

Design And Simulation of a Monofilar Helical Antenna for 5G and Beyond Applications

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Abstract—The helical antenna has been a staple in wireless communication applications for many years, particularly in very high and ultra-high frequency operations. Among a lot of variants one specific variant is the Monofilar Helical Antenna (MHA), characterized by a single conductor arranged in the form of a helix. In this paper, an MHA has designed using pure copper (99%) with a total length of 532.77 mm, operating within the C Band with a frequency range of 4-8 GHz. The resonance frequency was specifically set at 5.8 GHz. The dielectric material and conductor coating were made of FR4 epoxy (Lossy) and Perfect Electric Conductor (PEC), respectively, the latter serving as an excellent insulator. A coaxial feeding port was implemented at the bottom of the conductor. Simulated in the far field region, the monofilar helical antenna exhibited an S parameter of -25 dB, making it highly suitable for wideband and wireless communication applications. The VSWR measured at 1.01 indicated a near-perfect impedance match, ensuring higher efficiency. At the resonant frequency, the antenna demonstrated a directivity of 13.59 dBi, outperforming other antennas, with a main lobe magnitude of 11.6 dB and a gain of 11.53 dB, attesting to its exceptional performance. The ten turns of the helix and a circular aluminum ground plane contributed to the overall design, with other parameters calculated through mathematical analysis.

Index Terms—Monofilar helical antenna, VSWR, S-Parameter, Gain, Directivity, 5G.

I. INTRODUCTION

In the dynamic landscape of 5G and beyond, the seamless integration of channel estimation techniques [1], precoding strategies [2] renewable energy, and advanced antenna technologies extends to innovative designs like the monofiller helical antenna. Accurate channel estimation [3] guides precoding algorithms [4], optimizing communication performance, while advanced antenna technologies [5], [6] including channel modeling in Massive MIMO and beamforming [7], enhance spatial utilization. Simultaneously, antenna sites embrace sustainability by integrating renewable energy sources [8], aligning with the eco-friendly nature of monofiller helical antennas. This unique antenna design, with its compact structure and directional characteristics, further contributes to efficient spatial utilization. The holistic approach of combining advanced technologies with innovative designs underscores the commitment to both efficiency and environmental consciousness, shaping a

connected future driven by cutting-edge antenna solutions. A lot of researchers have done tremendous work for designing this unique antenna for 5G and beyond applications. The helical antenna described in [9], which operates between 5.8 and 5.9 GHz, was built using a 1.5 mm thick teflon substrate and is based on the strip-line construction. At 5.8 GHz and 5.9 GHz, respectively, this arrangement generated a maximum directivity of 12.2 and 13.1 dB. At 5.8 GHz, the antenna achieved a peak gain of 11.25 dB, while at 5.9 GHz, it reached 12.6 dB; both were excellent results, but they could have been even better. Here [10] we learn about a DMHA, or Dual-Mode Helix Antenna, which can pick up signals from both the sky and the ground. Linearly polarized omnidirectional patterns with a bandwidth of more than 2GHz are enabled by the DMHA's SFBHA for land-based applications. While in satellite mode, the QHA communicates via the GPS L2 band, showcasing how the DMHA's wire structure, developed by NEC, enables it to adapt to a wide frequency range that falls short of expectations. At the GNSS frequency bands, this work [11] presents a bifilar helical antenna with parasitic parallelogram loops that operates with a return loss of more than 10 dB and an axial ratio of less than 3 dB. The antenna shows promise for GNSS applications, but not for the 5G and beyond communication system, with RHCP gains of 3.8 dBic at 1217 MHz and 3.1 dBic at 1575 MHz. The prototype exhibited a negligible deviation of 1.1 dBi in azimuth, 0.37 dB in azimuthal gain fluctuation, and less than 5° in vertical beamwidth, as shown in this paper's [12] comparison of simulated and measured findings. This validates the optimization and prototype fabrication, launching the path for future tests with adaptive polarization and improved manufacturing techniques for improved geometric accuracy in prototypes, though not necessarily for 5G use cases.

In this paper, we have established an MHA, made of pure copper, functions in the 4-8 GHz C Band and has a resonance frequency of 5.8 GHz. The MHA, which relies on FR4 epoxy and Perfect Electric Conductor (PEC) as its dielectric materials, performs admirably in a variety of situations, including wideband and wireless communication. Its VSWR of 1.01 indicates good impedance matching, and its -25 dB far field S parameter and 13.59 dB resonant frequency directivity are further proof of its suitability. We have used the commercial software CST to accomplish the simulated results and to determine the antenna design parameters.

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II. HELICAL ANTENNA DESIGN AND SPECIFICATIONS

A few of the factors that define the monofilar helical antenna (MHA) are antenna radius, length, diameter, spacing, incidence angle, and operating frequency band (C Band). By selecting 5.8 GHz as the resonant frequency inside the C Band (5.3-6.3 GHz), the wavelength (λ) can be computed using the following formula and yielding 0.2 meters.

$$C = f\lambda, \quad (1)$$

Where, C = velocity of light, f = resonant frequency, λ = wavelength.

To design the conductor, we need to design a cylinder that consist of perfect electric conductor. The diameter of the conductor and spacing between coils needs to be measured by following formulas

$$D = \lambda/\Pi, \quad (2)$$

Where, D = Diameter of conductor. $\Pi = 3.14$ The diameter of the conductor is 16.46 mm (calculated) Hence there are one conductor of MHA needs to be spaced at a certain distance. One conductor with spiral bounding along the axis of cylinder. The spacing between coils works as a dice and it is denoted as S and following below formula.

$$S = \lambda/4, \quad (3)$$

Where, S = Spacing between coils. From equation (3), we get the spacing between coils is 12.93 mm. The number of turns which depends to produce more current from the bottom feed but the large number of turns increases narrow beamwidth. The antenna efficiency increases because of higher number of turns [4]. The narrow beamwidth can easily track the desired target and velocity of the object [3]. So we can easily use this antenna at a desired direction for axial mode operation. To avoid complexity of design, there took ten number of turns which helps to get simplicity design and good performance for axial mode operation. The length of the conductor is very important part to design BHA. The larger number of conductor increases loss of the antenna. The equation of length of conductor is given below.

$$L = \sqrt{(\Pi \times D)^2 + S^2} \times N, \quad (4)$$

Where, L = Length of conductor. D = Diameter of cylinder. S = Spacing between coils. N = Number of turns. From equation (4), we get the length of antenna is 532.77 mm for helix conductor.

The angle of incident which is denoted by α . The conductor is equal spacing. It is also known as pitching angle. The equation of angle of incident is given below.

$$\alpha = \tan^{-1} \frac{S}{C} \quad (5)$$

Where, S = Spacing between coils. C = Velocity of light. From equation (5), we get the value of pitching angle is 14° . The pitching angle makes the MHA more synchronous that receives equal current from feed line and equal current

distribution through the conductor during simulation. The radius of the conductor was taken 8.23 mm. Because small radius of conductor can minimize the larger area problem.

The values of performance parameters of monofilar helical antenna is showed in the following Table 2.

TABLE I: Performance Parameters.

Parameter Name	Value
Operating frequency (f)	5.8 GHz
Wavelength (λ)	51.72
Circumference (C)	51.72
Diameter (D)	16.46
No. of turns (N)	10
Spacing between turns (S)	12.93
Height of helix (H)	129.31
Pitching angle (α)	14°
Total length of helical antenna (L)	532.77
Wire diameter (d)	2
Ground plane (in diameter)	64
Length of matching coaxial (l_1)	12.93
Dielectric constant (ϵ_r)	4.4
Substrate thickness (h)	0.2

In order to attain maximum efficiency, a conductor material with a purity level of 99%, namely pure copper, is selected above alternative options such as gold, aluminum, and titanium. The copper conductor, due to its superior conductivity, surpasses other materials. The dielectric substrate, composed of FR4 epoxy with a relative permittivity of 4.4 and a thickness of 0.2 mm, acts as a barrier between the conductor and insulator. This substrate guarantees consistent dielectric constant stability across various temperatures and frequencies, hence reducing abrupt fluctuations in the vicinity of room temperature. Additionally, it minimizes reflection loss by inhibiting the flow of electric current outside of the conductor. In Fig. 1 we have portrayed the design of MHA with circular ground plane.

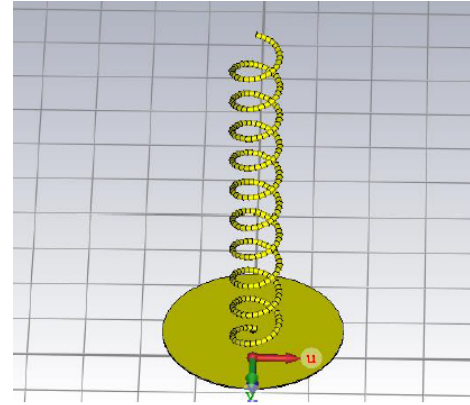


Fig. 1: Design of MHA with circular ground plane.

The dielectric possesses an external radius of 1.1 mm and an internal radius of 0.9 mm. It is covered with a perfect electric conductor (PEC) that has an external radius of 1.3 mm and an internal radius of 1.1 mm. The PEC coating improves the characteristics of a metallic component by providing insulation. The substrate and coating both possess a consistent thickness

of 0.2 mm, which aids in achieving a lightweight design for the antenna. In Fig.2 we have represented the design.

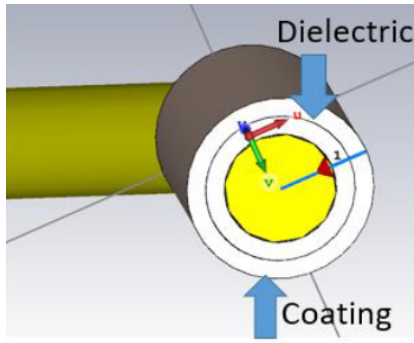


Fig. 2: Dielectric and Coating of MHA.

The ground plane of the monofilar helical antenna, constructed from affordable and lightweight aluminum, plays a vital role in reflecting the most amount of radiation along the axis of the helix. The antenna, employing a coaxial feed, attains substantial amplification and extensive frequency range, albeit with a limited emission pattern, rendering it appropriate for wireless communication purposes. The use of coaxial feeding provides the ability to position the feed in any desired direction in order to achieve impedance matching. The feeding structure consists of positioning the conductor on a circular ground plane and employing coaxial feeding, which guarantees uniform current distribution to achieve optimal performance. In Fig. 4 we have showed the ground plane of MHA.

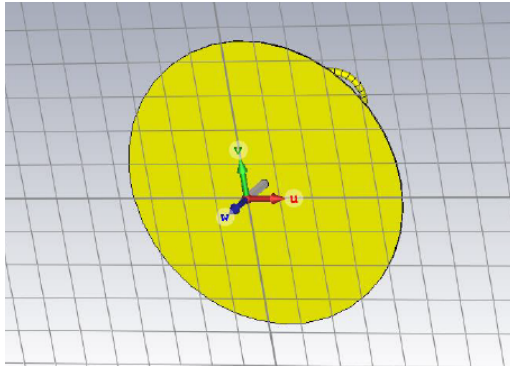


Fig. 3: Circular ground plane of MHA.

The coaxial feeding method offers the benefit of a straight-forward design, allowing the feed to be directed as required for achieving impedance matching. Utilizing an aluminum metal ground not only decreases the weight and expense, but also facilitates the placement of the antenna. The input impedance is configured at 50Ω in order to simulate the monofilar helical antenna. The antenna is strategically positioned to observe the farfield region and measure the electrical energy density. In Fig. 4 we have displayed the feeding port of MHA.

III. SIMULATION RESULT ANALYSIS

The 5.8 GHz band S parameter was derived after simulating at the resonant frequency. Reflection coefficient of -25 dB

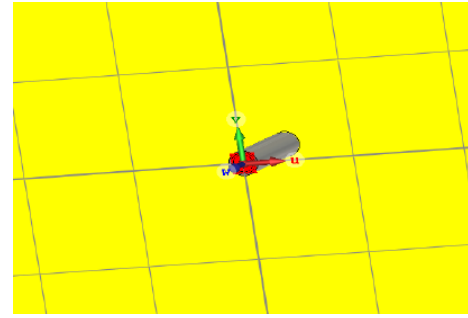


Fig. 4: Coaxial feeding port of MHA.

suggests limited bandwidth for 5G applications. The Monofilar Helical Antenna (MHA) was simulated at 5.8 and 5.9 GHz to observe the farfield area. Superior performance and a matched input-output current ratio are indicated by a low loss coefficient below -10 dB and a reflection coefficient near to the resonant frequency. A 5.8 GHz helical antenna with a dielectric resonator and cylindrical ground plane was presented. This antenna has a narrow radiation pattern yet excellent gain and bandwidth. Axial Ratio (AR) bandwidth makes the MHA unsuitable for high data rate transmission, but its low loss coefficients improve its performance for 5G, ultra-wideband, and wireless applications.

An antenna's impedance matching to its transmission line can be quantitatively described by the voltage standing wave ratio (VSWR). Consider the reflection coefficient as a critical variable. An antenna's performance is directly proportional to its VSWR value. Fig. 6 shows that, up to its near-resonant frequency of 5.8 GHz, the VSWR is very close to 1. The reflection coefficient determines the VSWR. Here, the values for the feeding port's VSWR plot are obtained from the VSWR measurement at the resonance frequency. According to the S parameter in Fig. 6, the feed port appears to have an exact value, suggesting that it feeds the current equally.

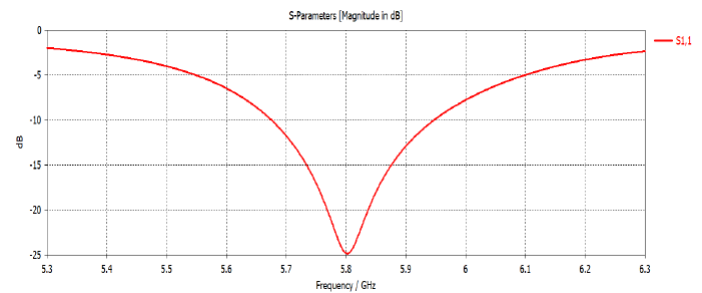


Fig. 5: S-Parameters of MHA.

The radiation pattern is defined as how the power radiated from the antenna in a certain direction. It has a major lobe which defines the maximum radiated power at a certain direction and are some minor lobes which defines the loss power radiated by antenna. It is the variation of the power radiated by an antenna as a function of the direction away from the antenna. This power variation as a function of the arrival

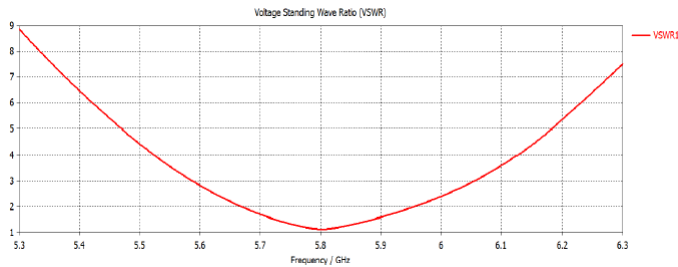
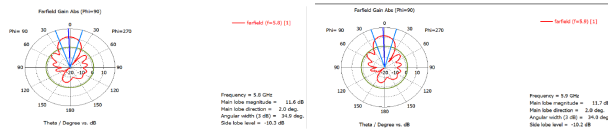


Fig. 6: VSWR of MHA.

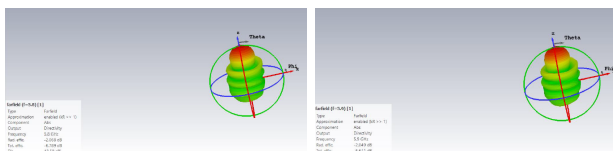
angle is observed in the antenna's far field. From this Fig.7(a) we get the main lobe direction was 2° at resonant frequency 5.8 GHz. The angular width or 3 dB half power beamwidth is at 34.9° . At main lobe direction 2° , the antenna radiates maximum power. In this direction, we get the value of main lobe magnitude is 11.6 dB which means better power radiated at this particular direction. The side lobe of this antenna at 5.8 GHz is -10.3 dB which is very low that means very small power radiated from this minor lobe. It is a great advantage for this antenna to get maximum power radiation from major lobe at 2° with less power loss at minor lobe. In axial mode operation, radiation density or power radiated along the axis of the helix conductor. So we can track the object at a particular location easily. At frequency band 5.9 GHz, the main lobe magnitude is 11.7 dB and main lobe direction is 2° , side lobe level is -10.2 dB as shown in the Fig. 7(b).



(a) Radiation pattern of MHA in polar format at 5.8 GHz (b) Radiation pattern of MHA in polar format at 5.9 GHz

Fig. 7: Radiation Pattern.

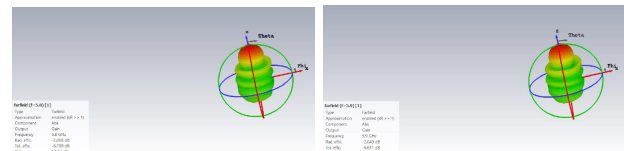
From the Fig 8(a), at resonant frequency 5.8 GHz, the value of directivity got 13.59 dBi. The antenna is highly directive and radiate mostly directional beam that implies more focused or directional antenna. The MHA is also directive at 5.9 GHz and it is a major advantage of this antenna. It represents the radiant intensity that MHA creates a particular direction against the average value of other direction. The value of directivity at 5.9 GHz is 13.74 dB as shown in Fig. 8(b).



(a) Directivity plot at 5.8 GHz of MHA. (b) Directivity plot at 5.9 GHz of MHA.

Fig. 8: Directivity of MHA.

From above Fig.9(a) the value of gain is 11.53 dB. So MHA has relatively high gain that indicates high power radiated by the antenna at resonant frequency. The high gain of MHA comparing other helical antenna is better. It has also major advantage for 5G applications which will power wide range of future industries from retail to education, transportation to entertainment and smart homes to healthcare. It will make mobile more essential than it is today. From Fig.9(a) we can see the maximum power radiated in z direction in farfield region. With coaxial probe feed, the high current radiated from the feed line of the conductor and maintain equal current distribution properly. This antenna was feeded such a way that maximum power raises in wanted z direction that defines that major lobe is directed to 0° of the radiation angle. This coaxial feeding is easy to fabricate and has better efficiency of this antenna. So this higher gain of antenna implies more effective in its radiation pattern. At other frequency band 5.9 GHz, the MHA has also comparatively high gain as shown in following Fig. 9(b). The gain at 5.9 GHz is 11.69 dB which means the antenna shows better performance from the frequency band 5.8 to 5.9 GHz. The feeding technique and design of this antenna help to get better performance of MHA. So the efficiency of the antenna is higher between 5.8 to 5.9 GHz frequency band and the more power radiated from z direction that can be used as UHF for transmission and reception of 5G applications.



(a) 3D Gain plot at 5.8 GHz of MHA. (b) 3D Gain plot at 5.9 GHz of MHA.

Fig. 9: Gain plot of MHA.

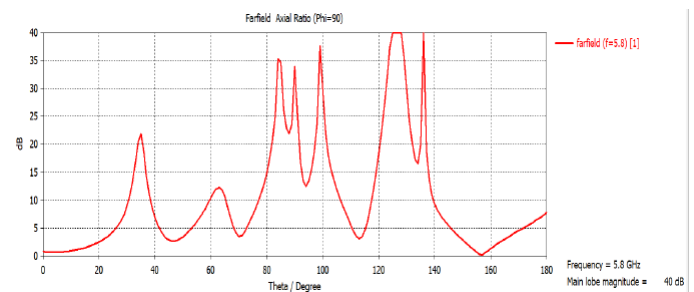


Fig. 10: Axial Ratio at 5.8 GHz.

Another term axial ratio which is important for in which the desired polarization is circular. It is the ratio of orthogonal components of E field. The figure of axial ratio is shown Fig. 10. The ideal value of axial ratio for circularly polarized fields is 0 dB. The lower value than 3 dB of axial ratio that indicates the deviation from circular polarized is less than 3 dB over the specified angular range. At resonant frequency 5.8 GHz, we got the value of axial ratio less than 3 dB that means good

TABLE II: Comparison between some existing works and our proposed work.

No	Name of Papers	Antenna Type	Frequency Band (GHz)	Materials	Length (mm)	S Parameter (dB)	Gain (dB)
1	M. Y. Zeain, M. Abu, Z. Zakaria [9]	Helical	4-8	Teflon Rod	530	-13.66	11.21
2	C.H Niow & K. Mouthaan [13]	Helical	2-3	Teflon Rod	200	<-10	20
3	Weikang Chan, Zhenyi Niu, Mengyuan Li [11]	Helical	0-1	Printed Strips	102	<-25	0.4
4	Achmad Munir & Hermanto [14]	Helical	3-4	Copper	51.6	<-13.52	5.12
5	Proposed MHA	Helical	4-8	Pure Copper	532.77	-25	11.53

circular polarized. So the good circular polarization means maximum power radiated from the conductor at farfield region. In addition the axial ratio tends to degrade away from the main beam of MHA. When the helix circumference is near the wavelength of operation, the antenna operates in axial mode.

A. Comparison Among Existing Works.

In reviewing Table II, it becomes apparent that Helical antennas exhibit a wide range of parameters, reflecting differences in design, feeding techniques, and the choice of materials, such as copper and Teflon rod. The frequency bands utilized in the design of these antennas vary, encompassing bands like L, S, and C, with some even extending into the MHz range. Researchers have explored different aspects, including helix length, the number of turns, and achieving a reflection coefficient below -10 dB, all of which play crucial roles in antenna performance.

Our proposed Helical antenna stands out in comparison to existing works, particularly in its efficiency within the C band and its superior reflection coefficient. The use of pure copper, coaxial feeding, and a circular aluminum ground plane contribute to impedance matching and reduced return loss. The design simplicity, with only ten turns, adds to its appeal, especially when considering cost and weight considerations. This is particularly advantageous in scenarios where other metal ground planes may not be available or suitable for wireless communication applications.

In a recent study [9], the authors observed an S-parameter of -13.66 dB, gain of 11.21 dB, VSWR of 1.52, and directivity of 12.2. Our design beats these values, with an impressive VSWR of 1.01 and almost no loss. Furthermore, our antenna performs significantly better in all metrics, with an S-parameter of -25 dB, a gain of 11.53 dB, and a directivity of 13.59 dB.

Notably, the MHA (Helical antenna) demonstrates excellent performance by producing higher current, aligning with the desired direction for radiation. The dielectric substrate, coated with FR4 epoxy, facilitates the efficient radiating of current. In the far-field region, simulation results at 5.8 GHz and 5.9 GHz showcase the MHA's robust characteristics, providing insights when compared to existing works.

B. Applications

A monofilar helical antenna with circular polarization that operates in the 4–8 MHz frequency band is very useful in a number of advanced measurement applications, among them some of the most valuable ones are described in below.

Earth observation and remote sensing: Instruments used in remote sensing to assess environmental factors including soil moisture, vegetation cover, and ocean salinity rely heavily on circularly polarized helical antennas. Since of its intrinsic circular polarization, the data is more accurate since it reduces multi path effects and improves penetration through surface layers and vegetation.

Communications: Strong ground-to-satellite and satellite-to-ground linkages are made possible by these antennas, which are perfectly adapted for high-frequency (HF) communication systems. Signal integrity is guaranteed by the circular polarization regardless of antenna orientation, which is especially helpful for moving or rotating platforms.

Direction Finding and Geolocation: Circular polarization reduces polarization mismatches in direction finding and geolocation systems which is the main success of our proposed design, resulting in more accurate signal direction measurements. Applications in military operations, maritime navigation, and search and rescue are critical to this skill.

Ionospheric Research: Monofilar helical antennas play a key role in this field of study, supporting the investigation of ionospheric behaviors and properties. When examining ionospheric propagation characteristics, the 4 to 8 MHz frequency region is especially relevant because circular polarization minimizes signal distortion which we can observe in impedance matching of our proposed design and fading brought on by ionospheric abnormalities.

Broadcasting and Signal Reception: These antennas are also used for transmitting and receiving signals in the high-frequency bands (HF bands). This ensures reliable performance even in difficult conditions where multipath and other signal degradation phenomena are present.

Scientific and Medical Instrumentation: Because of their stable signal transmission, which is made possible by circular polarization, they are used for a variety of scientific

and medical instrumentation applications. They offer accurate measurements and dependable data collecting.

To sum up, the monofilar helical antenna is a highly beneficial tool for a variety of measurement and communication applications due to its ability to function consistently in any direction and to match impedance effectively in the 4 to 8 MHz region which is very impressive in our work with reference to the S parameter.

IV. CONCLUSION

Having thoroughly examined and assessed the parameters of the antenna, it is evident that the MHA holds a significant advantage due to its heightened efficiency, rendering it well-suited for wireless communication applications. The circular polarization and compact size enhance its versatility, allowing deployment in various locations. Rigorous validation and comparison of the selected antenna structures were conducted using advanced commercial simulators. Design execution involved the utilization of "CST Microwave Studio" simulation software, with performance evaluations carried out in the far-field region. The MHA distinguishes itself with attributes such as high gain, exceptional directivity, a narrow beam, wide-angle axial ratio, and minimal return loss. These characteristics position the antenna as exceptionally efficient for applications like cellular communication and GSM modems paired with laptops or PCs. A pivotal aspect contributing to its success is the coaxial feeding beneath the conductor, facilitating high electrical power generation and uniform current distribution along the helix's axis. Consequently, the MHA exhibits notably elevated gain, directivity, and reduced return loss.

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