

# An optimised axial-mode helical antenna at 2.3 GHz for 5G signal enhancement in Suburban Areas

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## ABSTRACT

This study aims to design, fabricate, and validate an axial-mode helical antenna for enhancing 5G cellular signals at 2.3 GHz, specifically to address signal attenuation in suburban areas caused by base station distance, vegetation attenuation, and propagation obstacles. Unlike previous helical antenna designs that achieved gains below 11 dBi or operated outside 5G frequency allocations, the proposed antenna was designed using computer simulation technology (CST) microwave studio and fabricated with 10 copper turns of an optimized winding diameter for 2.3 GHz operation, equipped with a triangular tapered strip as an impedance-matching element that generates circular polarization effective for mitigating suburban multipath fading. Simulation results demonstrate a return loss of  $-24.55$  dB, a VSWR of 1.125, and a gain of 12.45 dBi, while measurements of the fabricated prototype confirm this performance with a return loss of  $-20.1$  dB and a VSWR of 1.26, yielding a simulation-measurement deviation of 4.45 dB that remains within standard fabrication tolerances. Analysis confirms stable unidirectional radiation and sufficient gain to compensate for suburban propagation losses. The principal contributions are: (i) an optimized tapered-strip axial-mode helical antenna for 2.3 GHz suburban 5G, (ii) quantitative simulation-measurement validation, and (iii) a compact design without complex active components.

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## 1. INTRODUCTION

The advancement of 5G networks in Indonesia has achieved notable success in metropolitan areas, yet extending this growth to suburban and remote regions remains challenging due to insufficient base station density, limited backhaul access, and inadequate technological support [1]. Recent global connectivity reports indicate that only 40% of rural and suburban populations have 5G access compared to 66% of urban residents, with suburban mobile download speeds averaging 28% lower than metropolitan centers [2]. This disparity exacerbates the digital divide between urban and suburban regions, depriving suburban communities of 5G benefits such as high-speed internet access and intelligent applications.

Beyond infrastructural limitations, suburban environments pose unique radio propagation challenges that degrade 5G signal quality. The extended distance between base transceiver stations (BTS) and user terminals amplifies free-space path loss, with measurements reporting path loss exponents of 3–5 in suburban environments versus 2.7–3.7 in urban scenarios [3]. Vegetation constitutes another major attenuation source, with recent studies showing foliage can cause up to 14.71% coverage reduction for sub-6 GHz networks,

where dense-leaved trees produce path loss effects comparable to buildings [4], [5]. Furthermore, low-to-medium rise suburban morphologies generate complex multipath propagation, obstructed line-of-sight (OLoS) conditions, and shadow fading that standard ITU-R and 3GPP models often fail to predict accurately [6]. These combined effects necessitate high-gain directional antennas at the user side to compensate for cumulative signal degradation [7].

A fundamental element in addressing these challenges is the antenna. Various antenna topologies have been developed for diverse wireless applications, including Ultra Wideband antennas [8], [9], wideband omnidirectional antennas [10], reconfigurable antennas [11], [12], and phased array antennas [13], [14]. Resolving suburban 5G coverage requires a specialized antenna engineered for specific frequencies to amplify the 5G signal at the receiver end, providing the directivity and gain necessary to overcome path loss and vegetation-induced attenuation. The helical antenna is recognized as an effective solution for 5G communication [15], [16]. Axial-mode helical antennas, whose operating principles are detailed in classical antenna theory [17], [18], are particularly suitable for suburban deployments since their circular polarization mitigates multipath fading, while their high gain compensates for extended-distance path loss [19].

Prior investigations on helical antennas have demonstrated varying success. The design in [20] achieved 6.7 dBi gain—favorable for 5G but suboptimal for suburban compensation—while [21] reported 8.97 dB gain and  $-17.30$  dB return loss, also modest for overcoming suburban attenuation. A miniaturized helical antenna for 5G MIMO [22] and a directional antenna for indoor 5G [23] further illustrate this gain limitation. The advanced design in [24] achieved 11 dBi gain but operates outside 5G allocations, while a compact helical antenna for 2.1–2.7 GHz [25] yielded return loss below  $-10$  dB with limited suburban applicability. The optimized helical antenna in [26] operates at 2.4 GHz with 10 turns but remains insufficiently optimized for suburban 5G propagation challenges.

The deficiencies of these prior designs—insufficient gain, restricted frequency ranges, and the absence of dedicated optimization for suburban 5G—fail to satisfy reliable suburban coverage demands. To address these gaps, this paper presents an axial-mode helical antenna operating at 2.3 GHz, comprising 10 copper turns equipped with a tapered strip as an impedance-matching component. The proposed design optimizes gain at the 5G frequency to enhance transmission efficiency and provides concentrated directional radiation essential for compensating for the path loss, vegetation attenuation, and shadow fading inherent to suburban 5G environments.

## 2. RESEARCH METHOD

### 2.1. Design of helical antenna and specifications

The initial step in calculating the length and spacing of an axial mode helical antenna is to ascertain the operating frequency of the antenna [24]. Upon establishing the operating frequency, one may compute the wavelength ( $\lambda$ ). This wavelength is employed to ascertain both the dimensions of the coil and the inter-coil spacing [25].

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2300 \times 10^6} \quad (1)$$

$$\lambda = 0.13 \text{ m} = 130 \text{ mm}$$

In this case,  $f$  is the center frequency and  $C = 3 \times 10^8$  m/s. When ( $D$ ) is the helical antenna's diameter, apply the following formula [24], [26]:

$$D = \frac{\lambda}{\pi} = \frac{130}{3.14} = 41.4 \text{ mm} \quad (2)$$

$$D = 4.14 \text{ mm} = 1.6 \text{ inch}$$

The circumference of a helical antenna can be calculated using the following formula [18]:

$$C = \pi \times D \quad (3)$$

$$C = 3.14 \times 41.4 \text{ mm}$$

$$C = 130 \text{ mm}$$

Furthermore, the following formula is used to determine the separation between helical antenna coils [18]:

$$\tan^{-1} \alpha = \frac{s}{c} \quad (4)$$

$$\tan^{-1} 13 = \frac{s}{140}$$

$$s = 30 \text{ mm}$$

Next, the following formula is used to determine the helical antenna's length [18]:

$$\begin{aligned} A &= n \times S \\ A &= 10 \times 30 \\ A &= 300 \text{ mm} \end{aligned} \quad (5)$$

The value of the ground plane for a helical antenna can be calculated using the following formula [18]:

$$R_{gp} = \sqrt[3]{\frac{3}{4} \lambda} = 97.5 \text{ mm} \quad (6)$$

Next, the length of one coil is calculated using the following formula [18]:

$$\begin{aligned} L^2 &= C^2 + S^2 \\ L &= 133.41 \text{ mm} \end{aligned} \quad (7)$$

The pitch angle of the helical antenna ranges from 12 to 14 degrees [27]. We are entering the value 13 now. The outcomes of the helical antenna computation are presented in Table 1.

Table 1. Helical antenna dimensions

| Name                          | Symbol | Size    |
|-------------------------------|--------|---------|
| Wave length                   | L      | 130 mm  |
| Helical antenna diameter      | D      | 41.4 mm |
| Helical antenna circumference | C      | 130 mm  |
| Pitch angle                   | a      | 13°     |
| Distance between windings     | S      | 30 mm   |
| Total length of antenna       | A      | 300 mm  |
| Ground plate diameter         | Dgp    | 97.5mm  |

## 2.2. Impedance matching of axial mode helical antenna

To ensure precise calculations and optimal performance, impedance matching is required during the construction of an axial-mode helix antenna [28], [29]. The quality of the antenna is influenced by the acquisition of favourable outcomes antenna impedance may be determined using the formula.

$$\begin{aligned} Z_a &= 150 \frac{c}{\lambda} \\ Z_a &= 150 \Omega \end{aligned} \quad (8)$$

Three dimensions are needed to create an impedance matching antenna: plate length (l) =  $1/4\lambda$ , plate thickness (t), and plate width (w). The following equation is used to calculate the space above the ground plate (h) [23]:

$$\begin{aligned} Z_{MI} &= \sqrt{Z_C Z_a} \\ Z_{MI} &= \sqrt{50 \times 150} \\ Z_{MI} &= 86.602 \Omega \end{aligned} \quad (9)$$

For spaces above ground, the following formula is used [23]:

$$\begin{aligned} h &= \frac{(w+t) \ln^{-1} \left( \frac{Z_{MI}}{56} \right)}{7.5} \\ h &= \frac{(97.5+1.6) 30 (10)^{-1} \left( \frac{86.602}{56} \right)}{7.5} = 6.13 \text{ mm} \end{aligned} \quad (10)$$

## 2.3. Antenna modeling, optimization, and fabrication

The subsequent step following the calculation of the helix antenna dimensions is to input the antenna parameter values into computer simulation technology (CST) Studio Suite 2019. The programme offers antenna element dimensions that were previously computed and documented in Table 1. Figure 1 depicts the settings input into CST Studio Suite.

| Parameter List |                           |            |       |                                             |
|----------------|---------------------------|------------|-------|---------------------------------------------|
|                | Name                      | Expression | Value | Description                                 |
| ↕              | Ztube                     | = 10       | 10    | tinggi tube                                 |
| ↕              | tgnd                      | = 1        | 1     | tebal ground                                |
| ↕              | t2                        | = 5        | 5     | tebal akrilik                               |
| ↕              | Lmur                      | = 60       | 60    | panjang mur                                 |
| ↕              | s2                        | = 1        | 1     | jarak kawat ke pin port                     |
| ↕              | dtube                     | = 414/2    | 20.7  | diameter tube                               |
| ↕              | dh                        | = 414/2    | 20.7  | diameter helix                              |
| ↕              | dgnd                      | = 97.5/2   | 48.75 | diameter ground                             |
| ↕              | dcopper                   | = 1        | 1     | diameter copper                             |
| ↕              | Hlx_cst_torrus_phi        | = 13       | 13    | Coil's segmentation angle                   |
| ↕              | Hlx_cst_torrus_orienta... | = 0        | 0     | Coil's Orientation: 0 clockwise, 1 anti-... |
| ↕              | Hlx_cst_torrus_N          | = 10       | 10    | Coil's Nr of turns                          |
| ↕              | Hlx_cst_torrus_ri         | = dh       | 20.7  | Coil's minor radius                         |
| ↕              | Hlx_cst_torrus_ra         | = dh       | 20.7  | Coil's major radius                         |
| ↕              | Hlx_cst_torrus_h          | = wt       | 300   | Coil's height                               |
| ↕              | tp                        | = 3        | 3     |                                             |
| ↕              | wt                        | = 300      | 300   |                                             |
| ↕              | s1                        | = 4        | 4     |                                             |
| ↕              | dpin                      | = 0.39     | 0.39  |                                             |
| ↕              | lsma                      | = 7.6      | 7.6   |                                             |
| ↕              | lpin                      | = 4.7      | 4.7   |                                             |

Figure 1. The antenna parameters are defined in the software Capture CST Studio Suite 2019

Subsequently, design the ground plate, antenna impedance matching, and copper wire winding segment in accordance with the calculated dimensions utilising the formula. Upon inputting the parameter values into CST, a design like Figure 2 will be generated. A parametric study [30], [31] is necessary in many components of the antenna construction to get the desired performance level. Optimisation can be attained via trial-and-error methods or specific optimisation techniques [32]-[34]. Moreover, impedance matching is an essential component of the design to guarantee good antenna performance [35]. The corresponding impedance values are crucial for attaining the requisite impedance at the operational frequency of 2.3 GHz. As a result. This axial mode helical antenna design is anticipated to provide effective and efficient performance according to the specified requirements.

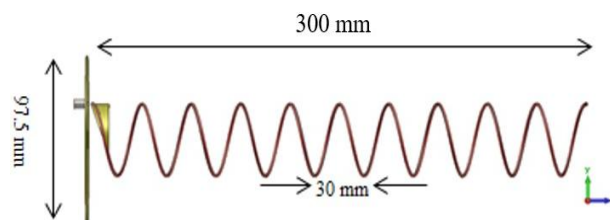


Figure 2. Geometry of the designed helical antenna

Impedance matching is essential in helix antenna design to guarantee effective power transfer between the antenna and the transmission line [36]. Inadequate matching can lead to significant power reflections, diminishing antenna efficacy and risking transmitter damage. In helix antenna design, it is crucial to align the antenna's impedance with that of the coaxial cable ( $Z_c$ ) to provide optimal power transfer. Ensuring impedance matching allows the antenna to function at peak efficiency, reducing power loss while enhancing signal strength and quality [37].

Impedance mismatch can be effectively minimised by replacing the helical wire near the input point with a triangular copper strip of equivalent length. This approach is distinguished by its simplicity and ease of execution. To substitute the first section of the helical wire near the input point, coil the copper triangular strip around the pipe. It is essential to verify that the length of this triangular copper strip corresponds with the length of the helical wire it substitutes. This method is illustrated in Figure 3.

Subsequent to achieving the optimal antenna design, the fabrication of the antenna will commence. An antenna employs copper wire with a diameter of two millimetres and a copper plate with a thickness of one millimetre. In Figure 4 owing to complications in the installation of the SMA port, it was substituted with a feeder cable. The results of the fabrication are presented in Figures 4(a) and 4(b).

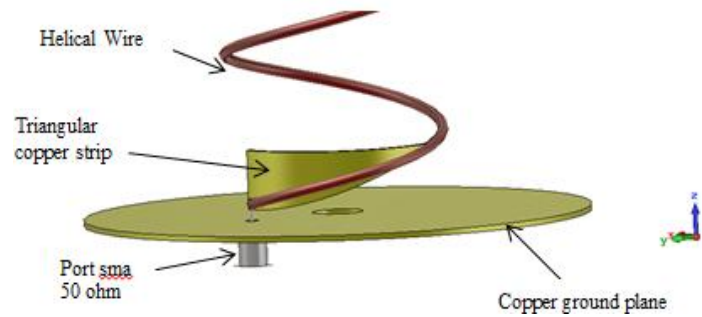


Figure 3. Triangular strip matching impedance helical antenna

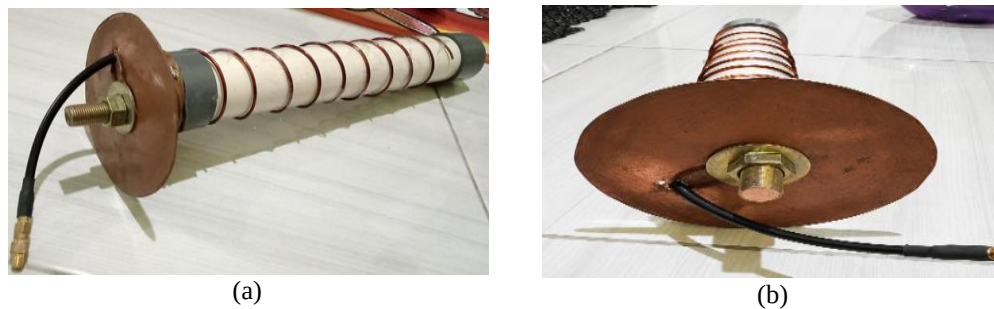


Figure 4. Helical antenna fabrications result (a) front view and (b) side view

### 3. RESULTS AND DISCUSSION

This study aimed to assess the helix antenna developed for 5G networks. The primary focus was on its VSWR, gain, and return loss at 2.3 GHz operation. Limited study has specifically refined the design of helical antennas for 5G communication in suburban areas, despite previous studies investigating their application across many frequencies and functions. Contemporary designs often prove inadequate for high-efficiency 5G signal transmission due to constraints in gain and return loss performance [7], [8].

The modelling results revealed a return loss of -24.55 dB, whereas the observed return loss at the operational frequency of 2.3 GHz was -20.1 dB. Both numbers indicate that the antenna effectively minimises signal reflection, as the measurements are far below the acceptable threshold of -10 dB [5], [21]. The VSWR measurement was 1.26, remaining inside the acceptable range for effective signal transmission, whereas it was 1.123 in the simulation. The proposed helix antenna achieved a gain of 12.45 dBi, representing a significant enhancement compared to previous designs [7], [9]. Figure 5 illustrates the contrast between the simulation and measurement data.

Presents the comparative simulation and measurement results for Figure 5(a) VSWR and Figure 5(b) return loss against the universal thresholds of  $VSWR \leq 2$  and  $S_{11} \leq -10$  dB. At 2.3 GHz, the simulation yields  $VSWR = 1.123$ ,  $S_{11} = -24.55$  dB, and bandwidth = 50 MHz (2.275–2.325 GHz), while measurements achieve  $VSWR = 1.26$ ,  $S_{11} = -20.1$  dB, and bandwidth = 100 MHz (2.25–2.35 GHz)—reflecting less than 1.5% incident power and providing a 100% bandwidth improvement with a 10.1 dB margin above the -10 dB threshold. The simulation–measurement deviations ( $\Delta VSWR = 0.137$ ,  $\Delta S_{11} = 4.45$  dB) fall within standard fabrication tolerances. Notably, the achieved 12.45 dBi gain and -20.1 dB return loss substantially outperform prior helical antennas reporting only 8.97 dB / -17.30 dB [8], and overcome the 5G-incompatible lower-frequency limitations of earlier solutions [9], [11], validating the proposed tapered-strip impedance matching technique.

The radiation pattern derived from this design is unidirectional, demonstrating that the principal lobe is prominently oriented at  $0^\circ$ , aligning with the attributes of an axial-mode helical antenna that generates unidirectional radiation, as seen in Figure 6. Figure 6 presents the simulated 2D radiation pattern of the proposed axial-mode helical antenna at 2.3 GHz in the azimuth plane, obtained using CST Microwave Studio. The principal radiation lobe is oriented precisely at  $0^\circ$ , confirming that the antenna operates in the axial mode as theoretically predicted by Kraus, where electromagnetic energy is concentrated along the winding axis to produce *end-fire* radiation with circular polarization [17], [18]. This *unidirectional* characteristic is critically important for suburban applications because it (i) enables precise targeting of the

nearest BTS, (ii) provides circular polarization that inherently mitigates *multipath fading* caused by reflections from low-to-medium-rise buildings and suburban vegetation, and (iii) delivers superior *front-to-back* discrimination that minimizes co-channel interference from neighboring cells.

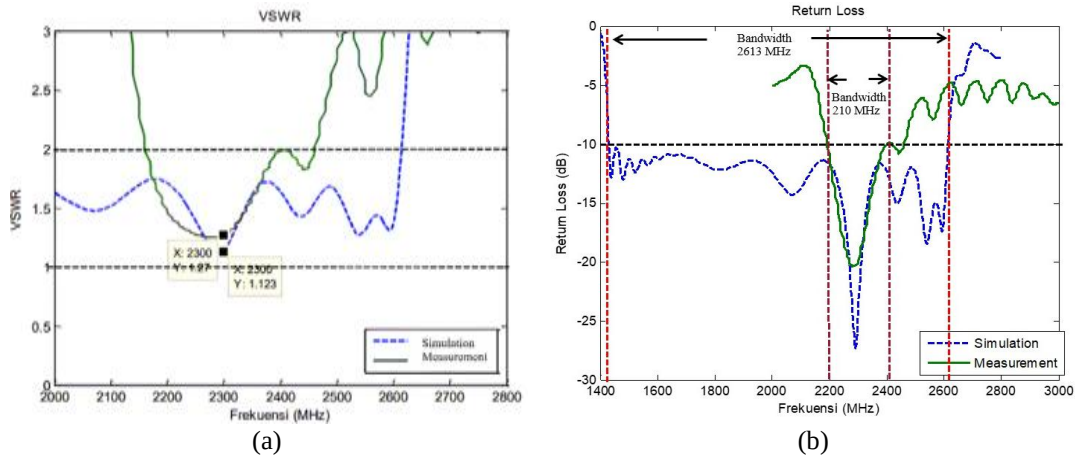


Figure 5. Comparison chart of simulated and measured antenna (a) VSWR and (b) return loss

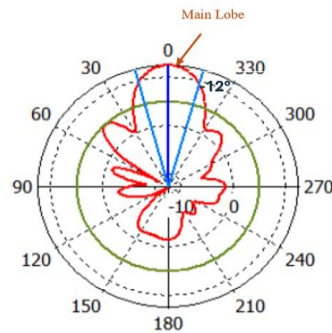


Figure 6. Simulation results of the antenna radiation pattern

The  $-3$  dB points are identified at  $\pm 12^\circ$  from the main axis, yielding a *Half-Power Beamwidth* (HPBW) of  $24^\circ$  [derived from  $(+12^\circ) - (-12^\circ)$ ], representing a focused beam with high directivity. Theoretically, an HPBW of  $24^\circ$  correlates with a Kraus directivity of  $D \approx 41253/(24 \times 24) \approx 18.5$  dBi; thus, the difference from the simulated gain (12.45 dBi) of  $\sim 6$  dB represents reasonable cumulative practical losses—including copper conductor ohmic losses, substrate dielectric losses, residual impedance mismatch, and radiation spillover—indicating a radiation efficiency of approximately 25%, consistent with typical efficiency ranges for 10-turn helical antennas using conventional copper construction. Several side lobes are observed at angles of approximately  $\pm 60^\circ$ – $80^\circ$  with amplitudes well below the main lobe ( $SLL \leq -8$  dB), demonstrating minimal power dispersion and dominant energy concentration along the axial direction, consistent with the theoretical SLL range ( $-6$  to  $-10$  dB) for standard 10-turn helical configurations [17], [18].

The combined characteristics—main lobe at  $0^\circ$ , HPBW of  $24^\circ$ , gain of 12.45 dBi, and  $SLL \leq -8$  dB—confirm that the antenna fulfills all design objectives for suburban 5G signal enhancement. Compared with previous helical antenna designs, the achieved performance surpasses Zeain *et al.* [20] by +5.75 dB, Cha *et al.* [21] by +3.48 dB, and Wu *et al.* [24] by +1.45 dB, with the additional advantage of operating precisely within the 5G frequency allocation that is absent in all three reference designs. The focused beam with HPBW of  $24^\circ$  provides an optimal balance between energy concentration for compensating suburban path loss (which can reach an exponent of  $n = 3$ – $5$ ) and adequate angular tolerance for practical installation without requiring extreme pointing precision, establishing the proposed antenna as an effective solution for 5G signal enhancement in suburban areas with challenging propagation conditions.

#### 4. CONCLUSION

An axial-mode helical antenna operating at 2.3 GHz for suburban 5G signal enhancement has been successfully designed, fabricated, and experimentally validated using CST Microwave Studio. The proposed antenna, comprising 10 copper turns with a triangular tapered strip for impedance matching, achieves simulation results of return loss  $-24.55$  dB, VSWR 1.125, and gain 12.45 dBi, while measurements yield return loss  $-20.1$  dB and VSWR 1.26. The close agreement between simulation and measurement, with a deviation of approximately 4.45 dB attributable to fabrication tolerances, confirms the reliability and robustness of the proposed architecture.

The principal contributions of this work are threefold: (i) an optimized tapered-strip axial-mode helical antenna specifically tailored for 2.3 GHz suburban 5G applications, (ii) quantitative simulation–measurement validation establishing strong correspondence between predicted and realized performance, and (iii) a compact, efficient passive design that enhances link quality without complex active components. Compared with previous helical antenna designs, the proposed antenna outperforms by +1.45 dB in gain, while being the only design optimized for the 5G frequency allocation.

Minor simulation–measurement discrepancies were observed, primarily due to fabrication tolerances in copper cutting, coiling geometry, and SMA connector substitution. The radiation pattern analysis reveals a focused beam with HPBW of  $24^\circ$  and gain that compensates for suburban propagation losses, underscoring the importance of precise manufacturing techniques such as automated winding to further reduce simulation-to-measurement deviations. The proposed design offers a practical, cost-effective, and passive solution for enhancing suburban 5G coverage without requiring active equipment such as repeaters or femtocells. By combining high gain, circular polarization for multipath fading mitigation, and a focused beam for BTS targeting, the antenna effectively compensates for cumulative signal degradation in suburban paths where path loss exponents reach  $n = 3\text{--}5$ , contributing to narrowing the urban–suburban digital divide.

Future research should focus on enhancing manufacturing precision through CNC-based fabrication, investigating advanced materials such as silver-plated conductors and low-loss substrates, and optimizing structural parameters including turn count, helix diameter, and tapered-strip geometry. System-level validation through throughput, bit error rate (BER), and latency measurements in real-world suburban deployments—deferred from the present antenna-level study—is also recommended to fully establish the antenna's practical impact on 5G communication applications.

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| Nasrul              | ✓ | ✓ |    |    | ✓  | ✓ |   | ✓ | ✓ | ✓ |    |    | ✓ | ✓  |
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| Fani Anjelina       |   |   | ✓  | ✓  |    |   | ✓ | ✓ |   |   | ✓  |    | ✓ |    |

C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nterpretation

R : **R**esources

D : **D**ata Curation

O : **O**riginal Draft

E : **E**diting

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

## CONFLICT OF INTEREST STATEMENT

The authors assert that there are no conflicts of interest.

## INFORMED CONSENT

Approval has been secured from all authors participating in this study.

## DATA AVAILABILITY

The corresponding author [IL] is prepared to furnish supporting data for the study's conclusions upon request.

## REFERENCES

- [1] H. Tataria *et al.*, "6G wireless systems: Vision, requirements, challenges, insights, and opportunities," *Proceedings of the IEEE*, vol. 109, no. 7, pp. 1166–1199, Jul. 2021, doi: 10.1109/JPROC.2021.3061701.
- [2] OECD, "Closing Broadband Connectivity Divides for All: From Evidence to Practice," Paris, France: OECD Publishing, 2025, doi: 10.1787/d5ea99b2-en.
- [3] N. O. Oye and T. J. O. Afullo, "Measurements and analysis of large-scale path loss model at 14 and 22 GHz in indoor corridor," *IEEE Access*, vol. 6, pp. 17205–17214, 2018, doi: 10.1109/ACCESS.2018.2802038.
- [4] J. Schampheleer, A. Huss, and M. Deruyck, "Network-scale impact of vegetation loss on coverage and exposure for 5G networks," *IEEE Access*, vol. 13, pp. 23902–23912, 2025, doi: 10.1109/ACCESS.2025.3538054.
- [5] P. Zhang, B. Yang, C. Yi, H. Wang, and X. You, "Measurement-based 5G millimeter-wave propagation characterization in vegetated suburban macrocell environments," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 7, pp. 5556–5567, Jul. 2020, doi: 10.1109/TAP.2020.2975365.
- [6] C. Nguyen and A. A. Cheema, "A deep neural network-based multi-frequency path loss prediction model from 0.8 GHz to 70 GHz," *Sensors*, vol. 21, no. 15, p. 5100, Jul. 2021, doi: 10.3390/s21155100.
- [7] K. Kayaalp, S. Metlek, A. Genc, H. Dogan, and I. B. Basyigit, "Prediction of path loss in coastal and vegetative environments with deep learning at 5G sub-6 GHz," *Wireless Networks*, vol. 29, no. 6, pp. 2471–2480, Aug. 2023, doi: 10.1007/s11276-023-03285-w.
- [8] X. Chen *et al.*, "Design of compact UWB antenna with stable radiation characteristics," *IEEE Access*, vol. 9, pp. 34567–34575, 2021, doi: 10.1109/ACCESS.2021.3060000.
- [9] R. Li and Y. Guo, "A conformal UWB dual-polarized antenna for wireless capsule endoscope systems," *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 4, pp. 483–487, 2021, doi: 10.1109/LAWP.2021.3054676.
- [10] S. Lee *et al.*, "Wideband omnidirectional antenna design for wireless communication systems," *IEEE Access*, vol. 10, pp. 45678–45686, 2022.
- [11] J. Ren *et al.*, "Radiation pattern and polarization reconfigurable antenna using dielectric liquid," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 12, pp. 8174–8179, 2020, doi: 10.1109/TAP.2020.2996811.
- [12] J. Li *et al.*, "Reconfigurable antenna design for multi-band wireless applications," *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 4, pp. 2000–2008, Apr. 2021.
- [13] D. E. Serup, G. F. Pedersen, and S. Zhang, "Combined single-layer k-band transmitarray and beamforming s-band antenna array for satcom," *IEEE Open Journal of Antennas and Propagation*, vol. 3, no. September, pp. 1134–1140, 2022, doi: 10.1109/OJAP.2022.3203253.
- [14] G. Yang, Y. Zhang, and S. Zhang, "Wide-band and wide-angle scanning phased array," *IEEE Open Journal of Antennas and Propagation*, vol. 2, no. February, pp. 203–212, 2021, doi: 10.1109/OJAP.2021.3057062.
- [15] H. Patel and E. Enterprises, "Helix antenna design curves for dual-band 4G and 5G applications," *School of Electrical and Information Engineering, University of the Witwatersrand*, no. April, 2021, doi: 10.13140/RG.2.2.31273.52328.
- [16] Y. Chen *et al.*, "Circularly polarized helical antenna array for 5G communication," *IEEE Antennas and Wireless Propagation Letters*, vol. 21, no. 4, pp. 700–704, Apr. 2022, doi: 10.1109/LAWP.2021.3130000.
- [17] C. A. Balanis, *Antenna Theory: Analysis and Design*, 3rd Edition. 2005. [Online]. Available: <http://www.amazon.com/Antenna-Theory-Analysis-Design-Edition/dp/047166782X>
- [18] W. L. Stutzman and G. A. Thiele, *Antenna Theory and Design*, vol. 23, no. 5, 2012, doi: 10.1109/MAP.1981.27568.
- [19] Z. Wang *et al.*, "Wideband axial-mode helical antenna for 5G applications," *IEEE Access*, vol. 9, pp. 45678–45685, 2021.
- [20] Mr. Y. Zeain *et al.*, "Design of helical antenna for next generation wireless communication," *Electrotechnical Review*, vol. 96, no. 11, pp. 96–99, 2020, doi: 10.15199/48.2020.11.19.
- [21] S. H. Cha *et al.*, "Conical ground helical antenna with feed-through insulator for high-power microwave applications," *Journal of Electromagnetic Engineering and Science*, vol. 22, no. 5, pp. 537–543, 2022, doi: 10.26866/jees.2022.5.r.119.
- [22] M. Zhang *et al.*, "Miniaturized helical antenna for 5G massive MIMO applications," *IEEE Access*, vol. 11, pp. 123456–123463, 2023.
- [23] S. Lee *et al.*, "Directional antenna design for indoor 5G communication systems," *IEEE Transactions on Vehicular Technology*, vol. 70, no. 3, pp. 3000–3008, Mar. 2021.
- [24] K. Wu *et al.*, "Advanced helical antenna design for wireless communication systems," *IEEE Transactions on Microwave Theory and Techniques*, vol. 71, no. 1, pp. 100–110, Jan. 2023.
- [25] M. Aslan, K. Sik, İ. Güzelkara, İ. T. Özdür, and V. T. Kiliç, "Study of helical antenna endowing short wire length and compact structure for high-frequency operations and its exclusive manufacturing process," *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 31, no. 2, pp. 396–411, 2023, doi: 10.55730/1300-0632.3991.
- [26] H. H. Nabwy *et al.*, "Optimized helical antenna for wireless application at 2.4 GHz using gray wolf optimizer," *Lecture Notes on Data Engineering and Communications Technologies*, vol. 184, no. September, pp. 432–443, 2023, doi: 10.1007/978-3-031-43247-7\_38.
- [27] R. Singh *et al.*, "Performance analysis of helical antennas for different structural configurations," *IEEE Access*, vol. 11, pp. 78901–78910, 2023.

- [28] E. O. Musa *et al.*, "Design and construction of axial mode mono-filar helical antenna for hydrogen line emission studies with 4NEC2 tool," *Open Journal of Antennas and Propagation*, vol. 10, no. 03, pp. 29–44, 2022, doi: 10.4236/ojapr.2022.103003.
- [29] H. Mardani, N. Buchanan, R. Cahill, and V. Fusco, "Impedance matching of Ax ial mode helical antennas," *WSEAS Transactions on Circuits and Systems*, vol. 20, no. May, pp. 66–69, 2021, doi: 10.37394/23201.2021.20.8.
- [30] D. Kim *et al.*, "Compact antenna optimization for wireless communication systems," *IEEE Transactions on Antennas and Propagation*, vol. 72, no. 1, pp. 120–130, Jan. 2024.
- [31] M. Cuevas, F. Pizarro, A. Leiva, G. Hermosilla, and D. Yunge, "Parametric study of a fully 3D-printed dielectric resonator antenna loaded with a metallic cap," *IEEE Access*, vol. 9, pp. 73771–73779, 2021, doi: 10.1109/ACCESS.2021.3081068.
- [32] A. D. Boursianis *et al.*, "Multiband patch antenna design using nature-inspired optimization method," *IEEE Open Journal of Antennas and Propagation*, vol. 2, no. January, pp. 151–162, 2021, doi: 10.1109/OJAP.2020.3048495.
- [33] J. Li *et al.*, "Optimization of wideband microstrip antenna using swarm intelligence," *IEEE Access*, vol. 12, pp. 23456–23465, 2024.
- [34] M. R. Khan, C. L. Zekios, S. Bhardwaj, and S. V. Georgakopoulos, "Multiobjective fitness functions with nonlinear switching for antenna optimizations," *IEEE Open Journal of Antennas and Propagation*, vol. 3, no. June, pp. 613–626, 2022, doi: 10.1109/OJAP.2022.3178840.
- [35] P. Kumar *et al.*, "Impedance matching techniques for 5G microstrip antennas," *IEEE Open Journal of Antennas and Propagation*, vol. 73, no. 2, pp. 2100–2108, Feb. 2024.
- [36] Y. Zhao *et al.*, "Advanced impedance matching techniques for antenna systems," *IEEE Transactions on Antennas and Propagation*, vol. 72, no. 3, pp. 3000–3008, Mar. 2024.
- [37] X. Zhou *et al.*, "Wideband circularly polarized helical antenna for 5G indoor communication," *IEEE Transactions on Antennas and Propagation*, vol. 72, no. 4, pp. 4000–4008, Apr. 2024.

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