Optimization and Performance Analysis of Spiro Helical Antenna Compared To Conventional Helix

V.APPALARAJU¹, S.ARUNA²

¹PG Scholar, Dept of ECE, Andhra University, Visakhapatnam, AP-India, E-mail: appalarajuvadaboyina@gmail.com.
²Asst Prof, Dept of ECE, AUCE (A), Andhra University, Visakhapatnam, AP-India, E-mail: aruna_ece@rediffmail.com.

Abstract: Helical antennas are most preferable antennas for getting the high gain and circular polarization over a wide band width. But here in this thesis create some modification in helical antenna to reduce the size and improving the gain, axial ratio, band width and VSWR by using doubly helical geometry. Which provides more gain and circular polarization but occupies volume ratio 2.5 to 3 times smaller than conventional helix having about the same radiation characteristics? This novel antenna is called Spiro Helical antenna. Based on simulation and measurement results indicate that the Spiro Helical antenna indeed provide high gain and circular polarization over wide band width finally the results are experimentally verified.

Keywords: Conventional Helical Antenna, Spiro Helical Antenna, Volume Ratio, Gain, Axial Ratio.

I. INTRODUCTION

A. Antenna Fundamentals

Radiation Pattern: Practically any antenna cannot radiate energy with same strength uniformly in all directions. It is found that the radiation is large in one direction while zero or minimum in other direction. The radiation from the antenna in any direction is measured in terms of field strength at a point located at a particular distance from the antenna. The field strength can be calculated by measuring the voltages at two points on the electric line of force and dividing the distance between the two points. units of radiation is volt/meter.

\[ \text{Normalized field pattern} = \frac{E_0(\theta, \phi)}{E_{\text{max}}(\theta, \phi)} \]

(1)

Radiation Intensity: the radiation intensity is defined as power per unit solid angle. It is expressed in W/Sr. The radiation intensity of an antenna

\[ U(\theta, \phi) = r^2 P_d(\theta, \phi) \]

(2)

The total power radiated can be expressed in terms of radiation intensity

\[ P_{\text{rad}} = \int_0^\pi \int_0^{2\pi} U(\theta, \phi) d\Omega \]

(3)

Directive Gain: The directive gain is defined as the ratio of the power density \( P_d(\theta, \Omega) \) to the average power radiated \( \frac{P}{P_{\text{avg}}} \)

\[ D = \frac{1}{(4\pi) \int_0^\pi \int_0^{2\pi} P(\theta, \phi) d\Omega} \left( \int_0^\pi \int_0^{2\pi} |P(\theta, \phi)|^2 d\Omega \right) \]

(4)

\[ D = \frac{4\pi}{\Omega_A} \text{ Directivity from beam area } \Omega_A \]

(5)

Antenna Efficiency: it is defined as power delivered to the antenna to the power radiated by the antenna

\[ \eta_r = \frac{P_{\text{rad}}}{P_{\text{rad}} + P_{\text{loss}}} \]

(6)

Effective Aperture: The effective aperture is the ability of antenna to extract energy from the electromagnetic wave. It is also called effective area

\[ A_e = \frac{P_{\text{received}}}{P_{\text{avg}}} \text{ m}^2 \]

(7)

Antenna Polarization: Polarization is nothing but physical orientation of electromagnetic wave in free space. Polarization of an electromagnetic wave describes the time varying direction and relative magnitude of the electric field vector. Thus conventionally; the polarization is described in terms of the electric field vector \( \mathbf{E} \). Polarization can be classified as linear polarization, circular polarization, elliptical polarization.

Linear Polarization: when the electric vector at any point in the free space is the function of time and if it is directed always along the line then the polarization is called linear polarization.

Elliptical polarization: The figure traced by the instantaneous electrical field vector is an ellipse, the field is said to be elliptically polarized field and the polarization is called elliptical polarization.

Circular Polarization: The instantaneous electric field vector traces a circle; the polarization is called circular polarization. In general, the electric field of a wave travelling
in the Z direction may have both a y component and an x component, with a phase difference \( \delta \) between the components, the wave is said to be elliptically polarized.

\[
E_x = E_1 \sin(\omega t - \beta z) \\
E_y = E_2 \sin(\omega t - \beta z + \delta)
\]

The ratio of the major axis to minor axis of the polarization is called the Axial Ratio (AR). If \( E_2 = E_1 \) and AR=1 and \( \delta = \pm 90^\circ \) then wave is called circular polarization.

II. CONVENTIONAL HELICAL ANTENNA

Helical antenna is basic simple broadband VHF and UHF antenna which provides circular polarization. It consists of a thick copper wire wound in the form of screw thread forming helix. Helix is a basic three dimensional geometric form. A helical wire on a uniform cylinder becomes a straight wire when unwound by rolling the cylinder on flat surface. Viewed end-on, a helix projects as circle. Thus, a helix combines the geometric forms of straight line, a circle and cylinder. In addition a helix has handedness, it can be either left or right handed.

\[
\frac{E_x^2}{E_1^2} + \frac{E_y^2}{E_2^2} = \sin^2 \delta
\]

For Gain Calculations,

\[
G = 15 \frac{C^2}{\lambda} nS \lambda
\]

For HPBW Calculations

\[
HPBW = \frac{52}{C \sqrt{nS} \lambda} \text{ degrees}
\]

For Axial Ratio

\[
AR = \frac{2n+1}{2n}
\]

III. SPIRO HELICAL ANTENNA

Helical antennas are always very better antennas for satellite communications because of their circular polarization and wide band width. In this thesis we proposed a new antenna with doubly helical geometry, which gives wide band width and better circular polarization but occupies volume 2.5 to 3 times smaller than a conventional helix, having about the same radiation characteristics. This novel antenna is called Spiro helical antenna. The main advantage of this antenna is we can easily construct by winding the primary helix on cylindrical structure of larger diameter. The primary helix has a radius \( a \) and pitch angle \( \alpha \). Once wrapped around a cylindrical surface of radius \( a \), the axis of the primary helix is transformed from a straight line into a helical curve of radius \( a + a' \) and pitch angle \( \alpha' \). It is now clear that a Spiro-helical antenna can be fully described by five parameters—two radii (\( a \) and \( a' \)), two pitch angles (\( \alpha \) and \( \alpha' \)), and the number of larger turns (\( N \)) on the cylinder of radius \( a \).

The Spiro-helical antenna is fed by means of a coaxial cable, with the inner conductor of the cable connected to the helix and the outer conductor becoming the ground plane. The idea of the Spiro-helical antenna was conceived to reduce the size of the conventional helical antenna, while maintaining the useful radiation characteristics such as circular polarization and wide bandwidth as shown in Fig.3. The conjecture that this geometry might result in size reduction originated from the fact that helical structures, such as those used in microwave tube amplifiers, exhibit slow wave properties. However, a slower propagation velocity corresponds to a smaller wavelength as implied from the relationship \( \lambda = \nu/f \), where \( f \) is the frequency. Thus, intuitively,
a helical antenna made of a spiral instead of a straight wire would allow smaller physical dimensions.

Fig.3. Spiro-helical antennas over a ground plane fed by a coaxial cable.

IV. PARAMETRIC EQUATIONS OF SPIRO-HELICAL ANTENNA

In order to facilitate the numerical analysis of the Spiro-helical antenna, a set of equations describing its geometry are needed. With the availability of these equations, the coordinates of an arbitrary point on the Spiro-helical structure are readily determined in terms of the parameters \( a \), and an axial dimension \( z_A \). Before embarking upon the derivation of equations for the Spiro-helical geometry, we first examine the parametric equations for a simple cylindrical helix, such as the primary helix with radius \( a \) and pitch angle \( \alpha \) shown in Figure 4. Furthermore, we use two sets of coordinates; namely the primed Cartesian coordinates \((x', y', z')\), and cylindrical coordinates for the geometry of primary helix, and the unprimed coordinates \((x, y, z)\) for describing the geometry of the doubly helical structure. The parametric equations of the primary helix are expressed as

\[
\begin{align*}
x' &= a' \cos \varphi' \\
y' &= a' \sin \varphi' \\
z' &= (a' \tan \alpha) \cdot \varphi'.
\end{align*}
\]

Once the primary helix is wound on a cylinder of radius \( a \) with a pitch angle as in Fig. 4b: the \( z' \) -axis assumes a helical shape of radius \((a+a_1)\). The parametric equations of the helically-shaped \( z_1 \)-axis, in analogy with (14), are expressed as

\[
\begin{align*}
x &= (a+a') \cos \varphi \\
y &= (a+a') \sin \varphi \\
z &= [(a+a')\tan \alpha] \cdot \varphi.
\end{align*}
\]

Next, let us consider an arbitrary point \( A \) on the \( z \)-axis in both primary helix (Figure 4a) and the Spiro-helical geometry (Figure 4b). The coordinates of this point are \( x, y, \) and \( z \) and in the Spiro-helical geometry are denoted as \( x_A, y_A, z_A \). The coordinate’s \( x_A, y_A, \) and \( z_A \) are related to each other through (figure 3.2). \( z_A \) can be determined in terms of \( z_A \) using the integral expression for length. That is,

\[
z'_A = \int_0^z \sqrt{(dx)^2 + (dy)^2 + (dz)^2} \\
= \int_0^z \left[ \left( \frac{dx}{dz} \right)^2 + \left( \frac{dy}{dz} \right)^2 + 1 \right]^{1/2} dz.
\]

Using chain-rule differentiation,

\[
\begin{align*}
\frac{dx}{dz} &= \frac{dx}{d\varphi} \frac{d\varphi}{dz} = \frac{(a+a')\sin \varphi}{\tan \alpha} = \frac{\sin \varphi}{\tan \alpha} \\
\frac{dy}{dz} &= \frac{dy}{d\varphi} \frac{d\varphi}{dz} = \frac{(a+a')\cos \varphi}{\tan \alpha} = \frac{\cos \varphi}{\tan \alpha} \\
\frac{dz}{dz} &= \frac{dz}{d\varphi} \frac{d\varphi}{dz} = \frac{(a+a')\tan \alpha}{\tan \alpha} \frac{d\varphi}{dz} = \frac{d\varphi}{dz}
\end{align*}
\]

and substituting in (20), yields

\[
z'_A = \int_0^z \frac{1}{\tan^2 \alpha} + 1 \right]^{1/2} dz
\]

\[
z'_A = \frac{z_A}{\sin \alpha}.
\]

Now, consider a point \( B \) on the primary helix such that \( z_B z_A \). The other coordinates of \( B \); namely, \( x_B \) and \( y_B \) are related to \( z_B \) through equations (21). We assume that the relations among primed coordinates remain locally valid after \( z' \)-axis is transformed into a helix. This assumption is valid if the shape of a single turn in the primary helix and in the spiro-helical structure remains the essentially the
same. Then introducing the vectors $\mathbf{AB}$, $\mathbf{OA}$ and $\mathbf{OB}$, we have

$$\mathbf{AB} = x'_y \hat{x} + y'_z \hat{y} \quad (22)$$
$$\mathbf{OA} = x_x \hat{x} + y_y \hat{y} + z_z \hat{z} \quad (23)$$
$$\mathbf{OB} = x'_y \hat{x} + y'_z \hat{y} + z'_z \hat{z} \quad (24)$$
$$\mathbf{OB} = \mathbf{OA} + \mathbf{AB} \quad (25)$$

And it can be shown, by inspection, that (without loss of generality it is assumed that the local $x'$-axis is perpendicular to the $z$-axis)

$$\hat{x}' = \cos \phi \hat{x} + \sin \phi \hat{y} \quad (26)$$
$$\hat{y}' = \cos \phi \hat{x} + \sin \phi \hat{y} \quad (27)$$
$$\hat{z}' = -\cos \alpha \hat{z} - \sin \alpha \sin \phi \hat{x} + \sin \alpha \cos \phi \hat{y} \quad (28)$$
$$\hat{z}' = \sin \alpha \hat{z} - \cos \alpha \sin \phi \hat{x} + \cos \alpha \cos \phi \hat{y} \quad (29)$$

Combining (23) through (29), yields

$$\mathbf{OB} = x'_y \hat{x} + y'_z \hat{y} + z'_z \hat{z}$$
$$= (x_x + x'_y \cos \phi - y'_z \sin \phi \sin \phi) \hat{x} + (y'_z \sin \phi + y'_z \sin \phi \cos \phi) \hat{y} + (z'_z \cos \alpha) \hat{z} \quad (30)$$

$$x = x_x = (a + a') \cos \phi + a' \cos \phi \cos \phi - a' \sin \phi \sin \phi \sin \alpha \quad (31)$$
$$y = y_y = (a + a') \sin \phi + a' \sin \phi \cos \phi + a' \cos \phi \sin \phi \sin \alpha \quad (32)$$
$$z = z_z = [(a + a') \tan \alpha - a' \sin \phi \cos \phi] \quad (33)$$

where, from (19)

$$\phi = \frac{z_x}{(a + a') \tan \alpha} \quad (34)$$

and from (22) and (18)

$$\phi' = \frac{z_y}{a' \tan \alpha \sin \alpha} \quad (35)$$

$z_A$ varies in the range $z_A$, $z_{A_{\text{max}}}$, where $z_{A_{\text{max}}}$ is the height of the Spiro-helical antenna. It is related to the number of turns $N$ (turns with the mean radius $a + a'$) according to the following relationship

$$z_{A_{\text{max}}} = 2\pi N (a + a') \tan \alpha \quad (36)$$

Equations (36) to (34) fully describe the geometry of Spiro-helical antennas. For Gain Calculations

$$G = \frac{\pi D}{\lambda_f} \left[ \frac{(n)^{\frac{1}{2}}}{\sin \theta} \right]^{0.6} \left[ \frac{\tan \theta_{12.5}}{\tan \alpha} \right]^{0.5} \quad (37)$$

For HPBW Calculations

$$\text{HPBW} = \frac{2\pi}{\lambda} \left[ \frac{n}{N + 5} \right]^{0.6} \left[ \frac{\tan \alpha}{\tan \theta_{12.5}} \right]^{0.5} \quad (38)$$

For Axial Raito

$$\text{AR} = \frac{1}{|L_A \sin \phi - (1/p)|} \quad (39)$$

For Volume Ratio

$$\text{Volume ratio} = \text{Spiro helical antenna volume} / \text{Conventional helical antenna}.$$
Optimization and Performance Analysis of Spiro Helical Antenna Compared To Conventional Helix

Fig. 7. Radiation pattern for no. of turns = 8.

Fig. 10. Radiation pattern for no. turns = 8.

TABLE I:

<table>
<thead>
<tr>
<th>Fig. no.</th>
<th>No. of turns</th>
<th>Ground loss</th>
<th>Spacing between</th>
<th>Le</th>
<th>Nr</th>
<th>Pitch angle</th>
<th>Axial ratio</th>
<th>ERPW</th>
<th>Directivity/dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>0.02</td>
<td>0.02</td>
<td>1</td>
<td>0</td>
<td>3.458</td>
<td>1.088</td>
<td>94.2</td>
<td>17403</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>0.003</td>
<td>0.003</td>
<td>1</td>
<td>0</td>
<td>3.458</td>
<td>1.088</td>
<td>94.3</td>
<td>17408</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>0.002</td>
<td>0.002</td>
<td>1</td>
<td>0</td>
<td>3.458</td>
<td>1.088</td>
<td>94.4</td>
<td>17409</td>
</tr>
</tbody>
</table>

B. Axial Mode Radiation Characteristics of Spiro Helical Antenna

Fig. 8. Radiation pattern for no. of turns = 6.

Fig. 9. Radiation pattern for no. of turns = 7.

C. Comparison of Gain of Spiro Helical Antenna with Conventional Helical Antenna

Fig. 11. Number of turns = 6.

Fig. 12. Number of turns = 7.

TABLE II:

<table>
<thead>
<tr>
<th>Fig. no.</th>
<th>No. of turns</th>
<th>Ground loss</th>
<th>Spacing between</th>
<th>Le</th>
<th>Nr</th>
<th>Pitch angle</th>
<th>Axial ratio</th>
<th>ERPW</th>
<th>Directivity/dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.02</td>
<td>0.02</td>
<td>0</td>
<td>1</td>
<td>3.458</td>
<td>1.088</td>
<td>94.5</td>
<td>17405</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.003</td>
<td>0.003</td>
<td>0</td>
<td>1</td>
<td>3.458</td>
<td>1.088</td>
<td>94.4</td>
<td>17408</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>0.002</td>
<td>0.002</td>
<td>0</td>
<td>1</td>
<td>3.458</td>
<td>1.088</td>
<td>94.4</td>
<td>17409</td>
</tr>
</tbody>
</table>
F. Axial Ratio For Helical Antenna For Different Values Of ‘a’ With Respect To Frequency

Input parameters:
a= 21, 16, 11 mm

G. Volume Ratio for Helical Antenna to Spiro Helical Antenna

Table III:

<table>
<thead>
<tr>
<th>Spiro helix turns</th>
<th>Conventional helix turns</th>
<th>Volume ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>8</td>
<td>2.88</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>3.6</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>3.6</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>3.09</td>
</tr>
<tr>
<td>7</td>
<td>13</td>
<td>3.34</td>
</tr>
<tr>
<td>8</td>
<td>14</td>
<td>3.15</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
<td>2.7</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

In this thesis, attention is focused on helical antennas which find important applications in communication systems, primarily because of their wide bandwidth and circular polarization. In satellite communication systems, propagation of radio waves through the ionosphere suffers Faraday rotation at some frequencies; thus circularly polarized waves would be desirable in order to maintain reliable data and information signal transmission. The wide bandwidth of helical antennas lies in the fact that they are of the traveling-wave type, while their circular polarization property may be attributed to their effective loop-dipole geometry. Study on helical antenna has been done intensively. Radiation pattern and its characteristics have been observed for different values of N, C and S using Mat lab software. A novel antenna that produces high gain and nearly circular polarization over a wide bandwidth and a broad beam width has been presented. This new antenna has radiation characteristics comparable to those of a conventional helix but occupies a much smaller volume.

The volume of a Spiro-helical antenna can be 2.5 to 3.21 times smaller than a conventional helix while preserving...
Optimization and Performance Analysis of Spiro Helical Antenna Compared To Conventional Helix

circular polarization and comparable gain and bandwidth. Axial-ratio characteristics have been computed for numerous cases. Axial ratio is more than 1, indicating elliptical polarization possible for the Spiro helix antenna. The gain increases with the number of turns for the Spiro helix antenna. The reduced size of the proposed antenna by a factor of 2.5 to 3, compared to a conventional helix with about the same radiation properties, and its low fabrication cost, makes this antenna very attractive to mobile and satellite communications and aerospace applications.

**Recommendations for Future Work:** Due to the fact that this antenna has not been previously researched, there are still many opportunities to learn more about it. The following is a list of suggestions for future investigations of the Spiro-helical antenna.

**Different Helical Shape:** The conventional helical shape determines the shape of the Spiro-helical investigated here, but the spiral wire can be used to create different overall geometries as well. The wire can be wound into a tapered helical antenna, a conical helical antenna, a spherical helical antenna, or any other number of designs. The tapered Spiro-Helical antenna is expected to offer wider bandwidths.

**Cavity Mounts:** No variation in ground plane has been evaluated in this thesis. A cavity mounted Spiro-helical antenna can be examined numerically and experimentally to further investigate the effect of this ground plane on radiation properties.

**Gain and Input Impedance Measurements:** The measurements conducted in this thesis were limited to far-field patterns only. Input impedance and gain measurements need to be performed to have a more realistic assessment of the performance of Spiro-helical antenna and its practical applications.

**VII. REFERENCES**