Comparison between MATLAB and CST Simulated Results of Helical Antenna Implementation for Ku-band Application

S. Z. Iliya, Y. A. Adediran, T. A Rahman, A.Y Abdulrahman, Hashim Uledi, O. Elijah

***Abstract* - This study implements the design of an axial mode helical antenna for Ku-band applications. It employs the design curves approach using MATLAB simulations for gain and bandwidth computations in relation to axial length and pitch angles. Same design parameters were used on CST microwave studio (CST 2010) to provide a basis for comparison between results obtained from MATLAB simulations with those from CST 2010. Calculated values of the normalized free space axial length gave a gain of 21.03 dBi at 14 λ axial length and a bandwidth of about 13% from MATLAB computations. However, same design parameters implemented on CST 2010 shows conflicting agreements with results obtained from MATLAB simulations, thus the need to itemize the limitations of this antenna design for Ku band satellite applications as a tool for further studies.**

Index Terms*— Axial length, normalized axial length, pitch angle, helical antenna.

I. INTRODUCTION

THERE are two basic propagation modes in helical antennas: the axial mode, which implies that the gain is best along the axis of the helix; and the normal mode, which simply means that the gain is null along the axis of the helix [1]. The former mode is of interest in this study. Helical antennas are widely used in satellite and navigation systems due to good circular polarization properties required for better propagation characteristics through the atmosphere. Excellent antenna gain and good axial ratio over wide frequency band are easily achieved by various helical antenna designs [2- 4].

Conventional axial mode helical antenna designs have been limited to WLAN and the C-band applications. However, where such designs for higher microwave frequencies are found, their gain margin is not sufficient enough, thereby limiting their applicability for satellite communication purposes. In this study attempt is made to make the axial mode helical antenna applicable to the Ku band frequency while maintaining a good gain margin required for satellite communications.

Modifications of the existing helical antenna design parameters by [5-17] and other referenced works were carried out in order to make the proposed study suitable for both Ku-band frequency and satellite applications.

The Ku-band axial mode helical antenna is made up of an array of isotropic point sources each representing a turn; the number of turns adds up to determine the helix length which is also a function of the pitch angle. Each isotropic point source (a turn) is capable of independently radiating a circularly polarized end-fire wave. The characteristics of Ku-band axial mode helical antenna are determined by axial length L_s, pitch angle α_1 circumference C, and operating frequency $f\,(GHz)$.

The axial ratio is the ratio of orthogonal components of an E-field. A circularly polarized field is made up of two orthogonal E-field components having equal amplitude, but is 90 degrees out of phase. The axial ratio is 1 (or 0 dB) due to the fact that the two components are equal in magnitude. For axial mode radiation, fields from all sources are in phase at a point on the helix axis $(\phi = 0)$. For the fields to be in phase (ordinary end-fire condition) requires that:

$$\psi = -2\pi m \qquad (1)$$

where m = 0, 1, 2, 3………..m, being the transmission order.

II. OVERVIEW OF THE KU BAND HELICAL ANTENNA DESIGN

The pitch angle α is increased by the proposed design with the variable γ, given α_1; where $\alpha_1 = \alpha + \gamma$. According to [6], the increment range of the pitch angle was $1^\circ \le \gamma \le 10^\circ$; while in the study the proposed pitch angle is in the range $5^\circ \le \gamma \le 20^\circ$.This range was assumed bearing in mind the limitations on the axial mode radiation condition for pitch angles which should not go beyond 20° as experimented by [5].

S. Z. Iliya is a PhD research student at the Wireless Communication Center, University Technologi Malaysia (UTM) (phone +60166955960; email: solozakwoi@gmail.com)

Y. A. Adediran, is a Professor and Head of Department of Electrical & Electronics Engineering, Univeristy of Ilorin Nigeria . email: yinusaade@yahoo.com

T. A Rahman, is a Professor and Director of the Wireless Communication Center (UTM) Malaysia

A.Y Abdulrahman, is on postdoctoral studies at the Wireless Communications Center, Univeristi Teknologi Malaysia (UTM)

Hashim Uledi is a PhD student at the Wireless Communications Center, Universiti Teknologi Malaysia (UTM).

O.Elijah is a PhD research student at the Wireless Communication Center, Universiti Teknologi Malaysia(UTM);email:elij_olak@yahoo.com

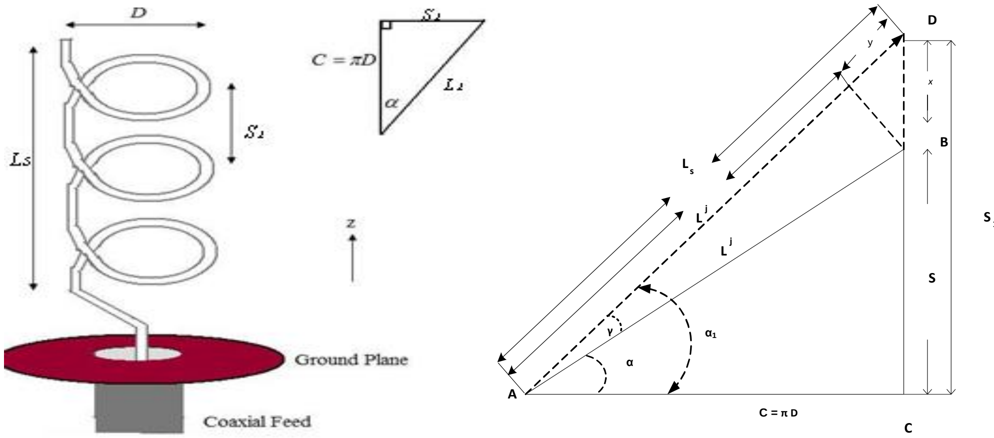


Figure 1: (a) Schematic representation of the geometry of the helical antenna and its associated parameters (b) Corresponding increment in axial length from L^j to L_S and turn spacing from S to S_1 while keeping the circumference fixed.

L^j is the axial length of the helix used by [6]. But from Fig 1, increment in pitch angle resulted to small increment in axial length of the helix (from L^j to L_S), which corresponds to the axial length in the implementation. Note that $L_S = L^j + y$; with y being small increment in the axial length of the helix. The turn spacing S is also increased from S to S_1, where $S_1 = S + x$, with x being small increment in turns spacing. Application of trigonometry to Figure 1(b) yields:

$$\tan\alpha_1 = \tan(\alpha+\gamma) = \frac{\tan\alpha + \tan\gamma}{1-\tan\alpha\tan\gamma} = \frac{S+x}{\pi D} \qquad (2)$$

Note that parameter y was necessary to ensure that the pitch angle was not too large and is kept within the radiation zone for helical antennas as experimented by [5]. If the increase is large, the pitch angle will be too large, exceeding the radiation limit for the axial mode helical antenna in free space. As shown in Figure 2, an increase in the pitch angle results to a corresponding small increment in the axial length for the proposed Ku-band helical antenna.

In this study, the design curves for the proposed helical antenna makes it possible to predict the gain and bandwidth, both as functions of axial length and pitch angle. The normalized axial length L_1 (in free space) is between 0.5λ and 14λ, the center frequency $f_c = 13GHz$, and the axial length of the helix is $L_S = 32cm$. The normalized axial length L_1 (in free space) for the Ku-band antenna is obtained as follows:

$$L_1 \approx 14\lambda = \left(\frac{L_s}{\lambda_{Ku}}\right) \qquad (3)$$

where Ku-band wavelength, $\lambda_{ku} = \frac{c}{f_c} \approx 23.1mm$, and speed of light $c = 3.0 * 10^8\ m/s$

This is the maximum normalized axial length (in free space) required to obtain the maximum gain in this study.

As observed in Figure 1(b), increase in pitch angle α will result to a corresponding small increase in L_1 for the purpose of this study. Then the gain is expressed as:

$$G_{Ku} = 10\log\left(\frac{8.5L_s + \lambda_{Ku}(7.75)}{\lambda_{Ku}}\right) \qquad (4)$$

The percentage bandwidth is obtained by using:

$$\%BW_{Ku} = \left(\frac{f_u - f_l}{f_u}\right)\times 100 \qquad (5)$$

where $\%BW_{ku}$ is normalized to the upper frequency. However an improved optimum pitch angle $\alpha_1 = \alpha + \gamma$ was proposed in [2], and the increment for the optimum pitch angle was given by the factor γ. The optimum pitch angle and axial length are related empirically as follows [2]:

$$\alpha_1 = \frac{[(21.9\times\log L_1) - 6.7]}{2.5} \qquad (6)$$

Figure 2 shows the plots of pitch angle variation with axial length, while Figure 4 shows variation of gain with axial length

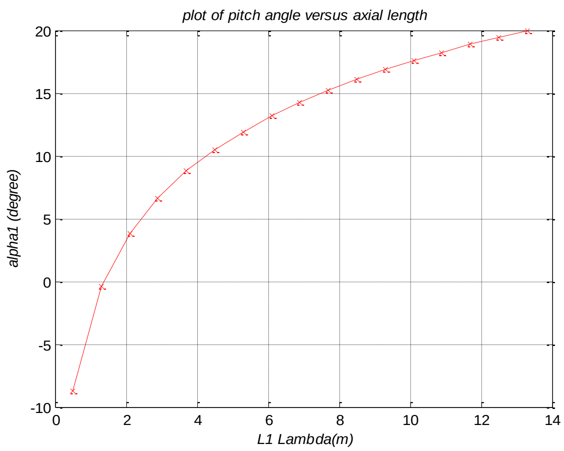


Figure 2: Simulated results of the pitch angle versus axial length (L_1)

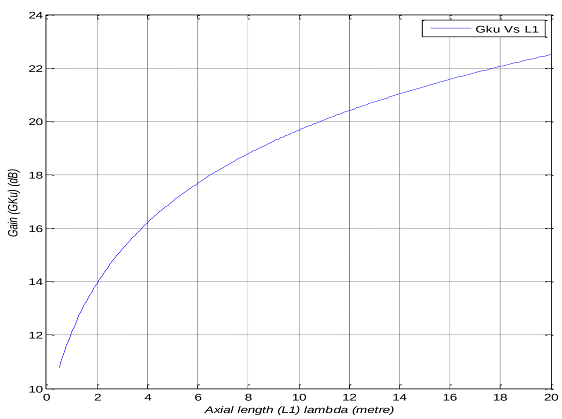
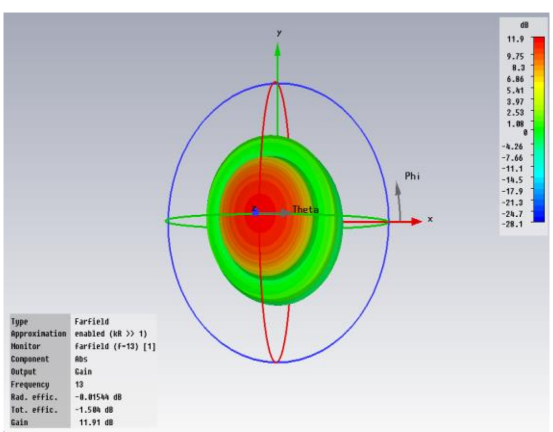


Figure 3: (a) Plot of computed gain versus axial length using MATLAB

Note that the gain values G_{ku} as seen in Figure 3(a) can be determined if parameter l_1 are known; and vice versa. For example, when $l_1 = 14\lambda$, $G_{ku} = 21.03dBi$ and when $G_{ku} = 14.0dBi$, $l_1 = 2\lambda$. The plot of % BW against pitch angle is shown in Figure 4.



(b) 3D plot of the Antenna pattern from CST showing the gain in *dB*

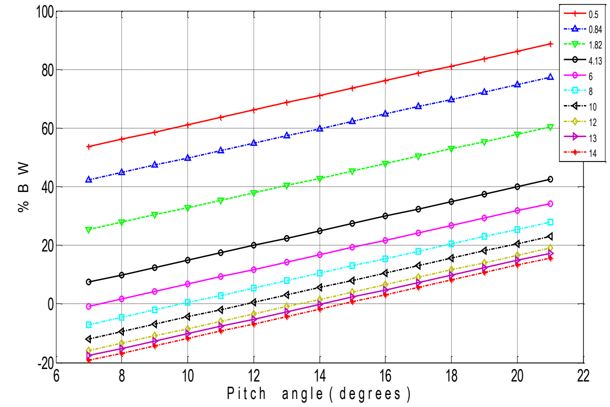


Figure 4: Graph of % bandwidth versus pitch angle for different values of axial length

The relationship between the normalized axial length and bandwidth is presented in Figure 5, while the dependence of antenna gain on pitch angle is shown in Figure 5.

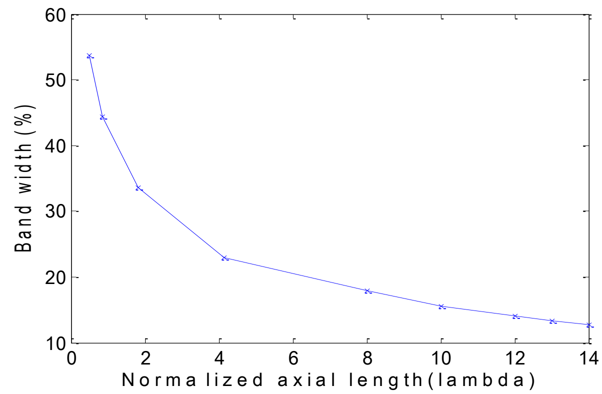


Figure 5: Relationship between the normalized axial length and bandwidth.

Figure 5 shows that the BW collapses with increasing axial length, as given by the following simple power-law: $BW = 40.4473 L^{-0.43}$

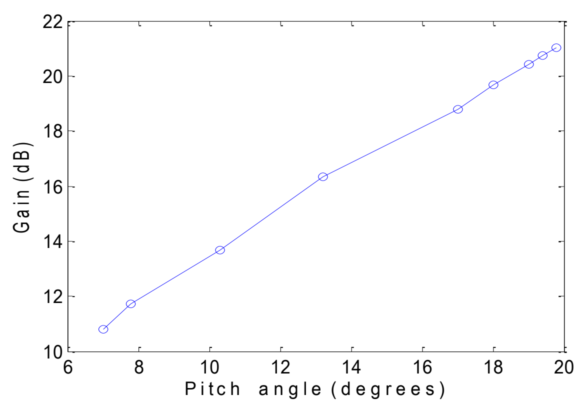


Figure 6: Relationship between antenna gains and pitch angle

Similarly, critical study of Figure 6 has revealed that antenna gain proportionally increases with increasing pitch angle, according to the following non-linear expression:

$$G = 3.0042\ \alpha^{0.63} \qquad (8)$$

The normalized radiation pattern and linear plot of the normalized power pattern of ordinary end-fire Ku-band helical antenna in dB are shown in Figures 7 and 8 respectively.

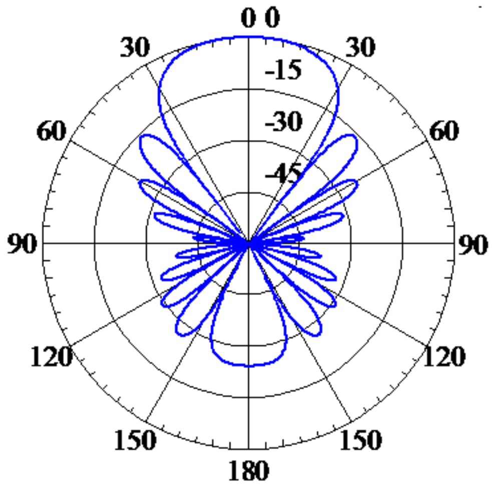


Figure 7: Normalized Radiation Pattern of Ordinary End-Fire Ku-band Helical Antenna in dBi.

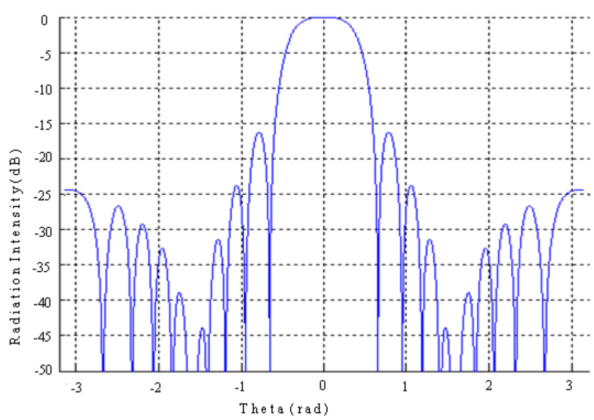


Figure 8: Linear Plot of the Normalized Power Pattern of Ordinary end- fire Ku-band helical antenna

III RESULTS AND DISCUSSIONS

A. *Design Curve Approach: MATLAB*

Computations of percentage bandwidth (% B.W) and pitch angle are presented in this section. The 32cm axial length (L_S) was obtained from the increment in pitch angle from 9.75 degrees in Jennings design for *C*-band to 19.8 degrees for the Ku-band design, as seen in Figure 1. The normalized axial length of $L_1 = 14\lambda$ was obtained by using 32cm axial length $L_S = 32cm$ and wavelength $\lambda = 23.1mm$. This was the maximum value of axial length which gave the desired optimum pitch angle of 19.8°. The maximum gain 21.0295 *dBi*, and the normalized *B.W = 12.7046 %* proposed in this paper were obtained from simulation.

$$\%BW_{Ku} = 2.5\alpha + 2.5\gamma - 21.9\ \log\left(\frac{L_s}{\lambda_{Ku}}\right) + 21 \qquad (9)$$

Equation (9) represents modification to Jennings' approach of computing the % BW in the proposed Ku-band study. The pitch angle was increased from $\alpha = 9.75^{\circ}$ to $\alpha_1 = 19.8°$ by the factor γ according to the following expression: $\alpha_1 = \alpha + \gamma$. Table I compares the C-band design in [6] and the present Ku-band design proposed in this study.

TABLE 1. COMPARISON OF C-BAND AND KU-BAND DESIGNS

Helical Antenna Parameters	Design methodology	
	Ref [6]	Present work
Axial length $L_s\,(cm)$	30.0	32.0
Normalized length $L_1\ \lambda$	5.50	14.0
Maximum possible gain (dBi)	17.5	21.0
Minimum gain (dBi)	9.10	10.8
Optimum pitch angle (degrees)	9.75	19.8
Normalized bandwidth (%)	30.0	13.0

TABLE II . RELATIONSHIP BETWEEN GAIN AND BANDWIDTH

Gain (dB)	BW %
10.8	53.7
11.7	44.3
13.7	33.6
16.3	22.9
18.9	18.0
19.7	15.6
20.4	14.1
20.7	13.3
21.1	13.0

The range in values for pitch angles and normalized axial length for this are $5 \le \gamma \le 20^{\circ}$ and $0.5 \le L_1 \le 14.4\lambda$. The plots of % BW against pitch angle for different axial lengths are shown in Figure 4. Table II shows the numerical values of antenna gain and bandwidth obtained from the design curves of Figures 3 and 4. The required bandwidth of the antenna, normalized to the upper frequency limit of 14 GHz for the Ku-band, was 12.7046%. The optimum pitch angle was approximately 14λ. It was seen that the optimum pitch angle α_1 fall out of the stable region of pitch angle α between $12°$ and $14°$ as claimed by [5] with about six (6) degrees. Increasing the pitch angle caused a decrease in the bandwidth. Bandwidth is seen to collapse with increase in pitch angle.

B. Design Simulations Using CST, based on parameters from empirical computations using MATLAB

The design parameters obtained from MATLAB were implemented for simulations using CST at center frequency $f_c = 13GHz$ with the following axial length values: $323mm$, $240mm$, $120\ mm$, $60mm$, and $30\ mm$. The wire radius $a = 0.231mm$ corresponding to the wavelength of the Ku band frequency from $a = \lambda/100$, $C = 18.5 = \pi D$, $r = \frac{D}{2}$ and a ground plane diameter being $\frac{3}{4}\lambda$ with $\lambda = 23.1mm$.

Simulation results from CST shows conflicting results compared to those obtained from the MATLAB design curve computations. For the MATLAB case, the gain and return loss tend to improve with increasing axial length at a fixed number of turn $N = 17$.Whereas, for the CST's case, simulation results show that the optimal values of the antenna gain is obtained when $L_1 = 60\,mm$.

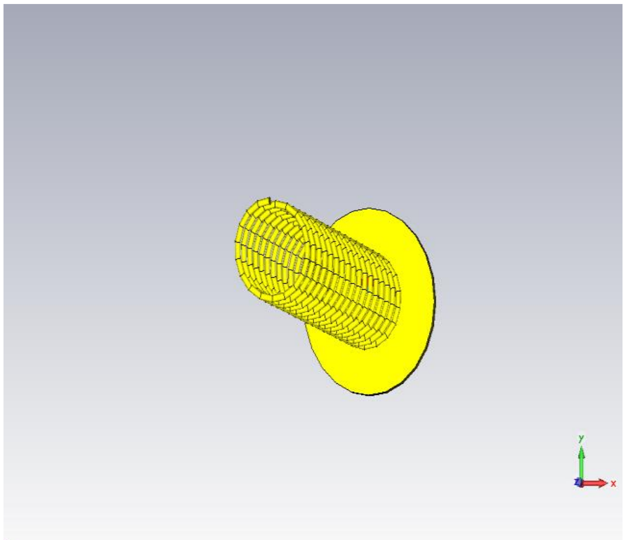


Figure 9: Perspective View of the Helical Antenna from CST 2010

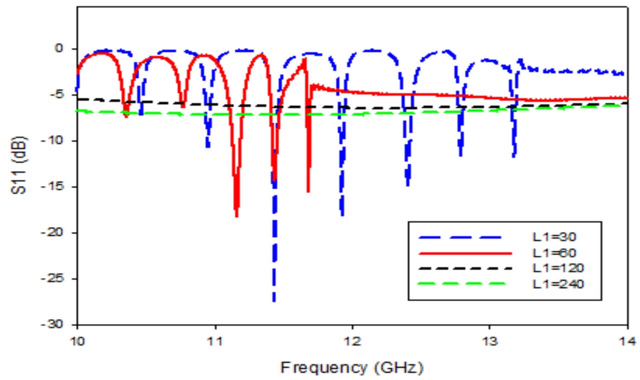


Figure 10: S11 (dB) versus Frequency (GHz)

As seen in this graph, the axial length is reduced, while the return loss is improved. The best return loss at this frequency is obtained when $L_1 = 30\,mm$ with a sharp drop of 1 *dB* in antenna gain. The normalized radiation pattern at varying axial lengths is shown in Figure11.

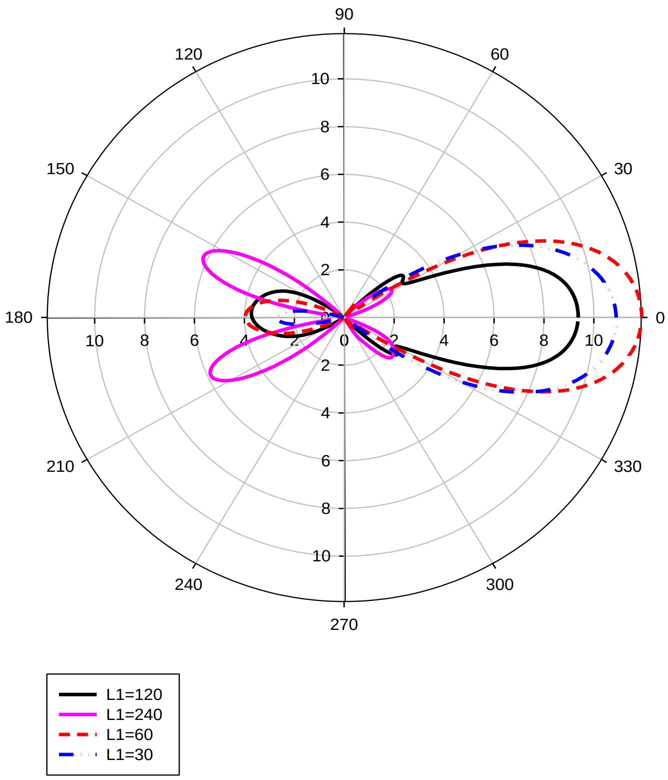


Figure 11: Normalized Radiation Pattern at Different Axial Length using CST Software

VI CONCLUSIONS

As summarized in Tables I and II, the resulting helical antenna has pitch angle of 19.8 degrees, normalized *B.W =12.7046%*, approximately 13 %, an axial length = *320mm* with a normalized axial length of 14λ, *N =17* turns and operates within the Ku-band *(12 – 14 GHz)*. The maximum gain which, is the main target in the study, was 21.023 *dBi* with a numerical directivity of (from pattern) of 22.7037. It has turn spacing between turn ($S_1\lambda$) = 0.2799, approximately = 0.3λ, with a circumference *(C λ)* =0.7799, approximately = 0.8 = 4/5. Further study of these results were obtained using CST transient solver; an advanced professional electromagnetic simulation software which gave conflicting results with the maximum directivity being only about 12.0*dBi*; it was also observed that increase in axial length did not necessarily improve the gain as was seen with design curve computations using MATLAB. The conductor radius *a*= 0.231 was used; a turn radius *r=3mm* was utilized in this simulation. As shown in Figure 11, the optimal performance was achieved when $L_1 = 60\,mm$.This shows that as the turn spacing becomes narrower, the interaction between the electric field components became better which increased the gain in the axial direction. This contradicts our initial finding based on the design curve computation results in which increment in pitch angle also led to a corresponding increment in axial length. This in turn increased the gain to about 21.023dBi in the study, thus making it suitable for satellite communication applications. However, with CST simulation, it can be concluded that the gain values obtained at this frequency do not make the proposed helical antenna applicable for satellite communications. This is because a gain margin of over 20*dB*i is needed for an effective communication between the earth station and the satellite in orbit.

CST's simulation software provides accurate 3D electromagnetic Electronic Design automation (EDA) solutions for the numerical solution of microwave & RF component design. It does take into consideration the physical properties of the materials used in the design for optimal solution, a feature that is not obtainable in MATLAB which mainly deals with the numerical translations of equations. This informs the reason why the results obtained with CST are not as fantastic as those obtained with MATLAB in this scenario.

V FUTURE WORK

Further studies would look into ways of improving return loss at higher axial lengths. Also the effect of turn radius *r* and pitch angle L_1 variation to referenced optimal pitch angle ranges should be studied with a view to improving the antenna gain.

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School of Electrical and Electronic Engineering The University of Adelaide Adelaide, South Australia, Australia shifu@eleceng.adelaide.edu.au, cfumeaux@eleceng.adelaide.edu.au, ccoleman@eleceng.adelaide.edu.au
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