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A Compact Two-port MIMO Array Antenna for ISM/5G NR/WLAN Band Applications

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MIMO (Multi-Input Multi-Output) systems have become one of the most studied topics in research because of its ability to increase the spectral efficiency (capacity) over a limited bandwidth. The use of multiple antennas leads to an additional dimension in the degree of multiple access to the network compared to the single-antenna case and thus offers an effective solution to increasing data rates for future generations of cellular radiotelephony. In this paper, a 2×6 MIMO antenna array structure is presented. HFSS software is used in the simulation process of the designed antenna. The proposed structure covers the frequency band ranging from 1.2 to 6.3 GHz. A thin Rogers 5880 RT substrate of $54 \times 60 \times 0.4$ mm^3 is used to design the antenna. The behavior of the MIMO antenna has been studied as a function of a certain number of parameters, namely: the distance separated MIMO antenna elements and the radius of the slot in the patch. The results show that the variation of these parameters affects the isolation. The design of the proposed antenna is done, by fixing the distance at $\lambda/2$ and the radius at 2.25 mm, in such a manner we get a high isolation between the radiating elements of about – 83.8 dB which will provide a reliable anti-interference performance for the system. The outcomes make this antenna a potential candidate for 5G application at the sub 6 GHz band.

Keywords: MIMO antenna, Isolation, Anti-interference, DGS, 6 GHz.

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1. INTRODUCTION

In the preceding few years, several applications have emerged such as the inevitable cellular telephony, private and domestic networks, internet access by satellite, satellite positioning systems, satellite television, etc. Due to this stupendous growth, telecommunication systems are limited by a growing need for frequency bands, high data rates, latency, etc [1]. These limitations slow down the development of new applications whose demand for spectrum resources is constantly increasing. Therefore, researchers and engineers in this field have joined their efforts to find new solutions to overcome these drawbacks, getting faster data transmission and high throughput. In order to address the concern, the deployment of lower frequencies of 5G NR sub-6 GHz and UWB technology are utilized at the present time. Nevertheless, UWB technology is mainly affected by multipath fading degradation [4]. Hence, MIMO antennas turned up a key solution to meet the multipath fading. By increasing the number of radiators at both transmitter and receiver sides, there is an excessive improvement in data rate and channel capacity [5]. To fulfill these requirements, the communication channels between the sender and receiver need to be totally uncorrelated 7]. That means multiple radiators in the transmitter and receiver ends should work individually [8]. There are two main reasons that increase the channel correlation, the first one is the coupling inside the structure of the antenna called isolation, and can be measured through the *S* parameters of the antenna. The second factor is the characteristics of the radiation pattern measured through the correlation coefficients of the antenna [10].

Patch antenna arrays are widely used because of their small size, their low weight, a low cost, and their easy manufacture. However, they have certain disadvantages, in particular the low passband and the dielectric and metal losses, in particular at high frequency, a relative low tolerance to manufacturing errors and an increased influence of surface waves. One solution for limiting dielectric losses and the influence of surface waves consists in choosing a substrate with a low loss tangent and a very thin thickness, but this leads to further reducing the bandwidth. The difficulty of realization lies not only in the radiating elements, but also in the power supply network. The access lines to the antennas can become very thin, which increases their losses and can generate parasitic radiation, with a degradation of the radiation pattern of the network, its gain, and an increase in the level of the secondary lobes [11]. A 2×4 MIMO antenna for mm-wave application is suggested in [12]. The presented antenna in [12] has high gain width dual band characteristics. A network of 8×8 cones consisting of staggered cones studied in the reference [13]. This antenna offers a gain of 32 dBi (radiating physical aperture of 30 mm × 30 mm), corresponding to an aperture efficiency of 28 % and a bandwidth of 29.5 %. Authors of Ref. [14] presented a four ports MIMO antenna for 5G millimeter waves applications. The antenna was fabricated and tested. Another example of a horn network is proposed in the reference [15]. In order to have a higher gain, this antenna contains 16×16 radiating elements, distributed over a panel of $68.5 \times 82.2 \times 10.1$ mm^3. The bandwidth of this antenna is 25.3 %, with a maximum

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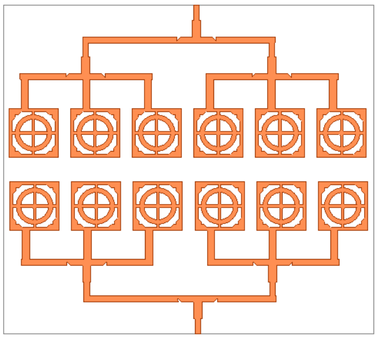
gain of 40.7 dBi. A phased array of 4 × 4 cones with an E-band orientable radiation pattern with a maximum gain of 15.2 dBi is presented in [16]. In [17], a defected ground four ports MIMO Antenna for 5G Millimeter Wave Applications is presented. Authors of Ref. [18] suggested an array antenna working at 38 GHz covering the USA band.

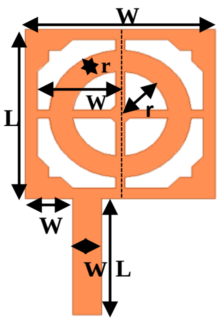
This work comprises three sections in addition to an introduction. The first will be devoted to presenting the design geometry of the 2 × 6 MIMO antenna. The second section will be allocated to the parametric analysis and the results of the study will be presented and thoroughly discussed. The paper will end up with a conclusion.

2. ANTENNA DESIGN GEOMETRY

In this section, the snapshot of the final MIMO antenna geometry is depicted in Fig. 1(a). The whole area occupied by the design is 54 × 60 × 0.4 mm³ and is realized on Rogers RT duroid/5870 substrates having a dielectric constant and height of 2.33 and 0.4 mm, respectively. The design progression of the required MIMO configuration initially starts with the modeling of a single-element patch antenna as shown in Fig. 1(b).



(a)



(b)

Fig. 1 – Proposed antenna design; (a) geometry of the 2 × 6 MIMO array antenna, (b) geometry of single antenna

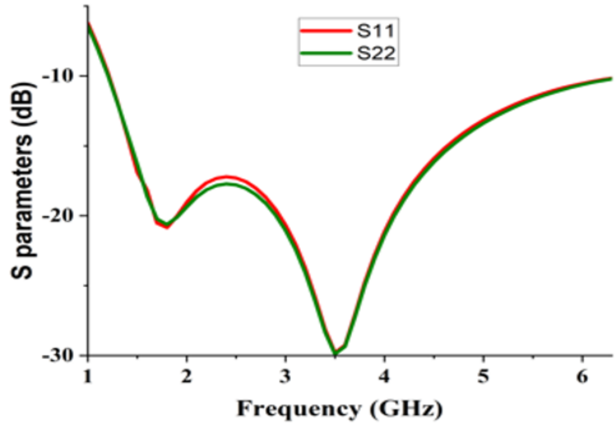
All the physical parameters mentioned in Fig. 1 are annotated in Table 1.

Table 1 – Antenna parameters

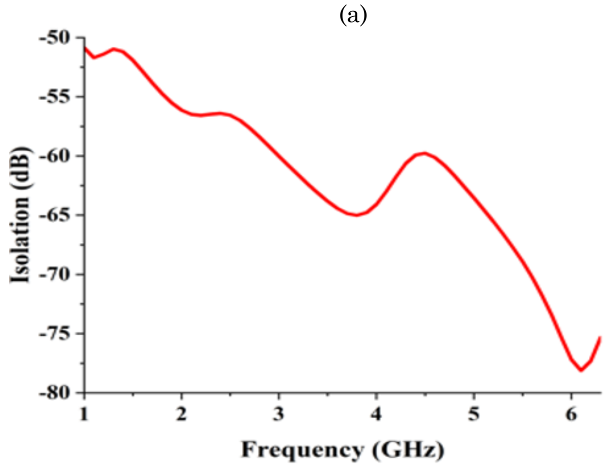
Parameters	Value (mm)	Parameters	Value (mm)
L_A	60	r_1	1
W_A	54	L_1	6
L	8	W_1	1.2
W	8	W_2	2
R	2	W_3	3.4

3. MIMO ANTENNA PARAMETRIC ANALYSIS

Design and performance optimization of the MIMO antenna is illustrated by showing the effect of such parameters on reflection coefficient and isolation due to the alteration in the dimensions of the radius r and the dimensions of the distance d. Hence, in this section, the simulated results of these effects on the MIMO antenna are carried out, and thoroughly discussed. S-parameters and isolation of the optimized MIMO antenna structure at $d = \lambda/2$ and $r = 2$ is shown in Fig. 2.



(a)



(b)

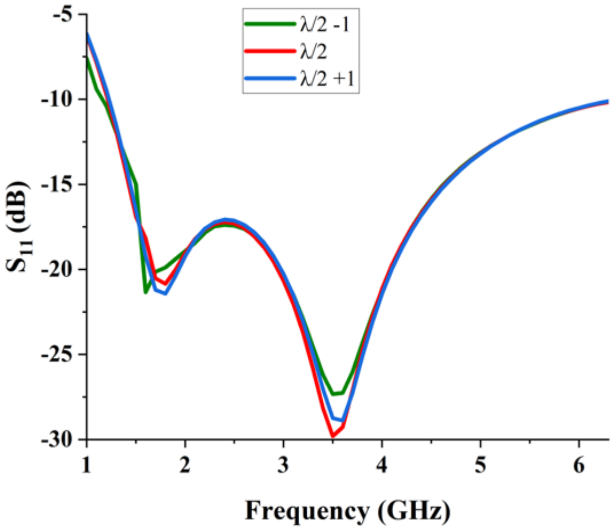
Fig. 2 – S-parameters of the MIMO array antenna; (a) S_{11} and S_{22}, (b) isolation

3.1 Effect of Distance Variation

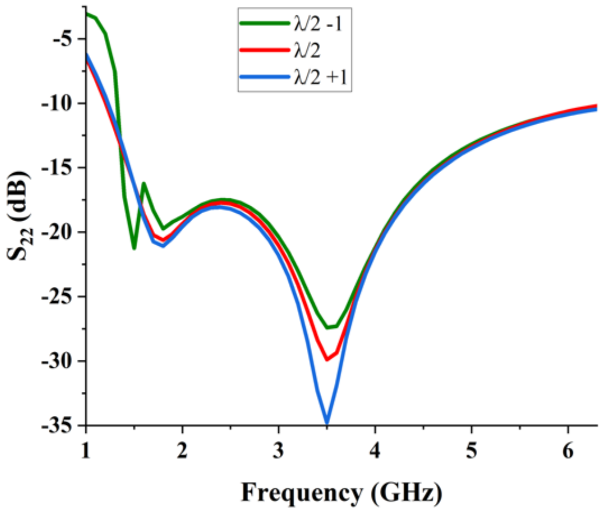
The effect of variations in the inter element distance d on the MIMO antenna parameters is studied and discussed in this section. First, the inner radius, r is set equal to 2 mm and we vary d from $\lambda/2 - 1$ to $\lambda/2 + 1$. Simulation will be carried out for reflection coefficient (S_{11} & S_{22}) and isolation. Table 3 summarizes the obtained results. As depicted in Fig. 3, the bandwidth of the proposed antenna array did not depend on distance d. There is a little shift in reflection coefficient. So, to choose the value of d, we have carried out a parameter study regarding of isolation. Fig. 4 shows the isolation of the presented antenna for deferent value of d.

From Fig. 3, Fig. 4, and Table 3, it can be seen that while increasing the distance d from $\lambda/2 - 1$ to $\lambda/2 + 1$, the MIMO antenna covers the same bandwidth ranging from

1.2 to 6.3 GHz, while a satisfactory reflection coefficient level of – 29.8 dB and good isolation of – 78.12 dB are achieved at a distance of $\lambda/2$. Besides, it is shown that when $d = \lambda/2$ and $d = \lambda/2 + 1$, the presented antenna gives reasonable isolation. So, $d = \lambda/2$ is the optimal dimension.



(a)



(b)

Fig. 3 – Effect of d on S-parameters (a) S_{11}; (b) S_{22}

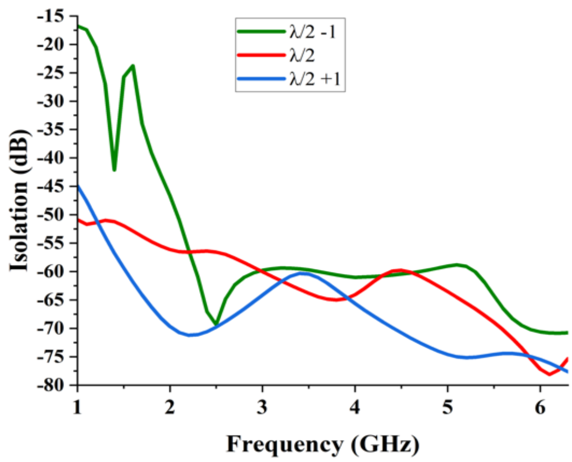


Fig. 4 – Effect of d on isolation

Table 3 – Performance parameters as a function of 'd'

Inter elements distance	S11 (dB)	Bandwidth (GHz)	Isolation (dB)
$d = \lambda/2 - 1$	– 27.3 dB	[1.2-6.3] = 5.1	< – 15
$d = \lambda/2$	– 29.8 dB	[1.2-6.3] = 5.1	< – 50
$d = \lambda/2 + 1$	– 28.8 dB	[1.2-6.3] = 5.1	< – 45

3.2 Effect of Radius Variation

In this part, we have evaluated the effect of the parameter r on the behavior of the antenna by fixing the distance d at $\lambda/2$ as good results are obtained at this value.

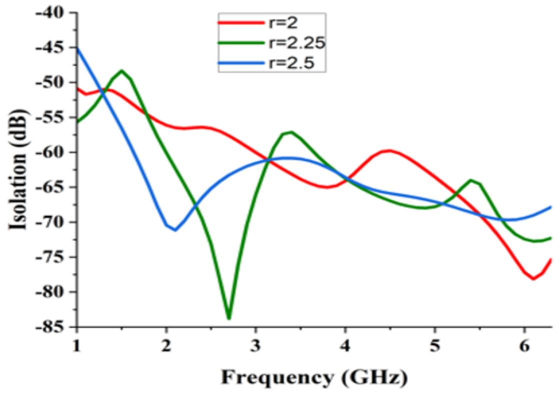


Fig. 5 – Effect of r on isolation

Table 4 – Performance parameters as a function of 'r'

Inner radius	S_{11} (dB)	Bandwidth (GHz)	Isolation (dB)
$r = 2$	– 29.8	[1.2-6.3] = 5.1	< – 50
$r = 2.25$	– 29.35	[1.2-6.3] = 5.1	< – 45
$r = 2.5$	– 29.77	[1.2-6.3] = 5.1	< – 47.5

From Fig. 6, and Table 4, it is clear that for $r = 2$ mm, 2.25 mm and 2.5 mm, the antenna offers same value of bandwidth. However, it is observed that for $r = 2.25$ mm, the system gives good results regarding isolation compared to other cases especially in the operating band. In fact, isolation helps in mitigating unwanted coupling. At two other values of r, the isolation is weaker while the reflection coefficient levels are also not satisfactory. Thus, $r = 2.25$ mm has been taken as an optimal value for designing the proposed antenna.

4. GAIN

Considering that the operational bandwidth is extremely broad, it is exceedingly challenging to draw radiation patterns at all frequencies. As a result, the gain versus frequency plot shown in Fig. 7 is a far more practical method to illustrate and justify the directional pattern obtained in Fig. 8. As depicted in Fig. 7, the antenna has a peak gain of around 16 dB at 5.60 GHz.

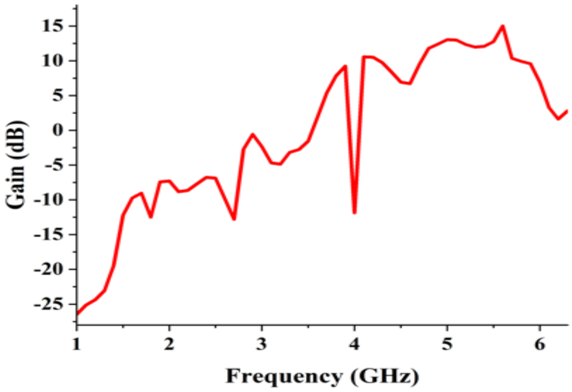
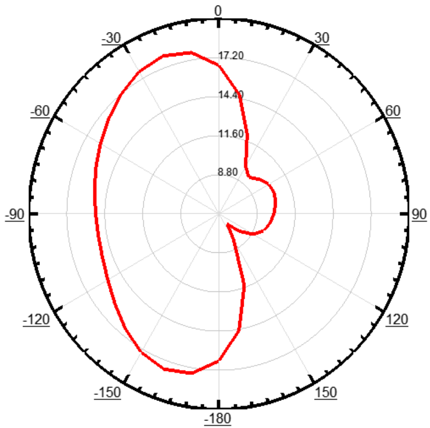


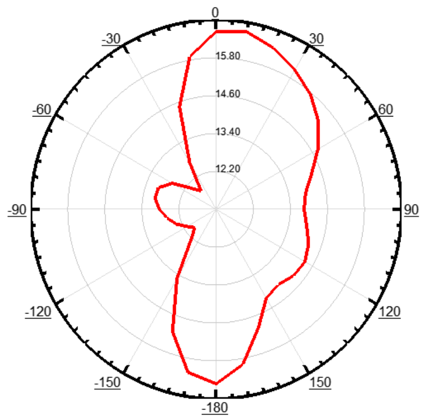
Fig. 7 – Gain versus frequency

5. RADIATION PATTERN

Fig. 8 shows radiation patterns at different frequencies (1.7 GHz, 3.5 GHz) for the proposed MIMO antenna, obtained from the HFSS software.



(a)



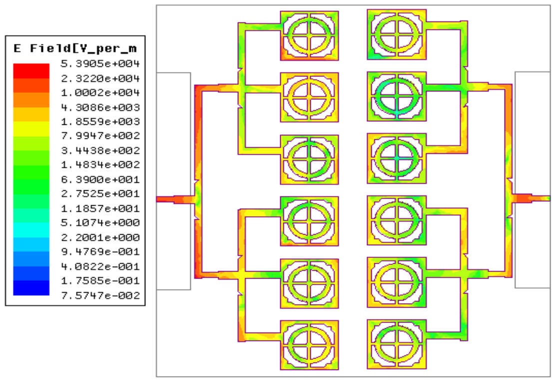
(b)

Fig. 8 – Radiation patterns at (a) 1.7 GHz, (b) 3.5 GHz

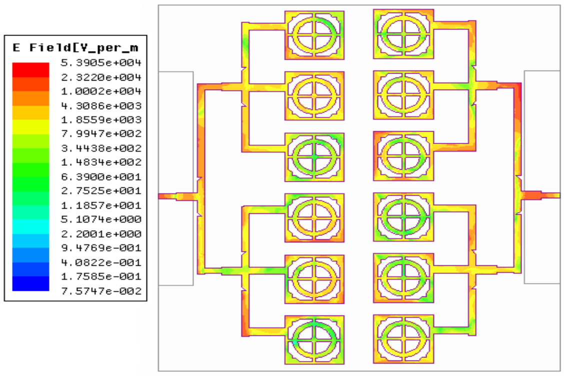
The radiation patterns of the suggested antenna are bidirectional. So, antenna could be efficient in radiating towards 180 degree and 0-degree directions.

6. SURFACE CURRENT DISTRIBUTION

To further explore the MIMO antenna's radiation mechanism, the current distributions on the surface of the MIMO elements are displayed in Fig. 9. The surface current distributions are observed at 1.7 and 3.5 GHz. As shown, the surface current predominantly distributes on the whole area whereas more current concentration is seen at the feed line.



(a)



(b)

Fig. 9 – Current distribution at (a) 1.7 GHz (b) 3.5 GHz

In summary, the suggested MIMO antenna performs better than the majority of the MIMO antennas shown in Table 5 and strikes a decent balance between bandwidth, isolation and miniaturized size.

Table 5 – Performance comparison with previous published literature

References	Size (mm^2)	Bandwidth (GHz)	Isolation (dB)
[19]	40 × 100	[3.5-3.6]	15
[20]	160 × 70	[5.6-5.67]	30
[21]	60 × 60	[2.31-4.99]	20
Proposed Antenna	**54 × 60**	**[1.2-6.3]**	**83.8**

7. CONCLUSION

In this paper, a high isolation multiple-input multiple-output (MIMO) antenna array is proposed. The designed MIMO antenna system has a wide band ranging from 1.2 to 6.3 GHz. The antenna achieves isolation of more than – 83 dB and a peak gain of 16 dB. Moreover, the 54 × 60 mm^2 sized compact MIMO antenna can be appropriate for integration into multiple 5G wireless devices for sub-6-GHz band.

REFERENCE

1. B.T. Ahmed, I.F. Rodríguez, *Wireless Networks* **28** No 5, 1977 (2022).
2. S. Chen, N. Lu, J. Sun, C. Zhou, C. Li, D. Wu, *Frontiers Phys.* **10** (2022).
3. Y. Gao, J. Wang, X. Wang, R. Shao, *Micromachines* **13** No 7, 1064 (2022).
4. J. Khan, S. Ullah, F.A. Tahir, F. Tubbal, R. Raad, *Electronics* **10** No 24, 3062 (2021).
5. Z. Wang, C. Li, Q. Wu, Y. Yin, *IEEE Access* **8**, 125565 (2020).
6. M. Sangwan, G. Panda, P. Yadav, *International Conference On Inventive Computation Technologies (ICICT)*, 912 (Coimbatore, India: 2020).
7. J. Mestoui, M. El Ghzaoui, M. Fattah, et al., *J. Ambient Intell Human Comput.* **11**, 3937 (2020).
8. N.O. Parchin, H.J. Basherlou, Y.I.A. Al-Yasir, A.M. Abdulkhaleq, R.A. Abd-Alhameed, *Sensors* **20**, 2371 (2020).
9. D. Wen, Y. Hao, H. Wang, H. Zhou, *IEEE Trans. Antenn. Propag.* **67** No 3, 1437 (2019).
10. E. Farahat, K.F.A. Hussein, *Prog. Electromag. Res. C* **101**, 159 (2020).
11. A. Rida, M. Tentzeris, S. Nikolaou, *IEEE Anten. Propag. Soc. AP-S Int. Symp.*, 2071 (2011).
12. B. Aghoutane, M. El Ghzaoui, S. Das, W. Ali, H. El Faylali, *Int. J. RF Microw. Comput. – Aided Eng.* **32** No 5, e23088 (2022).
13. S.R. Zahran, L. Boccia, G. Amendola, S. Moscato, M. Oldoni, D. Tresoldi, *15th Eur. Conf. Antenn. Propag., EuCAP*, 2021 (2021).
14. B. Aghoutane, S. Das, M. El Ghzaoui, B.T.P. Madhav, H. El Faylali, *AEU – Int. J. Electron. Commun.* **145**, 154071 (2022).
15. Y. Huang, X. Li, Z. Qi, H. Zhu, J. Xiao, J. Chu, *Asia-Pacific Microw. Conf. Proc. APMC*, 765 (2018).
16. M.M. Islam, et al., *Int. J. Antenn. Propag.* **2018**, 4267053 (2018).
17. M. Khalid, S. Iffat Naqvi, N. Hussain, M. Rahman, Fawad, S.S. Mirjavadi, M.J. Khan, Y. Amin, *Electronics* **9** No 1, 71 (2020).
18. Bilal Aghoutane, Sudipta Das, Hanan El Faylali, B.T.P. Madhav, Mohammed El Ghzaoui, Ali El Alami, *J. Circuits, Syst. Comput.* **30** No 05, 2150086 (2021).
19. A.M.A. Sabaawi, K.S. Muttair, O.A. Al-Ani, Q.H. Sultan, *Prog. Electromag. Res. C* **122**, 57 (2022).
20. J. Khan, S. Ullah, F.A. Tahir, F. Tubbal, R. Raad, *Electronics* **10** No 24, 3062 (2021).
21. I.S. Masoodi, I. Ishteyaq, K. Muzaffar, *Prog. Electromag. Res. Lett.* **102**, 37 (2022).

Компактна двопортова антенна MIMO-матриця для додатків діапазону ISM/5G NR/WLAN

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Системи MIMO (Multi-Input Multi-Output) стали однією з найбільш досліджуваних тем у дослідженнях через їх здатність підвищувати спектральну ефективність (ємність) в обмеженій смузі пропускання. Використання кількох антен призводить до додаткового виміру в ступені множинного доступу до мережі порівняно з випадком з однією антеною і, таким чином, пропонує ефективне рішення для підвищення швидкості передачі даних для майбутніх поколінь стільникового радіотелефонного зв'язку. У статті представлена структура антенної решітки MIMO 2×6. Програмне забезпечення HFSS використовується в процесі моделювання розробленої антени. Запропонована структура охоплює діапазон частот від 1,2 до 6,3 ГГц. Для розробки антени використовується тонка підкладка Rogers 5880 RT $54 \times 60 \times 0{,}4$ мм^3. Характеристики MIMO-антени були вивчені як функція певної кількості параметрів, а саме: відстані між елементами MIMO-антени та радіусу щілини в патчі. Результати показують, що зміна цих параметрів впливає на ізоляцію. Конструкція запропонованої антени виконана шляхом фіксації відстані на $\lambda/2$ і радіуса на 2,25 мм, таким чином була отримана висока ізоляція між випромінюючими елементами приблизно – 83,8 дБ, що забезпечить надійну захист від перешкод продуктивність для системи. Результати роблять цю антену потенційним кандидатом для застосування 5G у діапазоні нижче 6 ГГц.

Ключові слова: MIMO антена, Ізоляція, Захист від перешкод, DGS, 6 GHz.