Fractal Modified Reconfigurable Antennas for Modern Wireless Communication Systems: A Review

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Abstract: Today's wireless technology requires a compact and flexible single antenna that can operate as a multifunctional antenna based on the digital switching action of RF switches. Fractal technology transforms a conventional patch antenna into a multi-tuned or multi-band antenna. Therefore, it is essential to combine the properties of a fractal antenna with a reconfigurable antenna. Such reconfigurable fractal antennas integrate fractal geometry with tunable frequency selective surfaces (FSS), metasurfaces, and efficient RF switching technologies, achieving dynamic reconfigurability of frequency, radiation pattern, gain, and polarization with minimal loss. The entire review concluded that PIN diodes, varactor diodes, and RF-MEMS switches are most commonly used for switching with 0-2V external DC power supplies, providing real-time adaptability of the four reconfiguration mechanisms (frequency, pattern, polarization, and gain), gain-reconfigurable antennas are not available in the literature. Tunable FSSs will be used to accomplish this difficult task. Other solutions include multilayer FSSs and dual-feed configurations, which facilitate gain enhancement and linear-to-circular polarization reconfigurability. These antennas are ideal for next-generation wireless communications, satellite, and radar applications.
Keywords: Gain reconfigurable; Operating modes; Pattern reconfigurable; RF switches

1. Introduction

With the rapid growth of 5G, 6G, satellite communications, and IoT, there is a high demand for compact antennas that support multiple frequency bands and functions within a single device. By increasing the effective electrical length, reconfigurable microstrip antennas, combined with RF switches such as PIN diodes, varactors, and RF-MEMS as well as fractal topologies, allow seamless frequency tweaking and multiband operation while reducing antenna size [1]. The need for efficient, affordable fractal reconfigurable antennas that offer frequency, polarization, pattern, and gain reconfigurability with excellent performance is driven by the potential for additional loss and design complexity caused by switching components [2-10].

1.1. Motivation of Research

Modern 4G/5G/6G, IoT, and satellite systems require compact antennas that can support multiple functions across a large frequency range. Fractal geometries such as Minkowski, Hilbert, and Koch curves reduce antenna size by increasing electrical length, while active elements such as PIN diodes, varactors, and metasurfaces enable dynamic reconfiguration of frequency, pattern, gain, and polarization [11-14]. Therefore, fractal reconfigurable antennas offer a promising low-power and cost-effective solution to overcome fixed-band limitations and support next-generation wireless applications [15-27].

2. Related work

Only a small number of documented reconfigurable antennas offer polarization reconfigurability, such as linear polarization (LP) to left/right hand circular polarization (LHCP, and RHCP) switching [11, 12, 24,

27]; the majority concentrate on frequency agility throughout Sub-6 GHz (1.8-5.8 GHz) and millimeter-wave (28-38 GHz) bands [12-23, 26, 27]. Low-loss substrates like Rogers RT/Duroid 5880 (ε_r = 2.2) and Rogers RO3003 ($\varepsilon\varepsilon_r$= 3.03) are favored for high-frequency and high-efficiency applications, whereas FR-4 (ε_r = 4.4) is frequently utilized for inexpensive Sub-6 GHz devices. Reconfiguration is generally performed utilizing two or more PIN diodes, notably Skyworks SMP1320/1340, Infineon BAR64-02V/BAR63-02V, and MACOM MA4P7470, enabling around three to six distinct functioning modes. Table 1 tabularize the reconfigurable antenna comparisons those utilizes fractal concept in their designing.

Table 1. Reconfigurable antennas using fractal methods

Ref. [Year]	Reconfigure Antenna Type	Substrate Used (ε_r/ tan δ)	Antenna Size (mm^3)	Name of RF switches	No. of RF switches	Operating Modes	Frequency /bands (GHz)	Fractal
[11] 2020	Polarization	TLY-5 (2.2/0.0025)	40×40 ×1.6	PIN diodes	4	2	2.33–2.72, 2.98–3.40	Minkowski Island,
[12] 2021	Frequency and polarization	Rogers RT/ Duroid 5880 (2.2/0.0009)	50 ×110 ×1.56	PIN diodes	4	3	1.8, 2.48, 3.4	Minkowski, half-circled, and Koch
[13] 2021	Frequency	Flexible Polyamide (3.6/0.00025)	50 × 60 × 0.30	Two PIN and One Varactor	3	2	0.8–1, 2.3–2.6	Hilbert
[14] 2020	Frequency	FR-4 (4.4/0.02)	29.2×22 ×1.6	PIN diodes	1	2	3.5, 4.41, 5.8, 8.26, 10.48, 3.35, 14.42	Moore–Koch (Hybrid) fractal
[15] 2020	Frequency	FR-4 (4.4/0.02)	18.8×18.8 ×0.8	PIN diodes (HPND-4005)	2	1	2.2–8.4	three concentric ring-shaped fractals, Koch fractal (Triangular)
[16] 2021	Frequency	FR-4 (4.4/0.02)	Not Available	PIN diodes	4	2	2.4, 0.9	Sierpinski gasket
[17] 2026	Frequency	FR-4 (4.4/0.02)	28×24 ×1.6	PIN Diode (BAR64-02V)	2	3	2.4 / 5.2 / 5.8	CPW-fed slotted patch radiator
[18] 2026	Frequency and Pattern	FR-4 (4.4/0.02)	30×32 ×1.6	PIN Diode	2	4	3.5 Multi-band	Equivalent Circuit Modeling (ECM) with

							(Sub-6 GHz)	switchable stubs and parasitic elements
[19] 2026	Frequency and Gain	Rogers RT/Duroid 5880 (2.2/0.0009)	22×25 ×0.787	PIN Diode	3	4	5G / Lower 6G	Bio-inspired spider-shaped fractal radiator with defected ground plane
[20] 2026	Frequency	Rogers RO3003 (3.03/0.001)	15×18 ×1.52	PIN / Varactor Diode	2	3	32 GHz mm-Wave (28.0/ 38.0)	Hybrid switching using PIN and Varactor diodes for continuous mm-Wave tuning
[21] 2025	Frequency	Rogers RO4350B (3.48/0.037)	45×45 ×0.813	PIN Diode	4	8	10 GHz X-band (8.0–12.0)	Low-loss, high-gain corporate-fed 2×2 circular microstrip patch array
[22] 2024	Frequency	FR-4 (4.4/0.02)	35×40 ×1.6	BAR64-02V	2	4	2.45 GHz L-band to Ku-band	PIN diode-controlled multi-slot switching for satellite, military, and radar links
[23] 2023	Frequency	FR-4 (4.4/0.02)	32×34 ×1.6	PIN Diode	4	8	2.45 GHz ISM Band / Wireless	Dodecagon-shaped patch loaded with 3-delta parasitic decoupling structures
[24] 2024	Gain and Polarization	FR-4 (4.4/0.02)	40×40 ×3.2	BAR64-02 (FSS Tuned)	8	4	5 Multi-band (Sub-6 GHz)	Dual-polarized circular fractal antenna backed by tunable stacked Frequency Selective Surface (FSS)
[25] 2025	Gain	FR-4 (4.4/0.02)	45×45 ×3.2	BAR65-02, 115 (FSS Tuned)	4	2	3.5 Multi-band (Wireless)	Gain enhancement using tuned complementary Frequency Selective Surface (C-FSS) loading
[26] 2025	Frequency and polarization	Rogers RT/ Duroid 5880 (2.2/0.0009)	32 × 30 ×1.6	PIN diodes	2	3	2-8	Koch curve with hexagonal ring
[27] 2025	Frequency and polarization	FR-4 (4.4/0.02)	70 × 45 ×1.6	PIN diodes	4	3	3.7–5, 1.7–3.5, 1.4–4	star-shaped fractal

3. Limitations, Challenges and Research Gap

The addition of RF switching components and biasing networks increases the manufacturing complexity of existing reconfigurable antennas, introduces higher losses, and requires additional hardware. This increases the cost, takes up more space, requires separate DC control circuitry, and can impact the antenna's overall dependability, efficiency, and performance.

Based on current research, compact reconfigurable antennas that offer dynamic polarization conversion between LP and CP, extensive frequency switching in lower and higher bands, and gain reconfigurability in a single design are rare. The need for multifunctional antennas that can simultaneously offer frequency, pattern, polarization, and gain reconfiguration is further highlighted by the fact that gain-reconfigurable antennas based on tunable FSS or metasurfaces remain largely unexplored.

3.1. Problem Statement

Current antenna topologies are too small and redundant to simultaneously perform wideband frequency switching, polarization conversion, and dynamic gain/pattern control. Therefore, next-generation 5G/6G wireless systems require new, low-complexity reconfigurable antennas with integrated frequency, polarization, pattern, and gain reconfigurability, which can seamlessly operate in the sub-6 GHz and mm-wave bands.

3.2. Research Objectives

Based on the literature research gap and limitations following are the main objectives for the ongoing future researches: 1. Low frequency achievement with limited antenna size, 2. Multi-band dynamic frequency switching, 3. Polarization reconfigurability via multi-feed networks, and 4. Gain and pattern enhancement via tunable FSS.

The proposed research aims to design a compact fractal-based antenna that can operate in a limited area at low frequencies using a modified patch and ground structure. It further seeks to develop an RF-switched reconfigurable antenna that dynamically switches between the sub-6 GHz and sub-24 GHz bands, supports linear-to-circular polarization conversion using a multi-feed architecture, and incorporates a tunable FSS superstrate for gain enhancement and radiation pattern reconfigurability without increasing the complexity of the radiating element.

4. Key Contribution

In this proposed work a comprehensive literature review has been conducted based on the fractal curves modified reconfigurable antennas. The novel methods of designing of gain reconfigurable, pattern reconfigurable and polarization reconfigurable antennas have been discussed in the next sections. The article also determines which switch is best to achieve reconfigurability in the antennas and how many maximum numbers of modes can be evaluated using these RF switching components. This article also discusses the best cost-effective power supply for the diode switching and how to remedies the losses and complexity due to the additional RF switches and connecting wires.

5. Method, Experiments and Results

5.1. Methods for Reconfigurable Antennas

Table 2 summarizes the principal techniques used to realize antenna reconfigurability, including frequency, pattern, gain, and polarization control through RF switching, tunable feed networks, fractal structures, DGS, and FSS/metasurface-based configurations.

Table2. Methods for reconfigurable antennas

Type of Antenna	Methods
Frequency Reconfigurable	Switchable Slot Line Perturbations. Reconfigurable Defected Ground Structure (DGS). Varactor Diode Continuous Tuning. Fractal Geometry Iteration Switching. Switchable Parasitic Stub Loading.

Pattern Reconfigurable	Switchable Parasitic Elements (Yagi-Uda Type). Reconfigurable Defected Ground Structure (DGS). Switchable Feed Networks/Phase Shifters. Pixelated / Reconfigurable Metasurfaces (RIS/IRS). Corner Truncation & Corner Loading
Gain Reconfigurable	Switchable Active Radiating Aperture (Array Element Control). Tunable Frequency Selective Surface (FSS)/Metamaterial Superstrate. Reconfigurable Reflector/Director Spacing. Switchable Feeding Networks (Corporate Feed Tuning). Driven-to-Parasitic Mode Switching
Polarization Reconfigurable	Switchable Diagonal Corner Truncations. Cross-Slot Perturbations with Centrally Loaded Diodes. Switchable Dual-Feed Quadrature Couplers / Hybrid Rings. Reconfigurable Parasitic Corner Stubs. Varactor-Tuned Phase-Shift Feed Networks

5.2. HFSS Equivalent and Equivalent circuit of the RF Switches

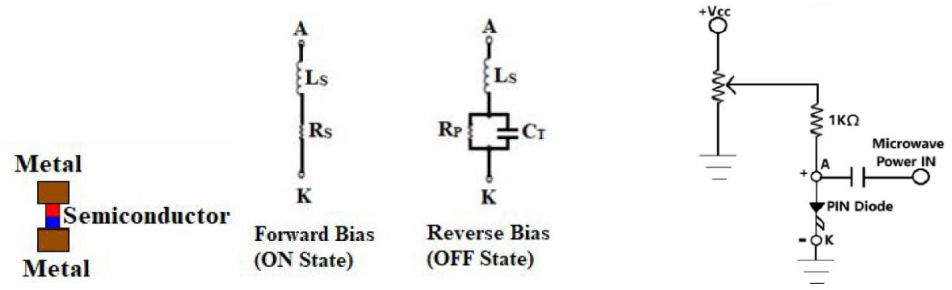
While designing the antenna, it is very important to know about the RF switches and their behavior with forward- and reverse-biased power supply. Table 3 shows the most widely used RF switches to reconfigure a designed antenna [19-22]. The values of these switches in the ON state and OFF state are displayed in Table 3.

Table 3. Equivalent circuit of the commonly used RF switches

RF Switch Name/No.	Equivalent Circuit in ON state	Values in ON state	Equivalent Circuit in OFF state	Values in OFF State
BAR64-02	R_S in series with L_S	R_S=2.1 Ω, L_S =0.6 nH	C_T in parallel with R_P, in series with L_S	C_T=0.17 pF, R_P=3 kΩ, L_S=0.6 nH
SMP1340-079LF	R_S in series with L_S	R_S=0.85 Ω, L_S=0.7 nH	C_T in parallel with R_P, in series with L_S	C_T=0.21 pF, R_P=5 kΩ, L_S=0.7 nH
Skyworks SMP1320	R_S in series with L_S	R_S=0.9 Ω, L_S =0.45 nH	C_T in parallel with R_P, in series with L_S	C_T=0.30 pF, R_P =10 kΩ, L_S=0.45 nH
MA4P7470F-1072T	R_S in series with L_S	R_S=0.6 Ω, L_S =0.5 nH	C_T in parallel with R_P, in series with L_S	C_T=0.18 pF, R_P =10 kΩ, L_S=0.5 nH
BAR63-02V	R_S in series with L_S	R_S=1.0 Ω, L_S =0.6 nH	C_T in parallel with R_P, in series with L_S	C_T=0.23 pF, R_P=5 kΩ, L_S=0.6 nH
BAR65-02V	R_S in series with L_S	R_S=3.0 Ω, L_S =0.6 nH	C_T in parallel with R_P, in series with L_S	C_T=0.5 pF, R_P=3 kΩ, L_S=0.6 nH

5.3. Power Supply for the RF Diode Switches

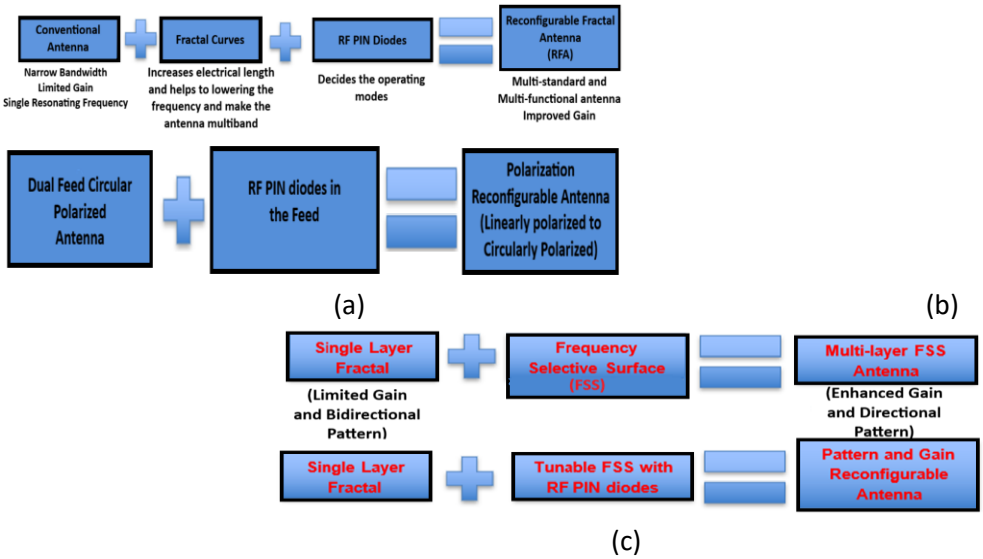
A simple DC bias supply shown in Figure 1(c) is commonly used to switch RF diodes between ON and OFF states by varying the applied voltage until conduction begins (ON state) or ceases under reverse bias (OFF state) [19-22]. To protect the antenna and RF circuitry from unwanted DC fluctuations, a DC-blocking or coupling capacitor, typically around 100 µF, is often incorporated in the feed network [23].



(a) (b) (c)

Figure1. Equivalent circuit of the diodes (a) HFSS model of PIN diode (b) RF switch equivalent circuit [19-22], and (c) Power supply for the RF switches [23].

5.4. Concept and Layout Methods for Future Reconfigurable Fractal Antennas



(a) (b)

(c)

Figure 2. Novel methods to construct reconfigurable antenna (a)Fractal frequency reconfigurable antenna, (b) polarization reconfigurable antenna, and (c)pattern and gain reconfigurable antenna.

Three new approaches to creating reconfigurable fractal antennas with multi-parameter agility are shown in Figure A frequency-reconfigurable fractal antenna is shown in Figure 2(a), where RF PIN diodes allow dynamic frequency switching and space-filling fractal geometry lengthens the electrical length for compact multiband operation. Polarization reconfigurability, where PIN diodes embedded within a dual-feed network manage the excitation phase to achieve smooth switching between linear polarization (LP) and circular polarization (CP), is shown in Figure 2(b). Using a tunable FSS superstrate, which typically increases gain by 3-6 dBi and changes the radiation pattern from bidirectional to unidirectional, Figure 2(b) illustrates pattern and gain reconfigurability. Polarization reconfigurability, where PIN diodes embedded within a dual-feed network manage the excitation phase to achieve smooth switching between linear polarization (LP) and circular polarization (CP), is shown in Figure 2(c).

5.5. Discussions

The review of fractal reconfigurable antennas shows that frequency, pattern, and polarization reconfiguration are the most widely investigated approaches, with PIN diodes serving as the preferred RF switching elements. The number of achievable operating states depends on the number and configuration of RF switches, while gain reconfigurability remains relatively unexplored, presenting opportunities for

the use of tunable FSS structures. It is concluded that multi-feed antenna achieves circular polarization, therefore, feed switching with RF switches may achieve Polarization reconfiguration between linear polarization (LP) and circular polarization (CP). Furthermore, combining fractal curves into rectangular/circular patch/ground of antennas improves miniaturization and achieves multiband operation, supports mitigate in-band applications interference. The incorporation of RF PIN diodes in the patch or feed network also enables dynamic switching between sub-6 GHz (5G n77/78/79 <6GHz) and mm-wave (n257-n262 >24 GHz) frequency bands, this will make reconfigurable fractal antennas suitable for modern wireless communication systems.

6. Conclusion

A comprehensive review is successfully conducted including comparative analysis of several reconfigurable fractal antennas. The study concluded commonly used switches (PIN diodes), power supply required, increases complexity, general losses due to addition of RF switches and connecting wires, maximum operating modes, new methods to achieve pattern, gain and polarization reconfigurability. In future, the research will be focused on developing low-loss, miniaturized, less-complex and highly integrated antennas that can perform simultaneous multi-parameter reconfiguration and unified operation in the sub-6 GHz and mm-wave/THz bands, dual-feed switching polarization reconfigure, tunable FSS pattern and gain reconfigure antennas for advanced wireless communication systems.

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