SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V13I4P107

Volume 13 Issue 4, 97-104, April 2026

Original Article

Frequency Reconfigurable Helical Loaded Hexagonal Cavity-Backed Antenna for Wideband Applications

Vinitkumar Jayaprakash Dongre[1*], Samita Kiran Bhandari[2], Kiran R. Rathod[3], Priya Chimurkar[4]

[1]*Department of Electronics and Telecommunication Engineering, Thakur College of Engineering and Technology, Maharashtra, India*
[2]*Department of Electronics and Computer Science, Shree L R Tiwari College of Engineering, Maharashtra, India*
[3]*Department of Electronics and Telecommunication Engineering, K J Somaiya Institute of Technology, Maharashtra, India*
[4]*Department of Electronics and Telecommunication Engineering, Sardar Patel Institute of Technology, Maharashtra, India*

**Corresponding Author : vinit.dongre@thakureducation.org*

Received: 14 January 2026 Revised: 22 February 2026 Accepted: 24 March 2026 Published: 30 April 2026

Abstract - *Helical antenna is prominently used in wireless communication due to the prominent properties of helical antenna with reference to the gain, polarization, and simpler geometry. In this paper, the work is focused on the frequency reconfiguration capability of the helically loaded hexagonal cavity-backed antenna. The optimization of helical antenna physical parameters is carried out in this research. The helical antenna parameters taken into consideration are bandwidth, gain, and radiation pattern in the 3–10 GHz frequency range. Frequency reconfiguration is achieved by using a Varactor diode, which gives the dynamic frequency variation of the resonance frequency of the helical-loaded hexagonal cavity-backed antenna. The proposed antenna provides multiband frequency operation in dynamic mode for wireless applications. The varactor diode demonstrates the frequency-shifting capabilities by increasing the electrical length of the antenna. By integrating the diode between two turns of the helical antenna, the antenna resonating frequencies are shifted from higher frequency operation bands toward lower frequency bands. The four resonance frequencies, 5.68 GHz, 6.99 GHz, 8.85 GHz, and 9.49 GHz, are shifted to lower frequencies of 3.90 GHz, 5.75 GHz, 6.85 GHz, and 9.63 GHz by integrating a varactor diode. The additional four resonance frequency bands are achieved, and that is on the lower frequency side.*

Keywords - *Helical Antenna, Frequency Reconfiguration, Varactor Diode, Circular Polarization, Wideband Antenna.*

1. Introduction

An antenna is the eye and ear of a communication system. An antenna is the interface between an electromagnetic wave and an electrical signal. An antenna acts as a transition structure between a transmission line and free space [1]. The property of the antenna as transmitting or receiving mode remains the same; this property of the antenna is called the property of reciprocity [2]. Helical antenna is popular in wireless communication due to the property of circular polarization and comparatively high gain. The helical antenna was first invented by J. D. Kraus. A helical antenna operates in normal radiation mode and axial radiation mode. The mode of operation depends on the axial length of the antenna [1]. Stutzman and Thiele, in their work, give the detailed expressions of helical antenna design and radiation mechanisms and give the analytical models [3]. The helical is loaded in the cavity to provide the axial mode in a very compact size. This work is the turning point in the attempt to provide the compact size as well as the conformability in the aerospace applications. There is an increasing demand for antennas that will operate for multiple frequencies with a compact size. For example, in an aircraft, there are around fifty antennas, and in a fighter plane, there are more than seventy antennas used. In this particular application, the number of antennas can be reduced by using a single antenna that can resonate for multiple frequencies.

This will lead to the significant requirement of the reconfigurable antenna, which may enable a dynamic shift in the antenna properties such as radiation pattern, polarization, and resonant frequency [4]. Various communication applications are the result of the researchers who have contributed to the development and optimization of helical antennas. In the year 1947, Kraus developed the fundamental principles and design guidelines of helical antennas.

In his initial papers, he explains that in axial mode, the helical antenna can produce circular polarization with high directivity [1]. The helical antenna design and basic theoretical framework were established by Kraus. The detailed analytical methods for evaluating antenna radiation properties and design parameters were provided by Stutzman and Thiele. The gain, bandwidth, and polarization of the antenna mainly depend on the parameters such as helix diameter, pitch angle, and number of turns [3].

2. Literature Review

Djordjevic et al., in their paper, claim to improve antenna gain and radiation efficiency by modification of the helical antenna ground plane [5]. Better bandwidth and radiation stability are provided by Caillet et al. by the quadrifilar helical antenna with a compact planar feeding network [6]. Helical antenna in an array fashion is prominently used for the higher gain, high directivity, and applications requiring high power. A high-power radial line helical array antenna capable of operating at higher power levels, demonstrating the scalability of helical antenna technology [7]. There is work on the size reduction of the helical antenna for biomedical and portable devices. Zhao et al. provided a compact-sized helical antenna, which is prominently used for wireless capsule endoscopy systems [8]. Bernhard presented the reconfigurable antenna systems and their applications in wireless communication networks [4]. The importance of frequency-reconfigurable antennas is highlighted by Haider et al., for spectrum efficiency improvement and reducing interference in wireless systems by reducing the use of multiple antennas. [9]. Despite all these developments, some more developments happened. However, most of these helical antenna designs are still limited to comparatively narrow frequency bands. Therefore, there is a need for a frequency-reconfigurable helical antenna that is capable of operating over a wide band.

There is a requirement for antennas that can operate over multiple resonant frequencies with a compact size. The major challenge in the compact antenna design is to maintain the antenna gain, bandwidth, and axial ratio. Helical antennas are widely used in satellite communication systems due to their high gain and circular polarization characteristics [3]. However, a conventional helical antenna is basically used for the lower band frequencies, such as WLAN and C-band. New design techniques are required to enhance the operational frequency range of helical antennas, as the classical design equations are limited to operate at frequencies in a comparatively lower frequency band [1]. This problem is overcome by the reconfigurable antenna design, which offers an effective solution by a single antenna to operate across multiple frequency bands without physical modification of the antenna structure [4].

The objective of this research is to implement frequency reconfiguration using varactor diodes, which enable dynamic frequency tuning in the frequency range of 3 to 10 GHz. Also, the objective of this work is to enhance the gain and bandwidth of the antenna. To meet different communication requirements, reconfigurable antennas are capable of tuning their operating frequency to the required frequency [4]. The reconfiguration can be achieved by different techniques such as electronic switching devices, mechanical adjustment, or tunable materials. These mechanisms alter the current distribution on the antenna structure, thereby modifying its radiation properties [9]. In this paper, varactor diode-based tuning is used for achieving frequency reconfiguration. Varactor diodes behave as voltage-controlled capacitors whose capacitance varies with the applied reverse bias voltage.

The effective electrical length of the antenna is dynamically changed by the variation in the capacitance of varactor diodes, which are integrated into the antenna. This variation leads to variation in the resonant frequency of the antenna. This method enables a single antenna structure to operate across multiple frequency bands, making it suitable for modern multiband wireless communication applications.

The reconfigurable antenna has several advantages, such as overall complexity, size, and cost of a system can be reduced by the use of a single reconfigurable antenna. The number of single-function antennas can be replaced. As the number of antennas is reduced, the subsequent power requirement will also be reduced. The reduction in power is a great advantage for portable and handheld applications. A single antenna is used for multiple frequencies, which ensures the consistency and similarity in the radiation pattern and gain of the antenna for all the frequencies used. Efficient use of the electromagnetic spectrum is possible by frequency reconfiguration, which avoids the co-site interference and jamming. [10]. There is a need for frequency reconfiguration for different applications, such as to change operating bands. An antenna can work on a single frequency. In the case of mobile, satellite communication, it is desirable to change the frequency band, so a reconfigurable antenna is needed [7].

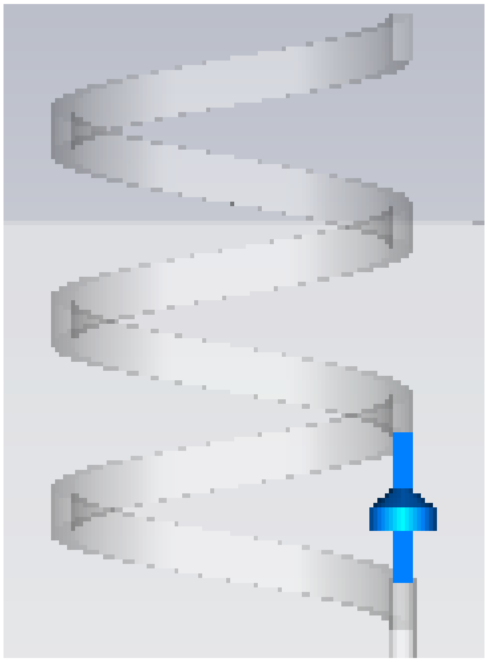
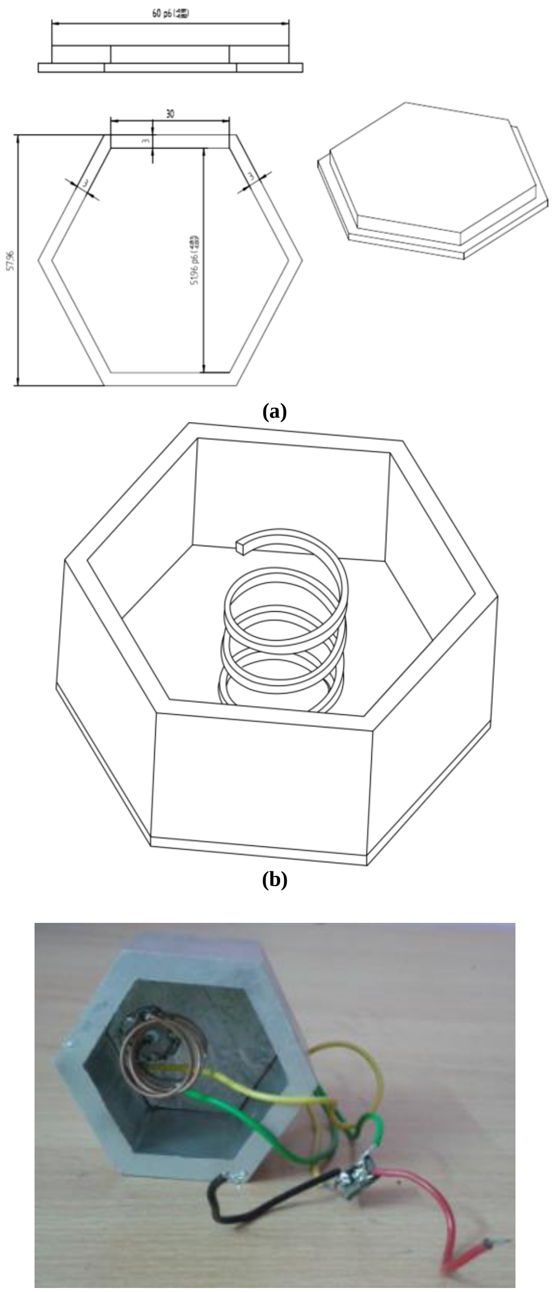


Fig. 1 Helix with varactor diode integrated



(a)

(b)

(c)

Fig. 2 (a) (b) Helical-loaded hexagonal cavity backed antenna drawing (c) Implemented antenna with varactor diode.

3. Hexagonal Cavity Backed Antenna Frequency Reconfiguration

In this paper, a varactor diode is used for the frequency reconfiguration of the hexagonal cavity-backed antenna. In the varactor diode, there is a very thin depletion layer whose characteristics are like a dielectric. The P and N region in the varactor diode is behaved as two plates of a capacitor. In the reverse bias operation of a varactor diode, the depletion layer increases. The capacitance in the diode is inversely proportional to the square root of the applied voltage.

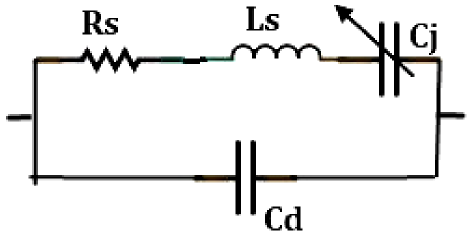


Fig. 3 Equivalent circuit for varactor

Fig. 4 Implemented biasing circuit for the diode

The reverse biased voltage is in the range of 0 to 12 V, and the capacitance change ratio is six times the initial capacitance. By varying the varactor diode capacitance, the antenna frequency is tuned accordingly as the varactor diode is integrated in the antenna. This way, the frequency reconfiguration is achieved.

The varactor diode is integrated between two turns of helical antennas, as shown in Figure 1. The helix has three turns, a pitch of 9 mm, a helix diameter of 16 mm, and a strip thickness of 2 mm, with a strip width of 1mm, which is selected to achieve the frequency reconfiguration.

3.1. Design of Hexagonal Cavity

After all these investigations of parameter variation, the helical-loaded hexagonal cavity-backed antenna is fabricated, as shown in Figure 2. There is no direct formulation available for finding the hexagonal cavity dimensions. Using the reference of cylindrical cavity, approximate dimensions are calculated. Helix is of with 3 numbers of turns, which is taken as it gives better bandwidth than 2 numbers of turns. The number of turns 4 is not used due to the requirement of compact size. The diameter of the helix is 16 mm, as it gives more resonant bands. Pitch of helix is 9mm. The cavity has a height of 25 mm and a wall thickness of 2 mm. Each side of the hexagon is 15 mm. The cavity is made up of aluminum.

3.2. Design of Reconfiguration Circuit

A varactor diode is connected between the helix to achieve the frequency reconfiguration. To achieve the tuning of resonant frequency, the varactor diode is placed between the two turns of the helical antenna. The Varactor diode model BB109 is used in the design. The antenna electrical length is varied by the reverse biasing of the varactor diode.

The equivalent circuit of the diode proposed by the inventor "Vendor" is an RLC series circuit with a parallel capacitance, as shown in Figure 3. In the varactor diode equivalent model, there are the standard values of resistor and indicators, Rs is 5 Ω and series inductance Ls is 5 nH. The variable capacitance offered by the varistor diode is shown as Cj. The varactor junction capacitance varied around six times by the applied DC biasing voltage of 0 to 12 V. Low impedance is offered to the RF signal by the capacitor Cd.

Figure 4 shows the implemented chip, which consists of a varactor diode (BB109) and a biasing circuit. The implemented chip has been connected to the helix to achieve frequency reconfiguration. Design of the above-mentioned specifications is fabricated and tested using a vector analyzer, Agilent Technologies N9916A.

The varactor diode, along with a biasing circuit, is implemented. The varactor diode is independently biased to change the electrical lengths of the corresponding modes and thereby change the resonant frequency of the corresponding modes. The bands are shifted to lower frequencies after connecting the varactor diode. Simulated and measured results are compared here. The simulation is done on the designed antenna without connecting the diode, and then connecting the diode in the helix as per the circuit design. The simulated result without implementing a diode is shown in Figure 5, and with diode integration is shown in Figure 6.

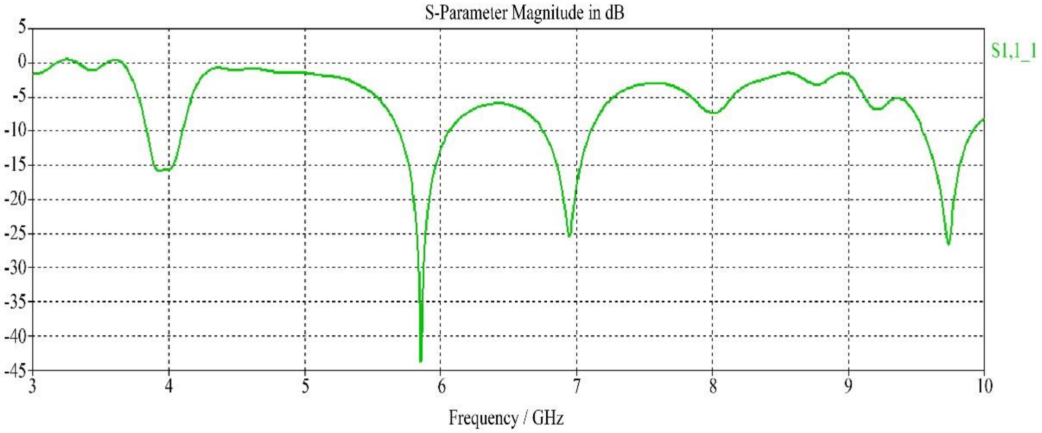


Fig. 5 Simulated result without implementing a varactor diode

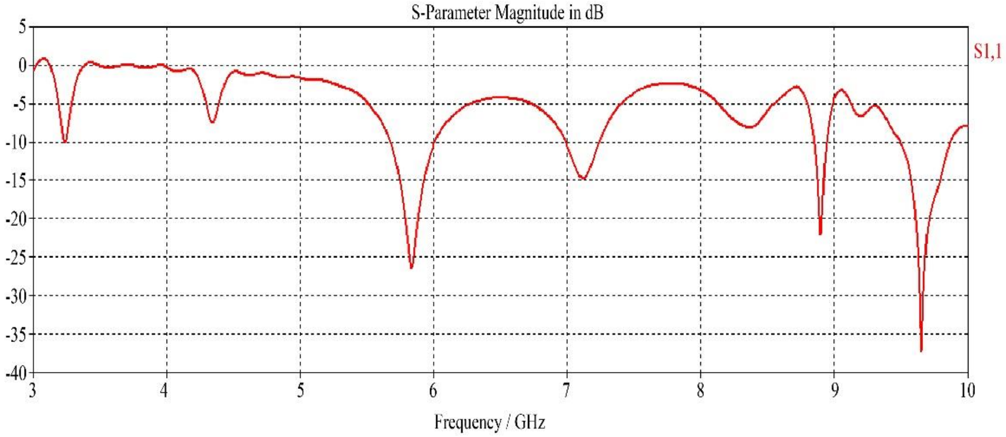


Fig. 6 Simulated result integrating the varactor diode

4. Results and Discussion

The helical-loaded hexagonal cavity-backed antenna was designed, fabricated, and tested. The simulation and the test results were compared. The antenna frequency reconfiguration was verified by comparing the results of the antenna integrated with a varactor diode and the antenna without varactor diode integration in a helix. The bandwidth of the antenna, resonant frequency range, and number of operating bands were obtained after experimentation. Simulation is done using CST-Microwave Studio, and experimental measurement is done by using a vector network analyzer, Agilent Technologies N9916A. Initially, the antenna was analyzed without integrating the varactor diode, which represents the baseline performance of the helical-loaded cavity-backed antenna. To create the reference for the frequency reconfiguration, the antenna is tested without integration of the varactor diode. The simulated result shows that the four frequency bands are observed in the frequency range of 3 to 10 GHz. The simulated results indicate four bands, which are at 5.68 to 6.00 GHz, 6.99 to 7.24 GHz, 8.85 to 8.95 GHz, and 9.49 to 9.86 GHz, resulting in a total simulated bandwidth of 1.04 GHz.

However, during measurement using a vector network analyzer for the antenna, two dominant operating bands were measured at 6.26–6.45 GHz and 6.95–7.50 GHz, with a total measured bandwidth of 0.55 GHz. Due to connector losses, practical measurement conditions, and attributed to fabrication tolerances, the number of bands is reduced. In the frequency region 6 to 7.5 GHz, the measured results showed agreement with the simulated results. The results demonstrate that the basic antenna structure without reconfiguration primarily operates in the C-band and lower X-band region, which is consistent with the expected performance of conventional helical antennas.

The frequency reconfiguration is achieved by integration of a BB109 varactor diode between two turns of the antenna. The electrical length of the antenna is modified by the voltage-controlled capacitance of the varactor diode. The shift in resonant frequency depends on the reverse bias voltage to the varactor diode. After integrating the varactor diode in the simulation, the results show four frequency bands, which are at 3.90 to 4.04 GHz, 5.75 to 5.96 GHz, 6.85 to 7.03 GHz, and 9.63 to 9.82 GHz, with a total bandwidth of 0.72 GHz, as compared to the non-reconfigurable antenna structure, where the resonant frequency shifted towards the downward side. This confirms that the presence of the varactor diode increases the effective electrical length of the antenna, resulting in resonance at lower frequencies. The experimental measurements also validate this behavior of frequency shift towards the downward side. The antennas with the varactor diode, for the measured results, show four operating bands. The frequency bands are 2.36 to 2.70 GHz, 2.80 to 2.92 GHz, 5.35 to 5.50 GHz, and 8.09 to 8.15 GHz, with a total bandwidth of 0.66 GHz. These results show that the integration of the varactor diode enables multiband operation across a wider frequency range, which extends the antenna operation to the S-band, C-band, and lower X-band frequencies.

4.1. Comparison between Simulated and Measured Results

There is a good argument observed between the simulated and measured frequencies. This is shown in Figures 7 to 11. The agreement is also observed in terms of the general trend of frequency reconfiguration and band shifting.

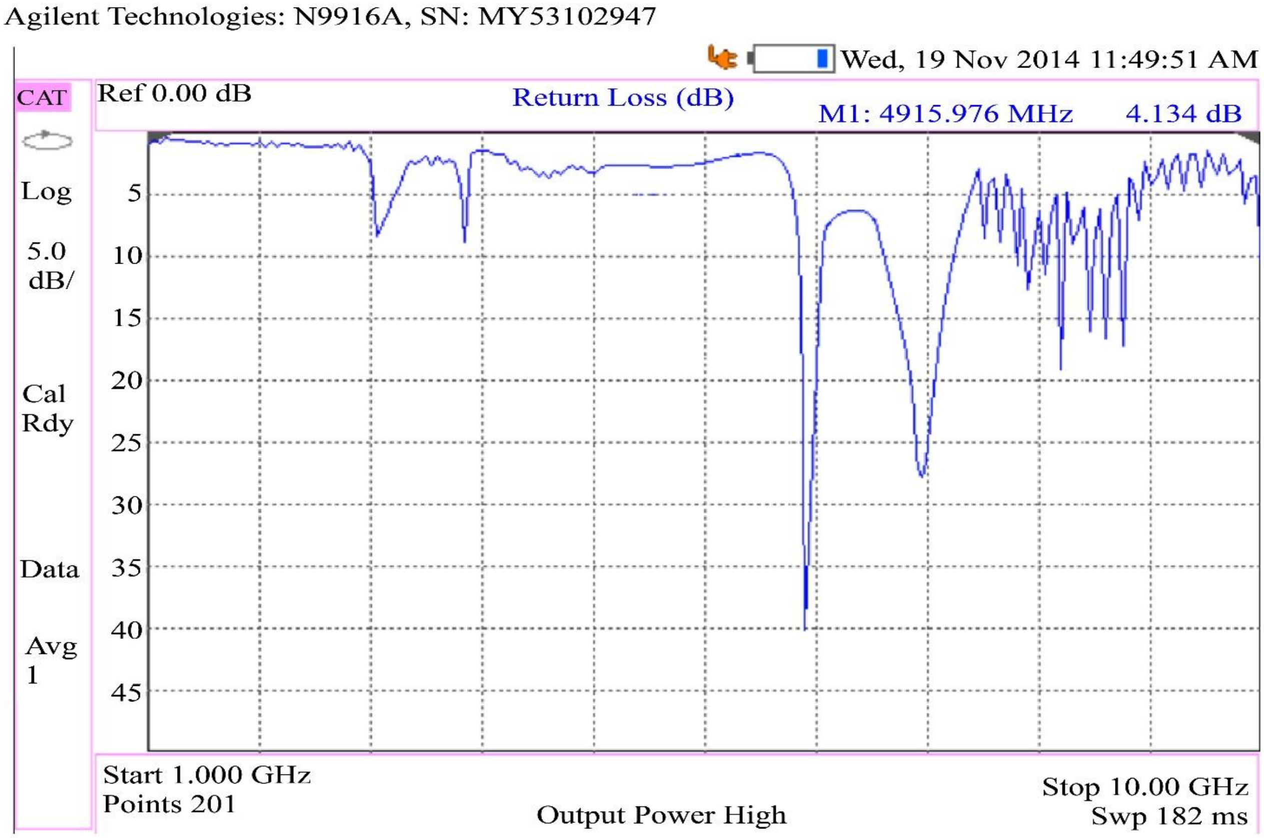


Fig. 7 Without a diode, the test result

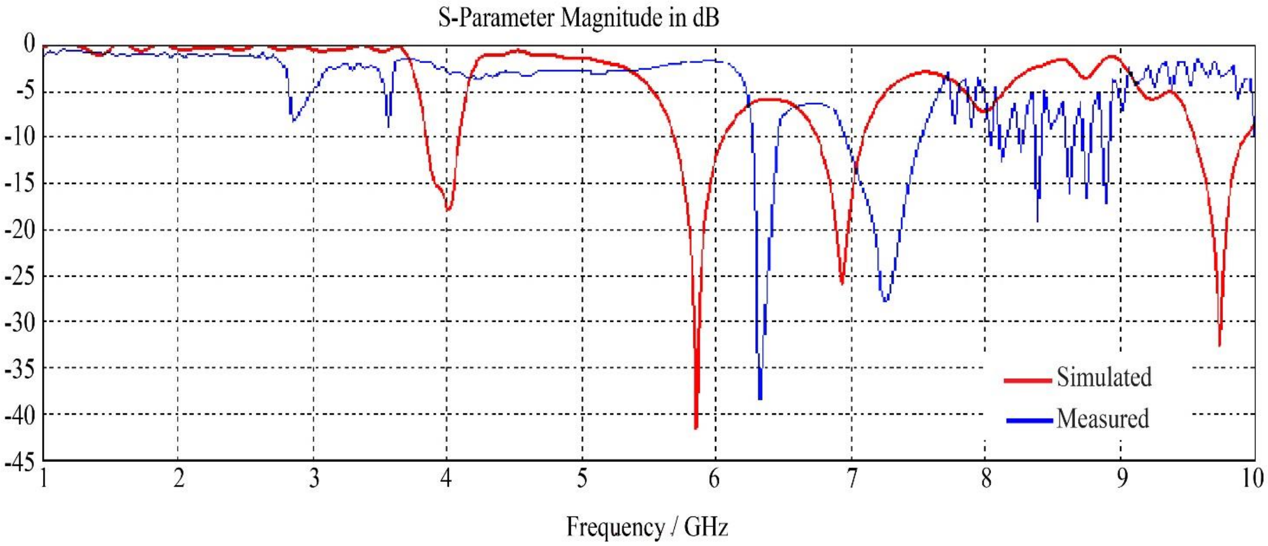


Fig. 8 Comparative results

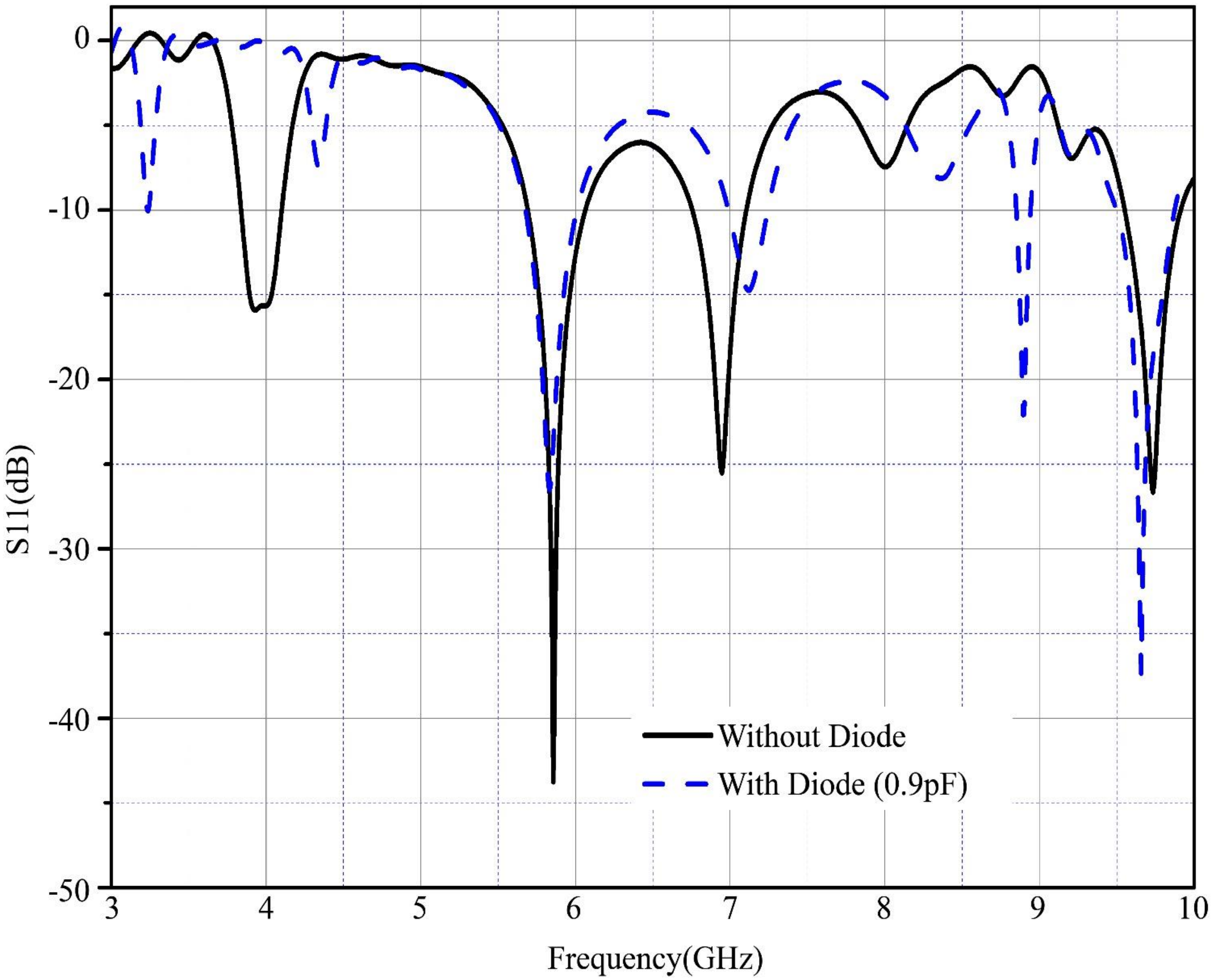


Fig. 9 Simulated comparative result

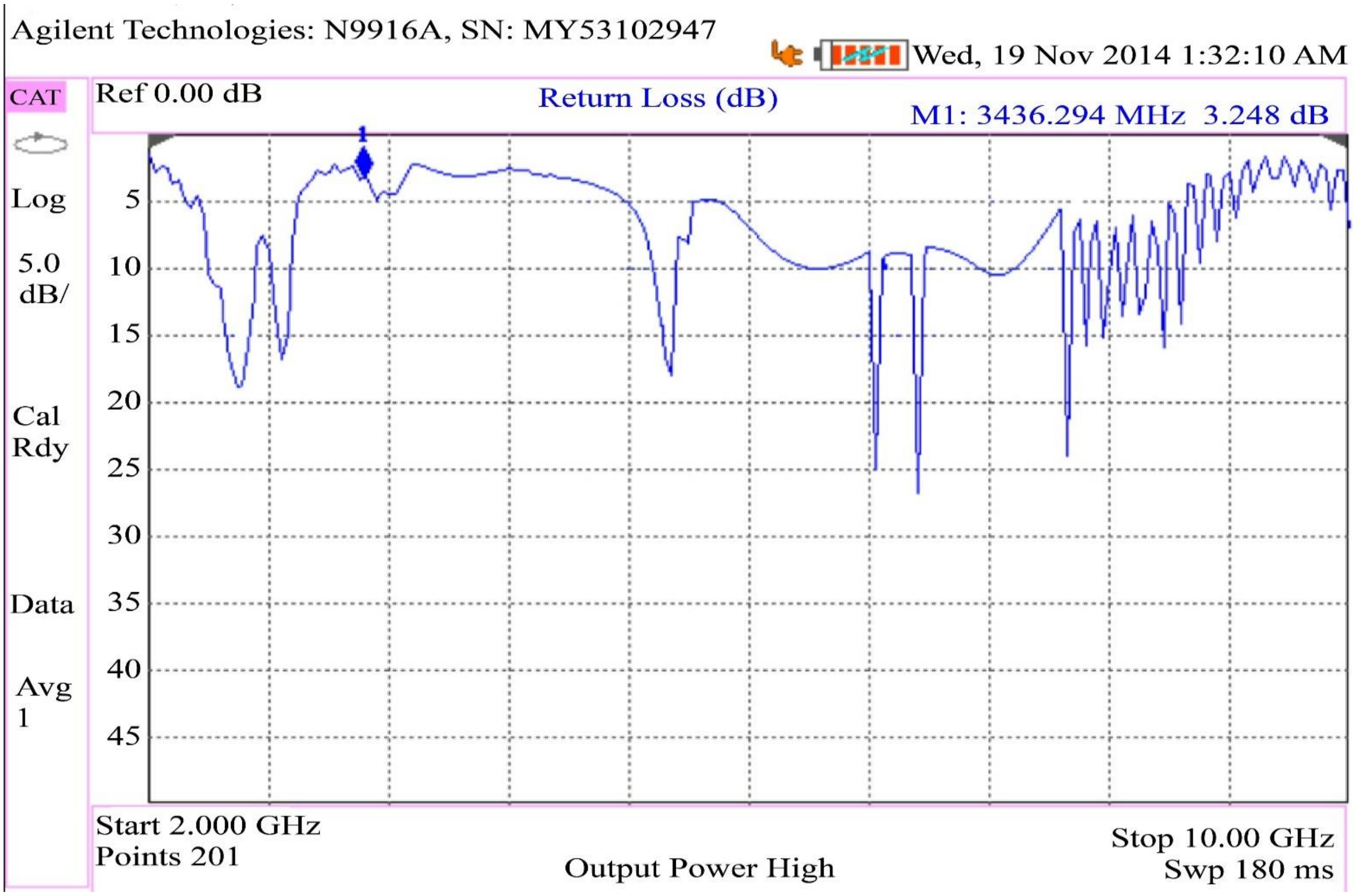


Fig. 10 With Diode test results

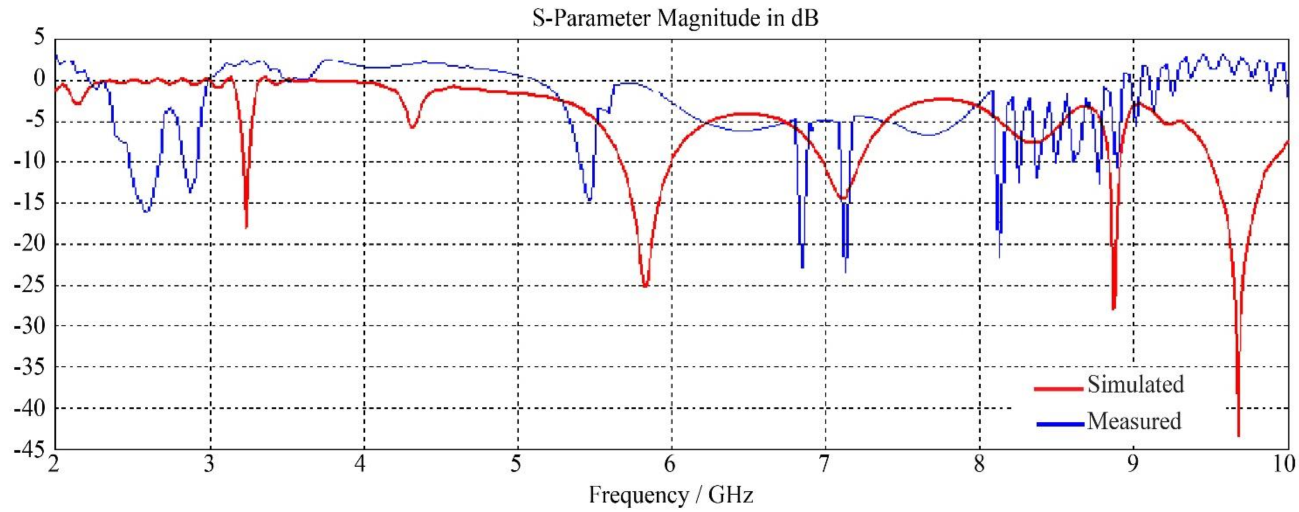


Fig. 11 With the diode comparative result

A comparison of simulated and measured results indicates good agreement. Minor discrepancies between simulated and measured resonant frequencies can be attributed to several practical factors such as manufacturing tolerances in the helix geometry, parasitic inductance and resistance of the varactor diode, imperfections in the biasing circuit implementation, losses introduced by the SMA connector, and measurement setup. Despite these differences, the overall frequency reconfiguration behavior is clearly observed in both simulation and measurement results, confirming the validity of the proposed design.

Table 1. Comparative results

Configuration	Mode of Experimentation	No. of Bands	Band1	Band2	Band3	Band 4	B.W(GHz)
With out diode	Simulated	4	5.68-6.00	6.99-7.24	8.85-8.95	9.49-9.86	1.04
	Tested	2	6.26-6.45	6.95-7.5	-	-	0.55
With Diode	Simulated	4	3.90-4.04	5.75-5.96	6.85-7.03	9.63-9.82	0.72
	Tested	4	2.36-2.7	2.8-2.92	5.35-5.50	8.09-8.15	0.66

4.2. Performance Improvement and Practical Implications

The integration of the varactor diode significantly enhances the functional flexibility of the antenna. While the antenna without a diode primarily operates in higher frequency bands, the reconfigurable configuration enables operation across multiple frequency regions, including 2.36 GHz to 8.15 GHz. This demonstrates that the antenna can dynamically adapt to different communication requirements. The proposed antenna, therefore, provides several advantages, such as multiband frequency operation, Dynamic frequency tuning capability, Compact antenna structure, and reduced requirement for multiple antennas in communication systems. Such characteristics make the antenna suitable for modern wireless communication systems, satellite communication, and adaptive RF systems, where the ability to operate over multiple frequency bands using a single antenna structure is highly desirable.

5. Conclusion

The significant impact of the hexagonal cavity is the multiband resonant frequency. The varactor diode demonstrates the frequency-shifting capabilities by increasing the electrical length of the antenna. By integrating the diode between two turns of a helical antenna, the antenna resonating frequencies are shifted from higher frequency operation bands toward lower frequency bands. For example, the first simulated band shifts from 5.68 GHz, which is observed without integrating the diode, to 3.90 GHz with integrating the diode. In the measured result, it is observed that the bands extend further down to 2.36 GHz. This frequency shift occurs towards the lower frequency side because the varactor diode capacitance increases the reactive loading of the antenna.

Further, the electrical length of the antenna increases. In addition to this, three other resonance frequencies, 6.99 GHz, 8.85 GHz, and 9.49 GHz, are shifted to lower frequencies of 5.75 GHz, 6.85 GHz, and 9.63 GHz by integrating a varactor diode. The additional four resonance frequency bands are achieved, and that is on the lower frequency side; consequently, the antenna resonance frequency shifts towards lower frequencies. The physical size of the antenna remains unchanged, resulting in a compact physical size.

Conflicts of Interest

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

References

[1] John D. Kraus, and Ronald J. Marhefka, *Antennas for All Applications*, 3rd ed., McGraw-Hill, pp. 1-938, 2002. [Google Scholar] [Publisher Link]

[2] Constantine A. Balanis, *Antenna Theory: Analysis and Design*, 2nd ed., Wiley, pp. 1-941, 1997. [Google Scholar] [Publisher Link]

[3] Warren L. Stutzman, and Gary A. Thiele, *Antenna Theory and Design*, Wiley, pp. 1-598, 1981. [Google Scholar] [Publisher Link]

[4] Jennifer T. Bernhard, *Reconfigurable Antennas*, Morgan & Claypool, pp. 1-65, 2007. [Google Scholar] [Publisher Link]

[5] Antonije R. Djordjevic, Alenka G. Zajic, and Milan M. Ilicss, "Enhancing the Gain of Helical Antennas by Shaping the Ground Conductor," *IEEE Antennas and Wireless Propagation Letters*, vol. 5, pp. 138-140, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[6] Mathieu Caillet et al., "A Broadband Folded Printed Quadrifilar Helical Antenna Employing a Novel Compact Planar Feeding Circuit," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 7, pp. 2203-2209, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[7] Xiang-Qiang Li et al., "A GW-level High-power Radial Line Helical Array Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 9, pp. 2943-2948, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[8] Dechun Zhao et al., "Miniaturization Design of the Antenna for Wireless Capsule Endoscope," *2010 4th International Conference on Bioinformatics and Biomedical Engineering*, Chengdu, China, pp. 1-4, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[9] N. Haider, D. Caratelli, and A.G. Yarovoy, "Recent Developments in Reconfigurable and Multiband Antenna Technology," *International Journal of Antennas and Propagation*, vol. 2013, pp. 1-14, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[10] H.T. Hui, E.K.N. Yung, and Y.M. Bo, "Experimental and Theoretical Studies of a DR Loaded Helical Antenna," *IEEE Antennas and Propagation Society International Symposium. 1995 Digest*, Newport Beach, CA, USA, pp. 1887-1890, 1995. [CrossRef] [Google Scholar] [Publisher Link]