PERFORMANCE ANALYSIS OF QUADRIFILAR HELICAL ANTENNA: A COMPREHENSIVE SURVEY

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Abstract: The electromagnetic spectrum band of frequency of 2.4 GHz to 5 GHz, were allocated to industry in the past, but recently in the advancement of Technology development the frequency band are been shared by Industrial, Scientific and Medical (ISM). Now, this band of frequency as also being used for Wi-Fi, Bluetooth, and cordless devices. Due to different types of antennas such as a Quadrifilar helical antenna, dielectric resonator antenna, microstrip patch antenna, etc. are used for the above-mentioned devices. However, due to small size and weight microstrip patch antenna become dominant in this field from last few years. In this paper, various antenna designs for ISM band application have been discussed with their performance analyses from various papers on which this survey is conducted. Alongside, the comprehensive survey examines the performance of QHAs, focusing on advancements in design, optimization techniques, and practical implementations was also examined. By reviewing recent literature, this article aims to provide a thorough understanding of the key performance metrics, challenges, and future directions in QHA research.

Keywords: Industrial, scientific and medical (ISM) radio Band, performance analysis, Quadrifilar antenna

1. INTRODUCTION

Antenna technologies have advanced significantly during the past few years in several domains, including wireless local area networks (WLAN) and Wi-Fi technology [1]. The ISM band is a radio frequency initially used only for commercial, scientific, and medical applications. Currently, the majority of wireless applications, Bluetooth devices, cordless phones, printers, keyboards, and mice, as well as gaming controllers, are utilized in this frequency range. Higher data rates, up to 300 Mbps, are needed for voice, video, and data communications in the 2.4 GHz range. The ISM band at 5 GHz is also used in business Wi-Fi applications. It connects two 2.4 GHz systems over a certain distance as a backhaul link. A large amount of bandwidth is available in the 60 GHz ISM band, allowing for very high data throughput wireless communication [2]. Numerous antennas including quadrifillar helical antennas have been covered in this study. This work places greater emphasis on helical antennas than on their equivalents because of several advantages, including their relatively wide impedance, ease of impedance matching, compact size, good radiation efficiency, light weight, and inexpensive construction [4]. Antenna design techniques encompass a wide range of methods and principles used to create efficient and effective antennas for various applications [6]. Antennas are essential components in wireless communication systems, radar systems, satellite communication, and many other technologies. The design of an antenna involves considerations such as frequency range, radiation pattern, polarization, gain, impedance matching, and size constraints (Jennie and Neduncheliyan, 2023). Quadrifilar Helical Antennas (QHAs) have gained prominence due to their ability to provide circular polarization and broad frequency coverage. Initially developed by Heinrich Hertz, QHAs have evolved through significant advancements in materials, design methods, and optimization techniques. The essence of antenna design is to convert electromagnetic signals through a specific structure to radiate or receive waves. Also, antenna geometries variation could disrupt transmission and its radiation pattern [5]. In antennas design should have a designated structure, characteristics, and specific applications. The helical antenna mode is influenced by several factors, such as the helix's diameter, the pitch (the distance between two consecutive turns), the length of the helix, and the operating frequency. By adjusting these parameters, the antenna's mode of operation can be optimized for specific applications. Helix antenna has a wide bandwidth, is simple to build, has a true input impedance, wide range of frequencies, from low to very high frequency bands. and can generate circularly polarized fields.

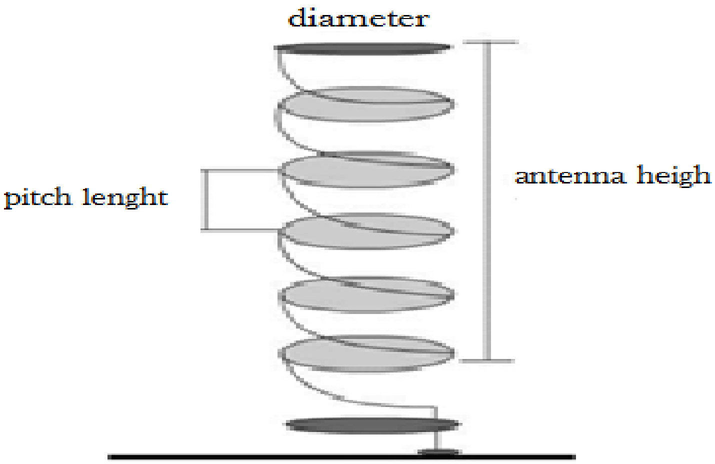

Figure 1. Pictorial view of Helical Antenna structure parameter [7]

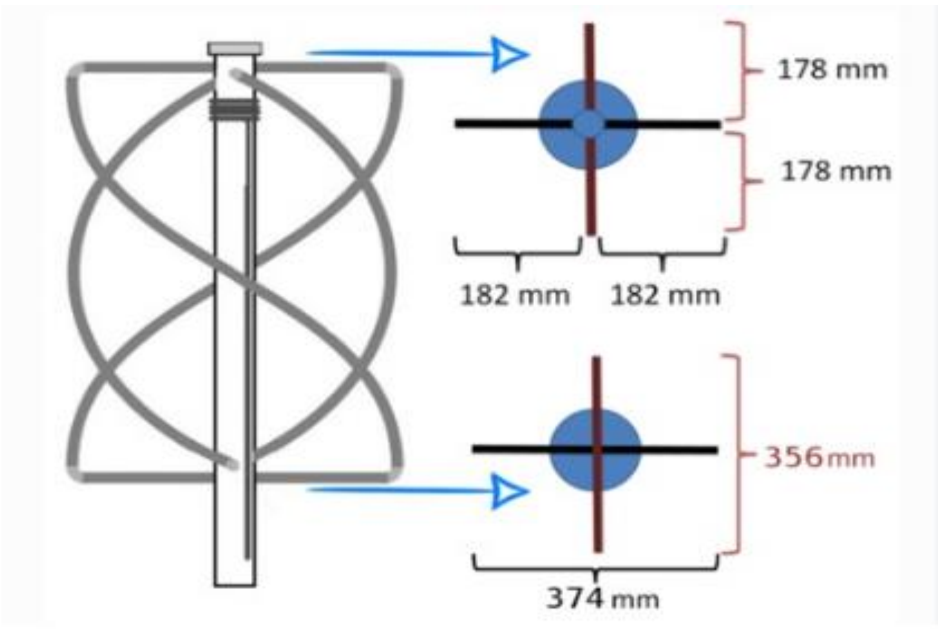

Figure 2. Side view of Quadrifillar Helical antenna [7]

However, this quadrifilar helix antenna (QHA) delivers outstanding performance for narrow band applications needing a broad beam width, cardioid-shaped, circularly polarized radiation pattern, and a compact structure, as per comparisons with other antennas. The fact that the QHA's radiation properties are comparatively unaffected by the presence of metal structures behind the antenna is another crucial factor to take into account (particularly in spacecraft applications) (Sarel, 2017). The quadrifilar helix is used for applications that require a cardioid-shaped, circularly polarized beam with a high front-to-back ratio. The QHA antenna is one of many antennas used to take pictures on non-geosynchronous spacecraft. Unlike conventional antennas, it does not have null spots immediately overhead or in other undesirable places. To achieve the desired characteristics several modifications were done in existing antenna structures some of which are discussed in Table 1.

Table 1. Challenges in antenna design

Sr No.	Design properties	Related work	Technique used in antenna design
1	Antenna miniaturization	[9], [10], [12]	Complementary split ring resonator [9]. Three-layer open loops and printed on a substrate with a high relative dielectricconstant [10]. Square patch antenna with a center square slot [12].
2	Multiband	[1], [3], [14], [17], [18], [19]	Modified inverted- L antenna with ground stub [1]. A printed monopole for WiFi and for WiGig channels high order mode patch antenna[3]. Two stacked concentric patches assembled by two orthogonally placed verticalprobes [14]. A spiral element and a parasitically coupled monopole element [17]. A segmented loop and a meander line structure [18].
3	Gain	[15]	A stacked concentric patch assembled by two orthogonally placed vertical probes[15].
4	Bandwidth enhancement	[1],[7], [16]	Modified inverted-L antenna with a ground stub [1]. The E shaped patch is selected [7]. Printed monopole using ring shape ground [16]
5	Better return loss	[8],[14]	Genetic algorithm technique is used in IE3D software [8], Two stacked concentric patches assembled by two orthogonally placed vertical probe[14].
6	Low cost	[3],[7]	PCB and plated through hole technology is used [3]. Microstrip patch antenna [7]

This paper is organized into seven sections. In section II, describes the literature survey on the work done by various authors on different antenna for ISM band. Section III addresses the various gaps of the study. In section IV, Various parameters like gain, bandwidth, return loss of antenna etc. are discussed. The performance analysis based on survey is given in section V. In this comparison is made on the bases of their result. Sections VI conclude the survey and finally in section VII future scope are discussed.

1. LITERATURE SURVEY

Keller et al., (2016) designed, fabricated and simulated a self-phased QHA for use in Army air-to-ground and airborne assisted ground-to-ground communication systems. The antenna operates very well over the intended TW-

400 radio frequency band of 1.765–1.805 GHz, with a realized gain of ~4 to 4.5 dB and functional beamwidth of ~90° to 110°.

Ghaffarian et al., (2016) created a single-layer compact feeding circuit and a broadband printed quadrifilar helical antenna (PQHA). At the base of the quadrifilar antenna is a low-cost single-layer feeding circuit made up of two 3 dB hybrid commercial couplers and a 180 compact rat race coupler. The axial ratio's large beamwidth (160) has a 20% bandwidth in the 1.9 to 2.3 GHz operational frequency range. Semi-omni radiation characteristics were attained by employing the proposed antenna in an array arrangement. The outcome demonstrated the designed antenna's favorable circular polarization radiation properties, making it a strong contender for use in a variety of TT&C and satellite communication systems.

Chiu et al. (2018) presented a printed QHA with a small footprint and low weight for use in handheld ultra-high frequency (UHF) radio frequency identifier (RFID) readers. The QHA's four arms use quarter-wavelength inverted-F resonators as their fundamental radiation components. The reader antenna's height is only 27 mm, making it small and still maintaining satisfactory electrical performance. A four-port quadrature phase feeding system made entirely of lumped elements is used to feed the antenna. With a measured reading distance along line of sight of 7.2 m for a commercially available and standard tag, the antenna demonstrated maximal gain of 3.2 dB at 920 MHz, making it appropriate for handheld ultra-high frequency radio frequency identification (UHF RFID) reader applications.

Mahdi and Seyed (2018) created a printed quadrifillar antenna QHA in the shape of a square with folded helices serving as the arm for satellite applications. The QHA building had four flat, printed walls with identical arm patterns on each one. Four flat substrates with removed ground layers were used to print the folded arm patterns, and these substrates were then connected to create the antenna construction. At an operating frequency of 435 MHz, this antenna was created in two forms, one with isolated arms and the other with connected arms. Since the BW may be extended up to 34%, the large antenna with connected arms performed better and can be utilized for wideband applications, whereas the small antenna with separated arms produced results that were suitable for a small satellite.

Ahmad et al, (2019) investigated, regarding its use in satellite communication, how the input and radiation properties of QHA performed in the presence of infinite and finite metallic ground surfaces. He noted that smaller metallic platforms acting as finite ground planes produce better 3 dB axial ratio beamwidth and boresight axial ratio, and that for the infinite ground plane, input parameters like impedance and voltage standing wave ratio (VSWR) are stable with wider half power beamwidth (HPBW). He came to the conclusion that using QHA on smaller metallic platforms, including nanosatellites and CubeSats, increased the antenna's circularly polarized beamwidth and boresight axial ratio.

Pinku et al, (2019) designed a QHA for Cube-Sats in the low earth and medium earth orbits using a combination of four helical antennas, each separated by 90°, and excited separately at the feeding point. The antenna is designed for operation at 4.5 GHz with an impedance bandwidth of 11.11 %. Simulated performance showed the designed antenna at a gain of about 4.2 dB at resonant frequency 4.5 GHz at Phi=80º and Theta=110º, which proves that the designed QFH antenna is a very good candidate for omnidirectional in Cube-Sats application.

Tanha and Fateha (2019) created a revolutionary wireless capsule endoscope quadrifillar antenna (WCE). The antenna's uniqueness lay in the way that each helix arm's angle was altered. The antenna's tiny size made it possible for it to be enclosed inside a typical capsule and swallowed once enclosed. Analyses of the antenna's performance in free space, the capsule, and a muscle layer body phantom model were conducted. According to the results, the antenna maintains safety standards inside the phantom model and is appropriate for use with WCE since it exhibits the necessary bandwidth, polarization, radiation pattern, and resonant frequency.

Zhong et al, (2020) created a portable dual-band printed quadrifilar helix antenna (QHA) that can operate in the GPS-L1 (1575 2MHz) and L2 (1228 2MHz) bands. Two connecting lines of different lengths are added as a radiating element to produce the dual working bands. The quarter-wavelength mode resonance of the closely spaced radiators greatly reduces the size of the antenna. According to measurements, the small proposed antenna can reach peak gains of 1.5 dBic and 2.6 dB at frequencies of 1228 MHz and 1575 MHz, respectively. The half-power beamwidths (HPBWs) at the L1 and L2 bands are as broad as 130º and 116º, respectively, and the axial ratios (ARs) are both below 2.5 dB. The developed antenna produced dual-band radiation while also being substantially more compact (0.1 0.21 0.2) when compared to previously published efforts.

Sun et al. (2022) conducted research on wideband and multilayer feeding network developed to excite the four basic modes of the proposed QHA through phase control in the experiment. The simulated and measured right-handed circular polarization (RHCP) radiation patterns agree quite well. The proposed QHA was also designed to cover several global navigation satellite system (GNSS) bands. The measured impedance bandwidth is 1.26–1.65 GHz (26.8%) and the 3 dB axial ratio bandwidth is 1.1–1.8 GHz (41.4%) in the endfire mode. It is shown that the proposed QHA can be easily operated in two endfire modes to have an equivalent isotropic pattern for flying objects. When the antenna is operating in the endfire mode, the gain is in the range of 2.1–3.5 dBi, and the radiation efficiency is 70%–85% in the operating band.

Youseff et al. (2017) design and implement a quadrifilar helix antenna are presented where the four arms are 3-D printed. The antenna structure is miniaturized by resorting to a combination of two approaches. The first approach is based on loading the tips of the four helical arms with circular conductive disks. The size and location of these elements directly affect the antenna's operating frequency. The second miniaturization approach is based on incorporating an FR-4 dielectric material into the vacant space between the four arms of the quadrifilar helix. As a result, the length of the antenna is reduced by a ratio of 43%. The quadrifilar helix antenna is also designed on top of a ground plane with an optimized conical shape and topology. The antenna is partially fabricated using 3-D printing additive technology, where measurements show great agreement with simulated results.

Musthafa et al. (2022) proposed a hybrid staircase-shaped (SSR) QHA radial, and it is formed by serially arranging several vertical and diagonal elements. The electric field lines from the vertical elements converge constructively to radiate with the axis normal. Besides, the circular spatial offsets between the adjacent diagonal and vertical elements induce a 90 ∘ delay in the field radiated. This hybrid shape launches an unprecedented theory facilitating normal mode of operation (MOOp) in QHA and generates CP over broad elevations and azimuths (0 ∘ < θ <80∘ and 0 ∘ < ϕ <360∘). Besides, the port-to-port 90 ∘ spatial offset and the GCPW architecture yield high isolation (> 20 dB). Unlike conventional GNSS-R antennas, this compact (170.5 mm × 132 mm) configuration operates in axial and normal mode, offers a broad beam coverage (237∘), minimizes pattern interference between the two QHAs upon gap-free stacking, and ensures high delay accuracy in the remote sensing data computed. Additionally, it supports proficient (efficiency > 0.9) Mult constellation remote sensing. The design prototype was fabricated and measured, and the measurements agreed well with the simulations.

Hongmei et al. (2020) presented a low-profile dual-band printed quadrifilar helix antenna (PQHA) with wide beamwidth for UAV GPS applications. The antenna is composed of a hollow dielectric cylinder with four arms of dual-helix metal strips and a hollow dielectric ring with four pairs of circular metal strips. To provide dual-band operation, different lengths of the dual-helix metal strips are applied. By loading the circular metal strips on the dual-helix metal strips, size reduction of the antenna height is realized. Moreover, wide beamwidth is obtained. A miniaturized quad-feed network is also designed to provide equal amplitude signals with sequentially quadrature phases. To validate the proposed structure, a prototype is fabricated. The height of the antenna is 18.5 mm. The experimental results show that good impedance matching (|S11| <; -18$ dB) and axial ratio (<; 2 dB) are obtained at GPS L1/ L2 bands. At 1.227 GHz, the measured 3-dB axial ratio beamwidths (ARBWs) are 186° and 187° at xoz and yoz planes, respectively. While the values are 167° and 163° at 1.575 GHz. The measured half-power beamwidths (HPBWs) are both more than 120° at the two bands. The results indicate that the proposed PQHA is a good candidate for UAV GPS applications.

Thus, in literature studied so far, several methods are given to use same antenna for more than one frequency that is one antenna can be used as a dual band antenna or multiband antenna. Moreover, special attention is given in the reduction of size of antenna, improving the bandwidth of antenna, reduction in mutual coupling and enhancing the efficiency of antenna. Antenna mentioned are also used for multiple input multiple output MIMO system as it offers increase in data throughput and link range without additional bandwidth or increased transmit power [11].

A. Gaps in the Study

i. Designs of antenna should be modified to have wider frequency in single antenna for various applications.
ii. A quadrifilar helix antenna is a type of antenna known for its circular polarization and omni-directional coverage, consisting of four helically wound conductors that are symmetrically spaced around a common axis.
iii. Antenna designs are complex.
iv. This design allows it to effectively transmit and receive signals in all directions, making it particularly useful for satellite communications, GPS systems, and meteorological satellites.
v. Its unique structure provides stable performance across a wide range of conditions, ensuring reliable communication where consistent signal quality is critical.

Signal impairment and Design Considerations for Terrestrial Antennas

i. Obstructions and Line-of-Sight (LOS)

Obstructions in the environment, such as buildings, trees, and terrain, can obstruct the direct line-of-sight (LOS) between the antenna and the intended communication target. These obstructions can cause signal blockage, attenuation, reflection, diffraction, or scattering. Design considerations should include evaluating the LOS path and identifying potential obstructions that may impact the antenna's coverage and signal quality. Antenna placement and orientation should be optimized to mitigate the effects of obstructions and maintain a clear LOS.

ii. Multipath Effects

Multipath effects occur when the transmitted signal reaches the receiving antenna via multiple paths due to reflections, diffractions, or scattering from surrounding objects or surfaces, delay spread in the time between the arrival of the direct path propagation and the reflected at the receiving antenna. Large delay spreads can cause inter-symbol interference, making it challenging to decode the received signal accurately. These effects can result in constructive or destructive interference, causing signal fading, distortion, or even complete signal loss. Multipath effects are particularly prominent in urban environments with tall buildings and complex topography.

iii. Fading and Shadowing

Fading and shadowing are phenomena that occur when the received signal strength fluctuates or attenuates due to variations in the propagation environment. Fading can be caused by signal interference, multipath propagation, or atmospheric conditions. Shadowing occurs when large objects or structures create a "shadow" region where the signal strength is significantly reduced. Design considerations should include predicting and minimizing the effects of fading and shadowing to ensure consistent and reliable signal reception.

iv. Atmospheric Conditions

Atmospheric conditions, such as rain, fog, snow, and atmospheric turbulence, can affect the propagation characteristics of electromagnetic waves. These conditions can cause signal attenuation, scattering, or signal dispersion, leading to degradation in signal quality or increased path loss. Antenna design should take into account the expected atmospheric conditions in the deployment area to ensure optimal performance under different weather conditions.

v. Temperature and Environmental Durability

Temperature variations and harsh environmental conditions can impact the durability and performance of terrestrial antennas. Extreme temperatures, moisture, humidity, corrosive elements, and exposure to UV radiation can degrade antenna materials, connectors, and electronics over time. Design considerations should include selecting robust and durable materials, protective coatings, and environmental sealing to ensure long-term reliability and performance stability.

vi. Electromagnetic Compatibility (EMC)

The electromagnetic compatibility of the antenna system with other nearby electronic devices and systems should be considered to prevent interference issues. Proper shielding, filtering, and grounding techniques should be implemented to minimize electromagnetic emissions and susceptibility to external interference.

1. PARAMETERS OF ANTENNA

A. Gain and Directivity

The gain of an antenna is a parameter which is used to measure the degree of directivity of the radiation pattern of theantenna. It is actually the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtainedif the antenna delivered all of the power equally in all directions [6]. The definition of gain requires the concept of anisotropic radiator; that is, one that radiates the same power in all direction. An isotropic antenna is just a concept, for all practical antennas should have some direction properties. The gain of antenna is measured in decibels (dB). For the gain of isotropic radiation measuring units are in dBi and for half wavedipole units are dBd. Gain and directivity are the same with a difference. Every practical antenna directs more energy in a single direction. It is interesting to observe how much power the antenna concentrates in a specific direction. The degree to which a lossless practical antenna (a = 1) concentrates the radiated power in comparison to an isotropic radiator can be used to visualize the antenna directivity. An antenna's directivity is defined as "the ratio of the radiation intensity from the antenna in a given direction to the radiation intensity in all directions." The total power radiated by the antenna divided by 4π determines the average radiation intensity. If the direction is not specified, the direction of maximum radiation intensity is implied." Stated more simply, the directivity of a non-isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source.

$$D = \frac{U}{U_o} = \frac{4\pi U}{P_{rad}} \qquad (2.8)$$

If the direction is not specified, it implies the direction of maximum radiation intensity (maximum directivity) expressed as;

$$D_{max} = D_o = \frac{U_{max}}{U_o} = \frac{4\pi U_{max}}{P_{rad}} \qquad (2.9)$$

Where D is directivity, U is radiation intensity, U_o is radiation intensity of isotropic source, U_{max} ismaximum radiation intensity, D_o is maximum directivity, and P_{rad} is total radiated power.

B. Beamwidth

Beamwidth of a pattern is the angular separation between two identical points on opposite side of the maximum pattern. A feature known as beamwidth is connected to an antenna's pattern. The angular distance between two identical locations on the opposite side of the pattern maximum is known as the beamwidth of a pattern. There are several beamwidths in an antenna pattern. The Half-Power Beamwidth is one of the most popular beamwidths (HPBW). Half power beamwidth, or HPBW, is the angle at which the main lobe's peak radiating power divides in half on either side. Beamwidth between first nulls, or BWFN, is the angle formed by the major lobe when two neighboring nulls are placed side by side.

C. Radiation pattern

Radiation pattern provides crucial information about the characteristics of an antenna essential for optimizing the coverage area, signal strength, and overall performance of wireless communication systems. The radiation pattern is typically determined in the far field region and is shown as a function of the directional coordinates. The two- or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius is the radiation attribute of most interest. Practical antennas radiate greater power in one direction and less or none at all in other others. At a location that is a fixed radial distance from the antenna's center, the amount of energy that is radiated in a specific direction is measured in terms of field strength or flux density.

D. Antenna Polarization

The term polarization has several meanings, in a strict sense; it is the orientation of the electric field vector E at some point in space. If the E – field vector retains its orientation at each point in space, then the polarization is circular or elliptical. In most cases, the radiated wave polarization is linearand either vertical or horizontal. At sufficiently large distancesfrom an antenna, beyond 10 wavelengths, the radiated, far fieldis a plane wave.

E. Return loss and VSWR

Return loss can be defined as the amount of power returned or reflected due to discontinuity in the path of transmission or the impedance mismatch. it is the measure of ratio of incidence or input power P_i to reflected power P_r or rejected power and returnd to any source that intended to transmit it. This represents the percentage of impedance matching between the two points in power transmission. The higher the impedance matching, the lesser the return loss.

$$\text{return loss} = 10\log\left(\frac{P_r}{P_i}\right) \quad (3.0)$$

B. Comparison of return loss

Return loss is the measure of the reflected energy from a transmitted signal. The grater the value, lesser is the energy reflected. The values of return loss are compared betweenantenna designs. The return loss is in dB. The comparison tableno. 3 is shown below.

Table 2. Comparison of return loss

S/ No.	Antenna Design	Return Loss (dB)
1	[8]	-28.5206
2	[13]	-32
3	[14]	-24

The ratio P_i/P_r should be high for good power transfer. VSWR means Voltage Standing Wave Ratio is a function of the reflection coefficient, the smaller the value of the VSWR the better the antenna is matched to the transmission line.

2. PERFORMANCE ANALYSIS BASED ON SURVEY

The performance analysis has been done based on differentparameter like gain, return loss and efficiency of antenna.

A. Comparison of gain

A comparison among the values of gain is being carried outfor the different proposed antenna design by different researchers.

Table 3. Challenges in antenna design

S/No	Antenna design	Gain (dBi)	Operating frequency (GHz)
1	[1]	2.28	2.45
2	[2]	3.2	56.1
3	[4]	3.4	2.6
4	[8]	5.65	2.4
5	[13]	2.7	2.4
6	[14]	8.9	2.48
7	[16]	2.75	2.4
8	[18]	2.5	2.4
9	[19]	2.5	2.5

The value of return loss is -10db which is good enough in most practical cases. From the above graph it can be analyzed that antenna design [13] has return loss more than -30db whichis the best from other two.

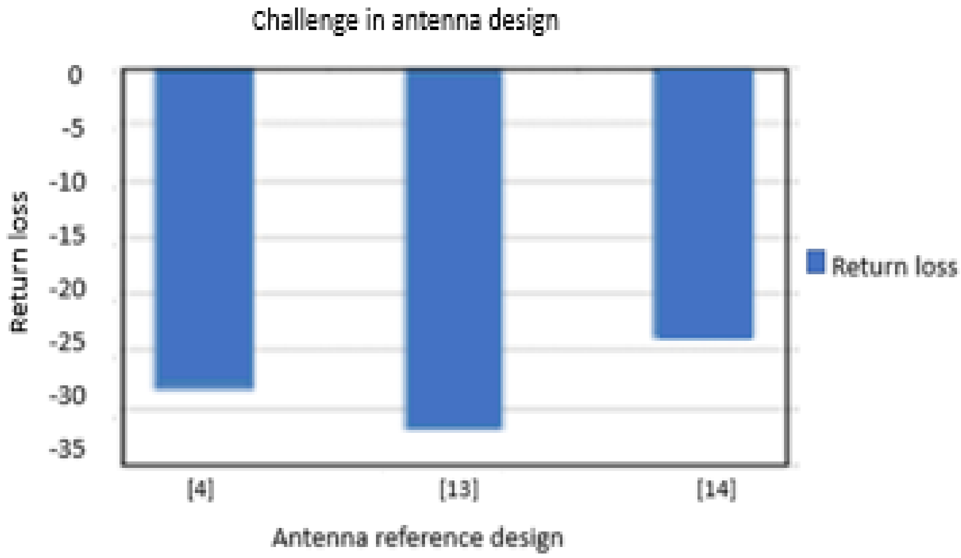

Figure 3. Example of a One-Column figure caption.

In most of the papers the gain value lies between 2 to 3.4dbi only some antenna provide gain more than 5dbi like [8] and [14]. The values of antenna efficiency are compared.

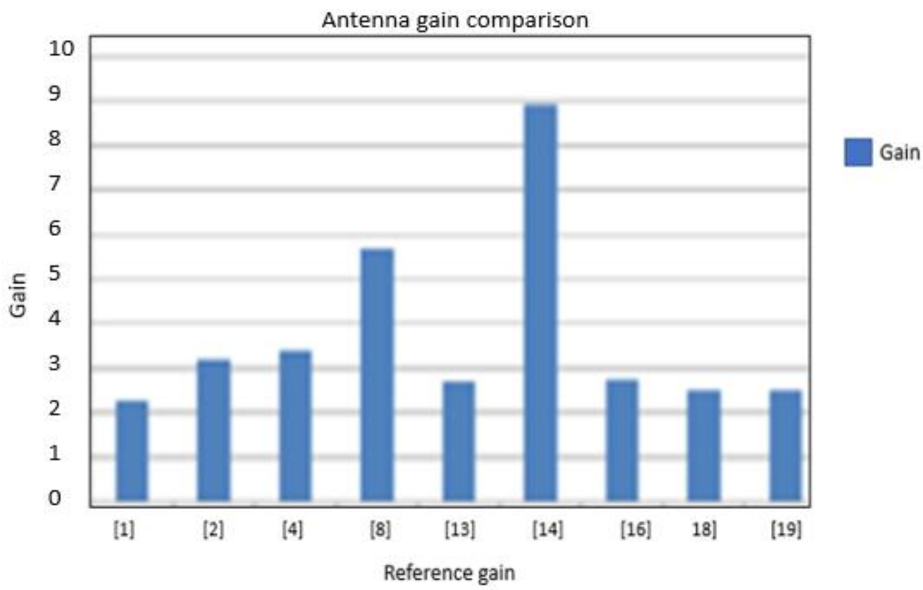

Figure 4. Comparison of the antenna gain

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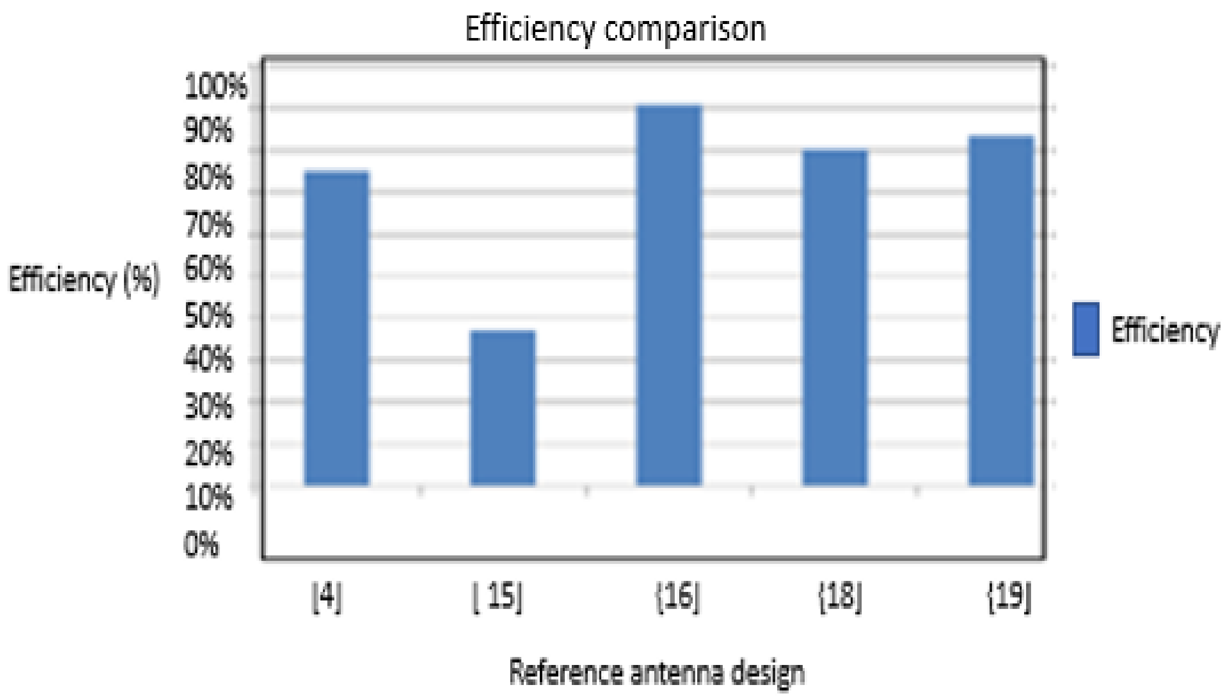

Figure 5. Example of a One-

The above comparison graph shows that the gain of antenna design [14] is the largest which is 8.9dbi and antenna design [1] provides lowest gain among all. observed that the antenna design of [16] has a greater value and [15] has lowest value.

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CONCLUSION

In this paper, the comprehensive survey on the performance analysis of quadrifilar helical antennas (QHA) highlights the antenna's significant role in satellite, GPS, and ground station applications due to its wide beam coverage, circular polarization, and compact design. The study emphasizes the importance of optimizing QHA designs for specific applications such as low-Earth orbit satellites, unmanned aerial vehicles (UAVs), and multi-band communication systems. Furthermore, advancements in miniaturization and multi-frequency designs have enabled the antenna to maintain high performance in small satellite platforms while ensuring reliable data transmission across various communication bands. The survey reveals that while the QHA has already shown robust performance, ongoing innovations in its design and integration with modern technologies will further enhance its role in future satellite communication systems. The survey also suggests that further research should focus on enhancing QHA's efficiency, bandwidth, and adaptability to diverse communication environments, particularly in compact and low-power systems.

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REFERENCES

1. Gye-Taek Jeong, Woo-Su Kim, Member 2012 "Dual-Band Wi-Fi Antenna with a Ground Stub for Bandwidth Enhancement" IEEE Antennas and Wireless Propagation Letters, Volume. 11.
2. Julien Hautcoeur, Larbi Talbi, and Khelifa Hettak,2013 "Feasibility Study of Optically Transparent CPW-FedMonopole Antenna at 60-GHz ISM Bands", IEEE transactions on antennas and propagation, vol. 61, no. 4, 1651
3. Dian Wang, Student Member, IEEE, and Chi Hou Chan 2016 "Multiband Antenna For Wifi And WigigCommunications" IEEE Antennas and Wireless Propagation Letters, Volume. 15.
4. Chien-Jen Wang And Kai-Lung Hsiao 2014 "CPW– fed Monopole Antenna For Multiple System Integration" IEEE Transactions On Antennas And Propagation, Volume. 62, No. 2.
5. Garg R.Bhartia P. and Ittipiboon A 2001."Microstrip Antenna Design Handbook Bostan Artech, House" pp 1-2.
6. Balanis C. A. 2005 "Antenna Theory Analysis & Design", Edition 3rd, John Wiley & Sons, Inc, Hoboken, New Jersey.
7. Zhongkun Ma and Guy A. E. Vandenbosch 2012 "Low- Cost Wideband Microstrip Arrays with High Aperture Efficiency" IEEE transactions on antennas and propagation, vol. 60, no. 6.
8. Shruti Vashist, M.K Soni, P.K.Singhal 2013 "Genetic Approach in Patch Antenna Design" International Journal of Emerging Science and Engineering (IJESE) ISSN: 2319–6378, Volume-1, Issue-9, 70.

9. Mohammad S. Sharawi, Muhammad U. Khan Ahmad B. Numan, And Daniel N. Aloi, 2014 “A CSRR Loaded MIMO Antenna System For ISM Band Operation” IEEE Transactions on Antennas And Propagation, Volume. 61, No. 8.
10. Changrong Liu, Student Member, IEEE, Yong-Xin Guo, Senior Member, IEEE, and Shaoqiu Xiao, Member IEEE, December 2014 “Circularly Polarized Helical Antenna for ISM-Band Ingestible Capsule Endoscope Systems” Transactions on Antennas and Propagation, Volume. 62, No. 12.
11. Henridass Arun, Aswathy K. Sarma, Malathi Kanagasabai, Member, IEEE, Sangeetha Velan, Chinnambeti Raviteja, and M. Gulam Nabi Alsath February17,2014 “Deployment of Modfiied Serpentine Structure for Mutual Coupling Reductionin MIMO Antennas” IEEE antennas and wireless propagation.
12. Changrong Liu, Student Member, IEEE, Yong-Xin Guo, Senior Member, IEEE, and Shaoqiu Xiao, Member IEEE, December 2014 “Capacitively Loaded Circularly Polarized Implantable Patch Antenna For ISM Band Biomedical Applications” IEEE Transactions on Antennas and Propagation, Volume. 62, No.5.
13. Chun-Cheng Lin And Jwo-Shiun Sun, 2015 “Circularly Polarized Dielectric Resonator Antenna Fed by Off-Centered Microstrip Line For 2.4-Ghz ISM Band Applications” IEEE Antennas And Wireless Propagation Letters, Volume. 14.
14. Qiang Liu, Junyu Shen, Jungang Yin, Hongli Liu, and Yuanan Liu, 2015, “Compact 0.92/2.45-GHz Dual-Band Directional Circularly Polarized Microstrip Antenna for Handheld RFID Reader Applications” IEEE Transactions On Antennas And Propagation, Vol. 63, No. 9.
15. Anastasios Paraskevopoulos, D. de S. Fonseca, Rob D. Seager, W. G. Whittow J. C. Vardaxoglou and A. A. Alexandridis 2016 “Higher-mode textile patch antenna with embroidered vias on-body communication” IET Microwaves, Antennas & Propagation, 2016, Vol 10, Iss.7 pp. 802-809.
16. R. Anitha, P. V. Vinesh, K. C. Prakash, P. Mohanan, and K. Vasudevan. 2016 “A Compact Quad Element Slotted Ground Wideband Antenna for MIMO Applications” IEEE Transactions on Antennas and Propagation, Volume 64, No. 10.
17. J. L. Buckley, Member, IEEE, K. G. Mccarthy, Member, IEEE, L. Loizou, Member, IEEE, B. O’flynn, Member, IEEE, And C. O’mathuna, Fellow, 2016 “A Dual-Ism-Band Antenna Of Small Size Using A Spiral Structure With Parasitic Element” IEEE Antennas And Wireless Propagation Letters, Volume. 15.
18. Parisa Forouzannezhad , Amir Jafargholi , Alireza Jahanbakhshi 2017 “Multiband compact antenna for near-field and far- field RFID and wireless portable applications” IET Microwaves, Antennas & Propagation Volume: 11, Issue: 4, 3 18 2017 pp 535-541.
19. Anitha Ramachandran, Sumitha Mathew, Vivek Rajan, and Vasudevan Kesavath, Senior Member, 2017 “A Compact Triband Quad-Element MIMO Antenna Using SRR Ring for High Isolation” IEEE Antennas and Wireless Propagation Letters, Vol. 16, 2017.
20. W. Sun, G. Su, L. Sun and X. Chen 2022, "A Pattern Reconfigurable Circularly Polarized Quadrifilar Helix Antenna Through Phase Control," in IEEE Transactions on Antennas and Propagation, vol. 70, no. 9, pp. 7766-7773, Sept. 2022, doi: 10.1109/TAP.2022.3164197.
21. Youseff. Tawk, M. Chahoud, M. Fadous, J. Costantine and C. G. Christodoulou, "The Miniaturization of a Partially 3-D Printed Quadrifilar Helix Antenna, 2017 " in IEEE Transactions on Antennas and Propagation, vol. 65, no. 10, pp. 5043-5051, Oct. 2017, doi: 10.1109/TAP.2017.2737039.
22. A. M. Musthafa, M. Khalily, A. Araghi, O. Yurduseven and R. Tafazolli, "Compact Multimode Quadrifilar Helical Antenna for GNSS-R Applications, 2022 "IEEE Antennas and Wireless Propagation Letters, vol. 21, no. 4, pp. 755-759, April 2022, doi: 10.1109/LAWP.2022.3144968.
23. Hongmei Liu, M. Shi, S. Fang and Z. Wang 2020 "Design of Low-Profile Dual-Band Printed Quadrifilar Helix Antenna With Wide Beamwidth for UAV GPS Applications," in IEEE Access, vol. 8, pp. 157541-157548, , doi: 10.1109/ACCESS.2020.3018906.