Design and Implementation of Stub-loaded Helical Antenna for UAV Data Radio Link

Z. H. Firouzeh, A. Safari-Hajat-Aghaei, and H. MirMohammad-Sadeghi

***Abstract*— Full Duplex data radio link based on spread spectrum in frequency band of 780-880MHz between Ground Station (GS) and Unmanned Aerial Vehicle (UAV) has been implemented by use of stub-loaded helical antenna. 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. The helix has the gain of 12.5dB and circular polarization to cover the the maximum range of 100km. 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. 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.**

***Index Terms*— GS Antenna, Helical Antenna, and Multipath.**

I. 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. The UAVs can be controlled by GS or Satellite Station (SS) to perform their missions [1], [2].

GS Antennas 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 and to decrease fading and interference, 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 track the UAV and direct the antenna to it.

Firstly, it is presented the optimized design of the helix, and matched to 50Ω in frequency bandwidth of 100MHz by new stub-loaded matching method. The dimensions and position of optimum stub matching is obtained by IE3D simulator. Also, helix antenna specifications such as radiation pattern, gain, HPBW, VSWR, and Axial Ratio (AR) are calculated. The implemented antenna will be tested and measured. Finally, the appropriate height for installing of the antennas is recommended in regard to LOS relations and multipath problems due to cover the maximum range of 100km.

II. 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].

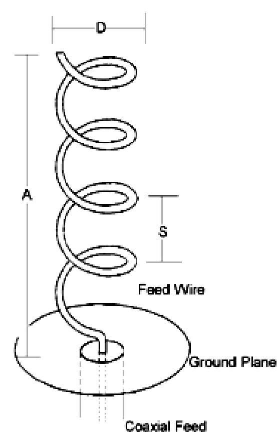

Fig. 1: The geometry of helix

The geometry of a helix has been depicted in Fig. 1. Helix radiates in two modes - normal and axial - on base of the ratio of circumference to wavelength. The axial mode has the maximum radiation at the direction of antenna axis. When the circumference of the helix is about one wavelength, the paraxial radiation is circularly polarized. Firstly, Kraus

Manuscript received December 11, 2006; revised January 7, 2007.

Z. H. Firouzeh is the research engineer of Information and Communication Technology Institute (ICTI), Isfahan University of Technology (IUT), 84154 Isfahan, Iran, Tel: (+98) 311 3912480, Fax: (+98) 311 3912481 (e-mail: zhfirouzeh@aut.ac.ir).

A. Safari-Hajat-Aghaei is the researcher of Information and Communication Technology Institute (e-mail: safari@icti.ir).

H. MirMohammad-Sadeghi is the researcher and the head of Communication Group of Information and Communication Technology Institute (e-mail: hamid@icti.ir).

introduced a few relations to calculate gain and HPBW of the helix, but the expected values were more than the real ones [3]. In 1980, King and Wong recommended the formula (1) to compute the gain according to the measurement [5].

$$G_P(dB) = 8.3\left(\frac{\pi D}{\lambda_P}\right)^{\sqrt{N+2}-1}\left(\frac{NS}{\lambda_P}\right)^{0.8}\left(\frac{\tan 12.5^o}{\tan\alpha}\right)^{\sqrt{N}/2} \qquad (1)$$

The parameters are N: number of turns, S: turn spacing, D: diameter of helix circumference, α: the pitch, and λ_P: the wavelength corresponding to the maximum gain. In 1995, Emerson proposed the relation (2) to predict the maximum gain for axial mode on base of numerical modeling [6].

$$G_{\max}(dB) = 10.25 + 1.22\overline{A} - 0.0726\overline{A}^2$$
$$\overline{A} = A/\lambda \qquad (2)$$

$\overline{A}$ is the normalized antenna length to the wavelength. It has the good accuracy to predict the gain, so we will use it to design the helix.

We would like to design the helix GS antenna at the center frequency of 830MHz for data radio link. It should have VSWR<2 (50Ω 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. 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 1.1λ for the circumference of the helix to have better performance.

According to [4]-[6] references, the number of turns and the dimensions of the desired helix antenna are as the following:

$$N = 13$$
$$S = 9.0\,cm \qquad (3)$$
$$D = 12.6\,cm$$

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^o but King & Wong's relations anticipate the gain of 14.4dB and the HPBW of 37^o. It is calculated 13.4dB gain based on Emerson's formulas.

The helical conductor diameter does not significantly affect the radiation properties of the helix and may range from 0.006λ and 0.05λ. 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 0.5λ 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 140Ω and 150Ω. With a suitable matching section, the terminal impedance can be made any desired value from less than 50Ω to more than 150Ω. 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-Ω helix impedance and a 50Ω 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. Fig. 2 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.

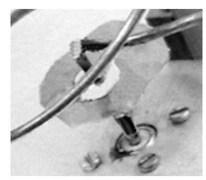

Fig. 2: The position of the circular stub

The designed helix is simulated by IE3D software to optimize the dimensions of helix and the location of the stub. The geometry of helix is depicted for simulation in Fig. 3. 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 obtained 45^o. Figures 4 and 5 illustrate far-field radiation patterns in vertical plane $\varphi = 0^o$ (XOZ) and azimuth plane $\varphi = 90^o$ (YOZ) at frequency of 830MHz, correspondingly. Both of radiation patterns are nearly similar; therefore, elevation and azimuth HPBW are equal to 31^o. The gain is computed 12.7dB. Fig. 6 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 Fig. 7, 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 value simulated in the direction of the helix axis. It is depicted AR is less than 1.8dB as shown in Fig. 8. The loss of plastic-cylinder structure is expected about 0.1dB.

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

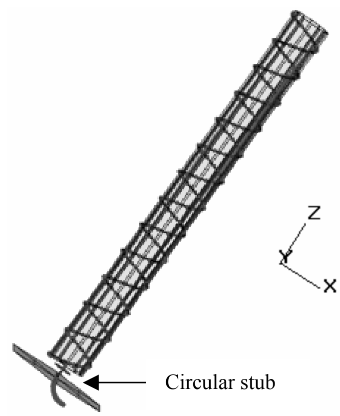

Fig. 3: Helix geometry simulated by IE3D software

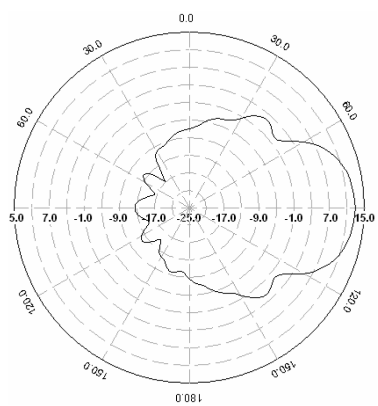

Fig. 4: Elevation-plane radiation pattern at 830MHz

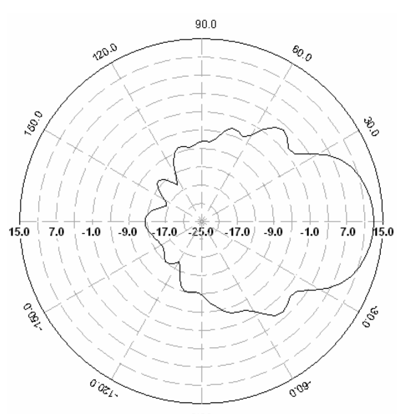

Fig. 5: Azimuth-plane radiation pattern at 830MHz

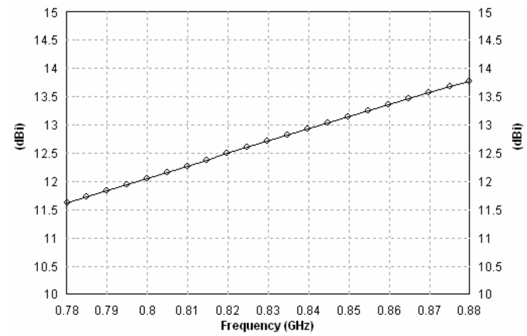

Fig. 6: Helix gain in frequency bandwidth of 100MHz

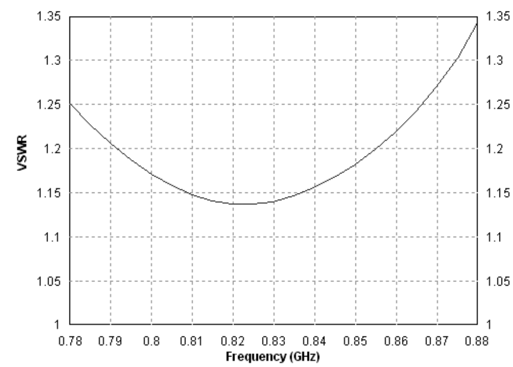

Fig. 7: Helix VSWR in frequency bandwidth of 100MHz

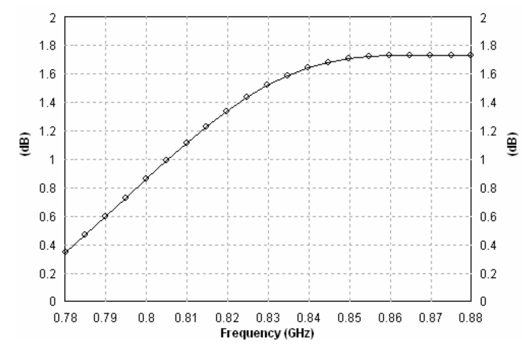

Fig. 8: Axial Ratio in the direction of helix axis

III. IMPLEMENTATION AND MEASUREMENT RESULTS

Helix was implemented according to the optimized dimensions as shown in Fig. 9. The angle of the first loop to connect to the feed rod relation to the ground plane is 45^{o} which is shown in Fig. 10. VSWR was measured by Network Analyzer. Fig. 11 indicates VSWR<2 in bandwidth of 100MHz and VSWR is 1.6 at 830MHz. Radiation pattern of helix was measured by open site method. The gain in the direction of helix axis is 12.5dB. Both elevation and azimuth HPBW are quite 32^{o}. It is found that there are good agreement between Emerson's relations and measurement. The antenna has the mechanical resistance against vibration and wind.

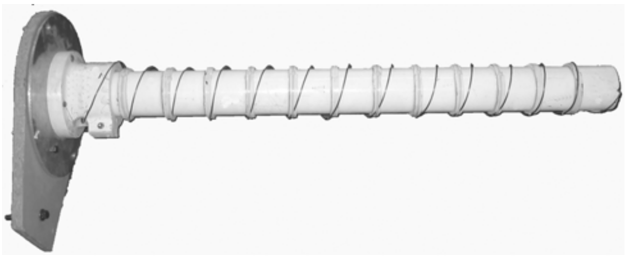

Fig. 9: Implemented helix antenna

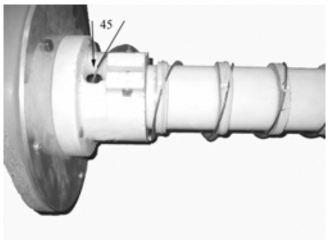

Fig. 10: Angle of 45° to connect the first loop to the feed rod

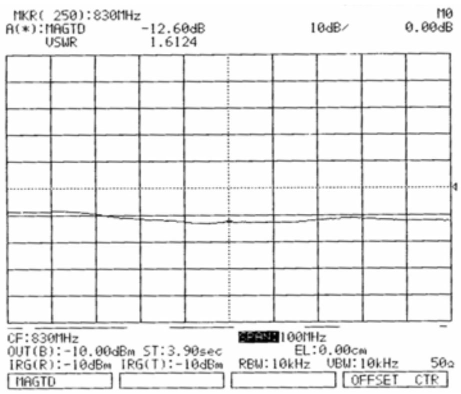

Fig. 11: Measured VSWR of helix antenna

IV. How to cover short and Long Ranges

Azimuth coverage of Helix is 360° and the maximum range is 100Km. Moreover, multipath effect and LOS rules should be regarded due to install GS antenna [10], [11]. In respect to the UAV flying height, it is recommended 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).

V. Conclusion

Design and implementation of stub-loaded helical antenna has 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. 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. Although helix can cover short and long ranges with high reliability, but Monopole antenna is preferred to cover short range – less than 5 Km.

According to the multipath effect and LOS relations, GS antenna 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.

References

[1] Munson K., *World Unmanned Aircraft*, JANE'S, NewYork, pp. 7-10, 1988.

[2] http://airtraffic1.stanford.edu/~uav/

[3] C.A. Balanis, Antenna *Theory, Analysis and Design*, John Wiley & Sins, 1997

[4] J.D. Kraus, *Antennas*, 2nd Ed., McGraw-Hill, 1988

[5] H. E. King & J. L. Wong, *Helical Antennas*, Chapter 13 of Antenna Engineering Handbook, 3rd Ed. L. Johnson, 1993

[6] Darrel Emerson, AA4FV, "The Gain of an Axial-Mode Helical Antenna", *The ARRL Antenna Compendium*, Vol. 4, 1995

[7] Robert S. Elliott, Antenna Theory and Design, John Wiley & Sons, revised Ed., 2003

[8] J. D. Kraus, "A 50-Ohm Input Impedance for Helical Beam Antennas", *IEEE Trans. Antenna Propagation*, Vol. Ap-25, No. 6, p.913, 1977

[9] *The ARRL Antenna Book*, The American radio Relay League, 15th Ed., 1988

[10] William C.Y. Lee, *Mobile Communications Engineering*, 2nd Ed., McGraw-Hill, 1997

[11] William C.Y. Lee, *Mobile Communications Design Fundamentals*, 2nd Ed., John-Wiley, 1993

[12] Z.H. Firouzeh, M.R Haji-hashemi, S.M. Moosavian, H. Mir-Mohammad Sadeghi, "Reduction of UAV body effect and Multipath fading in the high range of UHF radio link", *The 13th ICEE*, pp377-382, Zanjan University, May 2005

Z. H. Firouzeh was born in Isfahan, Iran, in1977. He received the B.Sc. degree in electrical engineering from Isfahan University of Technology (IUT), Isfahan, in 1999 and the M.Sc. degree in communications engineering from Amirkabir University of Technology, Tehran, Iran, in 2002.

He is currently a Research Engineer at Information Communication Technology Institute (ICTI) of IUT. So far, he has experienced in design and implementation of antenna, Radar, and wireless communication systems.

Also, he is a Ph.D. student in communications engineering at Amirkabir University of Technology. His research interests include antenna design and measurements, numerical techniques in electromagnetics, EMC/EMI, Radar scattering, wireless communications, and MMICs.

A. Safari-Hajat-Aghaei was born in Iran on August 31, 1971. He received the B.Sc. degree and the M.Sc in electronics engineering from Isfahan University of Technology (IUT), Isfahan, Iran in 1994, and in 2001, respectively.

He was the electrical and electronic equipments maintenance supervisor of Bandar Abbas Refinery Project, Bandar Abbas, Iran from 1995 to 1996.

Mr. Safari began to work in Information Communication Technology Institute (ICTI) of IUT. So far, he has experienced in design and implementation of analog and digital communication circuits and systems from base band to RF frequencies, such as wireless communication, solid state RF transmitters, low noise receiver front ends, signal generators & wide range frequency synthesizers, and high frequency modules (filters, amplifiers, mixers, detectors). Now he is the researcher and project manager at ICTI. My main interests are analog and digital systems design, satellite & mobile communications, FPGA/ASIC design, and instrumentation & control systems design.

H. MirMohamad-Sadeghi was born in Iran in 1964. He received the B.Sc. degree in electrical engineering from Isfahan University of Technology (IUT), Isfahan, Iran in 1987, and also the M.Sc in communication engineering in 1991.

He was a Graduate Teaching Assistant from 1987-1990 in Dept. of Elec. & Comp. Eng. of IUT, Research Engineer from 1987-1992 in Information and Communication Technology Institute (ICTI) of IUT, and Lecturer of Comp. Dept. of Sharif University of Technology from 1992-1994. In 1994, he joined of Isfahan University of Technology as a faculty member. Mr. MirMohamad-Sadeghi was the General Director of Information and Communication Technology Institute from 1994 to 2006 and he has been the Director of Communications Group of ICTI since 1994. His current research interests deal with Radar Technology, Communication Circuits & System Design, and Robotics.

Mr. MirMohamad-Sadeghi has been the recipient of numerous awards. During the periods of 2002 to 2005, he received Isfahan University Research Award because of lots of successful projects in Radar Technology, and Communication Systems areas. His team was the 3rd place winner of Robo Rescue, Robocup 2003 in Italy. Also, he was honored the 2nd award of 16th International Kwarizmi Award 2003, Iran.