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Antenna Utility for Revised Orientation towards Radio Waves

Anmol Oberoi[1] Rodney Lobo[2] Veena Divya K.[3]
Department of Instrumentation Technology[1,2],
Assistant Professor, Department of Instrumentation Technology[3]
R. V. College of Engineering, V. T. U.
Mysore Road, R. V. Vidyanikethan Post, Bangalore, Karnataka 560059,
India

Abstract: *A tracking system is used for observing or following objects on the move and supplying an ordered sequence of information, which in this case is the location data to a model, which is capable of providing display. As the name suggests, this tracking system is modelled using an antenna which is unidirectional, the YAGI-UDA. The antenna is designed so as to follow the motion of any air borne system with a frequency of 433 MHz. The GPS coordinates are received in a timely fashion in order to control the antenna direction and motion, so as to make it unidirectional and limits its use as an omnidirectional antenna. The tracking system uses a combination of mechanical devices in order to control to the movement of the antenna. The stepper motor is used to update the azimuth of the antenna and the servomotor is used to supply an update in the elevation relative to the airborne system. All of these mechanic motions are controlled with the help of the software control which consists of a microcontroller, which activates the drivers in order to run the mechanical motors in accordance with the change in the position of the airborne system. The system looks at incorporating modularity, portability and cost control keeping in mind the advances in technology and the limitations of the existing systems.*

Keywords: *Antenna, Radio waves, Yagi-Uda, Tracking system, Revised Orientation, GPS.*

I. Introduction

An antenna is a means of radiating or receiving radio waves. It is a metallic device, which may even be a rod or a wire. In other words an antenna is a transitional structure between free space and a guiding device. Certain air borne systems are designed for specific applications such as satellites for monitoring the climate conditions, satellites for telecommunication or for radio and television broadcasting, unmanned air vehicles for aerial security, aerial photography. Tracking of such systems becomes a matter of utmost concern due to their highest priority applications.

While many methods already exist for tracking of airborne systems, most of these systems lack portability due to their titanic size. This system aims at overcoming the above mentioned limitation and also improving the execution, taking into consideration various parameters. The system finds its application in various verticals which begin from defence and continue over confidential and specific frames such as satellites and spaceships. This system uses a directional antenna, namely the Yagi-Uda antenna, which moves in the direction of the airborne system and hence all the power is supplied into a single direction. This design achieves a very substantial increase in antenna’s directionality and the gain compared to a simple dipole.

Section I is an introduction on Antenna Tracking system and Section II makes it clearer by giving an insight on Anatomy of Tracking systems. The Section III throws light upon the existing Tracking systems. Design features are dealt with in section IV, which is followed by the methodology in the next section, consisting of proposed block diagram and its modules.

II. Existing Technology

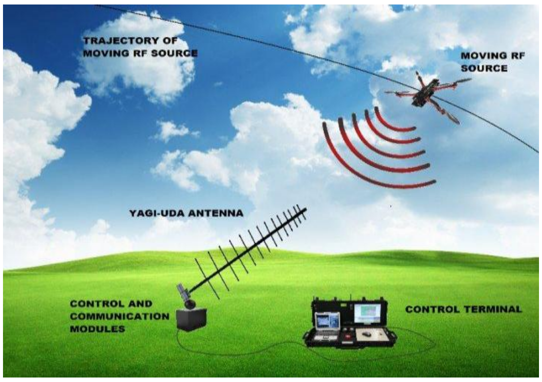
GPS tracking came about using satellites to determine location or position to with a high accuracy. This became a boonfor the military, allowing its units to be monitored and controlled from a remote location. This depicted its application in a very transparent way. Eventually, GPS technology was made public. This allowed the common man to take advantage of the satellite network. The public now has the access to GPS devices to navigate andreachtheir destination in the shortest amount of time.

While throwing some light upon the existing technology, one would never fail to mention some of its unmatched advantages which include extremely flawless and high range of tacking. But with such advantages, it includes limitations too which have been clearly noticed and eliminated in the current system under development. A few of these limitations are portability, modularity and not forgetting the extremely high cost of the system [1][3]. The system under consideration is built using different modules which is clearly depicted on the block diagram and hence it has positive stability The figure given below is a pictorial representation of what an existing system would look like, which very clearly shows they are not portable and as the system is very large, it increases its range enormously.

While not all existing systems use a directional antenna for better directivity and gain control, the system under consideration uses a Yagi-Uda Antenna for enhanced directivity when compared to the existing system. These existing systems use omni directional antennas [2].

Omni directional antennas supply equal power in all directions, this limitation is overcome by using a directional antenna which supplies all the power in the direction of concern and suppresses the power in other directions [3].

Fig. 1 Tracking system



III. Anatomy of tracking [7]

The functionality of the tracking systems are mentioned as follows:

- The system is in the ready state at first.
- As soon as an airborne system is located in its range of operation, the system starts to receive its GPS coordinates.
- On receiving the GPS coordinates, the azimuth and elevation are decoded.
- The software module updates the hardware module in accordance with the decoded values.
- The antenna, which is controlled by the hardware module, follows the air borne system and collects data from it.

IV. Design fetures of Yagi-Uda Antenna

A Yagi-Uda antenna is a widely used antenna design due to its high forward gain capability, extremely low cost and ease of construction as such, not taking the design in to consideration. It is commonly used as a roof top television or radio receiver; it can also be used as a transmitter antenna based on the application. Basically an antenna is a real system that matches or coupled the energy to the free space. A Yagi-Uda antenna is a directional antenna system consisting of an array of dipole and additional closely coupled parasitic elements, which are reflectors and directors.

The dipole element is directly connected to the transmission feed line and is responsible for energizing the entire structure. The reflector is 5% percent longer than the dipole and the dipole is 5% longer than the director element. The number of directors depends upon the gain and for achieving high gain it is better to have equally spaced elements with large number of directors. More directors mean better gain. The function of the parasitic element is to improve the radiation pattern in the forward direction. The reflector provides a 3db additional gain, but having one reflector provides little benefit.

There are no simple design rules or formulas for designing a Yagi antenna due to nonlinear relationship between physical parameters such as element length, diameter and position and electrical characteristics such as input impedance and gain but performance can be estimated by computer simulation [11].

V. Modus Operandi

A.The design and development of such a tracking system can be carried out in the following manner:

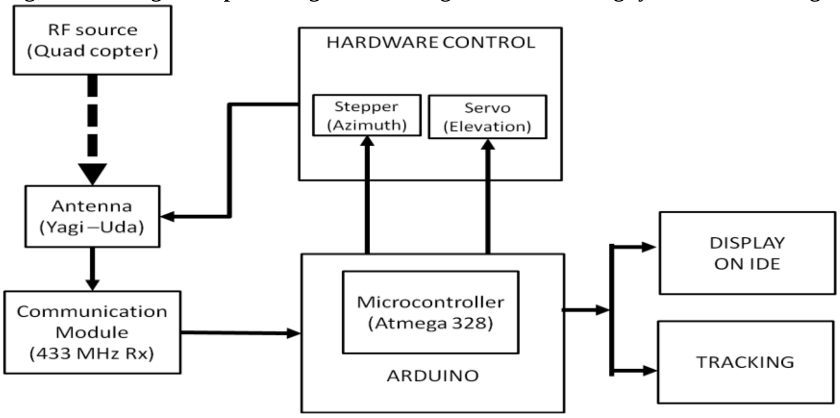
- Design of antenna for 433MHz frequency range-The antenna is designed using QY4 simulation software. The radiation patterns for the designed antenna with 5 elements is depicted in the following pages.
- Design of control system – The control system is the support module. Constructed using a structure to mount the antenna. The structure comprises of the stepper motor for relevant azimuth update and a

servo for relevant elevation update. All updates take place in accordance with the GPS modules received from the airborne system.
- Integration of modules- Various modules are integrated. These include the mounting of the antenna on to the control structure, whose movement is in turn controlled by a microcontroller, contained with a user fed program.

The above procedure is followed by testing the system which includes- Transmission of the UHF signal, tracking of the airborne system and data presentation at the ground station in order to depict the elevation, angle and various other parameters associated with the airborne system

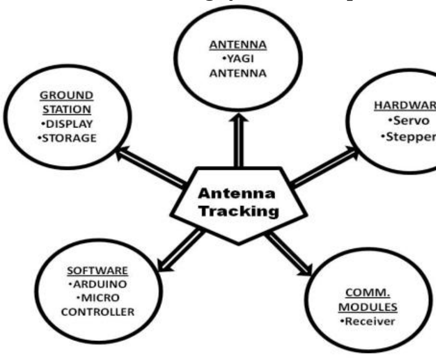
B. Block diagram

Fig. 2 Block Diagram representing the flow of signal once a tracking system is functioning.



C. Modules

Fig. 3 Various modules of the antenna tracking system, with specific elements used under each module.



VI. Antenna Tracking

The Yagi-Uda antenna is designed to have 5 elements. Three of which are reflectors. The antenna is designed using QY4 software. QY4 stands for quick yagi version 4, which is a software developed specifically for designing a YAGI UDA antenna. The software can help design antennas automatically or manually [10]. All the dimensions for a particular design frequency are judged with the help of a few parameters, namely the element diameter, operating frequency, number of directors and the spacing between each element.

The Yagi-Uda antenna is designed for the following specifications:

Frequency (MHz)	433
Boom Length (m)	0.45
Gain (db)	10.32
Diameter of elememts (m)	0.006
Front to Back ratio (db)	23.43
Input impedance (Ω)	17.8
Directivity (dB)	9.2

A. Range of length of different elements

Length of reflector= $0.47\lambda - 0.52\lambda$

Length of driven element= $0.45\lambda - 0.49\lambda$

Length of directors= 0.4λ – 0.45λ

B. Range of spacing between different elements

Spacing between reflector and driven element= 0.16 λ – 0.35λ.
Spacing between driven element and nearest director= 0.2 λ - 03λ.
Spacing between directors= 0.2 λ - 03λ.
Range of diameter of elements = 0.001λ – 0.003λ.

C. Directivity Calculation

Directivity of N element YagiUda antenna= 10logN + 2.2dBd.
For N=5, Directivity = 10log5 + 2.2 = 9.2dBd [13].

VII. UHF/VHF Range Calcultions [15]

Range of an antenna can be determined by carefully observing various parameters, which must be calculated or determined with testing. The parameters are as specified below.

A. Radio line-of-sight calculation

The radio line of sight calculation determines the theoretical maximum range. The actual range is usually lesser than this, because of the variables in transmitter power, receiver sensitivity, line losses and antenna efficiency. The calculation is carried out by the formula specified below.

$$D = 1.33(SQRT(2Hr) + SQRT(2Ht))$$

Where, D= distance to radio horizon(miles)
Hr= height of RX antenna(feet)
Ht= height of TX antenna(feet)

B. Line losses

The path followed by the Radio frequency energy, experiences a loss of power as it is sent to and from the antenna. The cause of this loss is imperfect shielding and due to reflection of energy through line couplers. Typical values for line loss of the most commonly used coaxial cable RG-58, is approximately 9.5 dB per 100 feet.

C. Path loss

The loss of power that occurs as the signal propagates through free space from the transmitter to the receiver is called path loss.

$$PL= 117 + 20\log(F) – 20\log(Ht*Hr) + 40\log(D)$$

Where, PL = path loss in dBm.
F = operating frequency in MHz.
Ht, Hr = height of transmit and receive antennas(feet).
D= distance between antennas(miles).

D. Antenna Gain

Antennas do not actually produce a gain as they are passive elements in an RF circuits. However they can produce an effective gain in a particular direction by focussing the energy in a specific plane or pattern.

E. Impedance matching

Antenna impedance relates the voltage to the current at the input to the antenna. If the impedance is a real number, then the voltage is in phase with the current. If the impedance is given by a complex number, then imaginary numbers give phase information. Maximum transfer of RF at the design frequency occurs when the impedance of the feed point is in accordance with the impedance of the feed line. This is known as impedance matching.

VIII. Radiation Patterns

A. Azimuth

Fig. 4 Linear radiation pattern

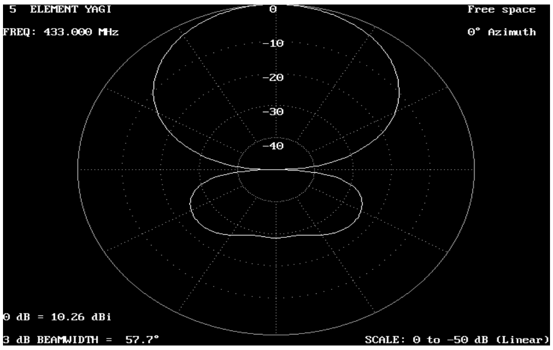
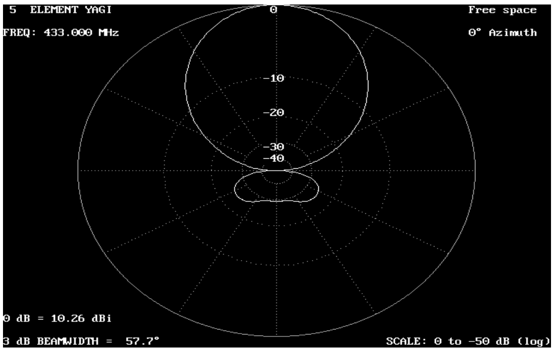


Fig. 5 Logarithmic radiation pattern



B. Elevation

Fig. 6 Linear radiation pattern

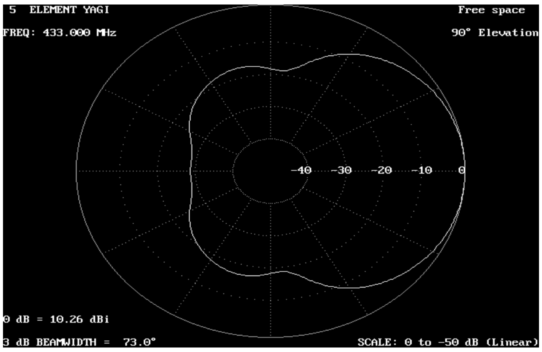
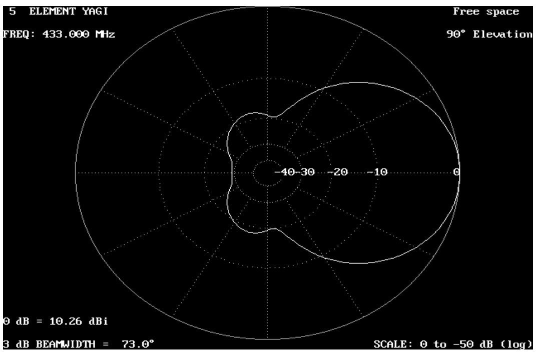


Fig.7 Logarithmic radiation pattern



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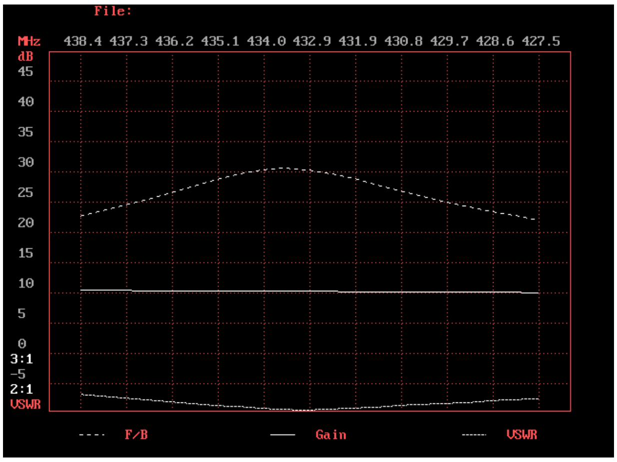
C. Gain

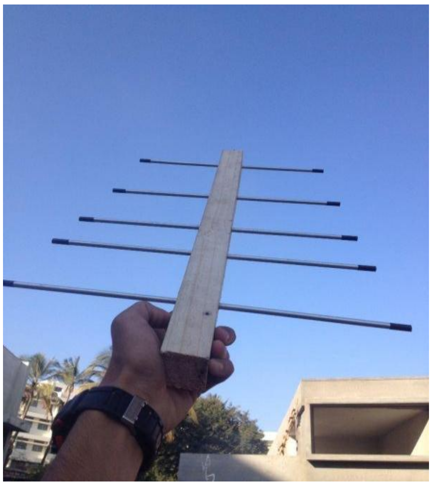
Fig. 8 Pattern for Gain, Front to back ratio and voltage standing wave ratio.



The antenna radiation patterns are sometimes known as the polar plots and play a major role in the overall performance of the yagi antenna. A plot of gain vs direction is called the radiation pattern. On increasing the number of directors within a given boom length, does not result in a better gain but gives a better control of the antenna ‘s pattern of a wider range of frequencies in the band of the design. By reducing the length of the directors and increasing the spacing between the directors results in a very clean pattern with good pattern bandwidth.

IX. Representation of Antenna Constructed for 433 MHz Frequency

Fig. 9 Yagi Antenna at 433MHz

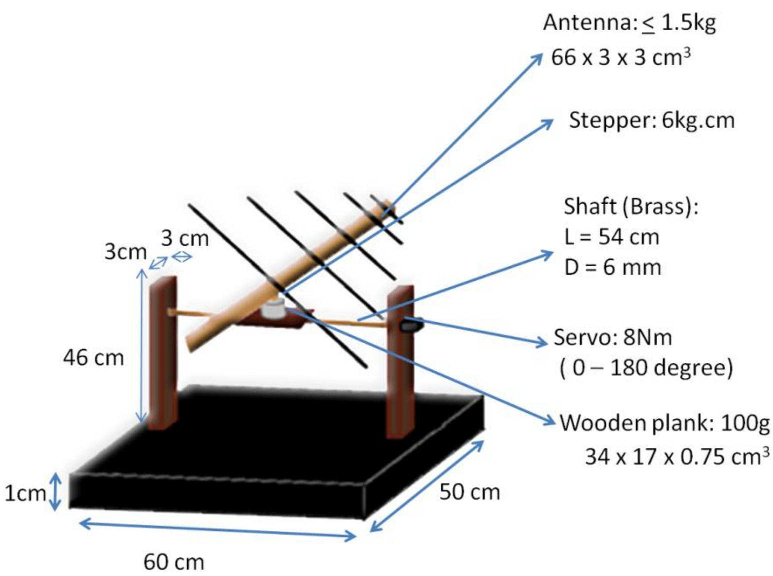


X. Hardware Breakdown

The hardware vertical of this tracking system concentrates as two major players of the antenna position and motion control, which are the stepper motor and the servomotor [14]. The stepper motor provides the necessary changes in the azimuth in accordance with the current positioning of the system to be tracked. This updation takes place on every received GPS co ordinate value. The servomotor contributes to the elevation change in accordance with the GPS co ordinates. The functioning of these two components in relation to each other depict the control system of this tracking system [16]. The system considerations are defined as follows.

Stepper motor provides a means of accurate positioning and speed control without the use of any feedback controllers or sensors. The stepper motor considered is a 5kg torque motor, as it needs to vary the azimuth of an antenna of a considerable weight. Figure 10 shows the physical properties of the model developed for tracking. The structure is a wooden crafted one, with two supporting pillars and a base. The supporting pillars are 46cm long each , with a width of 3cms. The pillars consist of a rotating base of dimensions 34, 17, 0.75. The square shape base has each side of 50cm. The rotating base consists of a shaft, which is a brass rod of 6mm. The antenna is mounted on the rotating base and the servo motor is installed onto one of the pillars for a motion of 0 to 180 degrees. The servo motor is a very important aspect as far as tracking is concerned, as it controls the elevation of the entire system and it must be strong enough to elevate the entire system. Keeping this in mind a servo motor of torque 9kg-cm was chosen as this could lift the complete weight of the base carrying the stepper motor and the antenna, both mounted on a base of over 1kg [4].

Fig.10 Physical properties of the structure developed for mounting the Yagi Antenna



GPS Module analysis

Transmitter:

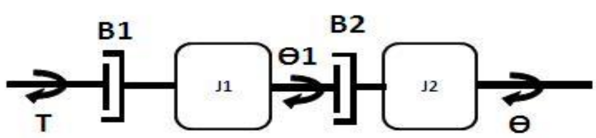
Working voltage: 3V - 12V for maximum power use 12V.
Working current: maximum less than 40mA and minimum 9mA.
Working frequency: 315MHz or 433MHz.
Transmission power: 25mW (315MHz at 12V). So this module transmits up to 90m in open area.

Receiver:

Working voltage: 5.0VDC +0.5V.
Working current: ≤5.5mA maximum.
Working frequency: 315MHz-433.92MHz. Bandwidth: 2MHz
The use of an optional antenna will increase the effectiveness of the wireless communication.

XI. Control System Design

Fig. 11 Free body diagram of rotating structure [12]



In the above free body diagram (FBD),

J1, J2 – Moments of inertia of rotating table and antenna respectively
B1, B2 – Coefficients of rolling friction of the shafts of rotating table and stepper respectively
T – Torque applied using the servo θ1 – Intermediate rotation
θ – Rotational output at the antenna

Consider the moment of inertia J1 which has the applied torque T. the opposing torque due to friction and moment of inertia are, TB1 and TJ1. From Newton's second law for rotational motion,

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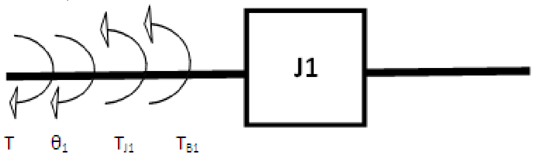
The FBD for J1 can be drawn as such,



$$T = T_{J1} + T_{B1} \quad (a)$$

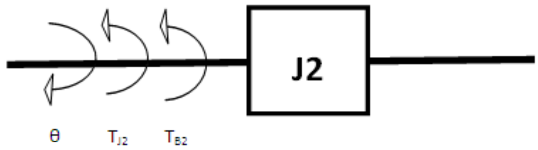
$$T = J_1 \frac{d^2\theta_1}{dt^2} + B_1 \frac{d\theta_1}{dt} \quad (b)$$

Taking Laplace Transform with zero initial conditions

$$T(s) = J_1 s^2 \theta_1(s) + B_1 s \theta_1(s) \quad (c)$$

$$T(s) = \{J_1 s^2 + B_1 s\} \theta_1(s) \quad (d)$$

Consider the moment of inertia J2 which has the applied rotation θ1. The opposing torque due to friction and moment of inertia are, TB2 and TJ2. The opposing torque due to stiffness is TK.
The FBD for J2 can be drawn as such,



From Newton's second law for rotational motion,

$$0 = T_{J2} + T_{B2} \quad (e)$$

$$0 = J_2 \frac{d^2\theta}{dt^2} + B_2 \frac{d(\theta_1 - \theta)}{dt} \quad (f)$$

Taking Laplace Transform with zero initial conditions

$$0 = J_2 s^2 \theta(s) + B_2 s \theta_1(s) - B_2 s \theta(s) \quad (g)$$

Rearranging the terms,

$$\theta_1(s) = \frac{-B_2 s}{J_2 s^2 - B_2 s} \theta(s) \quad (h)$$

Substituting (8) in (4)

$$T(s) = \frac{\{J_1 s^2 + B_1 s\}\{-B_2 s\}}{J_2 s^2 - B_2 s} \theta(s) \quad (i)$$

Hence the transfer function is,

$$\frac{\theta(s)}{T(s)} = \frac{-(J_2 s^2 - B_2 s)}{J_1 B_2 s^3 + B_1 B_2 s^2} \quad (j)$$

$$\frac{\theta(s)}{T(s)} = \frac{-(J_2 s - B_2)}{J_1 B_2 s^2 + B_1 B_2 s}$$

The various constants are found using simulations and calculations done by using the values of dimensions of the structures and they are listed as follows:

J1 - 0.08 kg.m^2
J2 - 0.02 kg.m^2
B1 - 0.6
B2 - 0.2

The final form of the transfer function after substituting the values is:

$$\frac{\theta(s)}{T(s)} = \frac{-(s - 10)}{0.8s^2 + 6s} \quad (k)$$

XII. Results

Table 1. Antenna UHF/VHF Range Calculations at 433MHz frequency:

Range Parameter	Value
Radio Line of Sight	13.5251 Miles
Line losses (Due to coax)	0.095 dB/ft
Antenna Gain	10.26 dB
Path Loss	46.3781 dBm
Height of transmitter= 33.75 ft	
Height of receiver=3.375 ft	
Frequency= 433MHz	
D=0.0088 miles	

Fig.12 Screenshot of the system developed with integration of various modules

Table 2. GPS Coordinate values received in terms of degrees and converted to linear values for the Antenna control (In accordance with Airborne system):

Degree values	Linear values
Vyoma workshop at RVCE Lat - 12.922490 Lon - 77.499359	Vyoma workshop at RVCE Lat – 110629.8016 Lon – 108518.3237 Avg. longitude – 108319.1906
Parking lot at RVCE Lat - 12.922608 Lon - 77.499359	Parking lot at RVCE Lat – 110629.8026 Lon – 108516.7733 Avg. longitude – 108319.1394
Amphitheatre at RVCE Lat - 12.922049 Lon - 77.498118	Amphitheatre at RVCE Lat – 110629.7979 Lon – 108518.5141 Avg. Longitude – 108319.3819

XIII.Conclusion

The performance of this system depends upon the antenna design. The antenna design is one the most crucial aspect of the system as it decides not only the specification of other parameters related to the system but also contributes to the tracking of the airborne system of a particular frequency range. Hence the antenna is modelled with the right set of dimensions to ensure that it functions for the exact same frequency range as that of the airborne system.

In this paper, the methodology to be followed in order to design the entire system which is range independent is discussed. The antenna performance is analysed by the appropriate simulations.

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