Novel Mode Conversion Technique of Helical Antenna using Cavity

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ABSTRACT
The condition for axial mode operation in helical antenna according to the classical design data is the helix circumference to wavelength ratio (C/λ) must be in a range of 0.8 to 1.2. In this paper the C/λ ratio is reduced to 0.2 for the wavelength 125 mm. It is achieved by loading the helix in a back cavity. The design concept of helical resonator filter is used for design of this antenna. If the same helix is used with 0.75 λ ground plane it operates in normal mode.

General Terms
Measurement, Performance, Design, Theory

Keywords
Helical antenna, normal mode, axial mode, helical resonator, quarter-wave transformer

1. INTRODUCTION
The helical antenna is an antenna consisting of a conducting wire wound in the form of helix. In most cases, helical antenna is mounted over a ground plane. It can be operate in two types of mode normal and axial. For axial mode operation according to the classical design data [1] [2], the helical antenna operates in the axial mode for the circumference to wavelength ratio ($0.8 < C/\lambda < 1.2$). The normal mode is supported if the length of the helix is small compared to the wavelength of operation.

The helical antenna can be used for satellite communication and for the aircrafts. The main disadvantage of helical antenna for the aircraft application is the shape and size of the helix which may affect the aerodynamic property of the aircraft; to solve this problem the helix is loaded in the cavity so that it can be inside the plane surface and will not affect the aerodynamic properties of aircraft.

The antenna can be consider as the band pass filter. For the compact size the concept of helical resonator is used for the design of helical loaded cavity backed antenna.

A helical resonator is a passive electrical component that can be used as a filter [3] as shown in Figure 1. Physically, a helical resonator is a wire helix surrounded by a square or cylindrical conductive shield. Like cavity resonators, helical resonators can achieve Q factors in the range of 1000s [4]. This is because at high frequencies, the skin effect results in most of the current flow on the surface of the helix and shield. Plating the shield walls and helix with high conductivity materials increases the Q beyond that of bare copper.

The length of wire is one quarter of the wavelength of interest. The helix is space wound; the gap between turns is equal to diameter of the wire.

2. HELICAL LOADED CAVITY BACKED ANTENNA DESIGN
For resonator with a circular cross-section the following set of equations are given [3]. The Inductance per axial inch is given by

$$L = 0.025n^2d^2\left[1 - \left({}^{d}/_{D}\right)^2\right]\mu H \qquad (1)$$

Where-
L is the equivalent inductance of the resonator in μH per axial inch.
D is the mean diameter of the turns in inches.
D is the inside diameter of the shield in inches.
N=1/τ is turns per inch, where τ is the pitch of the winding in inches.
The capacitance per axial inch is given by

$$C = \frac{0.75}{\log_{10}\left({}^{D}/_{d}\right)}\ pF\ per\ axial\ inch \qquad (2)$$

These equations are valid only for following conditions

$$\frac{b}{d} = 1.5$$

$$0.4 < \frac{d_0}{\tau} < 0.6$$

$$\frac{d}{D} = 0.55$$
$$\tau < \frac{d}{2} \quad (3)$$

Where-
b is the axial length of the coil in inches.
d_0 is the diameter of the conductor in inches.

2.3 The Axial Length of Coil

The axial length of coil is approximately equivalent to the a quarter wavelength. This actual length is much shorter than the free-space length, which is given by the expression-

$$\frac{\lambda}{4} = \frac{c}{4f_0} \quad (4)$$

Where-
c is speed of light in free space and
f_0 is operating frequency

The actual length of the coil in inches can be express by the following equation

$$b = \frac{250}{f_0\sqrt{LC}} \quad (5)$$

Where- f_0 is resonant frequency in megacycles per second.

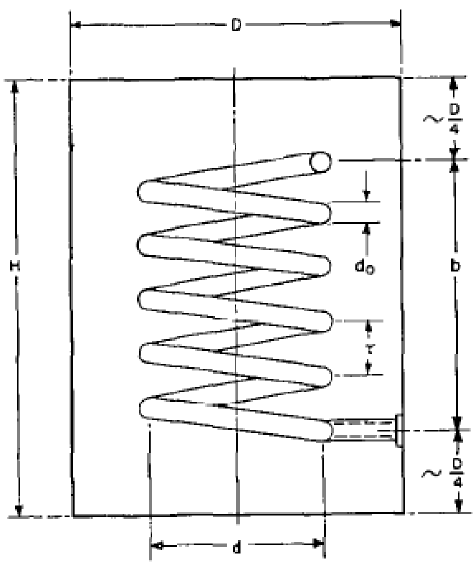

Figure 1 Helical resonators with circular cross section as helical loaded cavity backed antenna

This expression is base on theoretical consideration, but a working equation can be found with the help of the following expression

Wave velocity

$$v = f_0\lambda = \frac{2\pi\,RAD}{2\pi\sqrt{LC}} = \frac{1000}{\sqrt{LC}} \quad (6)$$

Because of the fringing effect and self capacitance of the coil, the electrical length of the coil is approximately 6% less than the quarter wavelength. The empirical value of b is reduced by 6% and is given by-

$$b = \frac{235}{f_0\sqrt{LC}} = \frac{0.94\lambda}{4} = 0.235\lambda \quad (7)$$

2.4 Outer Diameter of the Turns

We have condition

$$\frac{b}{d} = 4 \quad (8)$$

Outer diameter of the turns

$$d = \frac{b}{4} = \frac{0.235\lambda}{4} = 00588\lambda \quad (9)$$

2.5 The Inner Diameter of the Shield

The inner diameter of the shield

$$D = \frac{d}{0.45} = 0.131\lambda \quad (10)$$

2.6 The Number of Turns per Inch

The number of turns per inch is obtained by substituting equation (1) and (2) in equation (7)

$$\frac{1}{\tau} = n = \frac{1720}{f_0 bd}\left[\frac{\log_{10}\left(D/d\right)}{1-\left(d/D\right)^2}\right]^{1/2} \quad (11)$$

From the calculated values of b, d and D

$$\frac{1}{\tau} = n = \frac{2412.754}{\lambda} \quad (12)$$

2.7 The Total Number of Turns

The total number of turns is given by-

$$N = nb = \frac{1720}{f_0 D\left(d/D\right)}\left[\frac{\log_{10}\left(D/d\right)}{1-\left(d/D\right)^2}\right]^{\frac{1}{2}} \quad (13)$$

2.8 The Diameter of the Conductor (d_0)

$$0.4 < \frac{d_0}{\tau} < 0.6 \quad (14)$$

2.9 The Calculated Parameters for Centre Frequency of 2.4 GHz

The design parameters of helical loaded cavity backed antenna for centre frequency of 2.4 GHz are as follows-

The helix axial length (b=0.235λ) is 30 mm
The outer diameter of helix (d=0.0588λ) is 8 mm
The internal diameter of cavity (D=0.131λ) is 17mm
The inner height of cavity (H=0.3λ) is 41 mm
The number of terns (N=nb) is 1.64
The pitch of the helix (τ=1/n) is 18 mm
Number of terns per mm (n=2412754 λ) is 0.0546
The diameter of conductor of helix (d_0=0.4τ) is 8.9 mm

As the diameter of conductor of helix (d_0) is 8.9 mm and the outer diameter of helix (d) is 8mm, it is not possible to locate a helix of thickness of 8.9mm in cavity diameter of 8mm. To solve this problem instead of cylindrical wire conductor the strip size conductor is used. Considering the circumference of the conductor (8.9*π) is 28mm the strip weight of 11mm and thickness of 3mm (11+11+3+3=28) is used. The minimum requirement of the conductor diameter must be more than ten times the skin depth.

3. CHARACTERISTIC IMPEDANCE OF HELICAL RESONATOR

The Characteristic Impedance of helix Resonator-

$$Z_0 = 1000\sqrt{\frac{L}{C}} = 183nd\left[\left(1-\frac{d}{D}\right)^2 \log_{10}\left(\frac{D}{d}\right)\right]^{\frac{1}{2}} \Omega \qquad (15)$$

By using this formula the Characteristic Impedance of helix Resonator Z_0 is 24.62Ω.

The Characteristic Impedance of helix Resonator does not match with 50Ω impedance of SMA connector, which is used for connecting the coaxial input signal to antenna. Now there is a need of the impedance matching system to match 50Ω impedance of SMA connector to 24.62Ω Characteristic Impedance of helix Resonator.

4. QUARTER-WAVE TRANSFORMER FOR IMPEDANCE MATCHING

Quarter-wave transformers are primarily used as intermediate matching sections when it is desired to connect two waveguiding systems of different characteristic impedance. As shown in figure 2. Examples are the connection of two transmission lines with different characteristic impedances, connection of an empty waveguide to a waveguide partially or completely filled with dielectric, connection of two guides of different width, height, or both, and the matching of a dielectric medium such as a microwave lens to free space. If a match over a narrow band of frequencies suffices, a single section transformer may be used. To obtain a good match over a broad band of frequencies, two three, or even more intermediate quarter-wave sections are commonly used.

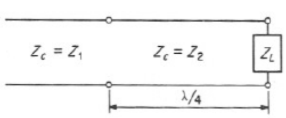

FIGURE 2
A quarter-wave transformer.

The essential principle involved in a quarter-wave transformer is readily explained by considering the problem of matching a transmission line of characteristic impedance Z_1 to a pure resistive load impedance Z_L as illustrated in Figure. If an intermediate section of transmission line with characteristic impedance Z_2 and a quarter wavelength long is connected between the main line and the load, the effective load impedance presented to the main line is

$$Z = Z_2 \frac{Z_L + jZ_2 \tan(\beta\lambda/4)}{Z_2 + jZ_L \tan(\beta\lambda/4)} = \frac{Z_2^2}{Z_L} \qquad (16)$$

If Z_2 is chosen equal to $\sqrt{Z_1 Z_L}$ then the $Z = Z_1$ and the load is matched to the main line. In other words, the intermediate section of transmission line of length λ/4 transforms the load impedance Z_L into impedance Z_1 and hence acts as an ideal transformer of turns ratio $\sqrt{Z_1 / Z_L}$. A perfect match is obtained only at that frequency for which the transformer is a quarter wavelength (or *nλ/2 + λ/4)* long.

Z_1= 24.62Ω, the impedance of antenna and the impedance of connector i.e. load is Z_L= 50 Ω. By using the above formula the impedance of quarter-wave transformer Z_2= 35.09 Ω. The length of quarter-wave transformer is λ/4, for 2.4 GHz frequency it is 31.25mm.

A commonly used substrate material is polytetrafluoroethylene (PTFE) which has a dielectric constant of 2.1 and a loss tangent of 0.0002 at 1MHz and around 0.0005 at microwave frequencies. This material has excellent resistance to chemicals used in the photo etching process. In order to increase the mechanical strength, it can be loaded with woven fiberglass mat or glass microparticles. This increases the dielectric constant to the range 2.2 to 3. The use of glass fiber results in some anisotropy in the dielectric constant. In the manufacturing process the glass fibers are generally aligned parallel with the substrate so the dielectric constant along the substrate is typically 5 to 10 percent larger than that normal to the substrate. By using ceramic powders as fillers, notably titanium oxide, much larger dielectric constants can be obtained. Typical values are in the range 5 to 15.

In this project for impedance matching the quarter-wave transformer is used. The transmission line is strip line; substrate material is polytetrafluoroethylene (PTFE) commonly known as Teflon which has a dielectric constant of 2.1 is used. The 3-D view is as follows.

5. RESULTS AND DISCUSSION

The helical antenna of 1.64 turns with 0.75 wavelength radiates in normal mode for center frequency of 2.4 GHz as shown in Figure 3. When the same helical antenna loaded in a cavity which is design on the basis of helical resonator filter, the antenna radiates in axial mode as shown in Figure 4. Many simulations were performed to examine the radiation characteristics of the radiation pattern of the Helical Loaded Cavity Backed Antenna. The 3-D modeling and simulation is done by using the SINGULA simulation software by Integrated Engineering Software. The fabrication of 60 mm rectangular base model is done in aluminum cavity and copper helix. The

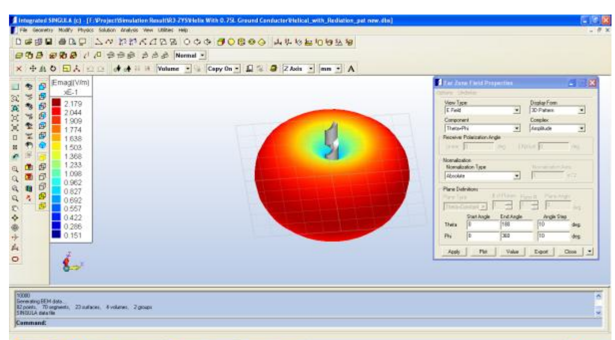

Figure 3 Radiation pattern of helix of 1.64 turns with 0.75λ Ground Plane

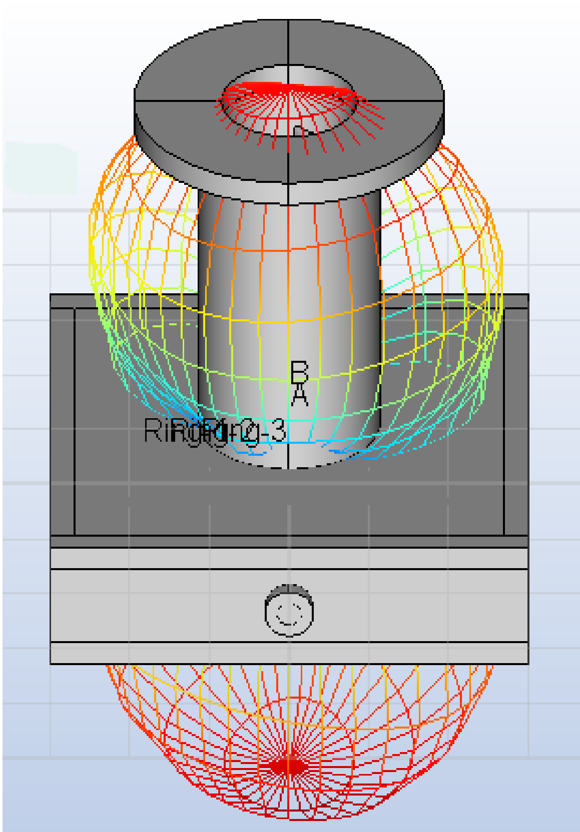

Figure 4 The radiation pattern of Helical Loaded Cavity Backed Antenna, 60 mm rectangular base

measurements were done for return loss, directivity and gain using RF vector network analyzer, Agilent N9923A mode.

For axial mode operation according to the classical design data the helical antenna operates in the axial mode in the frequency band where 0.8 <*C*/ λ <1.2 (*C* is circumference and λ is wavelength). For the center frequency 2.4 GHz (λ=125mm), the circumference of the helix should be 100mm< *C* <150mm but the circumference in this design is 25.13mm i.e. *C*/ λ is 0.2. For such smaller circumference the antenna operates in axial mode. The helix of 25.13mm circumference simulated with 0.75 λ ground conductor it radiates in normal mode. It is conclude by loading helix in cavity the mode of operation is change from normal mode to axial mode.

The gain of the antenna is moderate because the numbers of turns are 1.64 only. For axial mode operation according to the classical design data the helical antenna operates in the axial mode for more than 4 turns. If the number of turns increased the gain of the antenna will increase.

This antenna has only 1.64 turns which is unlike the conventional concepts of the helical antenna. The measured return loss S11=-15.30 dB for center frequency and 120 MHz is measured bandwidth of antenna. The Directive Gain of 5.55dB is achieved. The helix of 25.13mm circumference simulated with 0.75 λ ground conductor it radiates in normal mode.

The Quarter-wave transformer is used as intermediate matching section which matches the helix impudence of 24.62Ω to the 50Ω impedance of SMA connector.

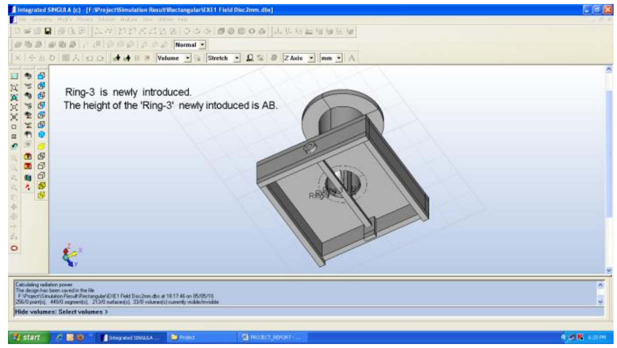

Figure 5 Internal structure of the Helical Loaded Cavity Backed Antenna

Figure 6 helical loaded cavity backed antenna, 60 mm rectangular base

6. CONCLUSION

The novel antenna that provides moderate gain and circular polarization over a wide bandwidth is simulated as shown in Figure 5. The fabrication and testing is done as shown in Figure 6. This new antenna occupies a much smaller volume. The size of the proposed antenna is reduced by a factor of 10, compared to a conventional helix. For axial mode operation according to the classical design data the helical antenna operates in the axial mode in the frequency band where 0.8 <*C*/ λ <1.2 for the center frequency 2.4 GHz the wavelength is (λ=125mm), the circumference of the helix should be 100mm< *C* <150mm but the circumference is 25.13mm i.e. 25% of minimum requirement. For such smaller circumference the antenna operates in axial mode.

The helix of 25.13mm circumference simulated with 0.75 λ ground conductor it radiates in normal mode. It is conclude by loading helix in cavity the mode of operation is change from normal mode to axial mode.

This antenna has only 1.64 turns which is unlike the conventional concepts of the helical antenna.

The reduced size of the proposed antenna by a factor of 10 to 17, compared to a conventional helix.

7. REFERENCES

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