



## **COMPACT AND EFFICIENT UWB ANTENNA FOR SMART VEHICLE COMMUNICATION SYSTEMS**

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### **ABSTRACT**

The most recent wireless technology is ultra-wideband (UWB), which makes use of a broad frequency range for efficient communication, fast data transmission, and precise position recognition. In this paper, a small antenna architecture based on CST software is developed with a width of 9 mm, length of 14 mm, and a height of 1 mm. The antenna is proposed in the frequency range 3-11 GHz, which is the ultra-wideband frequency spectrum. The simulation result of the above software includes a first frequency band of 0.542 GHz and a second frequency band of 3.4309 GHz, which covers several frequency bands. The new design is unique in being a Rubik's Cube antenna. The antenna we want has a reflection coefficient of less than -10 dB at all frequencies. The gain value lies between 0.5 dB and 3.8 dB, and the radiation efficiency and antenna efficiency vary from 60% to 88%. These outstanding characteristics position the proposed antenna in an essential position in contemporary wireless networks that utilize ultra-wideband technology.

### **KEYWORDS**

UWB applications, UWB Antennas, Antenna Design, microstrip antennas, reflection coefficient, high gain, VSWR.



## 1. INTRODUCTION

The current revolution of wireless communication technologies makes us look at the requirements of design of communication tools. Due to its powerful transmission speeds, high transfer rates, and low latency and energy consumption (Hasan, A., 2022), ultra-wideband (UWB) technology has created multiple applications in terms of new technology in the modern world. UWB technology is used in several applications as wireless sensor networks and biomedical imaging, and is not limited to satellite communication and military applications and reliable communications in diverse vehicle environments (Jasim et al., 2025; Muttair et al., 2022). Many antennas have been proposed in the literature due to the UWB band advantages (Muttair et al., 2021). The larger physical dimensions of the UWB antennas covered in [8] limit their use, especially in today's tiny devices, as they cannot extend to all of the internationally accepted UWB spectrum (3.1–10.6 GHz). The existence of sub-band systems within the UWB spectrum include Wireless Local Area Networks (WLAN), Wireless Fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX), and Industrial, Scientific, and Medical (ISM) bands (Barznji & Ameen, 2021). For this reason, notch-band UWB antennas have been developed for years. There has been a great deal of research on how to design new UWB antennas with notch features. It is crucial to remove the 5 GHz bands from the UWB spectrum in order not to obstruct ultra-wideband (UWB) signaling systems, as it has now become a standard feature of many applications. Accordingly, literature has been introduced on different UWB antenna systems (Muttair et al., 2022). Focus on designing potent antennas that have less interference. To fulfill the requirements of modern UWB applications, UWB antennas can give notch band characteristics without compromising overall bandwidth, gain, and radiation pattern performance (Jin et al., 2016). This benefits smaller electrical size given notch-band UWB antennas has been extensively studied in the literature for WLAN networks (Lee et al., 2017), for instance, one circular patch antenna with balanced notch band and common mode suppression was provided. This is known as UWB, and a small module called a circular patch antenna is employed to perform this function. The resonator was fed into the ring by a bandpass filter which generated the typical notch-band behaviour. So filtering the antenna means that it's bigger overall; the optimal size of an antenna is between 29.38 and 28.25 mm. A mushroom-shaped construction of electromagnetic gaps in the air had a correspondingly higher notch band in circular monopole antenna (Jaglan et al., 2018) to attain broad operating bands from 2.8 to 12 GHz. So, this antenna has several disadvantages, including structural issues and an increase in physical distance (40 to 50 mm). One quarter wave rectangular monopole antenna is now a W-shaped fractal antenna. Through successive slot iterations, we modified this configuration

in Fig.2, it is now a W-shaped fractal antenna in nature (Xu et al., 2018). In addition, a ground plane was incorporated, and two inverted L-shaped open ends were attached. The antenna has a large overall dimension of 31 mm × 27 mm with a working band in the range of 3-12 GHz and a notch band of 5.2-5.8 GHz. In contrast, a UWB antenna incorporating a multilayer artificial magnetic conductor was presented in (Nikolaou et al., 2022). A rectangular monopole antenna was initially modified to incorporate angles for a bandwidth improvement of the antenna. Two U-shaped slots were then inserted to form a notch band. In the end, to enhance the antenna's activity, the artificial magnetic conductor was introduced. Even if this antenna has a very high gain and two notch bands, it is limited in a few dimensions, such as having a small bandwidth of 4.8-10 GHz and a physical dimension of 33 mm x 33 mm, and with the total critical height of 7 mm.

A UWB antenna with a Pac-Man form was finally developed to operate within two separate notch bands (Kumar et al., 2021). Yet, the lack of correlation between the simulated and measured outcomes implies that the notch band is useless. In short, a UWB antenna that provides notch band capabilities for these applications should not compromise on other design requirements such as small size, broad bandwidth, steady radiation patterns, high gain, and geometric simplicity. Therefore, this article recommends an antenna with a wide operating range and notch-band capability for WLAN applications. The balance of the rest of the manuscript is divided as follows: Section 3 presents performance metrics; Section 2 describes the design of the proposed UWB antenna along with pertinent findings. Also, Section 3 provides a comparison of the proposed study with the most recent research, and Section 4 provides references.

## 2. PROPOSED ANTENNA DESIGN

The design approach for a new single-port UWB antenna is shown in Figs. 1(a) and 1(b). The proposed design includes a three-layered organization, with a ground plane at the lower and substrate at the mid region, as well as radiating patch with a microstrip feed line on top. The shape and thickness of concrete forms of materials for each layer are presented in Table 1. Substrate layer thickness is 1 mm, and copper ground plane and patch feed layer thickness is 0.05 mm. Figs. 1(a) and 1(b) provide a uniform arrangement of slot patterns etched into radiating patch and ground plane, which allows multi-band operation in most of the modern wireless systems like 5G, thus allowing the compact antenna to support a wideband operation.

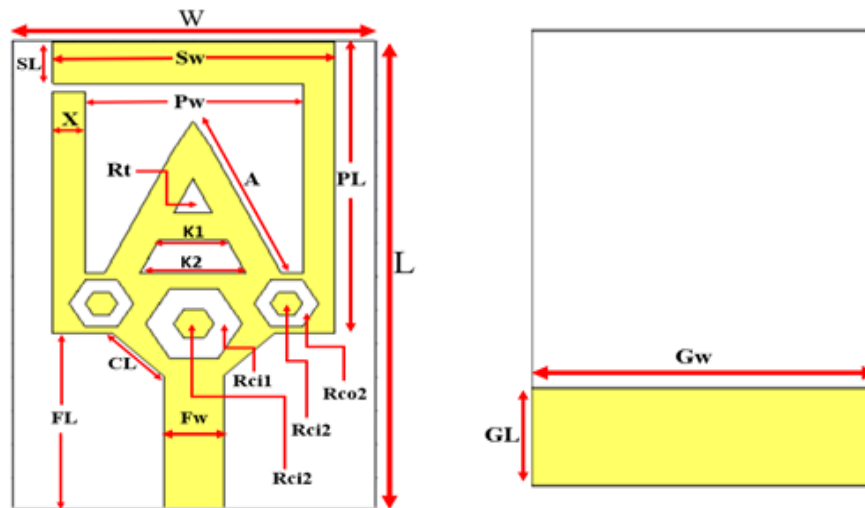


Fig. 1. The structural design in the simulation environments of the intended one-port antenna displays (a) the front layer and (b) the bottom layer.

Table 1. Lists and specifies the dimensional values (height, width, and length) for each parameter symbol on each layer of the suggested antenna.

| Parameters | Value (mm) | Parameters         | Value (mm) | Parameters         | Value (mm) |
|------------|------------|--------------------|------------|--------------------|------------|
| L          | 14         | PL                 | 8.68       | FL                 | 5.32       |
| W          | 9          | Pw                 | 5.40       | Fw                 | 1.50       |
| SL         | 1.25       | X                  | 0.80       | A                  | 5.03       |
| Sw         | 7          | CL                 | 1.77       | Rr                 |            |
| Rt         | 0.52       | Rco1(outer radius) | 1.2        | Rco1(inner radius) | 0.5        |
| h          | 1          | Rco2(outer radius) | 0.8        | Rco2(inner radius) | 0.4        |
| K1         | 1.69       | K2                 | 2.62       | Gw                 | 9          |
| GL         | 3          |                    |            |                    |            |

### 3. ANALYSIS OF ANTENNA RESULTS

In this part, the data and analytic techniques are presented, interpreting measurements obtained with its purpose-built antenna in the hope of obtaining an approximation of the operation of the antenna. At this point, basic statistics showed that the antenna performed as expected. Moreover, some other antennas, by others that have been proposed in literature, are in contrast for these findings.

#### 3.1. The reflection coefficient (S-parameter)

As shown in Fig. 2, the antenna operates dependably in the range of 3 to 11 GHz, and its reflection coefficient is -10 dB, giving it high reliability. Since the reflection coefficients were stable across the 5 resonant frequencies at 13.777, 15.7, 19.329, 33.320, and 18.439 dB, it follows that the antenna shows best performance at all 5 resonant frequencies as 3.99, 4.13, 6.01, 6.37, and 6.99 GHz; these 5 can suggest the resonant frequencies contribute to the peak power output. This is simply due to a comprehension that antenna performance parameters fit into the core rules of the UWB.

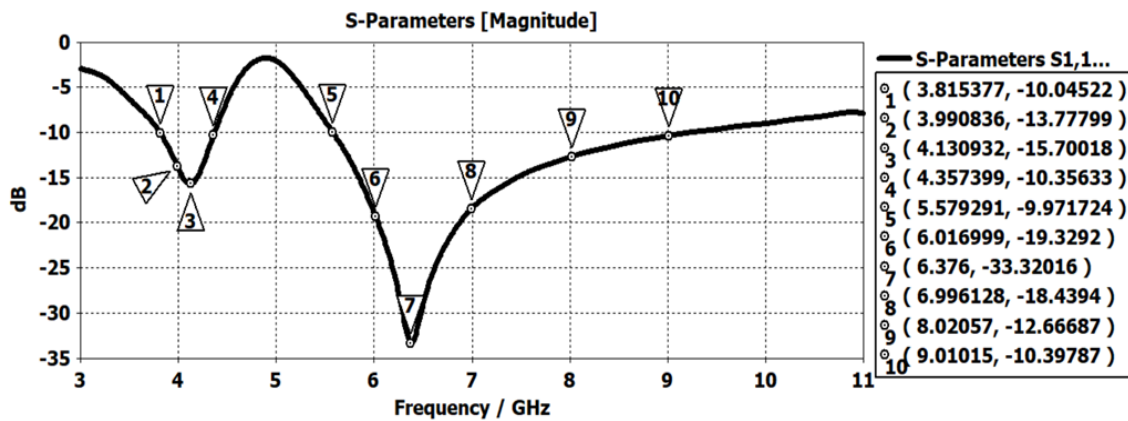


Fig. 2. Shows the operation of the proposed UWB antenna as plotted by its S-parameter in simulated environments

### 3.2. Radiation efficiency

The radiation efficiency of the antenna in the range of 3-11 GHz is depicted in the graph in Fig.3. It is clear from the graph that the antenna has performed exceptionally well in the range of 60% to 88% in terms of radiation efficiency. This is because of the techniques and innovative approach adopted in the design and development of the antenna, which has resulted in the achievement of high radiation efficiency. In addition, the ability of the antenna to support various UWB frequencies makes it suitable for use in 5G wireless communication.

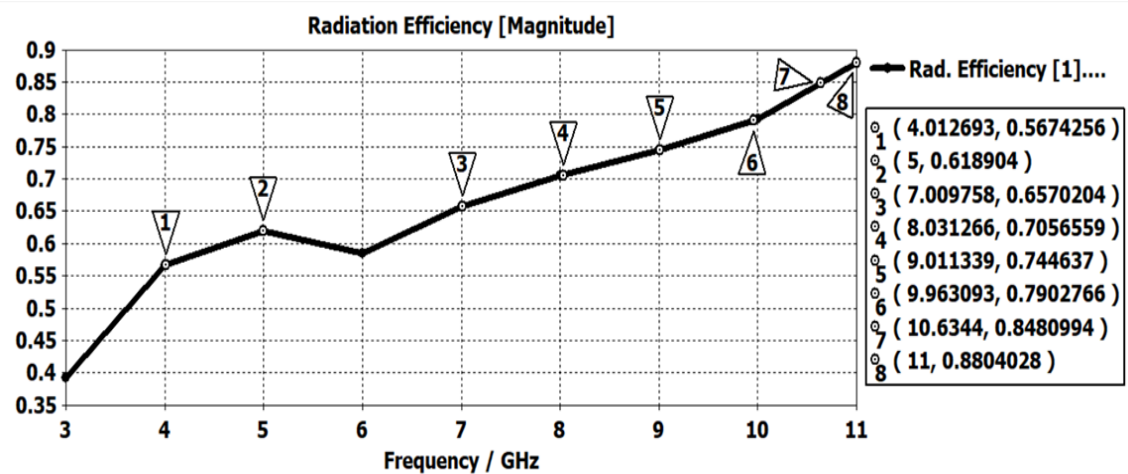


Fig. 3. The suggested antenna's radiation efficiency curves in simulation settings for the different UWB frequencies it can receive.

### 3.3. GAIN

Values of the gain of the antenna are depicted as shown in Fig. 4. The gain value of the antenna developed in this research has a minimum value of 0.5 dB and a maximum value of 3.8 dB, which is significant. The range of the gain value of the developed antenna makes the antenna suitable for different wireless communication needs.

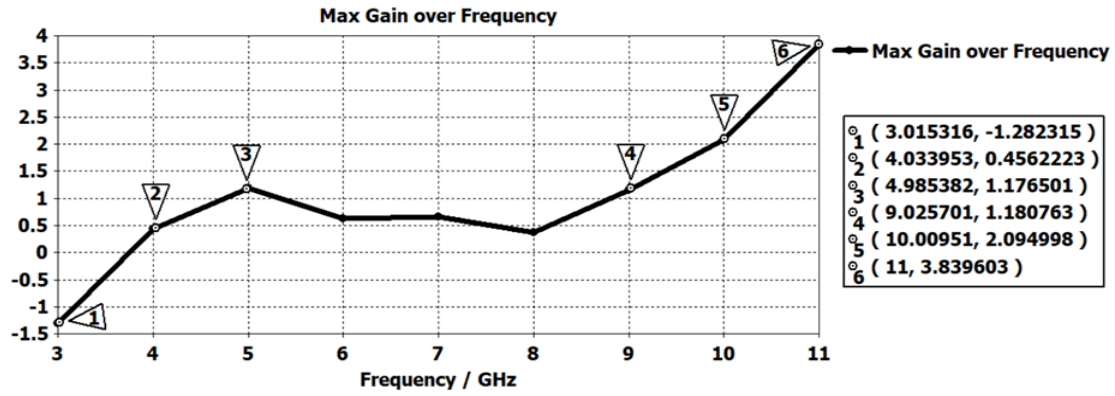


Fig. 4. Shows the proposed antenna's maximum and minimum gain values vs UWB frequencies in simulation environments.

### 3.4. VOLTAGE STANDING WAVES RATIO (VSWR)

VSWR is one of the most important parameters in determining the matching of the input impedance of the antenna to the impedance of the transmission line. It is defined as the ratio of the transmission line's highest to minimum voltage; more impedance matching is indicated by values nearer 1 (Mahbub et al., 2021; Muttair et al., 2023). The CST Studio Suite simulation program yielded an exceptional result within the parameters for the proposed antenna's VSWR of 1.044, as shown in Fig. 5.

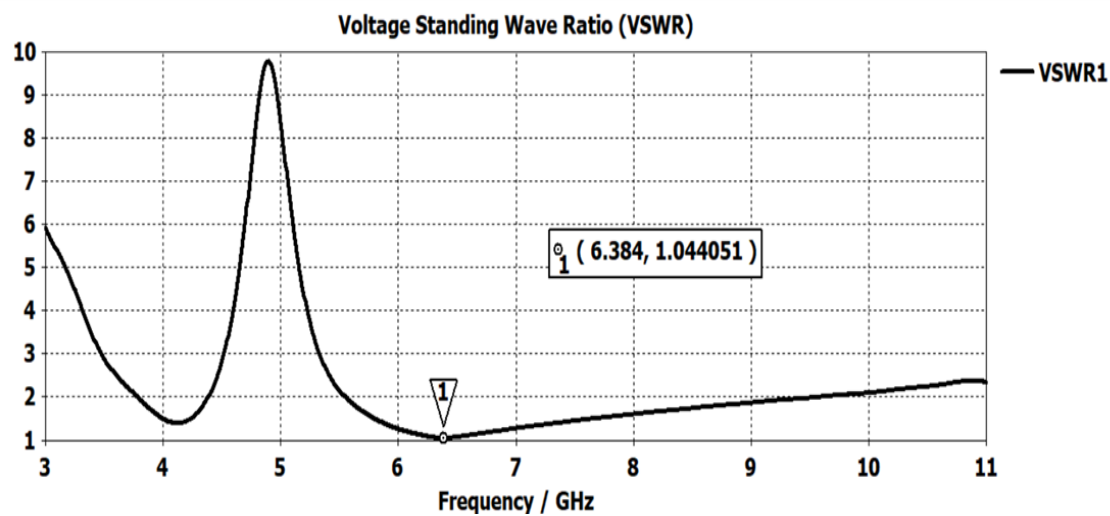


Fig. 5. VSWR of the antenna in simulation environments.

### 3.5. Comparison with previously proposed antennas

Table 2 of our paper provides a detailed comparison and highlights the good performance of our proposed antenna compared with antennas that have been previously published. Gain range, radiation ratio, bandwidth, operating frequencies, antenna size, as well as overall efficiency are compared. Table 2 confirms that our proposed antenna outperforms those offered by other researchers in earlier investigations in every way.

**Table 2. A thorough comparison between the findings of our investigation and those suggested by the most recent research.**

| Ref.                     | Antenna Dimensions (W × L × h) mm <sup>3</sup> | Fabrication Materials | Antenna Operating Frequency (GHz)                  | Bandwidth (GHz)              | Max. Gain (dBi)              | Efficiency (%)                   |
|--------------------------|--|-----------------------|--|------------------------------|------------------------------|----------------------------------|
| (Naji, 2020)             | 17 × 18 × 0.8                                  | FR4                   | 3.5<br>5.8   | 8.5<br>2.5                   | 1.83<br>1.37                 | 94<br>79                         |
| (Kulkarni et al., 2022)  | 30 × 30 × 0.8                                  | FR4                   | 4.80–5.99  | 1.19                         | 2.5                          | 85                               |
| (Benkhadda et al., 2023) | 24 × 30 × 1.6                                  | FR4                   | 2.19–4.43<br>4.8–7.76<br>8.04–11.32                | 2.24<br>2.96<br>3.28         | 1.074<br>4.19<br>4.01        | 68.35<br>64.15<br>62.7           |
| (Parasher et al., 2024)  | 33 × 22 × 1.6                                  | FR-4                  | 3.19–3.96<br>4.65–5.33<br>6.78–7.54<br>10.03–14.29 | 0.77<br>0.68<br>0.76<br>4.26 | 2.51<br>1.52<br>2.48<br>3.58 | 81.28<br>79.98<br>82.34<br>76.84 |
| (Wang et al., 2024)      | 40 × 43 × 1.6                                  | FR4                   | 2.30–2.50<br>3.65–9.77                             | 0.20<br>6.12                 | 3.62                         | NA                               |
| <b>This Work</b>         | 9 × 14 × 1                                     | Rogers 5880           | 3.8 – 4.35<br>5.6 – 9.1                            | 0.55<br>3.5                  | 3.8                          | 88                               |

#### 4. CONCLUSION

This paper describes a new concept compact antenna for operation at ultra-wideband (UWB). A remarkable 88% radiation efficiency was realized through fine-tuning by refinements. Modifications to the patch, substrate, and ground layers were mentioned as being crucial for antenna performance in the study. These alterations were found to significantly improve performance metrics, defining them as important engineering criteria. In particular, some thickness conditions were found to be most effective. It was demonstrated that increasing the perforation in the patch layer improved efficiency. In addition, patch, substrate, and ground layer thickness variations have significant consequences on the total antenna's performance. As a result, across wideband frequencies, the antenna has the best performance when using a 1 mm thick substrate, with both the patch and ground layers at a thickness of 0.05 mm. In the future, an innovative 14 × 9 MIMO antenna for use in spatial efficiency for better performance could be made to improve the general operation. By focusing on fractal geometry, this design will open up new ways forward for ultra-wide bandwidth, high gain, and wide transmission angles, as a perfect candidate for high signal strength applications.

#### 5. REFERENCES

Aitbar, I., Shoaib, N., Alomainy, A., Quddious, A., Nikolaou, S., Imran, M.A. and Abbasi, Q.H., 2022. AMC integrated multilayer wearable antenna for multiband WBAN applications. *Computers, Materials and Continua*, Vol.7, No.2, pp.3227-3241, doi: <https://doi.org/10.32604/cmc.2022.023008>.

- Barznji, A. and Ameen, J., 2021. Wi-Max Network Simulation For Salahaddin University New Campus. *Kufa Journal of Engineering*, Vol.12, No.4, pp.1-13, doi: <https://doi.org/10.30572/2018/kje/120401>.
- Benkhadda, O., Saih, M., Ahmad, S., Al-Gburi, A.J.A., Zakaria, Z., Chaji, K. and Reha, A., 2023. A miniaturized tri-wideband sierpinski hexagonal-shaped fractal antenna for wireless communication applications. *Fractal and Fractional*, Vol.7, No.2, pp.115, doi: <https://doi.org/10.3390/fractalfract7020115>.
- Hasan, A., 2022. Application-based performance monitoring heavy data transmission of Local Area Network. *Kufa Journal of Engineering*, Vol. 13, No. 3, pp.14-40, doi: <https://doi.org/10.30572/2018/KJE/130301>.
- Jaglan, N., Gupta, S.D., Kanaujia, B.K. and Srivastava, S., 2018. Band notched UWB circular monopole antenna with inductance-enhanced modified mushroom EBG structures. *Wireless Networks*, Vol.24, pp.383-393, doi: <https://doi.org/10.1007/s11276-016-1343-7>.
- Jasim, S.A., Al Grait, S.A. and Noori, A.S., 2025. Enhanced Design of a Triple-Band Microstrip Patch-Array Antenna Using a Multi-Split Ring Resonator. *Kufa Journal of Engineering*, vol. 16, no. 4, pp. 680–693, doi: <https://doi.org/10.30572/2018/KJE/160440>.
- Jin, Y., Tak, J. and Choi, J., 2016. Quadruple band-notched trapezoid UWB antenna with reduced gains in notch bands. *Journal of electromagnetic engineering and science*, Vol.16, No. 1, pp.35-43, doi: <https://doi.org/10.5515/JKIEES.2016.16.1.35>.
- Kulkarni, J., Sim, C.Y.D., Poddar, A.K., Rohde, U.L. and Alharbi, A.G., 2022. A Compact circularly polarized rotated L-shaped antenna with a J-shaped defected ground structure for wlan and V2X applications. *Prog. Electromagn. Res. Lett*, Vol.102, pp.135-143, doi: [https://doi.org/www.jpier.org/ac\\_api/preview.php?t=ab&id=22010305](https://doi.org/www.jpier.org/ac_api/preview.php?t=ab&id=22010305).
- Kumar, O.P., Kumar, P. and Ali, T., 2021. A compact dual-band notched UWB antenna for wireless applications. *Micromachines*, Vol.13, No. 1, p.12, doi: <https://doi.org/10.3390/mi13010012>.
- Lee, C.H., Wu, J.H., Hsu, C.I.G., Chan, H.L. and Chen, H.H., 2017. Balanced band-notched UWB filtering circular patch antenna with common-mode suppression. *IEEE Antennas and Wireless Propagation Letters*, Vol. 16, pp. 2812-2815, doi: <https://doi.org/10.1109/LAWP.2017.2748279>.

- Mahbub, F., Islam, R., Al-Nahiun, S.A.K., Akash, S.B., Hasan, R.R. and Rahman, M.A., 2021. A single-band 28.5 GHz rectangular microstrip patch antenna for 5G Communications Technology. In 2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC) (pp. 1151-1156). doi: <https://doi.org/10.1109/CCWC51732.2021.9376047>.
- Muttair K. S., Ali Z. G. Zahid, O. A. Shareef, Raed H. C. Alfilh, Ahmed M. Q. Kamil, and Mahmood F. Mosleh., 2022. Design and analysis of wide and multi-bands multi-input multi-output antenna for 5G communications. Indonesian Journal of Electrical Engineering and Computer Sciences, Vol. 26, No. 2, pp. 903-914., doi: <https://doi.org/10.11591/ijeecs.v26.i2.pp903-914>.
- Muttair K. S., Karrar K. A., Mujtaba Z. A., Oras A. S., and Mahmood F. M., 2022. New ultra-small design and high performance of an 8×8 massive MIMO antenna for future 6G wireless devices. Indonesian Journal of Electrical Engineering and Computer Science, Vol. 28, No. 1, pp. 587-599., doi: <https://doi.org/10.11591/ijeecs.v28.i1.pp587-599>.
- Muttair, K.S., Shareef, O.A., Mosleh, M.F., Zahid, A.Z.G., Shakir, A.M. and Qasim, A.M., 2023, September. A dual-element quad-port MIMO antenna modern design with ideal isolation correlation for 5G systems. In AIP Conference Proceedings, vol. 2804, no. 1, p. 020006, AIP Publishing LLC, doi: <https://doi.org/10.1063/5.0154576>.
- Muttair, K.S., Zahid, A.Z.G., Al-Ani, O.A.S., Al-Asadi, A.M.Q. and Mosleh, M.F., 2021. Antennas performance comparison of multi-bands for optimal outdoor and indoor environments wireless coverage. Indonesian Journal of Electrical Engineering and Informatics (IJEI), vol. 9, no. 4, pp. 846–858, doi: <https://doi.org/10.52549/ijeii.v9i4.3172>.
- Naji, D.K., 2020. Miniature slotted semi-circular dual-band antenna for WiMAX and WLAN applications. Journal of Electromagnetic Engineering and Science, Vol.20, No.2, pp.115-124, doi: <https://doi.org/10.26866/jees.2020.20.2.115>.
- Parasher, R., Yadav, D. and Saharia, A., 2024. Metamaterial-Based Octagonal Ring Penta-Band Antenna for Sub-6 GHz 5G, WLAN, and WiMAX Wireless Applications. Progress in Electromagnetics Research B, Vol. 104, pp. 109-129, doi: <https://doi.org/10.2528/PIERB23112603>.
- Wang, Z.G., You, R., Yang, M., Zhou, J. and Wang, M., 2024. Design of a Monopole Antenna for WiFi-UWB Based on Characteristic Mode Theory. Progress in Electromagnetics Research M, Vol.125, pp.107-116, doi: <https://doi.org/10.2528/PIERM24012611>.

Xu, H., Xu, K.D., Nie, W. and Liu, Y.H., 2018. A coplanar waveguide fed UWB antenna using embedded E-shaped structure with WLAN band-rejection. *Frequenz*, Vol.72, No.7-8, pp.325-332, doi: <https://doi.org/10.1515/freq-2017-0083>.