An Integrated Dual Antenna for Multi-Band Satellite Communication Applications

Karedla Chitambara Rao
Department of ECE, Aditya Institute of Technology and Management, Tekkali, India
rao.chiddubabu@gmail.com

Dasari Nataraj
Department of ECE, Swarnandhra College of Engineering and Technology, Narsapur, India
dasari.nataraj@gmail.com (corresponding author)

K. S. Chakradhar
Department of ECE, Mohan Babu University, Tirupati, India
chakradharec@gmail.com

G. Vinutna Ujwala
Department of ECE, St. Martin's Engineering College, Secunderabad, India
ujwala459@gmail.com

B. Sudhir
Department of ECE, Rajamahendri Institute of Engineering and Technology, Rajamahendrivaram, India
bsudhir539@gmail.com

M. Lakshmunaidu
Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, India
laxman.naidu@gmail.com

Harihara Santosh Dadi
Department of ECE, Aditya Institute of Technology and Management, Tekkali, India
dhhsantosh@gmail.com

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ABSTRACT

Satellite communication applications for a variety of platforms are expanding quickly as the current technology and the demand for multi-band antennas are driving up. Multi-band antennas are likely to be required for the majority of communication systems including commercial, amateur, and military ones. For military communications, various antennas are employed on a mast to cover different bands, particularly the multifunction mast-mounted antennas that are based on submarines. However, there will be limited space on the mast in case different antennas are used for different frequencies, a limitation which will restrict the ability of the submarine-based multifunction mast-mounted antenna to cover the different bands. Thus, instead of employing different antennas for different bands, a multi-band antenna can be used to compensate for the space limitation. Modern submarines should also be able to communicate with satellites. Designing an antenna for satellite communication is difficult because successful operation necessitates specific characteristics, such as low axial ratio, low Voltage Standing Wave Ratio (VSWR), high gain, high band width, and high 3 dB beam width. This work proposes an inventive design approach for an integrated dual antenna on a single ground for two bands, the L-Band and S-Band. The latter cover the five satellite communication applications, including sending (2500-2520 MHz) and receiving (2670-2690 MHz) bands of S-Band satellite communication, the Global Positioning System (GPS)-1575.42 MHz, the Global Navigational Satellite System (GNSS)-1610 MHz, and the Indian

Regional Navigational Satellite System (IRNSS)-1176.5 MHz. To examine important characteristics, including VSWR, gain, axial ratio, and 3 dB beam width, a simulation of an integrated dual antenna is constructed. The parameters are examined after the simulation in order to assess the proposed antenna's performance. The analysis results indicate that the proposed antenna is suitable for a variety of satellite communication applications, and highly suitable for both the L-Band and S-Band.

Keywords-helical antenna; dual-wire helical antenna; bow-tie technique; GPS; GNSS; IRNSS; S-Band satellite communication

I. INTRODUCTION

Satellites are nowadays essential for navigation, positioning, and space communications. The bands that satellites utilize include UHF, L, S, C, X, Ku, and Ka. S-band satellite communication is the most important communication type, since it allows voice, high-speed data, and video transmissions. It is also quick, simple, small, and efficient to create an antenna for S-band frequencies. Both sending and receiving can benefit from the use of S-Bands. Additionally, GPS, GNSS, and IRNSS are exclusively utilized for positioning and navigation. For GPS, GNSS, and IRNSS communications, the antenna is used in the receiving mode only, but it has to work for both transmitting and receiving purposes in S-band satellite communication. Moreover, the design of an antenna for the operation of satellite communication is a difficult task because it differs from the other antennas and requires certain features, such as circular polarization, low axial ratio, low VSWR, high gain, big bandwidth, and high 3 dB beamwidth.

Among the various parameters of an antenna, the circular polarization parameter is essential to obtain the successful operation between the user and the satellite. For these applications, helical antennas are best suited because of their unique characteristics, like circular polarization, wide bandwidth, simplicity, high directivity, low weight, and low-profile conformability. There are many shapes of helical antennas: monofilar, backfire bifilar, resonant quadrafilar, printed quadrafilar, and counter wound quadrafilar. Among these antennas, backfire bifilar helical antennas are the most suitable for satellite communication applications because of their advantages over monofilar and quadrafilar helical antennas. The advantages of backfire bifilar antennas are that no ground plane is required, they are not resonant, and they do not require any quadrature hybrid circuit. The backfire bifilar helical antenna can also be used as a better feed element for a parabolic reflector.

With benefits, like small size, high efficiency, and dependable signal reception, even with minor misalignment between the transmitting and receiving antennas, a bifilar helix antenna is important because it generates powerful circularly polarised radiation, which makes it especially helpful for satellite communication applications, where maintaining polarisation during transmission is essential. In other words, its circular polarisation capability essentially enables robust communication with satellites. Since bifilar helix antennas may be created to be somewhat small, they can be used on a spacecraft with limited room. Moreover, they can effectively concentrate the radiated power in a particular direction when they are built to produce high antenna gain.

GPS is a system of satellites in orbit that communicates to Earth exact information about where they are in space. GPS receivers, like navigation systems, receive the signals and use them to determine the precise position, speed, and time of the vehicle. Since GPS devices are so adaptable, they are practically used in every industry. They are useful for mapping forests, assisting farmers with field harvesting, and guiding aircraft both on the ground and in the air. Location, navigation, tracking, mapping, and timing are the five main categories of GPS applications.

The Russian Aerospace Defence Force uses a satellite-based navigation system, GNSS, which is quite similar to GPS. The United States Army developed GPS first in 1978, although GNSS was designed as a backup system. GNSS can be utilised globally for timing, velocity measurements, and weather positions. Although GPS and GNSS are maintained by separate nations, they both work in the same way. The US Air Force is the owner and operator of GPS. The Russian Space Forces own and maintain GNSS. IRNSS is a vital part of India's technological and strategic navigational developments. IRNSS was created to increase the country's navigational independence and lessen dependency on other systems. It is essential in tackling the particular geographic and security issues that India faces.

The S-band is a component of the electromagnetic spectrum's microwave band. An IEEE standard defines it for radio waves with frequencies between 2 GHz and 4 GHz, which cross the traditional 3.0 GHz line, separating UHF and SHF. Surface ship radar, weather radar, and some communication satellites - particularly those NASA uses to connect to the International Space Station and the space shuttles - all use the S-band.

A four-element MIMO antenna has been proposed with a defective ground structure for S-band satellite application in the frequency range of 2.62 - 2.79 GHz, which provides a return loss lower than -25 dB [1]. A circularly polarized microstrip patch antenna has been proposed for L-band satellite applications. The antenna was constructed in a rectangular shape, with optimized dimensions to resonate at frequency 1.59 GHz. The antenna exhibited a -10 dB return loss, a bandwidth of 600 MHz, and its gain was 1.68 dBi [2]. A rectangular microstrip patch antenna has been designed based on the substrate material Rogers RT/Duroid5880 at an operating frequency of 3.5 GHz. The designed antenna provides a return loss of -13.772 dB, 7.55 dBi gain, and 1.5152 VSWR [3]. A compact frequency reconfigurable antenna was proposed for the GPS based on the FR4 substrate. The proposed antenna provides a return loss of less than -10 dB and a gain of 7.035 dBi [4]. For the S-band and Ka-bands, a double-band shared aperture antenna was presented. A low-frequency patch antenna array and a high-frequency reflect array were combined to create a double-band shared aperture antenna. The latter was built using materials from the RT duroid 5880. At 3.5 GHz and 25.8 GHz, the proposed antenna generated gains of 13.7 dBi and 27.65 dBi, respectively [5]. Images were transmitted between satellites and ground stations using an S-band Cube Sat transceiver. The FR4 substance and flame-retardant epoxy resin served as its foundation. Its development was intended for 5G usage. The uplink and downlink bandwidths of 2.025 GHz to 2.11 GHz and 2.2 GHz to 2.29 GHz, respectively, were achieved [6]. The FR4 substrate material was proposed as the basis for a shared-aperture antenna. The thick patch antenna was constructed by enclosing an S-band thick patch with 16 Ka-band slotted cavity antennas. For the S-band (3.44 - 3.56 GHz), the measurement results indicate realised gains of 4.06 dBi to 5.35 dBi, and for the Ka-band (27.54 - 28.46 GHz) realised gains of 14.0 dBi to 14.5 dBi [7]. An epoxy-based reconfigurable antenna has been developed for CubeSats. At 2.4 GHz, the antenna's return loss was less than minus 10 dB [8]. A two-wire helix antenna that can be used for satellite communication applications was presented along with its design equations [9]. The most appropriate for satellite applications has been proven to be the backfire bifilar helical antenna due to its simplicity in S-band antenna design [10]. The connection budget for a signal travelling from an earth station to a satellite was calculated. In order to achieve successful communication, the link budget estimates indicated that an antenna's gain must fall between minus 3 dBi and +3 dBi [11]. A backfire bifilar helical antenna's characteristics can be improved using a variety of techniques, including FDTD, tapered feed, and flared open end [12-16]. For AMS systems, beam direction switching was removed using an array of two bifilar helical antennas [17]. Based on bandwidth augmentation techniques, the helix antenna was developed for GPS applications. Additionally, a slotted ground plane was employed, which boosts the gain even more [18]. The use of reconfigurable construction improves the bifilar helical antenna's characteristics [19]. A novel dual-band hexagonal has been designed for 5G applications at a frequency of 28.9 GHz and 33.74 GHz based on the shape of the metamaterial [20].

In past helix antenna literature, researchers have changed the open end, tapering feed, and beam direction of the helix antenna. Additionally, a dual-helix antenna for multi-band satellite communication applications has not been integrated. A new integrated dual-helix antenna design concept using the bow-tie approach is proposed in the current study to operate in multi-band operations.

II. ANTENNA DESIGN

The backfire bifilar helical antenna, or two wire helical antenna, served as the model for the proposed antenna. The two opposing wires that make up the backfire bifilar helical antenna are fed with balanced currents at one end. Those wires have an 1800 phase shift. It is a novel kind of antenna with circular polarization. When the current distributions in both arms of a bifilar helical antenna are balanced, circular polarization can be produced. The beam produced by the bifilar helical antenna is directed towards the feed point along the structure when it is operated above the cut-off frequency of the helical waveguide's primary mode.

In the present work, an integrated dual antenna is produced based on two antennas: the L-band and S-band, and is designed in three steps. Following the S-Band dual-wire helical antenna design (1st step), the L-Band dual-wire helical antenna design (2nd step) takes place. In the third step, an integrated dual antenna is built on a single substrate to cover several multi-bands.

A. Step 1 - Design of S-Band Dual-wire Helical Antenna

Step 1 involves increasing the number of helix wire turns and decreasing the distance between them in order to design an S-band dual-wire helical antenna. Two wires are connected at the termination end in the form of a bow-tie. This bow-tie shape will raise the antenna's axial ratio. Due to its high conductivity, copper is used to make the helix wires. The ground plane utilized for this antenna is round in shape.

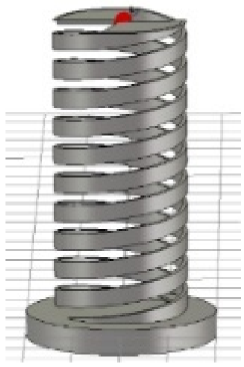

Fig. 1. S-Band dual wire helical antenna.

B. Step 2 - Design of L-Band dual-wire Helical Antenna

The L-Band dual-wire helical antenna is designed in Step 2 by decreasing the number of helix wire turns and increasing the helix wire width. Two wires are connected at the termination end to form a bow-tie. This bow-tie shape will raise the antenna's axial ratio. Due to its high conductivity, copper is used to make the helix wires. A circular ground plane is utilized for this antenna.

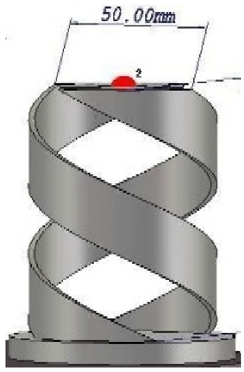

Fig. 2. L-Band dual wire helical antenna.

C. Step 3 - Design of an Integrated Dual Antenna

In the first and second step, individual antennas are designed for S-band and L-band based on the design parameters, which are listed in Table I . In the third step, the two individual antennas are integrated on a single ground, used as Teflon. The ground diameter of the integrated dual antenna is 140 mm. In addition, the horizontal and vertical feeding positions are used for the integrated dual antenna. The diameters of the S-band and L-band are 34 mm and 50 mm, respectively. Moreover, the lengths of S-band and L-band are 70.19 mm and 69.70 mm. In Figure 3, antenna1 denotes an S-band dual-wire helical antenna that is utilized for both transmitting and receiving. An L-band antenna, denoted as antenna2, is utilized for GNSS, IRNSS, and GPS applications. For both antennas, the bow-tie technique is used at the termination of their helix wire ends to increase gain as well as axial ratio.

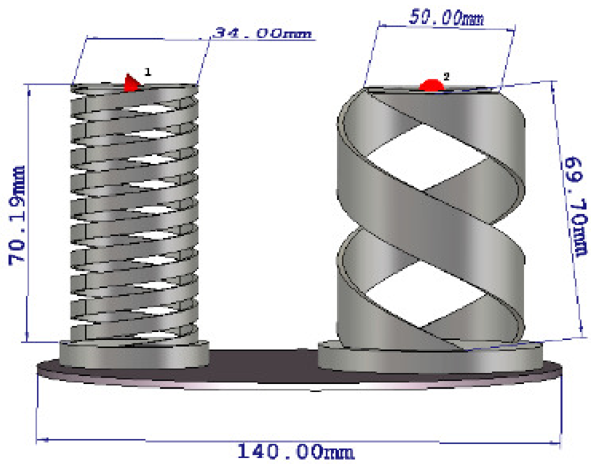

Fig. 3. An integrated dual antenna.

D. Design Equations

The following equations are used to design a dual-wire helix antenna [9]:

$$\text{Gain (G)} = 10.8+10\log [(C/\lambda)^2 \times N \times (S/\lambda)] \quad (1)$$

where N is the number of turns, C is the perimeter, and S is the coil spacing (λ/4).

$$\text{Total length of the wire} = NL \quad (2)$$

where L is the single turn length.

$$\text{Total axial length (A) of the antenna} = NS \quad (3)$$

$$\text{Diameter (D)} = \frac{C}{\pi} \quad (4)$$

$$\text{Angle of pitch } (\alpha) = \text{Tan} - 1(S/C) \quad (5)$$

$$\text{Diameter of the ground plate (Gd)} = 3\lambda/4 \quad (6)$$

$$\text{Arc length of the bow-tie} = \lambda/4 \quad (7)$$

$$\text{Bow-tie-side length} = D/2 \quad (8)$$

E. Design Parameters of an Integrated Dual Antenna

Based on the design parameters, an integrated dual antenna was designed. Table I lists all the design parameters.

TABLE I. DESIGN PARAMETERS

Parameter	Value
Ground diameter	140mm
Ground material	Teflon
Feed position	Horizontal and vertical
S-Band antenna diameter	34mm
L-Band antenna diameter	50mm
S-Band antenna length	70.19mm
L-Band antenna length	69.70mm
Bow-tie arc length -S band	22mm
Bow-tie side length – S band	15mm
Bow-tie arc length -L-band	20mm
Bow-tie side length – L- band	30mm

III. SIMULATION RESULTS

In order to obtain a range of characteristics at different transmitting and receiving frequencies, involving 3 dB beam width, axial ratio, gain, and VSWR, an integrated dual antenna was designed and simulated. Radiation characteristics, such as side lobe intensity and 3 dB beam width, were ascertained using the two-dimensional (2D) radiation pattern. By choosing the φ at a constant angle of 0^0 and varying the θ for various values, this design produced 2D elevation radiation patterns.

A. VSWR

In Figures 4 and 5, VSWR is shown versus frequency. Frequency is measured on the X-axis, while VSWR is measured on the Y-axis. Figure 4 displays the L-Band antenna's VSWR. It is observed that the VSWR value is greater than two and nearly acceptable. The S-Band antenna's VSWR is depicted in Figure 5. As can be seen, the VSWR value is less than two and is completely acceptable across the frequency range. The VSWR and return loss are both used to evaluate the antenna's performance. According to IEEE standards, the return loss should be less than -10 dB, and the VSWR should be less than or equal to two. For satellite communication applications, the VSWR value is acceptable if it is up to three.

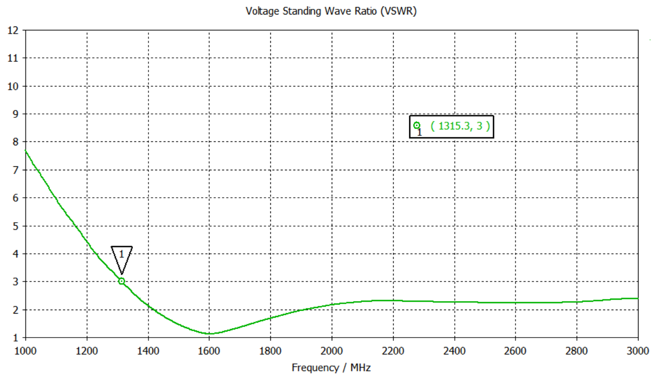

Fig. 4. VSWR for L-Band antenna.

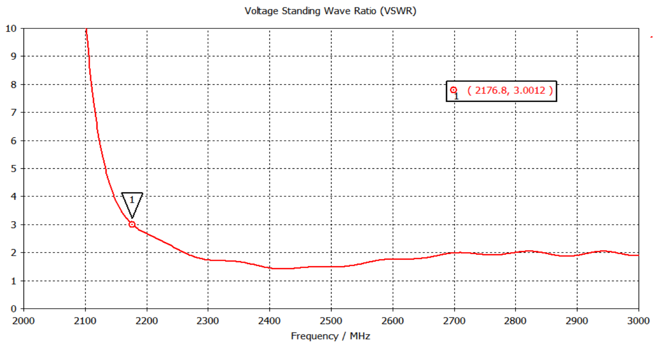

Fig. 5. VSWR for S-Band antenna.

B. Gain

Gain is shown versus frequency in Figures 6 and 7. Frequency is measured on the X-axis and gain is measured on the Y-axis. The antenna's gain is measured in dBi, and it should be greater than or equal to 3 dBi. The L-band antenna's gain is shown in Figure 6, where it is evidenced that its increase is higher than 3 dBi and nearly acceptable. The S-band antenna's gain is illustrated in Figure 7. The maximum gain value, which is 7 dBi, is achieved across the whole frequency range.

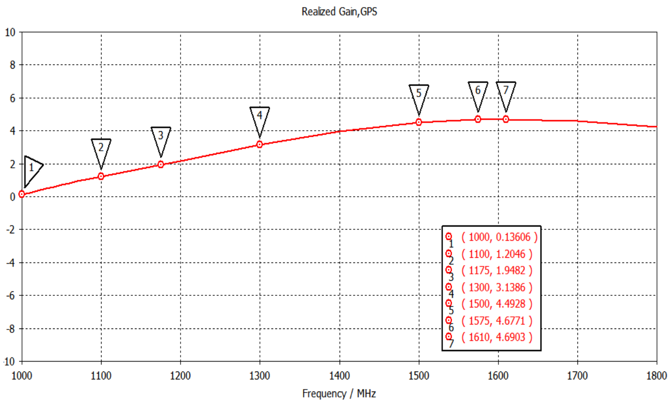

Fig. 6. Gain for L-Band antenna.

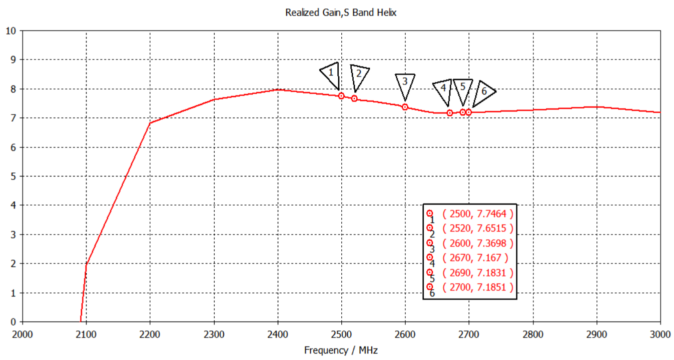

Fig. 7. Gain for S-Band antenna.

C. Axial Ratio

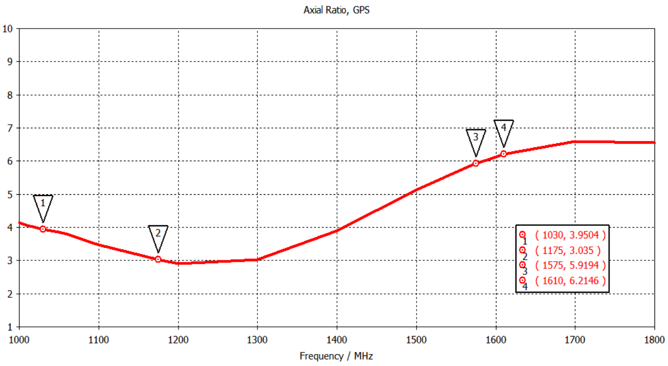

Fig. 8. Axial ratio for L-Band antenna.

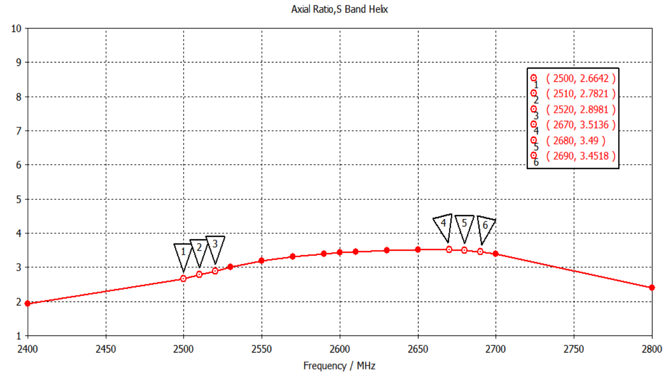

Fig. 9. Axial ratio for S-Band antenna.

The axial ratio is displayed against frequency in Figure 8 and Figure 9. Frequency is measured on the X-axis, while the axial ratio is measured on the Y-axis. The antenna's axial ratio parameter is measured in dB and it should be less than or equal to 3 dB. Figure 8 portrays the L-Band antenna's axial ratio. It is observed that the former is more than 3 dB, and is thus satisfactory. Since L-band antennas are primarily used for reception, their axial ratio is not a limitation. Axial ratio is not a restriction if an antenna is utilized for either transmitting or receiving. Figure 9 depicts the S-Band antenna. Its axial ratio, which is less than 3 dB, is nearly acceptable, as shown in Figure 9. Antennas that are utilized for both transmitting and receiving must have an axial ratio of less than 3 dB in order for the antenna and satellite to communicate successfully.

D. Two-dimensional Radiation Patterns

2D radiation patterns are essential to obtain the 3 dB beam width values, which are measured in degrees, while the coverage area of the antenna is decided based on them. The minimum 3 dB beam width value for an antenna is 17.20 to efficiently communicate with a satellite. Figures 10-14 depict the 2D radiation patterns from which a minimum 3 dB beam width of 73.10 is obtained at a frequency of 2500 MHz.

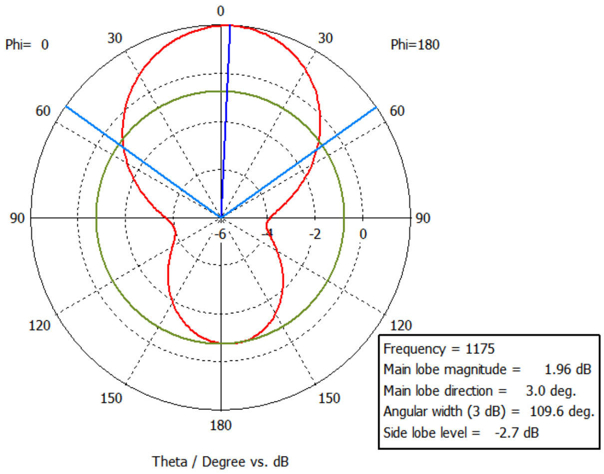

Fig. 10. 2D pattern at 1175 MHz.

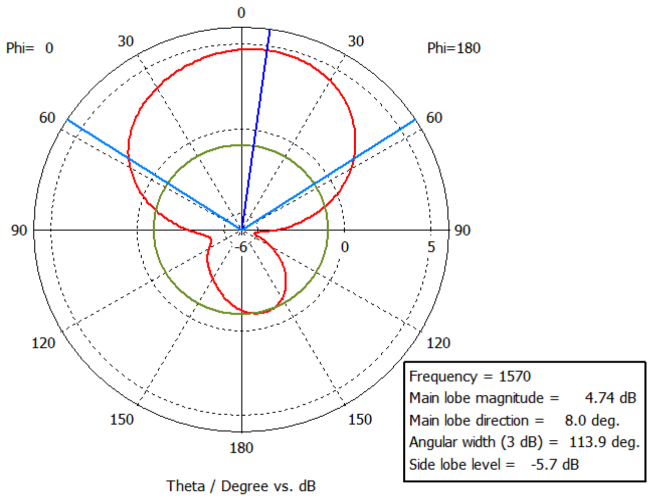

Fig. 11. 2D pattern at 1570MHz.

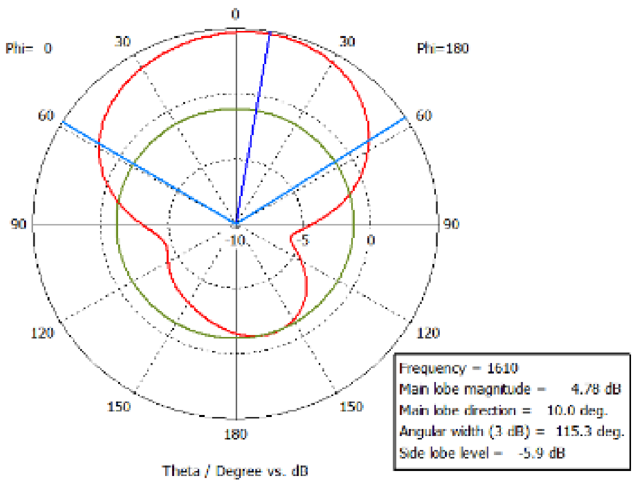

Fig. 12. 2D pattern at 1.602 GHz.

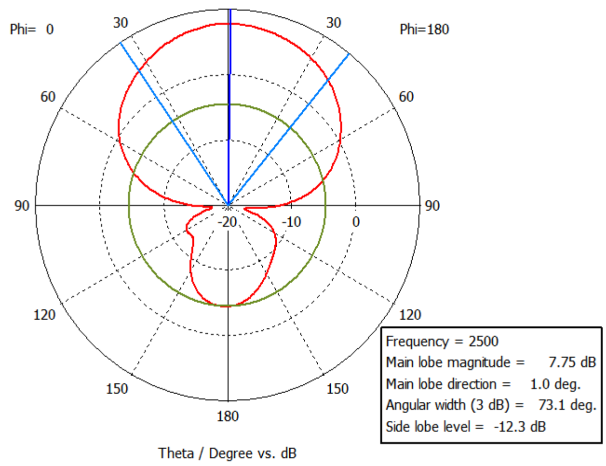

Fig. 13. 2D pattern at 2500 MHz.

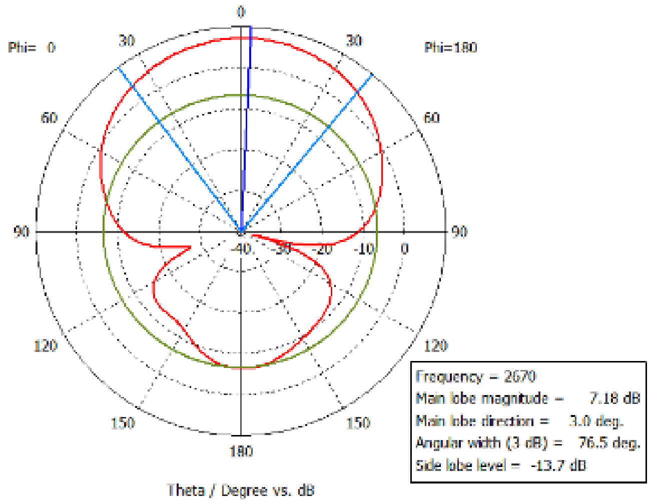

Fig. 14. 2D pattern at 2670 MHz.

Table II presents a comparison between this study's results and those of published works in the literature. In addition to operating in two bands, the proposed antenna is better designed than the antennas presented in [1-4, 6, 8, 18, 20]. Although the antennas in [5, 7] have a higher dimension, they have a dual band and a higher gain than the introduced antenna. The latter also has a wider bandwidth than those in previous studies, with the exception of [20], the antenna of which only covers one band. Furthermore, the L-Band and S-Band are both covered by the proposed antenna. Furthermore, the five satellite communication applications - GPS, GNSS, IRNSS, S-Band sending, and S-Band receiving - are covered by these two bands. After comparing the proposed antenna with those of previous research investigations, it is concluded that it is appropriate for multi-band operations, especially for multiple satellite communication applications.

TABLE II. COMPARISON WITH PREVIOUS WORKS

Reference	Bandwidth (GHz)	Gain (dBi)	Band	Operating frequency range (GHz)
[1]	0.17	10	S	2.62–2.79
[2]	0.6	1.68	L	1.58
[3]	0.023	7.55	S	3.5
[4]	2.05	7.03	GPS	1.575,3.34
[5]	0.2	13.7&27.65	S & Ka	3.5, 25.8
[6]	2	5	S	2-4
[7]	0.12&0.92	5.35&14.5	S & Ka	3.44-3.56, 27.54-28.46
[8]	2	-	S	2-4
[18]	1	10.75	GPS	1-2
[20]	4.84	7.1&7.3	Ka	28.9, 33.74
Proposed	4	7.7	GPS, GNSS, IRNSS, S-Band	1.575, 1.61,1.176, 2.5-2.52, 2.67-2.69

IV. CONCLUSIONS

Two dual-wire helix antennas, the S-band and L-band, with varying dimensions, have been combined to create an integrated dual-wire helix antenna. At the working frequencies of multi-band satellite communications, the same antenna was simulated and examined for critical properties, namely gain, axial ratio, Voltage Standing Wave Ratio (VSWR), and radiation patterns. Better values have been found based on the simulated findings for the VSWR, gain, axial ratio, and radiation pattern parameters. In addition, based on the simulation findings, the proposed antenna provides a VSWR ≤ 2, gain > 3 dBi, axial ratio < 3 dB, and 3 dB beam width > 73.1^0. The most appropriate and acceptable multi-band antenna for submarine-based satellite communication applications, according to the simulated results' analysis, is an integrated dual-wire helix antenna. Future goals of this work include constructing an antenna for high gain, wideband, and numerous applications by modifying the helix features at the helix-terminated end, such as turn count, coil spacing, ground planes, feeding techniques, material selection, and broadband procedures. There are several uses for the helix antenna if the number of turns is reduced and the width and spacing between the wires are increased. Reducing the spacing between helix wires and increasing the number of turns will make the helix antenna a high-gain antenna. For high-gain applications, like mobile satellite and 5G communication, this antenna can be either an octa-filar helix or a quadra-filar helix.

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