Defence Science Journal, Vol. 75, No. 3, May 2025, pp. 325-330, DOI : 10.14429/dsj.20901

Design of a 3D Printed Helical Antenna having High Gain for 2.4 GHz ISM Band Applications

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ABSTRACT

A helical antenna that is designed for circular polarisation throughout an extensive axial-ratio (AR) bandwidth is demonstrated. The antenna is constructed from copper wire and is supported by a 3D-printed polylactic Acid (PLA) structure. The antenna's performance (reflection coefficient, axial ratio, gain, and radiation pattern) is comprehensively analysed and influenced by the geometric characteristics of the helix and the quantity of PLA used inside the coil diameter. The pre-designed PLA framework is used to construct the antenna prototype by coiling a 1 mm diameter copper wire around it. The framework is equipped with threads that are designed to support the helix of the antenna, according to the specified number of turns and distance between each turn. The antenna is suitable for a wide range of ISM band applications, as it resonates at 2.45 GHz and has a high radiation efficiency of 99 %. Additionally, it has a maximum gain of 8.01 dB. The helical antenna has a bandwidth of $0.15\lambda 0$ at the central frequency and a 3 dB axial ratio bandwidth that spans from 2.3 to 2.5 GHz. The results demonstrate the ease and feasibility of producing highly efficient helical antennas using 3D printing technology.

Keywords: 3D printing; Helical antenna; Axial ratio; Circular polarization; High gain

1. INTRODUCTION

Helical antennas are esteemed for their extensive bandwidth and Circular Polarisation (CP) characteristics, leading to their increasing prevalence in various wireless communication platforms, including satellite communications, infrared, and radio frequency applications[6]. Helical antennas are predominantly employed in military applications requiring multifunctionality or spectrum agility, as well as in hospitals and other radiofrequency-sensitive environments with high-gain radar communication systems[7].

Circularly polarised antennas are used in a wide variety of modern applications, including satellite communication and polarised radar imaging, amongst others. Helical antennas are a feasible alternative for producing circularly polarised radiation with high gain. They provide a wide bandwidth and higher gain in a compact form[1]. Helical antennas are also a potential option for wireless communication. These antennas provide a wide frequency range and a significant amount of amplification, both of which are essential for the generation of circularly polarised emissions[4].

In addition to loop and straight wire forms, the helical antenna is a basic kind of antenna that covers both possibilities. This device operates in two primary modes: In the standard mode, the emission peaks perpendicular to the axis of the helix, like a monopole antenna, when the helix size is much less than the wavelength. as operating in axial mode, the peak emission shifts to the broadside as the circumference of the helix approaches one wavelength. The radiation may exhibit elliptical, planar, or circular polarisation, dependent upon the geometry of the helix[8].

In order to determine the kind of polarisation, the axial ratio is an important antenna feature that must be considered. For the purpose of determining the real antenna placement, it is essential. It is of the utmost importance to ascertain if an antenna is Left-Hand Circular (LHCP) or Right-Hand Circular (RHCP), since this distinction has the potential to result in a gain difference of up to 25 dB between an LHCP transmitting antenna and a RHCP receiving antenna[9]. It is also possible to improve performance and minimise polarisation losses by aligning the polarisations of the antennas that are used for sending and receiving signals. It is possible to ensure effective communication and increase overall antenna performance by conducting an accurate examination of the different forms of polarisation[2].

Within the realm of helical antennas that resonate at roughly 2.45 GHz, there is a limited body of research that brings together works that are similar. Two modes of operation are described in[10] for a helical antenna that is made using wire coiled in a screw-thread arrangement. These modes are normal and axial. When operating in axial mode, radiation is produced along the axis of the helix with a polarisation that is almost circular. This article presents the design of an axial-mode helical antenna that operates at a resonant frequency of 2.4 GHz. The antenna has circular polarisation and a directional gain of 10.16 dB. This technology is suitable for use in wireless applications in situations that are blocked, and there are plans to improve it so that it may be used underwater. Another example is provided

Received : 08 January 2025, Revised : 02 April 2025
Accepted : 29 April 2025, Online published : 08 May 2025

in[11], which describes a helix antenna that is similar to a spring in that it has a particular diameter and a certain amount of space between the windings. In order to accomplish this goal, a Wi-Fi signal amplifier operating at 2.4 GHz and displaying a nominal gain of 4.5 dBi with horizontal polarisation has to be developed. There is a big difference in size between our suggested helical antenna, which is roughly 7 centimetres, and this one, which measures 50 centimetres. According to[12-13], there are not many works that are comparable to this one. The dielectric materials that are used in the construction of an axial mode helical antenna include magneto-dielectric ferrite and polyethylene terephthalate (PET). The device can achieve a gain of 8.8 dBi and operates in a broad frequency range that extends from 1.76 to 4 GHz. Additionally, it has a bandwidth that spans from 2.4 to 4 GHz and has an axial ratio of 3dB. There is a revolutionary dual-band, four-arm helical antenna that is proposed in[12]. This antenna makes use of the 2.4 GHz band for WLAN and the 1.575 GHz band for GPS.

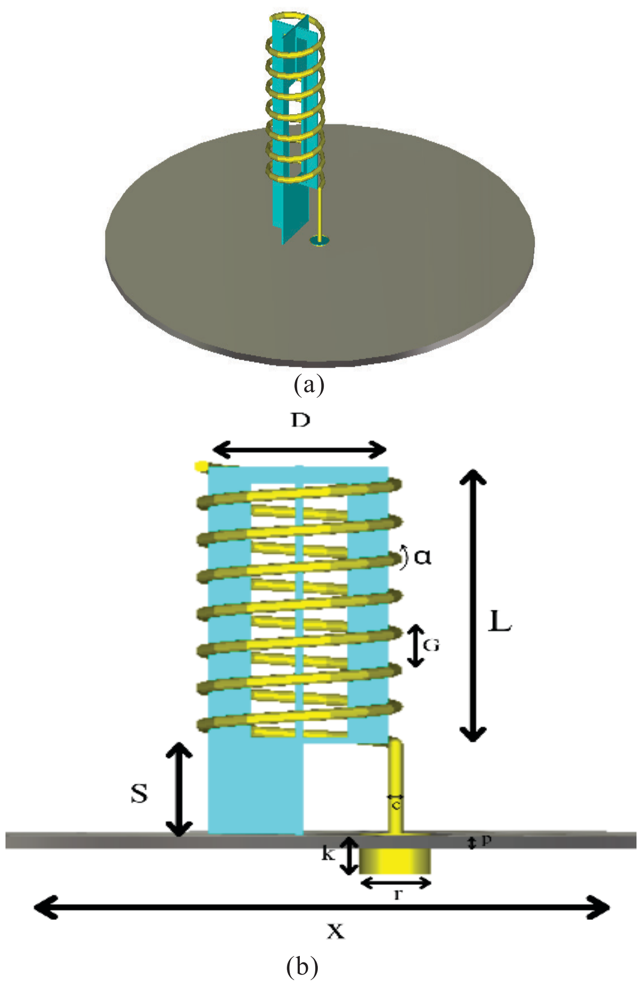


Figure 1. Proposed helical antenna, (a) Perspective view; and (b) Side view.

Using three-dimensional printing technology, this study investigates the design of a circularly polarised high-gain helical antenna that is capable of functioning at the 2.45 GHz ISM band. This antenna is suited for a wide variety of applications, spanning from the Internet of Things (IOT) to the biomedical industry. The helix of the antenna is intended to be readily twisted around a pillar-like cross-shaped PLA structure that is generated via the use of 3D printing technology. At the end of the day, the PLA structure will ultimately serve as a support mechanism that will firmly maintain the antenna's helix, which is made up of a copper wire with a diameter of 1 millimetre. CST Microwave Studio, which is a high-frequency electromagnetic solution, was used throughout the whole process of designing and analysing the proposed antenna. The antenna has a great radiation efficiency of 99% and a high gain of 8.01 dB at the ISM band frequency. Both characteristics are impressive. A nominal 3dB AR bandwidth is available for the antenna, which spans from 2.3 to 2.5 GHz. Additionally, the antenna has a -10dB impedance bandwidth of $0.15\lambda_0$ at 2.45 GHz. In Section 2, the antenna design and its specifications are investigated in detail, and in Section 3, a full presentation of the simulated and empirical results is provided as well as how the helical antenna is manufactured. The whole research work and its novelty has been conclusively discussed in Section 4.

2. METHODOLOGY

The suggested helical antenna's top and side views are depicted in Fig. 1(a) and 1(b). The antenna helix is a copper coil twisted around a PLA cross-shaped pillar made via 3D printing. PLA has 0.073 loss tangent and 3.47 permittivity[14]. Round copper discs with ten-centimetre diameters serve as antenna grounds. Fig. 1(b) shows the antenna construction attached to the coil end receiving its initial stimulation via coaxial feeding.

A total height of around 7 cm is associated with the helical antenna that has been proposed. This antenna has been designed to be compact and effective. This measurement considers both the helix and the copper ground plane that lies underneath it. The helix, which measures 4.8 cm in length, is the most important component. A wire made of copper with a diameter of 0.1 cm is used in the exact fabrication of this item. A helix with five turns is created by winding the wire in a spiral pattern. To ensure that the structure maintains a consistent and optimised layout for effective signal transmission, each turn is precisely positioned at an angle of 540 degrees. When it comes to achieving the impedance and radiation qualities that are required, it is vital to keep the spacing between successive helical turns at 0.96 cm. It is intended that the helix will produce a coil that has a diameter of 2.6 cm. The selection of this specific dimension was made in order to improve the size and performance of the

Table 1. Dimensions of fabricated antenna

Symbol	Description	Size
c	Wire diameter	1 mm
D	Coil diameter	26 mm
G	Distance between two successive turns	9.6 mm
k	Length of the coaxial port	7 mm
L	Total Length of the Helix	48 mm
p	Thickness of the copper ground plane	2 mm
r	Diameter of the coaxial port	9.6 mm
S	Length of the feed	15.61 mm
x	Diameter of copper ground plane	100 mm
α	Turn angle of the Helix	540°

antenna, hence making it suitable for applications that have space restrictions. The helix is attached to a ground plane made of copper, which provides structural support and stability via its attachment. Within the substrate, there is a copper ground plane that has a diameter of 10 cm and a thickness of 0.2 cm. This ground plane serves as a sturdy foundation for the antenna. For the antenna to be effective, it is essential that its dimensions be precise. This ensures that it satisfies the requirements that are required for the application that it is intended for. It is possible to get a clear visual representation of the antenna's design by looking at Table 1, which contains all the features along with the required symbols.

3. RESULTS, ANALYSIS & DISCUSSION

3.1 Simulated Results

Figure 3 displays the computationally determined reflection coefficient of the helical antenna that has been suggested. The result reveals that a -10 dB impedance bandwidth of 0.15 λ_0 can be achieved at the central frequency of 2.45 GHz, while a satisfactory return loss of 30dB is achieved. Figure 4 illustrates the circular polarisation performance of the suggested helical antenna. This performance demonstrates that an outstanding 3 dB AR bandwidth between 2.3 and 2.5 GHz is achieved at the ISM band. As a result, this antenna is suited for a wide range of applications. Since this indicates that the helical antenna has a strong circular polarisation in this frequency range, it is particularly suitable for circumstances in which a stable and uniform signal polarisation is required.

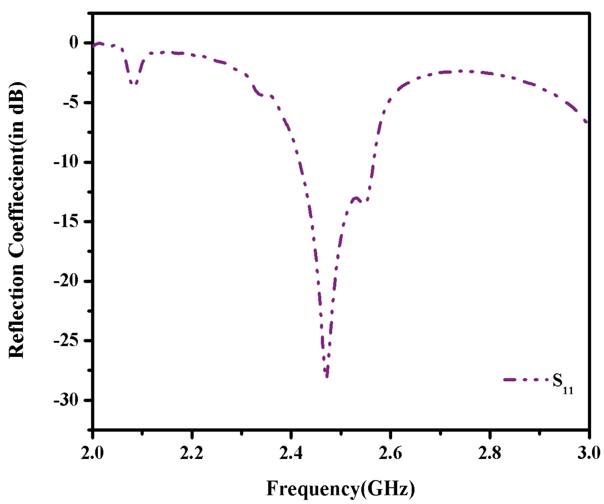


Figure 3. Simulated reflection coefficient plot.

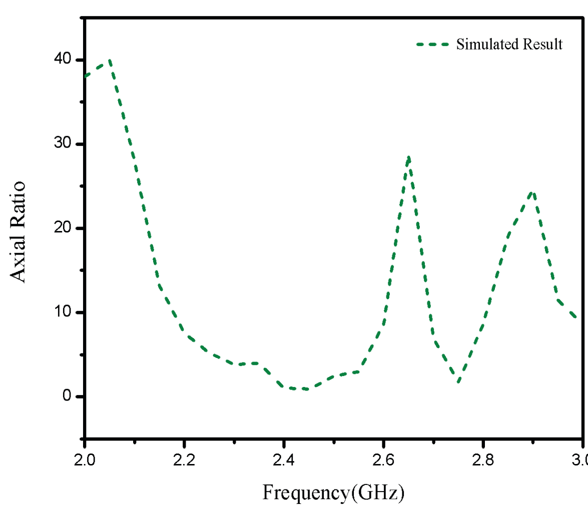


Figure 4. Simulated axial ratio vs frequency plot.

An illustration of the suggested antenna's three-dimensional radiation pattern can be seen in Fig. 5. This pattern makes it abundantly evident that the antenna operates

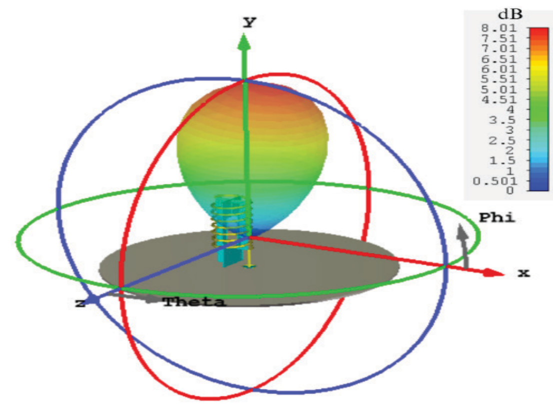


Figure 5. 3D radiation pattern plot at 2.45 GHz.

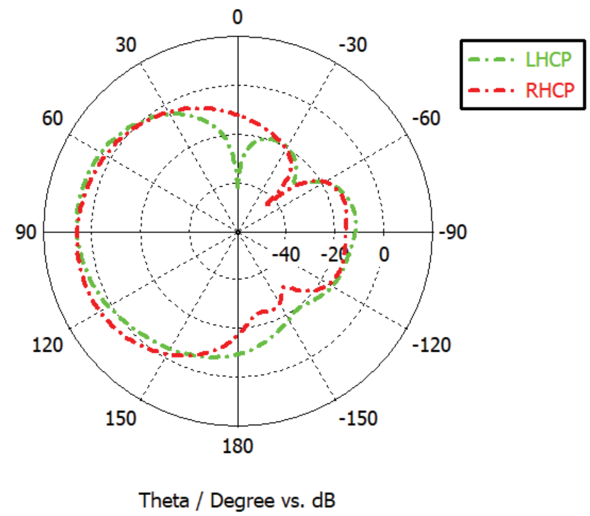


Figure 6. Simulated LHCP and RHCP plot.

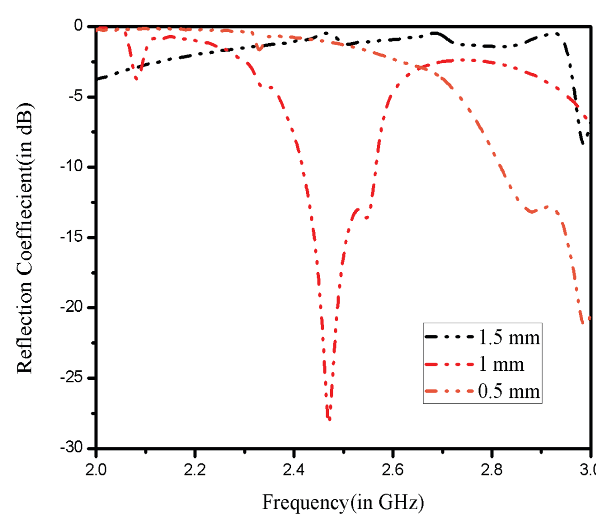


Figure 7. Comparison of reflection coefficient with different coil diameters.

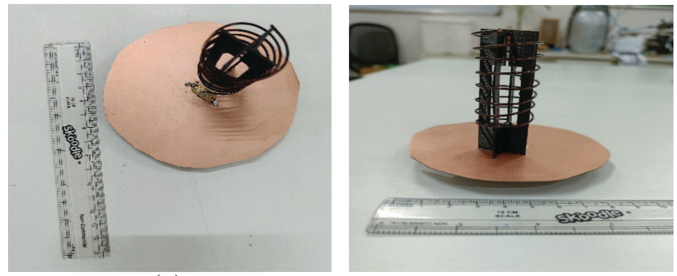
in axial mode at 2.45 GHz, and it also has a noteworthy gain of 8.01 dBi. A more accurate depiction of radiation strength and dispersion across a variety of directions is made possible by the linear scaling, which also makes it possible to conduct an in-depth analysis of the antenna's performance. Fig. 6, which depicts both LHCP and RHCP plots, is an illustration of the properties of the antenna that are associated with circular polarisation. One of the antenna's distinguishing characteristics is brought to light by this, which demonstrates the existence of dual polarisation. The fact that the antenna produces a stronger signal along the axis of the helix supports the hypothesis that it is transmitting a signal that is polarised in a circular fashion. Both the LHCP and the RHCP have radiation patterns that are symmetrical, which is consistent with the behaviour that is expected from a helical antenna that has a particular handedness. A directed circularly polarised beam may be generated by the helical antenna, as seen by the radiation pattern, which demonstrates that the antenna is capable of doing so. Because it has this feature, it is appropriate for a wide variety of applications.

3.1 Comparisons with Different Parameters

A comparison has been done between the result of the simulation and different scenarios, such as changing the diameter of the copper coil, in order to investigate the differences that take place in the results that are wanted. Copper wire comes in three distinct diameters: 0.5 mm, 1 mm, and 1.5 mm. We have compared the results for each of these three sizes on the copper wire. A comparison of the Reflection Coefficient for a number of different sizes can be seen in Figure 7. It is clear from the graph that the only time we are able to attain the resonant frequency is when the wire has a diameter of one millimetre. This is the only time we are able to meet this requirement. As an additional point of interest, the other diameters do not even come close to satisfying the requirements of the model. Additionally, we have compared the gain of the proposed antenna at 2.45 GHz as well as in broadband from 2 to 3 GHz. This is something that we have done. A vivid demonstration of the large gain that occurs when the diameter of the coil is 1 mm can be seen in Table 2.

Table 2. Comparison of gain with different coil diameters

Diameter of the coil (in mm)	Gain (in dB)	
	At 2.45 GHz	Broadband
0.5	4.5	4.49
1	8.01	7.67
1.5	4.75	4.75



(a) (b)

Figure 8. Proposed antenna design (a) Top view; and (b) Side view.

Figure 9. Measurement result with setup.

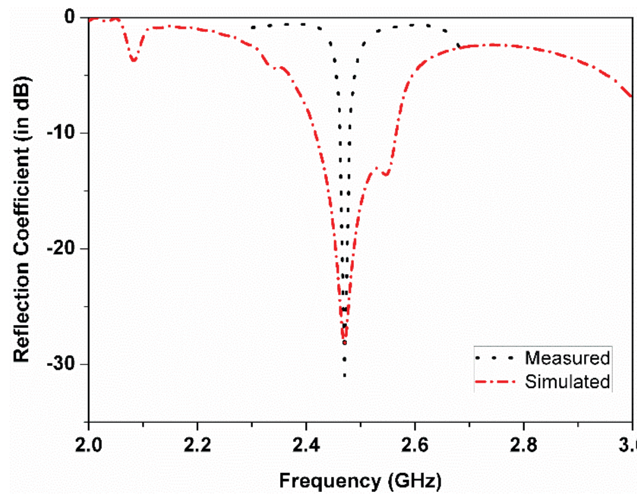


Figure 10. Simulated and measured reflection coefficient plot.

3.2 Experimental Verification

The antenna that is being recommended is built in the way that is shown in Fig. 8(a)-(b), and the experimental results that were acquired from the Anritsu MS46122B020 series VNA in the free space environment (shown in Fig. 9) are verified using the simulated antenna shown in Fig. 10 and 11.

Table 3. Radiation properties of various helical antenna types and their comparison

Antenna	AR bandwidth (%)	Max gain (dBi)	3D Size(λ_0^3)	RE (%)	Deployability	Reference
Proposed HP	24.48	10.2	0.82x0.82x0.57	>99	Yes	Proposed
MDHA	12.60	9.8	0.27x0.27x0.65	>90	Yes	[3]
WHA	50.30	10.5	0.85x0.85x0.98	>85	No	[5]

Nevertheless, the measured plot, which is a reflection of the performance of the antenna that was produced, displays a substantially narrower bandwidth at the same -10 dB level. This is the case despite the fact that the antenna was constructed successfully. This is due to the mistake that was brought about by the humans who were responsible for the building procedure. As a result of this distinction, the resonant frequency in both plots is quite close to one another, and there is only a little shift that can be seen between them. This demonstrates that the antenna that was produced is an exact approximation of the design that was simulated, and that it effectively meets the requirements of the frequency spectrum that is required. As can be seen in Figure 11, the response of the voltage standing wave ratio (VSWR) is pretty comparable to the one that was simulated at a frequency of 2.45 GHz.

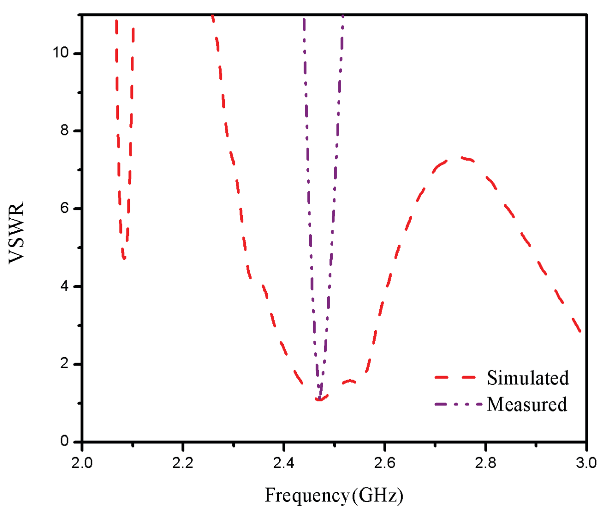


Figure 11. Simulated and measured VSWR plot.

An examination of the similarities and differences between our proposed helical antenna and a wide variety of other helical antennas is provided in Table 3. The comparison of radiation characteristics reveals without a reasonable doubt that the antenna that we have recommended has an unparalleled level of performance. The highest gain of our antenna, which is 10.2 dBi, is adequate when compared to the antennas of [3] and [5]. In addition, our antenna boasts a very high radiation efficiency of 99%, which is also extremely impressive. As opposed to [5], it is portable and has a decreased 3D dimension. In addition, it has a smaller footprint. Consequently, the innovation of the antenna that has been presented is warranted.

4. CONCLUSION

Helical antennas will undoubtedly serve as the cornerstone of advanced communication systems in the future. This single-band, circularly polarised helical antenna is shown to illustrate the simplicity of its fabrication using 3D printing technology. PLA is used to secure the slender antenna coil throughout the printing process of the antenna. The antenna has a narrow beamwidth, identified as an advantageous trait for a radiation pattern that is unidirectional, exhibiting high efficiency and circular polarisation. The simulated and tested data indicate promising outcomes, characterised by excellent radiation efficiency, satisfactory return loss bandwidth, and enough AR bandwidth. Both qualities are evident. The helical antenna is a viable option for wireless communication systems due to its portability, lightweight nature, and small dimensions. This makes it an optimal choice for use in wireless communication systems.

REFERENCES

1. Liu, C.; Guo, Y. -X.; Bao, X. & Xiao, S.-Q. 60-GHz LTCC integrated circularly polarized helical antenna array. *IEEE Transact. Antennas and Propa.*, 2012, **60**(3), 1329-1335. doi: 10.1109/TAP.2011.2180351.
2. Sharma, P. & Gupta, K. Analysis and optimised design of single feed circularly polarized microstrip antennas. *IEEE Trans on Antennas and Propag*, 1983, **31**(6), 949-955. doi: 10.1109/TAP.1983.1143162.
3. Song, Z.; Zheng, H.; Li, Y. & Li, E. Investigation of axial mode dielectric helical antenna. *IEEE Transact. on Antennas and Propa.*, 2022, **70**(5), 3806-3811. doi: 10.1109/TAP.2021.3125365.
4. Kraus, J.D. The helical antenna. Proceedings of the IRE, 1949, **37**(3), 263-272. doi: 10.1109/JRPROC.1949.231279.
5. Li, G., Gao, G., Liu, W. & Tian, Z. Tunable and flexible liquid spiral antennas. *Electron. Lett.*, 2017, 53, 648-650. doi:10.1049/el.2016.4528.
6. Balanis, C.A. Antenna theory analysis design, New Jeresy: John Wiley & Sons, Inc., 2005.
7. Muri, P.; Challa, O. & McNair, J. Enhancing small satellite communication through effective antenna system design. *In* Milcom 2010 Military Communications Conference, San Jose, CA, USA, 2010, pp. 347-352. doi: 10.1109/MILCOM.2010.5680405.
8. Salbani, M.F.; Abdul Halim, M.A.; Jahidin, A.H. & Megat Ali, M.S. Helical antenna design for wireless power transmission: A preliminary study. *In* 2011 IEEE International Conference on System Engineering and Technology, Shah Alam, Malaysia, 2011, pp. 192-195, doi: 10.1109/ICSEngT.2011.5993448.
9. Kunooru, B.S.; Nandigama, V.; Sandhya Rani, S. & RamaKrishna, D. Analysis of LHCP and RHCP for Microstrip Patch Antenna. *In* 2019 International Conference on Communication and Signal Processing (ICCSP), Chennai, India, 2019, pp. 0045-0049. doi: 10.1109/ICCSP.2019.8698034.
10. Jaafar, A.N.; Ja'afar, H.; Pasya, I.; Yamada, Y.; Abdullah, R.; Aris, M.A. & Redzwan, F.N.M. Analysis of helical antenna for wireless application at 2.4 GHz. *In* 2019 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE), Melacca, Malaysia, 2019, pp. 1-5. doi: 10.1109/APACE47377.2019.9020810.
11. Destria, N.; Artiyasa, M.; Gumilar, S.; Azhari, R.; Badrudin; Maulidan, M.A. & Pradiftha, J.A. Design of 2.4 GHz Helix antenna for increasing wifi signal strength using managal and wirelesmon application. *In* 2017 International Conference on Computing, Engineering, and Design (ICCED), Kuala Lumpur, Malaysia, 2017, pp.

1-5.
doi: 10.1109/CED.2017.8308117.
12. Sekelja, M.; Blazevic , Z. & Maslac, M. Helical antenna performance in wideband communications. *In* 2008 16th International Conference on Software, Telecommunications and Computer Networks, Split, Croatia, 2008, pp. 21-26.
doi: 10.1109/SOFTCOM.2008.4669445.
13. Xiao, W.–Z; Cheng, W.-C.J.; Sun, S. & Chen, G. –Y. Dual-band circularly polarized helical antenna for satellite buoy. *In* 2021 International Symposium on Antennas and Propagation (ISAP), Taipei, Taiwan, 2021, pp. 1-2.
doi: 10.23919/ISAP47258.2021.9614403.
14. Huber, E.; Mirzaee, M.; Bjorgaard, J.; Hoyack, M.; Noghanian , S. & Chang, I. Dielectric property measurement of PLA. *In* 2016 IEEE International Conference on Electro Information Technology (EIT), Grand Forks, ND, USA, 2016, pp. 0788-0792.
doi: 10.1109/EIT.2016.7535340.

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His contribution in the current study is designing, simulating, fabrication of the above prototype. Literature review and research required to develop the above novel structure of such size and also preparing the final manuscript.

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In the current studey he contributed by cross-checking results, checking viabiltiy as well as performing plagiarism checks.

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For the current study, he designed the 3D support cross-shaped structure for 3D printing.

Dr Gobinda Sen obtained his PhD degree in RF and Microwave Engineering from Indian Institute of Engineering Science & Technology, Shibpur, Howrah, India. He is working as Professor in the department of ECE at Institute of Engineering and Management, Kolkata, India.
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