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Adaptive micro strip antennas for 5G networks

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ABSTRACT

The advent of fifth-generation (5G) technology and progressing further to six-generation (6G) technology has created a new era of high-speed wireless communication, demanding antennas with enhanced capabilities to fulfill the dynamic demands of various applications. This paper presents novel approaches to designing antennas in the GHz frequency range for 5G networks by incorporating re-configurability features. Adaptive antennas provide the flexibility to alter their radiation configurations, frequencies, or polarization states, allowing them to optimize performance under different operating conditions. The theoretical foundations are explored, and reconfigurable antennas are simulated using HFSS, focusing on frequency and pattern variation at GHz frequencies using different types of switches such as pin diodes and rods. Through simulations, the antenna's S parameters are evaluated, demonstrating its capacity to meet the rigorous specifications of 5G applications. Its adaptive nature enhances connectivity and overall network performance, supporting the successful deployment and advancement of 5G technology in diverse real-world applications.

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1. INTRODUCTION

The swift progress in the technologies of wireless communication has made the fifth-generation (5G) networks to come into existence, promising extraordinary data rates, lesser latency, and immense device connectivity [1]. As 5G networks become increasingly ubiquitous, the demand for antennas that can adapt to the dynamic and diverse requirements of different communication scenarios becomes vital. The ability of the reconfigurable antennas to dynamically adjust to their properties as per the requirements has gained trivial attention as a noble solution to address the problems posed by the complex and diverse environments in which 5G operates. Traditional antennas, while effective in specific scenarios, may face limitations in providing optimal performance across the diverse use cases anticipated for 5G. Some of these challenges are superior mobile broadband, massive machine-communication, and ultra-reliable low-latency communication. Reconfigurable antennas offer a versatile solution by incorporating tunable elements that enable adjustments to key parameters like frequency, radiation pattern, and polarization. The motivation behind reconfigurable antenna design lies in its potential to enhance the coverage, capacity, and reliability of 5G networks. In urban environments, where signal interference and multipath fading can degrade performance, a reconfigurable antenna can dynamically adapt its configuration to mitigate these challenges. In rural or remote areas, where connectivity requirements may vary, the same antenna can be adjusted to optimize coverage and signal strength.

Recent studies and advancements in reconfigurable antennas show the evaluation of adaptability to achieve different aspects of 5G networks. Dangi *et al*. [1] provided a comprehensive systematic review on 5G technology, setting the context for the need for advanced antennas. Iqbal and Shereen [2] specifically focused on the design of radiation pattern and beam forming reconfigurable antennas for 5G applications. Hong *et al*. [3] presented a directional antenna design tailored for millimeter-wave frequencies to enhance 5G broadcasting coverage. The researchers [4], [5] introduced a frequency and radiation pattern and polarization based reconfigurable antennas for 5G applications. The researchers [6], [7] focused on millimeter-wave antennas specifically designed for smartphones, and 5G WAN applications. Orugu *et al*. [8] introduced a novel approach by utilizing metamaterials to inspire azimuth pattern reconfigurability in antennas. This work explores innovative materials and designs to achieve dynamic control over antenna patterns, contributing to the evolving field of reconfigurable antennas. Fan *et al*. [9] presented a millimeter-wave pattern-reconfigurable Vivaldi antenna utilizing graphene based tunable resistors. The integration of graphene introduces tunability, providing a unique mechanism for pattern adaptation in 5G antennas. Liquid metal-based yagi-uda antenna is proposed by Hao *et al*. [10] which does a pattern-reconfiguration. Liquid metal offers a flexible and adaptive medium for altering the antenna configuration, presenting a new avenue for achieving reconfigurability in 5G antennas. Santamaria *et al*. [11] explored for IoT applications a slot-based pattern reconfigurable electronically steerable parasitic array radiator (ESPAR) antenna. This work contributes to the expanding applications of reconfigurable antennas beyond traditional communication networks. Tu *et al*. [12] offers a survey on the integration of reconfigurable microstrip filters and antennas, highlighting recent advancements and identifying challenges. The authors discuss the significance of combining filtering and radiating functionalities in a single unit and explore the potential applications of such integrated systems.

Parchin *et al.* [13] delves into switching techniques employed in reconfigurable antennas. The survey provides insights into various methods, including pin diodes, fluidic channels, and varactor-loaded patterns. Understanding these switching techniques is crucial for designing antennas with adaptable characteristics. Parchin *et al.* [14] present a frequency-switchable patch antenna with a parasitic ring load for 5G mobile terminals. This work introduces a specific design and demonstrates its feasibility for next-generation mobile communication devices. The study contributes to the ongoing efforts in developing frequency-agile antennas for evolving wireless communication standards. The review incorporates studies on unconventional materials and designs for reconfigurable antennas. Singh *et al*. [15] explore a multistate frequency-reconfigurable monopole antenna employing fluidic channels, while Wang *et al*. [16] designed a reconfigurable-patch antenna utilizing the liquid metal movement. These approaches showcase the potential of novel materials and fluidic technologies in achieving reconfigurability. Ding *et al*. [17] present a varactor-loaded pattern reconfigurable patch antenna with shorting pins. The study focuses on the integration of varactors, providing tunability to the antenna's operating frequency. Understanding the performance of varactor-loaded designs is critical for optimizing reconfigurable antennas in practical applications. Recent contributions to the field are highlighted in [18], [19]. Sakkas *et al*. [18] introduce a frequency-selective reconfigurable antenna targeting wireless applications both in the S as well as in C bands, while Patel *et al*. [19] proposed using pin diodes a low-cost, multiband, high-gain microstrip radiating structure. These studies emphasize the practicality and potential commercial applications of reconfigurable antennas. Patel *et al*. [20] introduces reconfigurable antennas that is low-cost, and compact, using complementary split-ring resonator meta-surfaces. This innovative approach leverages meta-materials to achieve re-configurability, opening up new avenues for designing efficient and adaptable antennas for next-generation communication systems.

The literature review indicates a growing interest in reconfigurable antennas tailored for 5G applications. Researchers are exploring various strategies, including frequency adaptation, radiation pattern re-configurability, and the use of novel materials, to address the dynamic and diverse communication requirements of 5G networks. The studies presented in the literature showcase the multidimensional nature of reconfigurable antennas and their significant role in enabling the full potential of 5G technology. It provides valuable insights into the cutting-edge challenges, and subsequent directions in the field of reconfigurable antennas. This paper explores the fundamental concepts and design principles of reconfigurable antennas tailored specifically for 5G applications. The subsequent sections will give a theoretical foundation, practical implementation, and performance evaluation of the proposed reconfigurable antennas and results.

2. RECONFIGURATION ANTENNA TYPES AND TECHNIQUES

Classification of reconfigurable antennas is suggested based on reference papers [21]-[23]. Common classifications will be based on method of reconfiguration, design and structure considered, control mechanism used and application for which antenna is developed. Based on method of reconfiguration, classification is done based on frequency, beam structure, polarization used, radiation pattern adaptation and tunable impedance matching. Frequency reconfigurable antennas change their operating frequency or band of operation. This is often achieved by switching between different resonant structures, such as patches, slots, or other elements. Beam reconfigurable antennas [22] are capable of altering their radiation pattern, typically by adjusting the phase and/or amplitude of the signals feeding different elements or sub-arrays. This allows for steering the main beam or creating multiple beams in different directions.

Design of pattern reconfigurable antennas which are capable of adjusting their radiation pattern shape or characteristics is dealt in paper [23]. They have designed antennas that can switch between omnidirectional and directional patterns using MEMs switches. These classifications often overlap, as many reconfigurable antennas can fall into multiple categories depending on their design and application. Table 1 is a comparison table based on switching methodology.

The work presented in this paper is aimed to design adaptive antennas to attain frequency adaptability and radiation pattern re-configurability at GHz range for 5G and wireless local area network (WLAN) applications. Compared to other reported works, design of antenna is aimed to provide 4 different frequencies and radiation pattern variations with different switching methodologies and made a comparison. Unlike other papers, this paper uniquely presents and compares three distinct adaptive microstrip antenna designs using pin diodes, rods, and switches across different GHz bands in a single study. Use of FR4 and Rogers RT 5880—cost-effective and industry-relevant and simpler compared to usage of phase array and MEMs for steering beams. Ansys electronic desktop software tool is used to carry out the antenna designing.

Table 1. Comparison of papers according to switching methodology

Switching technology	Ref.	Reconfiguration type(s)	Frequency range (GHz)	Antenna types	Gain range (dB)	Applications	Notable contributions
Pin diodes	[2], [4], [14], [18], [19]	Frequency and pattern	2.4–5.8	Patch and slot	~5.7–6.5	5G, WLAN, and S/C bands	Cost-effective switch for dual-mode and multiband reconfig
RF MEMS	[23]	Pattern	8–10	Patch array	~7.5	mmWave beam steering	High isolation and compact MEMS-based beam switching
Liquid metal/ fluidic	[10], [15], [16]	Frequency and pattern	2.4–5.5	Yagi–Uda, patch, and mono	~4.8–5.5	IoT, Bio-medical, and compact 5G	Mechanical or fluidic reconfig with tunable frequency states
Mixed/ hybrid switching	[17], [21]	Pattern and frequency	2.0–6	Microstrip patch	~6.1–6.8	Smart antennas and 5G	Combination of varactors, pins, and MEMS for flexibility
Graphene/ varactor	[9], [17]	Pattern	2.0–30	Vivaldi and patch	~6.1–7.0	mmWave and smart antennas	Variable resistance and loading for beam shaping
Review/ survey	[5], [13], [22]	All	N/A	Various	N/A	General 5G and wireless	Broad overviews of technologies, classifi-cations, and challenges

3. METHOD

In this work three designs are considered based on [24], [25] to achieve adaptivity in frequency and radiation pattern.

The design steps followed are given below:

– With the specification considered, patch dimensions like length, width and thickness are calculated for the desired resonant frequency using:

$$L = \frac{c}{2f_0\sqrt{\epsilon_r}}\sqrt{\frac{\epsilon_r+1}{2}}$$

and

$$W = \frac{c}{2f_0\sqrt{\epsilon_r}}\sqrt{\frac{2}{\epsilon_r+1}}$$

where c and f_0 represent light speed and resonant frequency respectively, ϵ_r represent relative permittivity.

– Feed line should be designed to match the antenna impedance of 50 Ohms. The length (L) is typically kept short, depending on the layout of the antenna and the circuitry. W is calculated by calculating effective permittivity and using:

$$W = \frac{c}{2f_0\sqrt{\epsilon_{eff}}}$$

– The location and quantity of pin diodes used to switch between different options will be identified based on the number of frequencies that is required. The pin diode capacitance (C) for each frequency is calculated with the formula $C=1/(2\pi f_i)^2L$. The location of the pin diodes affects the antenna's performance, especially the radiation pattern. Place pin diodes at appropriate locations on the patch antenna.
– Design the biasing circuit for the pin diodes to switch between the desired frequencies. Choose appropriate biasing voltages and control mechanisms based on the pin diode specifications.
– The notches are created in the radiator and ground plane of a patch antenna to control the antenna's performance characteristics, including bandwidth, frequency tuning, polarization diversity, radiation pattern, impedance matching, and isolation. Generate the notch responses by etching slots in the radiator and ground plane to get required responses.
– Simulate the antenna in HFSS and verify and fine-tune the design through simulation and testing.Check for BW, return loss, and radiation pattern.

4. DESIGN AND RESULT DISCUSSIONS

This section discusses various antenna design configurations along with their corresponding performance results. Each design addresses specific application needs and highlights different techniques for achieving reconfigurability and adaptability.

4.1. Design-1: frequency reconfigurable antenna with pin diodes

In the first work, a micro strip patch antenna is designed to switch between 4 different frequencies from 7.2 to 7.8 GHz. Substrate considered have permittivity ξr=4.4, Thickness of dielectric substrate (h): 1.6 mm. The patch antenna with the model shown in Figure 1 is designed with HFSS tool. Switching between 4 different frequencies is achieved using pin diodes. Table 2 shows the frequency variation and reflection coefficient for the reconfigurable antenna depicted in Figure 1.

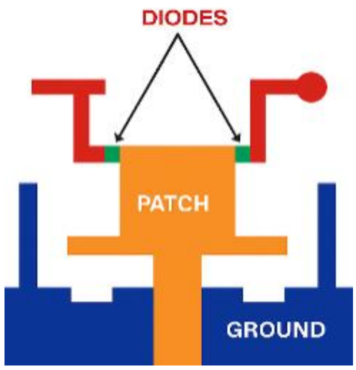


Figure 1. Structure of reconfigurable antenna for 4 frequencies

Table 2. Frequency variation and reflection coefficient

Switch positions	X–frequency in GHz	Y-S_{11} in dB
On-Off	7.2525	-20.1684
Off-On	7.1400	-22.8897
Off-Off	7.5225	-36.9343
On-On	6.8025	-16.6898

Figure 2 shows frequency variation for 4 different combinations of two pin diode switches used in the antenna design. It is observed that reflection coefficient is different at different frequencies. At 7.52 GHz, reflection coefficient is -36 dB while at 6.8 GHz, reflection coefficient is -16 dB. But values are acceptable for most of the applications.

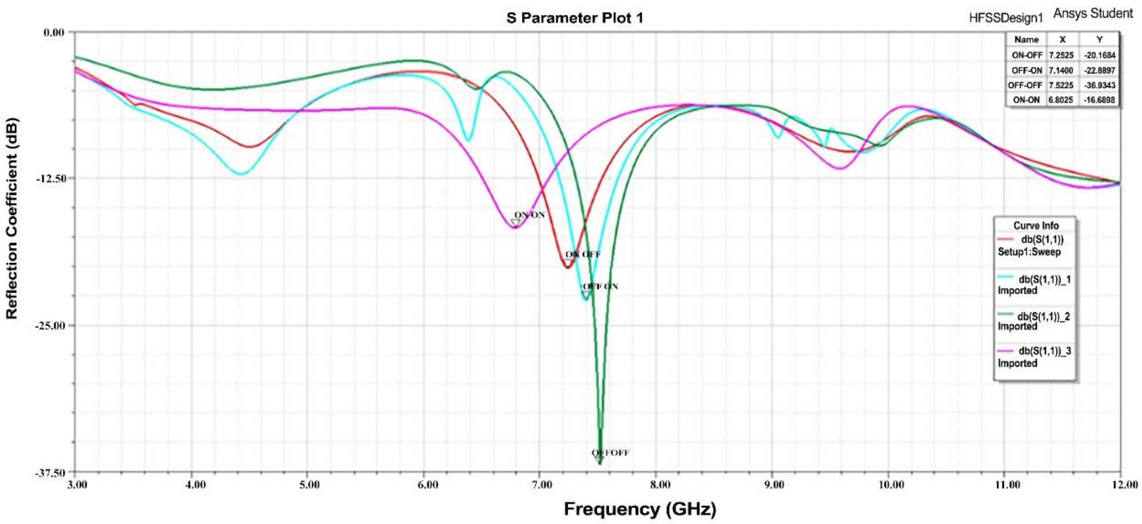


Figure 2. S-parameter graph for 4 different frequencies

4.2. Design 2: adaptive antenna for 5G and WLAN application with conducting rods

In the second design, a micro strip patch antenna is designed to get frequency adaptively for 5G and WLAN applications. Resonant frequencies considered are: 28 GHz (for 5G) & 2.4 GHz (for WLAN), the substrate used is FR4 epoxy with ξr=4.4, substrate thickness considered is h=1.6 mm. In reconfigurable antennas, conducting rods can be a tool to switch between functional frequencies. Figure 3 depicts reconfigurable antenna with conducting rods. By activating or deactivating certain rods, the antenna can switch between two frequency bands. These rods are typically added above or below the main patch radiator, and they alter the electromagnetic fields around the patch, affecting its radiation characteristics. These rods are often placed along the edges or corners of the patch. The attachment can be done using soldering, conductive adhesive, or other suitable methods. In this work conducting rods are used to close the connection to achieve antenna operation for 5G band, the open conducting rods make the antenna work for WLAN uses. The reflection coefficients at two different frequencies are shown in Figure 4. Figure 4(a) illustrates the dip at frequency 28.25 GHz, while Figure 4(b) shows it at 2.4 GHz. In both cases, reflection coefficient is below -45 dB at operating frequencies and is well suited for 5G and WLAN applications.

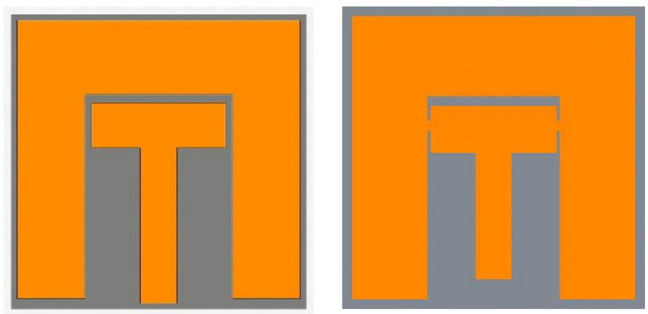
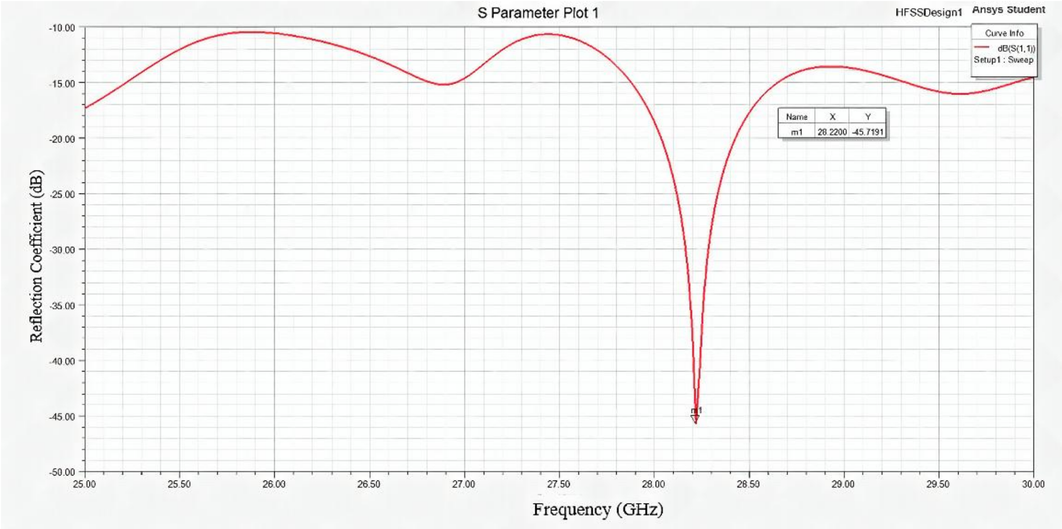


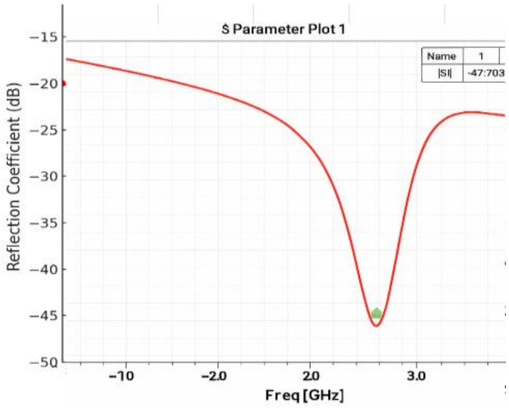
Figure 3. Reconfigurable antenna with conducting rods

4.3. Design 3: adaptive antenna for changing radiation pattern with switching

In the third design, reconfigurable micro strip patch antenna is designed to attain changing radiation patterns. This antenna is designed for operating frequency of 60 GHz. Rogers RT 5880 substrate is used with ξr=2.2, with substrate thickness h=0.381 mm. A rectangular patch with dimensions 2.4×2.5 mm^2 is bounded by additional hollow rectangular patch measuring 3×4.75 mm^2. Patch thickness is 0.381 mm thick. Figure 5 shows the assembly of the antenna design. Coaxial probe feeding is done with a joining diameter of 0.14 mm. Two switches are used to change the radiation patterns.



(a)



(b)

Figure 4. Reflection coefficients at; (a) 28.25 GHz and (b) 2.4 GHz

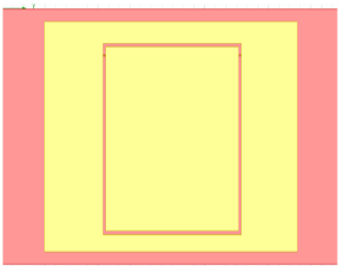
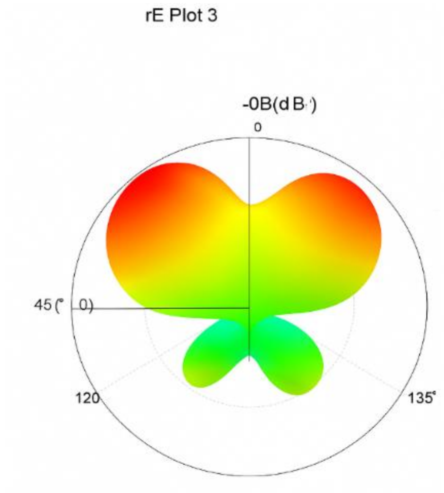


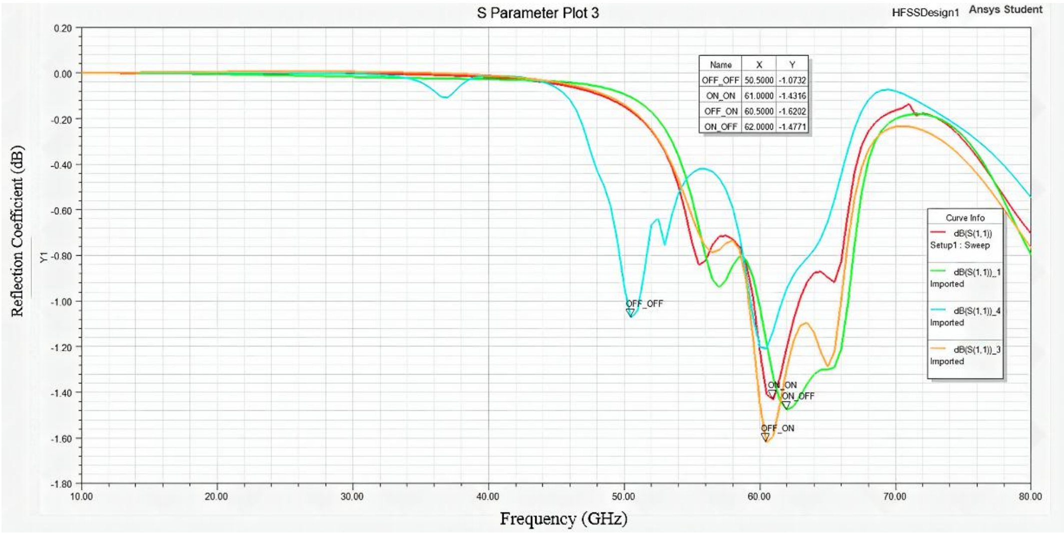
Figure 5. Antenna structure and switching status for different patterns

The projected design at 60 GHz frequency shown in Figure 6 presented a good gain of 6.4 dB. Gain for the off-on and On-off states is 6.4 dB but for On-On state, gain is 5.4 dB. The Figure 6(a) illustrates radiation pattern diversity in plane, with 38° for Mode 1, -38° for Mode 2 and simultaneously towards the angles of ±41° for Mode 3. For OFF, OFF state, there is shift in frequency and hence is neglected. Figure 6(b) shows reflections coefficients for different switch positions.

A comparison is made on the three designs considered to achieve re-configurability and summarized in Table 3. All three designs are done at GHz range, suitable for 5G applications and patch antennas are designed. FR4 epoxy is used in first two designs while Rogers RT 5880 with permittivity 2.2 is used in third design. Feeding is done through transmission line in first two designs while coaxial cable is used in third design. First two designs are for frequency re-configurability while the third one is to change radiation pattern.



(a)



(b)

Figure 6. Design at 60 GHz; (a) radiation pattern and (b) reflection coefficients for different switch positions

Table 3. Assessment of antennas designed

	Design-1	Design-2	Design-3
Antenna type	Patch	Patch	Patch
Dimensions (in mm)	31×23×1.6	30×26.5×1.6	6.73×3.34×0.381
Substrate (dielectric const.)	FR4 epoxy (4.4)	FR4 epoxy (4.4)	Rogers RT 5880 (2.2)
Reconfiguration type	Frequency	Frequency-based on application	Radiation direction
Feeding technique	Transmission line	Transmission line	Coaxial
Switching method	Pin diodes	Conducting rods	Switches
Frequency range (in GHz)	7.2-7.8 GHz	28 & 2.4 GHz	60 GHz

5. CONCLUSION

This work does a detailed survey of constructing reconfigurable antennas. These antennas are classified and grouped based on the parameters for which re-configurability is required. Three design methods are considered to attain reconfiguration with respect to frequency and radiation pattern. A compact micro strip antenna with frequency shifting characteristics is aimed in design-1, 5G and WLAN adaptable antenna is considered in design-2 and pattern re-configurability is achieved in design-3. It is evident that with patch antenna, one can design antennas with adaptable characteristics which are cost effective and useful for different applications. Further work can be done to achieve polarization adaptability and using other types of switches. This work is simulation-based using HFSS, and physical prototype implementation is planned as the future work. Prototyping high-frequency antenna at 60 GHz is challenging as it require high-precision fabrication.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Kanakatte Lakshmi Narayana Sudha	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	
Sapna Pallipadi Jayaprakash		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		
Deepa Neralahalli Prakash		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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