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RESEARCH ARTICLE

DESIGN, SIMULATION AND PERFORMANCE EVALUATION OF HELICAL ANTENNA FOR 4G AND 5G MOBILE NETWORKS COMPLIANCE

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ABSTRACT

The 5G cellular network aims to address bandwidth needs due to the large number of subscribers worldwide. However, higher-bandwidth antennas are needed to integrate into the design. Helical antennas offer design simplicity, gain, and wider bandwidth, but their radiation pattern narrows bandwidth as diameter and turn increase. This paper aims to develop and evaluate the performance of helical antennas at different dimensions and turns for 4G and 5G network frequency applications. The study used MATLAB 2021a to design and simulate helical antennas with various turns. Parameters like width, spacing, and radius were calculated using an online helical antenna calculator at seven frequencies corresponding to 4G and 5G cellular networks. Major antenna properties, which include gain, directivity, bandwidth, efficiency, voltage standing wave ratio, return loss, front-to-back ratio, full null beam width, half power beam width, back lobe, main lobe, and side lobe, were evaluated. The study demonstrates that all simulated helical antennas show a continuous increase in gain with an increase in frequency. Directivity increases at lower frequencies but converges at higher 5G frequencies. The bandwidth also increases with frequency, making all helical turns suitable for 4G and 5G bandwidth, especially at higher frequencies. Efficiency also increases with frequency, with 2 and 4-turn helical antennas showing better performance at optimal frequencies. The 3-turn helical antenna meets the best VSWR and return loss standards, but its VSWR and return loss converge as frequency increases. The front-to-back ratio indicates that all helical antennas are more directional at higher frequencies. The back lobe decreases with frequency, while the main and side lobes are more pronounced at lower frequencies but converge at higher frequencies. Helical antennas with all realised turns show good characteristics with little tradeoff and are suitable for 5G bandwidth use at higher frequencies, and 2-turns offer potential for compact, miniaturised mobile device antenna applications.

KEYWORDS

Helical, Antenna, turns, 4G, 5G, Bandwidth

1. INTRODUCTION

Rapid advancements in wireless communication technology enable cellular service providers to offer a wide range of services for potential future uses (Venu et al., 2022). Antennas are essential components of every wireless system, and they must adapt to meet the growing demands of communication systems for better performance and faster data rates (Zhao, 2023). As a result of this, a lot of research has been extended to the working bandwidth of antennas through different geometries and configurations in the last decades (Adewumi et al., 2022; Karami et al., 2022). Researchers have constantly aimed to improve antenna properties like gain, input impedance, bandwidth, and compactness (Adewumi et al., 2021; Liya and Jayakrishnan, 2022). Globally, the number of mobile devices and subscribers using wireless communication network channels has increased dramatically in recent years. Overcoming the issues of limited bandwidth, poor gain, poor directivity, and the dimensions of the antennas utilised at various frequencies has proven to be a significant task.

Helix antennas are easy to construct, have a large bandwidth, a circularly polarised signal, and high directivity, making them suitable for high bandwidth and gain requirements in the new generation of networks, especially in the 4G and 5G frequency bands. Meanwhile, a major problem arises from the radiation pattern of a helical antenna operating in normal mode, which mostly depends on the diameter value and number of turns. This paper presents the design, simulation, and performance evaluation of different turns of helical antennas to meet the required properties of 4G and 5G mobile network antennas relative to gain, directivity, bandwidth, antenna efficiency, VSWR, return loss, front-to-back ratio, full null beam width (FNBW), half power beam width (HPBW), main lobes, side lobes, and back lobes.

2. HELIX ANTENNA DESCRIPTION

The helical antenna, often known as the helix, has a lengthy history and has been the subject of countless studies and developments for more than six decades (Uluslu, 2023). A helical-shaped conductor coupled to the ground plane makes up the helical antenna, as shown in Figure 1. The helix antenna's radiation behaviour varies depending on the design structure, and as a result, antenna performance in terms of polarisation and radiation pattern may vary. The helical antenna's construction provides a wide

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bandwidth with circular polarisation characteristics (Yousef et al., 2023). Helical antennas are easy to put together, have a very directional pattern, have a large operational bandwidth, and their working frequency range is extremely broad, operating in both the VHF and UHF bands. Normal mode (electrically small broadside) and axial mode (electrically large end-fire) are the two most common operating modes for helical antennas (Ghosh and Harackiewic, 2022).

The normal mode occurs when the direction of radiation is at a maximum normal to the axis of the helix and the length of one turn of the helix is much less than the design wavelength (L<< λ) (Amneelahi et al., 2022). The radiation field is parallel to the helix axis in the typical mode of radiation, and the waves being radiated have circular polarization. A helical antenna emits radiation in a pattern that combines that of a short dipole and a loop antenna based on the helix's diameter (D) and turn spacing (S) parameters. The limited bandwidth and low radiation efficiency of this mode of operation are drawbacks. The waves in the axial mode of radiation are circularly or nearly circularly polarised and radiate in the end-fire direction along the helical axis by raising the radius to the order of one wavelength (λ), and separation of roughly λ/4 results in this mode of operation (Parsche, 2023). The axial beam produces minor lobes at oblique angles due to the radiation pattern, which is broad and directed.

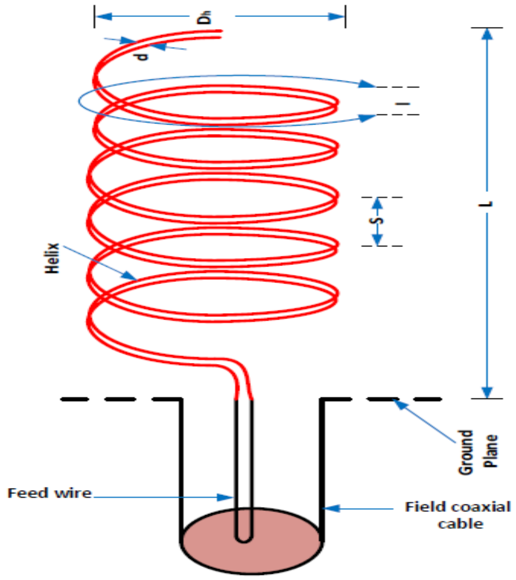

Figure 1: Sketch Diagram of helix antenna

3. Helix Antenna Design And Simulation Methods

The helix antenna dimensions (width, radius, and spacing) of each selected turn were obtained at the selected 4G (0.8, 1.2, 2.4 GHz) and 5G (3.5, 5.3, 7.5, 10.5 GHz) frequencies using the Helix antenna online software calculator. The dimensions obtained for the helix antennas of the specified number of turns are shown in Tables 1 and 2.. Each helix dimension was further simulated in MATLAB 2021a through codes developed in the C++ programming language to obtain the physical structures of each helix relative to their number of turns, as depicted in Figures (2a) to (2e). The helix turns were further simulated using Matlab to obtain each helix properties such as gain (dB), directivity (dB), bandwidth, antenna efficiency, VSWR, return loss (dB), and the radiation pattern parameters, namely HPBW (degree), FNBW (degree), front-to-back ratio (dB), side lobe level (dB), main lobe (dB), and back lobe (dB).

Table 1: Dimensions of the designed 2, 3 and 4 turns helix antennas at the selected frequencies

Designed Frequency (GHz)	2-Turns designed dimensions			3-Turns designed dimensions			4-Turns designed dimensions		
	Width (mm)	Radius (mm)	Spacing (mm)	Width (mm)	Radius (mm)	Spacing (mm)	Width (mm)	Radius (mm)	Spacing (mm)
0.80	1.35	23.20	25.30	1.52	21.40	23.60	1.48	19.60	21.80
1.20	1.45	22.30	24.60	1.36	20.50	22.40	1.48	18.40	20.70
2.40	1.53	21.40	23.50	1.42	19.60	21.40	1.56	17.30	19.80
3.50	1.48	20.10	22.30	1.52	18.30	20.50	1.41	16.40	18.10
5.30	1.36	19.20	21.40	1.40	17.40	19.60	1.45	15.70	17.30
7.50	1.42	18.10	19.20	1.36	16.40	18.10	1.43	14.50	16.20
10.50	1.42	16.00	17.20	1.26	13.20	14.20	1.32	12.90	13.80

Table 2: Dimensions of the designed 5 and 6 turns helix antennas at the selected frequencies

Designed Frequency (GHz)	5-Turns designed dimensions			6-Turns designed dimensions		
	Width (mm)	Radius (mm)	Spacing (mm)	Width (mm)	Radius (mm)	Spacing (mm)
0.80	1.43	17.70	19.50	1.50	15.10	17.40
1.20	1.52	16.70	18.30	1.54	14.10	16.20
2.40	1.45	15.70	17.20	1.36	13.20	15.40
3.50	1.37	14.50	16.20	1.56	12.60	14.00
5.30	1.50	13.20	15.40	1.35	11.80	13.60
7.50	1.35	12.30	14.60	1.40	11.60	13.10
10.50	1.41	11.40	13.50	1.32	11.40	12.20

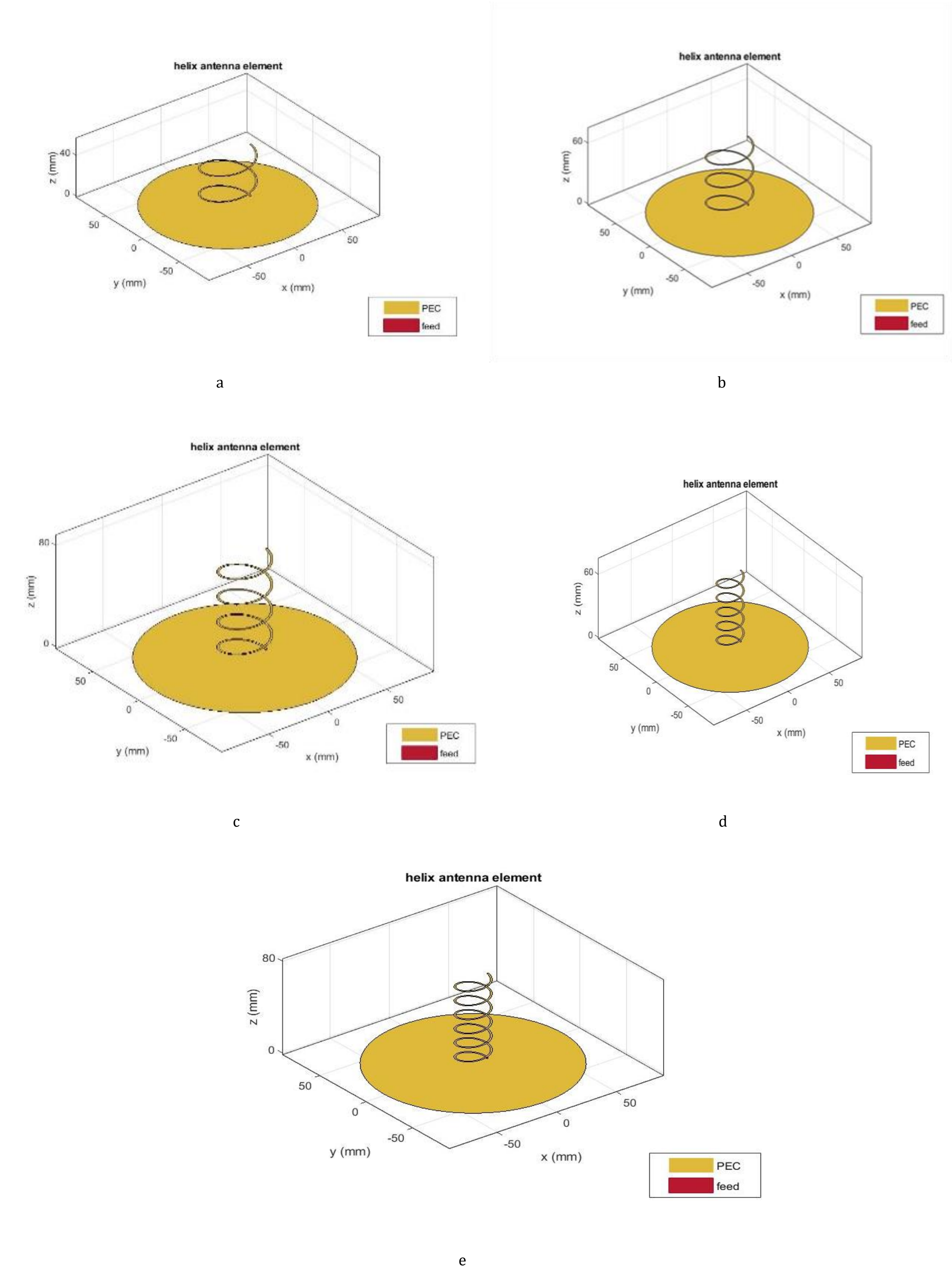

Figure 2: Structures of the simulated Helix Antennas (a) 2-turns (b) 3-turns (c) 4-turns (d) 5-turns (e) 6-turns.

4. Results And Discussions

Figure 3 shows the variations in the realised helix antenna turns with gain, directivity, bandwidth, and the helix antenna efficiency with frequency. It was observed that each helix turn shows a perpetual increase in gain with an increase in frequency. Meanwhile, the gains were poor at lower frequencies, basically 4G frequencies of 0.8 GHz to 2.4 GHz, which implies that the helix turns will be most suitable for 5G antenna applications where good gains are required. All the helical antenna turns show a significant increase in directivity at lower frequencies of 4G before linear convergence towards the same value as the frequency increases. It was observed that all the helical antenna turns failed to resonate at 0,8, and 1,2 GHz, even some at 2.4 GHz, and the bandwidth was null at these frequencies, but a reasonably higher bandwidth was obtained at 7.5 and 10.5 GHz, with all helical antenna turns given an equal bandwidth of 20 at 10.5 GHz. It was also witnessed that all the helical antenna turns efficiency increased with an increase in frequency, with the 2-turns and 4-turns having the highest efficiency at maximum frequency.

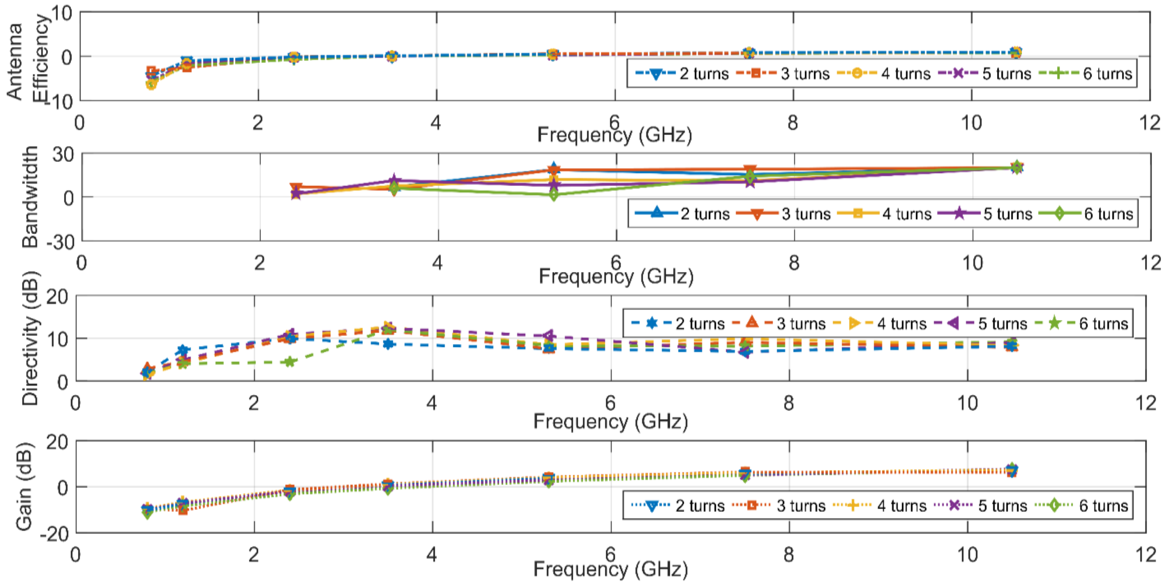

Figure 3: Variations of Gain, Directivity, Bandwidth and the efficiency of the realized Helix antenna turns with frequency

Moreover, figure 4 shows variations in return loss and VSWR of the realised helix antenna turns with frequency. It has been established in the literature that an antenna with higher values of return loss is regarded as a quality antenna; hence, observation from Figure 4 shows that, on average, the 3 and 4-turn helical antennas have relatively higher return losses than others and will be the most suitable in applications where higher return losses cannot be traded off. It was also noticed that all the turns of the helical antennas realised are useful for quality return loss applications at higher frequencies. It has also been established in the literature that a good practical antenna VSWR should be less than or equal to 2. Observation from the results in Figure 4 shows that the 3-turn helical antenna has the best VSWR with an average of 1.75 dB. These observations imply that the 3-turn helical antennas will be the most suitable for quality return loss and VSWR applications at the 4G and 5G frequencies under consideration.

Figure 5 shows the variations in radiation parameters of the realised helix antenna turns with frequency, namely, front-to-back ratio, FNBW, and HPBW turns with frequency. It was witnessed that the 6-turn helical antenna has the highest front-to-back ratio of an average of 16.29 dB, which implies that it is the most directional with good reception from the front, followed by the 5-turn helical antenna with an average of 14.95 dB, and the 2-turn helical antenna was next with an average of 13.6 dB. Hence, the 3- and 4-turn helical antennas are less directional, with poor reception from the front. Observations also show that the front-back ratio was significantly higher at higher frequencies than at lower frequencies, which implies that the realised helical antenna turns are more directional with good reception at higher frequencies.

Moreover, the variations in FNBW with frequency were more pronounced at 4G frequencies (lower frequencies) than the 5G frequencies (higher frequencies) with the 2-turns helical antenna having the highest average FNBW of 198.71 degrees while 6-turns has the least with average FNBW of 125.43 degree which implies that 2-turns has the widest coverage but less directional, while 6-turns is the most directional with less coverage, each can be used for specific applications based on requirements. Furthermore, it was equally observed that the HPBW decreased with an increase in frequency, particularly at 5.3 GHz and above, with 2 and 6-turn helical antennas having the highest average HPBW of 68.43 and 72.14 degrees, respectively, which implies that these two realised antennas have the highest resolution capacities. Observation also shows that all the realised turns of the helical antenna demonstrated higher HPBW (less directional) at the lower frequencies of 0.8 and 1.2 GHz, respectively.

Figure 6 shows variations of the backlobe, mainlobe, and sidelobe levels of the radiation pattern of the realised helix antenna as it turns with frequency. It was witnessed that the back lobe decreases with an increase in frequency, with the 6-turn helical antenna having the least average back lobe of -9.45 dB, followed by the 5- and 2-turn helical antennas with an average back lobe of -6.87 and -6.81 dB, respectively. 5-turns has the highest average main lobe of 8.08dB followed by 3-turns with an average main lobe of 7.45dB while 4-turns have the least average main lobe of 6.56 dB. Moreover, the side lobes which represent unwanted or poor radiation were higher at frequencies 2.4 and 3.5GHz compared to other frequencies, with 5-turn having the highest and 6-turns having the least side lobes, this implies that 6-turns have the best radiation efficiency.

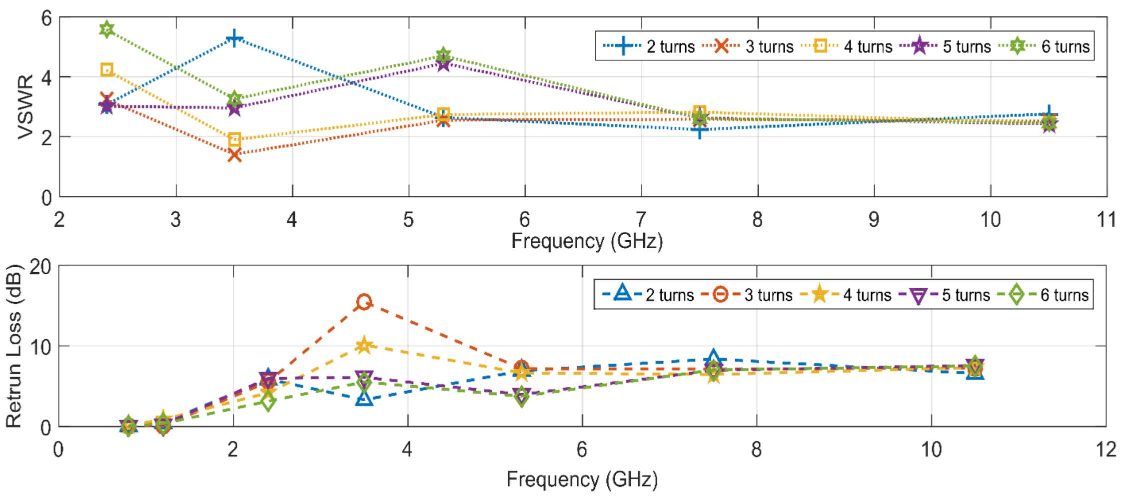

Figure 4: Variations of return loss and VSWR of the realized Helix antenna turns with frequency

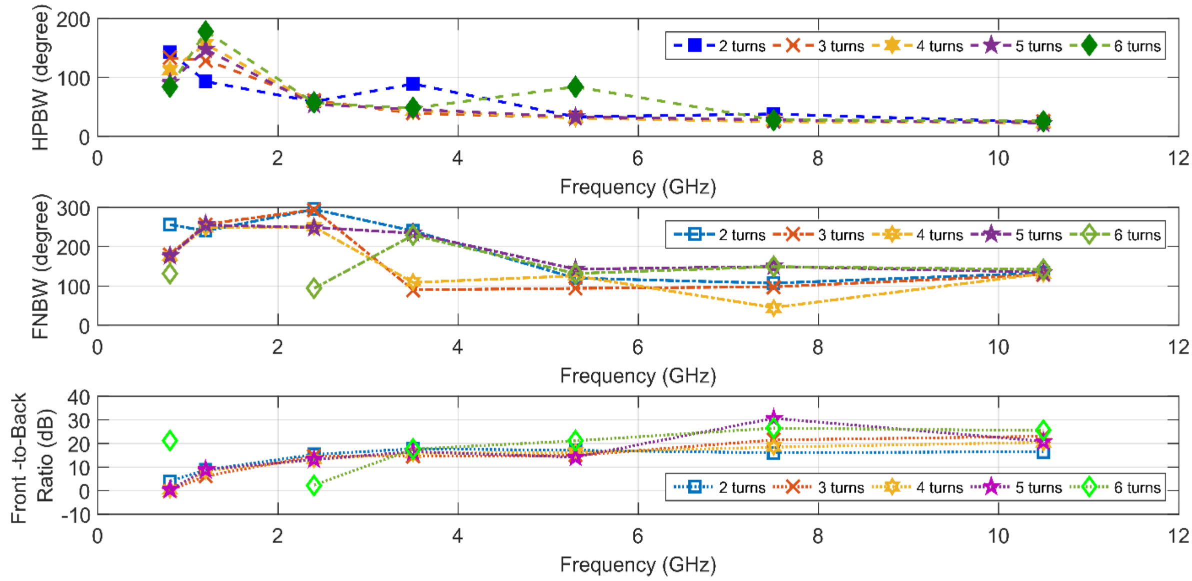

Figure 5: Variations of Front-to-Back Ratio, FNBW and HPBW of the realized Helix antenna turns with frequency

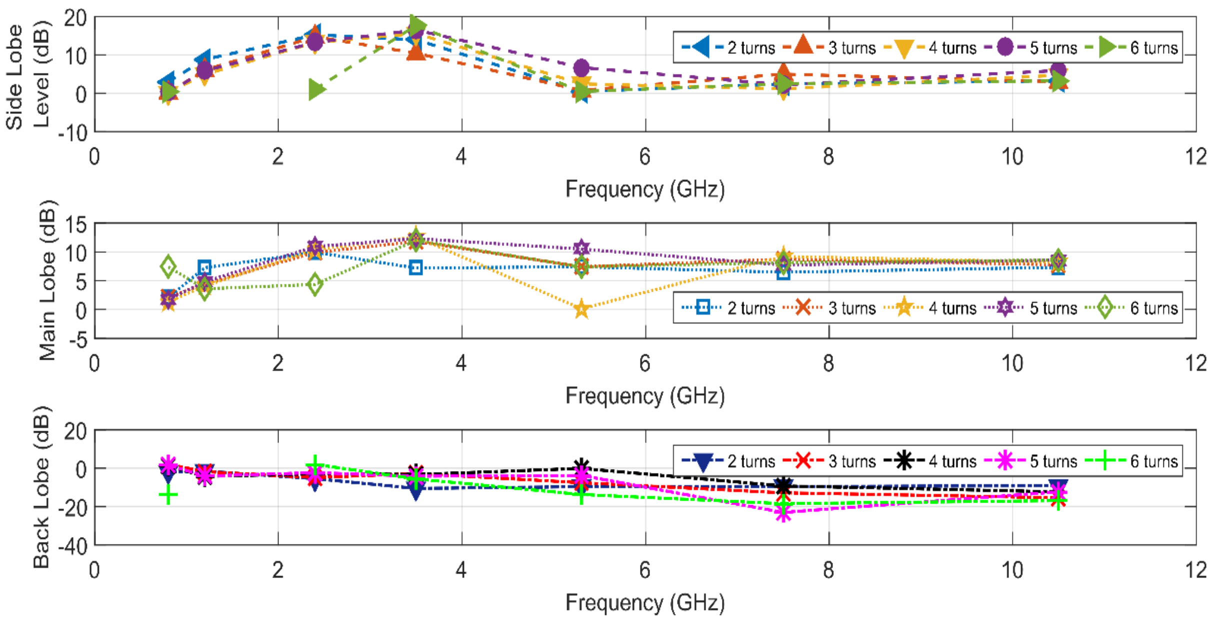

Figure 6: Variations of the Back Lobe, Main Lobe and Side Lobe Level of the realized Helix antenna turns with frequency.

5. Conclusion

The global increase in mobile device usage has led to a need for wireless communication network channels. Helix antennas, which offer advantages such as ease of construction, bandwidth, high directivity, and circularly polarised signals, are suitable for current-generation networks. However, their size poses challenges for compact mobile device applications. This study examines the performance characteristics of different helical antennas at 4G and 5G frequencies using simulation techniques and finds that gain increases with frequency increase and directivity increases at lower frequencies but converges at higher frequencies. Efficiency increases with frequency, with 2-turns and 4-turns showing better performance at optimal frequencies. The 3-turn helical antenna meets VSWR and return loss standards. The FNBW implies that the 2-turn helical antenna has the widest coverage, while the 6-turn helical antenna is the most directional, and the HPBW implies that 2-turn and 6-turn helical antennas have the highest resolution capacities. The study suggests that all helical antenna turns have good characteristics with few tradeoffs, making them suitable for higher-frequency applications.

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