Chapter 7. **Helical Loaded Cylindrical Cavity**

**Back Antenna Array**
7.1 Introduction

In this chapter, a cylindrical cavity back helical antenna in array of 2×2 is designed and fabricated. A helix is placed in a cavity and parameters such as the helix diameter, helix turns, area of cross section of the helix element, cavity height and cavity diameter play a vital role in its reflection coefficient and antenna impedance. It has been proved in literature survey that the antenna characteristics such as radiation pattern, reflection coefficient and gain can be improved by building an array of the radiating elements placed such that the radiation pattern is additive. Hence, an array of helices placed in individual cavities is designed in a circular array, with a phase shifting method [66].

In an array, electrical size of the antenna is comparatively large so it takes a long period of time for simulation in the SINGULA simulation software. The array antenna design in this chapter and the next chapter is done by using the HFSS simulation software. The software includes post-processing commands for analyzing this behavior in detail. HFSS is a commercial finite element method solver for electromagnetic structures from ANSYS. The single cylindrical cavity loaded helical antenna is designed through various design options and finally the best performing cavity is considered for the array design. In the next section, single cylindrical cavity loaded helical antenna is discussed.

Fig. 7.1 Single cylindrical cavity helical loaded cavity back antenna.
7.2 Cylindrical Cavity Design

The essential parameters for the design of a Helical Antenna in a cavity are helix parameters and cavity parameters. Helix parameters include, design frequency \( f \), helix axial length \( b \) and Mean diameter of helix \( d \) while the cavity parameters include Inner height of cavity \( H \) and Internal diameter of cavity \( D \) as shown in Fig.7.1. These parameters can be calculated by using the boundary conditions (5.3) to (5.6). Based on these equations, various possible combinations for design parameters are made; all these combinations are designed and simulated. Table 7.1 shows some of the possible combinations for designs. These combinations will help in determining the best design concerning the required parameters.

Table 7.1 Design variations for a cylindrical cavity.

<table>
<thead>
<tr>
<th>Design No.</th>
<th>Helix Axial Leng. ( (b) )</th>
<th>Helix Dia. ( (d) )</th>
<th>Wire Dia. ( (d_0) )</th>
<th>Cavity Dia. ( (D) )</th>
<th>Turn Spacing ( (\tau) )</th>
<th>Ratio</th>
<th>Turns per inch</th>
<th>No. of Turns</th>
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<td>0.22</td>
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<td>0.41</td>
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<td>22</td>
<td>1.6</td>
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Based on the values of ‘b’, ‘D’ and ‘d₀’ a range of values were found for the Helix diameter ‘d’, turn spacing ‘τ’ and number of turns ‘N’ parameters. For each value combination, different simulations are lead. Thirty eight design simulations are done for variation in number of turns and helix diameter. Based on the design parameters, the values of 18 design parameters were considered for a cylindrical cavity design. The Helix diameters are \( d = 14.69 \) mm, 16.32 mm and 18.35 mm were selected and reflection coefficient was plotted as shown in Fig. 7.2, 7.3 and 7.4 respectively. It is also shown in Table 7.2 for comparison purpose. It is noted that a better reflection coefficient is obtained when the number of turns of the helix is taken as ‘two’.

Table 7.2 Simulated results of reflection coefficient of cylindrical cavity.

<table>
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<tr>
<th>Design No.</th>
<th>Frequency (GHz)</th>
<th>2.0</th>
<th>2.1</th>
<th>2.2</th>
<th>2.3</th>
<th>2.4</th>
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<td>-2.36</td>
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<td>-4.72</td>
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<tr>
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<td>-2.19</td>
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<td>4</td>
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<td>-0.55</td>
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<td>16.32</td>
<td>3</td>
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<td>-3.57</td>
<td>-4.11</td>
<td>-2.09</td>
<td>-0.27</td>
<td>-1.52</td>
</tr>
<tr>
<td>17</td>
<td>18.36</td>
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<td>-2.85</td>
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The highest reflection coefficient at 2.4 GHz frequency is -4.93 dB for 14.69 mm helix diameter and for two turns of helix. Out of 18 designs, three designs were selected based on their comparatively better reflection coefficient plots. Those three designs were made into arrays, and the results were compared. With each design different findings were obtained. Efforts were taken to reduce the size of the cavity. In the next section, the cavity array of 2×2 is discussed.

Fig. 7.2 Reflection coefficient (dB) for helix diameter 14.69 mm in a cylindrical cavity.

Fig. 7.3 Reflection coefficient (dB) for helix diameter 16.32 mm in cylindrical cavity.
7.3 Cylindrical Cavity 2×2 Array Design

Design 5 of Table 7.2 is given satisfactory results, and different array combinations are made with it. The basic design structure had two types of feeding methods, Plus-type feeding method and H-type feeding method, which are shown in Fig 7.5. The H-type feeding method did not work out efficiently, so most of the designs were made with the Plus-type feeding method.

Fig. 7.5 Feeding techniques, (a) Plus-type feed and (b) H-type feed.
Moreover, after deciding the dimensions of the cavity and the helix, the distance of the helix feed from the centre was equated. After many combinations of trial, it was seen that the best performance of the total antenna is obtained when the total feed distance from the centre is calculated as $\lambda/4$. This feed distance is the summation of the centre feed, the distance between the main feed and the radiating element, and the height of the radiating element from the base.

To avoid use of the quarter wave transformer, various combinations were tried to do the impedance matching of the helix and cavity. Instead of a wire conductor, a strip conductor is used for the helix. Cross section area of the conductor is increased, which causes impedance to get compatible with that of the coaxial feed of 50 $\Omega$. Different strip heights varying from 6 mm to 10 mm were implemented and widths were altered as 1 mm, 1.5 mm and 2 mm. Various designs were implemented and the reflection coefficient and design specifications are shown in Table 7.3.

![Simulation design of the helical loaded cavity back antenna in 2x2 array.](image)

Fig. 7.6 Simulation design of the helical loaded cavity back antenna in 2x2 array.
Table 7.3 Design comparison table of the designed and simulated results.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Design and Parameter</th>
<th>Reflection Coefficient Graph</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Feed length = 22.5mm, Feed spacing = 2mm, Helix: ( d=14 \text{mm}, N=1.5, \tau=14 \text{mm} ), Strip = 1.5x6mm, Cavity: ( D=40 \text{mm}, H=56 \text{mm} ).</td>
<td>![Reflection Coefficient Graph 1]</td>
</tr>
<tr>
<td>2</td>
<td>Feed length = 24.075mm, Feed spacing = 4.5mm, Helix: ( d=14 \text{mm}, N=2, \tau=14 \text{mm} ), Strip = 2x6mm, Cavity: ( D=36 \text{mm}, H=56 \text{mm} ).</td>
<td>![Reflection Coefficient Graph 2]</td>
</tr>
<tr>
<td>3</td>
<td>Feed length = 24.075mm, Feed spacing = 4.5mm, Helix: ( d=14 \text{mm}, N=2, \tau=14 \text{mm} ), Strip = 2x8mm, Cavity: ( D=24 \text{mm}, H=50 \text{mm} ).</td>
<td>![Reflection Coefficient Graph 3]</td>
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<th>Reflection Coefficient Graph</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Feed length = 24.075mm, Feed spacing = 4.5mm, Helix: $d=14\text{mm}$, $N=2$, $\tau=14\text{mm}$, Strip =1x8mm, Cavity: $D=36\text{mm}$, $H=56\text{mm}$</td>
<td><img src="image1.png" alt="Graph" /></td>
</tr>
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<td>5</td>
<td>Feed length = 24.075mm, Feed spacing = 4.5mm, Helix: $d=14\text{mm}$, $N=2$, $\tau=14\text{mm}$ Strip =1x8mm, Cavity: $D=36\text{mm}$, $H=50\text{mm}$</td>
<td><img src="image2.png" alt="Graph" /></td>
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<td>6</td>
<td>Feed length = 24.075mm, Feed spacing =4.5mm, Helix: $d=14\text{mm}$, $N=2$, $\tau=14\text{mm}$ Strip =1x8mm, Cavity: $D=36\text{mm}$, $H=56\text{mm}$</td>
<td><img src="image3.png" alt="Graph" /></td>
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<th>Reflection Coefficient Graph</th>
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</thead>
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<td>7</td>
<td>Feed length = 24.075mm; Feed spacing = 4.5mm Helix: (d=14\text{mm}, N=2, \tau=14\text{mm}) Strip =1x6mm Cavity: (D=36\text{mm}, H=56\text{mm}).</td>
<td>![Reflection Coefficient Graph 1]</td>
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<tr>
<td>8</td>
<td>Feed length = 24.075mm, Feed spacing = 4.5mm, Helix: (d=14\text{mm}, N=2, \tau=14\text{mm}) Strip =2x8mm, Cavity: (D=24\text{mm}, H=50\text{mm}).</td>
<td>![Reflection Coefficient Graph 2]</td>
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<td>9</td>
<td>Feed length = 24.075mm, Feed spacing = 2mm, Helix: (d=14\text{mm}, N=2.5, \tau=14\text{mm}), Strip =2x6mm, Cavity: (D=24\text{mm}, H=50\text{mm}).</td>
<td>![Reflection Coefficient Graph 3]</td>
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<td>Feed length = 24.075mm, Feed spacing = 2mm, Helix: $d=14\text{mm}$, $N=2$, $\tau=14\text{mm}$ Strip =1×6mm, Cavity: $D=24\text{mm}$, $H=50\text{mm}$</td>
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<td>12</td>
<td><strong>H type feed</strong> Feed length = 31mm, Feed spacing = 2mm, Helix: $d=8\text{mm}$, $N=2$, $\tau=14\text{mm}$ Strip =1×6mm, Cavity: $D=40\text{mm}$, $H=54\text{mm}$</td>
<td><img src="image12" alt="Reflection Coefficient Graph" /></td>
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<td>Feed length = 15mm, Feed spacing = 2mm, Helix: $d=14\text{mm}$, $N=2$, $\tau=14\text{mm}$ Strip =1x8mm Cavity: $D=28\text{mm}$, $H=60\text{mm}$</td>
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<td>Feed length = 15mm, Feed spacing= 3mm, Helix: $d=14\text{mm}$, $N=2$, $\tau=14\text{mm}$ Strip =1x8mm, Cavity: $D=24\text{mm}$, $H=60\text{mm}$</td>
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<td>Feed length = 15mm, Feed spacing = 2mm, Helix: $d=14\text{mm}$, $N=3$, $\tau=14\text{mm}$ Strip =1x10mm Cavity: $D=24\text{mm}$, $H=60\text{mm}$</td>
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<td>Feed length = 15mm, Feed spacing = 1mm, Helix: (d=14)mm, (N=2.5), (\tau=14)mm, Strip =1×10mm, Cavity: (D=28)mm, (H=60)mm</td>
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<tr>
<td>17</td>
<td>Feed length = 15mm, Feed spacing = 1mm, Helix: (d=14)mm, (N=2.5), (\tau=14)mm, Strip =1×10mm, Cavity: (D=24)mm, (H=60)mm</td>
<td><img src="image2.png" alt="Graph 2" /></td>
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<tr>
<td>18</td>
<td>Feed length = 15mm, Feed spacing = 1mm, Helix: (d=14)mm, (N=2), (\tau=14)mm, Strip =1×10mm, Cavity: (D=24)mm, (H=60)mm</td>
<td><img src="image3.png" alt="Graph 3" /></td>
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</table>
18 different helical loaded cavity back antenna in 2×2 array is designed by variation in the array parameters, cavity parameters and helix design parameters. The feed length and feed spacing are the array parameters. Cavity internal diameter \((D)\) and cavity internal height \((H)\) are cavity parameters. Helix diameter \((d)\), number of turns \((N)\), turn spacing \((\tau)\) and strip dimension are the helical antenna parameters. All these parameters with their specific values are shown in Table 7.3.

The poor matching is seen in design 1 to design 12 because these designs are the part of process how final design is achieved by variation in cavity parameters. The design 13 to design 18 has array feed length of 15 mm, cavity internal diameter of 24 mm, cavity internal height of 60 mm, the helix mean diameter as 14 mm and copper strip size of 10×1 mm. Except design 14, which has a strip size of 8×1 mm. There is a variation in the number of turns of the helix loaded in the cavity and feed spacing. The spacing between the array feed line and cavity bottom is considered as feed spacing that is shown in Fig 7.7.

The design 14 has a three-turn helix with a strip size of 8×1 mm and feed spacing of 3 mm. The bandwidth of 1.6 GHz (66.67 %) is observed from 2.4 GHz to 4.00 GHz. The band is shifted towards the higher frequency. By changing the feed spacing as 2 mm, in design number 15, the bandwidth of 0.5 GHz (20.83 %) from 3.3 GHz to 3.8 GHz is achieved. Again, the band is shifted towards the higher side of frequency.

![Fig. 7.7 Feed spacing in helical loaded cavity back 2×2 antenna array.](image)
In design 17 two and half turn helix with 1 mm, feed spacing gives a bandwidth of 0.9 GHz (37.5 %) from 2.9 GHz to 3.8 GHz. The frequency band is shifted towards the lower side of the frequency, but still it is not including 2.4 GHz as the centre frequency. In design number 18, two-turn helix with 1 mm feed spacing, gives the bandwidth of 1.0 GHz (41.67 %) from 2.1 GHz to 3.1 GHz. The bandwidth of this design can be further improved by increasing the feed spacing.

The designs considered for fabrication had the simulation bandwidth of 2.24 GHz (93.33 %) from 1.56 GHz to 3.80 GHz. Such a large bandwidth is achieved by increasing the feed spacing. It is the array design of the two-turn helix, helix mean diameter of 14 mm and copper strip size of 10×1 mm. The cavity internal diameter of the 24 mm and cavity internal height of 60 mm, array feed length of 15 mm with 3 mm feed spacing. Fig. 7.8 shows the simulation frequency band comparison between 2.24 GHz band design with design 14.

The helical loaded cavity back antenna in 2×2 array is fabricated in an aluminium cavity and a two turn copper helix as shown in Fig. 7.9. The size of the array is 75×75×63 mm. Hence, the electrical size of array is with a height of 0.5λ and length of 0.6λ. The distance between the two cavities is λ/4. Phase rotation technique is used while designing an array wherein each helix is rotated by 90° so that the losses due to
interference are minimized and circular polarization performance can be improved. Plus-feed is implemented for the array feed. Each element in the 2×2 array was placed such that its radiation pattern is additive.

Fig. 7.9 Helical loaded cavity back 2×2 antenna array of helix diameter 16 mm and cavity diameter 28 mm (a) top view (b) front view.

Fig. 7.10 Reflection coefficient measurement setup for helical loaded cavity back 2×2 antenna array.
7.4 Results and Discussion

A novel design of helical loaded cylindrical cavity back 2×2 array antenna is designed and fabricated in aluminium cavity and two turn copper helix. The reflection coefficient measurement setup and measured bandwidth is shown in Fig. 7.10 and Fig. 7.11. It can be seen that the resonance is obtained at 2.478 GHz with a reflection coefficient of -31.86 dB. The measured bandwidth of the array is 2.45 GHz (102.08%) frequency range is from 1.46 GHz to 3.91 GHz. Agilent Technologies N9912A spectrum analyser of frequency range from 2 MHz to 6 GHz is used for the bandwidth measurement. The simulation bandwidth of 2.24 GHz (93.33 %) from 1.56 GHz to 3.80 GHz is observed. Measured bandwidth is higher than the simulation bandwidth. The simulation gain of the antenna is observed as 10 dB at 2.4 GHz frequency, which is shown in Fig. 7.12.

In the design of this antenna, length of the strip, the diameter of the helix and the number of turns of the helix are very important. Change in a few millimetres in the dimensions has caused a huge difference in the radiation pattern and the resonant frequency.

![Fig. 7.11 Measured reflection coefficient (dB) of helical loaded cylindrical cavity back 2×2 array antenna.](image-url)
The feed is a 50Ω coaxial cable SMA connector. A helical array can be formed by positioning the helices such that the fields from the elements add in some directions and cancel in others. This design proposed for the helices sequential rotation technique is used to improve the circular polarization performance of the antenna. In this technique, $90^0$ rotations are given to each element of the array. The radiation pattern of the antenna array is shown in Fig. 7.13.

The power handling capacity of the helical loaded cylindrical cavity back $2\times2$ array antenna is calculated from the maximum electric field. The maximum electric field is $2.1587\times10^4 \text{ V/m}$ for input power of 1 W as can be seen in Fig. 7.14. If the vacuum state is maintained in the feed system and assuming the breakdown threshold is $50 \text{ MV/m}$ under vacuum condition [23], the power handling capacity for this feed system could reach $(50 \times 10^6/2.1587 \times 10^4)^2 = 5.3648 \text{ MW}$. In another case taking the breakdown threshold to be $3 \text{ MV/m}$ in the atmosphere then this array has a power handling capacity of $(3 \times 10^6/2.1587 \times 10^4)^2 = 19.3134 \text{ kW}$ in the atmosphere.

![Gain (dB) plot of helical loaded cylindrical cavity back $2\times2$ array antenna at 2.4GHz frequency.](image)

Fig. 7.12 Gain (dB) plot of helical loaded cylindrical cavity back $2\times2$ array antenna at 2.4GHz frequency.
Summary

It is observed that a helix behaves differently when it is inserted in a cavity made up of aluminium conductor. Its characteristics are closer to a resonator. It is a compact size conformal 2×2 array with the height of 0.5λ and length of 0.6λ. The measured bandwidth of array is 2.45 GHz (102.08%) from 1.46 GHz to 3.91 GHz and simulation bandwidth of 2.24 GHz (93.33 %) from 1.56 GHz to 3.80 GHz is observed. Measured bandwidth is higher than the simulation bandwidth. The simulation gain of antenna is observed as 10 dB at 2.4 GHz frequency. The maximum power handling capacity of
array antenna was $5.3648 \, MW$ in vacuum and which dropped down to $19.3134 \, kW$ in the atmosphere. The power handling capacity of array antenna is high.

The effect of cavity height, diameter and strip height also influence the reflection coefficient. It is seen that as the strip height increases from 8 mm to 10 mm, the reflection coefficient changes. The input feed types are also altered namely ‘plus’ type and ‘H’ type and are applied to the design out of which a ‘plus’ type of feed was used which gave better results in context of reflection coefficient and radiation pattern. A phase rotation technique has been used in the array so that the radiation pattern is mutually additive and losses due to interference can be minimized. This is an exemplary design, through which a helical antenna that has advantages like circular polarization and resistive impedance was confirmed by inserting it in a cylindrical cavity. This has applications in aircrafts where not only antenna characteristics but also the aerodynamic properties matter the most.