JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **16** No 3, 03006(5pp) (2024)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **16** № 3, 03006(5cc) (2024)

REGULAR ARTICLE

Advanced 2 × 1 MIMO Antenna Design for 5G Wireless Communications with Equivalent Circuit Integration

N. Meskini[1], B. Aghoutane[1,*] ✉, H. Bezzout[1], H. El Faylali[1], Ch R. Prasad[2], M. El Ghzaoui[3]

[1] *Faculty of Sciences, Ibn Tofail University, Kenitra, Morocco*
[2] *Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India*
[3] *Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fes, Morocco*

(Received 10 April 2024; revised manuscript received 17 June 2024; published online 28 June 2024)

This study proposes a novel approach to designing reconfigurable multiple input multiple output (MIMO) antennas operating at 26 GHz. The design process begins with determining the dimensions of polygonal patches using a transmission line model, followed by the implementation of quarter-wavelength transformers for the microstrip feed lines. The antennas are constructed on FR4 substrate, chosen for its accessibility and cost-effectiveness, with specific electromagnetic properties. A 2 × 1 MIMO antenna configuration is suggested by combining traditional polygon-type patch radiation antennas on a 50 mm × 30 mm ground plane. To address impedance mismatch issues when connecting reconfigurable antennas to a common feed line, an equivalent circuit model is employed. This model incorporates lumped elements such as capacitances, resistors, and inductors to simulate the antenna's behavior accurately. Adjustments to these components are made to achieve desired S_{11} and S_{22} characteristics. The proposed design is evaluated through simulations using HFSS and AWR, demonstrating its effectiveness in achieving the desired performance metrics. Overall, this research presents a comprehensive approach to designing reconfigurable MIMO antennas, offering insights into practical implementation and performance optimization in wireless communication systems.

Keywords: MIMO Antenna, Equivalent Circuit, Gain, 5G.

DOI: 10.21272/jnep.16(3).03006 PACS number: 84.40.Ba

1. INTRODUCTION

As cellular technologies advance, antennas must be able to operate well in a wide range of frequency bands in order to support a wide range of applications. There may be physical space constraints in the system, though, if several antennas with various frequencies and orientations are integrated. In response, there is an increasing trend toward antenna designs that combine many antenna functions into a single emitter structure [1]. The advantages of microstrip patch antennas are their low profile, low weight, affordability, and compatibility with flexible or plastic technology [2]. A significant issue in antenna design is ensuring impedance matching, especially for reconfigurable antennas that have varying electrical lengths at different frequencies [3].

Moreover, the reconfigurability of microstrip patch antenna designs across several frequencies is improved by the use of switching capabilities [4]. Reconfiguration entails modifying the electromagnetic fields or current distribution of the antenna, frequently by adjusting the radiation or impedance characteristics. Reconfiguration mechanisms can be activated by mechanical, electrical, or optical components. Examples of mechanical actuators, electrically triggered elements, or optically triggered mechanisms are slotted structures in the ground plane or patch. In [5] proposed an artificial switch to regulate resistance components, while another technique makes use of the liquid material's flow inside tubes that are engineered into the antenna for switching. In [6] a square-slotted patch antenna for 5G, showing strong performance through rigorous analysis, advancing efficient antenna design for high-bandwidth wireless communication. In [7] Proposes GPEEC model for analyzing antennas with lumped LC loads, integrating into optimization for systematic manipulation of radiation modes, validated through theoretical and experimental verification for mobile terminal applications. In [8] introduces a mm-wave microstrip patch antenna with silo slots on Rogers 5058 substrate, showcasing dual operating bands at 28.1 GHz and 37.9 GHz, with peak gains of 5.2 dBi and 6.5 dBi, suitable for 5G applications in the 28/38 GHz.

This study introduces a new method for designing reconfigurable MIMO antennas at 26 GHz. It involves determining polygonal patch dimensions and using quarter-wavelength transformers for microstrip feed lines. Antennas are built on FR4 substrate, with a 2 × 1 MIMO configuration on a 50 mm × 30 mm ground plane. An equivalent circuit model addresses impedance mismatch, with adjustments made for desired performance. Simulations in HFSS and AWR validate the

---

[*] Correspondence e-mail: bilal.aghoutane@gmail.com

Cite this article as: N. Meskini et al., *J. Nano- Electron. Phys.* 16 No 3, 03006 (2024) https://doi.org/10.21272/jnep.16(3).03006

design's effectiveness. Overall, the research offers a comprehensive approach to optimizing reconfigurable MIMO antennas for wireless communication systems.

2. MIMO ANTENNA CONFIGURATION

The capacitors positioned across the polygons are the primary means by which the electrical length of the proposed reconfigurable polygon patch antenna is altered. Furthermore, by matching the impedances according to the resonance frequencies, the capacitance values are modified to ensure that the wave is properly transmitted from one patch to the next. Different operation frequencies are achieved depending on whether artificial switches permit transmission across the patches. This is because the electrical dimension of the antenna is altered. The transmission line model [8] is used to determine the antennas' fundamental parameters. AWR software proved used to analyze the equivalent lumped circuit model and ANSYS HFSS software was used to run full wave simulations for the proposed MIMO antenna.

2.1 Proposed Model

The size of the polygon's patches for the 26 GHz antennas are first determined using the transmission line model. The quarter wavelength transformer is then used to determine the microstrip feed line for the 26 GHz antenna. Fig. 1 depicts the reconfigurable single element antenna that was constructed on the FR4 substrate. The relative permeability of FR4, a commercially accessible, reasonably priced, and workable substrate, is 4.3, and its tangent loss is 0.019. There is a millimeter-sized space left between each radiating patch. The substrate's height (*h*) is 1 mm. The calculated dimensions for the radiating element of the antenna are presented in Table 1.

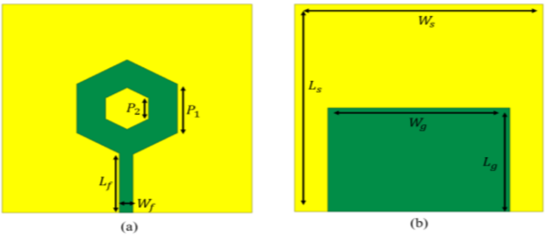
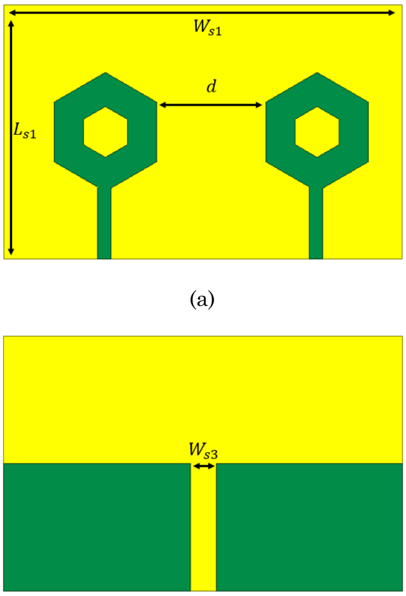


Fig. 1 – Signal element

The suggested 2 × 1 MIMO antenna set is shown in Fig. 2. It is achieved by fusing a traditional polygon-type patch radiation antenna. The suggested MIMO antennas are positioned as shown on a 50 mm × 30 mm ground plane that has been etched with a 1 mm thick layer.

Table 1 – Dimensions of designed antenna

Dimension	Value (mm)	Dimension	Value (mm)
P_1	1	W_g	22
P_2	7	L_g	15
L_f	8.4	W_{s1}	50
W_f	1.6	L_{s1}	30
W_s	30	d	12.8
L_s	30	W_{s3}	3



(a)

(b)

Fig. 2 – Two Element

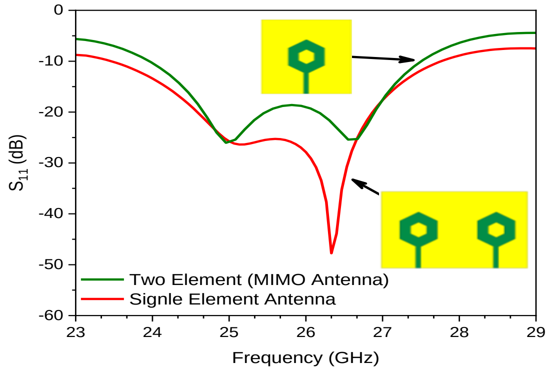


Fig. 3 – Comparison S_{11} between single element and two elements

Fig. 3 illustrates a detailed comparison between the S_{11} parameters of both single-element and two-element systems within the context of the study. In the analysis, it is observed that the two-element system showcases a marginally broader bandwidth spanning from 23.4 to 27.8 GHz, in contrast to the narrower bandwidth of the single-element system ranging from 23.9 to 27.5 GHz. This discrepancy in bandwidth performance between the two systems hints at potential benefits in terms of frequency coverage that may be obtained by utilizing the two-element system configuration. Fig. 4 illustrates a comparison of the Voltage Standing Wave Ratio (VSWR) between single-element and two-element systems. In the case of the two-element system, the VSWR measures at a lower value of 0.6. Conversely, for the single-element system, the VSWR is notably higher, recorded at 5.3. This comparison highlights a significant disparity in VSWR between the two configurations. A lower VSWR indicates better impedance matching and less signal reflection, which is favorable for system performance. Therefore, the two-element system appears to exhibit superior impedance characteristics compared to the single-element system, as evidenced by its substantially lower VSWR value.

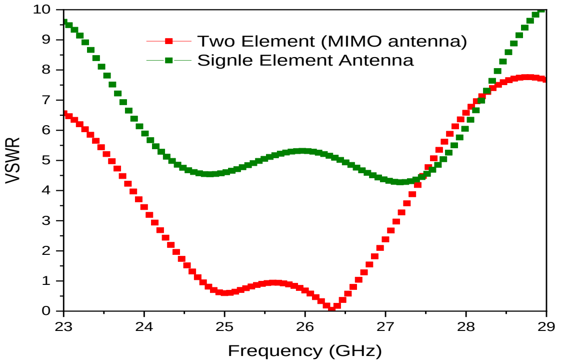


Fig. 4 – Comparison VSWR between single element and two elements

2.2 Equivalent Circuit

When a reconfigurable antenna is connected to a common feed line, an impedance mismatch issue is likely to arise. The equivalent circuit model gives a solid method to solving this problem by simply adding a lumped element for each section of the antenna. To obtain the proper value for this element, the antenna must be appropriately modeled. In this study, we employed a fairly complete equivalent circuit that included models for the various elements of the antenna, which are described in depth in this section. The two identical parts of the suggested antenna are each represented using lumped elements such as capacitances, resistors, and inductors. Together, these components create an equivalent circuit model, facilitating comparison of actual performance with HFSS and AWR simulations. As depicted in Fig. 5, adjustments to the components are made to achieve the desired S_{11} and S_{22} characteristics.

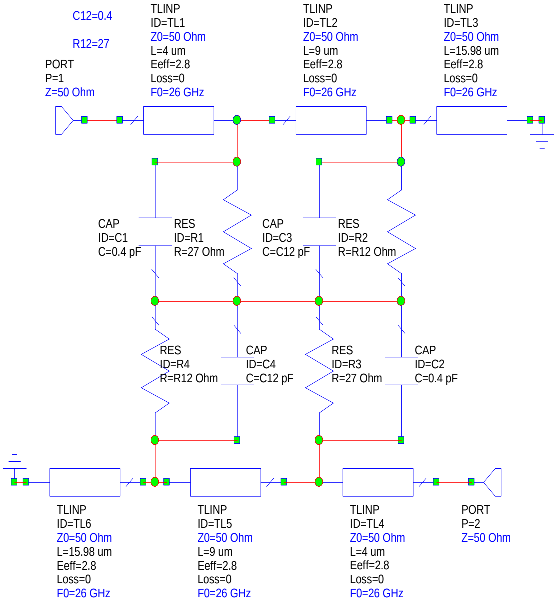


Fig. 5 – Circuit Model of the proposed MIMO Antenna

3. RESULTS AND DISCUSSION

The comparison depicted in Fig. 6 between the simulated and equivalent circuit representations for the S_{11} parameter provides valuable insights into the modeling and analysis of the system's performance. The bandwidth of the simulated model, ranging from 23.5 to 27.8 GHz, is slightly wider than that of the equivalent circuit model, which spans from 23.8 to 27.5 GHz. Fig. 7 presents the comparison between simulated and equivalent circuit representations for the S_{22} parameter. In the simulated model, the bandwidth extends from 23.8 to 27.6 GHz, whereas in the equivalent circuit model, the bandwidth spans from 23.5 to 27.8 GHz.

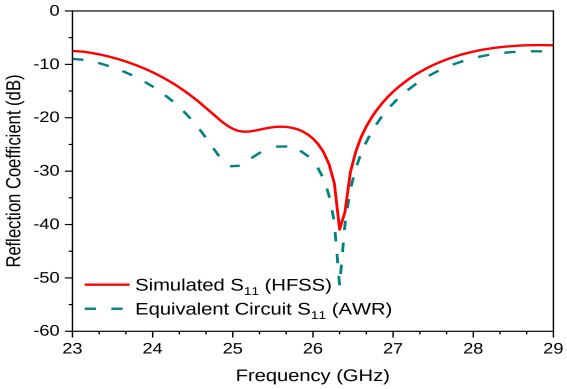


Fig. 6 – Simulated and Equivalent circuit for S_{11}

This variance suggests that the simulated model may capture additional frequency components or exhibit a broader frequency response compared to the simplified equivalent circuit model. The difference in bandwidth underscores the significance of model accuracy and complexity. While simulated models aim to comprehensively capture real-world intricacies despite their computational intensity, equivalent circuit models offer a more streamlined representation that sacrifices some detail for computational efficiency.

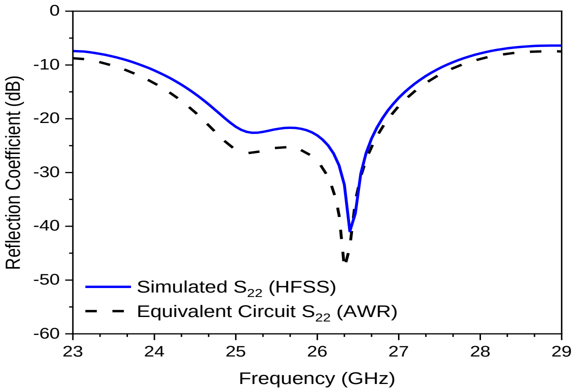


Fig. 7 – Simulated and Equivalent circuit for S_{22}

Fig. 8 displays the three-dimensional gain pattern for the proposed Multiple Input Multiple Output (MIMO) antenna. The gain of the antenna is approximately 14 dB, observed at the resonant frequency of 26 GHz. This depiction of the gain pattern provides valuable insights into the antenna's radiation characteristics, illustrating how signal strength varies across different angles and orientations. The high gain of 14 dB indicates the antenna's effectiveness in transmitting and receiving signals efficiently, particularly at its resonant frequency.

Fig. 9 presents the E-plane (red curve) and H-plane (green curve) radiation patterns for the proposed Multiple Input Multiple Output (MIMO) antenna.

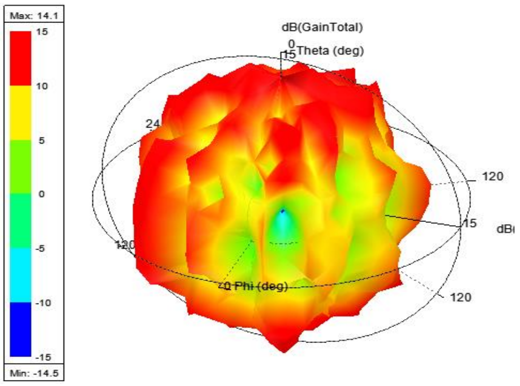


Fig.8 – Gain 3D for proposed MIMO Antenna

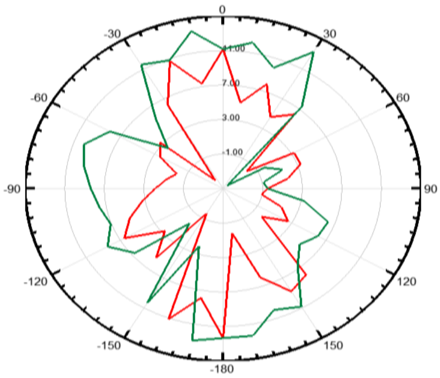


Fig. 9 – E-plane (red curve) & H-plane (green curve) of the proposed MIMO Antenna

These patterns illustrate simulated radiation characteristics at the operational frequency of the antenna. In the E-plane (electric plane), represented by the red curve, the highest radiation is observed at a 180-degree angle. This indicates the direction in which the antenna radiates most effectively in the plane perpendicular to the direction of the electric field. Conversely, in the H-plane (magnetic plane), depicted by the green curve, the primary radiation beam is oriented towards -180 degrees. This signifies the direction of maximum radiation in the plane perpendicular to the magnetic field.

4. CONCLUSION

In conclusion, this article offers a thorough analysis of the proposed MIMO antenna system, highlighting its performance characteristics and capabilities. The comparison between simulated and equivalent circuit models emphasizes the importance of selecting appropriate modeling approaches. The visualization of gain patterns demonstrates the antenna's strong signal transmission and reception abilities, particularly at its resonant frequency of 26 GHz, achieving a gain of approximately 14 dB. Additionally, the examination of E-plane and H-plane radiation patterns provides crucial insights into the antenna's directional radiation properties. Overall, this research contributes valuable knowledge to antenna design and technology, with implications for various wireless communication applications.

REFERENCES

1. T. Nahar, S. Rawat, *Wireless Pers. Commun.* **129**, 1585 (2023).
2. A.S.A. Gaid, M.A.M. Ali, A. Saif, W.A.A. Mohammed, *Cogent Eng.* **11** No 1, (2024).
3. S. Dwivedi, *IGI Global*, 201 (2023).
4. B. Aghoutane, N. Meskini, M. Elghzaoui, H.E. Faylali, *International Conference on Electronics, Control, Optimization and Computer Science (ICECOCS)* **2018**, 1, (2018).
5. J. Dong, Y. Zhu, Z. Liu, M. Wang, *Nanomaterials* **11** No 12, 3400 (2021).
6. N. Meskini, B. Aghoutane, H. Hiddar, T. Islam, M. El Ghzaoui, H. El Faylali, *J. Nano- Electron. Phys.* **15** No 4, 04030 (2023).
7. Y. Dou, H. Chen, *IEEE J. Multiscale Multiphys. Comput. Techn.* **8**, 123 (2023).
8. H. Hiddar, B. Aghoutane, T. Islam, B. Belkadi, S. Das, A. Filali-Maltouf, *J. Nano- Electon. Phys.* **15** No 5, 05029 (2023).
9. C.A. Balanis, *Modern Antenna Handbook* (New York: Wiley: 2011).

Удосконалений дизайн антени MIMO 2 × 1 для бездротового зв'язку 5G з інтеграцією еквівалентної схеми

N. Meskini[1], B. Aghoutane[1], H. Bezzout[1], H. El Faylali[1], Ch R. Prasad[2], M. El Ghzaoui[3]

[1] *Faculty of Sciences, Ibn Tofail University, Kenitra, Morocco*
[2] *Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India*
[3] *Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, Fes, Morocco*

У цьому дослідженні пропонується новий підхід до проектування реконфігурованих антен із багатьма входами й виходами (MIMO), що працюють на частоті 26 ГГц. Процес проектування починається з визначення розмірів багатокутних ділянок за допомогою моделі лінії передачі, після чого впроваджуються чверть хвильові трансформатори для мікросмугових ліній живлення. Антени побудовані на підкладці FR4, вибраній через її доступність і економічну ефективність, зі спеціальними електромагнітними властивостями. Пропонується конфігурація антени 2 × 1 MIMO шляхом поєднання традиційних антен багатокутного типу на площині заземлення 50 мм x 30 мм. Для вирішення проблеми невідповідності імпедансу під час підключення реконфігурованих антен до загальної лінії живлення, використовується модель еквівалентної схеми. Модель містить зосереджені елементи, такі як ємності, резистори та котушки індуктивності, щоб точно імітувати поведінку антени. Коригування цих компонентів здійснюється для досягнення бажаних характеристик S11 і S22. Пропонована конструкція оцінюється шляхом моделювання з використанням HFSS і AWR, що демонструє її ефективність у досягненні бажаних показників продуктивності. Загалом це дослідження представляє комплексний підхід до проектування реконфігурованих антен MIMO, пропонуючи розуміння практичної реалізації і оптимізації продуктивності в системах бездротового зв'язку.

Ключові слова: MIMO антенна, Еквівалентна схема, Підсилення, 5G.