Design and Implementation of Ground Station Antennas for UAV Data Radio Link in UHF Band

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Abstract

In this paper, design and implementation of Ground Station (GS) antennas are presented to control UAV by use of data radio link between UAV and GS based on spread spectrum in frequency band of 780-880MHz at the maximum range of 100Km. Gain, frequency bandwidth, polarization, radiation pattern, and the height of installed antenna from the ground are very important in regard to UAV maneuver and desired range. Helix and omni-directional antennas are designed and implemented to cover short and long ranges. Helix is designed based on Emerson's relations and optimized by IE3D to match to 50Ω in frequency range of 100MHz by new stub-loaded method. Monopole antenna is designed and optimized by Fidelity software. After implementation, measurement results are in a good agreement with the simulation. Then, we demonstrate how we can dominate the ground effect and multipath effect by use of two-antenna system.

1. Introduction

Unmanned Aerial Vehicle (UAV) is a remotely piloted or self-piloted aircraft that can carry cameras, sensors, communication equipments or the other payloads. They commonly operate in military operations and scientific research, perform powerful intelligence collection capability, and hence highly reduce the human risk and operation cost. Their autonomous flight and powerful sensing capability further facilitate their operations of flights beyond the visual ranges [1, 2].

GS Antennas should have appropriate frequency bandwidth, polarization, gain, and radiation pattern on the basis of radio link specifications. It is necessary to use directional antennas to cover long ranges because of their high gain. The Antenna polarization of the UAV is vertical, and the direction of its installed antenna most often changes due to maneuvering fast around the GS; therefore, it is necessary to choose circular or slant (+45/-45) polarization for GS Antennas. Meanwhile, it is used spread spectrum methods such as frequency hopping to increase link security, so the Antennas should be relatively wideband. Since the desired system is based on Ground Control Station (GCS), i.e., it can find the location of UAV by GPS or received RF signals; thus, it can direct Antenna to the UAV and track. However, the fast maneuvering of UAV around the Ground Station, especially in the time of taking-off and landing should be regarded; consequently, GCS can not follow the UAV simultaneously and quickly. Moreover, the UAV can be controlled visually, so omni-directional antenna can be utilized in the short ranges -less than 5 km.

Monopole antenna which is a vertical-polarized omni-directional antenna will be designed, simulated by Fidelity simulator, and optimized. Helix antenna has been used to cover ranges more than 5Km to establish data radio link. It is designed, and matched to 50Ω in frequency bandwidth of 100MHz by new stub-loaded matching method. The dimensions and position of optimum stub matching is attained by IE3D simulator. Also, helix antenna specifications such as radiation pattern, gain, HPBW, VSWR, and Axial Ratio (AR) are calculated. The implemented antennas will be tested and measured. In the end, the appropriate height for installing of the antennas is proposed in regard to LOS relations and multipath problems.

2. Design and simulation of the monopole antenna

We would like to design a quite wideband vertical-polarized omni-directional antenna which covers 360° around the GS at the maximum range of 5Km. A thick-rod monopole antenna with bent ground plane has the preceding characteristics. The dimensions have been shown in Figure 1. The λ/4 monopole antenna is simulated at the center frequency of 830MHz by Fidelity simulator.

![Figure 1: λ/4 monopole antenna with bent ground plane](image-url)
Figure 2: Simulated VSWR of \( \lambda/4 \) monopole antenna

Figure 3: Radiation pattern of \( \lambda/4 \) monopole antenna

The results are depicted in Figure 2 and Figure 3. Figure 2 shows the antenna has very good matching in frequency bandwidth of 100MHz with VSWR<2. Radiation pattern is omni-directional in the azimuth plane. Figure 3 shows the main beam is at the elevation angle of \( 40^\circ \) with the maximum gain of 3dB. The loss in the horizontal plane is about 4dB which is not important because of the high level of received power in the short ranges.

3. Design and optimization of Helix

Helix antenna has many applications to establish any data radio links between UAV and GS. Circularly polarized axial-mode helical antenna prepares GS antenna to be able to receive signals in the different conditions of maneuvering and to solve the wave propagation problems. The UAV has the vertical-polarized antenna, so the helix antenna will receive the signals with loss of 3dB in all directions [3, 4].

Several relations have been introduced to design of helix antenna [4-6]. Investigation of these formulas by IE3D software to design of practical helix antenna indicates Emerson's relations are more accurate [6]. The antenna parameters are functions of the dimensions of helix, the center frequency, the ground plane size and shape, the helical conductor diameter, the helix support structure and the feed arrangement [4-6]. Some references suggest choosing 1.1\( \lambda \) for the circumference of the helix to have better performance.

We would like to design the helix as a GS antenna at the center frequency of 830MHz for data radio link. It should have VSWR<2 (50\( \Omega \) system) and AR<2dB in frequency bandwidth of 100MHz. LOS link calculation shows that GS antenna with the minimum gain of 12dB throughout the bandwidth is required to cover 100km range. According to [4,6] references, the number of turns and the dimensions of the desired helix antenna are as the following:

\[
N = 13 \\
S = 9.0 \text{ cm} \\
D = 12.6 \text{ cm}
\]  

The parameters are N: number of turns, S: turn spacing, and D: diameter of helix circumference. Kraus's relations predict the gain of 16.5dB and the HPBW of 29\(^\circ\) but King & Wong's relations anticipate the gain of 14.4dB and the HPBW of 37\(^\circ\) [4,5]. It is calculated 13.4dB gain based on Emerson's formulas [6].

The helical conductor diameter does not significantly affect the radiation properties of the helix and may range from 0.006\( \lambda \) and 0.05\( \lambda \). The diameter conductor is presumed 2.7mm. The helix may be supported by a few radial insulators mounted on an axial dielectric or tube whose diameter is a few hundredths of wavelength, by one or more longitudinal dielectric rods mounted peripherally or by a thin-wall dielectric tube on which the helix is wound. We use Thin-wall plastic cylinder to support the helix. The ground plane may be flat (either circular or square) or cup-shaped forming a shallow cavity or replaced by loops. The diameter or side dimension of the ground plane is calculated 0.5\( \lambda \) at the low frequency of bandwidth. If the diameter of the ground plane is lengthened, the level of side lobes will be increased. We use a flat 320mm-diameter circular ground plane for the helix. The antenna parameters of helix are not sensitive to the calculated dimensions and it works well in a wide bandwidth [7].

The input impedance of an axial-mode helical antenna is between 140\( \Omega \) and 150\( \Omega \). With a suitable matching section, the terminal impedance can be made any desired value from less than 50\( \Omega \) to more than 150\( \Omega \). Thus, by bringing the last 1/4turn of the helix parallel to the ground plane in a gradual manner, a tapered transition between the 140- or 150-\( \Omega \) helix impedance and a 50\( \Omega \) coaxial line can be readily accomplished. This can be done with either axially or peripherally fed helices but is more convenient with a peripheral feed [8,9]. A new stub-loaded matching is proposed for helix in frequency bandwidth of 100MHz. This method is easy, flexible, tunable and low loss. Figure 4 shows the feed rod is passed through the circular stub. The diameter and thickness of the copper-circular stub are 50mm and 1mm, respectively. The position of stub is changeable.
and tunable. Meanwhile, the input impedance of helix is dependent on the thickness of the feed rod and the angle of the first loop relating to the ground plane. The plastic-cylinder structure is connected to the ground plane by Teflon flange.

Figure 4: The position of the circular stub

The calculated helix is simulated by IE3D software to optimize the dimensions of helix and the place of the stub. The geometry of helix is depicted for simulation in Figure 5. Simulation results show that the helix without stub-matching has the directivity of 12.8dB and VSWR of 2.5; consequently, the antenna efficiency and gain will be 80 percent and 11.8dB, respectively. After simulation of helix with 50mm-diameter circular stub, the most favorable height of the stub is obtained 30mm above the ground plane. In addition, the angle of the first loop relation to the ground plane is attained $45^\circ$. Figures 6 and 7 illustrate far-field radiation patterns in vertical plane $\phi = 0^\circ$ (XOZ) and azimuth plane $\phi = 90^\circ$ (YOZ) at frequency of 830MHz, correspondingly. Both of radiation patterns are nearly similar; therefore, elevation and azimuth HPBW are equal to $31^\circ$. The gain is computed 12.7dB. Figure 8 shows the antenna gain from 11.8dB at 780MHz has been increased to 13.8dB at 880MHz. As a result, the beamwidth is increased at low frequencies and vice versa. As shown in Figure 9, VSWR is 1.14 at 830MHz and less than 1.35 throughout the frequency bandwidth. It is found that the circular stub can accomplish a very good matching with loss of around 0.15dB. The axial ratio is the values simulated in the direction of the helix axis. It is depicted AR is less than 1.8dB as shown in Figure 10. The loss of plastic-cylinder structure is expected about 0.1dB.

Considered altogether, these pattern, polarization and impedance characteristics represent remarkably good performance over a wide frequency range for a circularly polarized beam antenna.

Figure 5: Helix simulated by IE3D software

Figure 6: Elevation-plane radiation pattern at 830MHz

Figure 7: Azimuth-plane radiation pattern at 830MHz

Figure 8: Helix gain in frequency bandwidth of 100MHz

Figure 9: Helix VSWR in frequency bandwidth of 100MHz
4. Implementation and measurement results

After manufacture of monopole antenna as shown in Figure 11, VSWR and radiation patterns were measured. Figure 12 illustrates the monopole antenna has $VSWR \approx 1.13$ at 830 MHz. The monopole antenna is omni-directional in the azimuth plane. According to Figure 13, the measured elevation radiation pattern is presented at 830MHz. HPBW of the vertical plane is about 65°. The gain of monopole antenna is 2.5dB at the elevation angle of 40° and the loss is 2dB in the horizontal plane.

Helix was implemented according to the optimized dimensions as shown in Figure 14. The angle of the first loop to connect to the feed rod relation to the ground plane is 45° which is shown in Figure 15. VSWR was measured by Network Analyzer. Figure 16 indicates VSWR<2 in bandwidth of 100MHz and VSWR is 1.6 at 830MHz. Radiation pattern of helix is endfire with the gain of 12.5dB in the direction of helix axis. HPBW in both of the elevation and azimuth planes are quite 32°. It is found that there are good agreement between Emerson’s relations and measurement. The antennas have the mechanical resistance against vibration and wind.
5. Short and long ranges coverage

Helix should cover 360° at the maximum range of 100Km. Moreover, multipath effect and LOS rules should be regarded due to install GS antennas especially helix antenna at the height of 4m. The first break point—the furthest break point away from GS—is at the range of 21Km [11,12]. The multipath loss can not degrade the data radio link in this range because of the high level of received power. It is necessary to elevate helix axis up about 4° to compensate the ground effect on the radiation pattern. The flight tests confirmed the preceding recommendation [12].

Although the desired system is based on Ground Control Station (GCS), i.e., it can find the location of UAV by GPS or received RF signals; therefore, it can direct the helix to the UAV and track. In the other hand, the fast maneuvering of UAV around the Ground Station, especially in the time of taking-off and landing should be regarded; consequently, GCS can not follow UAV simultaneously and quickly. Moreover, UAV can be controlled visually, so omni-directional antenna can be utilized in the short ranges (less than 5 km). A RF switch can be utilized in GS Transceiver due to select the desired antenna electronically.

6. Conclusion

Design and implementation of Ground Station (GS) antennas have been presented to control UAV by use of data radio link between UAV and GS based on spread spectrum in bandwidth of 780-880MHz at the maximum range of 100Km. Helix and omni-directional antennas have been designed and implemented to cover short and long ranges with high reliability. Monopole antenna is used for short range—less than 5 Km. It has been designed, simulated and implemented. Measurements indicate monopole antenna has VSWR<2 in 780-880MHz frequency band. Vertical-plane HPBW is about 65°. The gain of monopole antenna is 2.5dB at the elevation angle of 40° and the loss is 2dB in the horizontal plane.

Helix antenna has been used to cover ranges more than 5Km to establish radio data link. It has been designed, simulated and matched to 50Ω in frequency bandwidth of 100MHz by new stub-loaded matching method. It has VSWR<2 in bandwidth of 100MHz. Radiation pattern of helix is endfire with the gain of 12.5dB in the direction of helix axis. HPBW in both of the elevation and azimuth planes are quite 32°. It is found that there are good agreement between Emerson’s relations and measurement.

According to the multipath effect and LOS relations, GS antennas should be installed at the height of 4m in regard to the UAV flying height. It is necessary to elevate helix axis up about 4° to compensate the ground effect on the radiation pattern. The flight tests confirmed the preceding hints.

7. References