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Frequency Reconfigurable Antennas for WiMAX and WLAN Systems Utilizing Switching Techniques

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Abstract: Since they can be used with a single antenna to cover multiple bands of wavelengths, frequency reconfigurable antennas have become an essential technology for modern cellular networks. They provide an efficient solution for WiMAX or WLAN applications by decreasing the antenna size, hardware complexity and system cost. This review article provides a summary of FRA and highlights some popular switching technologies such as PIN diodes, varactor diodes, RF MEMS, and optical switches. The antenna arrangement for multi-band wireless communication systems is investigated, including the standards used, benefits and drawbacks of these switching systems. Other important performance parameters such as return loss, bandwidth, gain, VSWR and radiation parameters are also compared. A literature review shows that PIN diode switching is the most feasible solution due to its low cost, high switching speed and ease of use. The investigation reviews the state-of-the-art research challenges and future research directions related to the development of next generation small, effective and highly efficient FRA for wireless networks.

Keywords: Frequency Reconfigurable Antenna, WiMAX, WLAN, PIN Diode, Varactor Diode, RF MEMS, Optical Switch, Microstrip Patch Antenna, Multiband Antenna, Switching Technique, Wireless Communication, Antenna Reconfiguration.

I.INTRODUCTION

Wireless communications equipment has been rapidly developing, which has compounded the need for a small, good quality, multi-frequency antenna. Modern wireless networks, including worldwide Interoperability for Microwave Access (WiMAX) networks and Wireless Local Area Networks (WLAN), require reliable antennas that operate across a range of frequencies, with a high gain, wide bandwidth, and stable radiation pattern. Wireless equipment was initially larger, more expensive, or more complex due to the necessity of separate antennas for various communication standards [1]. To overcome these limitations, FRA have been developed and proven to be a practical and flexible solution.

A FRA is an antenna that can switch between different frequency bands without requiring any physical changes to the shape or dimensions. The reconfiguring allows the antenna to be used over multiple bands of frequencies by incorporating switching elements into the antenna. These antennas boost spectrum use, reduce requirements for hardware, and enhance wireless communication systems' flexibility [2]. The use of spectrum in WiMAX (2.3-2.7 GHz, 3.3-3.8 GHz), WLAN (2.4 GHz, 5.2 GHz and 5.8 GHz), cognitive radio, IoT, satellite communication and 5G wireless networks have thus been receiving considerable attention.

PIN diodes, varactor diodes, RF MEMS, and optical switches that proposed frequency customisation. PIN diodes are the most often used because of their quick switching speed, low switching power consumption, simplicity in costs [3] [4]. Varactor diodes can modulate frequencies continuously by varying the capacitance, whereas RF MEMS switches are capable of very good isolation and low insertion loss, but are more complex to fabricate and require larger actuation voltages. While optical switches provide a higher degree of electromagnetic interference protection and isolation, they are still very expensive and difficult to install.

Recently, a number of FR microstrip patch antenna structures have been suggested to increase the gain of the impedance spectrum, the performance of electromagnetic radiation and choice of frequency. These designs utilize combination of multiple slot design, defective ground structure (DGS), different types of metamaterials and parasitic components. All these advances have yielded very small antennas that are capable of making the electrical characteristics match a broad spectrum of wireless transmission channels. However, the practical use of reconfigurable antennas remains constrained due to issues such as integration of the bias network, switching losses, inefficiency, and complexity of design.

In the context of the WiMAX and WLAN applications with proper switching protocols, this study provides an in-depth analysis of FRA. It covers new advances in antenna design, reviews the pros and cons of various switching apparatus and examines their operation. This document's following portions are organized as following. The antenna specifications for the WiMAX and WLAN protocols are described in Section II. The switching methods used in FRA such as PIN diode, varactor diode, RF MEMS and optical switching are discussed in Section III. In Section IV a survey and comparison of current FRA methods and those published in the literature is provided. The last section summarizes the findings and suggests some avenues for further research.

II. Review of WiMAX and WLAN Antenna Requirements

Wireless communication approaches like WiMAX and WLAN for contemporary quick data rates, and efficient spectrum usage are necessary. WiMAX normally works in the 2.3-2.7 GHz and 3.3-3.8 GHz frequency ranges, whereas WLAN usually employs the 2.4 GHz, 5.2 GHz, and 5.8 GHz bands. Antennas intended for such uses should have a wide impedance bandwidth, high gain, minimal return loss, good radiation efficiency, steady radiation configurations, and small dimensions to accommodate portable wireless devices. FRA have become a popular solution because modern communication systems frequently run over numerous frequency bands. These antennas may automatically transition across various operating frequencies using appropriate switching methods, allowing a single compact antenna to handle both WiMAX and WLAN applications while lowering system size and enhancing performance in general.

III. Switching Techniques Used in Frequency Reconfigurable Antennas

A. PIN Diode Switching Technique

The PIN diode is the most often used switching element in frequency reconfigurable antennas due to its simple biasing circuit, low cost, small size, and fast switching speed. It is made up of a P-type region, an intrinsic (I) layer, and an N-type region. When forward biased, the diode acts as a low-resistance conductor (ON), enabling current to pass via the antenna and modifying its efficient electrical length. Under reverse bias, it acts as a high-resistance element (OFF), disrupting the current route and altering the resonance frequency. This method allows a single antenna to work over many frequency bands, making PIN diodes ideal for WiMAX and WLAN applications. Their low power use, quick switching ability, and ease of integration with microstrip antennas have made them the best option in the majority of practical reconfigurable antenna design applications.

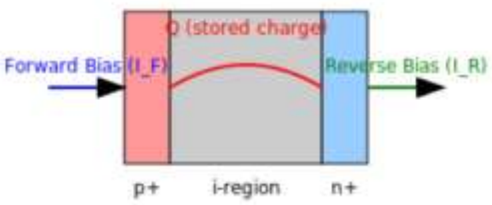

Fig. 1. PIN Diode Switching Technique [3]

B. Varactor Diode Switching Technique

A varactor diode is a voltage-controlled semiconductor device that allows for continuous frequency tweaking in reconfigurable antennas. Despite a PIN diode, which switches among working frequencies discretely, a varactor diode modifies its junction capacitance in response to the reverse-bias voltage. The antenna's electrical length is changed by the variable capacitance, thereby allowing for continuous adjustment of the resonant frequency throughout a particular range. Varactor diodes are frequently used when smooth frequency change is required in tunable microstrip antennas. They frequently have greater insertion loss and lower power carrying capabilities than PIN diodes, given their great tuning flexibility. Because of this, its use is more appropriate for tasks that call for constant frequency adjustment as opposed to straightforward ON/OFF switching.

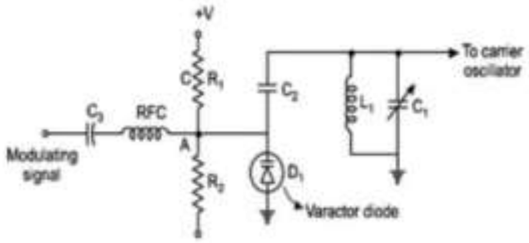

Fig.2 Varactor Diode Frequency Modulator [4]

C. RF MEMS Switching Technique

RF MEMS switches tiny physical switches allow for frequency customization for manually connecting or unplugging the RF signal line. They feature excellent separation, high linearity, very low integration loss, as well as low power consumption when compared to semiconductor switching. RF MEMS switches are perfect for high-frequency or microwave applications since they provide the least amount of signal deformation. However, in contrast to PIN diodes, they need extremely high actuation volts and complex fabrication processes, which increases manufacturing expenses and reduces switching speed. Despite these restrictions, RF MEMS switches are commonly used in high-performance reconfigurable antennas where minimal RF loss and great efficiency are required.

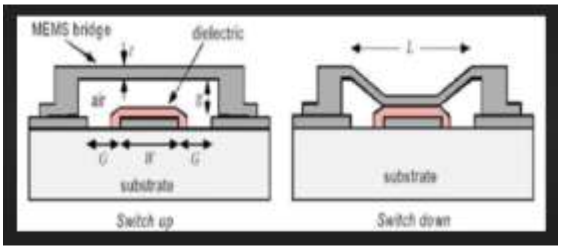

Fig.3. Operation and structure of RF MEMS [5]

D. Optical Switching Technique

A complex frequency reconfiguration technique that uses light to change the conductivity of a photoconductive semiconductor switch built into the antenna structure. When irradiated by a laser or LED source, the semiconductor conducts, altering the antenna's current distribution and resonant frequency. In a lack of light, the switch reverts to its nonconductive condition. Optical switches offer excellent isolation, resistance to electromagnetic interference, or electrical isolation between the control circuit and the RF system [6]. These qualities make them ideal for high-frequency and military communication systems. Nevertheless, optical switching necessitates the use of an external optical source, which increases system complexity and implementation costs. It is employed than PIN diodes in commercial WiMAX and WLAN antenna designs. Table 1 shows the pros and disadvantages of switching techniques in a tabular format.

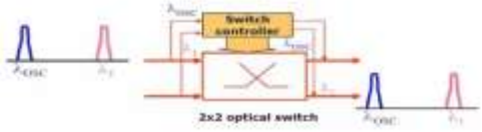

Fig.4. Optical Circuit Switching [6]

Table 1: Comparison of Switching Approaches

Switching Technique	Advantages	Limitations	Typical Applications
PIN Diode	Low cost, fast switching, easy biasing	Discrete frequency switching	WiMAX, WLAN, 5G
Varactor Diode	Continuous frequency tuning	Higher insertion loss	Tunable antennas
RF MEMS	Low insertion loss, high isolation	High actuation voltage, expensive	Satellite, radar
Optical Switch	High isolation, EMI immunity	Complex optical control, high cost	Defense, high-frequency communication

IV. RELATED WORK

For wireless communication researchers to build FR that can serve WiMAX, WLAN, 5G, and IoT services.Here, investigated to offer frequency agility; PIN diode-based switching has been the most commonly employed technique given its inexpensiveness, fast switching speed, and simplicity of assembly. This section evaluates the stated design approaches and effectiveness achievements and looks at recent research findings.

Bayer Keskin *et al.* (2025) introduced a PIN diode-based monopole radio for wideband wireless applications. The antenna structure had a non-integrity ground structure (DGS) with rectangular openings to enhance the interference matching or BW optimization. The ON/OFF states of the PIN diodes were changed which changes the current arrangement and optimum electrical length of the radiator, allowing for frequency customisation. In the OFF mode, the antenna covered a wide frequency range of 2.68-8.55 GHz, including WLAN (5.2 GHz), ISM (5.8 GHz), and lower X-band applications. The working frequency was then switched to Ku-band (12.7-15.65 GHz) when the switch was activated. The maximum gain of the antenna in UWB mode was approximately 2.36 dBi and 3.85 dBi in Ku-band mode, indicating good frequency switching performance. The findings indicated that an increased frequency versatility can be achieved while keeping the system compact, by using a PIN diode switching technique along with the slot and DGS techniques.

Ganesh *et al.* (2025) presented a multiband hybrid frequency or design changing antenna for Wi-Fi 6E, WLAN. A half-hexagonal radiating element with two PIN diodes and a frequency selective surface (FSS) reflector was used for the antenna to change the rate and the radiation designs. The antenna could be configured to work at 3.3 GHz, 3.5 GHz, 5.1 GHz, 5.3 GHz and 6.5 GHz and would thus be compatible with many sub-6 GHz wireless protocols by changing the state of the PIN diode. The FSS gain of the antenna over the actual antenna configuration (without FSS) was 2-4 dBi. The results of the test experiments were very similar to the simulation results, thus validating the effectiveness of the proposed architecture for small, multiband wireless communication systems.

R. Chi and Zhang, (2026) created a multimode FRA for WiMAX and 5G networks. In the proposed antenna, two PIN diodes were placed inside the feeding element (or in the emitting limbs) of the trident shaped microstrip radiator. Using the diode states, it was possible to control the antenna so as to function in single band, dual band, and triple band states. The 3D dimensions of 30 mm × 37 mm × 1.6 mm enabled superior miniaturization and multiband operations, which were made possible by the architecture, for applications such as WiMAX, WLAN and 5G, which require dynamic frequency selection.

Atul Varshney *et al.* (2026) lifted off using a tiny slotted and WLAN applications. The antenna used PIN diode switching and slot loading to achieve different frequencies. For this purpose, four switching modes with a gain higher than 5.18 dBi and a radiation efficiency higher than 85% were practically demonstrated using a vector network analysis. The test iteration proved to have the same radiation properties and is suitable for frequency-agile communication systems, SDR and IoT gateways [7].

Mansuri *et al.* (2025) One PIN diode frequency was developed to use in a variety of wireless networks. The proposed antenna is based on single PIN diode with slot loaded radiating circuits, which enables dual frequency function, whereas conventional antennas are based on a switching mechanism comprising of several components. The simplified switching architecture provides excellent radiation efficiency, matching, and reduces the fabrication complexity and biasing circuit. The results demonstrated that the antenna was ideal for small wireless equipment that need low-cost frequency reconfiguration since it was able to move between two operational bands with acceptable return loss, gain, and radiation efficiency [8].

Cildir and Gozel (2024) The diode was integrated with circular. With adjusting the reverse bias voltage from 0 to 3 V, the antenna was able to tune continuously from 0.85 GHz to 1.3 GHz, resulting in a tuning range of 53%. The researchers also reduced the size of the antenna by nearly 80% with respect to a conventional circular patch antenna without compromising the radiation performance and impedance matching. It was concluded that varactor diodes can be used in small, frequency agile wireless systems [9].

Sameer S. Tathare and P. Goswami, (2025) developed a reconfigurable antenna using 4 carefully positioned varactor diodes. Identical gain or impedance characteristics throughout several working bands were validated by CST Microwave Studio permitted both frequency adjustment or pattern-based radiation modification. The analysis acknowledged the more complicated nature of the biasing circuit while highlighting the low DC power consumption or commercial availability of varactor diodes [10].

Donelli et al. (2024) demonstrated electronically reconfigurable MEMS-controlled parasitic components. Their design allowed for dynamic beam steering while preserving great radiation effectiveness and little signal loss. The scientists proved that RF MEMS technology outperforms conventional semiconductor switches in terms of electrical efficiency, making it ideal for smart antenna arrays in modern communications networks [11].

Zhang et al. (2024) advancements in optical-switch-based and photoconductive switches are increasingly being used for frequency, polarization, and radiation-pattern

reconfiguration, particularly in millimetre-wave and terahertz systems. Optical switching removes a demand for complicated RF bias devices & lowers interference from electromagnetic waves when contrasted with conventional electrical switching. The scientists stated that optical switching holds great promise for future high-frequency communication systems, however further integration and fabrication advancements are needed [12].

This leads to the conclusion that switching remains a viable option for WiMAX and WLAN FRA due to its excellent combination of price, performance, and ease of manufacturing. The investigators are also investigating varactor diodes, RF MEMS, or optical switching approach to achieve consistent tuning, lower loss parameters, or improved separation. Future antenna designs are likely to prioritize smaller structures with higher gain, wider bandwidth, lower power consumption, and adaptive frequency adaptability for next-generation wireless networks. Table 2 presents a comparison of existing works.

Table 2: Comparison of Recent Frequency Reconfigurable Antenna Designs

Reference	Switching Technique	Antenna Structure	Operating Bands	Gain	Main Results
Keskin et al. (2025)	PIN diode	Reuleaux triangle monopole with DGS	2.68–8.55 GHz, 12.7–15.65 GHz	2.36–3.85 dBi	Wideband/UWB and Ku-band reconfiguration.
Ganesh et al. (2025)	PIN diode + FSS	Half-hexagonal radiator	3.3, 3.5, 5.1, 5.3, 6.5 GHz	+2–4 dBi	Frequency and radiation-pattern reconfiguration.
Chi and Zhang (2026)	PIN diode	Trident-shaped microstrip antenna	WiMAX/WLAN/5G	—	Four frequency-switching modes with compact design.
Atul Varshney (2026)	PIN diode	Slotted CPW-fed antenna	WLAN/ISM	>5.18 dBi	Four operating modes with high efficiency.
Cildir and Gozel (2024)	Varactor diode	Circular microstrip patch	0.85–1.30 GHz	2–4 dBi	53% continuous tuning and 80% size reduction.
Sameer S. Tathare & P. Goswami (2025)	Four varactor diodes	Multi-band microstrip antenna	Sub-6 GHz 5G	3–5 dBi	Frequency and pattern reconfiguration for 5G.
Donelli et al. (2024)	RF MEMS	MEMS-controlled antenna array	Microwave & mmWave	8–12 dBi	Beam steering with low loss and high isolation.
Zhang et al. (2024)	Optical switch	Reconfigurable antenna	mmWave & Terahertz	5–12 dBi	High isolation and EMI immunity for high-frequency applications.

V. CONCLUSION AND FUTURE WORK

This research conducted a comparative analysis for WiMAX and WLAN networks using PIN diodes, varactor diodes, RF MEMS, and optical switching technologies. PIN diodes are the most suitable for compact and low-cost antenna configurations, whereas varactor diodes allow for constant adjustment. RF MEMS and optical switches provide greater RF performance for sophisticated communication networks, but at a higher complication and cost. In general, FRA are still a promising alternative for increasing spectrum usage and enabling modern multi-band wireless communication devices.

Future research must focus on creating energy-efficient reconfigurable antennas for WiMAX, WLAN, 5G, and 6G technologies. The use of new materials, metamaterials, AI-based optimization, and hybrid switching approaches can enhance antenna efficiency, dependability, and frequency agility while lowering design difficulty and power usage.

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