A Compact dual band MIMO Antenna for wireless communication applications

Fouad FERTAS[1], Khelil FERTAS[1], Mouloud CHALLAL[1], IEEE, Senior Member

Signals and Systems Laboratory, Institute of Electrical and Electronic Engineering, University M'Hamed BOUGARA of Boumerdes, Boumerdes, Algeria

e-mail: f.fertas@univ-boumerdes.dz, khelil.fertas@g.enp.edu.dz, mchallal@gmail.com

Abstract: In this study, a compact dual band 2-element Multiple Input Multiple Output (MIMO) multiband antenna is designed. Two radiating patches make up the suggested antenna, which aims to produce multiband resonance antenna. The 45×33 mm2 two element MIMO antenna is printed on a 1.6 mm thick FR-4 substrate with a dielectric constant of εr = 4.3 and a loss tangent of 0.02. An optimized dual band antenna was produced as a result of a parametric research based on the FDTD technique, which improved the structure's performance with regard to operational bandwidth. Additionally, a separate 50Ω-fed two-element MIMO arrangement is taken into consideration. By introducing spatial diversity into the MIMO arrangement, good isolation can be achieved without the need to use well-known techniques of decoupling structures. Results shows that the system has a mutual coupling of less than -15 dB between the various elements and operates on two bands: "3.5GHz WiMAX." and "4.2 GHz " Moreover, an analysis of the Diversity Gain (DG), Envelope Correlation Coefficient (ECC) and Channel Capacity Loss (CCL) parameters shows that they satisfy the practical standards: DG > 9.80, ECC < 0.06, and CCL < 0.4 bits/s/Hz over the relevant bands.

Keywords: CPW-Fed; Dual Band Antennas; WLAN/ WiMAX; MIMO Antenna; MIMO Metrics

1. INTRODUCTION

The use of MIMO antenna technology is growing more widespread in modern wireless communication networks. This method is often used to improve channel capacity and address multipath fading without using additional bandwidth or transmit power [1,2]. multiband operational features like Bluetooth, Wi-Fi, WiMAX, and other comparable technologies that are being integrated into a single mechanism are necessary for modern mobile devices [3]. In addition to being qualified for 5G mobile terminals, this technology is used in 4G mobile terminals, However, there are two main obstacles to overcome in the design of printed MIMO antennas: improving isolation between the antenna parts and downsizing. Numerous methods were developed and published in the literature [4–10] to overcome these problems. [4] describes a dual-band mm-wave 4-element MIMO antenna for fifth generation (5G) wireless applications. The antenna elements are orthogonally placed to each other as a design concept to enhance the isolation between the elements up to 30 dB. [5] Proposed a compact CPW-fed 2/4-element MIMO antenna design for WLAN, WiMAX, and satellite bands with an operational bandwidth spanning from 2.3 THz to 2.7 THz and from 5.5 THz to 8.9 THz. The suggested design achieves high isolation using frequency selective surface technique, it provides more than −30 dB isolation between the different ports, [6] Suggests a four-element MIMO design consists of two bevelled circular antennas with a common partial ground. This antenna achieved bandwidth from 5.22 GHz to 14.89 GHz and offers isolation better than 15 dB in most of the operational bands while isolation more than 20 dB in the entire X-band, The Envelope Correlation Coefficient (ECC) of the antenna is less than 0.017 and DG is more than 9.9175, A 4-element half-circle-form printed MIMO antenna that operates at 2.2–2.45 GHz, spanning several of the 4G and WLAN frequencies, is described in another paper [7]. The envelope correlation coefficient, or ECC, for it is 0.3. For the ISM band, authors in [8] suggested a modest 4x4 MIMO antenna consists of four L-shaped with a rectangular slot at the center and truncated edges at the corner of each patch element with improved isolation and ECC < 0.5, and DG of about 10 dB. A 4-port MIMO antenna is recommended for WLAN applications in [9], [10] propose MIMO antenna with dual polarization (1x2) based on the cavity-backed bowtie with parasitic elements and has a wide impedance bandwidth and acceptable isolation. however, only the simulated diversity performance figures were shared.

typically, these antennas often offer two or three frequency bands and a bigger substrate size. Alternatively, the isolation is not good enough [11–19].

This research proposes a 45×33 mm^2 small 1×2 dual-band coplanar waveguide (CPW)-fed MIMO antenna. The structure is printed on a FR-4 substrate with a relative permittivity of 4.3 and a thickness of 1.6 mm. Reduced coupling over the dual bands is the consequence of improving the isolation between the radiating elements through the application of the spatial diversity technique. Additionally, the MIMO antenna's diversity performance metrics are examined with respect to the ECC, CCL parameters. With the use of Finite Difference Time Domain analysis (FDTD), the suggested MIMO antenna is studied and simulated.

2. DESIGN OF SINGLE ELEMENT ANTENNA AND RESULTS

A. Design and Configuration of a Single Element Antenna

a 30×30 mm2 CPW-fed monopole antenna is developed on a FR-4 substrate and is used as a reference antenna for the MIMO construction. For frequencies lower than 6 GHz, the FR-4 dielectric is widely utilized in antenna construction due to its good electrical characteristics and low cost. The radiating parts of the antenna are made of copper, with a thickness of t = 0.03 mm. To enable dual-band behavior, three stubs of length L1, L2, and L3 are loaded onto a basic fork-shaped stub Fig. 1 shows the antenna design, and Table I summarize the dimensions.

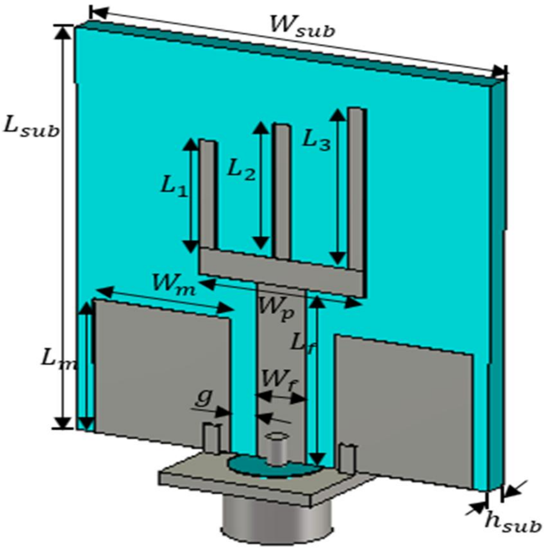


Figure 1: geometry of the proposed antenna

TABLE I. dimension values of the reference antenna

Parameter	Value (mm)	Parameter	Value (mm)
W_{sub}	25	L_2	10
L_{sub}	30	L_3	12
Wf	2.94	W_m	8.3
L_f	13	L_m	10
W_p	10	h_{sub}	1.6
L_1	8	g	1.7

B. Results and Discussions

The development of dual-band properties for multiband applications is the goal of this project. For the intended resonance frequencies to be reached, the stubs lengths (L_1, L_2 and L_3) of the suggested antenna have independent adjustment options. The matching return loss are depicted in Figure 2. The two frequency bands, "3.5GHz WiMAX" and "4.2/6.5 GHz " are covered and meet the prescribed bandwidths, according to the simulated scattering-parameters. The Improvement in the impedance bandwidth and three resonances are produced by superimposing three stubs with different sizes.

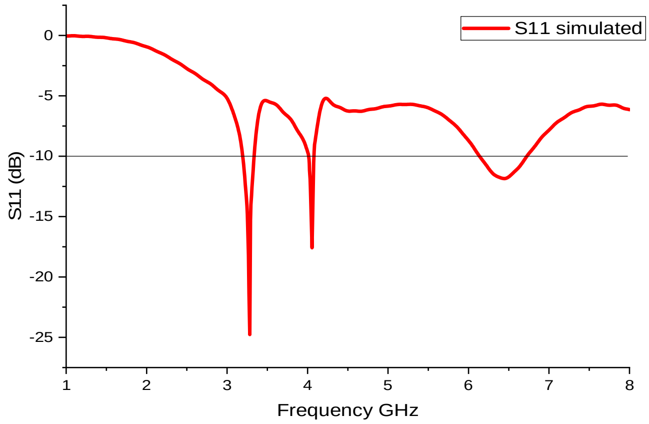


Figure 2: Return loss of the reference antenna

3. DESIGN OF THE PROPOSED 1X2 MIMO ANTENNA AND RESULTS

A. Design and Configuration of MIMO Antennas

Fig. 3 shows the proposed single element antenna being used to construct a 1×2 MIMO antenna. Identical antennas are positioned orthogonally to maximize the polarization diversity in the proposed MIMO antennas and ensure sufficient isolation. The MIMO antenna is 45 by 33 mm2. On each of the antenna's feeding microstrip lines, two SMA connectors were connected.

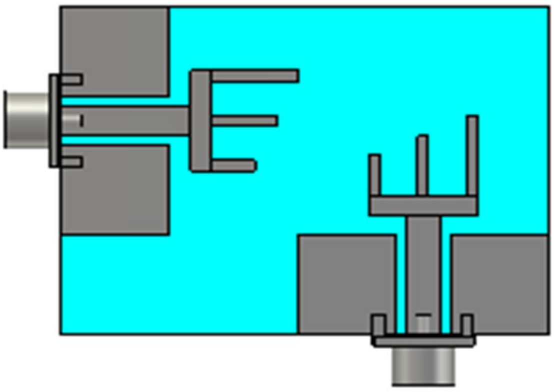
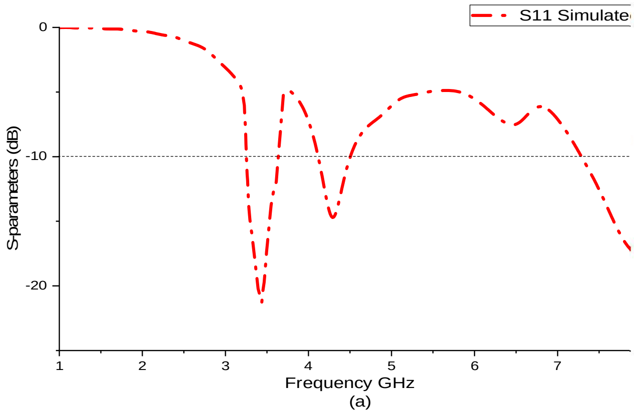


Figure 3: Configuration of the 2-element Dual Band MIMO antenna

B. *Results and Discussions*

1) *S-Parameters Analysis*

The simulated S-parameters for port-1 are contrasted in Figures 4(a) and (b). The outcomes of the experiment demonstrate that the two frequency bands of "3.5 GHz WiMAX" and "4.2 GHz " provides adequate bandwidth. features, from 3.10 GHz to 3.60 GHz and from 4 GHz to 4;6 GHz. Even though there is still sufficient bandwidth in the antenna to achieve the desired band characteristics, there is a slight shift in the reflection coefficient. In the regions of operation, the separation between the antenna components of the MIMO antenna is better than 15 dB, demonstrating good isolation.



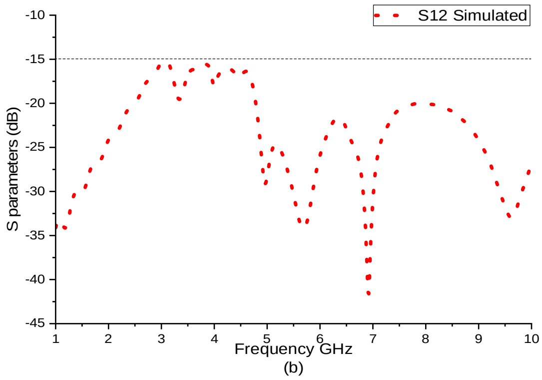
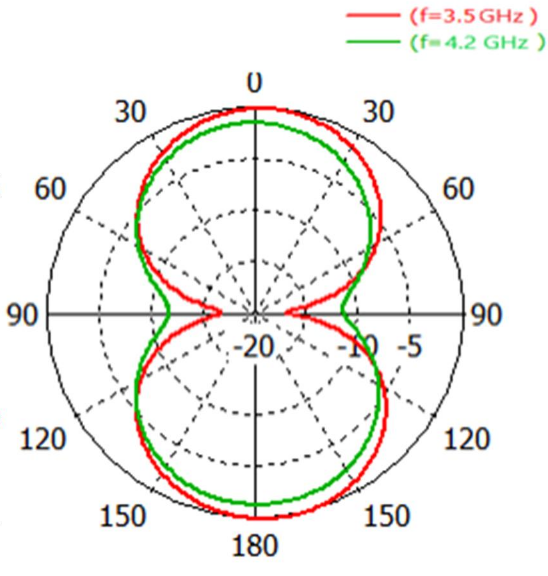


Figure 4 Simulated: (a) Reflection coefficient, and (b) mutual coupling of the 1×2 MIMO antenna

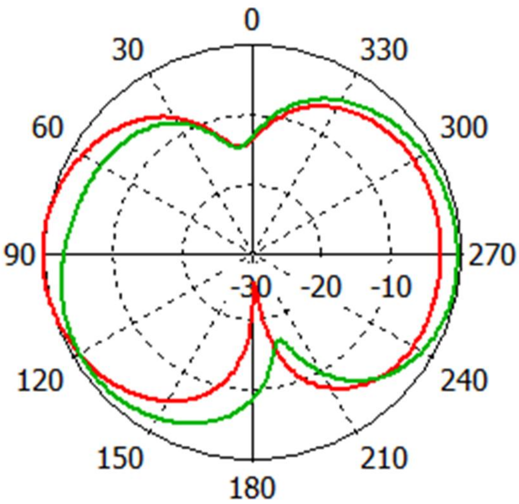
2) Radiation Pattern

The simulated two-dimensional radiation patterns for antenna-1 on the E and H planes at 3.5 and 4.2 GHz frequencies, which translate to φ=0° and θ =90°, respectively, are displayed in Figure 5.

Figure 5 shows the simulated radiation patterns of antenna 1 (Ant. 1) for frequencies of 3.5 GHz and 4.2 GHz on the E and H planes, which correspond to φ=0° and φ=90°, the antenna exhibits a bidirectional radiation in both plane



(a)



(b)

Figure 5 Simulated E and H plane 2-D radiation patterns of the MIMO antenna for 3.5 GHz and 4.2 GHz (a) Ant-1 φ=0° (b) θ =90°.

3) MIMO Parameters

In this part, the diversity performance of the proposed MIMO antenna is evaluated. This can be accomplished by examining the ECC, DG, and CCL measures. The scattering parameters are used to evaluate them.

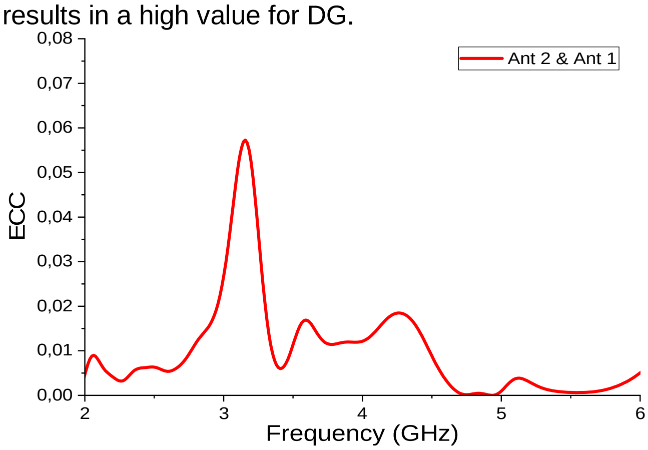
A. "Envelop Correlation Coefficient (ECC)" and "Diversity Gain (DG)"

ECC and DG are used as performance metrics for MIMO antenna diversity in order to assess the antennas overall system performance and antenna efficiency. By utilizing the ECC and DG, the MIMO system designer can assess the level of coupling that develops between the system's antenna ports and the quantity of transmission power loss that results from diversity methods used on the module. Reducing ECC to the lowest feasible level and raising DG between port pairs to the maximum feasible level are required in order to minimize mutual coupling. DG is mathematically related to ECC by Equation (1), while ECC is conceptually connected to the MIMO antenna's scattering matrix by Equation (2).

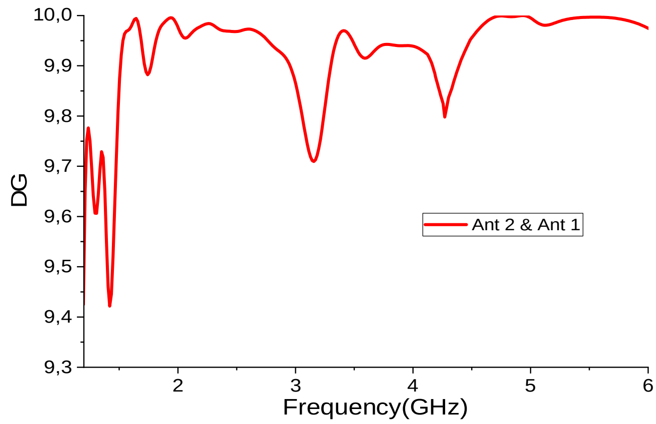
$$DG = 10\sqrt{1 - ECC^2} \qquad (1)$$

$$ECCij = \frac{\left|S_{ii}^{*}S_{ij}+S_{ji}^{*}S_{jj}\right|}{\left(1-|S_{ii}|^2-|S_{ji}|^2\right)\left(1-|S_{jj}|^2-|S_{ij}|^2\right)} \qquad (2)$$

Figure 6 shows the simulated DG and ECC. A practical MIMO system requires an ECC smaller than 0.5 in order to function reliably. The suggested 2x1 MIMO antenna's ECC, as indicated in Figure 6(a), is less than 0.06, indicating that the performance of each MIMO antenna element is somewhat affected by the performance of the others. The DG is shown in Figure 6(b), where it is around 10 dB (the ideal scenario) across the operational bands. Because of its low ECC value, the proposed MIMO antenna is an excellent option for applications involving diversity. that results in a high value for DG.



(a)



(b)

Figure 6: (a) ECC (b) DG between antenna elements of the proposed 2-element Dual Band MIMO antenna

B. Channel Capacity Loss (CCL)

A useful MIMO metric for describing the channel capacity loss of a MIMO system is CCL. It provides data on the maximum message transmission limit on the communication channel without loss; in practice, this should be less than 0.4 bits/s/Hz. Equations (3) – (4) are used to determine the CCL:

$$CCL = -\log_2 \det(\alpha^R) \qquad (3)$$

$$\alpha^R = \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix} \qquad (4)$$

$$\alpha ii = 1 - \sum_{n=1}^{N} |S_{in}|^2 \text{ , For } i = 1,2$$

$$\alpha ij = -\left(\sum_{n=1}^{N} S_{in}^{*} S_{nj}\right), \text{ For } i,j=1,2$$

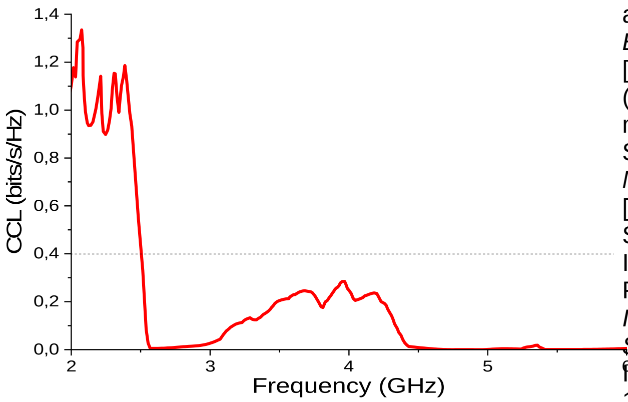


Figure 7: channel capacity loss (CCL) between antenna elements of the proposed 2-element dual band MIMO antenna.

As seen in Figure 7, the proposed 2-element MIMO antenna's observed CCL is less than 0.4 bps/Hz within the operating bands.

4. CONCLUSION

The radio electric characteristics of a newly constructed dual band single antenna element fed by CPW have been investigated in this work. As this structure uses the "3.5 GHz WIMAX" and "4.2 GHz " bands. These reference elements have led to the suggestion of two-element MIMO antennas, the S-parameters are assessed to make sure they match the ones from the simulation. DG, ECC, The *Channel Capacity Loss* CCL were examined and found to be within permissible limits. enhanced dimensions featuring MIMO and strong diversity features metrics indicate that this MIMO antenna is a good option for multiband applications.

References

[1] A. B. Numan, M. S. Sharawi, A. Steffes and D. N. Aloi, "A defected ground structure for isolation enhancement in a printed MIMO antenna system," 2013 7th European Conference on Antennas and Propagation (EuCAP), Gothenburg, Sweden, 2013, pp. 2123-212

[2] Lee, H., Jeon, J., Park, D., Shin, H., & Kim, H. (2022). MIMO antenna performance with isolator. *Microwave and Optical Technology Letters*, *64*(5), 946-952.

[3] Ikram, M., Sharawi, M.S. and Shamim, A. (2018), Compact circular connected monopole antenna arrays for wideband MIMO applications. IET Microw. Antennas Propag., 12: 2122-2127. https://doi.org/10.1049/iet-map.2018.5071

[4] Cuneray, K., Akcam, N., Okan, T., & Arican, G. O. (2023). 28/38 GHz dual-band MIMO antenna with wideband and high gain properties for 5G applications. *AEU-International Journal of Electronics and Communications*, *162*, 154553.

[5] Sharma, M. K., Sharma, A., & Kumari, R. (2024). A CPW THz-MIMO antenna with reduced mutual coupling using Frequency Selective Surface for future wireless applications. *Optical Materials*, *148*, 114929.

[6] A. Rani, B. Sharma, N. Saluja, G. Singla and T. Sabapathy, "A Compact MIMO Antenna with High Isolation and Gain-Bandwidth Product for Wireless Personal Communication," *2022 IEEE 11th International Conference on Communication Systems and Network Technologies (CSNT)*, Indore, India, 2022, pp. 1-5, doi: 10.1109/CSNT54456.2022.9787672.

[7] A. T. Hassan and M. S. Sharawi, four element half circle shaped printed MIMO antenna, Micorw. Opt. Technol. Lett., vol. 58, no. 12, pp. 2990-2992, 2016.

[8] Suganya, E., Prabhu, T., Palanisamy, S., Malik, P. K., Bilandi, N., & Gehlot, A. (2023). An isolation improvement for closely spaced MIMO antenna using λ/4 distance for WLAN applications. *International Journal of Antennas and Propagation*, *2023*(1), 4839134.

[9] C.-Y. Chiu and R. D. Murch, ''Compact four-port antenna suitable for portable MIMO devices,'' IEEE Antennas Wireless Propag. Lett., vol. 7, pp. 142–144, Feb. 2008.

[10] Lee, H., & Lee, B. (2016). *Compact Broadband Dual-Polarized Antenna for Indoor MIMO Wireless Communication Systems. IEEE Transactions on Antennas and Propagation, 64(2), 766–770.* doi:10.1109/tap.2015.2506201

[11] Fertas, F., Challal, M., & Fertas, K. (2020). A compact slot-antenna with tunable-frequency for WLAN, WiMAX, LTE, and X-band applications. *Progress In Electromagnetics Research C*, *102*, 203-212.

[12] Fertas, F., Fertas, K., Denidni, T. A., & Challal, M. (2023). Design of miniaturized tri-band antenna based on differential evolution algorithm. *Microwave and Optical Technology Letters*, *65*(3), 930-935.

[13] Fertas, K., Kimouche, H., Challal, M., Ghanem, F., Fertas, F., & Aksas, R. (2017, October). Development of a novel UWB planar antenna using a genetic algorithm. In *2017 5th International Conference on Electrical Engineering-Boumerdes (ICEE-B)* (pp. 1-4). IEEE.

[14] Fertas, F., Challal, M., & Fertas, K. (2020). Miniaturized quintuple band antenna for multiband applications. *Progress In Electromagnetics Research M*, *89*, 83-92.

[15] Fertas, F., Challal, M., & Fertas, K. (2017, October). Design and implementation of a miniaturized CPW-fed microstrip antenna for triple-band applications. In *2017 5th International Conference on Electrical Engineering-Boumerdes (ICEE-B)* (pp. 1-6). IEEE.

[16] FERTAS, F., CHALLAL, M., & FERTAS, K. (2019, November). Design and implementation of a multiband Quasi-Yagi antenna. In *2019 International Conference on Advanced Electrical Engineering (ICAEE)* (pp. 1-5). IEEE.

[17] FERTAS, F., CHALLAL, M., & FERTAS, K. (2019, November). Multi-L slots antenna for multiband applications. In *2019 International Conference on Advanced Electrical Engineering (ICAEE)* (pp. 1-5). IEEE.

[18] Fertas, K., Fertas, F., Challal, M., & Denidni, T. A. (2023). A novel miniaturized V-shaped monopole antenna for GSM/WiMAX/WLAN applications. *Frequenz*, *77*(3-4), 155-162.

[19] Fertas, K., Fertas, F., & Challal, M. (2023, October). Reconfigurable UWB Monopole Antenna with WLAN Band-Notch Characteristic. In *2023 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)* (pp. 048-051). IEEE.