

Demonstration of Helical Antenna Stability beyond C-Band Frequency

Rahul Yadav, VinitKumar Jayprakash Dongre

Departement of Electronics & Telecommunication Engineering, Mumbai University, India

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ABSTRACT

The paper demonstrates design of helical antenna to achieve stable frequency response and impedance matching beyond C-band microwave frequency. An impedance matching cavity is developed for excitation of higher order modes along with the fundamental mode in the helical antenna. Triple frequency bands are resonated by loading the designed helical antenna inside the cavity and a dual band response is realized by introducing variation in feed pin height with an incremental offset of 0.1λ to the initial height which is taken as 0.2λ . The broadband gain for all the designs and a detail analysis of modes along the helical antenna loaded in rectangular cavity is reported. A highest measured bandwidth of 5.4 GHz and a peak gain of 10.65 dB is obtained. The antenna being compact and conformal in design may find its application for terrestrial, aerospace communication and personal wireless communication.

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Corresponding Author:

Rahul Yadav

Departement of Electronics & Telecommunication Engineering,

Thakur College of Engineering & Technology, Mumbai University,

Shyamnarayan Thakur Marg, Kandivli (E), Mumabi-400101, India

Email: ryrahul Yadav01@gmail.com, dongrevinit@gmail.com

1. INTRODUCTION

The helical antenna was first introduced by J.D. Kraus in 1946 and it is one of the most common antennas used for Satellite communication. Another feature as discussed in [1]-[5] which makes the helical antenna more demanding is its power handling capacity. But the limitation in helical antenna arrived when the existing equations and proof given by Kraus and other authors in [6] showed that the stability in helical antenna is only limited to WLAN and C-band frequencies and its response becomes unstable for higher range of frequencies. So a demand arises to demonstrate and develop helical antenna that can still be operated for higher range of frequencies. The conventional helical antennas have generally a single resonant mode [7]-[8]. However in [9], the higher order mode can be realized by modifying the ground plane and geometry of the helical antenna. Although the helical antenna is a three dimensional entity whose modes are characterized by the half wave sine variation along x, y and z axis, for simplicity the modes can be reduced to TM_{mn} by observing the wavelength variation in x and y direction from top view.

The paper presents a design of 1½ turn's cavity backed rectangular helical antenna which shows a stable frequency response below -10 dB. Copper material is used in the implementation of helix and the cavity is fabricated using aluminum metal. The designed 1½ turn's helical antenna is then loaded inside the cavity. The loading of helical antenna inside the cavity makes the design conformal in nature and suitable to be used for aero dynamical applications [10]-[11]. The designed cavity which backs the helical antenna acts as a modified ground plane and thus helps to confine the near field electric vector. A tunable multiband response is realized by varying the orientation of helix with respect to the walls of cavity. The effect of variation in height of feed pin on frequency range is also reported here. The modes along the helical antenna are analyzed by plotting the resonance curve and current distribution at the respective resonant frequency. A

comparative analysis for the plot of reflection coefficient and gain is also done for understanding complete behavior of helical antenna inside the cavity.

2. THEORY & DESIGN APPROACH

A $1\frac{1}{2}$ turn's helical antenna is designed with rectangular configuration as shown in Fig.1. The conventional design of helical antenna in [12] explains that to have proper circular orientation of electric fields, the helix should have atleast three turn and for that its circumference (C) should be in between 0.75λ - 1.33λ . However a critical range for the number of turns can be maintained as $1\frac{1}{2}$ if the near field can be confined with proper orientation. Now with the decrease in helical turns, there is possibility that the higher modes may not be excited but this can be accounted by modifying the antenna ground plane which is discussed in section 2.1. The pitch angle of helix has been kept as 14 degree and the diameter and height of helical antenna are calculated as;

$$C = \pi.d \quad (1)$$

$$H = N.S \quad (2)$$

Where, d-diameter, H-height, S-spacing, N-number of turns

The parametric values of helical antenna are illustrated in Table1. It is important to note that the helix geometrical configuration plays an important role in the efficient radiation mechanism and impedance matching. The rectangular configuration is choose so that a non-uniform current distribution along the helical length can be obtained which will thus help to excite multiple bands. So a rectangular helix of strip width of 2mm and thickness of 1mm is taken.

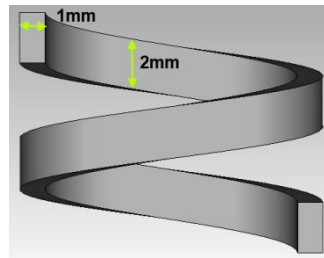


Figure 1. Helix geometrical configuration

Table 1: Parametric values of helical antenna

Sr. no	Parameters	Values (mm)
1	Circumference	31.4
2	Diameter	10
3	Height	7.5

2.1. Desing and analysis of Impedance matching cavity and Helix Loading

To demonstrate a stable response of helical antenna at higher range frequencies, a rectangular cavity has been designed as shown in Fig.2a. Assuming $13.6 \text{ GHz} \pm 1.4 \text{ GHz}$ as the critical range of frequency, the cavity height is calculated as 20mm from inner dimension and the ground base as $(24 \times 24) \text{ mm}$ which are function of operating wavelength.

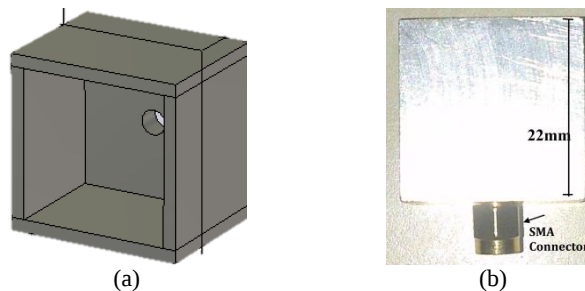


Figure 2. Cavity design (a) Perspective view (b) Font view of fabricated cavity

It is important to note that the higher range of frequency has been selected only to achieve impedance matching with respect to the helix and excitation. Figure 2b shows that a standard 50Ω SMA connector is used for the excitation of helical antenna.

The modelled and fabricated design of cavity backed 1½ turns helical antenna is shown in Fig.3. The location of feed pin is chosen at the center of the ground base to provide uniform reflection of near field electric vector from the cavity walls which then excites higher order modes in the antenna along with the fundamental mode. The designed helical antenna is loaded inside the rectangular cavity with the intension of achieving helix mode of propagation form normal to axial. A detail analysis of cavity backed helical antenna being with investigation of inductance and capacitance per axial inch. The rectangular cavity which is acting as a resonator here has enclosings in all the directions except the direction of propagation. The inductance and capacitance per axial inch is given by [13],

$$L \approx 0.025n^2d^2[1-(d/W)^2]\mu H \quad (3)$$

$$C \approx \frac{0.75}{\log_{10}(W/d)} pF \quad (4)$$

Where d- diameter of helix, W-width of ground base
Equation 1-2 are valid only if

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

$$0.4 < \frac{d}{W} < 0.5$$

It is important to note that the impedance matching cavity inner dimensions can also be calculated as;

$$W = \frac{d}{0.41} = 0.8\lambda \quad (5)$$

Next to achieve manual reconfigurability of multi-band response, the helical antenna is rotated about its axis from 0° and 45° position in anticlockwise direction as shown in Fig.4. Rotations at all other odd angles will provide similar results since the design of cavity is symmetrical about x-axis and y-axis. It can be seen from Fig.4a-b that as the orientation of helix is varied with respect to the walls of cavity, the parameter spacing between the cavity wall and helix changes and this will lead to increased reflection of electric fields inside the cavity which eventually excited hihger order modes.

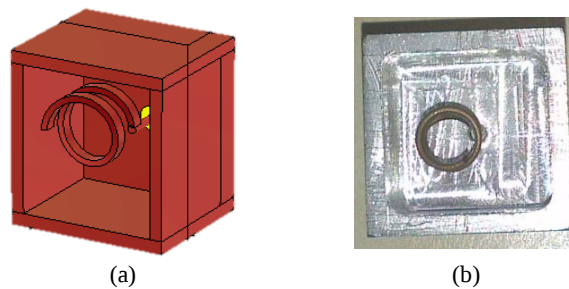


Figure 3. Cavity backed Helix (a) simulated perspective view (b) implemented top view

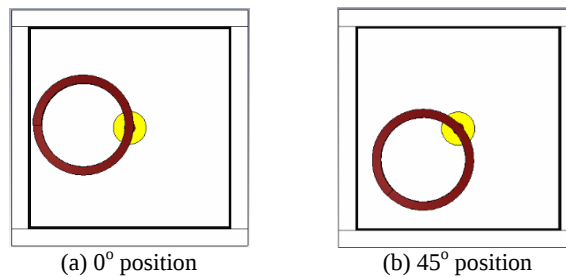


Fig. 4 Helical antenna rotation inside the cavity

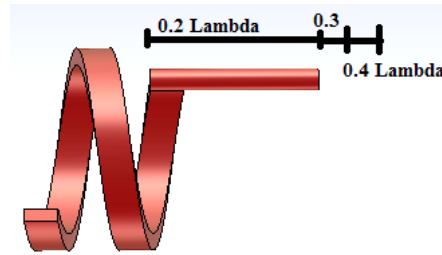


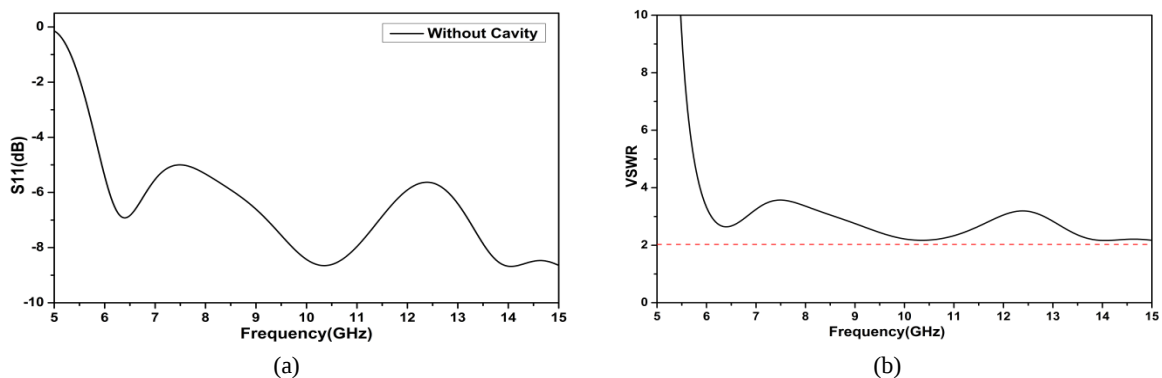
Figure 5. Pin height variation

Later to investigate the effect of variation in feed pin height which is initially kept as 0.2λ , the height is incremented with an offset of 0.1λ as shown in Fig.5. The increase in feed pin height increases the antenna physical dimension and thus a frequency response is achieved for both higher and lower frequency range. The next section discusses the results of helical antenna with and without cavity, impact of variation in the orientation of helix with respect to the walls on frequency response, and increase in feed pin height along with the investigation of modes with cavity loading.

3. RESULTS AND DISCUSSION

To investigate the effect of cavity which backs the helical antenna, initially a helix is simulated without the use of rectangular cavity so that a comparative analysis can be made. Simulations are performed using Computer Simulation Tool (CST microwave studio) which uses Finite Integral Technique to solve to electromagnetic problem. The boundary conditions which play an important role in the numerical analysis are kept as open space around the antenna and a range of 5-15GHz find the highest frequency of resonance. Figure 6a shows the plot of reflection coefficient (S_{11}). It is observed that since the helical turns are too low, the antenna result of S_{11} is not below -10dB and from Fig.6b, it explains that the VSWR is not below 2 indicating that there is no impedance matching in helical antenna for higher range of frequencies and the resonant modes are too weak. However these can be improved by loading the $1\frac{1}{2}$ turn helical antenna in a rectangular cavity resonator.

The results for cavity loaded helix are shown in Fig.7. Triple frequency bands are resonant when the helix is at 0° position as shown in Fig.7a which taken as the reference position of helix with respect to the cavity walls. These frequency bands are at 7.23 GHz, 10.7 GHz, and 14.17 GHz with a bandwidth of 610 MHz, 528 MHz and 956 MHz respectively. It is observed that at 0° position of helix, the spacing between antenna and cavity decreases which leads to more reflections of electric fields from the cavity wall and thereby exciting three different resonant frequencies. The strong reflections of electric field from the walls provide an excellent reflection coefficient of -49.8 dB at 7.23 GHz. This shows that the helical antenna is now operating well for higher range of frequencies. Similarly at 45° position as shown in Fig.7b, a triple band response is realized at 11.54 GHz, 13.74 GHz, and 14.52 GHz with a bandwidth of 940 MHz, 453 MHz and 1.35 GHz respectively. However at 45° since the reflection of fields is now from the corner of the walls, therefore its results in less value of resonance compared to 0° position. The comparative plot of voltage standing wave ratio for all the position as shown in Fig.7c shows that the results are well within the acceptable range of VSWR and expressing a degree of impedance matching. The plot of resonance curve in Fig.7d for all even angles has three peaks which interprets that the higher order modes are also excited in the antenna. Similar is the case for 45° position of helix in inside the cavity.

Figure 6. Plot of helix without cavity (a) Reflection coefficient (S_{11}) (b) Voltage standing wave ratio (VSWR)

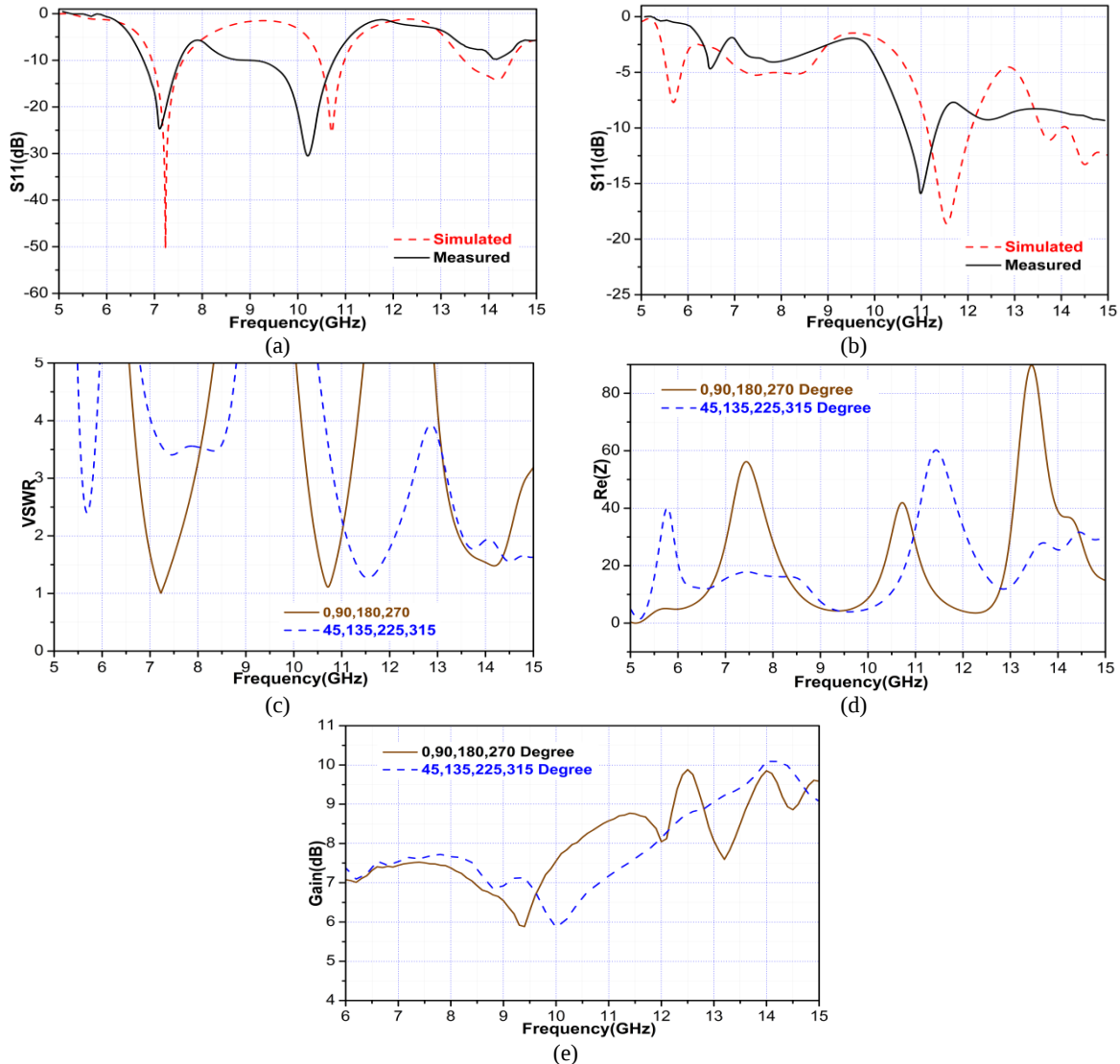


Figure 7. Plot of cavity Backed helix (a) S_{11} at $0^\circ, 90^\circ, 180^\circ, 270^\circ$ position (b) S_{11} at $45^\circ, 135^\circ, 225^\circ, 315^\circ$ position (c) Comparative VSWR at all positions (d) Comparative resonance curve at all positions (e) Comparative gain at all positions

A comparative plot of broadband gain for cavity backed helix is shown in Fig.7e. It is found that the peak gain at all even angle ($0^\circ, 90^\circ, 180^\circ$ & 270°) is same which 9.9dB and at all the odd angles ($45^\circ, 135^\circ, 225^\circ, 315^\circ$), the peak gain is 10.1dB. This is due to the even symmetry followed by the design in 'x' and 'y' direction. The more confinement of electric fields at odd angle position of helix lead to higher gain compared to even angle position of helix.

The mode numbers are found [14]-[16], by obtaining the current distribution of helical antenna at each resonant frequency. Figure 8 shows the current distribution of helical antenna at each resonant frequency at 0° position. Since the geometry of antenna is three dimensional, it is difficult to realize the mode along each of the co-ordinate axis. However we can analyze it by examining the dominant area of current distribution and the orientation of current vector along the helical antenna. The mode number 'P' is always one here because in z-direction the dominant current is observed along the helix feed pin. Therefore for 0° position of helix inside the cavity at f1-TM₂₁₁ mode, at f2-TM₄₂₁ mode and at f3-TM₃₀₁ mode is observed. Similarly at 45° , TM₁₁₁, TM₂₁₁ and TM₃₂₁ modes are observed at the respective resonant frequency as shown in Fig.7b.

Now with the achievement of stable response in helical antenna with cavity loading, the effect of variation in helical antenna feed pin height is investigated as it plays an important role in the impedance matching at higher range of frequencies. It is found that as the height of feed pin increase, this put an increase in the overall antenna geometry and thus the band shifts accordingly to higher and

lower range of frequency.

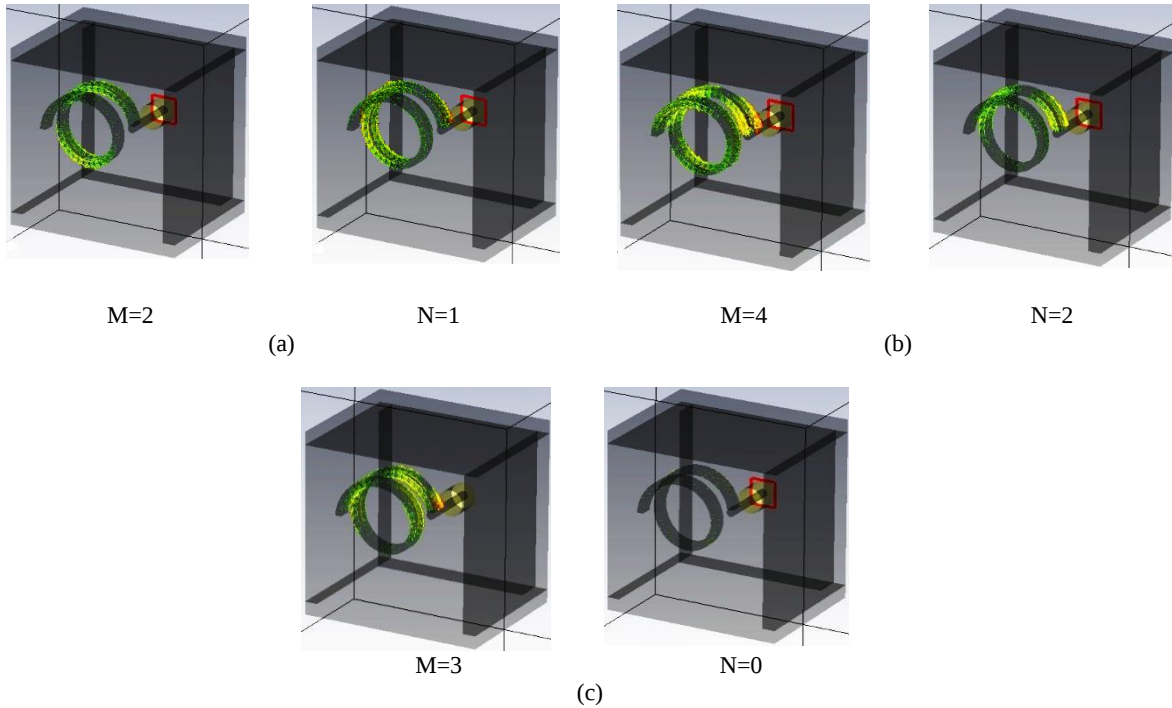


Figure 8. Surface current at (a) $f_1 = 7.23$ GHz (b) $f_2 = 10.7$ GHz (c) $f_3 = 14.17$ GHz

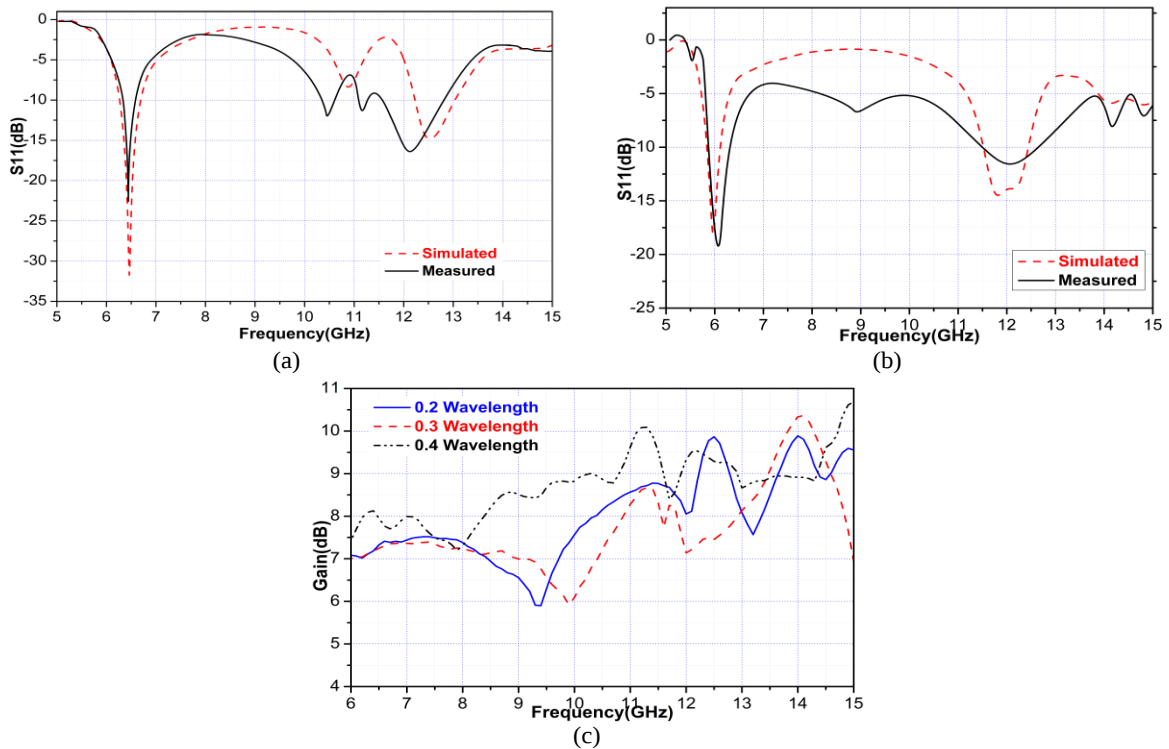


Figure 9. Comparative plot for variation in feed pin height (a) S_{11} for 0.3λ (b) S_{11} for 0.4λ (c) Gain

Figure 9a-b shows the shifts in frequency bands subjected to variation in feed pin height. The increment in feed pin height by an offset of 0.1λ from the reference height which was 0.2λ shows that for 0.3λ dual frequency bands are resonated at 6.46 GHz, 12.54 GHz and for 0.4λ the dual frequency bands are resonated at 5.97 GHz and 11.82 GHz.

This interprets that helical antenna can be effectively used for both lower and higher range of frequencies as the helix feed pin dimensions increases. Figure 9c shows the comparative plot of broadband gain of feed pin height variation in helical antenna. It is important to note that the case of 0.2λ which is the reference height is same as that of cavity loaded helix at 0° position of helix. A slight improvement in the gain is observed for 0.3λ and 0.4λ height of feed pin which is 10.35dB and 10.65dB respectively.

In the fabrication of cavity backed helical antenna, the helix is made using copper and the impedance matching cavity which is acting as modified ground plane to the antenna is fabricated using aluminum metal as shown in Fig.3b. It is found that the joint connection between helix and the feed pin plays an important in the distribution of current along the helical antenna. In the modeling of antenna in Computer Simulation Tool, the joint connection between helix and feed pin is abrupt however this has been improved in the practical implementation of helix as shown in Fig. 10.

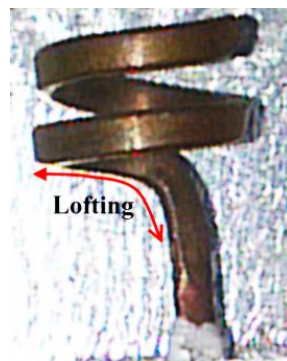


Figure 10. Lofted helix

The geometrical operation of lofting has been employed to enhance the flow of current from the feed along the helix. The lofting certainly improves the current distribution along the antenna and thereby increases the overall bandwidth of the antenna. To verify this, a comparison is made between measured results with and without lofting. Figure.11 shows the plot of reflection coefficient for cavity loaded helix at 45° position. The overall bandwidth is found to be 5.4GHz which greater than the simulated result. Figure 12-13 shows the measured plot of reflection coefficient for antenna feed pin height variation with 0.3λ and 0.4λ respectively and again an improvement in the overall bandwidth is noticed. It has been observed that the simulated results and measured results are in close agreement in case of helix without lofting and an improvement in the overall bandwidth is obtained by employing lofted helical antenna inside the cavity. Table 2 shows the complete observations of helical desing proposed in this paper to obtain a better understanding of helix behavior.



Figure 11. Comparative plot of measured reflection coefficient of cavity backed helix at 45° position

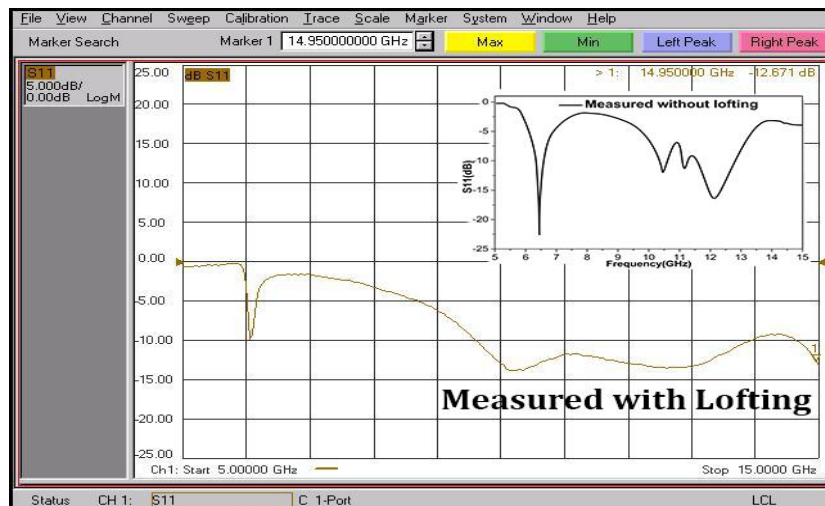


Figure 12. Comparative plot of measured reflection coefficient for 0.3λ feed pin height

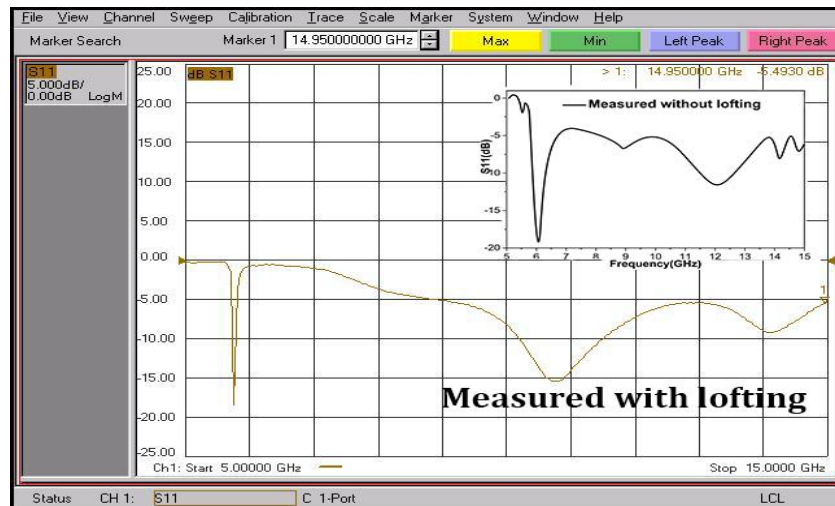


Figure 13. Comparative plot of measured reflection coefficient for 0.4λ feed pin height

Table 2: Result analysis of proposed helical designs

Design	Simulated B.W (GHz)	Measured B.W(GHz) without lofted helix	Measured B.W(GHz) with lofted helix	Simulated Gain (dB)
Unloaded helix	-	-	-	poor
Cavity Backed helix at $0^\circ, 90^\circ, 180^\circ, 270^\circ$ (0.2λ)	2.17	2.6	5.2	9.9
Cavity Backed helix at $45^\circ, 135^\circ, 225^\circ, 315^\circ$	2.47	0.65	5.4	10
Feed pin height (0.3λ)	1.22	2.07	4.7	10.35
Feed pin height (0.4λ)	1.26	1.6	1.4	10.65

4. FUTURE WORK

There exists a wide scope in the optimization of cavity which backs the helical antenna and a greater degree of gain and bandwidth enhancement in just $1\frac{1}{2}$ turn helical antenna can be achieved. Also a significant directive pattern of electric field for long distance communication can be achieved by designing array of such compact and conformal cavity backed helical antenna and for this, special feeding networks need to be designed. So the future work is intended to develop a wide band impedance matching feeding network and also to incorporate RF switches like PIN diode, Varactor diode to achieve electronic re-configurability in the design.

5. CONCLUSION

A compact and conformal helical antenna design has been presented with a stable frequency response beyond C-band frequency. It is found that modification in ground plane which is the rectangular cavity here in the design plays an important in confinement of near field electric vector. Also the orientation of helix inside the cavity should be appropriately adjusted to provide multiple reflections of electric fields from the walls of the cavity and thereby increasing the number of resonant bands. The antenna can be made to operate for both lower and higher range of frequencies with an excellent isolation between the bands by tuning the height of helical antenna feed pin.

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BIOGRAPHY OF AUTHOR



Rahul Yadav received B.Tech degree from NMIMS University in 2011 and completed Masters in Engineering from Mumbai University in 2013. His area of interests are, design of reconfigurable antenna for cognitive radio, hybrid cavities and wideband planar antennas.