in terms of gain, reflection coefficient, and bandwidth is summarized in Table 2. It is observed in this table that the simulation results of the proposed antenna are preferable as they are acceptable in gain, bandwidth, and S11 compared to the other configurations (I and II).

3. MIMO ANTENNA DESIGN AND ANALYSIS

As presented in Fig. 3, the previous antenna element structure is towards the multi-port configuration such that each of the flower-shaped element is placed to achieve good isolation and compact construction.



(a)



(b)

Fig. 2 – Simulation results for different design steps (a) S11 parameters versus frequency (b) gain versus frequency

Furthermore, the single element is rotated in four rotations with a 90-degree shift such that the central operating frequency of the MIMO antenna and single element be close to each other with a negligible deviation. The total size of the proposed MIMO structure is 22 × 22 × 1 mm³, the ground plane as obtained for the antenna element is adopted in the MIMO configuration for each element of it, as illustrated in Fig. 3(b). The recommended structure's final parameters are presented in Table 3.

The simulated results of *S*-parameters for the MIMO antenna are shown in Fig. 4. It is observed that the

Table 2 – Simulation results for different cases of single element antenna

Configurations	Operating frequency (GHz)		Gain (dB)		S_{11} (dB)		Bandwidth (GHz)	
	1st band	2nd band	1st band	2nd band	1st band	2nd band	1st band	2nd band
Configuration I	29.5	39.5	– 5.57	3.63	– 26.41	– 26.31	1.6	2.4
Configuration II	29.6	39.4	– 7.33	3.77	– 26.41	– 29.15	1.6	2.4
Proposed antenna	29.8	39.6	– 3.19	4.39	– 15.30	– 19.64	1.6	2.3

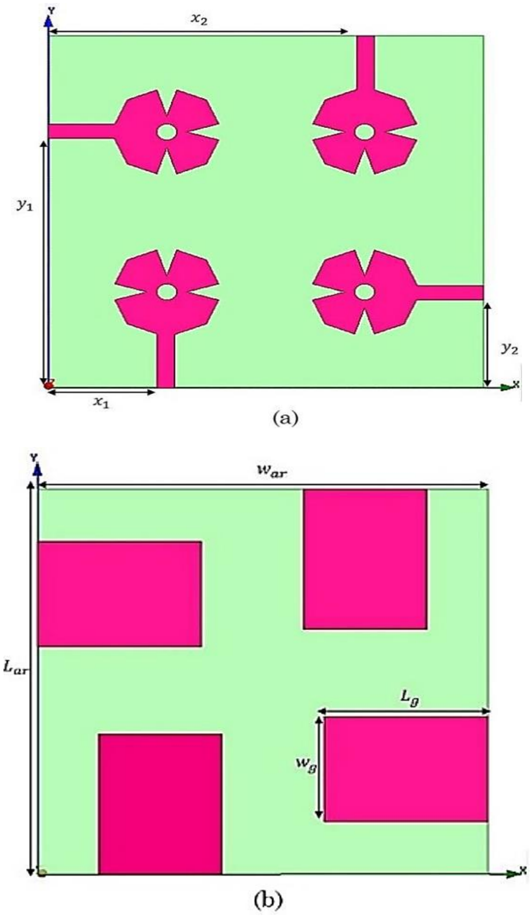


Fig. 3 – Design of the four elements MMW dual-band MIMO antenna (a) top view and (b) bottom view

Table 3 – Dimensions of the proposed MIMO antenna

Parameter	Value (mm)
War	22
Lar	22
x_1	5.5
$x_2 = y_1$	15.6
y_2	6.4

MIMO covers the two band of 29 GHz and 39 GHz, and the isolation between the elements is less than 25 dB in the two bands. The simulated gain versus frequency of the proposed MIMO antenna is shown in Fig. 5.

The maximum simulated gain of about 3.04 dB is obtained at 29.61 GHz and about 8.11 dB at 39.5 GHz. The gain values shown in Fig. 5 confirm that the proposed MIMO antenna has an increasing effect on the gain compared to the single element values.

Table 4 summarized the simulation results of the proposed MIMO antenna.

Table 4 – Summary of the simulation results of the proposed MIMO antenna

Parameter	Operating frequency (GHz)		Gain (dB)	
	1st band	2nd band	1st band	2nd band
Proposed MIMO antenna	29.8	39.5	3.04	8.11

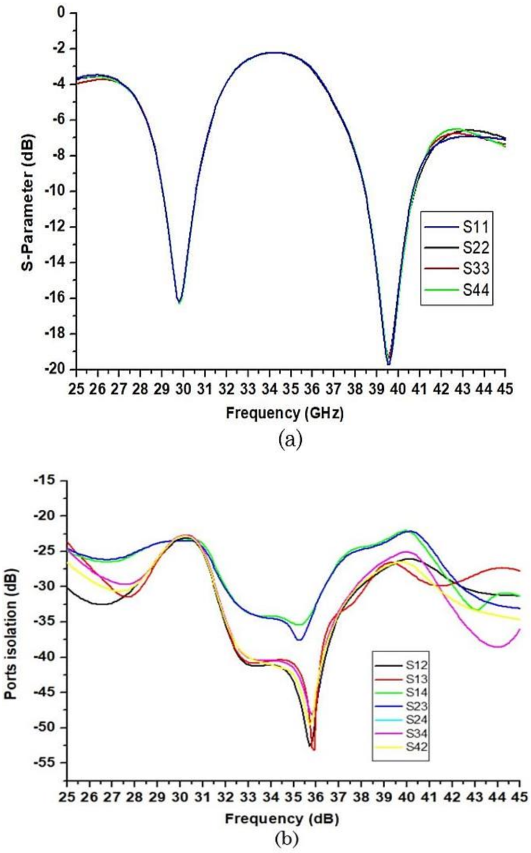


Fig. 4 – Simulated results of the MIMO antenna, (a) S-parameters (b) isolation

4. RADIATION CHARACTERISTICS

The radiation patterns (gain) are depicted in Fig. 6. This figure shows only the HFSS simulation radiation pattern of a single port for discussion in the E and H planes since the four MIMO elements are identical.

As noticed from Fig. 6, the MIMO element provides a bi-directional E-plane pattern and a nearly omni-directional H-plane radiation at the first simulated frequency of 29 GHz. Besides, at the second frequency of 39 GHz, it provides a directional H-plane radiation and an omni-directional E-plane pattern, which resembles an "O" shape, and this may be a result of the higher density of the originated surface current that mainly circulates and concentrates around the slot for the resonant frequency of 39 GHz.

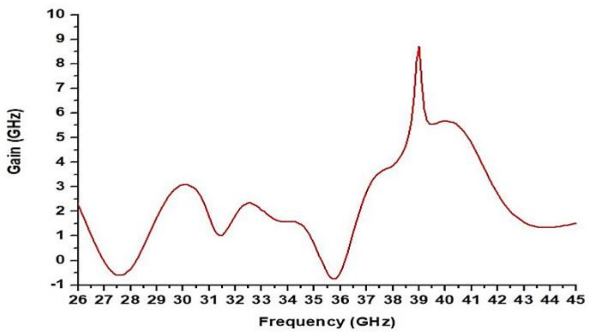


Fig. 5 – Simulated gain vs. frequency of the proposed MIMO antenna

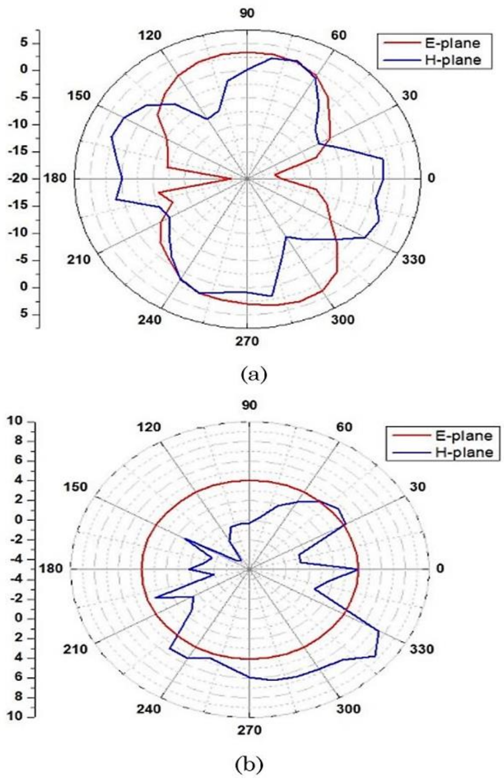


Fig. 6 – The radiation pattern of the proposed MIMO antenna, (a) at *f* = 29 GHz and (b) at *f* = 39 GHz

As shown in Fig. 7, the simulated surface current at 29 GHz and 39 GHz has been presented, the partial distribution of the surface current is observed near the edge of the feeder for both bands, 29 GHz and 39 GHz. The surface current concentration is a little high and is visualized along the edges of the circular and triangular slots incorporated into the radiating patch, especially for the 39 GHz band.

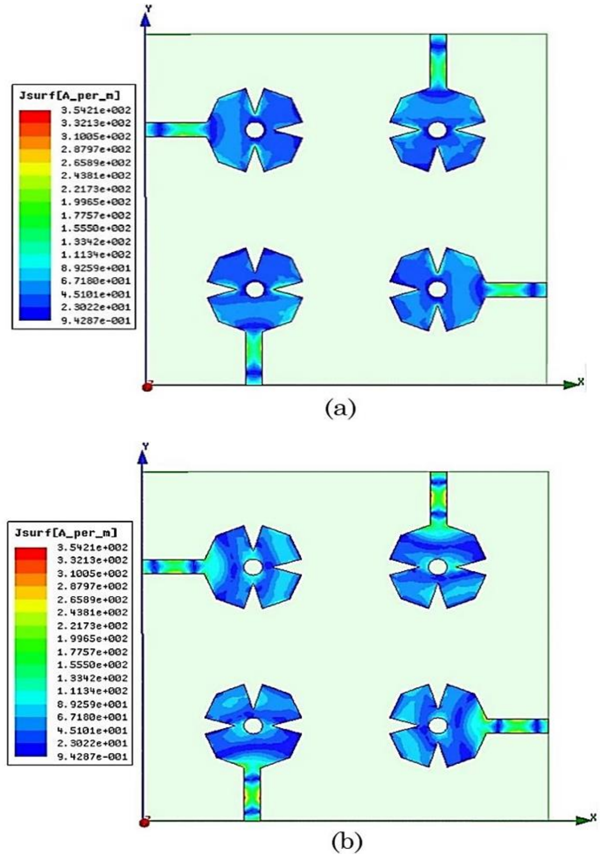


Fig. 7 – The simulated surface current distribution of the MIMO antenna at (a) *f* = 29 GHz and (b) at *f* = 39 GHz

5. CONCLUSIONS

In this paper, a flower-shaped four-element-based MIMO antenna with dual operating millimeter-wave bands was proposed for 5G application systems. The suggested MIMO has a compact size of $22 \times 22 \times 1$ mm^3. It's used to improve the overall gain of the antenna, which offers a peak gain of 3.04 dB at the first band, 29 GHz, and 8.11 dB at the second band, 39 GHz. This patch array configuration is designed and analyzed using HFSS. It is also a good candidate for 5G applications.

REFERENCES

1. W. Ali, S. Das, et al., *Microsyst. Technol.* **27**, 283 (2021).
2. Y. Ghazaoui, A.E. Alami, M.E. Ghzaoui, S. Das, E. Baradand, D.S. Mohapatra, *Journal of Instrumentation* **15**, 1 (2020).
3. M. Ikram, N. Nguyen-Trong, A. Abbosh, *IEEE Antenn. Wirel. Propag. Lett.* **19** No 4, 710 (2020).
4. J. Huang, G. Dong, J. Cai, H. Li, G. Liu, *Electronics* **10**, 542 (2021).
5. P. Xingdong, H. Wei, Y. Tianyang, L. Linsheng, *China Commun.* **11** No 11, 16 (2014).
6. *5G Americas White Paper: Advanced Antenna Systems for 5G* (2019).
7. M. El Ghzaoui, A. Hmamou, J. Foshi, J. Mestoui, *J. Circuits, Syst. Comput.* **29**, 2050257 (2020).
8. M. Nabil, M.M.A. Faisal, *Design, Wirel. Pers. Commun.* **116**, 2761 (2021).
9. N. Marriwala, C.C. Tripathi, D. Kumar, S. Jain, *Mobile Radio Communications and 5G Networks – Lecture Notes in Networks and Systems*, **140** (Springer Singapore: 2021).
10. T. Okan, *Int. J. RF Microw. Comput. Aided Eng.* **30**, e22236

(2020).
11. B. Aghoutane, S. Das, H.E. Faylali, B.T.P. Madhav, M. El Ghzaoui, A.E. Alami, *Anal., J. Circuits, Syst. Comput.* **30**, 2150086 (2021).
12. M.N. Hasan, S. Bashir, S. Chu, *J. Electromagn. Wave. Appl.* **33**, 1581 (2019).
13. P. Njogu, B. Sanz-Izquierdo, A. Elibiary, S.Y. Jun, Z. Chen, D. Bird, *IEEE Access* **8**, 228711 (2020).
14. J. Bang, J. Choi, *IEEE Access* **8**, 139715 (2020).
15. B. Aghoutane, S. Das, M.E. Ghzaoui, B.T.P. Madhav, H.E. Faylali, *AEU – Int. J. Electron. Commun.* **145**, 154071 (2022).

Чотирипортова дводіапазонна MIMO-антена у формі квітки 29/39 ГГц міліметрової хвилі для додатків 5G

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У дослідженні представлено квіткообразну конструкцію антени з багатьма входами і виходами (MIMO) з подвійними широкими робочими діапазонами в області міліметрових хвиль (MMW), запропоновану для додатків 5G. Антенна система складається з чотирипортового антенного масиву, розміщеного зі зсувом на 90 градусів; його витравлювали на недорогій діелектричній підкладці FR-4 із загальним розміром 22×22×1 мм^3. Метою роботи є розширення смуги пропускання запропонованої MIMO-антени, а також збільшення коефіцієнта підсилення антени. Щоб збільшити коефіцієнт підсилення, ми використовували кілька одиночних антен, а для збільшення пропускної здатності додали кілька отворів до запропонованих антен. Антени масиву призначені для забезпечення дводіапазонної роботи на частотах 29 ГГц (n257) і 39 ГГц (n259). Результати моделюються з використанням HFSS, прийнятне підсилення досягає 3,04 дБ і 8,11 дБ у першому та другому діапазонах відповідно, тоді як ширина смуги імпедансу, досягнута конструкцією, становить близько 1600 МГц (28,9-30,5 ГГц) на 29,8 ГГц і близько 2330 МГц (38,43-40,76 ГГц) на 39,6 ГГц з коефіцієнтом відбиття S_{11} приблизно – 16,20 дБ і – 19,27 дБ відповідно. Запропонована антена може бути бажаним вибором для додатків 5G через її низьку вартість, невеликі розміри, високу продуктивність з точки зору пропускної здатності та підсилення.

Ключові слова: 5G, MIMO-антена, Дводіапазонна антена, Пікове підсилення, Пропускна здатність.