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Using the Parasitic Element Method to Reduce the Mutual Coupling in the Design of (2x1) MIMO Triple-Band Antenna for 5G Wireless Transmission Application

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Abstract

This study presents the design and analysis of a compact (72x46) mm2 broad-band printed MIMO (2x1) antenna. The antenna is intended to operate at frequencies (15.5-22.5-29.5) GHz and is specifically developed for wireless power transmission in fifth-generation (5G) applications. The MIMO antenna is fabricated on an FR4 substrate with an electronic conductivity (E) of 4.4, a height of 1.6mm, and a tand value of 0.025. The patch is designed in the form of a circular ring consisting of two large circles engraved on the front side of the FR4 material, the first with a radius of 12.999 mm from which a small circle with a radius of 10 mm is cut, and its center is 3 mm away from the large circle on the y-axis. The parasitic technique was used in this antenna to reduce the mutual coupling between two ports, which consist of 6 rectangular pieces that are hollow from the, inside to prevent the transmission of the wave from the first port to the second and vice versa, which causes the loss of transmitted energy. The design and simulation results of this MIMO antenna were achieved using the Cognitive Simulation Technology (CST) Microwave Studio software package version 2024. The simulation revealed that the S-parameter for the 2-port is below -17 dB, and the mutual coupling for these ports is significantly low, measuring less than -50 dB.

Keywords: MIMO Antenna, Mutual Coupling, Parasitic Element Method, Tunnel Method, λ/4 Slot Method, Wireless Power Transmission and Fifth Generation (5G).

1 Introduction

MIMO wireless communication systems depend on integrating several antennas within the mobile device (Jamshed et al., 2021). Employing several antennas can enhance the transmission rate, offering users greater multimedia, real-time video communication, and data transfer capabilities (Alkaraki & Gao, 2020). MIMO technology is expected to be prevalent in all forthcoming wireless generations (Yadav et al., 2018). Consequently, it is imperative to meticulously design and characterize the antenna component of the system to enable the system to attain its projected high data rates (Tang et al., 2020).

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The major drawback of MIMO antennas is the mutual coupling that is present between MIMO elements (Chandel & Gautam, 2016). The electromagnetic interaction between the MIMO system's components is known as mutual coupling (Masoodi et al., 2021). Either the electromagnetic interaction between the elements or the surface current flowing from one element to another is responsible for the mutual coupling (Khan et al., 2020). Mutual coupling is a function of the relative position between elements and becomes large for small spacing (Salih & Nangir, 2024). Without the mutual coupling, the output power value is approximately equal to the input power, thus, the total efficiency is relatively high (Li et al., 2019). With mutual coupling, the coupling power reduces the output power and the total efficiency (Iqbal et al., 2017). As the distance between MIMO parts increases, researchers are currently searching for methods that provide very high isolation while achieving minimal size (Zhao et al., 2019). It is worth mentioning that reducing the mutual coupling will reduce the envelope correlation for a highly efficient antenna (Sanad & Hassan, 2014).

A. Tunnel Method

This method aims to locate the zone that has the least effect on the antenna characteristics such as impedance matching, bandwidth, etc (European 5G Observatory al., 2020), and a change has to be made to it to reduce its surface current density that is responsible for mutual coupling (Babuet al., 2011). The surface current (I) that flows between elements can be estimated from the following equation (Patil et al., 2020; Gurjar et al., 2019).

Where J: is the surface current density

A): is the surface area

This method will increase the surface area (A) by digging a tunnel at the ground plane with height (ho) and width (wo) on the space between MIMO elements (Tang et al., 2019; Narteni et al., 2021). Therefore, the surface current will travel a long distance from one element to another (Salih & Abdullah, 2019) as shown in Figure (1), and the current density (J) will be decreased (Alibakhshikenari et al., 2020).

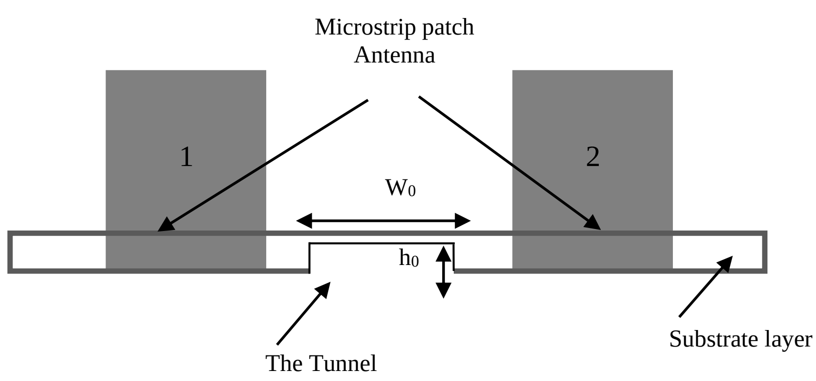


Figure 1: Building a Tunnel between Radiation Elements

This method can be used to obtain single-band, dual-band and triple-band MIMO antennas (Masoodi et al., 2021; Ramakrishna et al., 2021), and can be classified into two kinds.

B. Tunnel Method with Sharp Edges

A tunnel of this kind has a pair of sharp edges on both sides to increase the surface area (Rajkumar et al., 2019), as shown in Figure (2).

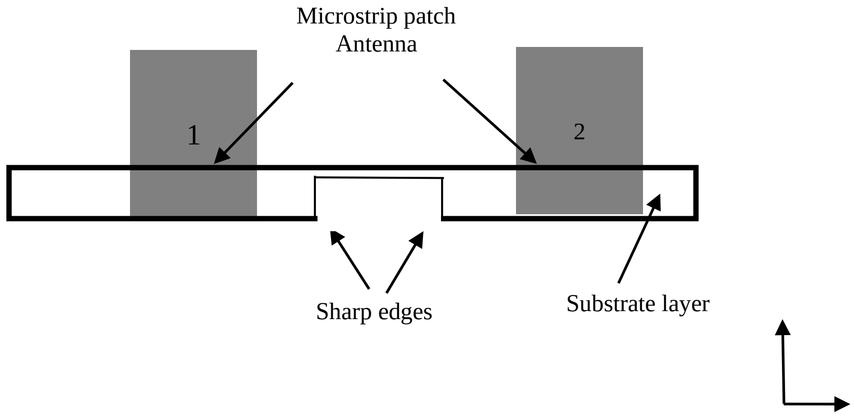


Figure 2: Tunnel with Sharp Edges

C. Tunnel with Stair Edges

In this kind, opposite stairs have been introduced in the tunnel (Luo et al., 2017), as shown in Figure (3), to increase the surface area.

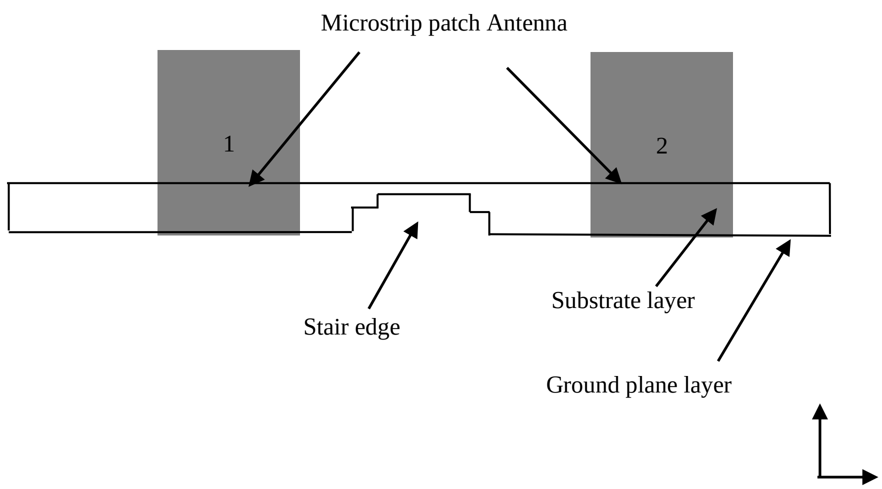


Figure 3: Tunnel Method with Stair Edge

D. Parasitic Element Method

A parasitic element is a specific element of a specified shape and size that can be placed between MIMO elements without physical contact, or fixed to the ground plane as a resonator (Neamah et al., 2023; Unisa & Gowda, 2022). In order to reduce the overall coupling, this parasitic element will produce opposing coupling fields on both sides to attenuate the initial field (Jabire et al., 2021). The driving current supplied to element -1 is represented by I excited, the coupling current between the patches and the parasitic element by I coupling par, and the coupling current between the patch element -1 and element -2 by Icouplingz, as shown in Figure (4). (Zhao et al., 2019). The coefficient

(a) denotes the coupling factor between element -1 and element -2, while the coefficient (B) denotes the coupling factor between the parasitic element and element -1. (Addepalli & Anitha, 2020). The over-coupling current Icoupling of the victim antenna can be derived from the following equations (Khan & Khattak, 2020).

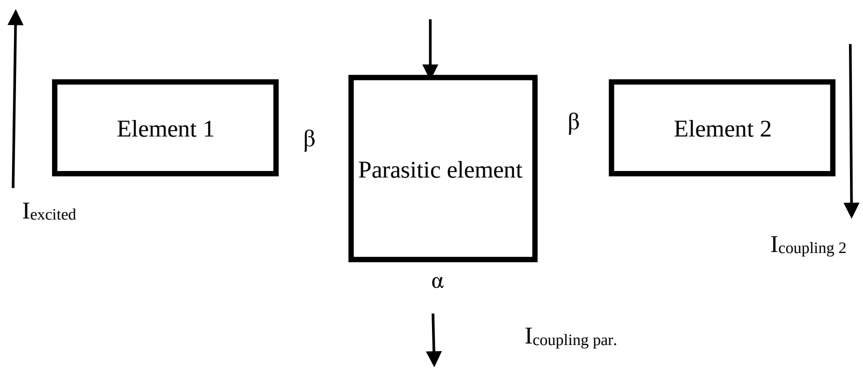


Figure 4: Block Diagram of Parasitic Element Operation

It is clear that if (2) has theright tunning value and becomes approximately equal to (a), then I coupling may be eliminated. Before inserting the parasitic element between MIMO elements (Addepalli & Anitha, 2020), it must be tested alone and its characteristics like centre frequency, bandwidth, return loss, transmission coefficient, and gain should be analysed (Salih et al., 2023). There are many techniques for parasitic element testing with the help of the developed software such as CST microwave studio and HFSS (Khan et al., 2015). The most frequently used method is the frequency domain simulation (Azarm et al., 2018). The parasitic element will be designed on the same dielectric substrate of the patch antenna and inserted between two - port waveguides (Kang et al., 2015) according to Figure (4). The CST program optimizes and modifies the distance between the close side of the parasitic element and the planar waveguide.

E. λ/4 Slot Method

By making two slots in the ground plane that are λ/4 lengths long and correspond to the quarter wavelength of the resonance frequency, mutual coupling between elements can be decreased (Ghimire et al., 2019; Biswal & Das, 2018). As a result, these slots will function as a band-stop filter for surface currents and any electromagnetic waves with wavelengths that match this λ (Salih & Abdullah, 2023). A (2x1) MIMO monopole antenna operating at 5G triple band frequencies was designed in this paper. With a certain design and dimensions, the parasitic element—the second method—was employed to lessen the reciprocal coupling between the two ports.

2 Antenna Design

The proposed antenna is a MIMO (2x1) monopole triple band antenna consisting of two ports operating at frequencies (15.5-22.5-29.5) GHz compact size (72×46) mm^2. The MIMO antenna is printed on anFR4 substrate with E, = 4.4, h = 1.6mm and tand = 0.025 (Maturi & Harikrishna, 2020). The patch is designed in the form of a circular ring consisting of two large circles engraved on the front side of the FR4 material, the first with radius R1 from which a small circle with radius R2 is cut, and its center is C away from the large circle on the y-axis, as in Figure (5).

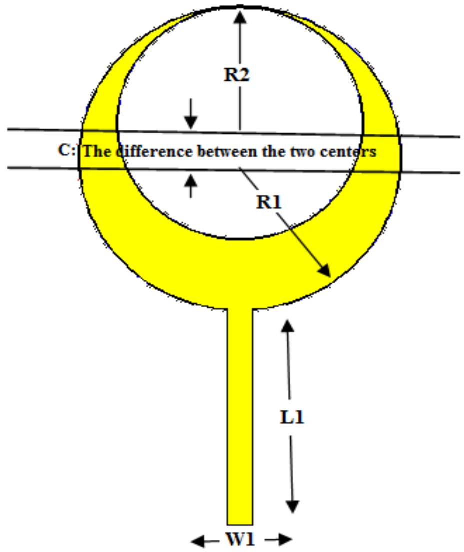
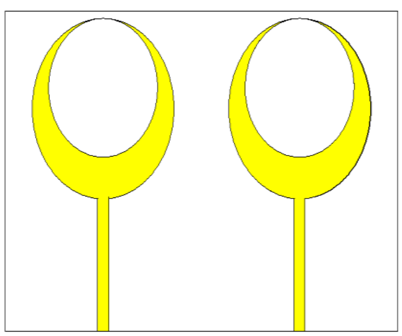
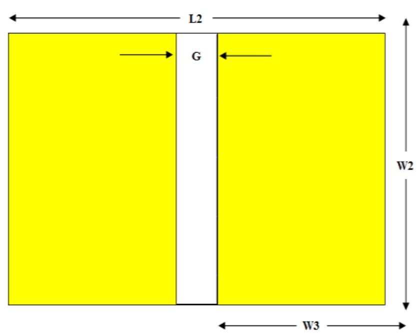


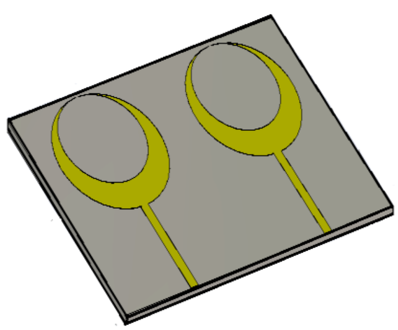
Figure 5: Printed MIMO Antenna Without Parasitic

As seen in Figure (6), the MIMO antenna is intended to be implemented by two patches spaced a specific distance apart, each with its own feed. Table 1 lists all of the patch's and MIMO antenna's measurements.





(a) (b)



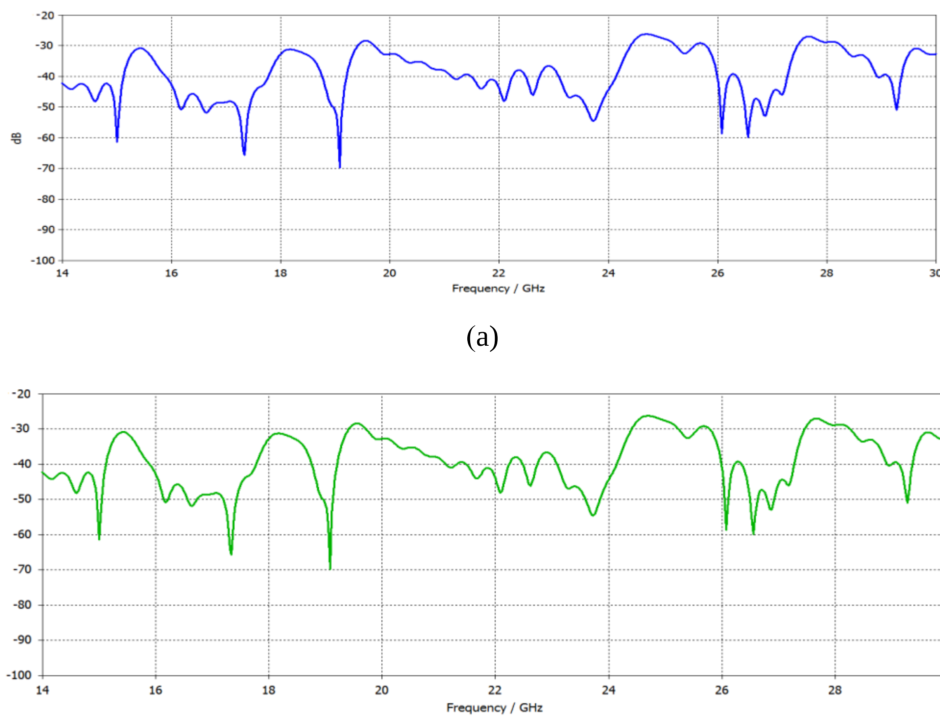
(c)

Figure 6: Printed MIMO Antenna Without Parasitic (a) Top View (b) Back View (c) 3D View

Table 1: The Optimum Design Dimensions of MIMO Antenna

Dimensions	Value
L1	24 mm
L2	72 mm
W1	2 mm
W2	46 mm
W3	32 mm
R1	12.999 mm
R2	10 mm
C	3 mm
G	8 mm

When simulating the MIMO antenna using the CST program before adding the brastic between the two ports, it was found that the isolation between the two ports S_{12} and S_{21} are low, as in Figure (7). This causes a weakness in the efficiency of the antenna's operation, as the antenna loses part of the signal without benefiting from it.

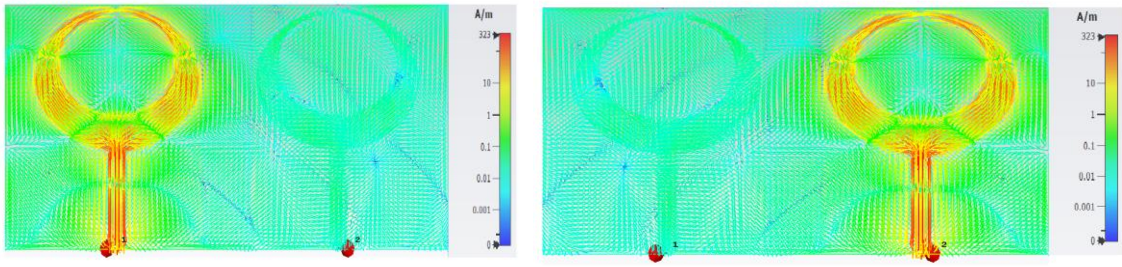


(a)

(b)

Figure 7: Reflection Coefficient: (a) S_{12}. (b) S_{21}.

Since there is no spacer between them to stop the transmission of that antenna in this situation, it performs poorly. Figure (8) illustrates the isolation between the two ports. As a significant portion of the signal moves from the first port to the second and vice versa, this will increase the mutual coupling.



(a) (b)

Figure 8: Current Distribution (Surface Current) MIMO Antenna without Parasitic: (a) Port 1, (b) Port 2

The parasitic is incorporated into the MIMO antenna's front face in the form of six hollow rectangular pieces from the inside as shown in Figure (9) with specific dimensions of length and width as in Table 2. Its benefit lies in reducing the signal exchange between the two antennas to prevent signal loss as a result of this exchange and transmission. Printed MIMO Antenna with s Parasitic and shown in (Figure 10, 11).

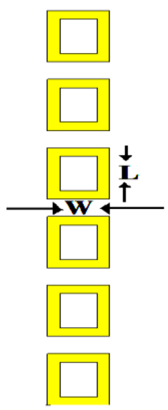


Figure 9: Dimension of Parasitic

Table 2: The Optimum Design Dimensions of Parasitic MIMO Antenna

Material type	**Copper**
Conductor thickness	0.035 mm
L	5 mm
W	4 mm

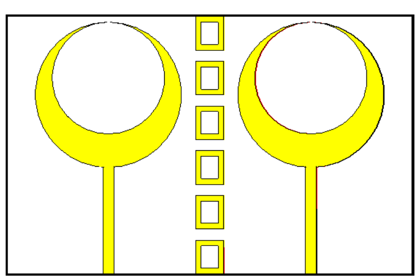
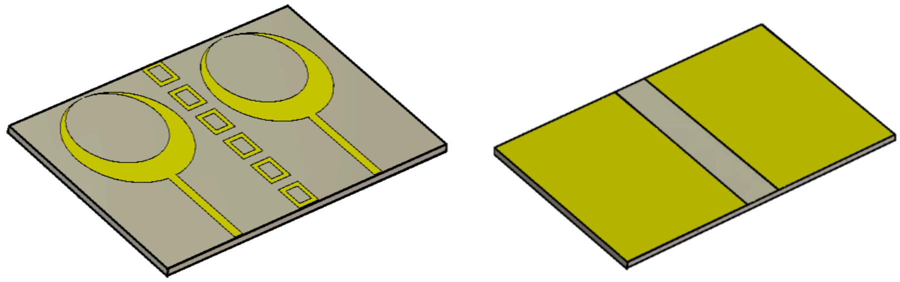


Figure 10: Printed MIMO Antenna with s Parasitic



(a) (b)

Figure 11: Printed MIMO Antenna with Parasitic. (a) 3D Top View (b) 3D Back View

Figure (12), shows the S -S-parameter after adding an extra parasiti. The S_{11} and S_{22} were imiroved to less than -17 dB in all areas between frequencies (15.5-22.5-2.5) GHz, The transmission of the signal from the first antenna to the second S_{12} antenna and from the second antenna to the first antenna S_{21} has become much less than the previous cases, which the insulation between the two antennas was increased from -30 dB to below -50 dB, so the mutual coupling was reduced to the lowest possible.

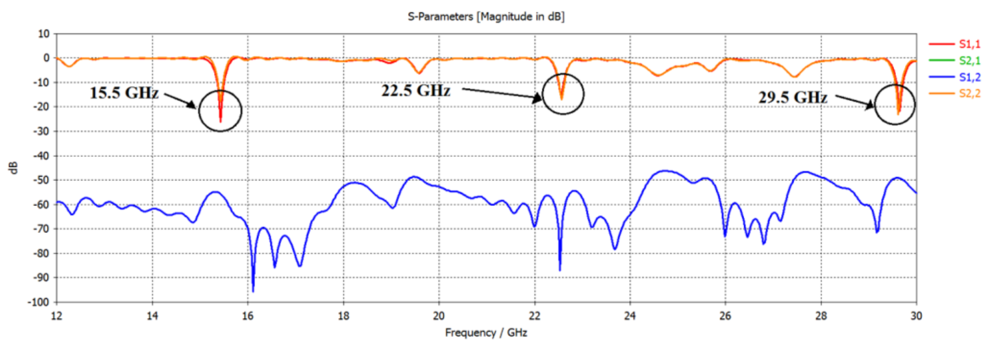
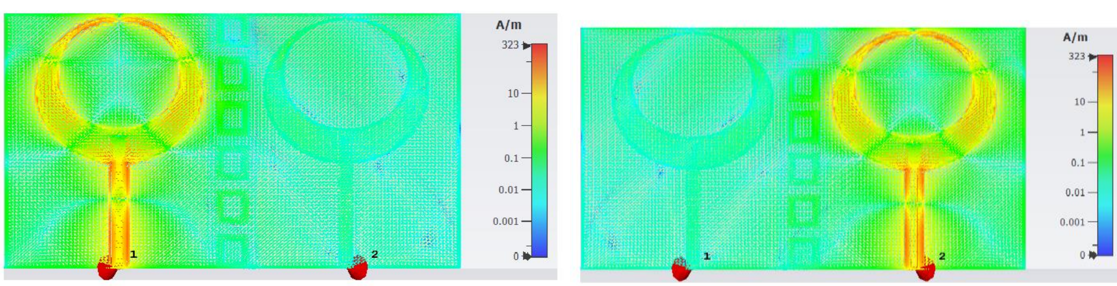


Figure 12: S - Parameter with Simple Parasitic

Mutual coupling as shown in Figure (13) has become less than the first case. The method of designing the parasitic led to the prevention of the exchange of signals between the two antennas (Ren et al., 2014), and improvement in the signal of the S- parameter in general and this is what we aspire to reach.



(a) (b)

Figure 13: Current Distribution (Surface Current) MIMO Antenna with Parasitic: (a) Port 1, (b) Port 2

3 Simulation of Antenna Design

a. Reflection Coefficient

The reflection coefficient was defined as the ratio of the power reflected to the source (P_r) to the power transmitted from the source (P_i) (Zhao et al., 2014). The analysis of the reflection coefficient enables the determination of power loss during transmission from a transmitter to an antenna (Neamah et al., 2023). Figure (5) displays the reflection coefficient values (in dB) measured about frequency. The S_{11} and S_{22} was improved to less than -17 dB in all areas between frequencies (15.5-22.5-2.5) GHz as shown in Figure (14).

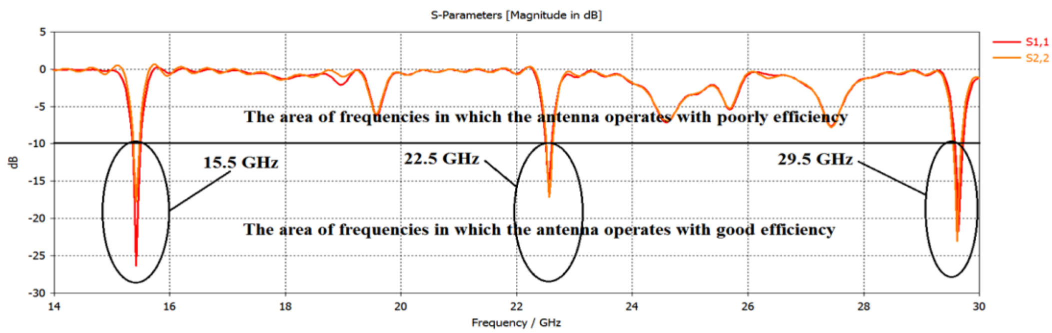
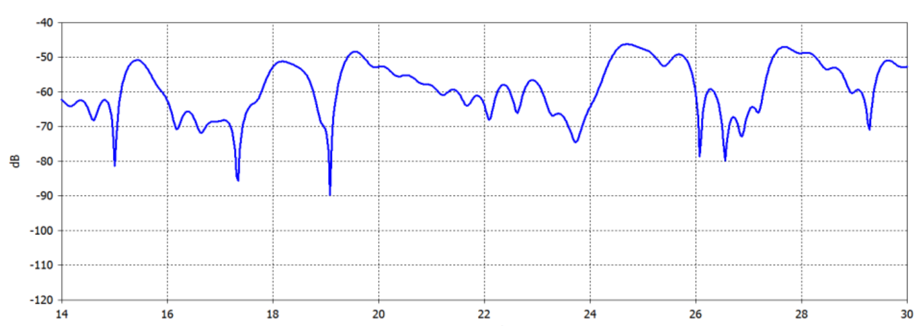


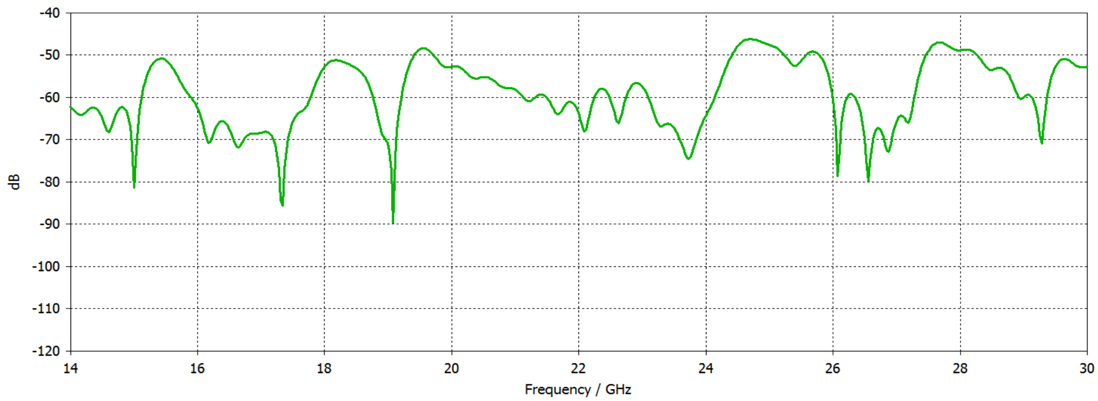
Figure 14: Reflection Coefficient

b. Mutual Coupling Enhancement

The main issue with MIMO systems is mutual coupling. The mutual coupling between MIMO elements is the main disadvantage of MIMO antennas. The electromagnetic interaction between components of a MIMO system is known as mutual coupling (Mikki & Antar, 2015). Either the electromagnetic interaction between the elements or the surface current flowing from one element to another is responsible for the mutual coupling. Mutual coupling is a function of the relative position between elements and becomes large for small spacing (Parchin et al., 2020). Without the mutual coupling, the output power value is approximately equal to the input power, thus, the total efficiency is relatively high. With mutual coupling, the coupling power reduces the output power and the total efficiency. parasitic elements achieve asmall size and offer very high isolation. It is important to note that for a highly effective antenna, decreasing the mutual coupling will decrease the envelope correlation. (Neamah et al., 2023). In this design, the insulation between the two ports was increased to below -50 dB, so the mutual coupling was reduced to the lowest possible as shown in Figure (15).



(a)



(b)

Figure 15: Reflection Coefficient: (a), S_{12}. (b) S_{21}.

c. Voltage Standing Wave Ratio (VSWR)

For optimal energy transmission from the transmitter to the antenna via the feeder line, it is necessary to ensure that the feeder line is properly matched to the antenna (Al-Fayyadh et al., 2017). To accomplish this, the VSWR must fall within the range of 1 to 2 at the intended frequency of the antenna (Alnahwi et al., 2018). Figure (16) plots the VSWR response against frequency. The value of VSWR is confined between 1.0917 and 1.4417 for frequencies (15.5-22.5-2.5) GHz and this is a value since the largest part of the signal will be transmitted and a small part of the signal will suffer from reflection.

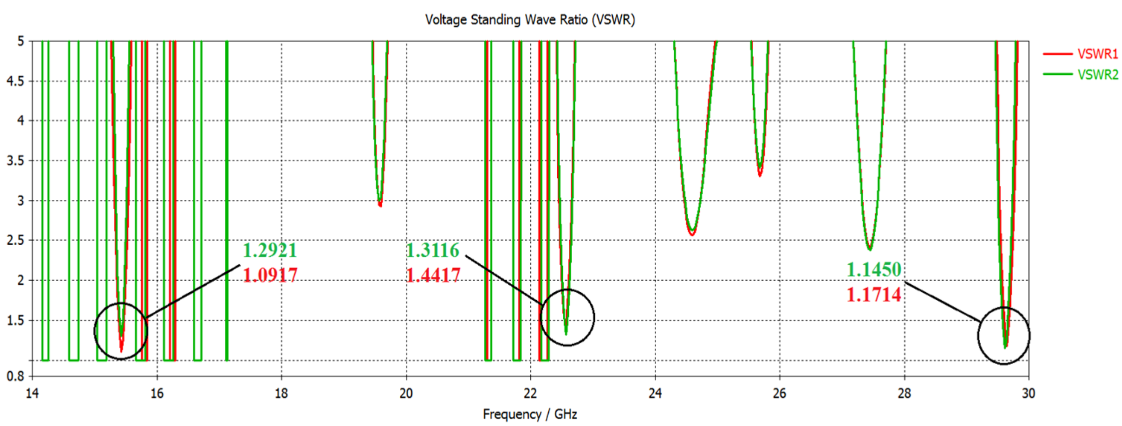
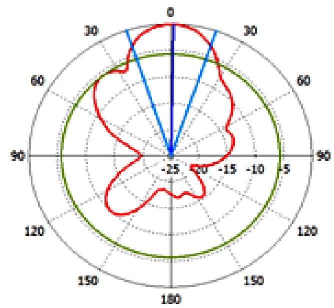


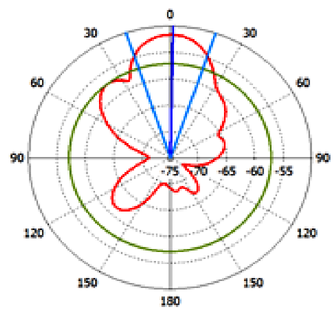
Figure 16: VSWR vs. Frequency of the Antenna

d. Radiation Pattern

Figures (17) and (18) respectively display the MIMO antenna's E-plane patterns and H-plane patterns at (15.5-22.5-2.5) GHz. Figure (19) displays this MIMO antenna's 3D radiation patterns.

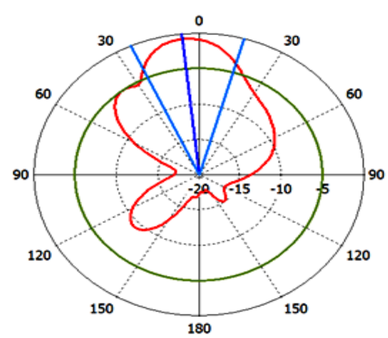


(a)

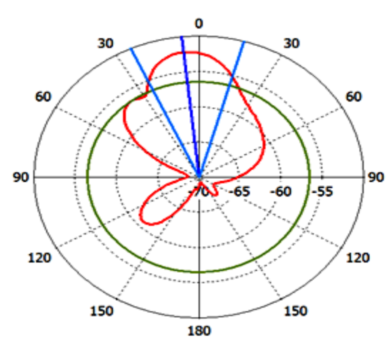


(b)

Figure 17: E-plane Pattern of the MIMO Antenna (a) Port 1 (b) Port 2

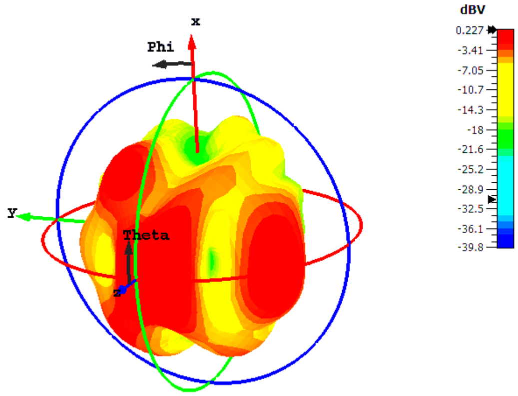


(a)

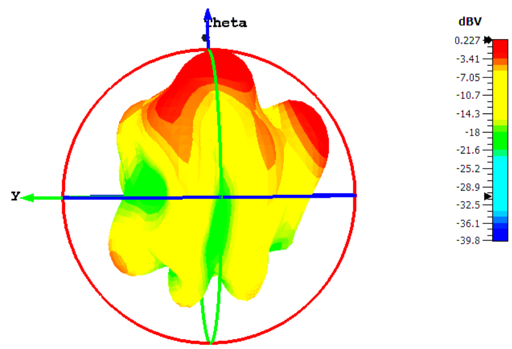


(b)

Figure 18: H-plane Pattern of the MIMO Antenna (a) Port 1 (b) Port 2



(a)



(b)

Figure 19: 3D radiation pattern of the MIMO antenna (a) Port 1 (b) Port 2

4 Conclusion

Multiple antennas are integrated into mobile devices that use multiple-input multiple-output (MIMO) wireless communication technology. Employing several antennas can enhance the transmission rate, so offering users greater multimedia, real-time video communication, and data transfer capabilities. An analysis and design of a triple band MIMO antenna for 5G applications that operates at frequencies between (15.5-22.5-29.5)GHz. The overall size of this MIMO antenna is quite compact, measuring (72x46) mm^2. A double-layer FR4 substrate is used to manufacture the MIMO antenna. Utilising Computer Simulation Technology (CST) 2024, This MIMO antenna's design and simulation results have been completed. Parasitic Element Method There are a lot of parasitic element types that have been utilized to reduce mutual couplings and in his work, a new design of parasitic element is presented which has 6 rectangular pieces that are hollow from the, inside to prevent the transmission of the wave from port one to port two, and vice versa, which causes the loss of transmitted energy. The parasitic was successful in bringing the mutual coupling down to a value below -50 dB. within the range frequencies used in this antenna, which are (15.5-22.5-2.5) GHz, also S_{11} and S_{22} is less than -17 dB, this means that the two antennas transmit the signal by 94 %, and these results are good for transmitting the signal at its maximum strength without losing the return power.

5 Funding

There is no funding for that paper.

6 Conflict of Interest

There are no conflicts of interest involved in this study.

References

[1] Addepalli, T., & Anitha, V. R. (2020). A very compact and closely spaced circular shaped UWB MIMO antenna with improved isolation. *AEU-International Journal of Electronics and Communications*, *114*, 153016. https://doi.org/10.1016/j.aeue.2019.153016

[2] Addepalli, T., & Anitha, V. R. (2020). Compact two-port MIMO antenna with high isolation using parasitic reflectors for UWB, X and Ku band applications. *Progress In Electromagnetics Research C*, *102*, 63-77.

[3] Al-Fayyadh, H. Q., Abdulhameed, A. A., Abdullah, A. S., & Alsabbagh, H. M. (2017). Flexible (2x1) MIMO antenna with electromagnetic band gap unit cell for WiMAX applications. *Turkish Journal of Electrical Engineering & Computer Sciences*, *25*(4), 3061–3072. https://doi.org/10.3906/elk-1603-94

[4] Alibakhshikenari, M., Babaeian, F., Virdee, B. S., Aïssa, S., Azpilicueta, L., See, C. H., ... & Limiti, E. (2020). A comprehensive survey on "Various decoupling mechanisms with focus on metamaterial and metasurface principles applicable to SAR and MIMO antenna systems". *IEEE Access*, *8*, 192965-193004. https://doi.org/10.1109/ACCESS.2020.3032826

[5] Alkaraki, S., & Gao, Y. (2020). Mm-wave low-cost 3D printed MIMO antennas with beam switching capabilities for 5G communication systems. *IEEE access*, *8*, 32531-32541. https://doi.org/10.1109/ACCESS.2020.2973087

[6] Alnahwi, F. M., Abdulhameed, A. A., Abdullah, A. S., Ullah, A., & Abd-Alhameed, R. A. (2018). Mutual coupling reduction of a dual-band 2× 1 MIMO antenna using two pairs of λ/4 slots for WLAN/WiMAX applications. In *Loughborough Antennas & Propagation Conference 2018 (LAPC, 2018)*, 2018. https://doi.org/10.1049/cp.2018.1431

[7] Azarm, B., Nourinia, J., Ghobadi, C., Majidzadeh, M., & Hatami, N. (2018). A Compact WiMAX Band-Notched UWB MIMO Antenna with High Isolation. *Radioengineering*, *27*(4), 983-989. https://doi.org/10.13164/re.2018.0983

[8] Babu, J. K., Krishna, S. R. K., & Reddy, P. L. (2011). A review on the design of MIMO antennas for upcoming 4G communications. *International journal of applied engineering research*, *2*(1), 85.

[9] Biswal, S. P., & Das, S. (2018). A low-profile dual port UWB-MIMO/diversity antenna with band rejection ability. *International Journal of RF and Microwave Computer-Aided Engineering*, *28*(1), e21159. https://doi.org/10.1002/mmce.21159

[10] Chandel, R., & Gautam, A. K. (2016). Compact MIMO/diversity slot antenna for UWB applications with band-notched characteristic. *Electronics Letters*, *52*(5), 336-338. https://doi.org/10.1049/el.2015.3889

[11] European 5G Observatory. National 5G spectrum assignment. https://5gobservatory.eu/

[12] Ghimire, J., Choi, K. W., & Choi, D. Y. (2019). Bandwidth enhancement and mutual coupling reduction using a notch and a parasitic structure in a UWB-MIMO antenna. *International Journal of Antennas and Propagation*, *2019*(1), 8945386. https://doi.org/10.1155/2019/8945386

[13] Gurjar, R., Upadhyay, D. K., Kanaujia, B. K., & Sharma, K. (2019). A novel compact self-similar fractal UWB MIMO antenna. *International Journal of RF and Microwave Computer-Aided Engineering*, *29*(3), e21632. https://doi.org/10.1002/mmce.21632

[14] Iqbal, A., Saraereh, O. A., Ahmad, A. W., & Bashir, S. (2017). Mutual coupling reduction using F-shaped stubs in UWB-MIMO antenna. *IEEE access*, *6*, 2755-2759. https://doi.org/10.1109/ACCESS.2017.2785232

[15] Jabire, A. H., Abdullahi, A. G., Saminu, S., Jajere, A. M., & Sadiq, A. M. (2021). Mutual coupling reduction for triple band MIMO antenna using stub loading technique. *Sule Lamido University Journal of Science and Technology (SLUJST)*, *2*(1), 53-64.

[16] Jamshed, M. A., Ur-Rehman, M., Frnda, J., Althuwayb, A. A., Nauman, A., & Cengiz, K. (2021). Dual band and dual diversity four-element MIMO dipole for 5G handsets. *Sensors*, *21*(3), 767. https://doi.org/10.3390/s21030767

[17] Kang, L., Li, H., Wang, X., & Shi, X. (2015). Compact offset microstrip-fed MIMO antenna for band-notched UWB applications. *IEEE antennas and wireless propagation letters*, *14*, 1754-1757. https://doi.org/10.1109/LAWP.2015.2422571

[18] Khan, M. I., & Khattak, M. I. (2020). Designing and analyzing a modern MIMO-UWB antenna with a novel stub for stop band characteristics and reduced mutual coupling. *Microwave and Optical Technology Letters*, *62*(10), 3209-3214. https://doi.org/10.1002/mop.32425

[19] Khan, M. S., Capobianco, A. D., Naqvi, A., Shafique, M. F., Ijaz, B., & Braaten, B. D. (2015). Compact planar UWB MIMO antenna with on-demand WLAN rejection. *Electronics Letters*, *51*(13), 963-964. https://doi.org/10.1049/el.2015.1056

[20] Khan, M. S., Iftikhar, A., Shubair, R. M., Capobianco, A. D., Asif, S. M., Braaten, B. D., & Anagnostou, D. E. (2020). Ultra-compact reconfigurable band reject UWB MIMO antenna with four radiators. *Electronics*, *9*(4), 584. https://doi.org/10.3390/electronics9040584

[21] Li, D. H., Zhang, F. S., Cao, L. X., & Zhao, Y. (2019). A compact dual band-rejected MIMO Vivaldi antenna for UWB wireless applications. *Progress In Electromagnetics Research Letters*, *86*, 97-105. https://doi.org/10.2528/PIERL19062506

[22] Luo, C. M., Hong, J. S., & Amin, M. (2017). Mutual Coupling Reduction for Dual-Band MIMO Antenna with Simple Structure. *Radioengineering*, *26*(1), 51–58. https://doi.org/10.13164/re.2017.0051

[23] Masoodi, I. S., Ishteyaq, I., Muzaffar, K., & Magray, M. I. (2021). A compact band-notched antenna with high isolation for UWB MIMO applications. *International journal of microwave and wireless technologies*, *13*(6), 634-640. https://doi.org/10.1017/S1759078720001427

[24] Maturi, T., & Harikrishna, B. (2020). Electronic band-gap integrated low mutual coupling dual-band MIMO antenna. *International Journal of Electronics*, *107*(7), 1166-1176. https://doi.org/10.1080/00207217.2020.1726483

[25] Mikki, S. M., & Antar, Y. M. (2015). On cross correlation in antenna arrays with applications to spatial diversity and MIMO systems. *IEEE Transactions on Antennas and Propagation*, *63*(4), 1798-1810. https://doi.org/10.1109/TAP.2015.2398113

[26] Narteni, S., Vaccari, I., Mongelli, M., Aiello, M., & Cambiaso, E. (2021). Evaluating the Possibility to Perpetrate Tunneling Attacks Exploiting Short-Message-Service. *Journal of Internet Services and Information Security*, *11*(3), 30-46. https://doi.org/10.22667/JISIS.2021.08.31.030

[27] Neamah, W. A., Al Sabbagh, H. M., & Al-Rizzo, H. (2023). A Compact Two-Element Linearly and Orthogonal Circularly Polarized MIMO Antenna System for 5G Cellular and WLAN/Wi-Fi 6E Application. *IEEE Access*. https://doi.org/10.1109/ACCESS.2023.3312122

[28] Neamah, W. A., Al Sabbagh, H. M., & Al-Rizzo, H. (2023). New design of a compact 1× 2 Super UWB-MIMO antenna for polarization diversity. *Iraqi Journal for Electrical and Electronic Engineering*, *19*(1), 111-118. https://doi.org/10.37917/ijeee.19.1.14

[29] Neamah, W. A., Salih, A. A. K., Aklo, N. J., & Nangir, M. (2023, September). Design of three selectable notched bands UWB antenna for wireless application. In *AIP Conference Proceedings* (Vol. 2845, No. 1, 050014). AIP Publishing. https://doi.org/10.1063/5.0157611

[30] Parchin, N. O., Al-Yasir, Y. I., Basherlou, H. J., & Abd-Alhameed, R. A. (2020). A closely spaced dual-band MIMO patch antenna with reduced mutual coupling for 4G/5G applications. *Progress In Electromagnetics Research C*, *101*, 71-80. https://doi.org/10.2528/PIERC20013001

[31] Patil, P. S., Parab, G., & Metkari, D. (2020). Mutual coupling reduction techniques on a multiband compact planar MIMO antenna. *International Journal for Research in Applied Science and Engineering*, *8*(7), 2025-2032. https://doi.org/10.22214/ijraset.2020.30733

[32] Rajkumar, S., Anto Amala, A., & Selvan, K. T. (2019). Isolation improvement of UWB MIMO antenna utilising molecule fractal structure. *Electronics Letters*, *55*(10), 576-579. https://doi.org/10.1049/el.2019.0592

[33] Ramakrishna, C., Kumar, G. S., & Reddy, P. C. S. (2021). Quadruple band-notched compact monopole UWB antenna for wireless applications. *Journal of Electromagnetic Engineering and Science*, *21*(5), 406-416. https://doi.org/10.26866/jees.2021.5.r.49

[34] Ren, J., Hu, W., Yin, Y., & Fan, R. (2014). Compact printed MIMO antenna for UWB applications. *IEEE antennas and wireless propagation letters*, *13*, 1517-1520. https://doi.org/10.1109/LAWP.2014.2343454

[35] Salih, A. A. K., & Abdullah, A. S. (2023, March). Design and analysis of a compact dual-band printed rectenna circuit at WiFi and GSM frequencies for microwave power transmission. In *AIP Conference Proceedings* (Vol. 2591, No. 1). AIP Publishing. https://doi.org/10.1063/5.0129460

[36] Salih, A. A. K., & Nangir, M. (2024). Design and Analysis of Wireless Power Transmission (2X1) MIMO Antenna at 5G-Frequencies for Applications of Rectenna Circuits in Biomedical. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, *15*(3), 203-221. https://doi.org/10.58346/JOWUA.2024.I3.014

[37] Salih, A. A. K., Nangir, M., Neamah, W. A., & Hassan, S. H. (2023, September). Design a compact UWB antenna for breast tumor detection system. In *AIP Conference Proceedings* (Vol. 2845, No. 1). AIP Publishing. https://doi.org/10.1063/5.0170497.

[38] Salih, A. A., & Abdullah, A. S. (2019). Design and analysis of a single-band printed rectenna circuit at WiFi frequency for microwave power transmission. *Iraqi Journal for Electrical and Electronic Engineering*, *15*(2), 33-39.

[39] Sanad, M., & Hassan, N. (2014). Novel wideband MIMO antennas that can cover the whole LTE spectrum in handsets and portable computers. *The Scientific World Journal*, *2014*(1), 694805. https://doi.org/10.1155/2014/694805

[40] Tang, Z., Wu, X., Zhan, J., Hu, S., Xi, Z., & Liu, Y. (2019). Compact UWB-MIMO antenna with high isolation and triple band-notched characteristics. *IEEE access*, *7*, 19856-19865. https://doi.org/10.1109/ACCESS.2019.2897170

[41] Tang, Z., Zhan, J., Wu, X., Xi, Z., Chen, L., & Hu, S. (2020). Design of a compact UWB-MIMO antenna with high isolation and dual band-notched characteristics. *Journal of Electromagnetic Waves and Applications*, *34*(4), 500-513. https://doi.org/10.1080/09205071.2020.1724200

[42] Unisa, S. A., & Gowda, K. S. J. (2022). Estimating CSI for Future Generation MIMO Networks Using Deep Learning Techniques and its Applicability to Varied Environments. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 13(4), 124-136. https://doi.org/10.58346/JOWUA.2022.I4.008

[43] Yadav, D., Abegaonkar, M. P., Koul, S. K., Tiwari, V. N., & Bhatnagar, D. (2018). Two element band-notched UWB MIMO antenna with high and uniform isolation. *Progress In Electromagnetics Research M*, *63*, 119-129.

[44] Zhao, J. Y., Zhang, Z. Y., Liu, Q. Q., Fu, G., & Gong, S. X. (2014). Printed UWB MIMO antenna with different polarizations and band-notch characteristics. *Progress In Electromagnetics Research Letters*, *46*, 113-118. https://doi.org/10.2528/PIERL14050502

[45] Zhao, Y., Zhang, F. S., Cao, L. X., & Li, D. H. (2019). A compact dual band-notched MIMO diversity antenna for UWB wireless applications. *Progress In Electromagnetics Research C*, *89*, 161-169. https://doi.org/10.2528/PIERC18111902

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