5G WIRELESS APPLICATIONS USING RECONFIGURABLE ANTENNAS: A REVIEW

Abstract

This review explores recent advancements in multi-band reconfigurable antennas, highlighting their crucial role in meeting the stringent demands of fifth-generation (5G) wireless communication systems, particularly in the context of device miniaturization. We analyze various reconfiguration techniques, including electronic switching (specifically PIN diodes and varactor diodes) and their impact on operational frequency, radiation pattern, and polarization. The paper details the characteristics of reconfigurable antennas such as broad bandwidth, significant gain, high efficiency, and compactness, which are essential for 5G applications like massive multiple-input multiple-output (MIMO) systems, cognitive radio, and enhanced spectrum efficiency. We provide a critical comparison of different reconfigurable antenna types based on their performance metrics and discuss the challenges and future research directions, including integration with AI and novel materials.

Keywords: Reconfigurable Antennas, Frequency Tuning, 5G, Beam Steering, PIN Diode, MIMO.

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I. INTRODUCTION

The rapid evolution of wireless technology, particularly with the advent of 5G, necessitates highly adaptable and efficient antenna systems. The objectives of 5G technology, which include high data rates, minimal latency, and enhanced spectrum efficiency, drive the demand for antennas that can adjust their operational parameters dynamically [1-2]. Reconfigurable antennas offer a promising solution by providing adaptability in operational frequency, radiation pattern, and polarization, achieved through modifications of their physical characteristics using techniques such as electronic switches, optical switches, or meta-materials. This adaptability is critical for addressing the push towards miniaturization in wireless devices while maintaining dependable and effective communication [3-9].

This review aims to provide a comprehensive overview of the latest developments in reconfigurable antennas for 5G wireless applications. We specifically focus on how reconfigurability addresses the key requirements of 5G, such as massive MIMO, millimeter-wave (mmWave) bands, low latency, high reliability, and device miniaturization [8-9]. The paper critically analyzes various reconfiguration methods, including electrical and mechanical switching approaches, and compares their performance metrics and trade-offs [9]. Furthermore, we identify current research gaps and propose future directions for the development of reconfigurable antennas. This review fills a gap by offering a focused and quantitative comparison of reconfigurable antenna types specifically tailored to the emerging needs and challenges of 5G ecosystems.

The integration of terrestrial mobile communications with space communications within the 5G network is expanding the scope of potential use cases. This integrated approach facilitates communication services in rural and underserved areas and simultaneously caters to the high demands of densely populated urban areas by supporting on-premises local networks [7]. Moreover, the integrated 5G terrestrial network supports diverse applications such as content acquisition and distribution, highly distributed IoT networks, and private mobile and nomadic deployments, thereby maximizing coverage, scalability, and flexibility across various geographical regions and user scenarios.

II. RECONFIGURATION METHODS AND ANTENNA TYPES

Reconfigurable antennas are frequently utilized in multi-band systems due to their capacity to dynamically adapt to spectrum restructuring. In contrast to traditional antennas, which are limited to a single band, this requirement for accommodating multiple antennas arises as wireless communication services broaden. As a result, this leads to the proliferation of larger devices, complex circuitry, and constrained bandwidth [10-11]. A planar antenna with hexa-band frequency reconfigurability was developed [12] and realized using a 1.6 mm thick substrate of dielectric constant 4.4, introducing a truncated ground plane (Fig. 1). The antenna functions across five distinct frequency modes, determined by the configuration of two lumped elements, covering multiple wireless applications, with a Voltage Standing Wave Ratio value below 1.45. In [13], An inverted planar F antenna developed for wide area wireless network mobile phone integrates a PIN diode to facilitate reconfigurability. In its activated state, this antenna can operate across three Global SM bands and Universal Mobile Telecommunication System bands, while under its deactivated state, it functions solely within the GSM900 band.

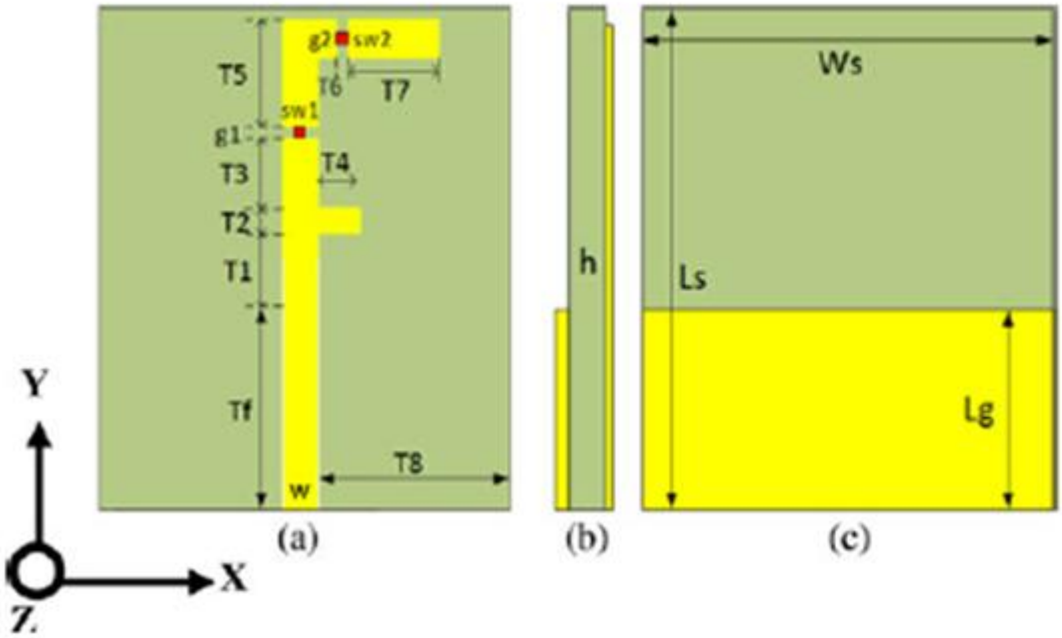

Figure 1: Multiband Reconfigurable antenna.

1. Frequency Reconfigurable Antennas

Frequency reconfigurable antennas (Fig. 2) use RF-switches to toggle between various frequencies as and when required. Among the varied applications of these antennas are MIMO systems, cognitive radio systems, and biomedical applications [8,14]. The frequency reconfigurable antenna in [15] is intended for cognitive radio applications. Capable of flexible reconfiguration, this antenna can span a broad operating band from 3.0 GHz to 10 GHz, encompassing six distinct narrow band frequencies ranging from 5 GHz to 10 GHz. The antenna described in reference [16] has the capability to switch between multi-band mode and wide-band mode by altering the switch state, as illustrated in Figure 2. The dimensions of the elliptical monopole are calculated using equation [13] to attain a lower frequency of approximately 1.3 GHz:

$$f = \frac{c}{\lambda} = \frac{30 \times 0.24}{l \times r} \text{GHz} \ldots (1)$$

$$r = \frac{a \times b}{2 \times l} \qquad \ldots (2)$$

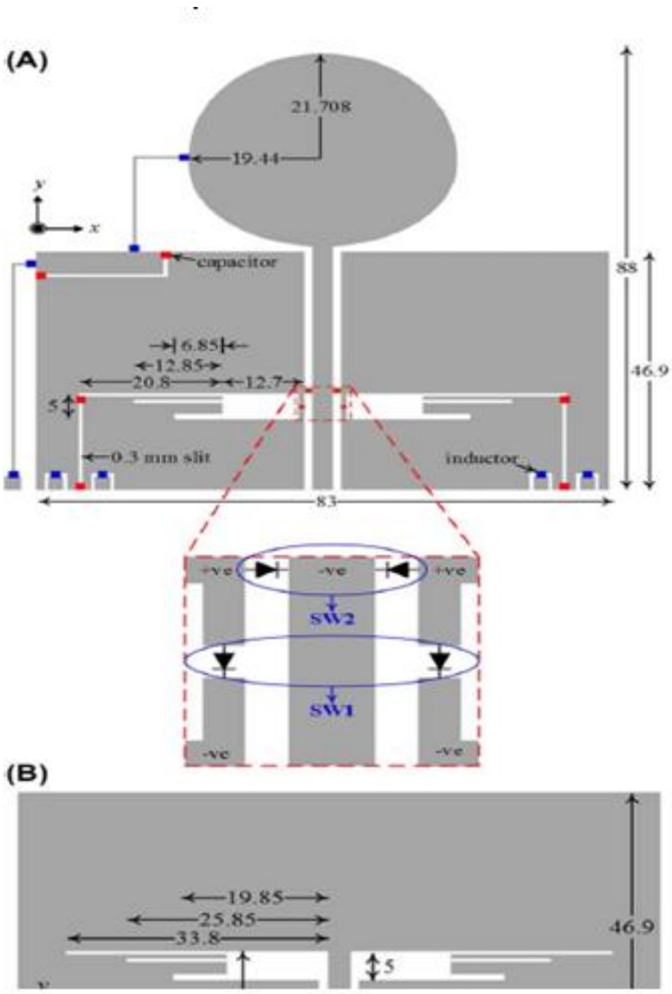

Figure 2: Frequency Reconfigurable Antenna. (A) zooming view of the switches (B) Reference antenna

In the equation, 'c' represents the speed of light, 'k' represents the wavelength, 'l' signifies the height of the elliptical wire, and 'r' denotes the equivalent radius of the elliptical monopole. 'a' stands for the semi-major axis, while 'b' represents the semi-minor axis. All measurements of 'a', 'b', 'l', and 'r' are expressed in centimetres.

To enable multiband operation, two pairs of PIN diodes (denoted as SW1 and SW2) are strategically positioned along the Co-Planar-Waveguide-fed line. A 100 pF capacitor is integrated across the 0.3 mm slit to function as a DC blocker, while a 27 nH inductor serves as an RF choke. Multiband functionality is activated by utilizing the multiband slot dipole with a CPW-fed line. During this mode, SW1 is deactivated while SW2 is activated, effectively isolating the wideband monopole. This configuration enables the antenna to function across frequencies of 2.4, 3.5, and 5.2 GHz (Fig. 3). Conversely, activating wideband mode involves turning on SW1 and turning off SW2.

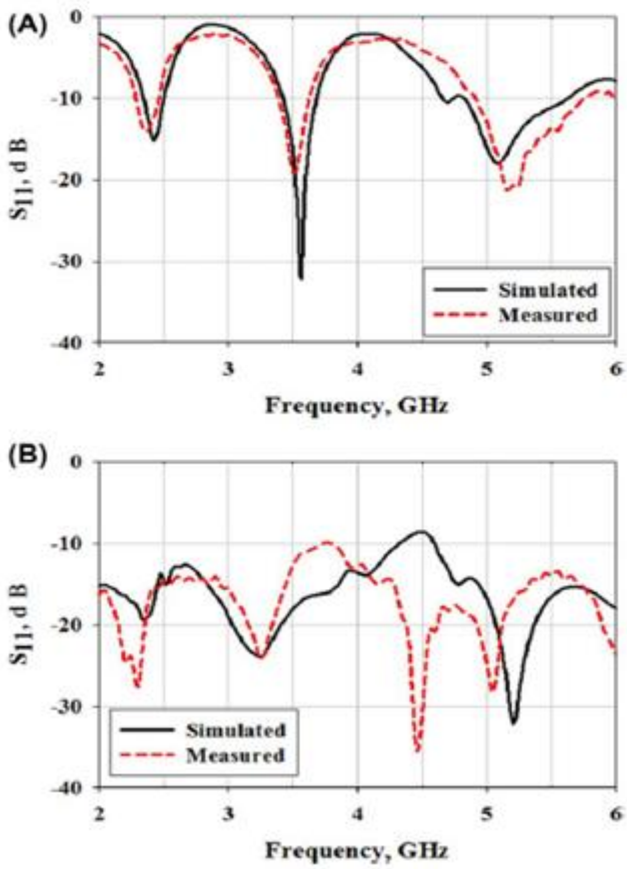

Figure 3: Simulated and measured S11 (A)Multiband mode (B) Wideband mode

2. Radiation Pattern Reconfigurable Antennas

Radiation pattern reconfigurable antennas have the ability to adjust their radiation pattern while operating at a fixed frequency. An innovative pattern reconfigurable antenna design was presented in [17] for millimeter-wave operation. This is a dielectric resonator antenna (DRA) equipped with the capability to reconfigure its radiation pattern (Fig.4). To achieve reconfigurability in the azimuth plane, a design incorporates six symmetrically positioned electromagnetic bandgap (EBG) sectors around the Dielectric Resonator Antenna (DRA). Each sector consists of twenty-six circular mushroom-like EBG unit cells.

To enable 360-degree pattern reconfigurability with minimal diodes, a network of metallic veins printed on a conductor-backed dielectric slab groups and interconnects the vias within each EBG sector. Additionally, a switching PIN diode is integrated into the circuit to control beam steering across the entire azimuth plane. This diode directs the beam towards the desired sector by toggling it on and off. A prototype of the 60 GHz DRA, incorporating this EBG switching circuit, has been fabricated and tested. The results show 360-degree pattern reconfigurability in the azimuth plane, achieving a realized gain of 4.2 dBi and impedance matching levels of less than -16 dB across the desired bandwidth. In summary, this proposed antenna system offers beam-steering capabilities across the 360-degree azimuth plane, demonstrating promising performance metrics. Further exploration of radiation pattern reconfigurable antennas is discussed in [18-20].

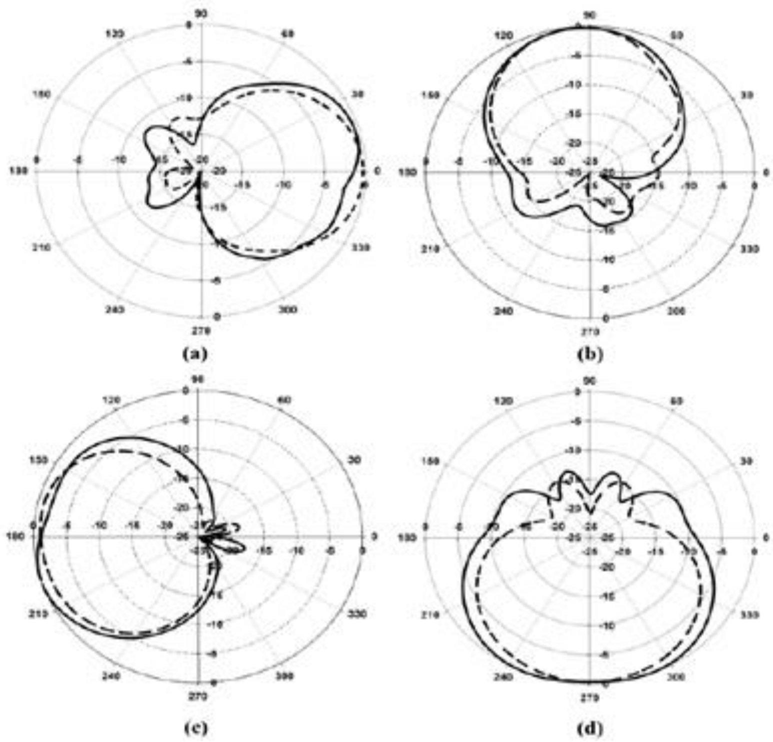

Figure 4: Simulated (dashed) and measured (solid) radiation patterns in the azimuth plane for different diode combination states: (a) Diodes 2,3,4,5 ON (b) Diodes 4,5,6 ON (c) Diodes 1,2,5,6 ON (d) Diodes 1,2,3 ON

3. Polarization Reconfigurable Antennas

Polarization reconfigurable antennas have the capability to adjust their polarization orientation while maintaining a spontaneous radiation pattern and frequency. In reference [21], a circular polarization technique is introduced for application in 5G wireless communication systems. The method facilitates operation in both right-hand and left-hand circular polarization modes using two PIN diodes. In a study referenced as [22], the authors propose a square patch antenna with a microstrip line feed. This design integrates two independently biased PIN diodes to switch between right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP). Figure 5 illustrates the gain improvement achieved through diode switching for the same antenna. Meanwhile, in reference [23], a coplanar waveguide-fed antenna capable of switching between LHCP and RHCP is presented. Additionally, in reference [24], the antenna demonstrates vertical and horizontal polarization modes depending on the chosen feed mechanism.

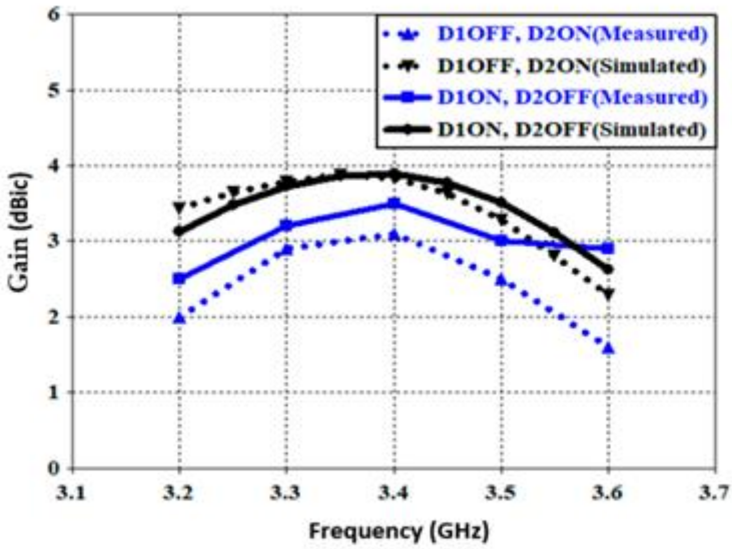

Figure 5: Measurement and simulation results for maximum gain

4. Hybrid Reconfiguration Antennas

Hybrid reconfigurable antennas are equipped to concurrently adjust multiple attributes, such as radiation pattern and frequency, to achieve a targeted configuration, as demonstrated in [8]. In [25], frequency reconfiguration is enabled by varactor diodes, while the patch's truncated corners facilitate the switch between linear and circular polarization. Similarly, frequency and polarization reconfigurability are accomplished in [26] utilizing varactor diodes and orthogonal feed points. In the same report authors have suggested that the polarization diversity can be accomplished by toggling the Single-Pole Double-Throw (SPDT) switch, which is managed by the DIP switch within the feed configuration.

III. CONCLUSION

This review has highlighted the significant role of reconfigurable antennas in addressing the complex and evolving demands of 5G wireless communication systems. We have explored four primary categories of reconfigurable antennas, each offering distinct capabilities and benefits.

Frequency reconfigurable antennas, which utilize RF-switches to toggle between different frequencies, are crucial for applications in cognitive radio systems, MIMO systems, and biomedical devices. Radiation pattern reconfigurable antennas, capable of adjusting their radiation pattern at a constant frequency, are exemplified by innovative designs such as the Dielectric Resonator Antenna (DRA) with EBG sectors, enabling 360-degree beam steering. Polarization reconfigurable antennas offer the flexibility to change their polarization orientation while maintaining consistent radiation patterns and frequencies, as demonstrated by techniques enabling both right-hand and left-hand circular polarization using PIN diodes for 5G applications. Finally, hybrid reconfigurable antennas demonstrate the ability to concurrently modify multiple attributes, such as radiation pattern and frequency, to achieve specific desired configurations.

The critical analysis reveals that while reconfigurable antennas offer immense potential, their widespread adoption is contingent on overcoming challenges related to integration complexity, performance degradation due to switching elements, and the need for sophisticated control mechanisms. Future research should prioritize the integration of artificial intelligence and machine learning for intelligent antenna control, the exploration of novel materials like metamaterials for enhanced performance and miniaturization, and the development of additive manufacturing techniques for cost-effective fabrication. Additionally, further investigation into energy harvesting integration and the joint optimization of antennas with other system components will be vital for realizing the full potential of these adaptable solutions in next-generation wireless technologies

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