Dynamical Optimization of L-band Quadrifillar Helical Antenna using CST for 5G and Space Satellite Broadcasting System Applications

Olufunke Janet Alao[1]*, Adekunle Titus Adediji[2], Joseph Sunday Ojo[2], Theophilus Ewetumo[2]

[1]Satellite System Department, Radio Frequency and Microwaves Division,

Center for Satellite Technology Development,

National Space Research and Development Agency, Abuja

[2] Physics Department, Federal University of Technology, Akure

*Corresponding author email: [1]alaoolu@rocketmail.com

Abstract

An optimization of quadrifilar helical antenna is presented in this paper. The radiation characteristic is achieved by the geometry of the helices, the dimensions of the radiation is determined by the height and frequency of the operation. The antenna provides a gain of 2.8 dB at 1.5 GHz. An impedance bandwidth of more than 12% is observed at an acceptable return loss greater than -10 dB. The bandwidth, defined for an acceptable standing wave ratio at around 1.5, is about 5% across 1.2 GHz -1.8 GHz of L-Band. The antenna is fed by a single feed network with equal magnitude and 90° phase shift. The antenna final simulation obtains excellent circular polarisation, good gain greater than 3.5 dB at bore-sight, and good axial-ratio performance over a wide angular range for L-band. The optimized antenna will find applications in, low-altitude satellites, unmanned aerial vehicles, 5G mobile applications, mobile-satellite service (MSS), satellite navigation such as global position system (GPS), and global navigation satellite system (GLONASS),

Key Words: Quadrifillar Helical Antenna, L-Band, and CST circular polarization.

1. Introduction

The past two decades have witnessed radical growth in terms of research and development in wireless communication technology. Applications of circular polarized (CP) antennas have been expanding in satellite communication [1] Global Navigation Satellite System (GNSS), space applications to mention but a few. On many occasions, Quadrifilar Helical Antennas (QHAs) are widely used in many applications because of their properties. This is mainly because of its simple-shaped radiation pattern and wide circularly polarised beam [2].

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Circularly polarised antennas are required to have low cross-polarization over the entire upper hemisphere. QHA consists of four helical wires wound around a longitudinal axis and rotated 90° with respect to one another [3]. The length of each wire is approximately an odd integer and multiples of the quarter wavelength (λ/4) or (3λ/4) resonant configurations are generally used for the open-ended QHA and even integer multiples of the half-wavelength (λ/2) or configurations are generally used) for short-circuited QHA [4]. The radiated field is circularly polarised if each radiating wire is fed with equal amplitude and a phase progression of 90° [5]. The radiated pattern is also a quasi-omnidirectional in the upper hemisphere. In terrestrial communication antenna handheld radio devices are used in relaying communication from point to point. This is often hindered by polarization losses, linear (vertical) polarized whip, monopole, or flexible stub antenna is traditionally used for its simplicity and compatibility [6]. Signal losses of over 20 dB occur due to polarization misalignment in the vertical-to-vertical polarization link. To provide radio coverage to a desired terrestrial region and to ensure a stable communications link, these polarization losses must be minimized. One method for ensuring this is to provide an antenna for space and terrestrial terminals with a low-profile, and circularly polarized antenna [7]. Owing to the antenna structure and excellent circular polarization, it is more desirable in communication devices operating in the L-bands region. Quadrifillar antenna has attracted various studies and developments for different applications. In satellite communication, a quadrifillar antenna was designed to resonate at the GPS L2 frequency band that is 1227.75 +/- 10 MHz having 90^{o} phase feeds to obtain a circularly polarized electric field. Simulation NEC electromagnetic code results show that the bandwidth of the antenna for SWR 2 is about 50 MHz from 1205 MHz to 1260 MHz The antenna gives a fairly directional pattern in its elevation plane at its resonant frequency of 1228 MHz and the simulated front-to-back ratio is more than 20dB with a front gain of nearly 6 dB , Sonia *et al.,* (2013) developed an S-band quadrifillar helical antenna for satellite applications and using the numerical method, a new matching technique was used to improve the voltage standing wave ratio the result shows that at zenith the antenna is 6dB, axial ratio 1dB, and VSWR < 2 with a bandwidth of 120 MHz [8].

1.1 5G satellite broadcasting

The shift from 4th generation (4G) to 5th generation operations is driven by machine learning and artificial intelligence. 5G broadcasting networks offer more capacity, faster data transfer, and more bandwidth, but they also raise the requirement for intelligent modelling, planning, and dynamic optimization [9]. The smooth wireless connectivity of 5G networks cannot be achieved without effective antennas, even though 3rd and 4th generation continue to release more specifications to meet the new demands and push the communication industries deeper into the demand for high rate data and applications [10–11]. Therefore, 5G broadcasting systems require an efficient antenna that can fight interference. Nevertheless, dual-element arrays, and substrate integrated waveguide (SIW) technology are employed to enhance achieve directional radiation but still impairing with attenuations.

In order to compensate for the attenuation of the 5G broadcast signals, Hong et al. (2021) developed a directional horn antenna. The antenna's dimensions were 28.2 mm in length and 28.6 mm in breadth, and the dielectric plate was made of FR4 material, which has a relative permittivity of 4.4 [12]. The antenna's maximum gain is 8.06 dB, and a gain of more than 6.5 dB results in a bandwidth of almost 2 GHz. This offers a standard technique for 5G millimeter wave directional antennas. [14] The most challenging part of this process is designing the antenna; the primary challenge is still the conflict between the requirement for a larger bandwidth and a smaller device. A quadrifllar antenna is omnidirectional, circularly polarized, wide bandwidth, and light weight making it effective at delivering signals in areas with interference and multiple paths [16]. Additionally, CP antennas are growing in popularity since they can receive signals in all planes with high radio signal absorption and reflection lower environmental multipath losses, and withstand hatch weather [17–18]. In a setting with multipath fading channels, CP also resolves phase issues. Hence, a study on CP antennas such as quadrifilar helical antenna is beneficial for future developments in 5G and beyond wireless communications [19].

2 Material and Method

The antenna geometry is obtained using computer-simulated Technology (CST). The process is to analyse the radiation characteristics, directivity, polarisation, input matching, and gain. The quadrifiliar helical antenna is modelled and simulated in L-band frequency. The design model consists of the number of turns N, radius r, and the length of the element L_e which is determined by $\frac{1}{4}\lambda$, and axial length which determines the antenna characteristics is L_a. The classic equation of quadrifilar antenna is expressed as [20]:

$$L_a = N\sqrt{\frac{L_e - Ar_0}{N^2} - 4(\pi r_0)^2} \tag{1}$$

The geometrical configuration and performance of QHA is characterized by the dimension of quadrifillar helix antenna (QHA). Based on the antenna measurement, the dimensions of the antenna are computed as shown in Table 1. The model of QHA is simulated and set to operate in (1.2 GHz – 1.8 GHz). The dimension of QHA is optimized to obtain the performance of QHA at the centre frequency of 1.5 GHz.

Table 1: Antenna Parameters

S/N	Parameters	Value
1	Number of turns (N)	0.275
3	Centre frequency (GHz)	1.50
3	Helix height (h_0)-(mm)	61.30
4	Helix height (h_1)-(mm)	65.05
5	Diameter (d_0)-(mm)	29.42
6	Diameter (d_1)-(mm)	33.22

3. **Result and Discussion**

QHA model is meshed with a given mesh segment radius and simulated to achieve the appropriate dimension of the antenna as shown in Figure 1.

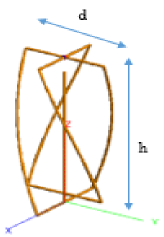

Figure 1: QHA geometry configuration

The antenna is simulated to achieve circularly polarised radiation, mainly to be a right-handed phase (RHP) gain and a very low left-hand phase (LHP) gain GNSS signals are transmitted by the satellites as right-hand circularly polarized (RHCP) and reject signal with opposite sense [12]. The receive antenna should also be an RHCP and strongly reject (LHCP) signal. The QHA is modeled, and simulated by using CST microwave electromagnetic antenna simulator software. The software is used to design and analyze the antenna performance; The QHA structure is arranged in two bifilar loops parallel and out phased by 90° to each other based on perfect electrical conductor material [13-15]. The simulation was run and the directivity of RHC is 2.7dBi equivalent at an elevation of 30° and a width beam 171° at LHP mode simulated directivity is -6 dBi at an elevation of 88° and 3dB beam width of 67° very narrow beam width based on canter frequency 1.5 GHz as presented in Figures 2 and 3. The results show that the antenna responds to the RHP signal and does not sense circular RHCP signal direction. The radiation attributes are an important parameter that directly contributes to the quality of the L1 frequency band for global navigation signals. The discrepancies between right- and left-hand 1.5 GHz are quite wide which indicates that the antenna responds well to its target operating frequency as a right-handed circular polarised antenna (RHCP).

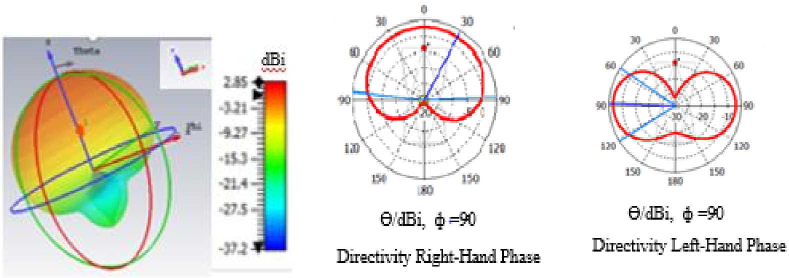

Figure 2: QHA RHCP and LHCP directivity in (3D and polar patern) at 1.5 GHz (φ = 90°)

Sweeping through the frequency, it was established that the antenna gain increases with frequency as shown graphically in Figure 3 that is, the maximum gain is obtained at around 1.8 GHz

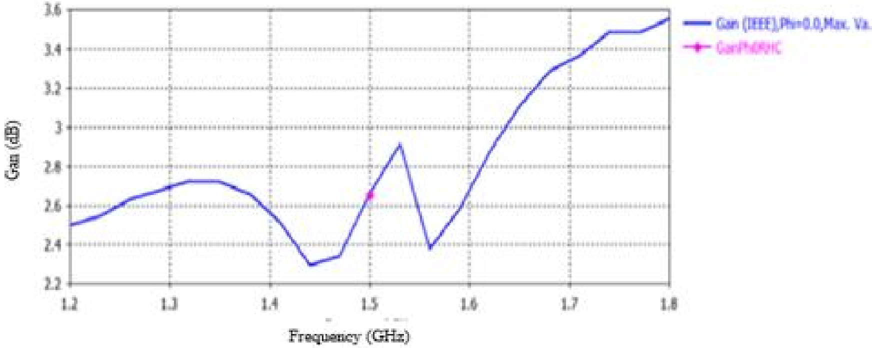

Figure 3: QHA Gain at varying frequency

In novel, circularly polarized (CP) antennas are insensitive to polarization locations and eliminate interference from opposite signals such as the rotating Faraday signal effect caused by the ionosphere and other interferences. To compensate for the gain stability for the L-band, QHA is configured in LHCP and RHCP to enhance the RF link performance. The simulation result depicted in Figure 4 represents the emission analysis of a QHA operating at 1.5 GHz configured as a combined RHCP/LHCP antenna. The result shows the simulated gain increase from 2.7 to 29.5 dB at azimuth, and the polarization is swapped to LCHP/RCHP the gain increased from -6 dB LCHP to 2.8 dB at 157^{o} which is are good value for L-band applications.

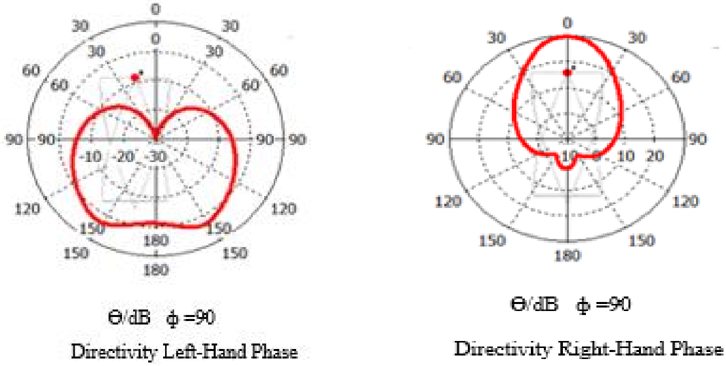

Figure 4: Simulated gain for LCHP / RCHP and RCHP /LCHP at 1.5 GHz (φ = 90^{o})

For the reflection coefficient, the simulated value of return loss (S_{11}) for L-band QHA antenna is -18 dB, and the accepted voltage standing wave ratio VSWR is less than 2 as measured in Figure 5 depicts how much power delivered to the antenna. The impedance of the antenna is lower for the perfect match of the antenna, the optimized reference impedance simulated a value of 50 Ω to achieve a perfect match at the port of the antenna which will be applied at the transmission line of the antenna in practical.

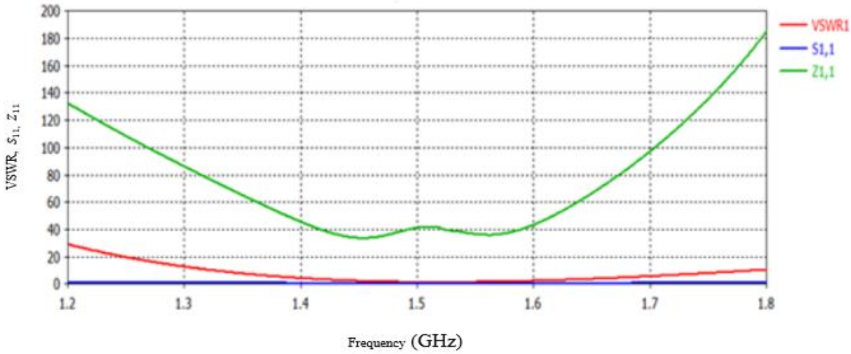

Figure 5: Voltage standing wave ratio (VSWR), reflection coefficient (S_{11}) and impedance (Z_{11}) of QHA at L-band frequency.

The impedance is constant over the span of the L-band region. The result on the graph in Figure 6 shows that at any frequency band within the L-band region, 50Ω port impedance is recommended at the input of the antenna to achieve maximum output signal at any desired frequency within the L-band.

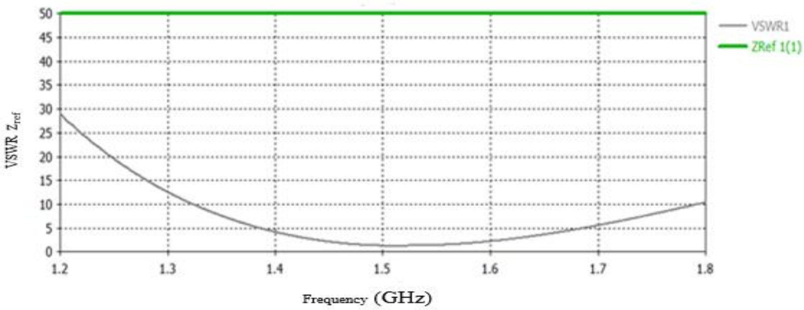

Figure 6: Plot of VSWR and reference impedance

The axial ratio is achieved at 40 dB.mainlobe of the antenna, this value represents the peak power or the energy that is radiated by the antenna to the corresponding value of its directivity. For an antenna to be considered a good antenna, it should have a high directivity measure at a degree radiated focused on a single direction or a particular plane. Axial ratio as a function of theta angle for which the antenna maintains circular polarization. Figure 7 shows the boresight at 127^{o} gain of 40dB at the desired frequency band, showing that the antenna performs well when placed on a vertical plane or flat plane. It was found that tilling the antenna or rotating in the xy plane direction affects the gain of the antenna at various elevation angles especially at the lower angles. It also reduces the gain and peak at the resonant frequency of L-band 1.5 GHz.

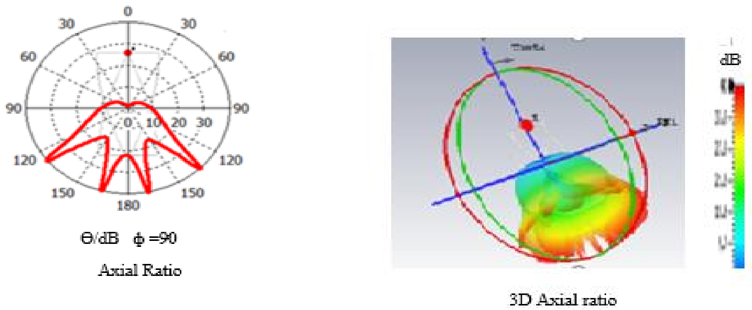

Figure 7: Axial ratio for the circularly polarized antenna

4 Conclusion

Quadrifilar helix antenna (QHA) was simulated using a computer-simulated microwave studio at a target frequency of 1.5 GHz. It was observed in the simulation that the QHA antenna is providing the acceptable gain of 2.8 dBi with an impedance bandwidth of 12 % at the central frequency of 1.5 GHz. The antenna offers right-hand circular polarization (RHCP) at the operating frequency of 1.5 GHz. The radiation and impedance characteristics have been simulated and measured to evaluate its performance for the L-bands region. The configuration of QHA has been evaluated in terms of its frequency and the result shows that the antenna performs well at the centre frequency and above. The azimuth plane was also found to radiate effectively in axial mode with a gain of 40 dB. The simulation measurement shows a good result and the QHA antenna shows a good performance by emitting the maximum gain at its axis.

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