

Original Article

Bandwidth and Gain Enhancement with Experimental Validation of a Helical Antenna Using Hexagonal Cavity Loading

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Abstract - Helical antennas are prominently used in wireless and satellite communication. Helical antennas exhibit circular polarization, wide bandwidth, and relatively high gain. However, to enhance the bandwidth and gain that to with a compact antenna size of antenna is a challenge for modern broadband communication systems. This paper includes the design, analysis, fabrication, and experimental validation of a helical antenna loaded inside a hexagonal cavity for bandwidth and gain enhancement. The antenna is designed for the frequency range of 3–10 GHz. The research is focused on the effect of parameters of helical antenna, like number of turns, pitch, strip width, and helix diameter on antenna performance characteristics such as bandwidth and gain. Parametric analysis is carried out to identify the optimal design configuration. By increasing number of turns of helix improves the bandwidth and improves the number of resonant bands, while variations in pitch and strip width influence the gain and frequency response of the antenna. With reference to the simulation results, an optimized antenna with three turns and a hexagonal aluminum cavity is fabricated and testing is done by using a vector network analyzer. The simulated results give a bandwidth of 1.04 GHz with four resonant bands, while the fabricated prototype achieves a measured bandwidth of 0.55 GHz with two resonant bands. The proposed cavity-backed helical antenna provides enhanced bandwidth and gain characteristics and may be effectively used in broadband wireless communication and satellite communication applications.

Keywords - Helical antenna, Hexagonal cavity, Gain improvement, Bandwidth enhancement, Wideband antenna.

1. Introduction

In wireless communication applications transmitting and receiving antennas plays an important role. Electromagnetic signals are transmitted in the space by the antennas. An antenna acts a transducer which converts electromagnetic wave to electrical signal and vice versa. In the wireless communication antenna is an important part; which affect the range of communication and quality of signal directly. The response of the antenna remains same whether application of antenna for the purpose of transmission or reception. This property of antenna is called as reciprocity [1, 2].

The helical antenna provides comparatively high gain, wide bandwidth and circular polarization so helical antennas are prominently used in satellite and other wireless communication systems. J. D. Krause invented helical antenna in 1946, by the imperial results he describes the operating modes and radiation characteristics of helical antenna [1].

Analytical and Method of Moments (MoM) as numerical techniques are the two methods for analysis and modeling of helical antenna. Radiation pattern and other performance parameters of helical antennas were studied by early researchers [3]. Suitability of helical antenna for communication systems is made by the appropriate characteristics such as gain, bandwidth, radiation pattern, polarization and input impedance of antenna.

In modern communication systems there is a continuous need of improvement in antenna characteristics which improves the performance also there is need to reduce the antenna size, weight, and cost. The antenna performance is mainly depends on Impedance bandwidth, gain, and axial ratio. Available space for antenna and weight is limited is most of the applications such as aircraft, spacecraft and portable communication devices [4]. In wireless communication applications helical antennas is prominent contender because



of simple structure, ease of fabrication, and circular polarization with comparatively high gain. These antennas are prominently used in satellite communication, navigation systems, and wireless sensor networks.

However, conventional helical antenna designs were mostly limited to frequency bands such as the 2.4 GHz WLAN band and C-band frequencies. Conventional design equations contributed by Kraus and other researchers are most of the time limited in maintaining stable performance at higher frequencies [1, 5]. Therefore, there is a need of new helical antenna structures and designs are required particularly for higher operating frequency and wide range frequencies.

In this paper, a helical antenna loaded inside a hexagonal cavity is designed, fabricated and tested. The research is focused on the effect of various parameter of the helix are optimised to get the maximum possible antenna bandwidth and gain in the 3 to 10 GHz frequency range.

Helical antenna invented in year 1947. Since then has been used because of their circular polarization and broadband characteristics. The design invented by Kraus is the basic principles and radiation mechanisms of axial-mode helical antennas, which are popularly, used for satellite communication [1]. Later, Balanis provided detailed theoretical analysis and design formulas and methods for antenna parameters including gain, bandwidth, and axial ratio and other parameters also [2].

Many researchers contributed in modifications of helical antenna to improve the radiation performance. Kilgus proposed the multi-element fractional-turn helices for improvement in gain and radiation characteristics [6]. Djordjevic et al. contributed in axial-mode helical antennas to improve gain and radiation efficiency by shaping the ground conductor [7].

The work is also done to reduce antenna size and improve compactness. Takacs et al. worked on quadrifilar helical antennas and archive the reduction in the height of antenna also maintains circular polarization [8]. Caillet et al. improves the bandwidth by a folded printed quadrifilar helical antenna with a compact feeding structure. [9].

Other papers have investigated dielectric loading and cavity structures in helical antennas. Hui et al. empirically clams the improvement in impedance matching and radiation performance by dielectric resonator loaded helical antenna [10]. Spencer discussed the antenna with helix as a resonator filters in the paper and achieves high quality factor and compact size of antenna [11]. High-power is handled by helical antenna arrays. Research carried out by Li et al. on a radial line helical array antenna which provides high gain and improved radiation characteristics [12]. These types of array antennas are used in radar and satellite communication. In

addition, compact antenna designs have been proposed by Huang et al. for biomedical and telemetry applications, a miniaturized antenna for capsule telemetry systems [13]. Zhao et al. presented a compact antenna design for wireless capsule endoscopy applications [14].

Recently for 5G communication networks and satellite broadband communication, research in broadband and compact helical antennas has carried out. Recent studies have explored new fabrication techniques, wideband antenna structures, and improved circular polarization performance [15]. However, achieving a compact antenna structure with high gain, wide bandwidth, and stable circular polarization remains a challenge, particularly for antennas operating over a wide frequency range.

Most of the studies on helical antennas focus on axial-mode or quadrifilar helical antenna structures designed for limited range of frequency bands. Many designs are developed on classical equations proposed by Kraus, which are mainly suitable for narrowband operation.

Although several techniques for helical antenna have been proposed for size reduction of antenna, there are few studies on cavity-loaded helical antenna structures for improving gain and bandwidth simultaneously. In particular, the helix loaded in a hexagonal cavity has not been widely investigated for broadband operation in the 3–10 GHz frequency range.

Therefore, the present work is focused on a helical antenna loaded in a hexagonal cavity. To achieve improved antenna gain and bandwidth for wideband wireless communication the optimization of various design component and parameters of helix are varied and the optimisation is carried out by the imperial method. So many variation in the design are carried out in this paper to achieve the optimisation.

2. Helical Antenna Design for Cavity

The Helical antenna design for cavity as shown in Figure 1 the analysis is based on transmission line with quarter wavelength. A helix is located in the cavity and connected to the cavity at bottom end. The cavity shapes can be cylindrical. To improve the Q-factor and minimise the losses good conducting material is used for the fabrication.

Copper and silver are the best option as a very good conducting material but that are expensive. The alternative is aluminium which is used for the cavity and helix is made up of copper. This design is a compact as compared to the helix also provides high quality (Q) factor. Here, the use of cavity serves is useful in reduction of the size of antenna and to achieve the compact size. This way two purposes; to reduce size of helix and to obtain compact physical size to attain high bandwidth is achieved.

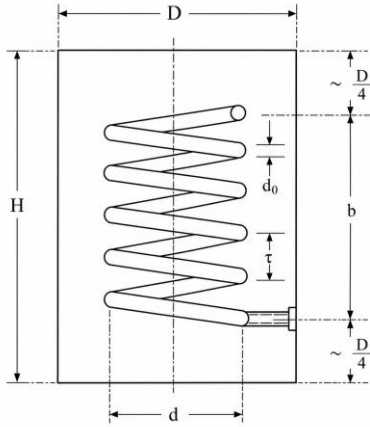


Fig. 1 Helical antenna design for cavity

Where,

- D = Inner Diameter of Helix (in mm)
- d_0 = Diameter of Conductor of Helix (in mm)
- d = Outer Diameter of Helix (in mm)
- b = Helix Axial Length (in mm)
- H = Inner Height of Cavity (in mm)
- τ = Pitch of Helix (in mm)

2.1. Design of Helix

The helix doesn't make with copper wire but made with the copper strip of width 2 mm. The outer diameter of helix is selected as 16 mm. Figure 2 shows the helix simulated with copper strip.

2.2. Design of Hexagonal Cavity

Design of Hexagonal shaped cavity is shown in Figure 3. There is no direct formulation available for finding hexagonal shape cavity dimensions. Using reference of design equations of the size of cavity is determined for frequency 5.2 GHz. Table 1 shows the parameters calculated. 25 mm is the cavity height, and 2 mm thickness of. Hexagon side of 15mm is selected. The cavity is made up of aluminium. To enhance bandwidth, gain the helix number of turns of helix, pitch of helix and helix strip dimensions are varied. Simulation is done by varying one parameter at a time and remaining parameters are kept constant.

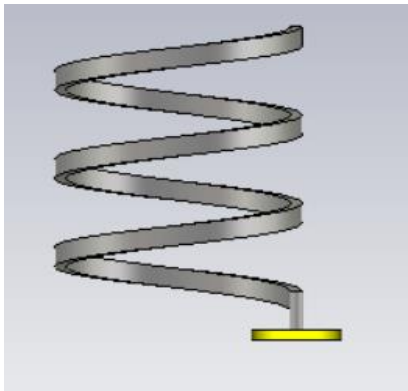
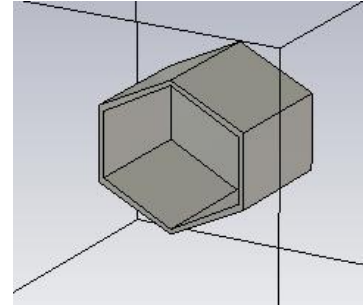
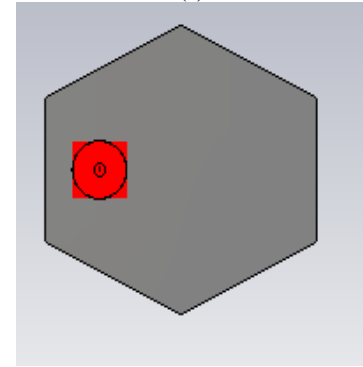


Fig. 2 Helix Design



(a)

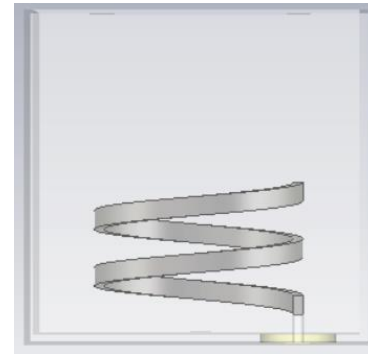


(b)

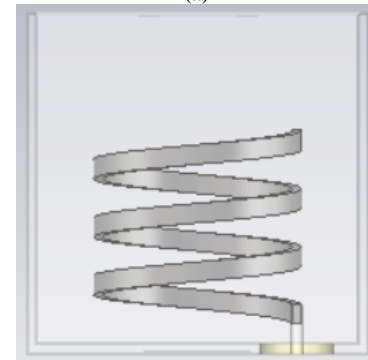
Fig. 3 Cavity Design (a) Perspective view, and (b) Back view.

3. Number of Turns Variation

For turns variation pitch is kept 6 mm, Diameter of helix is 16 mm, strip width is 1 mm and strip thickness is 2 mm. The number of turns varied from 2, 3 and 4 as shown in Figure 4. For each turn variation analysis of bandwidth, gain and radiation pattern is done.



(a)



(b)

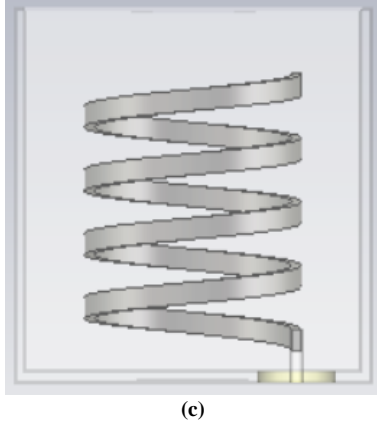


Fig. 4 Number of turns variation (a) 2 turns (b) 3 turns, and (c) 4 turns.

3.1. Bandwidth Analysis

Reflection coefficient (S11) graph for N=2 is shown in Figure 5. Bandwidth analysis is given in Table 2. Here resonant bands obtained are three. Bandwidth increases as resonant frequency increases. Total bandwidth obtained is 0.31 GHz.

Reflection coefficient (S11) graph for N=3 is shown in Figure 6. Bandwidth analysis is given in Table 3. Here resonant bands obtained are three. Bandwidth increases as resonant frequency increases. Total bandwidth obtained is 0.7 GHz.

Reflection coefficient (S11) graph for N=4 is shown in Figure 7. Table 4 gives Bandwidth analysis for the same. Here number of resonant bands are 4. Total bandwidth obtained is 1.4GHZ.

3.2. Gain Analysis

Gain plot for N=2 is shown in Figure 8. Gain analysis is given in Table 5. Gains obtained are 2.9 dB, 7.2 dB, 7.7 dB at frequencies 4.09 GHz, 6.28 GHz, 7.64 GHz respectively. Maximum gain obtained is 8.71 dB at 8 GHz frequency.

Figure 9 shows gain plot for N=3. Table 6 gives gain analysis for the same. Gain obtained is 4.98dB, 7.21dB, 8.13dB, 7.8dB at 4.13GHz, 5.99GHz, 7.01GHz, 9.21GHz respectively. Maximum gain obtained is 8.73 dB at 3.7GHz frequency.

Figure 10 shows gain plot for N= 4. Table 7 gives gain

analysis for the same. Gain obtained are 7.27 dB, 8.56dB, 8.93dB, 7.3dB at 5.76GHz, 6.61GHz, 7.41GHz, 9.92GHZ respectively. Maximum gain obtained is 8.93bdB at 7.39GHz frequency.

4. Antenna Fabrication and Testing

After all these investigation of parameter variation the helical loaded hexagonal cavity backed antenna is fabricated. Helix of with 3 numbers of turns is taken as it gives better bandwidth than 2 number of turns. Number of turn 4 is not used due to requirement of compact size. Diameter of helix is 16 mm as it gives more resonant bands. Pitch of helix is 9 mm. Figure 11 shows implemented antenna. Cavity is made up of aluminium and helix is made up of copper. The testing setup using vector network analyser is shown in Figure 12.

The analysis started with the simulation of helical antenna with ground plane Figure 13 shows reflection coefficient (S11) plot for the same. From S11 plot for antenna without cavity is observed that result of S11 is not below -10 dB.

When antenna is enclosed by hexagonal shaped cavity following results are obtained. Figure 14 shows simulated result and Figure 15 shows tested result. It is observed that when helix is enclosed by cavity performance improves.

Figure 16 shows comparative simulated and tested results. Table 8 gives analysis for simulated and tested results. It is observed that in simulation four resonant bands are obtained and bandwidth is 1.04 GHz. Practically two resonant bands are obtained and bandwidth is 0.55 GHz. This section explains the impact of parameters of helix which are helix number of turns, helix pitch, and helix strip width on bandwidth, gain and radiation pattern. Diameter of helix is varied to analyse antenna.

Helix with three turns, pitch is 9 mm, strip width 2 mm and diameter 16 mm is used to implement antenna. Because two turns gives less bandwidth and four turn will not give compact size. Pitch 9 mm is taken as varactor diode is to be placed in turn of helix for reconfiguration. Diameter 16 mm gives more resonant bands. Proposed cavity backed helical antenna design we practically implemented and compared with the simulated results for the validation of results. Simulated bandwidth is 1.04GHz and tested bandwidth is 0.55GHz. Next chapter explains implementation of frequency reconfiguration in the designed antenna.

Table 1. Parameters for cylindrical cavity

Parameter	Expression for Calculation	Value obtained
Helix Axial Length (b)	$b = 0.235\lambda$	14mm
Outer Diameter of Helix (d)	$d = 0.0588\lambda$	4mm
Inner Diameter of Helix (D)	$D = 0.131\lambda$	8mm
Inner Height of Cavity (H)	$H = 0.3\lambda$	18mm
Number of Turns per mm (n)	$n = N/b$	0.142 turns/mm

Pitch of Helix (τ)	$\tau = 1/n$	7.14mm
Diameter of Conductor of Helix (d_o)	$d_o = 0.4$	3mm
Circumference of Conductor (c)	$c = d_o$	9mm

Table 2. Bandwidth analysis for N=2

Resonant frequency (GHz)	FH (GHz)	FL(GHz)	B.W (GHz)	Total B.W (GHz)
4.09	4.11	4.07	0.04	0.31
6.28	6.34	6.23	0.11	
7.94	8.02	7.85	0.16	

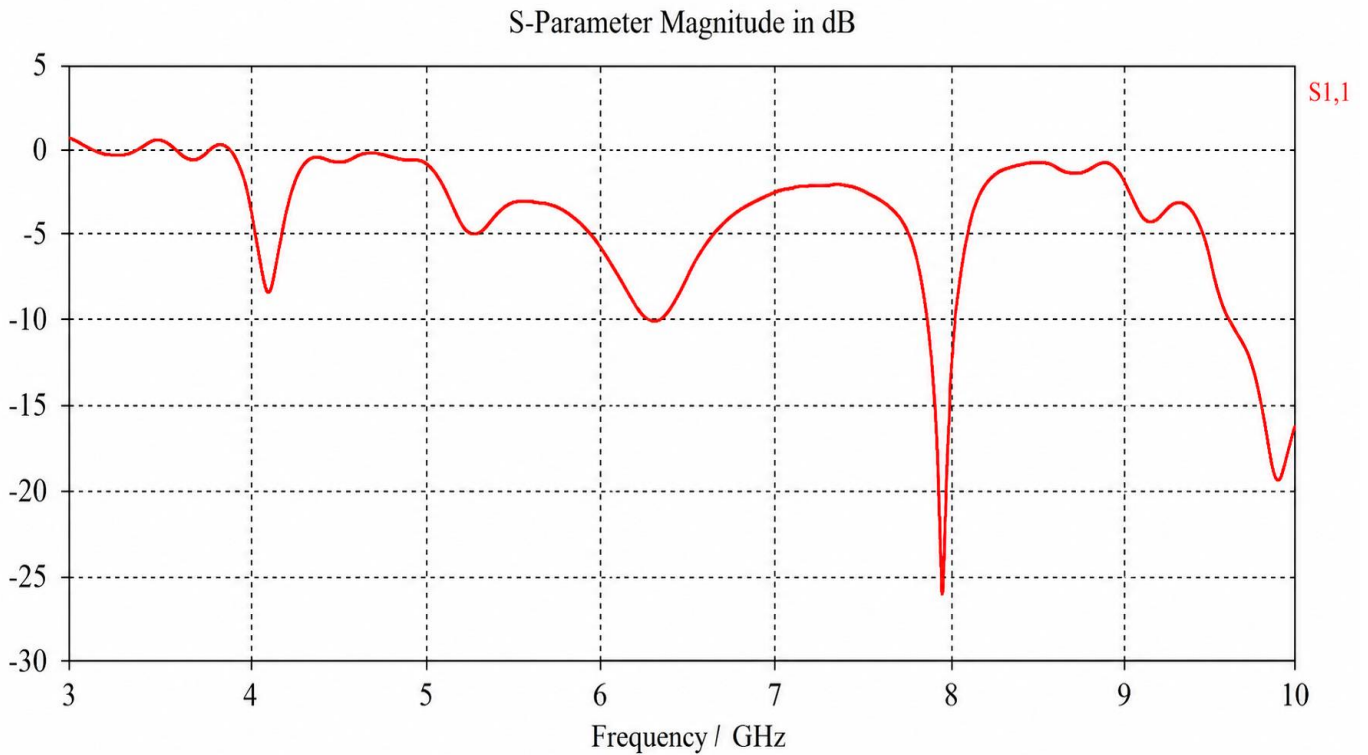


Fig. 5 S11 plot for N=2

Table 3. Bandwidth analysis for N=3

Resonant frequency (GHz)	FH(GHz)	FL(GHz)	B.W(GHz)	Total B.W (GHz)
4.13	4.19	4.07	0.11	0.7
5.99	6.14	5.86	0.27	
7.01	7.09	6.9	0.19	

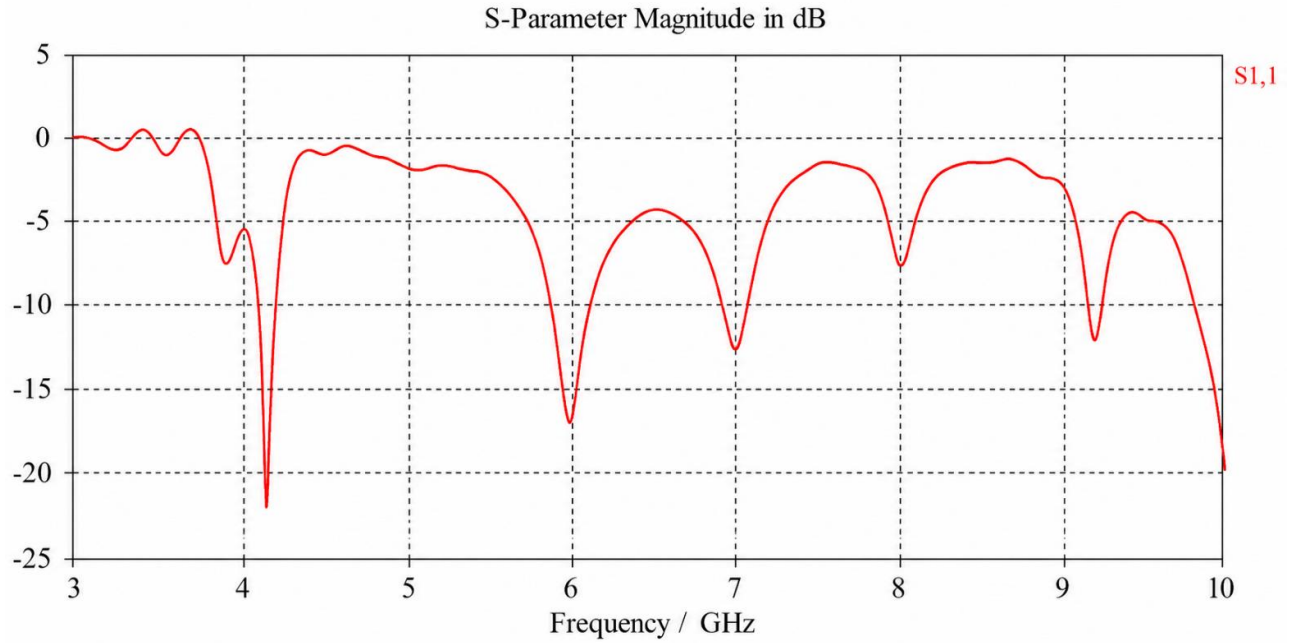


Fig. 6 S11 plot for N=3

Table 4. Bandwidth analysis for N=4

Resonant frequency (GHz)	FH (GHz)	FL(GHz)	B.W(GHz)	Total B.W(GHz)
5.76	5.9	5.64	0.25	1.4
6.61	6.73	6.5	0.22	
7.41	7.45	7.33	0.12	
9.92	10.2	9.72	0.47	

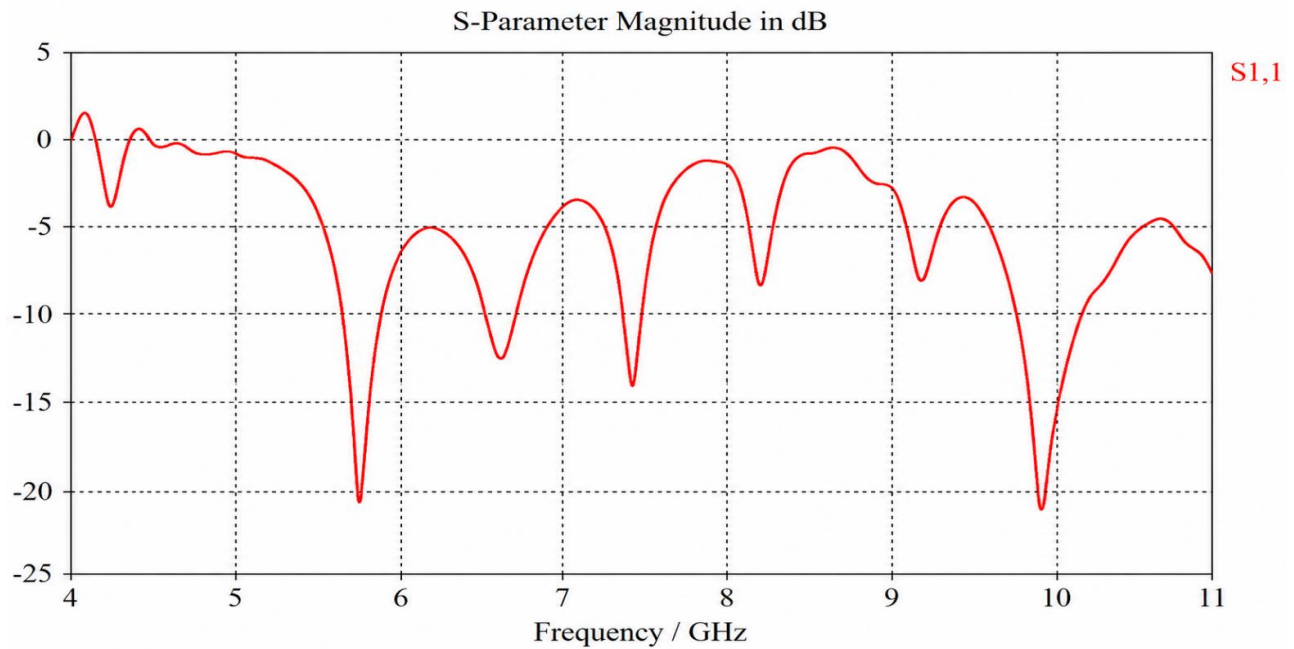


Fig. 7 S11 plot for N=4

Table 5. Gain analysis for N=2

Resonant Frequency(GHz)	Gain(db)	Maximum Gain(db)	Frequency at maximum gain.(GHz)
4.09	2.9	8.71	8
6.28	7.2		
7.64	7.7		

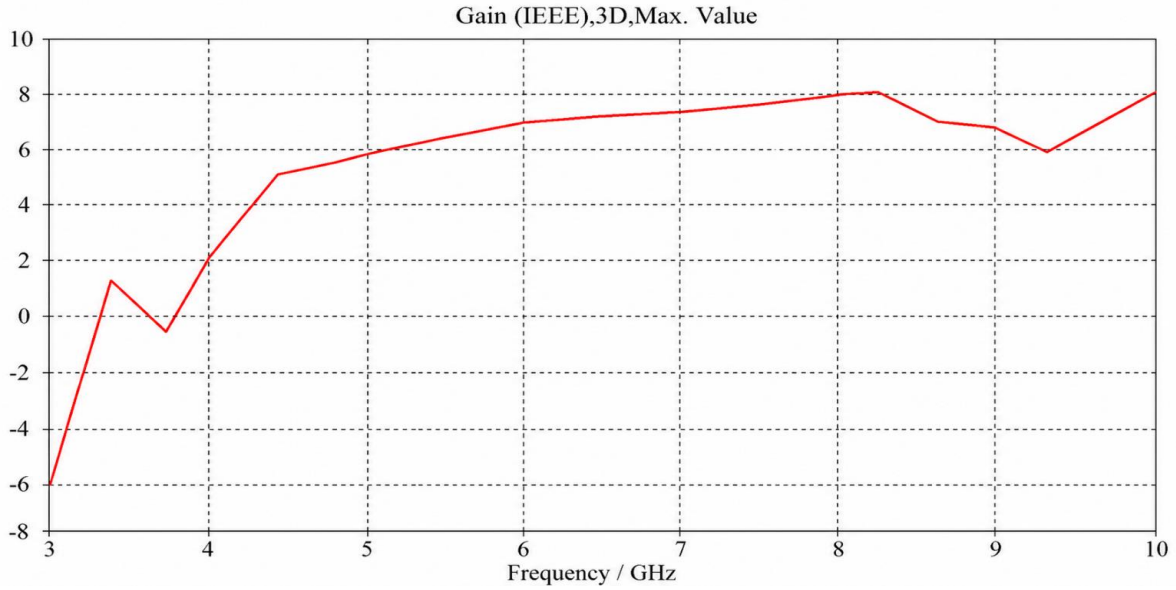


Fig. 8 Gain plot for N=2

Table 6. Gain analysis for N=3

Resonant Frequency(GHz)	Gain(dB)	Maximum Gain(dB)	Frequency at maximum gain.(GHz)
4.13	4.98	8.73	3.7
5.99	7.21		
7.01	8.13		
9.21	7.8		

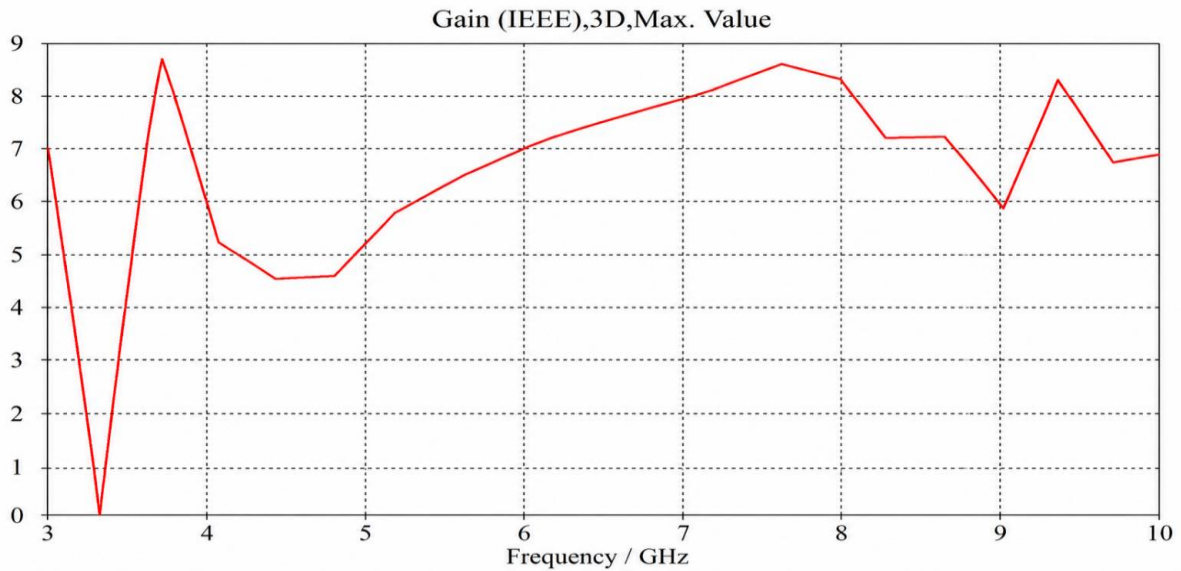


Fig. 9 Gain plot for N=3

Table 7. Gain analysis for N=4

Resonant Frequency(GHz)	Gain(db)	Maximum Gain(db)	Frequency at maximum gain.(GHz)
5.76	7.27	8.93	7.39
6.61	8.56		
7.41	8.93		
9.92	7.3		

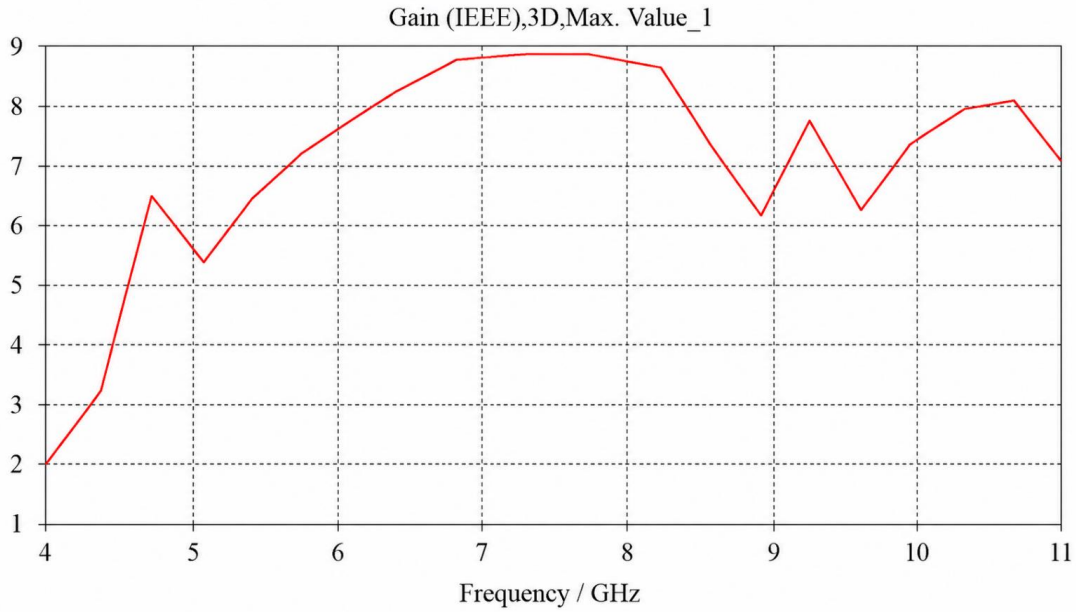


Fig. 10 Gain plot for N=4



Fig. 11 Implemented antenna



Fig. 12 Testing setup vector analyser

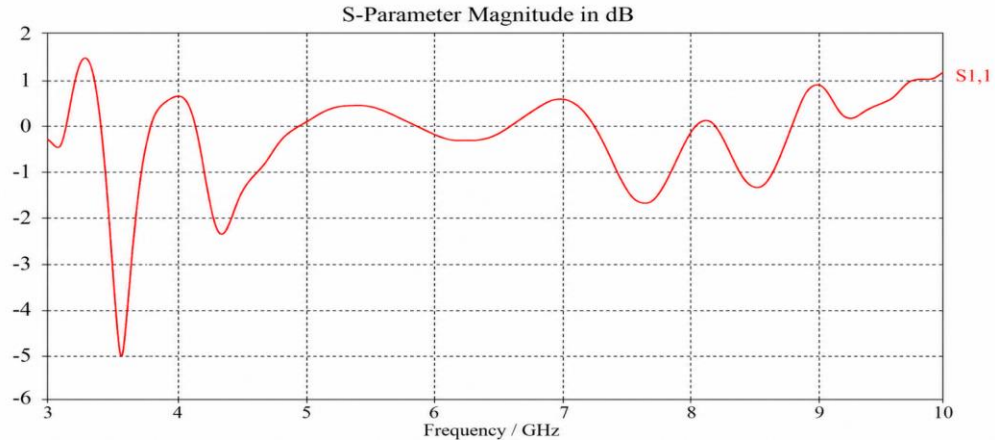


Fig. 13 S11 plot for helix without cavity

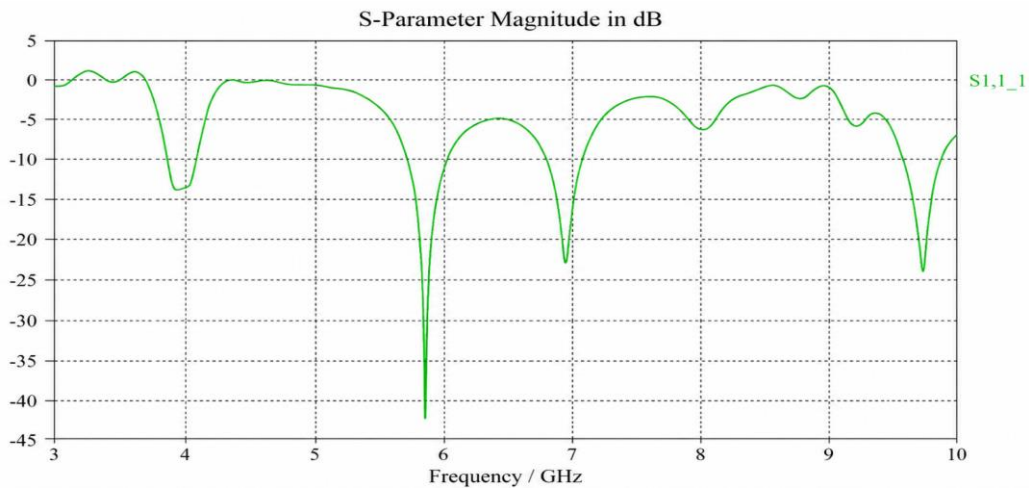


Fig. 14 Simulated result

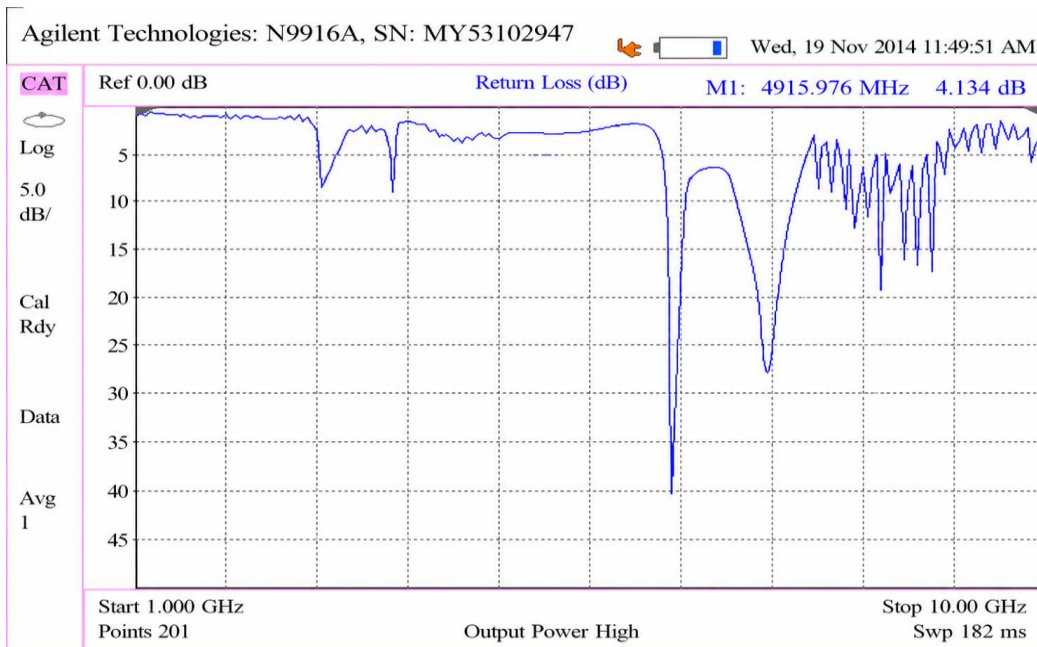


Fig. 15 Tested result

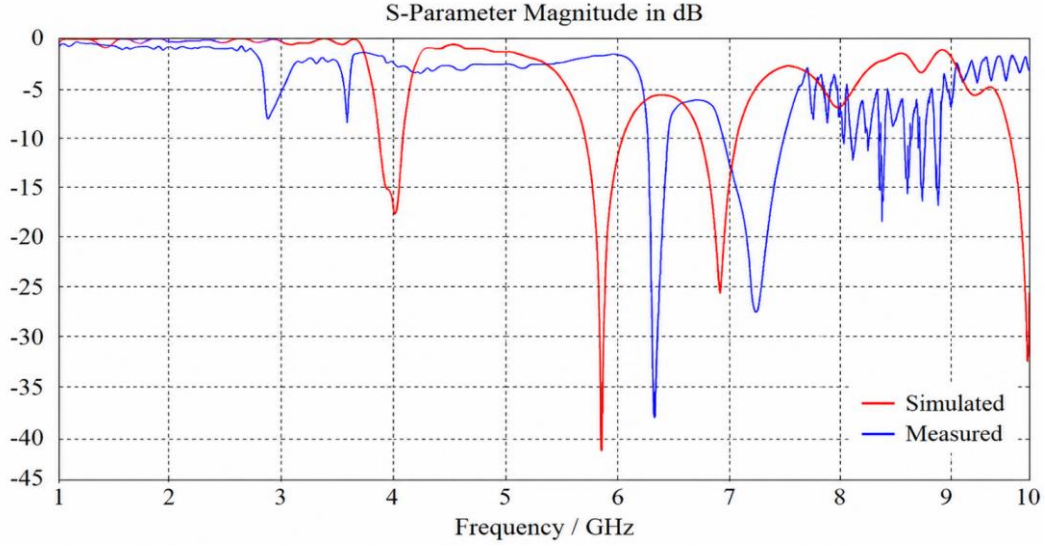


Fig. 16 Comparative result

Table 8 Comparative analysis of result

Mode of Experimentation	No. of Bands	Band 1	Band 2	Band 3	Band 4	Total Bandwidth (GHz)
Simulated	4	5.68-6.0,	6.99-7.24	8.85-8.95	9.49-9.86	1.04
Tested	2	6.2-6.45	6.95-7.5	-	-	0.55

5. Results and Discussion

The overall bandwidth, gain and radiation patterns are obtained for the same. The analysis for these parameters is done individually, as well as comparatively. Following sections give the impact on bandwidth, gain and radiation patterns by the parametric variations and frequency reconfiguration.

5.1. Impact on Bandwidth by Parametric Variations

This section discusses the impact on bandwidth due to the number of turns variation, pitch variation, strip size variation and helix diameter variation.

5.1.1. Number of Helix Turns Variation

Figure 17 shows the reflection coefficient due to number of turns variation. Turns of two, three and four are considered. As number of turns increases number of resonant bands also increases. Bandwidth is increases with increase in number of turns. Bandwidth for two turns is 0.31 GHz, for three turns is 0.7GHz, for four turns 1.4GHz.

5.1.2. Pitch Variation

Figure 18 shows comparative S11 plot for pitch variation. Pitch is varied from 6mm-9mm. Here four resonant bands are obtained for all pitch of helix. Impact of increase in helix pitch angle increase structural height of helix which results the reduction of resonating frequency and slightly shifts the resonant bands towards lower frequency.

5.1.3. Strip Width Variation

Figure 19 shows comparative S11 plot for strip size variation. Here strip width is varied as 1mm, 2mm, 3mm and 4mm. Resonant bands obtained are three for each case. Increasing the strip width by an offset of 1 mm does not significantly affect the frequency response, as the spacing between the cavity walls and the helical structure remains constant.

5.1.4. Diameter Variation

Figure 20 shows comparative S11 plot for helix diameter variation. As diameter of helix increase number of resonant bands and bandwidth increases. The diameter increase leads to more interaction and reflection of Electric fields with the cavity wall and thereby helps to excite more number of frequency bands. Also increase in helix diameter, increases the physical dimension of helix and hence the frequency response eventually starts to shift towards lower end of fundamental resonant spectrum.

5.2. Impact on Gain by Parametric Variations

In this section the impact on gain due to the parametric variations of number of turns, pitch variation, strip size variation and helix diameter variation are explained with experimental validation.

5.2.1. Number of Helix Turns Variation

Figure 21 shows gain plot for number of turns variation. Peak gain for two turns is 8.71dB, for three turns 8.73 dB and for four turns 8.93 dB. The gain for two and three turns of

helix ia almost same. There is significant increase in gain is observed for four turn helix. The power radiated is depend on the structural height of helix so there is increase in gain with increase in number of turns.

5.2.2. Pitch Variation

Figure 22 shows comparative gain plot for pitch variation. For 6 mm pitch peak gain is 8.73dB, for 7mm gain is 8.74 dB, for 8 mm pitch gain is 9.1 dB, for 9 mm pitch gain is 9.28 dB.

There is significant increase in gain for 8 and 9 mm peach. The increase in peach increases the height of antenna which results in increase in the gain.

5.2.3. Strip Width Variation

Figure 23 shows impact of the strip size variation. Peak gain for 1 mm strip size is 10.81 dB, for 2 mm gain is 14.87 dB, for 3 mm 8.54 dB and for 4 mm gain is 12.4 dB.

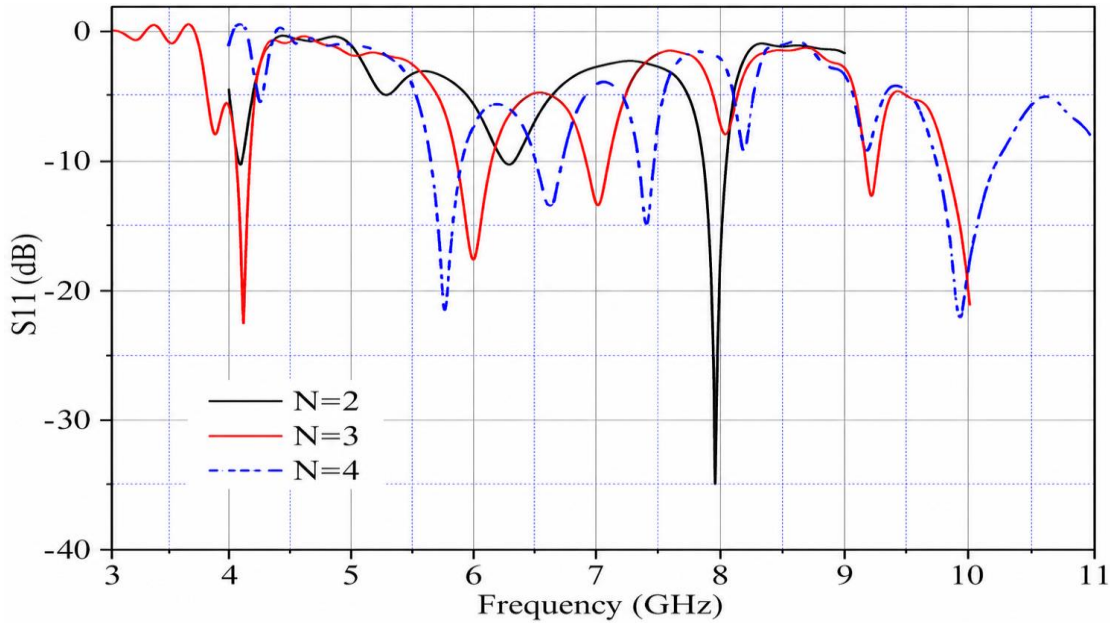


Fig. 17 S11 plots for helix number of turns variation

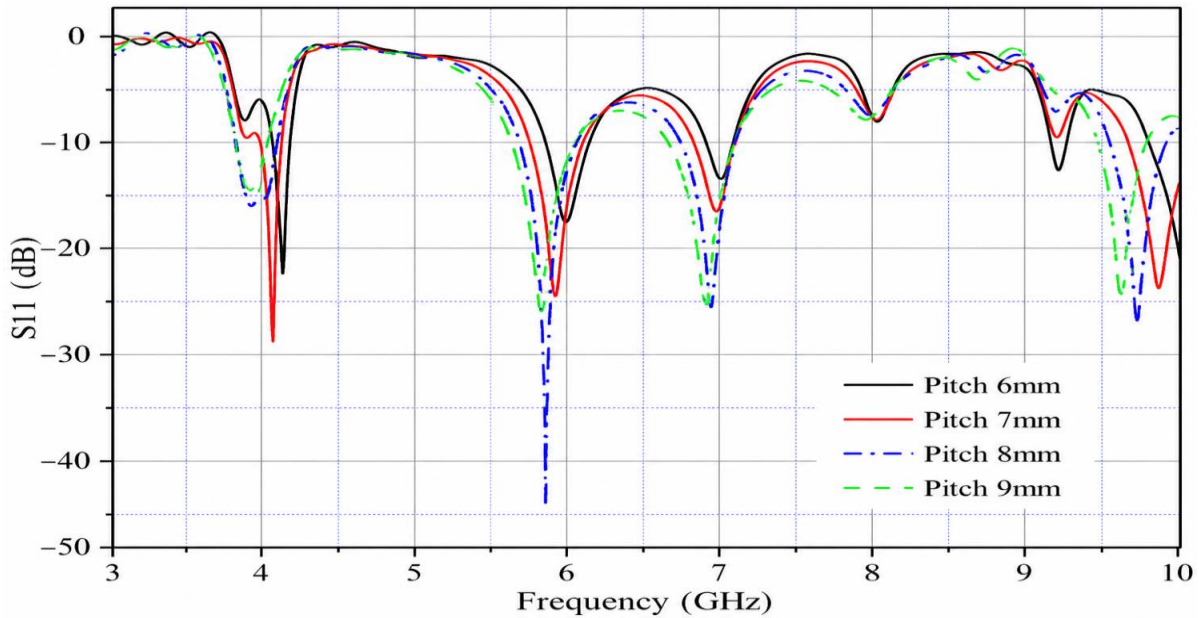


Fig. 18 Comparative S11 plot for pitch variation

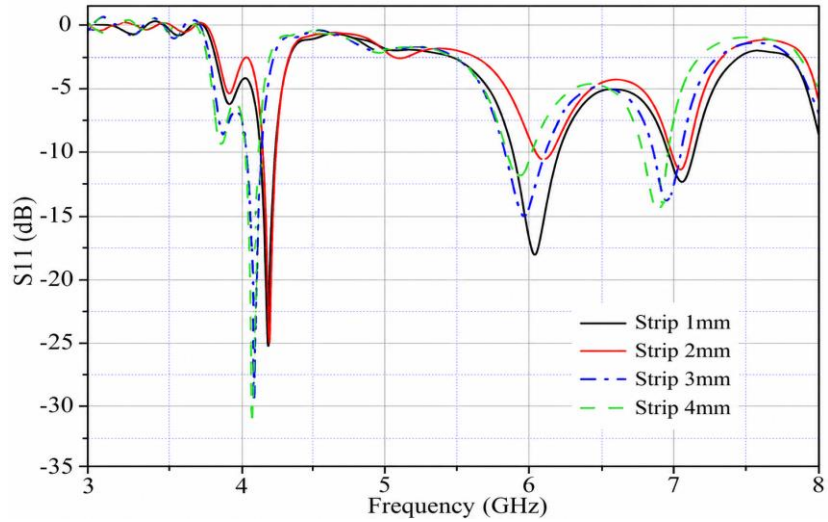


Fig. 19 Comparative S11 plot for strip size variation

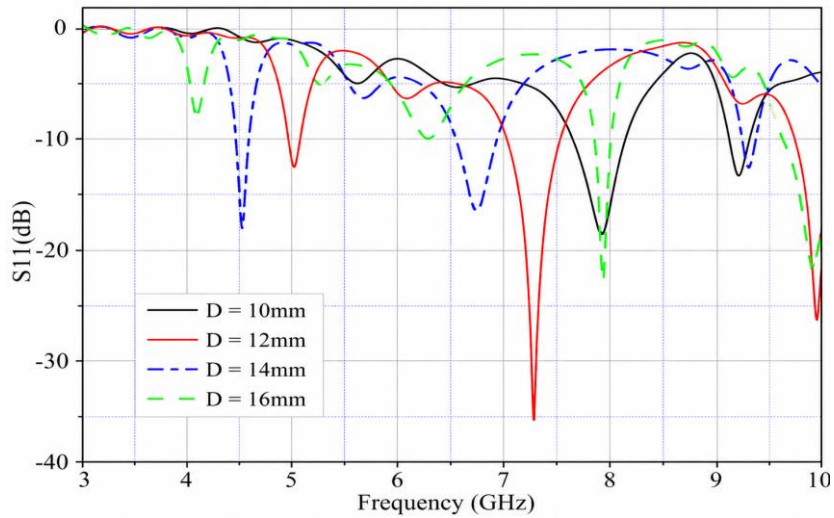


Fig. 20 Comparative S11 plot for diameter variation

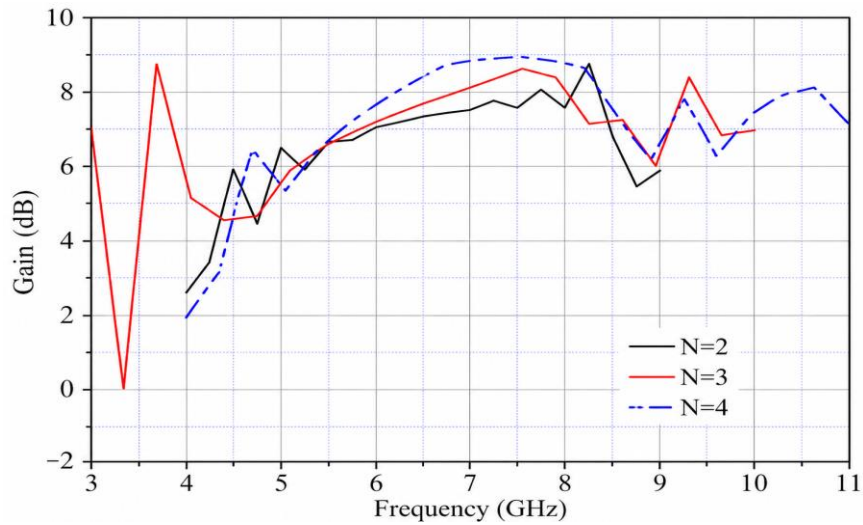


Fig. 21 Comparative gain plot for turns variation

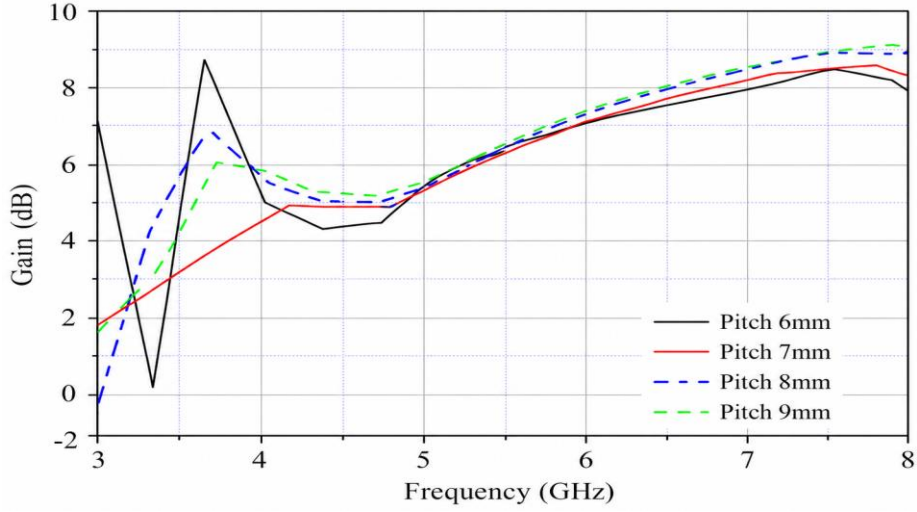


Fig. 22 Comparative gain plot for pitch variation

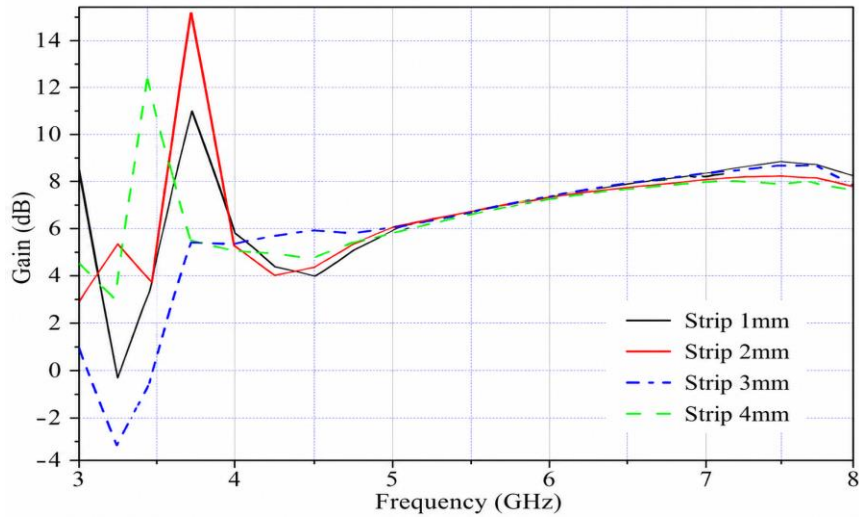


Fig. 23 Comparative gain plot for strip size variation

Table 9. Comparative bandwidth analysis

	No.of turns	No.of bands	Band 1	Band 2	Band 3	Band 4	B.W (GHz)
Turns variation	2	3	4.7-4.11	6.23-6.34	7.85-8.02	_____	0.31
	3	4	4.07-4.19	5.86-6.14	6.9-7.09	9.16-9.27	0.7
	4	4	5.64-5.9	6.5-6.73	7.33-7.45	9.72-10.2	1.4
Pitch variation	Pitch (mm)						
	6	4	4.07-4.19	5.86-6.14	6.9-7.09	9.16-9.27	0.7
	7	4	3.97-4.13	5.75-6.12	6.84-7.1	9.68-10.	1.5
	8	4	3.83-4.09	5.7-6.06	6.76-7.09	9.55-9.91	1.43
	9	4	3.84-4.03	5.69-6.06	6.67-7.07	9.48-9.78	1.46
Strip width	Stripwidth(mm)						
	1	3	4.12-4.23	5.89-6.19	6.96-7.12	_____	0.57

variation	2	3	4.14-4.23	6.03-6.15	6.98-7.09	_____	0.33
	3	3	4.02-4.12	5.86-6.1	6.85-7.03	_____	0.48
	4	3	4.02-4.1	5.84-6.03	6.78-6.96	_____	0.35
Diameter variation	Diameter (mm)						
	10	2	7.37-8.35	9.03-9.47	_____	_____	1.4
	12	2	4.96-5.08	7.02-7.72	_____	_____	0.81
	14	3	4.43-4.66	6.54-6.93	9.24-9.37	_____	0.74
	16	3	6.23-6.34	7.85-8.03	9.54-10	_____	0.71

6. Conclusion

The helix parameters, helix number of turns, helix pitch of helix, strip size, diameter are varied to analyse the impact on bandwidth, gain, radiation pattern of antenna. Radiation pattern is not much considered in this case. All the designs are simulated using CST Microwave Studio. Using analysis of all parameters optimum design is fabricated and tested using vector analyser Aligent Technologies N9916A. Using varactor diode frequency reconfiguration is achieved in fabricated design.

The designed helical loaded hexagonal cavity backed antenna is working at 3GHz to 10GHz frequency range. If number of turns of helix is increased, bandwidth increases. Also number of resonant bands are increased with increase in number of turns. Number of turns will not much effect on gain. The increase in helical antenna pitch results in increase of antenna height which impacted the gain positively. Increase in the strip width doesn't vary the frequency response greatly. Gain increases as strip size increases.

Also variation in the antenna physical parameters like helix diameter and introduction of dielectric core plays important role in gain and bandwidth enhancement. A more peculiar observation was made in helix diameter variation design that the antenna radiation pattern starts becoming omnidirectional in nature as diameter of helical antenna begins to increase inside the hexagonal cavity. If diameter of helix increases number of resonant bands is increases. Simulated and tested results for implemented antenna are approximately same.

It has been observed that in reconfiguration design, the practical and simulated results are almost similar. Slight difference in results is due to fabrication limitations.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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