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Design and Construction of Axial Mode Mono-Filar Helical Antenna for Hydrogen Line Emission Studies with 4NEC2 Tool

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Abstract

Antennas have come to play a significant role in the reception and transmission of electromagnetic radiation or signals which in turn have improved scientific research in the various areas where they have been used. Astronomy is not left out; as a study of everything beyond earth's atmosphere, useful signals have to travel great distances to reach us. Hence the need for equipment to detect such signals. The Helical Antenna is known to possess high gain (directivity) and can process signals with any type of orientation/polarization which implies high sensitivity hence the desire to use it. Simulation was done using the legacy 4NEC2 software. The purpose of this paper is to design a circularly polarized helical antenna operating in axial mode that is suitable for detection of neutral hydrogen line emission at the frequency of 1420 MHz and to show how it can be used as a feed for an off-set parabolic dish.

Keywords

Helical Antenna, Hydrogen Line, 4NEC2, Perspex Glass, Offset Parabolic Dish

1. Introduction

An antenna is a metallic structure that converts electric power into (radio waves) electromagnetic waves and *vice-versa*. It is electrically connected to the receiver or transmitter to receive or transmit radio electromagnetic waves in all horizontal directions equally or in a particular direction of propagation.

Antennas can provide a simple way to transfer signals. Several antenna types with different sizes, shapes, and unique performances have been developed for particular applications. Some types of antennas are Yagi-Uda, Dipole, Quad, Quagi, and Helical Antenna.

In Radio Astronomy, astronomers use radio antennas (also called telescopes) to explore the Universe by detecting radio waves emitted by a wide range of objects in space. Radio astronomers study objects that radiate or absorb energy at frequencies within the radio spectrum: when ground-based, studies are conducted wherever the atmosphere is at all transparent in the range 13 MHz to 2000 GHz. W. Baan [1].

The Helical antenna is an interesting antenna due of its unique characteristics; it is simple to design, capable of high gain, wide bandwidth (**Figure 5**), and circular polarization. It has been widely used as simple and practical radiators over the last five decades due to their remarkable and unique properties Tariq [2]. One of its unique characteristics is the fact that it can be deployed both as transmitting and receiving antenna. According to Stanislav [3], an antenna is defined as a transmitting antenna when it converts oscillating electric current into electromagnetic radiation, while a receiving antenna converts electromagnetic radiation into a time harmonic current.

A principle in the detection of radio signals from space is the Hydrogen atom that makes a transition from its aligned state to an anti-aligned state and emits radio energy at a wavelength of 21 cm or a frequency of 1420 MHz. The line emitted at radio wavelength are many others fainter than optical lines, therefore the detection of new lines in large observable quantity is possible with the use of large antennas or modern day telescopes with sensitive feeds (**Figure 19**).

The Helical Antenna is chosen because of its high directivity that is the ability to concentrate radiated power in one direction hence the suitability for the H1 emission where neutral Hydrogen gas have to brave the distance between space and earth to reach us.

This paper derives its motivation from designing an antenna to achieve the above purpose.

2. Antenna Design and Construction

Antenna design is very specialized as it requires theoretical and largely empirical work and lots of experimentation. It will involve understanding the fundamental antenna theory and operating principles from textbooks and articles, calculations and simulations (using software), and the final construction of an antenna with close to 100% efficiency. Generally, the procedure in terms of materials and method in the design and construction of a helical antenna is as follows:

2.1. Antenna Design

A directional helical antenna operating in axial mode is designed in this work (**Figure 2**). The dimensions of the helix structure are determined from the selected radio frequency (or wavelength) of propagation.

The geometry of a uniform mono-filar helix antenna is shown in **Figure 1**. If one turn of the Helix is unrolled on a flat surface, then the circumference C, the spacing S and turn length L are related by the triangle shown in **Figure 1**. It is then a simple matter to define the geometrical parameters of the helix, Jansen & Juan-Pierre [4]:

The circumference of the helix is given as

$$C = \pi d_H \tag{1}$$

where π is a constant equal to 22/7, d_H is the diameter of the helix (in meters). C (in meters) has to be about a wavelength (~1λ) to ensure axial mode operation, as described by Kraus and Kumar as shown in **Figure 2** [5] [6].

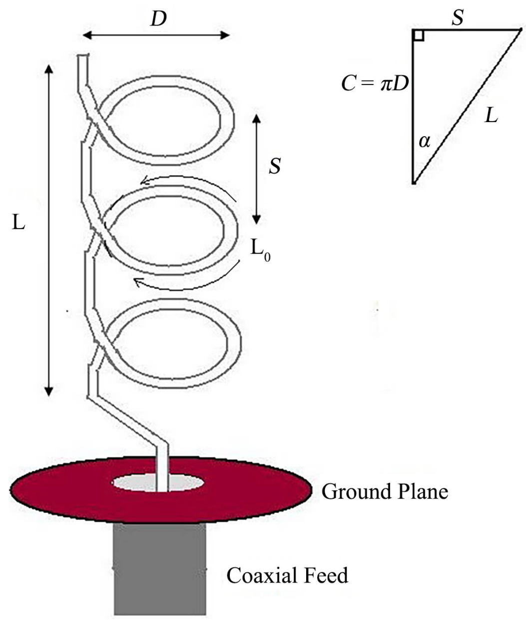

Figure 1. Antenna Design. Image of 3 turn mono-filar axial mode helical antenna mounted over a circular ground plane and the triangle describing the relationship between the circumference, turn spacing and Pitch angle.

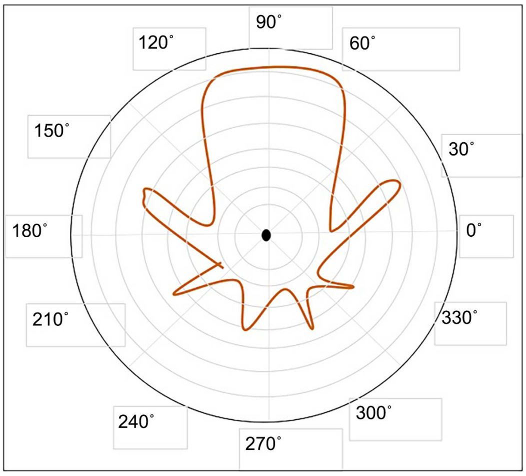

Figure 2. Picture of Axial Mode Radiation pattern over 360˚ electromagnetic field showing the main lobe (90˚N), side and back lobes.

The wavelength can be gotten from

$$V = \lambda f \tag{2}$$

where V (m/s) is the speed of light in a vacuum, f (Hz) is frequency and λ is the wavelength.

The spacing between the helix turns is given by Kumar [6];

$$S = C \tan\alpha \text{ or } 1/4\,\lambda \tag{3}$$

S (meter) and α (degrees) is the pitch angle. From Equation (3), the pitch angle of the windings is obtained as,

$$\alpha = arc\tan\left(\frac{S}{C}\right) \tag{4}$$

From **Figure 1**, the length of one turn is obtained from the triangle using Pythagoras theorem,

$$L = \sqrt{S^2 + C^2} \tag{5}$$

L (meters). Thus, the axial length (*i.e.* total length) of the helix can be computed from:

$$A = NS \tag{6}$$

where N is the no of turns. Also, the Ground Plane diameter is given as;

$$G_{pD} = 3/4\,\lambda\text{, Kumar [6]} \tag{7}$$

From Equation (1), the diameter is givens as:

$$d_H = \frac{C}{\pi} \tag{8}$$

2.2. Simulation

The 4NEC2 software developed by Arie Voors was used to model and simulate the antenna. It can be used to calculate and plot Gain, Front to back ratio, Voltage Standing Wave Ratio (VSWR), Radiation pattern (Azimuth and Elevation), Smith chart and other various parameters (**Figures 3-5**). The software can be found and downloaded free of charge from the Internet, Arie V. [7].

Simulation Results

Using the calculated design values in **Table 2** at the center frequency of 1420 MHz and 21 cm wavelength, the following results were obtained, Arie V [7].

2.3. Method

Helical antenna is designed from the loop antenna and many small loop antennas joined together forms the helical antenna. It consists of thick copper wire or tubing wound in the shape of helix or screw thread and used as an antenna in conjunction with flat metal plate called a ground plate (**Figure 4**, **Figure 6**). The ground plane is made of sheet or screen of radial and concentric conductors. It exhibits circular polarization, Kumar [6]. The Axial Ratio (AR) of an antenna is the ratio between the major and minor axis of a circularly polarized antenna pattern. For an antenna to have perfect circular polarization, the Axial ratio would be close to 1 (0 dB) as in Figure 7 and circular polarisation is described here by the multicolours in Figure 8.

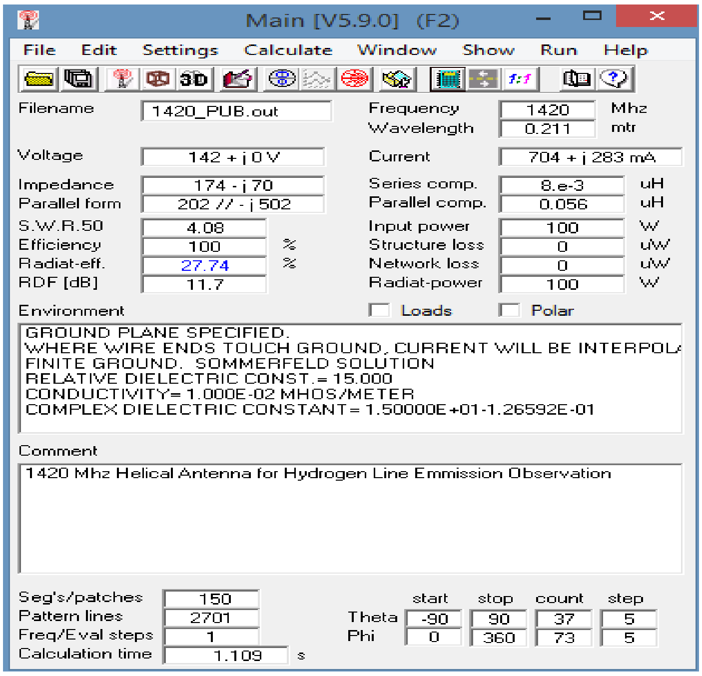

Figure 3. Main Window Screenshot of 4nec2 simulation output window parameters showing SWR, efficiency, input power and structural loss etc.

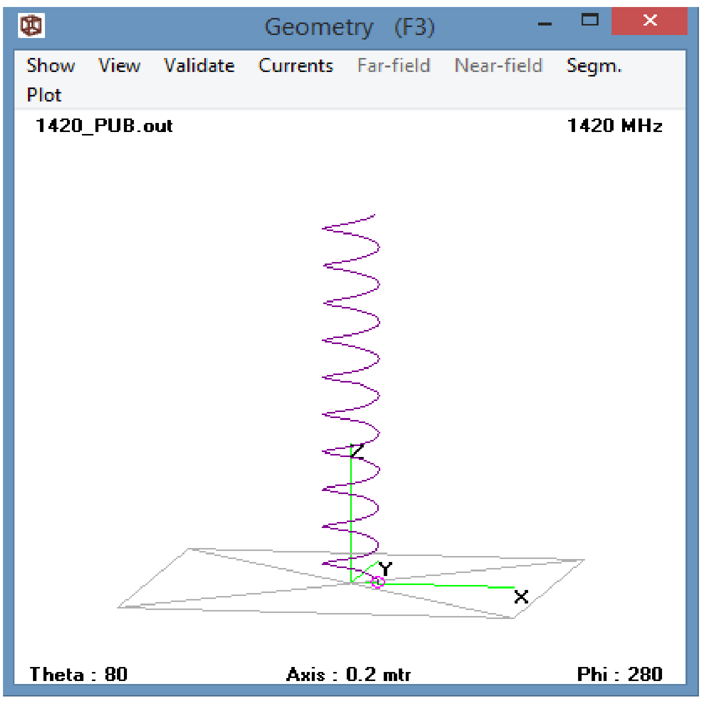

Figure 4. 4nec2 helical antenna wire geometry.

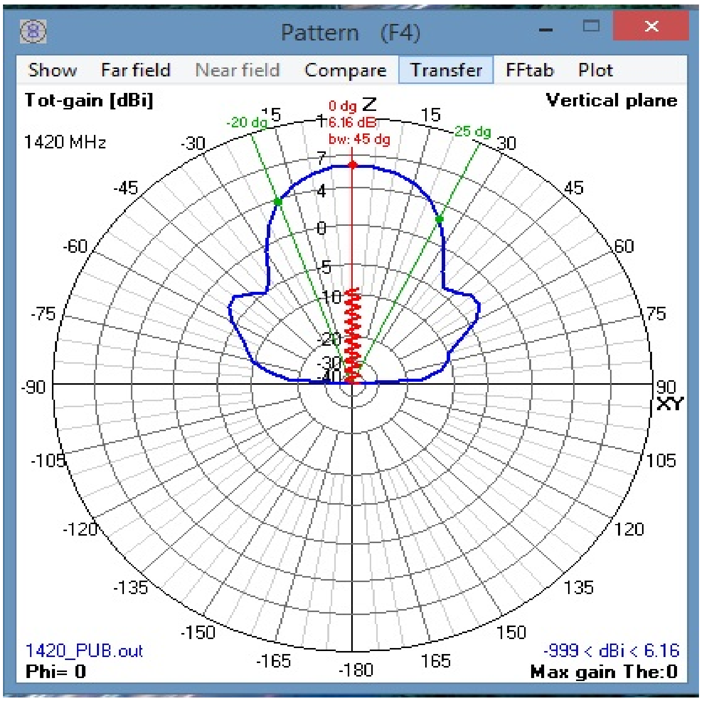

Figure 5. Antenna Geometry showing a Sketch of the radiation pattern with antenna wire situated in the middle, and radiation beam width of 45 degrees over 360˚ field.

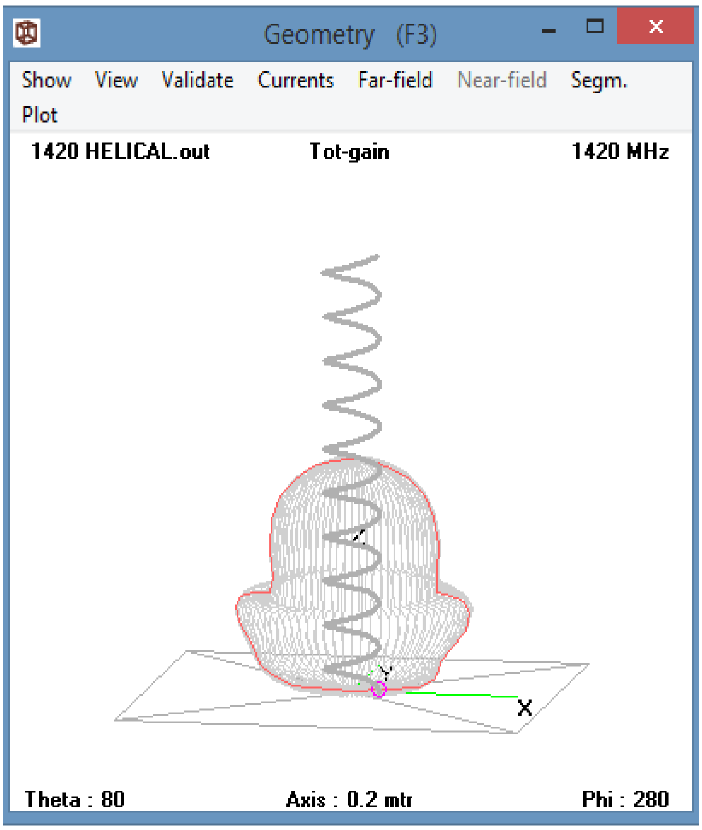

Figure 6. Screenshot of helical antenna wire showing radiation pattern geometry.

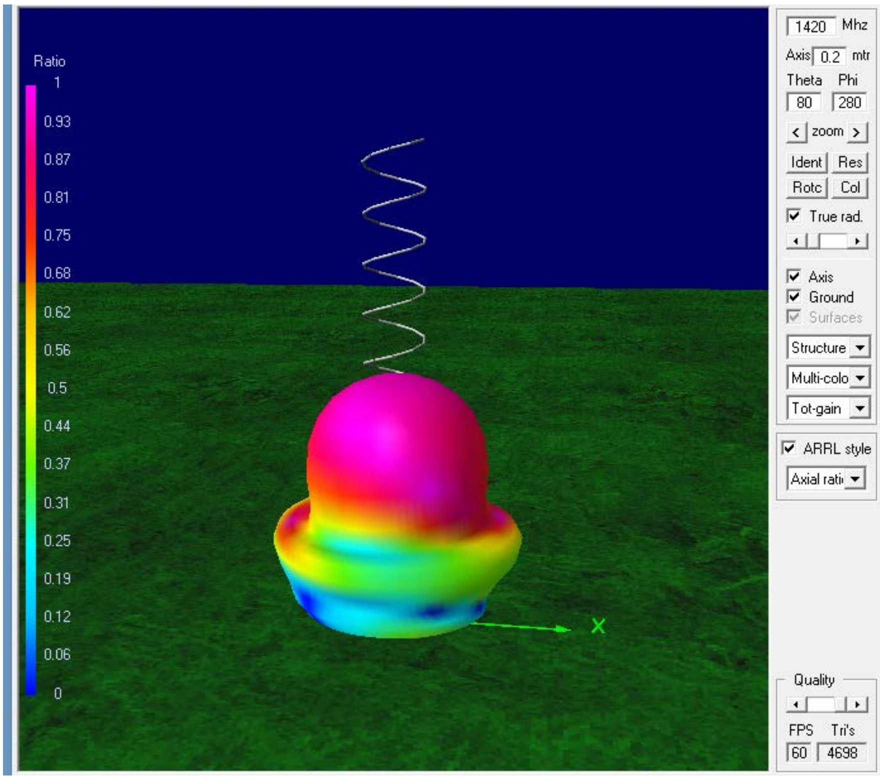

Figure 7. Axial Ratio showing 3Dimensional multi-colored view of the 0.93 Axial ratio with Antenna wire.

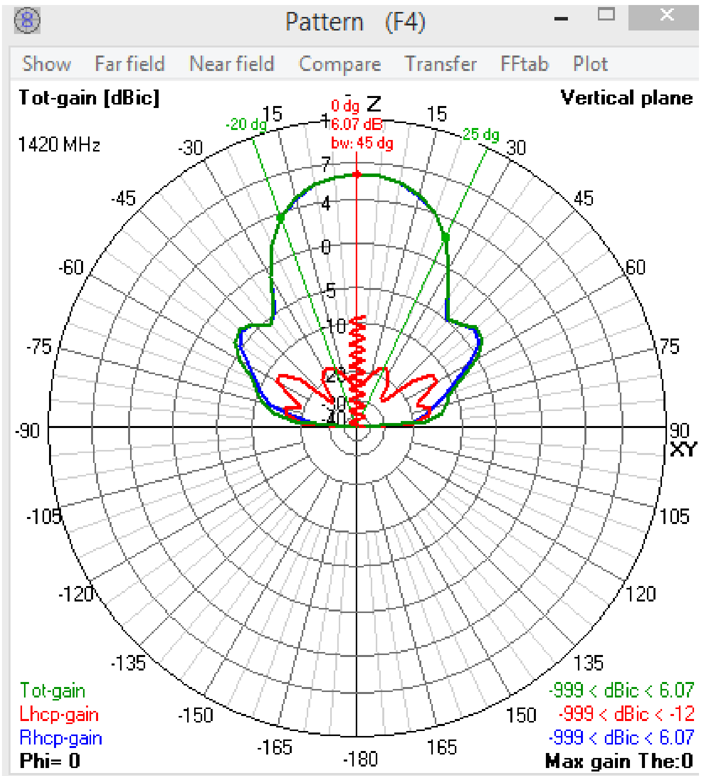

Figure 8. 3D multi-colored view of the radiation pattern with 6.16 dB gain.

The size of the ground plane is also critical, and it is usually chosen to be between 0.5 - 0.75λ, Juan Pierre Jansen [4].

Therefore we used the data from (Table 1 & Table 2) simulation to construct the Antenna. A flat circular aluminum sheet was used as ground plane reflector.

2.3.1. Fabrication

Two equally measured flat colored Perspex glass sheet (dimensions below) was used as support for the helical wire. Holes of 0.2 cm drilled into them at 5.3 cm spacing this corresponds to Equation (3) for the purpose of holding the loop of each turn as the wire spirals upward. Each sheet has 0.5 cm width hole hewn in the middle to an equal length of 29.2 cm, both sheets are then fused together. See Figures 9-13 for details. A 14 SWG Copper wire was fed through the holes of the fused support structure from the base through to the top in helix fashion.

An SMA connector was soldered to the backside of the reflector with the inner pin passing through the reflector plate and soldered to the edge of the tapered impedance matching (see Figure 14) structure which has already been soldered to the end of the last turn.

Table 1. The values below were used as input for simulation and are obtained using Equations (1, 3, 4, 5, 6, 7 & 8) above Kumar G., Kraus [5] [6].

Operating frequency, f	1420 MHz (Megahertz)
Wavelength	21 cm
Circumference of Helix,	21 cm = λ (λ = lambda, for radiation in Axial mode)
Helix diameter d_H	6.68 cm
Spacing btw turns S	5.3 cm
Length of one turn L	21.6 cm
No of turns N	10
Axial Length A	53 cm
Ground Plane diameter G_{pD}	~16 cm

Table 2. Materials used and specifications in centimeters (cm).

S/No.	Material	Dimension; Properties (cm)
1	Perspex Glass	• Diameter = 6.68, Thickness = 0.4, Length = 58.4, ε_r = 3.2, Refractive Index = 1.5, Density = 1.18 g/cm^3, Melting Point = 160˚.
2	Aluminum sheet as ground plane reflector	Thickness = 0.02, G_{pD} = 15.75.
3	Copper Wire	• 14 AWG, Length = 216.
4	No. of Holes; Hole diameter	• 10, 0.3

The support structure with wire in **Figure 15** is then fused/inserted into the ground plane reflector as seen in **Figure 13**.

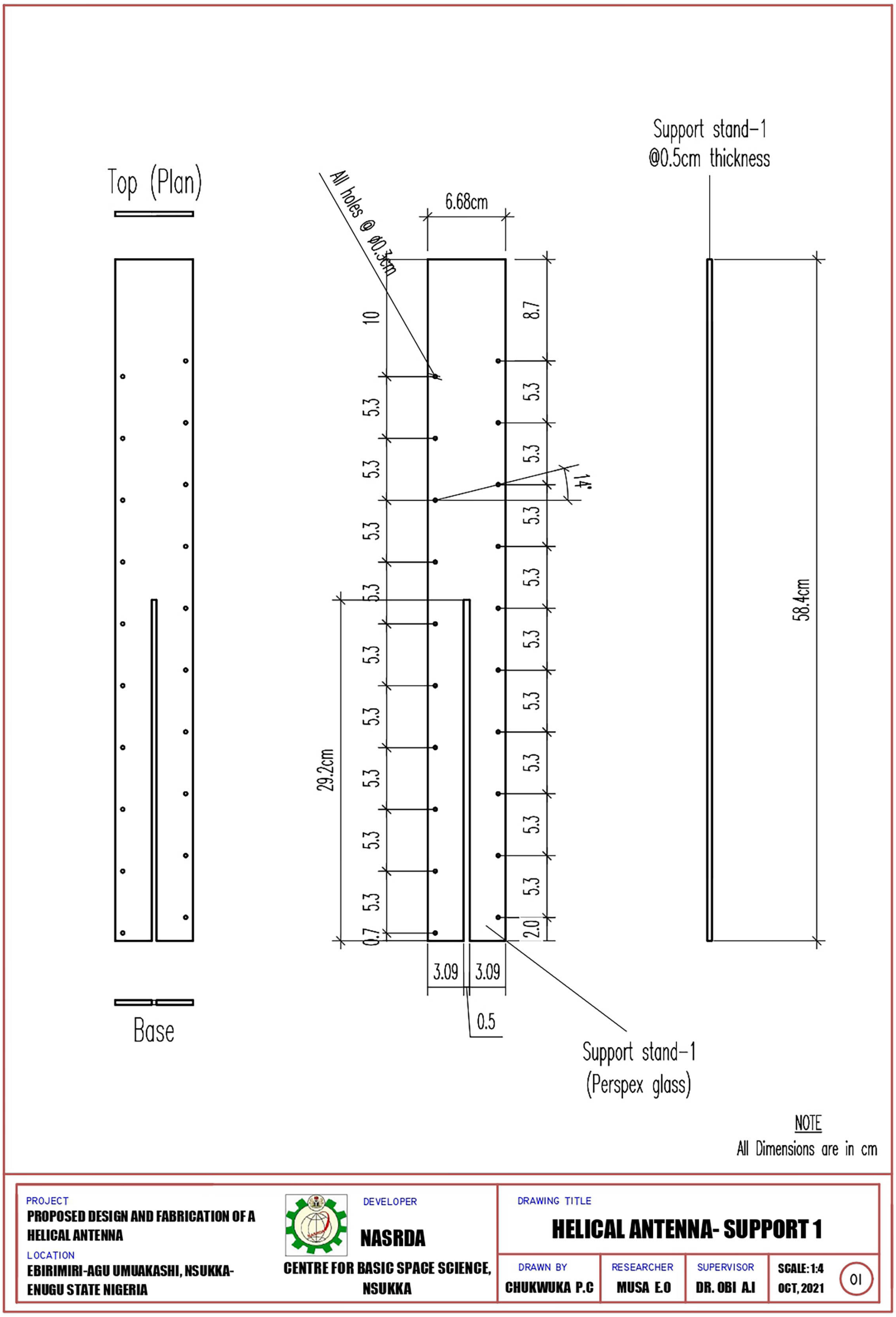

Figure 9. First Support structure. Drawing shows the dimensions of the structure including length of base, hole spacing/circumference, thickness and height.

2.3.2. Support Structure

The support drawings below were done using Autodesk and Revit online tools [8] [9].

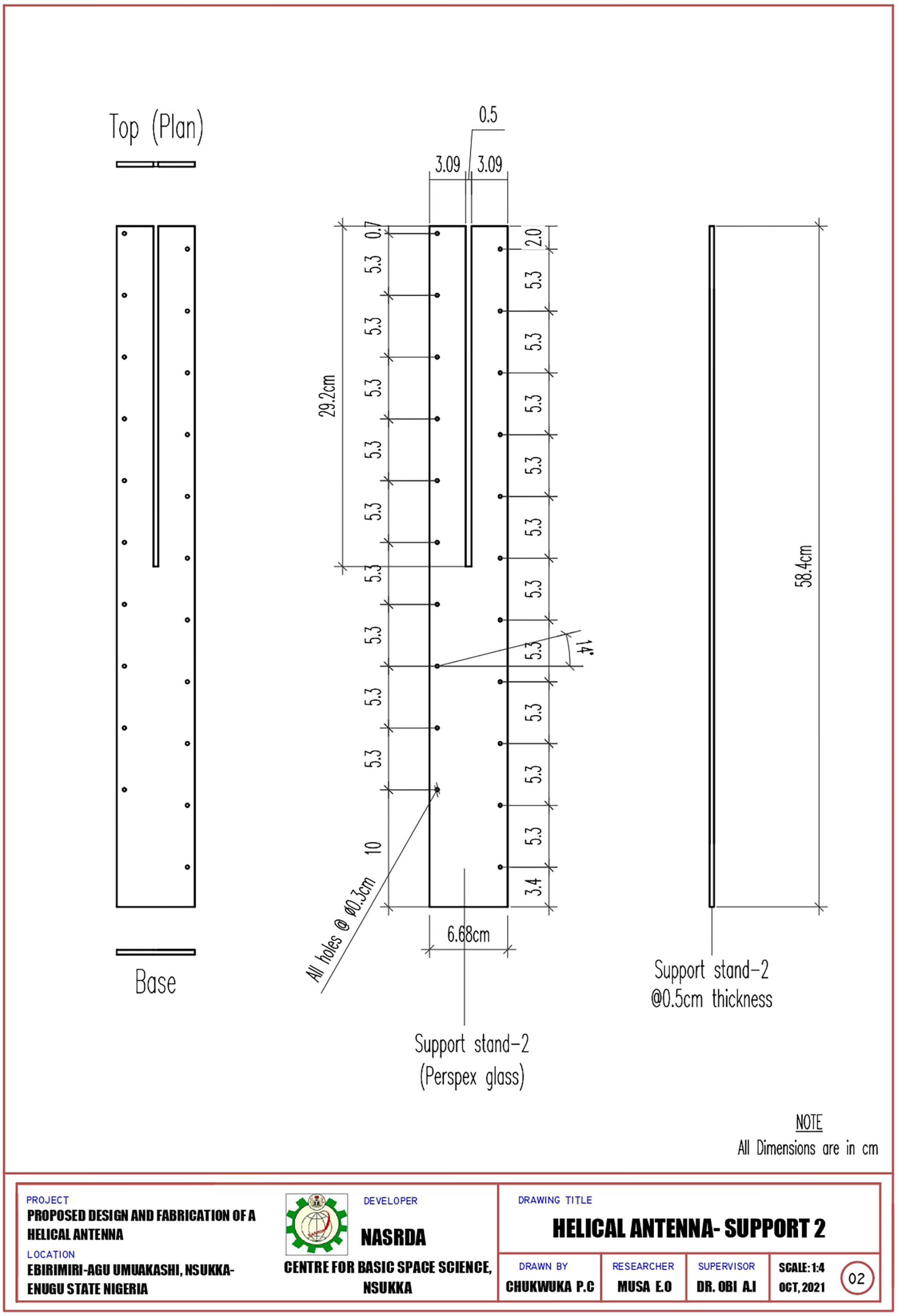

Figure 10. Second support structure. Drawing of the dimensions for the second support structure same as in **Figure 12**.

3. Results and Discussions

Discussion

These key parameters constitute/serve as indicators for the determination of the performance of a Helical Antenna: Gain, Radiation Efficiency, Beam width, SWR, and Impedance values. Each of the above when high or low has a significant effect on the overall output/ performance of the antenna structure.

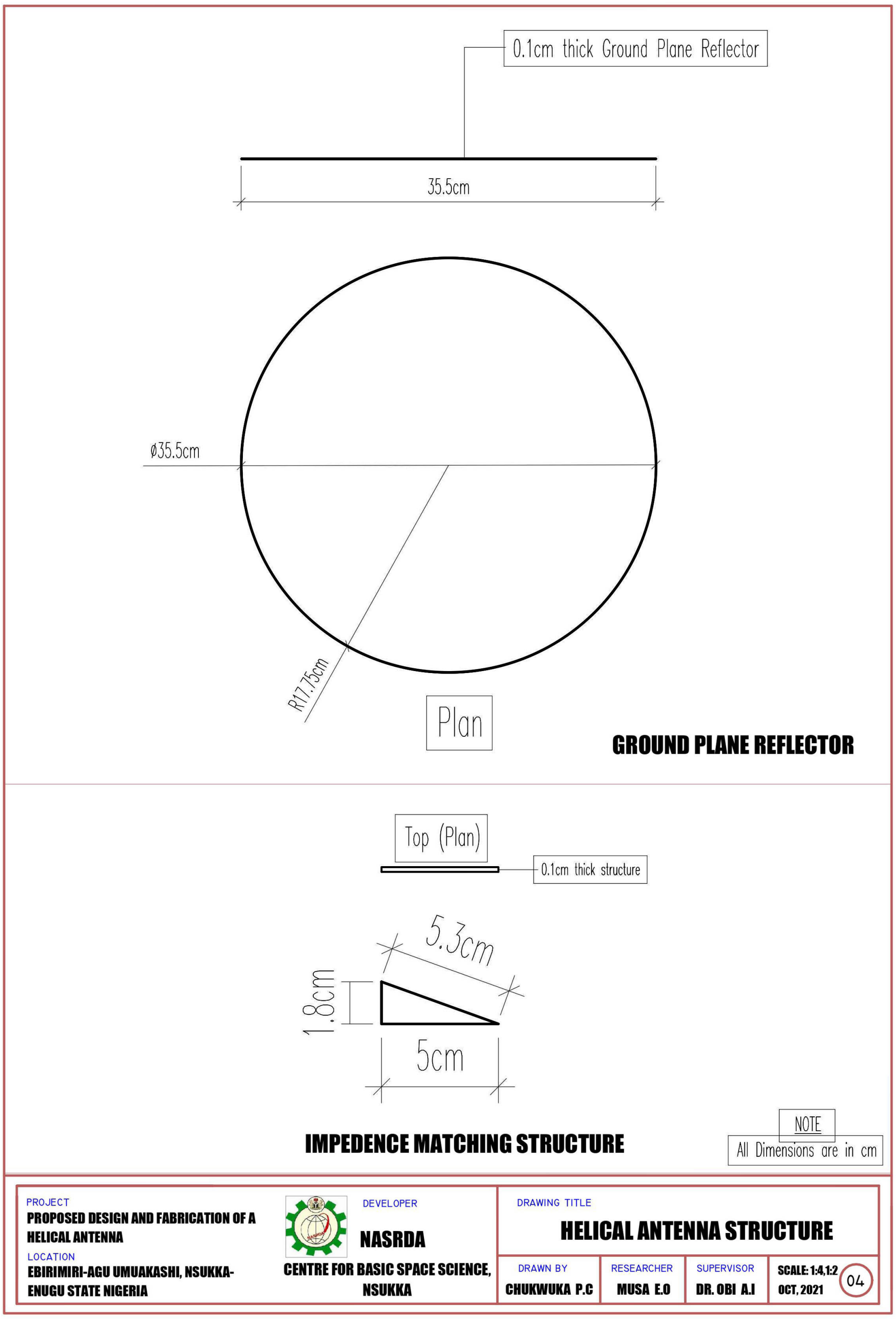

Figure 11. Showing ground plane reflector diameter, circumference, thickness measurements and impedance matching structure dimensions.

However, the gain is proportional to the no of turns N. From N = 5 and above, the beam width narrows increasing the directivity/ gain. The fewer the turns, the wider the beam width and this significantly reduces the gain as described by Tushar [10].

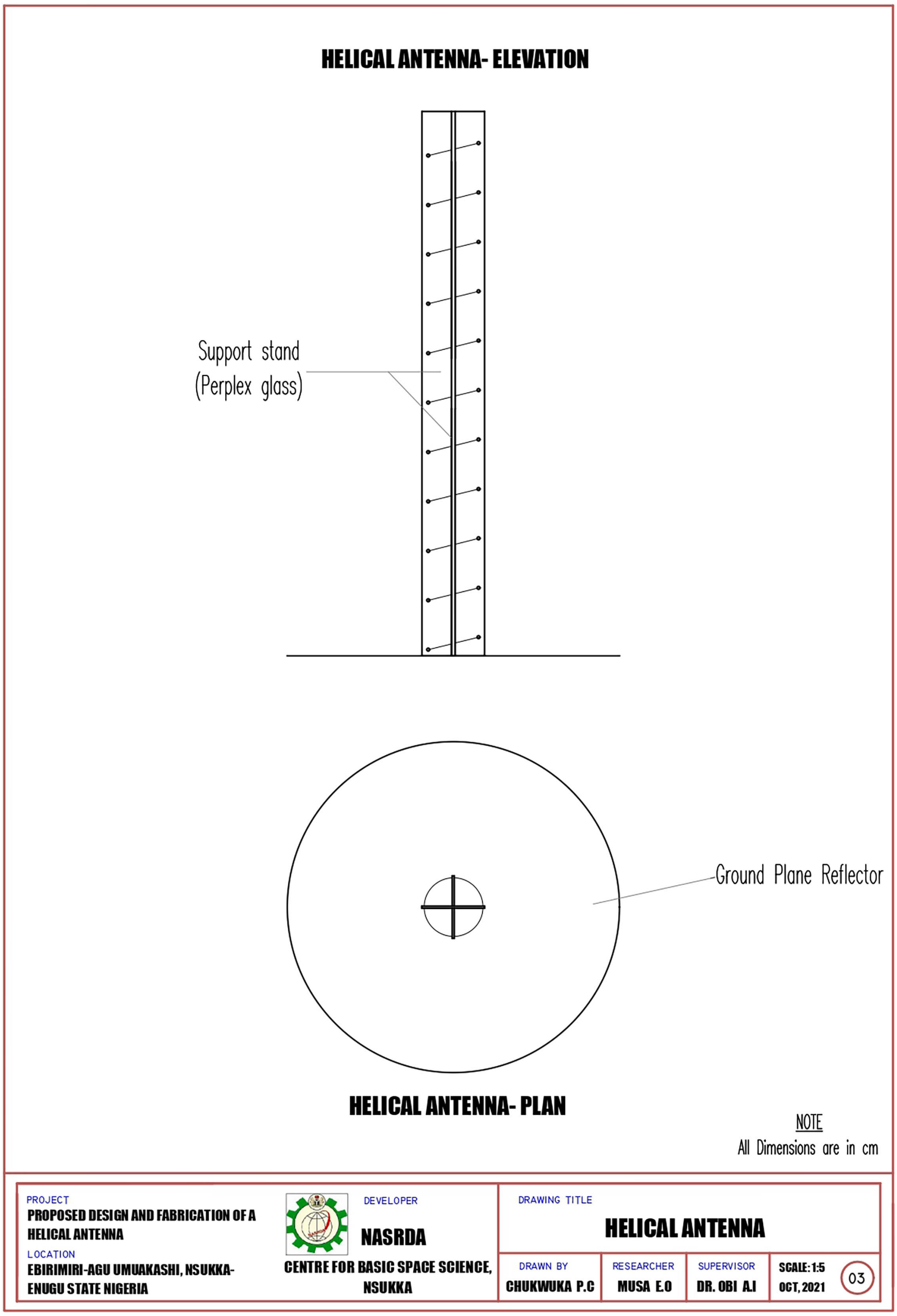

Figure 12. Showing support stand elevation, helical wire pitch angle, and the support structure sitting plan on ground plane reflector.

Figure 13. Showing SMA connector inner pin soldered to the triangular metal strip impedance matching structure.

Figure 14. SMA connector attached to the backside of the reflector.

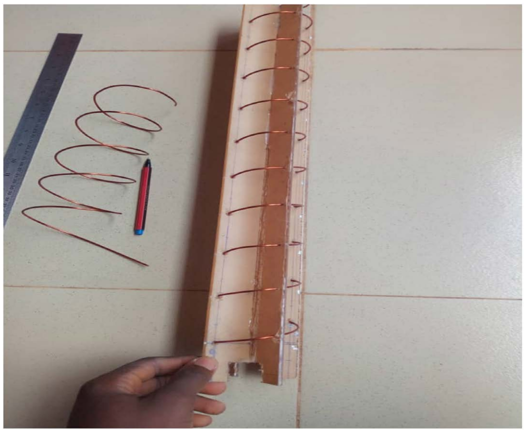

Figure 15. Showing the fused support structure and copper wire.

Helical antennas are known to possess a characteristically high input impedance as discovered by Kraus [5] and noted by Stanislav [3], the fabricated antenna follows in the same footprint with impedance of 174ohms (see **Figure 3** and **Figure 16**). Hence, a thin triangular metal strip taper was used as an impedance matching structure to step down the impedance to a comfortable 50 ohms to guard against signal reflections due to miss-match as shown in Figure 13.

In Figure 17, a frequency sweep was done between 1410 to 1440 MHz at the step size of 2 MHz to view closely the progression; relationship between frequency and Gain, SWR, and Impedance. The gain vs frequency (Figure 17) plot shows a steady gradual increase/rise in gain as frequency increases, Zeain [8]. This explains why the helix has a wide frequency band width. VSWR is mostly affected by the wire radius, thinner wires are not mostly affected (Figure 18).

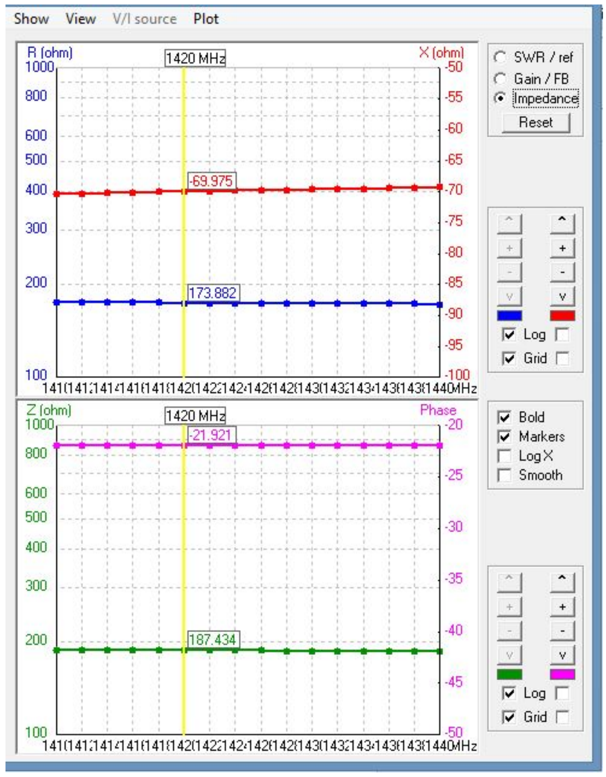

Figure 16. Impedance vs Frequency.

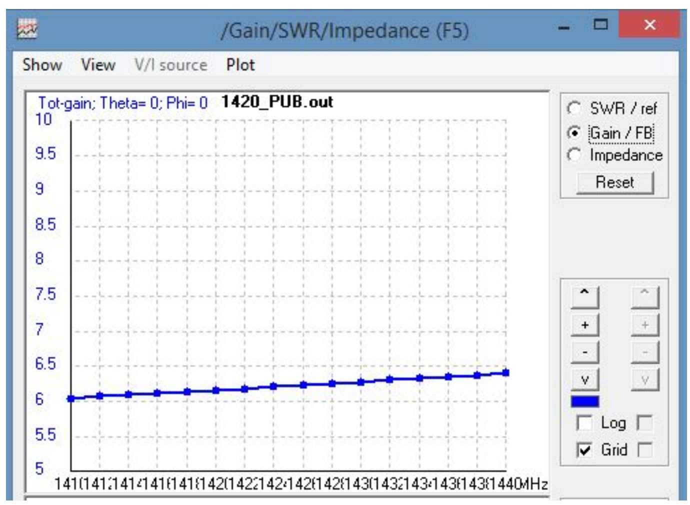

Figure 17. Gain vs Frequency plot.

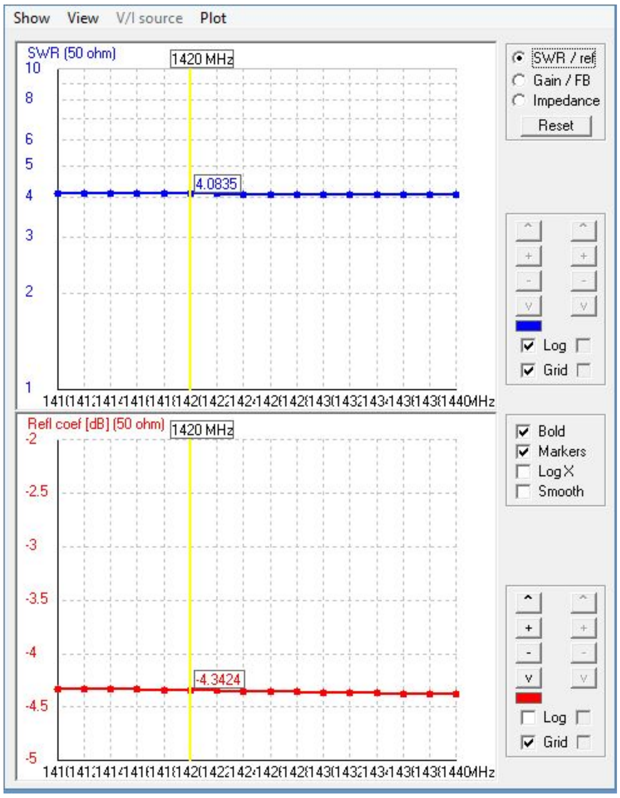

Figure 18. Showing a plot of SWR against frequency at center frequency of 1420 MHz.

Figure 19. Fabricated Antenna mounted as feed on a 2.4 metre off-set Parabolic Dish at the Observatory Complex of the Centre for Basic Space Science, Nsukka.

4. Conclusions

From simulation results, the antenna has 100% efficiency for its size which depicts flawless communication at the designed frequency of 1420 MHz. There is no structural loss in any dielectric, and losses based on coupling to the device as the SWR is 3.6.

The antenna fabricated has 6.16 dB gain at 1.420 GHz center frequency with

45 degrees beam width. It can be used as feed for off-set parabolic dishes (**Figure 19**).

The subject for future work which we have commenced, intends to complete the fabrication of a Small Radio Telescope backend to detect H1 emission with the designed Antenna; using its results as a demonstration technique for the purpose of Astronomy Outreaches in Nigeria.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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