Helical Antenna Design for Automated UAV Tracking System

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Abstract—**Recently, the use of unmanned aerial systems (UAS) has increased dramatically in the civilian and military environments. The current paper is mainly concerned with the limitations of radio communications between a UAV and ground control stations. A new approach will be presented by creating a dynamic ground control station that can automatically and real-time track a UAV that has a 5.8 GHz video transmitter on board. To do that, an axial mode helical antenna is proposed. The antenna is simulated and the performance analysis is presented. Helical antennas play an important role in establishing communications for UAV. Also it describes a portable tracking antenna system that is used for line of sight communications with the small UAVs. Our antenna is mechanically rotated in an elevation and azimuth mode in response to the tracking signals derived from the UAV video link transmissions. The antenna tracking system with 7 turns and a pitch angle of 18º has achieved good results. This satisfies the requirements for establishing a reliable communication in UAV applications.**

Index Terms—**unmanned aerial system, radio communication, ground station, video transmitter, helical antenna, line of sight.**

I. Introduction

Antennas are essential devices for any communication system. With the passage of time, the antenna had a growing role in the Unmanned Aerial Vehicle (UAV) technology. A critical requirement in the reliability of a UAV mission is communication with the ground control station. For reliable communications and visual direction maintenance of the plane, different antenna types have been used. Helical antennas were first described by Kraus in 1947 and are commonly used for transmitting/receiving data in line-of-sight networks such as ground-to-satellite communication systems. A typical helical antenna consists of a single conductor wound into a coil that is attached to a large ground plane. An antenna is defined by the IEEE Standard Definition of Terms for Antennas as “the part of a transmitting or receiving system which is designed to radiate or to receive electromagnetic waves” [1].

A transmitting antenna converts oscillating electric current into electromagnetic radiation, while a receiving antenna converts electromagnetic radiation into a time harmonic current.

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For different applications, it is important to have a reliable data transmission of high quality video signals, between an unmanned aerial vehicle and the ground station.

An example of an application like this would be to fly an UAV over dangerous areas such as flooded areas or forest fires and from a safe distance, see what the areas look like. The helical antennas operate in two modes: the normal-mode and the axial-mode. In normal-mode helical antennas have omnidirectional radiation pattern, while the axial-mode helical antennas have directional radiation pattern and the wave is circularly polarized [2]. Making a comparison, the axial-mode helical antenna is preferred because in the field of UAV high directivity and circular polarization is required. The benefit of this helix antenna is that it has a wide bandwidth, is easily constructed, has real input impedance and can produce circularly polarized fields.

Gain is one of the most frequently used terms to describe the performance of an antenna and it is closely related to directivity. While directivity and gain are terms based on the magnitude of the radiated power pattern, gain takes into account the antenna’s efficiency while directivity does not. Gain is defined as “the ratio of the radiation intensity in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotopically” [1].

The gain of the helical antenna is highly dependent on the number of turns. This can be achieved by arranging the rings on the top of each other with equal spacing. This will give the possibility of maintaining the undesired harmonics [3]. For a better antenna gain, the length of the wire must be increased. This may lead to a large number of turns which increases the size of the helix and also makes it heavier. In this situation an array of helices is more appropriate [4].

On the other hand, the gain can also be enhanced by increasing the pitch angle, which describes how much a helix antenna grows in the z-axis per turn. [5] Also, in this case there are two modes of radiations, the normal mode and the axial mode. When the dimensions are smaller than the wavelength the helical antenna works in the normal mode. Radiation reaches its highest level in the perpendicular plane of the axis of helix [6].

In this case, the antennas that operate in normal mode have low efficiency because they have a small size comparing to the wavelength. The axial mode occurs when the circumference of the helix is equal to one wavelength. Now, in this case, radiation reaches its maximum power which flows in the same direction of the antenna axis.

A helical antenna has a circularly polarized or an ellipse pattern. All this things are dependent on the length of the helix and the pitch angle. Linear polarization appears when we have a small pitch angle.

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The difference between the two modes is that in the axial mode radiation reaches its maximum value along the helix axis, where in the normal mode the radiation reaches its maximum value in the normal direction of the helix [7].

The following will be presented further on in this paper: section II refers to the constructional details and parameters of the proposed antenna, section III presents the simulation results and section IV is devoted to the conclusions.

II. Construction Details and Parameters

The geometry of a typical helical antenna is shown in Figure 1. Common parameters of helical antennas used in this section are defined as follows with lengths being given in meters [2]:

C – circumference of the helix = $\pi \cdot D$ (1)

D – diameter of the helix

N – number of turns

S – gap spacing in-between turns = $c \cdot \tan(\alpha)$ (2)

L – length of one turn

α – pitch angle

A – axial length = $N \cdot S$ (3)

S_g – Spacing from ground plate to the beginning of the helix's first turn

The properties of helical antennas have been known for years, but are difficult to analyze and derive. Even so, good approximations have been made over the years from experimental analysis. A helical antenna can be best approximated as a combination of two basic radiating elements: a linear antenna and a loop antenna. If one loop of the helical shown in red in the figure 1 was unwound, a wire of L length would be left. The pitch angle, or angle of inclination of the spiral is designated as α.

The circumference of the spiral C is equal to $\pi \cdot D$, where D is the diameter of the spiral if viewed from above. If the pitch angle were to be increased to 90° then the coil would be stretched out into a rod, also known as a linear antenna [8]. On the other hand, as the pitch angle decreases all the way to 0°, the coil becomes more and more compressed until it becomes a simple a loop antenna [8]. The properties of a helical antenna can be described as an approximation of everything between the minimum and maximum pitch angle α, or a mixture of linear and loop antenna theory [9]. The radiation characteristics of a helical antenna can be controlled by varying its geometry, which in turn changes the mode and subsequently the bandwidth over which the antenna operates.

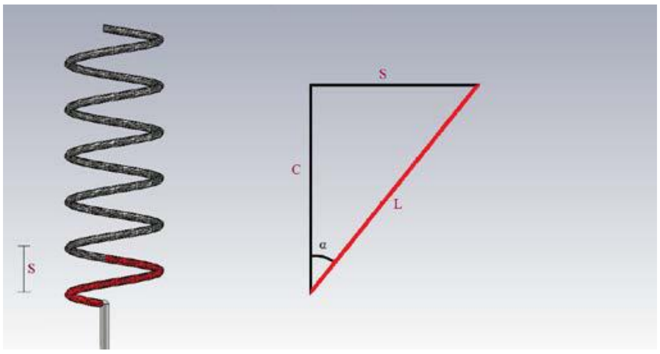

Figure 1. Helical antenna geometry

The antenna was designed to operate at the frequency of 5.8 GHz. In Table I we have the parameter range for optimum performance of the helical antenna. Two of the parameters can be chosen without calculations. These parameters are the number of turns which is selected to be 7 turns, and the pitch angle (α) which is selected to be 18º.

The geometry of the antenna is described in the subsequent paragraphs. One of the most important parameter of the antenna is the wavelength (λ)

$$\lambda = \frac{c}{f}, \tag{4}$$

where λ stands for wavelength, f is consistent with an operating frequency and c is the speed of light, $3{\cdot}10^8$ m/s

$$\lambda = \frac{3 \cdot 10^8}{5.8x \cdot 10^9} = 5.1\,cm \tag{5}$$

Table I. Parameters for the Optimum Performance for the Helical Antenna

Parameter	Optimum Range
Circumference	0.75 λ < C < 1.33 λ
Pitch Angle	11º < **α** < 20º
Number of Turns	3 < N < 15
Wire Diameter	Negligible Effect
Ground Plane Diameter	>0.5 λ

The space between the turns of the helix (S) can be calculated as follows:

$$S = \frac{\lambda}{4} = \frac{5.1}{4} = 1.275\,cm \tag{6}$$

The diameter (D) of the helix wire is given by:

$$D = \frac{\lambda}{3} = \frac{5.1}{3} = 1.7\,cm \tag{7}$$

Next, the circumference (C) is calculated by:

$$C = \pi D = 1.7\pi = 5.34\,cm \tag{8}$$

The gain of antenna (G) is calculated by:

$$G = 10.8 + 10\log\left(\frac{c^2 NS}{\lambda^3}\right) = 12.5\,dBi \tag{9}$$

N is the number of turns, S is the spacing between the turns and λ is wavelength.

The directivity of helix antenna can be approximated:

$$D = \left(\frac{12c^2 NS}{\lambda^3}\right) = 13.2\text{ dBi} \tag{10}$$

All the data calculated above are centralized in Table II.

Table II. Estimated Parameters for the Antenna

Parameter	Value
Center frequency	5.8 GHz
Number of turns (N)	7
Pitch angle (α)	18º
Wave length (λ)	5.1 cm
Spacing between turns (S)	1.27 cm
Wire diameter (D)	1.7 cm
Circumference (C)	5.34 cm
Gain (G)	13.21 dBi
Directivity (D)	15.2 dBi

The 3D model of the proposed antenna is shown in Figure 2.

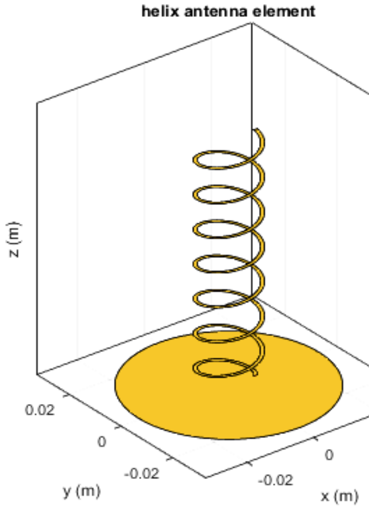

Figure 2. 3D Design view of the proposed antenna

III. Simulation Results

In the following section the graphs of the antenna simulation and its performance analysis are presented. The performance is presented through the radiation pattern in azimuth and elevation, the directivity, the gain and the return loss.

The radiation pattern or "antenna pattern" is the graphical representation of the radiation properties of the antenna as a function of space. That is, the antenna's pattern describes how the antenna radiates energy out into space (or how it receives energy).

There are two main types of plane patterns: azimuth and elevation. Azimuth represents the x-axis movement view of the antenna pattern.

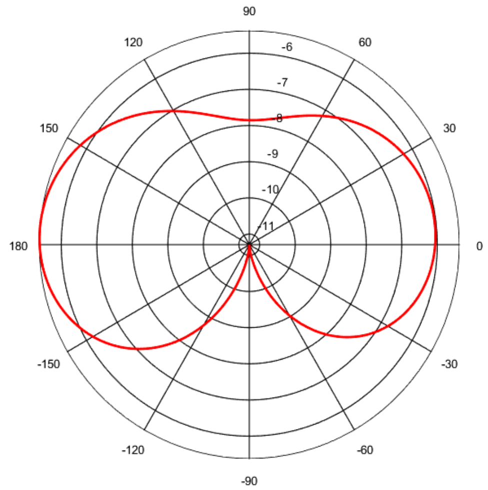

Figure 3. Azimuth pattern

The second type of plane patterns is the elevation plane diagrams. The elevation plane diagram represents a cross section of the antenna radiation pattern if you were to look at it from eye level with the access point from a particular angle on the horizon.

It can be observed that a maximum gain of 11.7 dBi is achieved at the frequency of 5.8 GHz. However, the calculated value of the gain is 12.5 dBi.

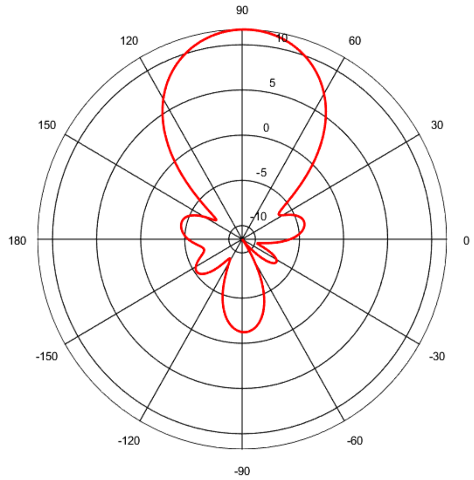

Figure 4. Elevation pattern

Another important parameter to evaluate the antenna performance is the power gain. This describes the peak value of the gain, the gain in the direction of the main lobe's antenna.

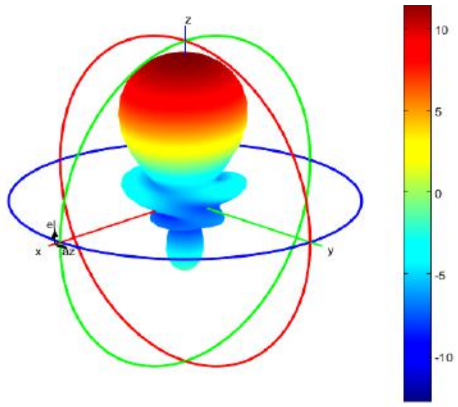

Figure 5. Antenna gain

VSWR (Voltage Standing Wave Ratio) is an important parameter for the performance of any RF device. This is a figure that indicates the proportion of radio waves arriving at the antenna input that are rejected as a ratio against those that are accepted. This means the amount of signal reflected by a connector is the major factor contributing to the total signal efficiency.

VSWR is the ratio of voltage applied to voltage reflected. Since it is a linear measurement, it can be useful when displaying larger reflections due to the fact that small differences are not compressed as they are in a logarithmic measurement.

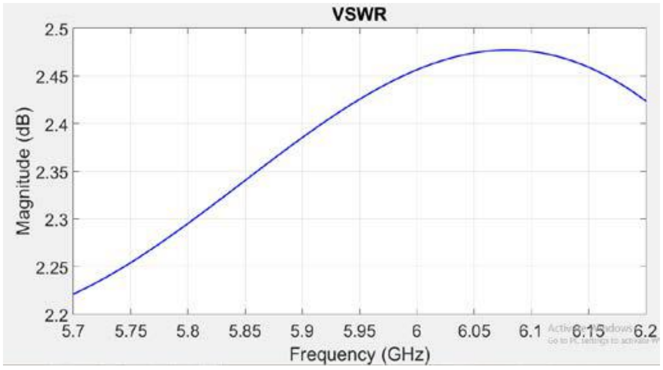

Figure 6. Simulated VSWR

It can be observed that the return loss at the resonant frequency of 5.8 GHz is -12.7 dB. This shows that the return loss is more negative and hence the power fed is absorbed and less reflected.

The results show that there is a discrepancy of 0.8 dB between the calculated and the simulated gain.

IV. Design of Automated Tracking System

Integration of the dynamic tracking directional antenna was almost straight forward with minimal issues and materials costs. Key design considerations included design and mounting of the gimbaled antenna, algorithm and software design, ground station telemetry interface.

The tracking system uses a low-cost gimbal, designed in CATIA Software. It is a 2-axis design and it has an appropriate rate of acceleration and velocity, range of motion and payload capacity.

This antenna tracker is designed to handle up the helical antenna with 7 turns. The design is as compact as possible while still accommodating many different medium sized antennas.

The only extra parts needed are servos, a few screws (M2 around 8-10 mm and M3 around 8-10 mm) and two bearings. For a good motion two servos were used: one for panning and one for tilting.

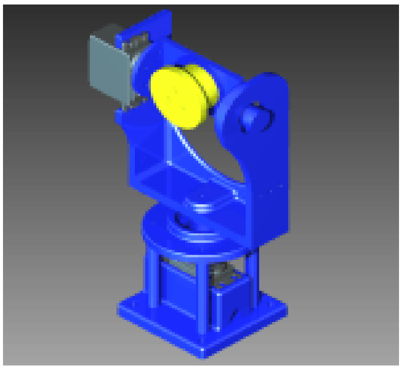

Figure 8. Automated Tracking System

The tracker calculates the position of a remote vehicle using its own GPS position and GPS telemetry from an UAV. It then uses this information to aim a directional antenna at the vehicle. Using a correctly aligned directional antenna significantly improves the range over which signals can be both sent and received from a ground control station.

V. Conclusion

The paper addresses some data about an enhanced axial mode helical antenna for unmanned aerial vehicle (UAV). We present a new set of data related to the optimal design of helical antennas (located above a smaller ground plane) with respect to the maximal gain, the axial ratio, the operating bandwidth and the input impedance. The antenna is simulated and analyzed and the performance assessment is presented. The simulation results show that we have an error of only 6.4% on antenna gain. Furthermore, the enhanced results are achieved by reducing the diameter of the ground plane. Thus it is recommended that the proposed antenna can be used for our dynamic tracking system. The speed at which UAVs are embraced by emergency response teams could include many factors such as: affordability, usability, sensor payloads, operations and maintenance, mission integration, reliability, and survivability. In the case of this effort a simple affordable dynamic tracking directional antenna improved the performance and reliability of UAV communications and therefore utilization.

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