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Low-Profile Helical Antenna for Space Application

F. Sadeghikia[1*] and A. Karami Horestani[2]

1, 2. Aerospace Research Institute, Ministry of Science, Research and Technology, Iran

*Postal Code: 1465774111, Tehran, IRAN

Sadeghi_kia@ari.ac.ir

The aim of this study is to examine the effects of diameter of ground conductor in an axial mode helical antenna on some of the characteristics of the antenna. It is shown that a proper ratio of diameter of ground plane to diameter of helix can be chosen to make a trade-off between the performance of helical antenna and its mass budget. It is shown through computational analysis that this optimum ratio is about 1.5. The results show that an increase in this ratio increases the mass budget, but it does not improve the antenna performance significantly. The simulation results also indicatethat this ratio is independent of the number of helix turns. After measurement, it was found that the simulation results of the antenna well agreed with its measured results acquired at the anechoic chamber.

Keywords: Axial mode helical antenna; Gain; Ground plane dimension, Space application

Numerical

D	Diameter
N	Number of helix turns a Pitch angle
D_g	Diameter of the circular flat ground
f	Frequency range
C	ircumference of the helix
R	Wire radius
Λ	wave length
HPBW	Half power beamwidth

Introduction

Helical antennas can be considered as the work horse of space communications, both on satellites and at ground stations. Helix antenna has different modes of radiation. Axial mode helical antennas are widely used in space communication systems due to their circular polarization and wide-band features. Generally, the radiation characteristics of a helical antenna and its input impedance can be controlled by changing the geometrical parameters of the antenna, including the helix diameter D, the ground diameter D_g, the pitch angleα, and the number of turns N [1].

Reducing the antenna dimensions is a critical design specification and is equally important for assessing other metrics including radiation characteristics [2-3]. Mass budget is one of the most critical limitations of any space vehicular system that directly impacts the launching requirements. In space applications, minimizing the physical dimensions of the antenna, while achieving optimal radiation characteristics, is highly desirable [4]. With the limited mass budget in space applications, a trade-off between the antenna characteristics such as gain and bandwidth and its physical size and mass is required.

The basic concept of axial mode helical antennas and the corresponding design equations were established by Kraus in 1947 [1]. However, comparisons with the computational and experimental results over the past decades have shown that the proposed design equations in the literature are not sufficient. As a result, many empirical equations and optimizations were proposed during the past seven decades to design and optimize helical antennas [4-10]. Many researchers have investigated the impact of the size and shape of ground conductor on the gain of antenna and its bandwidth [8-14]. In [14] the effect of size of ground plane onthe performance of helical antenna, especially its bandwidth, was examined. It has been reported that the widest bandwidth can be achieved when the diameter of ground plane equals the diameter of helix [14]. However, our experimental and numerical studies show that this ratio does not result in an optimum helical antenna neither in terms of bandwidth nore in terms of radiation gain.

1. Assistant Professor (Corresponding Author)
2. Assistant Professor

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It is important to put an extra emphasize on tight requirements in space applications, because in these applications very limited size and mass budget is applied. Thus,a compromise between the antenna radiation characteristics and its physical size and mass is necessary. Therefore, we believe more investigations are required to devise an efficient method to design a low profile helical antenna with optimum radiation characteristics and minimum mass budget for space applications.

A preliminary study on helical antennas was presented by the authors in [15].

The goal of this research is to more deeply investigate the effects of the ground conductor on some of the radiation characteristics, such as gain, bandwidth, front to back ratio, half power beam width (HPBW) and side lobe level (SLL) of an axial mode helical antenna and to make a trade-off between these parameters and the size and mass of the antenna for space application. Moreover, several antennas with different sizes of ground plane are fabricated and experimentally tested. It is shown that, based on the findings of the investigation, a low profile helical antenna with maximum gain can be designed. The proposed antenna is fabricated, and its radiation characteristics are experimentally measured.

The Antenna Structure

The geometry of an axial mode helical antenna is illustrated in Fig. 1.The antenna consists of a conductor wound in the form of helix with the parameters listed below in Table 1.The circumference of the helix is C=1.12λ, which is in the permitted range of circumference of an axial mode helical antenna (0.8 $<C/\lambda<1.2$) [1]. The input port of the antenna is well matched. The material considered for the antenna and its ground plane is copper. The feed point of the helix is at distance x = 0.8 cm from the center point of the ground plane. The ratio of the diameter of circular flat ground D_g to the diameter of helix D is considered to be in the range of 0.8 $<D_g/D<$ 3.4.

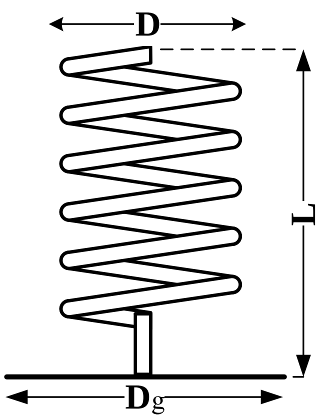

Fig. 1. Geometry of an axial mode helical antenna

Table 1. Main specifications of the antenna

Parameter	Quantity
Number of helix turns (N)	5.25
Pitch angle (α)	11.35°
Helix diameter (D)	8.4 cm
Diameter of the circular flat ground (D_g)	0.8 $<D_g/D<$3.4
Frequency range (f)	0.93 GHz $<f<$ 1.63 GHz
Center frequency	1.28 GHz
Circumference of the helix (C)	1.12λ
Wire radius (r)	0.2 cm

Parametric Study

Study on the ground section

Numerical investigation on the diameter of circular ground plane and its impacton the radiation characteristics of antenna are presented in this section. In the computational analysis, the dimensions of helix are kept constant and the diameter of ground plane is changed. The gain of the antenna for different values of D_g / D,inafrequency band between 0.8 to 1.6 GHz,is shown in Fig. 2. The radiation gain shown in this figure is computed in the axial direction of the helix. It is observed in this figure that the maximum gain gradually increases with increasing the D_g/D ratio, while the sensitivity of the gain plots to the frequencydecreases. Clearly, the helix with the largest ground conductor has the highest gain.

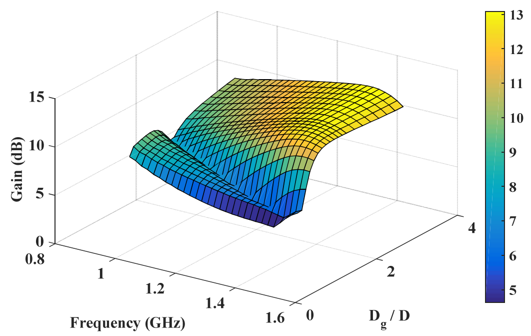

Fig. 2. Axial gain versus frequency of a helical antenna for different D_g/D ratios

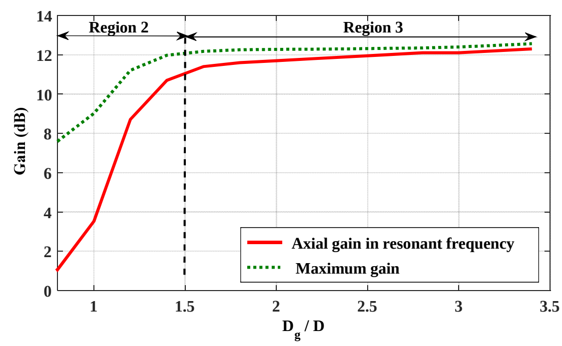

Fig. 3. Gain versus D_g/D ratio of a helical antenna

Figure 3 shows the effect of the D_g/D ratio on the axial gain (solid line) and the maximum gain (dashed line)at the center frequency of$f$ = 1.28 GHz.Two distinct regions are observed in this plot. In the first region, increasing the D_g/D ratio between 0.8 and 1.5 increases antenna gain drastically which demonstrates that ground dimension impacts the gain of antenna significantly. In the second region ($1.5<D_g/D<3.4$), the gain still increases, but ata much slower rate.Moreover, the figure shows that the D_g/Dratio also changes the maximum gain. However, the changes are not significantfor$D_g/D>1.5$. From these observations it can be concluded that $D_g/D=1.5$ is an optimum ratio whichresults in anacceptable gain in the axial direction.

It is important to note that, as shown in Fig. 3, increasing the ratioDg/D from 1 (which is suggested in [14]) to 1.5, results in about 7dB increase in the radiation gain of the antenna. Also, note that further increase in the ratio Dg/D to 3 (i.e. doubling the diameter) increases the radiation gain only by 1dB. This, shows that while an optimum bandwidth can be achieved by setting Dg/D = 1, the optimum point to achieve maximum radiation gain, while minimizing the size and mass of the antenna is to set Dg/D = 1.5.

Variations of the front-to-back ratio of the simulated helix versus frequency for different ratios of D_g/D are illustrated in Fig. 4. The front to back ratio shows the ratio of power gain in the forward direction to that ration in the backward direction. At the ratios above 1.5($D_g/D>1.5$), the front to back ratio gradually increases which is desirable in helical antenna design.

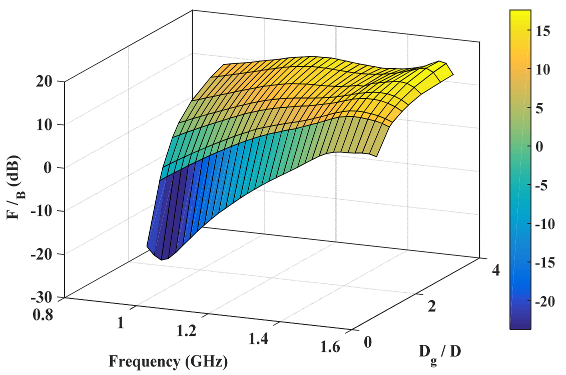

Fig. 4. Front to back ratio versus frequency of a helical antenna for different D_g/D ratios

To study the effect of dimensions of ground plane on operating bandwidth of antenna, the permitted axial ratio is considered to be between 0dBi and 3dBi when the maximum radiation is along the axis of the antenna. This polarization bandwidth sets the range over which the antenna operation is approximately circularly polarized.Percent bandwidth is defined as$200 \times \frac{f_H - f_L}{f_H + f_L}$.

The results of these studies are summarized in Fig. 5. This figure shows the effect of varying the D_g/D ratio on the operating bandwidth and gain of helical antenna. Both bandwidth and gain graphs have the same trend.The bandwidth is ranging from 26% to 58% when D_g/D varies between 1 and 3.4. However, the rate of variation of the bandwidthdecreasesforD_g/D >1.5. The simulated bandwidth is 48%forD_g =1.5 D.Note that this result is different from the conclusionin [14]. This difference may be due to the narrow-band quarter-wavelenght impedance transformer that is used in the helical antenna in that work.

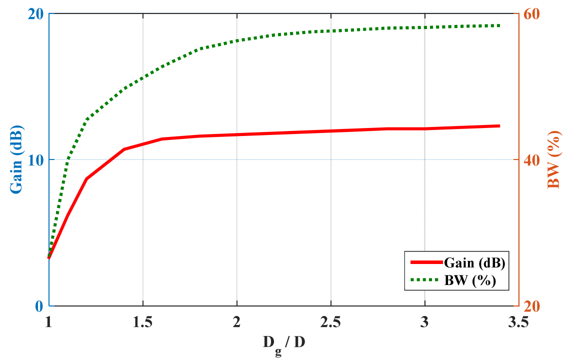

Fig. 5. Gain and bandwidth of a helical antenna versus D_g/D ratio

Fig. 6 depicts the variations of the half-power beam width (HPBW) and side lobe level (SLL) of the antenna when D_g/Dratio is changed between 1 and 3.5. The figure shows that thereis an inverse relationship between the antenna HPBW and sidelobes. It is shown that while the maximum HPBW is achieved when $D_g \cong 1.5\ D$, SLL is inversely proportional to the size of ground plane, attaining its minimum value when the ratio of $D_g/D$is maximized (D_g/D= 3.4 in this study).

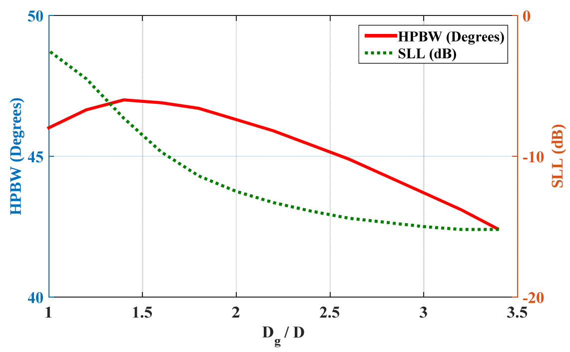

Fig. 6. The 3 dB beamwidth and sidelobe level of a helical antenna versus D_g/D ratio

In summary, from the simulation results shown in Figs. 5 and 6 it can be concluded that the helix with the largest ground plane has the highest gain and bandwidth as well as the smallest *SLL,* while its beamwidth is not optimum. However, note that increasing the diameter of the ground plane increases the physical size and mass of the antenna, which is not desirable especially in space applications. Considering that the gain and bandwidth of the antenna reach a saturation level for D_g /D=1.5, it can be concluded that D_g/D=1.5 is an optimum point to compromise the antenna mass and radiation characteristics.

Study on the helical section

To investigate the impact of the helical parameters on the conclusion made in the previous section, Fig. 7 shows the radiation gain of the antennaversus the ratioD_g/D for different number of helix turns,N. The figure shows that all gain curves demonstrate the same trend, andD_g /D=1.5 is an optimum ratiofor the antennas with different turns.

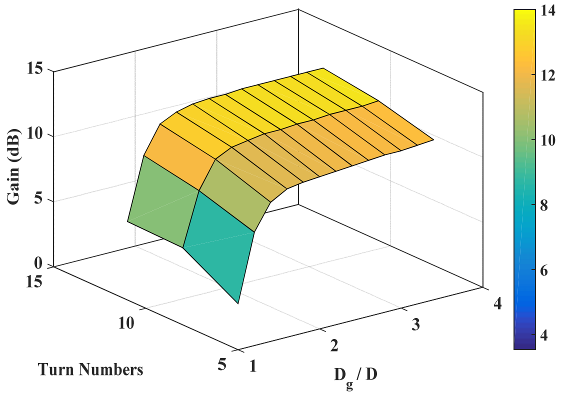

Fig. 7. Gain versus D_g/D ratio for different numbers of helix turns

Measured Results

To validate the proposed conclusions of the previous section, a realized axial mode helical antenna with a copper ground plate is fabricated with the dimensions shown in Table1. Two other prototypes with the same dimensions, but one with a ground diameter of D_g / D = 2 and the other with D_g / D = 3 are also fabricated and measured as shown in Fig. 8. Table 2 shows the measured gains of all three prototype antennas in the axial direction. It can be observed that the measured gains follow the simulated data quite well. Both the numerical and experimental results show that increasing the D_g / D ratio results in an increase in the maximum gain of the antenna. However, the gain improvement is not significant. Thus,D_g / D = 1.5 can be considered as the optimum ratio, especially when the size and mass of the antenna is a concern.

Table 2. Axial gain of the antenna at the center frequency

D_g / D	Simulation gain	Measured gain	Measured HPBW	Simulated HPBW
3	12.1 dB	11.97 dB	44.1°	43.9°
2	11.7 dB	11.27 dB	44.7°	46.3°
1.5	11.0 dB	10.27 dB	47.5°	47°

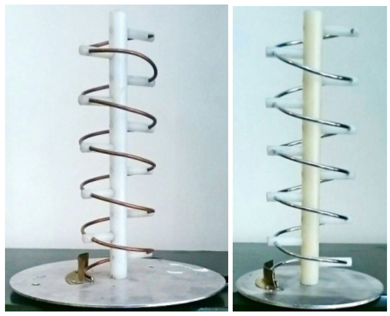

Fig. 8. Photograph of fabricated prototypes of helicalantenna

Conclusion

In this investigation, the effects of the size of ground plane of an axial mode helical antenna on its radiation characteristics, namely, its gain, bandwidth, HPBW and SLL havebeen studied. It has been shown that for D_g / D,the gain and bandwidth of an axial mode helical antenna are almost linearly proportional to the dimensions of antenna ground plane,sothat an increase in the diameter of ground plane results in an increase in both gain and operating bandwidth of antenna. However, further enlarging the ground plane has a negligible effect on the gain and bandwidth of the antenna. It has also been shown that the largest HPBW is achieved when the diameter of the ground plane equals 1.5 times the diameter of the helix. Another extremely important factor in the antenna design, especially in the space applications, is the very limited mass budget associated with the antenna system. Thus, it is highly desirable to achieve satisfactory radiation characteristics while having compact size antennas. To this end, a trade-off has to be made between the required radiation characteristics and mass budget limits. This goal can be achieved if the diameter of ground conductor of 1.5 times the diameter of the helix is chosen.The numeric results and conclusion havebeen validated by the fabrication and experimental measurement of several prototypes of the antenna. Good agreement between measurement and simulation results has been observed.

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